Research Infrastructure Quality Assurance

GAW Report No. 257

Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Centre Europe

El Arenosillo Atmospheric Sounding Station, Huelva, Spain
17–28 June 2019

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

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VICEPRESIDENCIA CUARTA DEL GOBIERNO
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

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TABLE OF CONTENTS

1. INTRODUCTION

During this intercomparison, the RBCC-E transferred its own absolute ozone calibration, obtained by the Langley method at the Izaña Observatory (IZO). A discussion about the calibration of the reference instrument (B#185) is presented in Section 3. All the participating instruments were provided with a provisional calibration at the end of the campaign, which can be considered as the final calibration constants for most of them. A detailed calibration report for each instrument is available online. A calibration history of the Brewers which have participated in previous campaigns has also been included in this document. A participant's list is presented in Table 1.

The results of the blind comparison with the reference instrument, Brewer #185, showed very satisfactory results, in agreement with previous campaigns. 6 instruments showed an agreement better than 0.5% which represent (31%) of the participating instruments. 74% of the instruments showed an agreement inside a 1% range (see Figure 1). A good agreement with reference instrument Brewer #185 using the final calibration constants, within the range of ±0.5%, was achieved.

Table 1. Participant List of El Arenosillo 2019 campaign

Institution	*IP*	*Brewer*	*Country*
Thessaloniki University	A. Bais	005	Greece
International Ozone Services	V. Savastiouk	017	Canada
State Meteorological Agency of Spain	J. Moreta	033	Spain
State Meteorological Agency of Spain	A. Díaz	070	Spain
Manchester University	J. Rimmer	075	UK
State Meteorological Agency of Spain	J. Moreta	117	Spain
Manchester University	J. Rimmer	126	UK
INTA	J.M. Vilaplana	150	Spain
State Meteorological Agency of Spain	A. Díaz	151	Spain
Kipp & Zonen	Pavel Babal	158	Netherlands
PMOD/WRC	L. Egli	163	Switzerland
State Meteorological Agency of Spain	A. Díaz	166	Spain
Manchester University	J. Rimmer	172	UK
Japan Meteorological Agency	H. Fujiwara	174	Japan
RBCC-E / State Meteorological Agency of Spain	A. Redondas	185	Spain
State Meteorological Agency of Spain	A. Díaz	186	Spain
Environment Canada	M. Brohart	190	Canada
Office Nationale de la Météorologie	S. Baika	201	Algeria
DMI	N. Jepsen	202	Denmark
DMI	N. Jepsen	228	Denmark

Blind Days Ozone Deviations to Brewer IZO#185

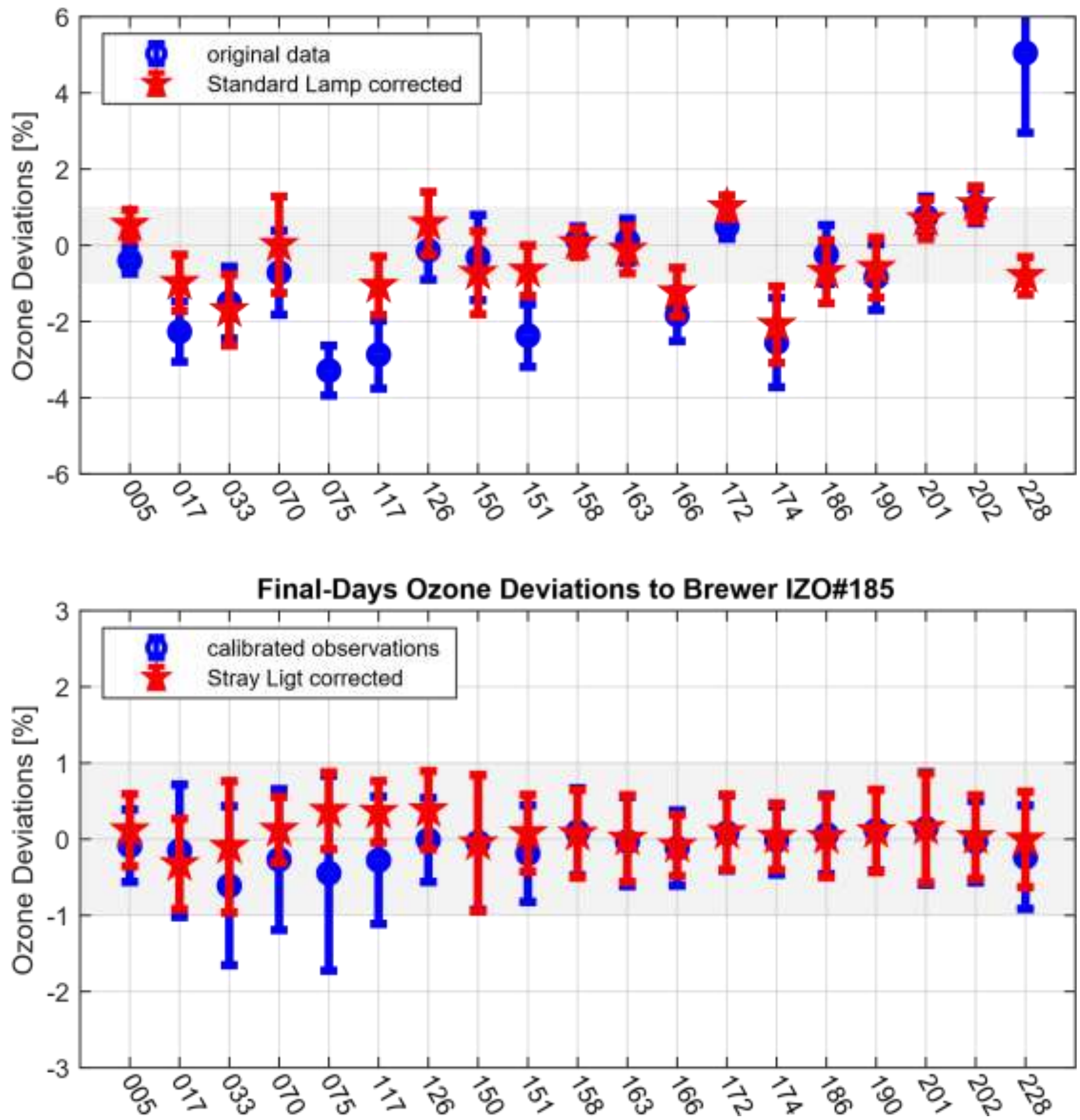


Figure 1. Ozone relative percentage differences of all El Arenosillo 2019 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the blind period in the upper panel are reprocessed using the initial calibration constants, with (red) and without (blue) standard lamp correction. Final days on the lower panel were reprocessed using the final calibration constants after maintenance, with (red stars) and without (blue dots) stray light correction on a single Brewer. Error bars represent the standard deviation.

2. SUMMARY

2.1. CAMPAIGN CONDITIONS AND SCHEDULE

The weather conditions during the campaign at the El Arenosillo Observatory (1860 m) were good, allowing for a minimum of 150 near-simultaneous direct sun ozone measurements with the reference instrument, Brewer #185, which was enough to perform a reliable calibration for all instruments (Figure 1). Moreover, the measurement routine schedule designed to maximize the number of ozone observations during the campaign worked properly, reaching with all instruments a large percentage of potential near-simultaneous ozone measurements. As shown in Figure 2, the total ozone content during the campaign ranged between 300 and 350 DU. Most observations (≈ 75%) were within the 350–600 DU ozone slant column (OSC) range (see Figure 3). The internal temperature was approx. 30 ±10 ◦C (see Figure 4).

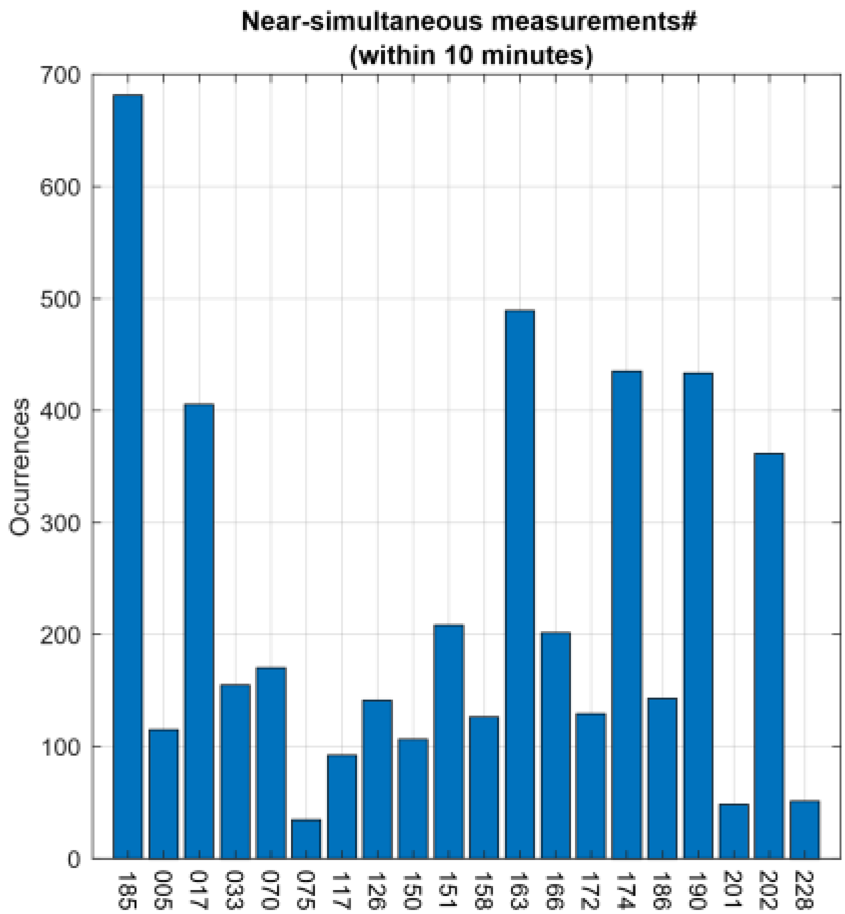


Figure 1. Number of near-simultaneous ozone measurements

The actions carried out each day of the campaign are shown in Table 1. The first day was dedicated to the installation of the instrument. The next two/three days (depending on the weather conditions) were "blind". During blind days any manipulation of the instrument that can produce a change to the initial calibration should be avoided. After that, the routine schedule could have been interrupted to perform whatever maintenance tasks were needed (dispersion tests, lamp calibrations, and so forth). In this campaign, maintenance was performed by IOS and Kipp & Zonen experts on 15 instruments. These actions are summarized on the maintenance sheet. Finally, the programmed

UV day measurements were considered as blind and final days for UV and ozone measurements, respectively.

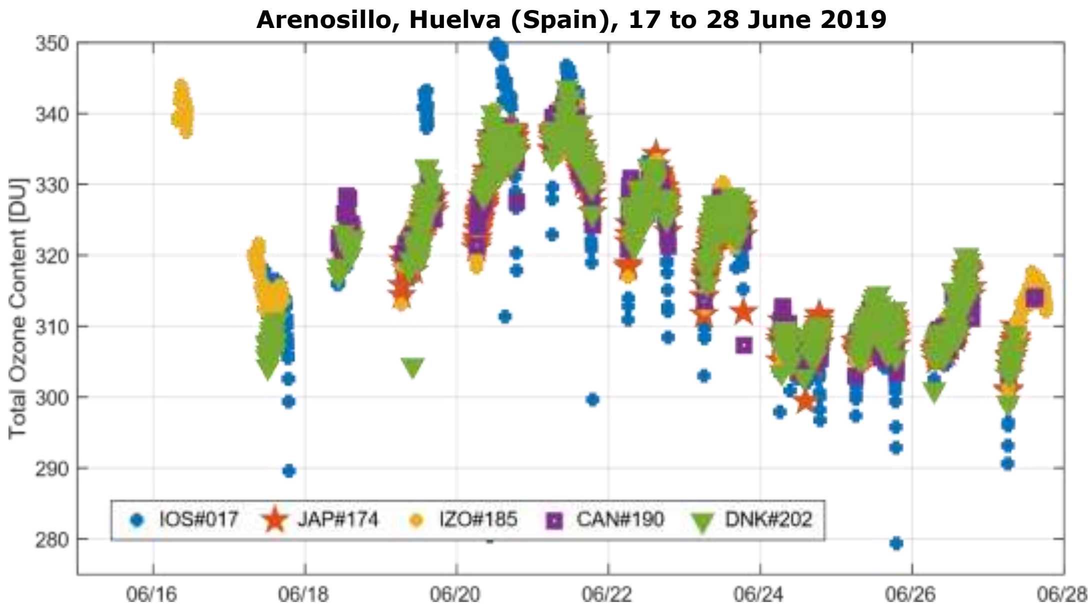


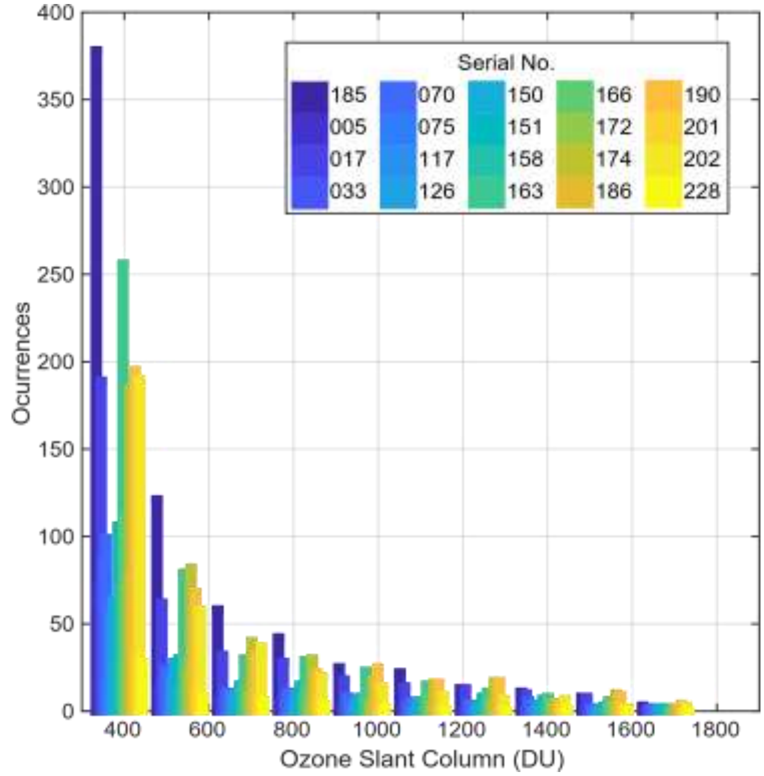
Figure 2. Total ozone for the campaign for instruments which did not require maintenance.

Table 1. El Arenosillo 2019 Campaign Schedule

Day	*Action*	*Notes*
Mon June 17th (168)	Installation	
Tue June 18th (169)	O_3 measurements	Blind days
Wed June 19th (170)	O_3 measurements	Blind days
Thu June 20th (171)	O_3 measurements / O_3 services	Service days
Fri June 21st (172)	O_3 measurements / O_3 services	Service days
Sat June 22nd (173)	O_3 measurements / O_3 services	Service days
Sun June 23rd (174)	O_3 measurements / O_3 services	Final ozone days / ATMOZ field campaign
Mon June 24th (175)	O_3 measurements	Final ozone days / ATMOZ field campaign
Tue June 25th (176)	O_3 measurements / UV	Final ozone days / UV comparison with QASUME
Wed June 26th (177)	O_3 measurements / UV	Final ozone days / UV comparison with QASUME
Thu June 27th (178)	O_3 measurements / UV	Final ozone days / UV comparison with QASUME
Fri June 28th (179)	Packing	

OSC measurements by instrument

Figure 3. Frequency distribution of ozone slant column ranges



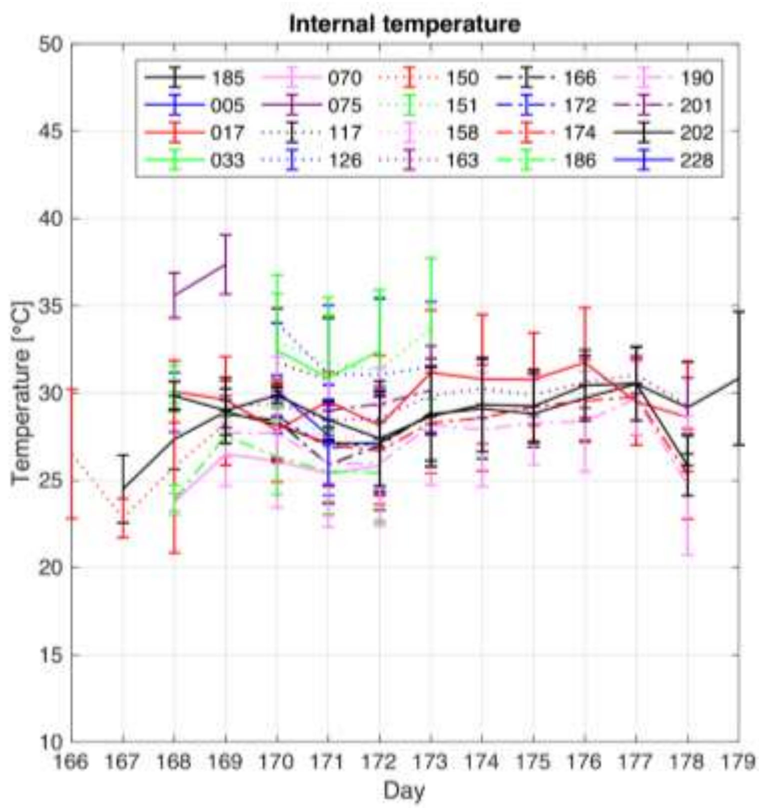


Figure 4. Internal temperature of participating Brewer instruments

2.2. BLIND COMPARISON

During the blind period, the instruments were working with their home calibration and ozone is calculated using these calibration constants. An initial comparison with the Brewer reference gives us an idea of the initial status of the instrument, i.e., how well the instrument performed using the initial calibration constants (those operational at the instrument's station). Moreover, it is possible to detect changes in the instrument response due to travel using internal tests, such as the standard lamp test, performed before and after travel.

The standard lamp (SL) test is an ozone measurement using the internal halogen lamp as a source. In the local station, this test is performed routinely to track the spectral response of the instrument and therefore the ozone calibration. A reference value for the SL R6 ratio is provided as part of the calibration of the instrument. The ozone measurement is routinely corrected assuming that the deviations of the R6 value from the reference value are the same as those changes in the extraterrestrial constant (ETC). This is the so-called standard lamp correction. Hence, it is reasonable to investigate if the observed R6 changes are related to similar changes in the calibration constant. If this were to be the case, then the ETC constant should be corrected by the same change in the SL R6 ratio as $ETCnew = ETCold - (SLref - SLmeasured)$.

Figure 5 and Table 2 show the difference between the calculated and referenced R6 values, and as shown, most of the Brewers presented variations of ±10 units which suggests that the instruments have remained stable since their last calibration. Note that Brewer #075 does not perform standard lamp measurements during blind days and #228 shows a huge change due to maintenance.

However, comparison with a reference instrument is the only way to assess whether the SL measurements properly track changes on the calibration constants or if the change observed is due to an emission spectrum change. We must note that not all instrumental changes are properly tracked by the standard lamp. For example, filter deterioration or linearity problems are not detected by the standard lamp measurement.

The results of the blind comparison with reference instrument Brewer #185 showed very satisfactory results.

In line with previous campaigns, 6 instruments showed an agreement better than 0.5%: MAD#070, UK#126, COR#151, K&Z#158, WRC#163, and MAD#186. These instruments represent 31% of all the participating Brewers. Moreover, 74% of the instruments showed an agreement inside the 1% range. The standard lamp results for the blind days are summarized in Figure 6.

The stray light effect observed in the single Brewers can be seen in Figure 7, with a prominent ozone slant column dependence in ozone measurements. The stray light correction implemented on the final calibration is explained in detail in the next section.

Table 2. Standard lamp record during blind days with comparison with the reference value and mean total ozone deviation with the reference for the blind days without and with correction (SLC). The last column shows that standard lamp correction improves the comparison with the reference.

	brw	*SL_blind_ Reference*	*mean_ SL*	*difference*	*std_table _blind_sl*	*mean*	*std_ t1*	*mean_ slc*	*std_ slc*	*SL correction*
TSK#005	5	1838	1825	13	3	-0.3	0.3	0.6	0.3	0
IOS#017	17	1680	1656	24	5	-2.3	0.7	-0.8	0.5	1
SCO#033	33	2325	2328	-3	2	-1.2	0.6	-1.5	0.6	0
MAD#070	70	1685	1675	10	3	-0.3	0.4	0.5	0.5	0
UK #075	75	1714	NaN	NaN	NaN	-3.3	0.6	NaN	NaN	1
MUR#117	117	1620	1589	31	7	-2.8	0.8	-0.9	0.5	1
UK #126	126	2075	2062	13	5	0	0.6	0.8	0.6	0
ARE#150	150	322	328	-6	1	-0.2	1.1	-0.6	1.1	1
COR#151	151	1880	1852	28	3	-2.4	0.9	-0.5	0.5	1
K&Z#158	158	558	558	0	4	0.1	0.3	0	0.3	0
WRC#163	163	274	278	-4	2	0	0.5	-0.3	0.6	0
ZAR#166	166	1955	1944	11	2	-1.8	0.7	-1.1	0.5	1
UK #172	172	444	436	8	2	0.4	0.3	1	0.3	1
JAP#174	174	605	597	8	1	-3	0.9	-2.5	0.8	1
IZO#185	185	362	362	0	1	0	0	0	0.1	0
MAD#186	186	315	322	-7	1	-0.3	0.7	-0.7	0.7	0
CAN#190	190	410	406	4	1	-1.2	0.7	-0.9	0.7	1
TAM#201	201	348	349	-1	2	0.8	0.5	0.8	0.5	1
DNK#202	202	270	269	1	2	1.1	0.5	1.1	0.5	0
DNK#228	228	242	336	-94	0	5.4	1.9	-0.8	0.6	1

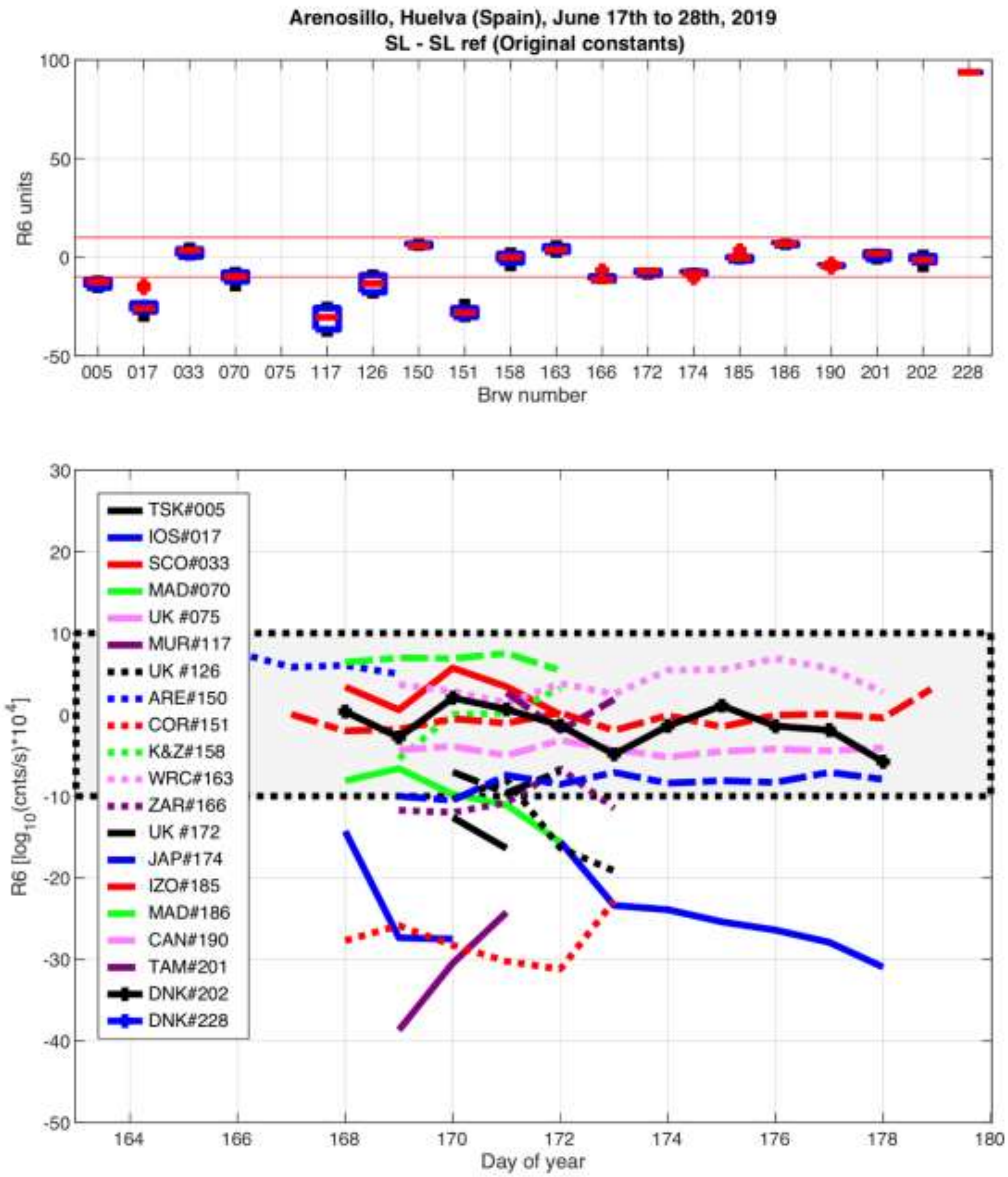


Figure 5. Standard lamp R6 difference to R6 reference value from last calibration during the blind days before maintenance. Variations within the ±10 range (≈ 1% in ozone) are considered normal, whereas larger changes would require further analysis of the instrument's performance.

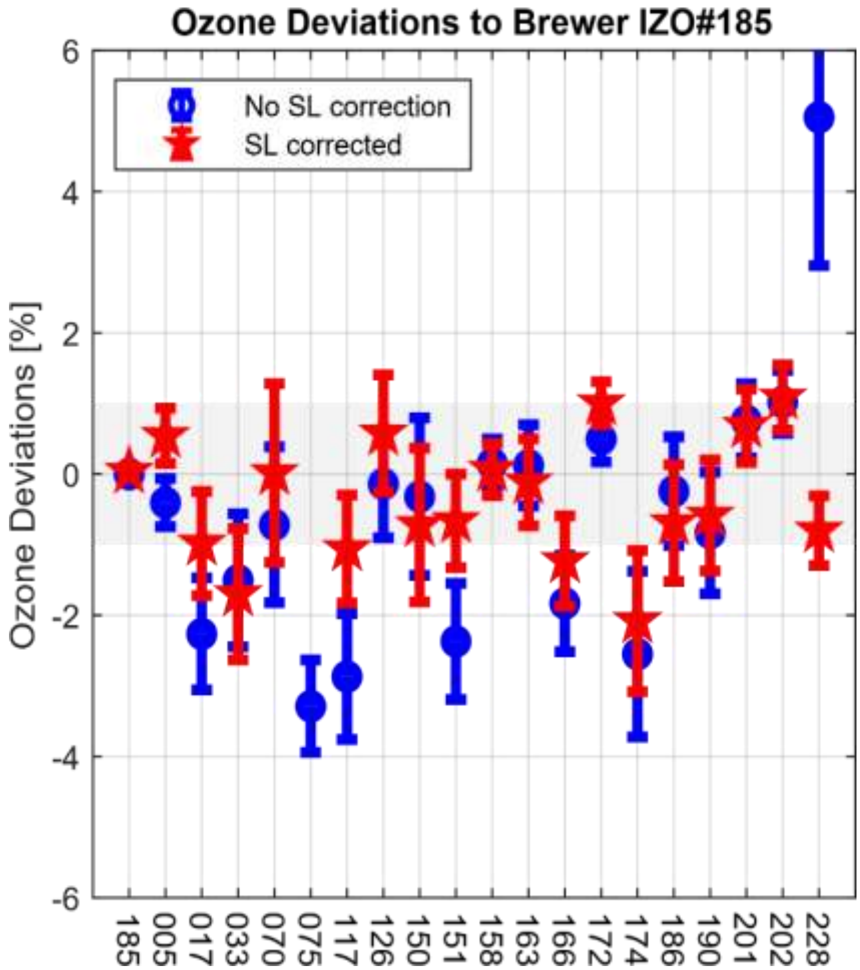


Figure 6. Ozone relative percentage differences of all El Arenosillo 2019 participating instruments to RBCC-E travelling standard IZO#185. Ozone measurements collected during the blind period are reprocessed using the initial calibration constants, with (red) and without (blue) standard lamp correction. Error bars represent standard deviation.

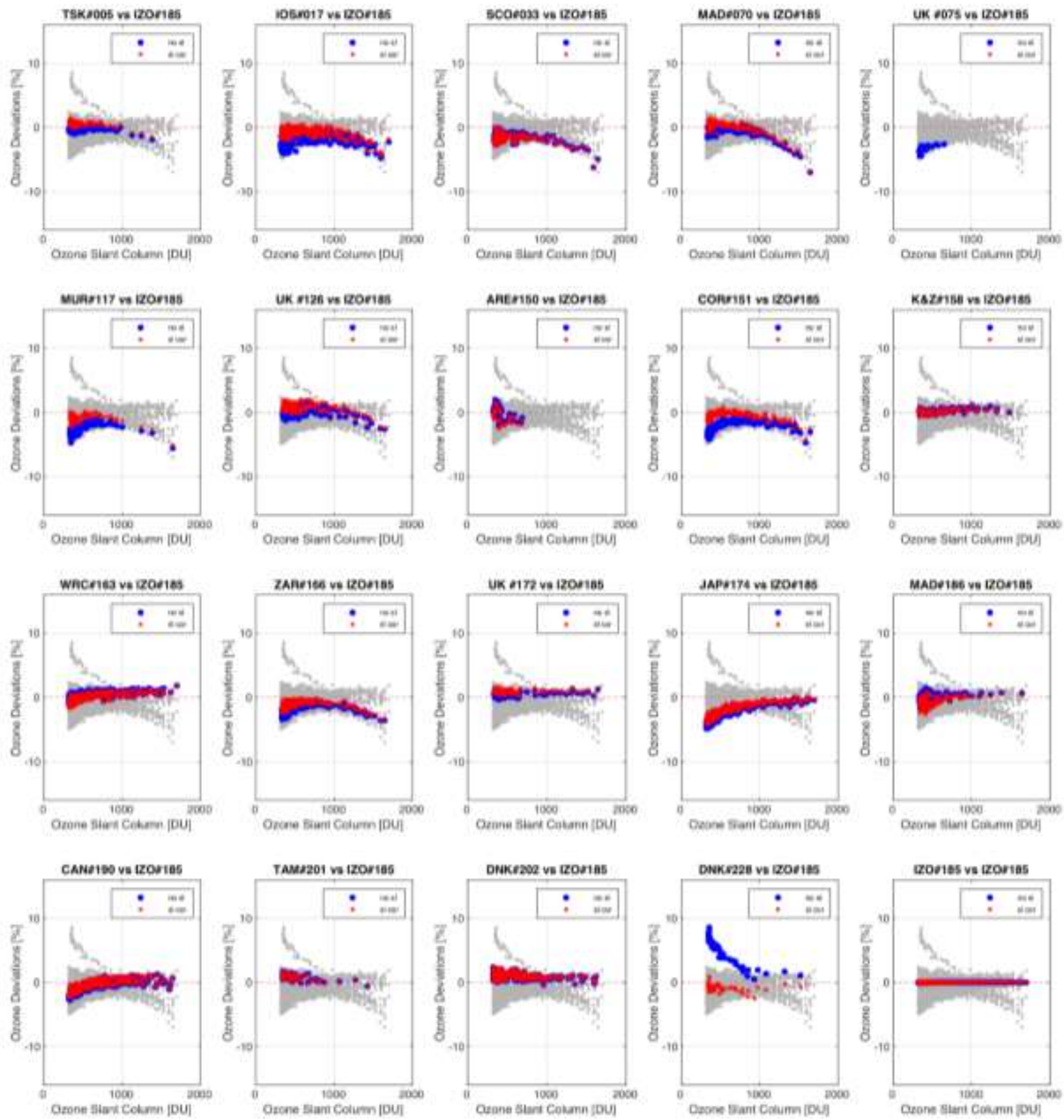


Figure 7. Blind days ozone relative differences (percentage) of all El Arenosillo 2019 Brewer instruments with respect to the RBCC-E travelling standard Brewer #185. Ozone measurements collected during the blind period (before maintenance) were reprocessed using the initial calibration constants, with (red stars) and without (blue stars) standard lamp correction. Grey dots mean ozone deviations for all participating instruments.

2.3. FINAL CALIBRATION

We define the final days as those available after the maintenance work has been carried out on each participating instrument. These days are used to calculate the final calibration constants, so efforts were made not to manipulate the instruments during this period. Furthermore, the SL R6 value recorded during the final days is normally adopted as the new reference value. It is also expected that this parameter will not vary by more than 5 units during this period. Figure 8 shows the differences between the daily standard lamp R6 ratio and the proposed R6 reference value during the final days. As expected, the recorded SL values did not vary by more than 5 units during this period.

Deviations of ozone values for all the participating instruments from the RBCC-E travelling standard Brewer IZO#185 are shown in Figure 9. We have recalculated the ozone measurements using the final calibration constants, with and without stray light correction in the case of single Brewer instruments. The ozone underestimation due to the effect of stray light in single Brewers and the correction applied by the model are depicted in Figure 10 (details of these corrections are found in Redondas et al. (2018b)).

All Brewers were calibrated using the one parameter ETC transfer method, i.e., the ozone absorption coefficient was derived from the wavelength calibration (dispersion test) and only the ozone ETC constant is transferred from the reference instrument. The two parameters calibration method is also used as a quality indicator. For all the instruments, the one parameter and two parameters ETC transfer methods agreed with each other within the ±10 units limit for ETC constants and ±0.001 atm/cm for the ozone absorption coefficient (one micrometre step), which is an indication of the quality of the calibration provided. With these tolerance limits, a good agreement of the reference instrument Brewer #185 using the final calibration constants, within the range ±0.5%, was achieved.

In Table 3 we summarize the mean differences, with and without applying stray light correction, with respect to the reference instrument. Ozone was calculated using the final calibration of the instrument.

Table 3. Ozone deviation with respect to the reference calculated with the final calibration

	mean (no stray light corr.)	*std (no stray light corr.)*	*mean (stray light corr.)*	*std (stray light corr.)*
TSK#005	−0.1	0.5	0.1	0.5
IOS#017	−0.1	0.9	−0.3	0.6
SCO#033	−0.6	1.1	−0.1	0.9
MAD#070	−0.3	0.9	0.1	0.4
UK #075	−0.5	1.3	0.4	0.5
MUR#117	−0.3	0.8	0.3	0.4
UK #126	0	0.6	0.4	0.5
COR#151	−0.2	0.7	0.1	0.5
ZAR#166	−0.1	0.5	−0.1	0.4

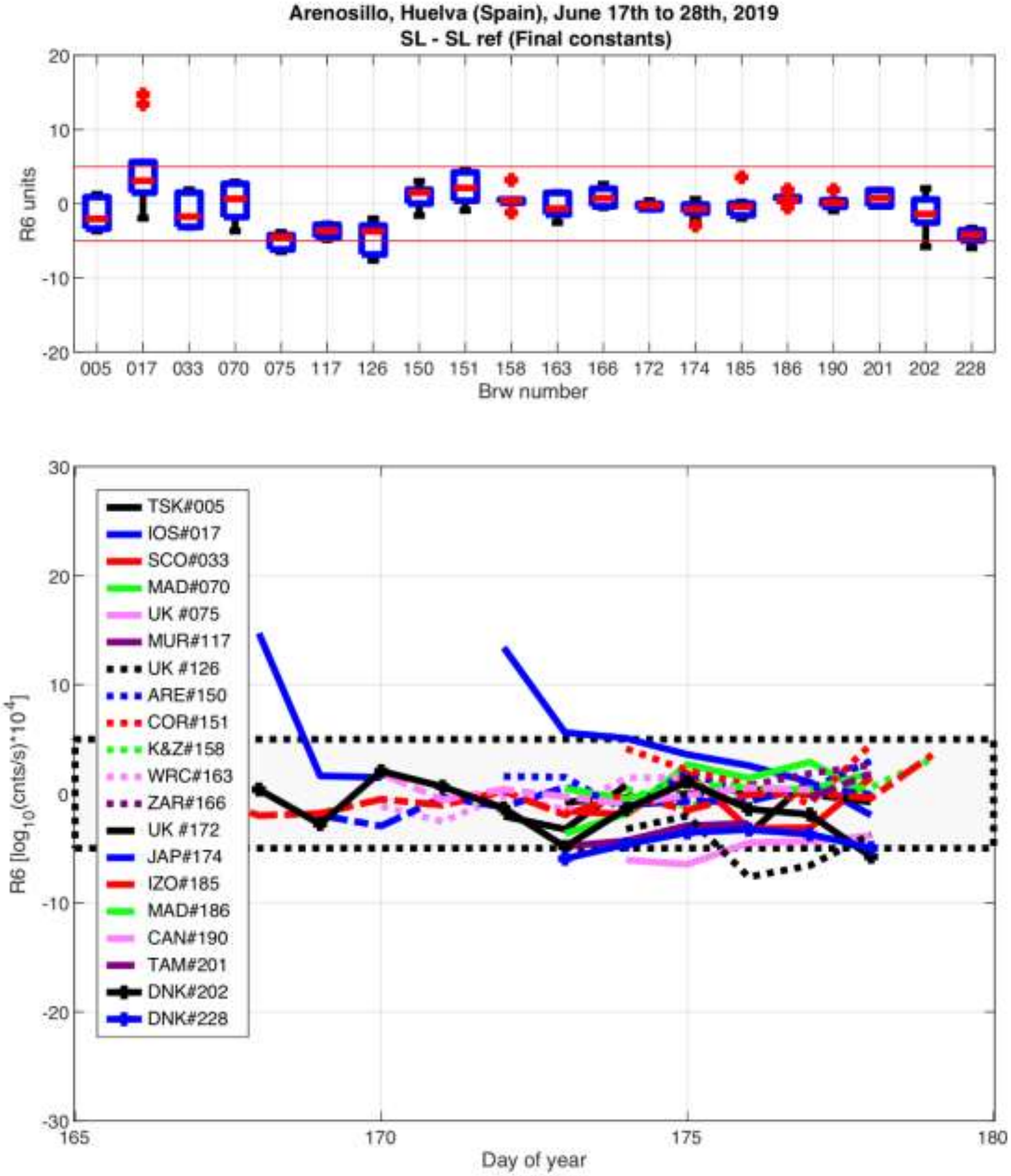


Figure 8. Standard lamp R6 ratio to R6 reference from the last calibration differences during the final days grouped by Brewer serial number (above) and as a function of time (below). The shadow area represents the tolerance range (±5 R6 units).

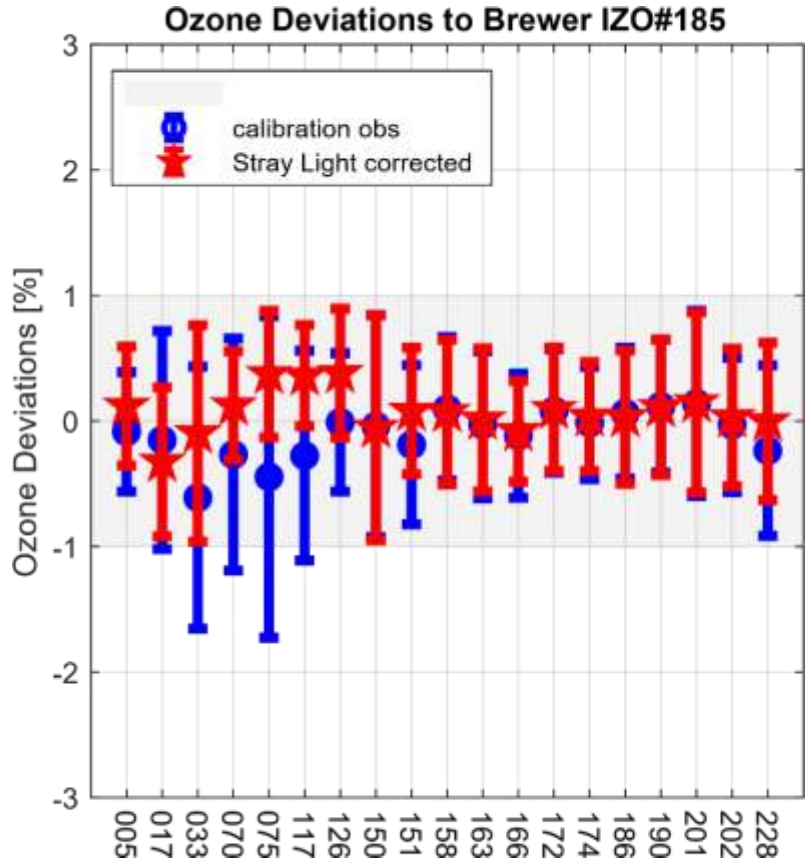


Figure 9. Ozone relative percentage differences of all El Arenosillo 2019 participating instruments with respect to the RBCC-E travelling standard IZO#185. Ozone measurements collected during the final period are reprocessed using the proposed calibration constants, with (red plots) and without (blue plots) stray light correction. Error bars represent the standard deviation.

Finally, in Figure 11 we show the individual differences, with and without applying the stray light correction, with respect to the reference instrument.

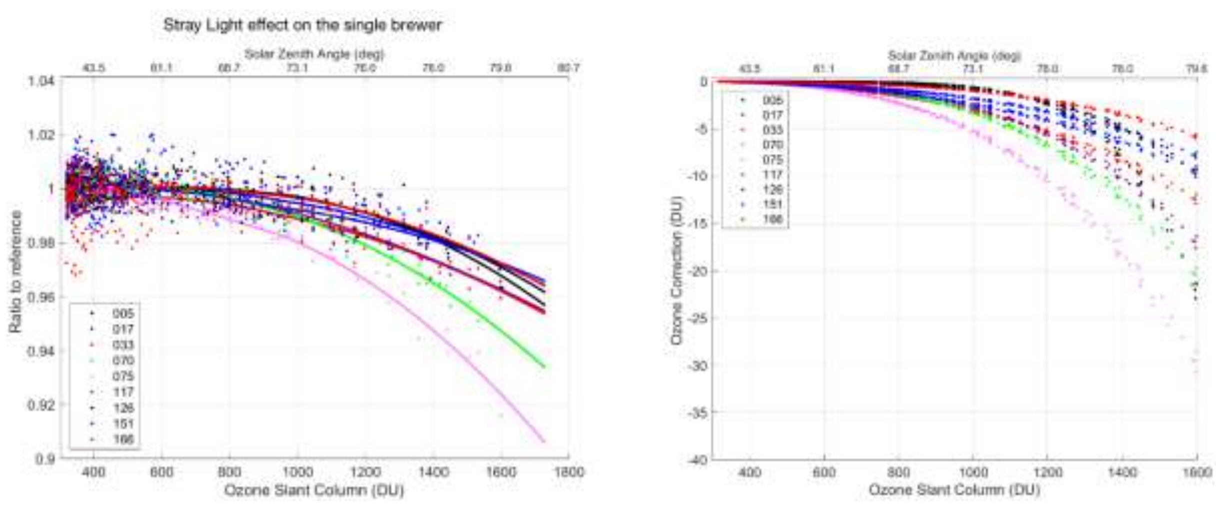


Figure 10. Ozone relative percentage differences of the single Brewers at El Arenosillo 2019 with respect to RBCC-E travelling standard IZO#185, showing the underestimation of the ozone measurements at solar Zenith angle above 70◦ (left) and the correction applied by the model in Dobson Units (right)

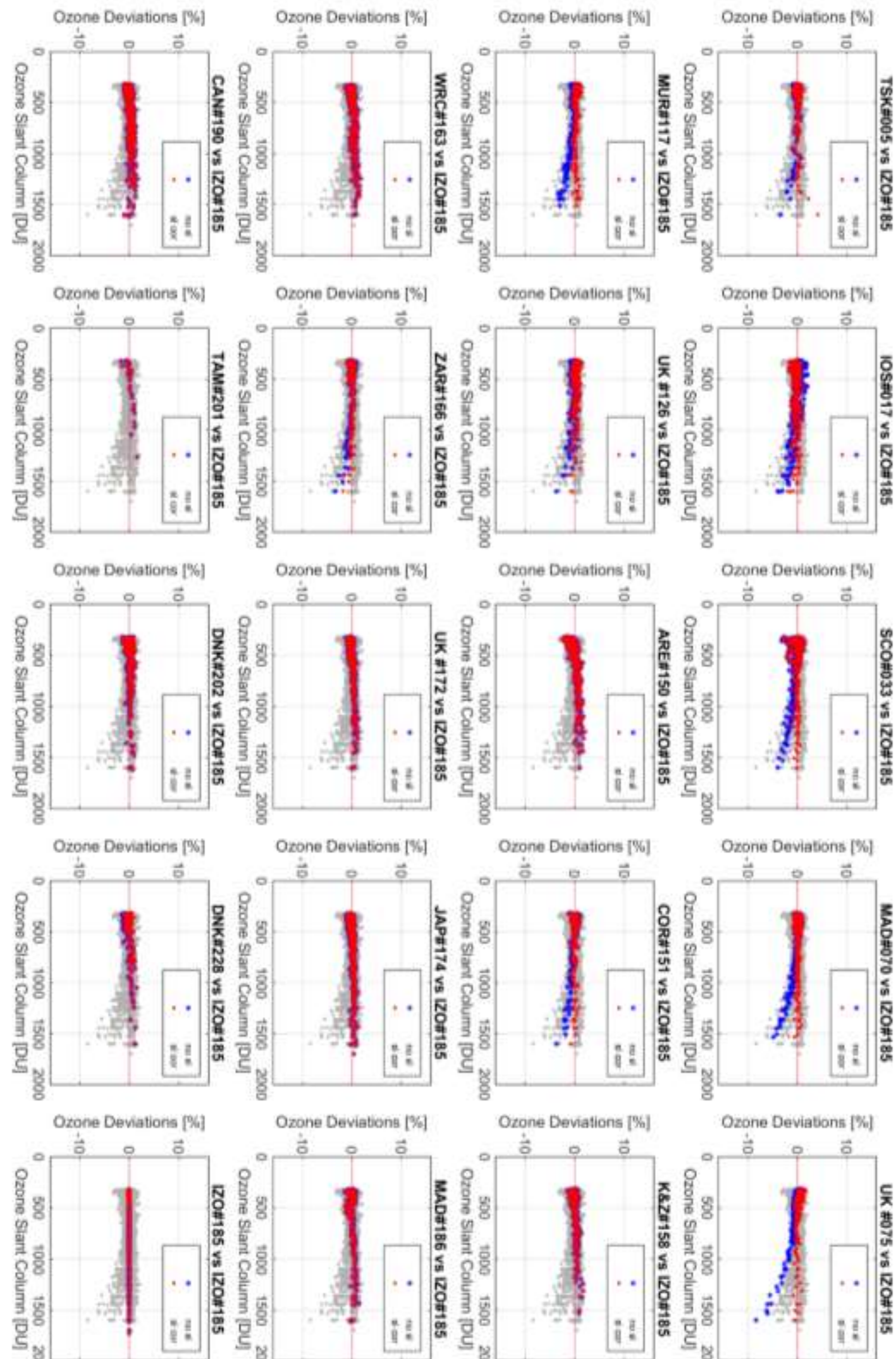


Figure 11. Final days ozone relative differences (percentage) of all Brewer instruments at El Arenosillo 2019 with respect to the RBCC-E travelling standard Brewer #185. Ozone measurements collected during the final period (after maintenance) were reprocessed using the final calibration constants, with (red stars) and without (blue stars) stray light correction. Grey dots mean ozone deviations for all participating instruments.

3. RBCC-E BREWER REFERENCE

The RBCC-E was established at the Izaña Atmospheric Research Centre in 2003. It comprises three MkIII.

Brewer spectrophotometers: a Regional Primary Reference (Brewer #157), a Regional Secondary Reference (Brewer #183) and a Regional Travelling Standard (Brewer #185). The WMO Scientific Advisory Group (WMOSAG) on Ozone authorized in 2011 the RBCC-E to transfer its own ozone absolute calibration.

The IZO CCL (Central Calibration Laboratory) reference transferred to the campaigns is the mean of the three independently calibrated Brewer instruments. This methodology can be summarized in three steps:

1. Instrumental characterization: Determination of linearity (Fountoulakis et al., 2016), temperature coefficients (Berjón et al., 2017), and filter attenuation (Redondas et al., 2018b).
2. The absorption coefficient is determined by measurements of the spectral lamp emission lines using the methodology of Gröbner et al. (1998) and Redondas et al. (2018b).
3. The ETC is onsite and determined by the Langley Method (León-Luis et al., 2018; Redondas, 2003; Ito et al., 2014; Redondas et al., 2014).

Points 1 and 2 of this methodology were tested and validated with the cooperation of Meteorological Institutes during the ATMOZ project, in which the RBCC-E participated together with the Dobson World and Brewer European Calibration Centres. The methodology used is described in Redondas (2003); Redondas et al. (2018b); Ito et al. (2014). The current status and maintenance of the RBCC-E is discussed in León-Luis et al. (2018).

Regarding the IZO CCL, it is worth noting that:

- The three instruments are calibrated independently. The Langley calibration is performed continuously onsite, except for the period from November to February when the required minimum air mass is not reached.
- The methodology, code and data used on the calibration are publicly available on the web, and so are reproducible. This includes the QA/QC protocol and the Triad Langley calibration.
- There is continuous assessment of the triad based on the comparison with the total ozone observations at Izaña Observatory provided with the FTIR, DOAS and ECC Ozonesonde techniques, which are recognized as part of the NDACC programme.

The calibration of the RBCC-E triad against the World Brewer Triad (WBT) was established by a yearly comparison with the travelling standard Brewer #017 operated and maintained by International Ozone Services Inc. (IOS) and checked at the station by means of the Langley extrapolation method. In addition, during the RBCC-E Brewer intercomparison campaigns, the travelling standard #185 is compared with other reference instruments wherever possible. These reference instruments include: IOS travelling reference #017, Brewer #145 – operated by Environment and Climate Change Canada (ECCC) – and the Kipp & Zonen travelling reference #158. The first two instruments provide a direct link to the WBT. A report of the comparison between references can be found in Redondas et al. (2018a). As suggested by WMOSAG, the link to the WBT will be conducted by joint Langley campaigns at Mauna Loa or Izaña stations, but this Langley intercomparison has not been possible since 2014.

Table 1. Calibration and instrument checklist of Brewer#185

Ref. checklist: B#185	*Description*	*Passed?*	*Value*	*Comments*
Calibration data				
Ref. of travelling standard	RBCC-E B#185			Own Langley
Is the standard calibrated?		Y		
% difference before travel			0.31	
% difference after travel			−0.13	
Calibration data				
HP/HG	Is the test repeatable to within 0.2 steps?	Y		
SH	Is the shutter delay correct?			
RS	Is the test within ± 0.003 from unity for illuminated slits and between 0.5 and 2 for the dark count?	Y		
Dead time	Is it between 28 and 45 ns for multiple-board Brewers and 16 and 25 ns for single-board ones?	N	29	
Standard lamp	Is SL ratio R6 within 5 units from calibration?	Y	362	
Standard lamp	Is SL ratio R5 within 10 units from calibration?	Y	490	

Table 2. Standard lamp R6 ratio for the reference instrument

	Date	*SL*	*se*	*N*
"Lab"	21 Oct 2018	364.6	0.1	92
"Maintenance"	08 Apr 2019	362.3	0.1	64
"Huelva 2019"	12 Jun 2019	361.9	0.4	15
"Izaña"	01 Jul 2019	365.8	0.1	118
"Grounded"	29 Oct 2019	363.9	0.1	182

3.1. RBCC-E BREWER REFERENCE SPECTROMETER CALIBRATION

As a preliminary and subsequent task during all the calibration campaign, the reference instrument (Brewer #185) was analysed in detail. In this way, its instrumental parameters – dead time (DT), temperature dependence, filter characterization as well as its ozone absorption coefficient calculated from a dispersion test – were compared with the values recorded prior and after the campaign. A summary with the main parameters of Brewer #185 checked before the instrument departed for the campaign is presented in Table 1. A detailed instrumental report is available in the QA/QC protocol.

However, the Langley technique is the best procedure to detect if the calibration of the instrument has changed. The stability of the instruments of the Triad are analysed in periods determined by events than can affect the calibration. During these periods the Langley Plot are averaged to obtain the ETC. During 2019, the events associated with Brewer#185 are summarized in Table 2 and plotted as vertical lines on the figure of the standard lamp record Figure 1 which include the intercomparison campaign.

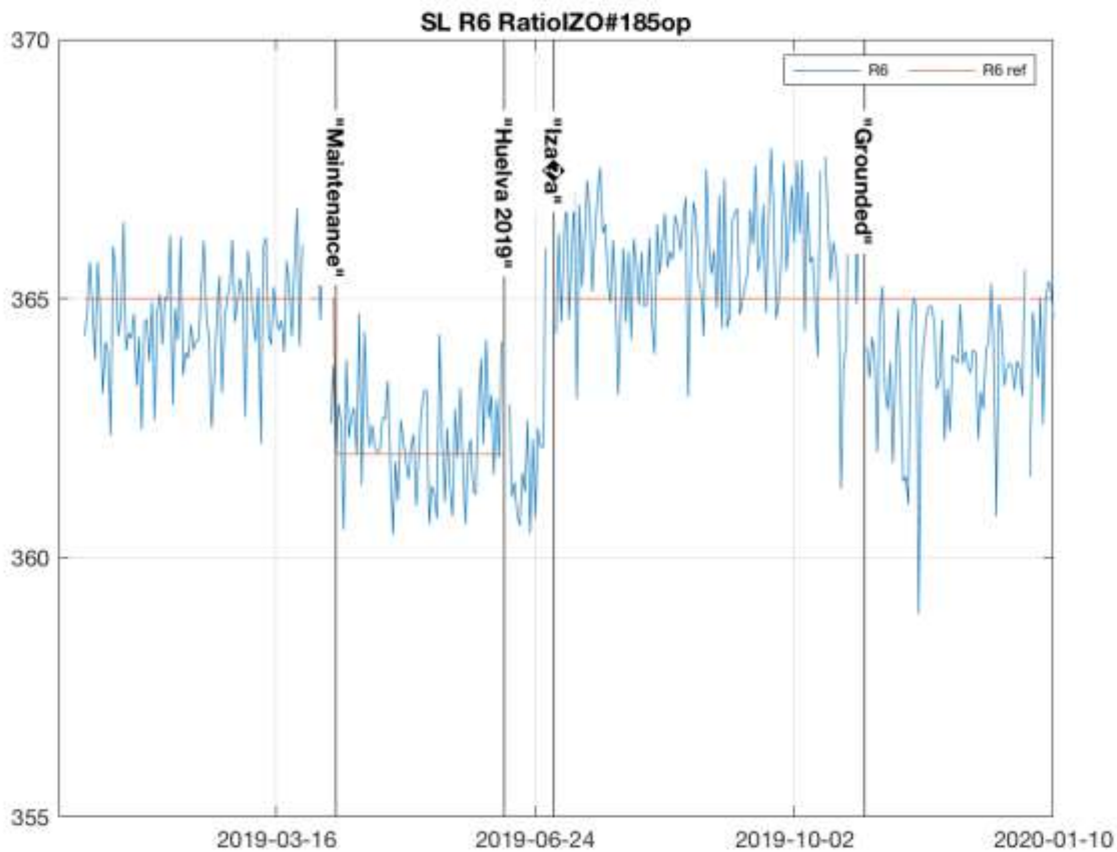


Figure 1. Standard lamp R6 measurements for Brewer #185 during the year. The vertical lines indicate relevant events in the instrument’s operation.

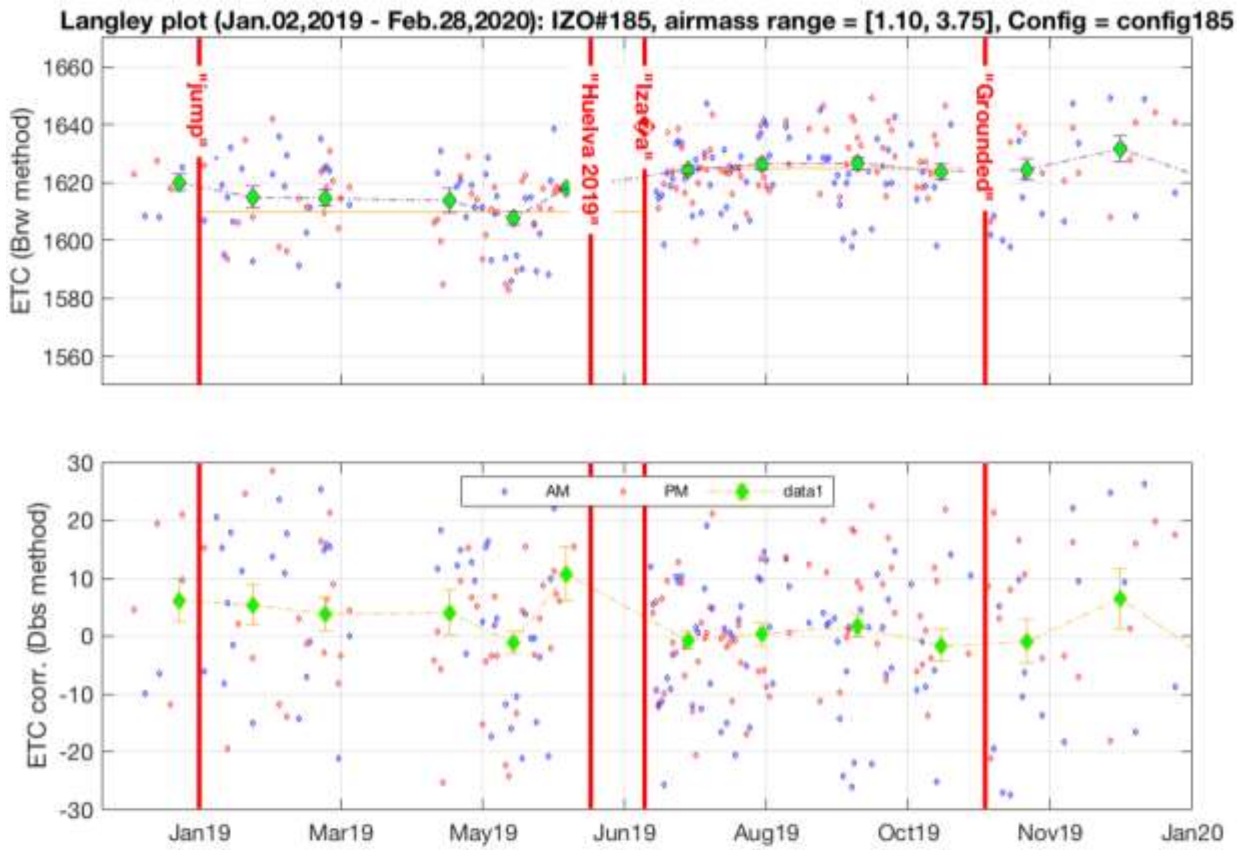


Figure 2. Langley ETC calculation for Brewer #185 during the year. The upper panel shows the Brewer Langley (standard) and the lower panel, the Langley using the Dobson method which gives the ETC correction. The blue (red) dots correspond to Langley results derived from AM (PM) data. The dashed line represents monthly means of both AM and PM Langley results. The vertical red lines indicate relevant events in the instrument's operation.

Table 3. Extraterrestrial constant of Brewer#185 (ETC) and the mean values and standard deviations and number of Langley events (N) before and after the El Arenosillo campaign, using the standard Langley method (brw) and Dobson method (dbs)

	labels	*ETC*	*brw*	*se*	*dbs*	*Se*	*N*
25 Jan 2019	"jump"	1610	1612	14	2	1.4	91
12 Jun 2019	"Huelva 2019"	1610	NaN	NaN	NaN	NaN	NaN
01 Jul 2019	"Izaña"	1625	1626	11.4	0	1	134
29 Oct 2019	"Grounded"	1625	1622	15.6	−3	2.2	52

Figure 2 shows the Langley values calculated before and after the campaign from the morning and afternoon observations made during this year, summarized in Table 3. As can be observed, the ETC values obtained before the campaign (1612) are very close to 1610, which were used as the operative ETC for this instrument but differ from the values after campaign (1625). The Standard lamp record (Figure 1) also reflects this change in the response and allows us to determine that the change was made during the return travel of the instrument. The travelling calibration used during the campaign must correspond with the period before the campaign.

The stability of Brewer#185 can also be checked by comparing it with the two Brewers of the RBCC-E Triad which remain at IZO, Brewers #157 and #183. This comparison is performed for two date ranges: before the campaign, using data from 15 April 2019 to 14 June 2019, and after the campaign, using data from 30 June 2019 to 15 August 2019. Figure 3 shows the daily relative difference with respect to the Triad's mean for the ozone observations of the three instruments before and after the intercomparison campaign. Figure 4 further shows the relative differences with respect to the Triad's mean by OSC range. The mean value for the whole Triad of the differences before the campaign is 0.31 and the corresponding value for the period after the campaign is −0.13. It is important to note that it is the mean of these reference instruments which was transferred during the Huelva 2019 campaign. The ozone measured by the travelling #185 is 0.5% higher than the other two members of the Triad (Figure 3). Therefore its calibration was slightly adjusted accordingly. At the campaign, the ETC of 1620 instead of 1610 was used with no other modifications to the calibration file.

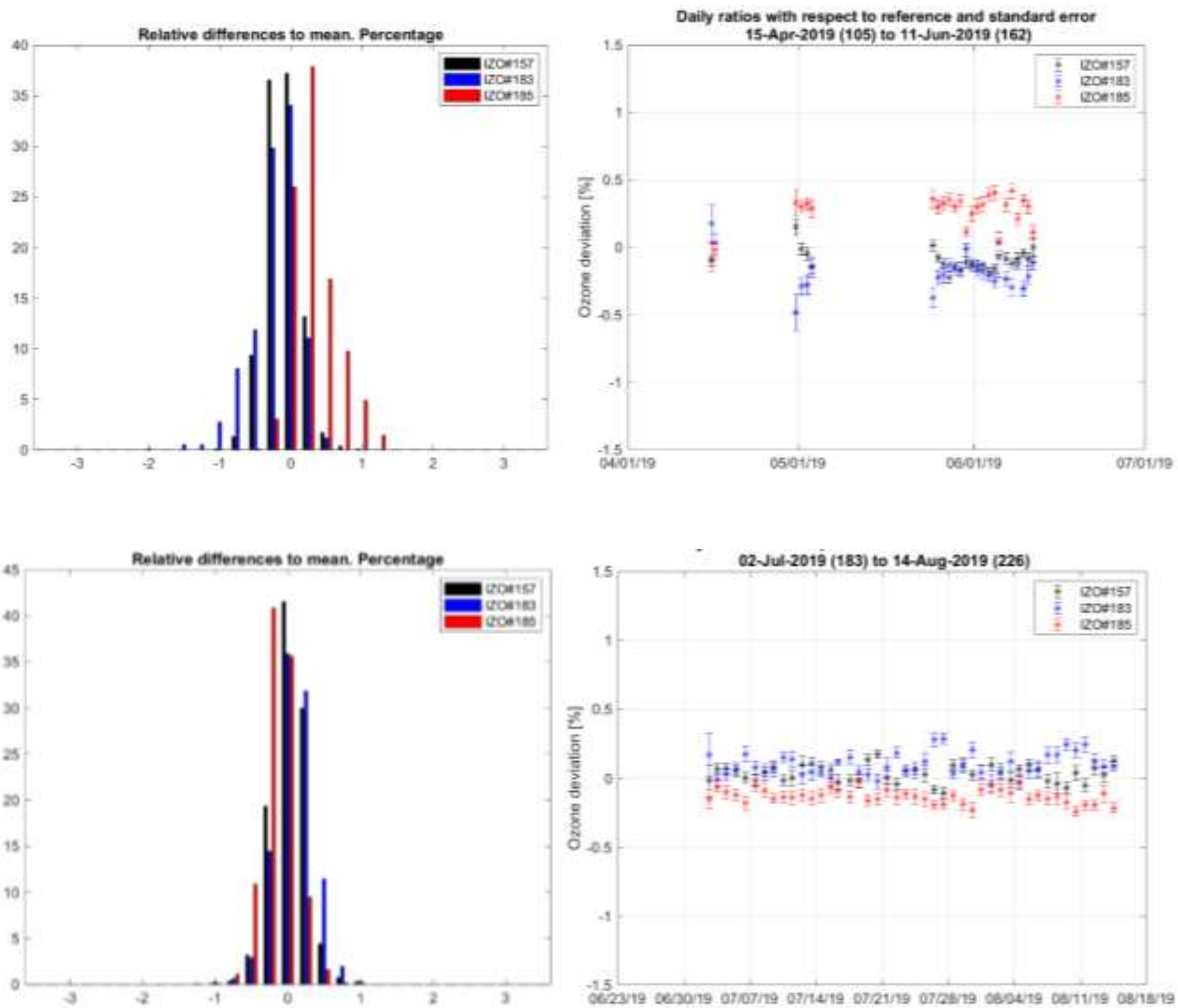


Figure 3. Deviations from near-simultaneous ozone measurements of RBCC-E Brewers (serial nos. #157, #183 and #185) to the Triad's mean (left) and temporal evolution of daily mean deviation of near-simultaneous ozone measurements (right). In the latter figure, the error bars represent the standard error. Data before (top) and after (bottom) the intercomparison

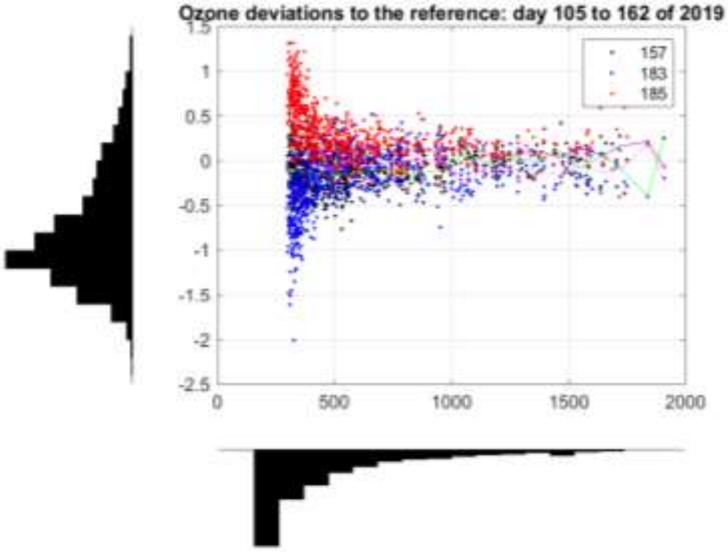
Table 4. ETC values calculated from comparison between the RBCC-E instruments

Instrument ID	*Initial Date*	*Final Date*	*ETC Operative*	*O_3 Abs. Coeff. Op.*	*ETC 1P*	*ETC 2P*	*O_3 Abs. Coeff. 2P*
157	15-Apr-2019	14-Jun-2019	1610.0	0.342	1615.7	1617.8	0.342
183	15-Apr-2019	14-Jun-2019	1610.0	0.342	1615.3	1613.9	0.342
157	30-Jun-2019	15-Aug-2019	1625.0	0.342	1620.7	1615.7	0.343
183	30-Jun-2019	15-Aug-2019	1625.0	0.342	1618.3	1622.8	0.341

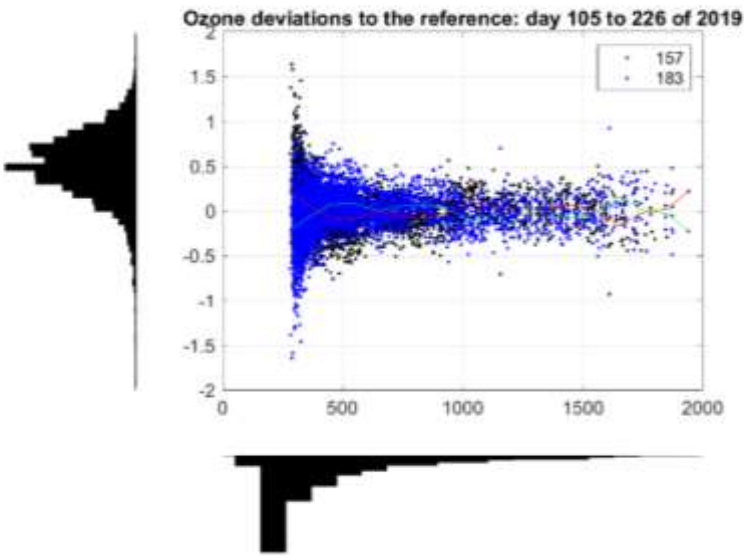
Table 4 shows the ETC values calculated from 1-point and 2-point methods when Brewer #185 is calibrated from the other two instruments of the RBCC-E Triad. These results can be compared to the operative values of the ETC and ozone absorption coefficient, which are also included in Table 4. This calibration shows a very good agreement between the independent calibrations obtained by Langley and the cross calibration between the reference instruments. Finally, to show the stability of the Brewers which remained at IZO, Figure 5 shows the daily relative difference of #157 and #183 with respect to their mean for the whole period analysed, from 15 April to 15 August 2019.

3.2. SUMMARY

- The reference triad shows a good agreement before and after the campaign with mean differences of 0.31% before and −0.13% after the campaign.
- The calibration of the travelling changes after the campaign. This change is produced "after" the campaign as the standard lamp test record suggests.
- This calibration change is confirmed by the Langley of the instrument and the cross calibration and comparison with the other two Triad members.
- The travelling #185 measure was +0.5% above the mean of the reference. The calibration used in the campaign was adjusted during the campaign to reflect the mean of the three referenced instruments.



OSC range	B#157	B#183	B#185
All	-0.1 +/-0.23	-0.2 +/-0.34	0.3 +/-0.31
< 350	-0.1 +/-0.31	-0.6 +/-0.38	0.7 +/-0.32
< 500	-0.1 +/-0.23	-0.2 +/-0.27	0.4 +/-0.25
< 700	-0.1 +/-0.18	0 +/-0.2	0.2 +/-0.17
< 1000	-0.1 +/-0.16	0 +/-0.2	0.1 +/-0.15
< 1200	0 +/-0.13	-0.2 +/-0.17	0.1 +/-0.14
> 1200	0 +/-0.18	-0.1 +/-0.16	0.1 +/-0.18



OSC range	B#157	B#183	B#185
All	0 +/-0.23	0.1 +/-0.27	-0.1 +/-0.22
< 350	0.1 +/-0.32	0 +/-0.35	-0.1 +/-0.3
< 500	0 +/-0.22	0.2 +/-0.26	-0.2 +/-0.22
< 700	0 +/-0.19	0.1 +/-0.21	-0.2 +/-0.19
< 1000	0 +/-0.17	0.1 +/-0.2	-0.1 +/-0.15
< 1200	0.1 +/-0.18	0 +/-0.22	-0.1 +/-0.14
> 1200	0 +/-0.21	0.1 +/-0.22	-0.1 +/-0.19

Figure 4. Deviation from near-simultaneous ozone measurements by OSC. Data before (top) and after (bottom) the intercomparison

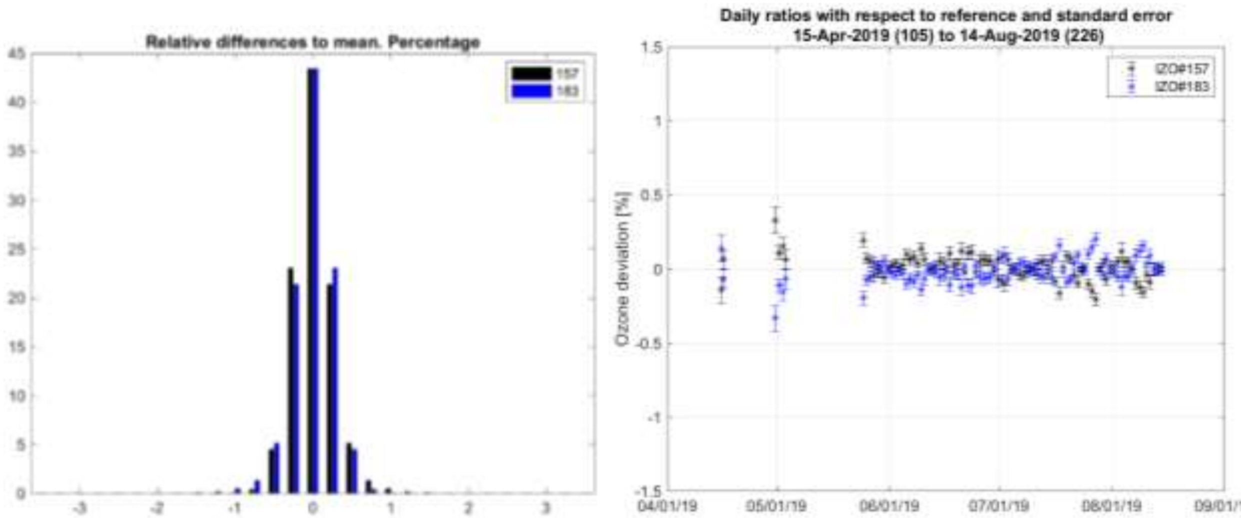


Figure 5. Deviations from near-simultaneous ozone measurements of Brewers #157 and #183 with respect to their mean (left) and temporal evolution of daily mean deviation from near-simultaneous ozone measurements (right). In the latter figure, the error bars represent the standard error. Data shown cover the whole period analysed in this report.

4. BREWER TSK#005

4.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019 at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer TSK#005 participated in the campaign from 17 to 26 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer TSK#005 correspond to Julian days 166–177.

For the evaluation of the initial status, we used 112 simultaneous direct sun (DS) ozone measurements from days 166 to 171. For final calibration purposes, we used 376 simultaneous DS ozone measurements taken from day 172 to 177.

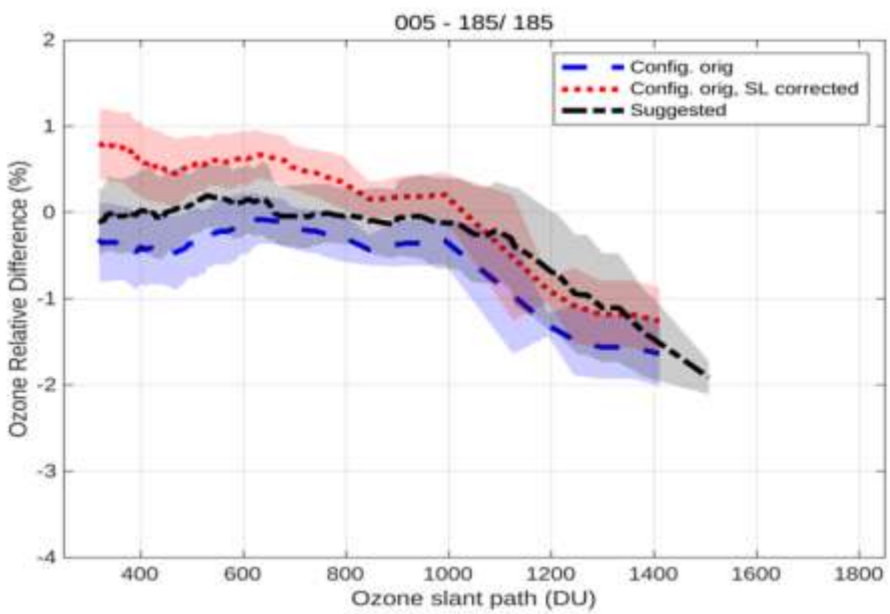


Figure 1. Mean DS ozone column percentage difference between Brewer TSK#005 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current Instrument Constant File (ICF) (ICF15117.005, blue dashed line) produces ozone values with an average difference of approx. 1% with respect to the reference instrument. The SL correction (red dotted line in Figure1) slightly improves the comparison with Brewer IZO#185.

As a Mk. II model, Brewer TSK#005 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 0.4.6).

The lamp test results from Brewer TSK#005 are quite noisy, especially since the fall of 2018, when a downward trend also becomes quite noticeable (see Figure 3). During the present campaign, after the maintenance on day 171, the standard lamp ratios stabilized around values 1818 and 3530 for R6 and R5 respectively. These values have been calculated with the current temperature coefficients, which seem to be performing reasonably well. Note however that the noise of the R6 data precludes a detailed analysis of the temperature.

Regarding other instrumental tests, the CZ scan of the 296.728 nm mercury line is slightly outside tolerance limits. Results of the dead time (DT) tests are quite noisy and they also seem to show a small difference of 1 ns, with the DT value changing from $3.8 \cdot 10^{-8}$ s to $3.7 \cdot 10^{-8}$ s. However, we have decided to keep the current value. Results from CI scans are inconclusive because of the maintenance carried out in the SL housing. All the other parameters show reasonable results.

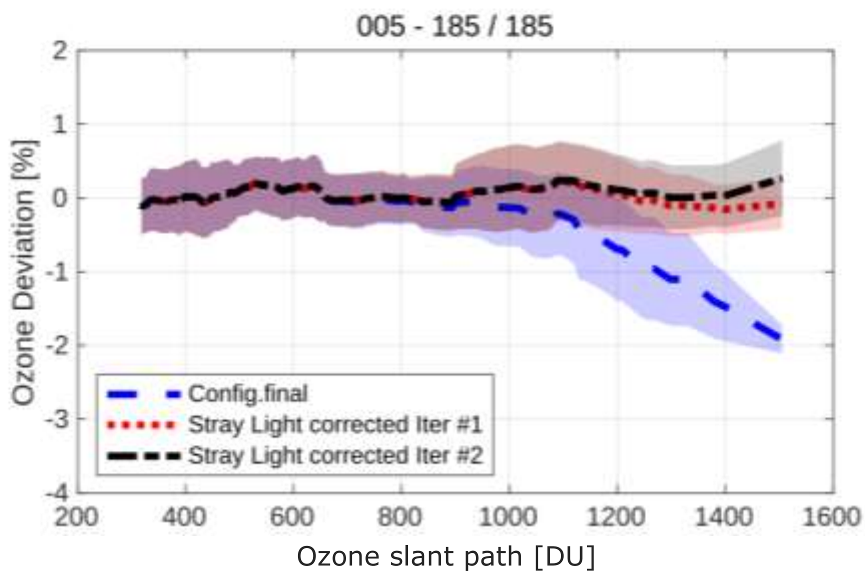


Figure 2. Mean DS ozone column percentage difference between Brewer TSK#005 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are show in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

Concerning the filter's performance, we do not suggest the application of any correction. There are few data points from the filter tests in the FIOAVG file and the comparison with the reference instrument is reasonably good without the application of filter corrections.

The sun scan tests (SC) at the instrument's station before the campaign and those performed during the first days of the intercomparison confirm the current cal step value of 159 within a step error of ±1.

We do not suggest changing the ozone absorption coefficient of 0.3336, because the cal step has not changed and because it produces a good comparison with the reference instrument, IZO#185.

Taking this into account, we suggest few changes to the configuration of Brewer TSK#005.

4.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer TSK#005 have been quite noisy over the last 2 years, especially since November 2018. The old R6 reference value was 1838 and we suggest updating it to 1818.
2. We suggest a new R5 reference value of 3530.
3. For Brewer TSK#005, stray light has an important effect on measurements taken at large ozone slant paths. We suggest the application of a stray light correction with parameters $k = a = -6.4$, and $s = b = 8.72$.
4. Finally, we suggest updating the ETC value from 3030 to 3020.

4.1.2. External links

Configuration file
http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/005/ICF17219.005

Calibration report
https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=758913418

Calibration reports detailed
Historic and instrumental
http://rbcce.aemet.es/svn/campaigns/are2019/latex/005/html/cal_report_005a1.html

Temperature & filter
http://rbcce.aemet.es/svn/campaigns/are2019/latex/005/html/cal_report_005a2.html

Wavelength
http://rbcce.aemet.es/svn/campaigns/are2019/latex/005/html/cal_report_005b.html

ETC transfer
http://rbcce.aemet.es/svn/campaigns/aro2019/latex/005/html/cal_report_005c.html

4.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

4.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance is noisy but quite stable until approx. November 2018, when the noise increases, and a downward trend becomes very noticeable. These changes are also very noticeable in the lamp's intensity, as shown in Figure 5. During the campaign, after the maintenance on day 171, the R6 and R5 values stabilized at approx. 1818 and 3530. Note that, despite all the noise observed in R6, it only changes by 20 units from the reference value provided in the previous campaign (1838).

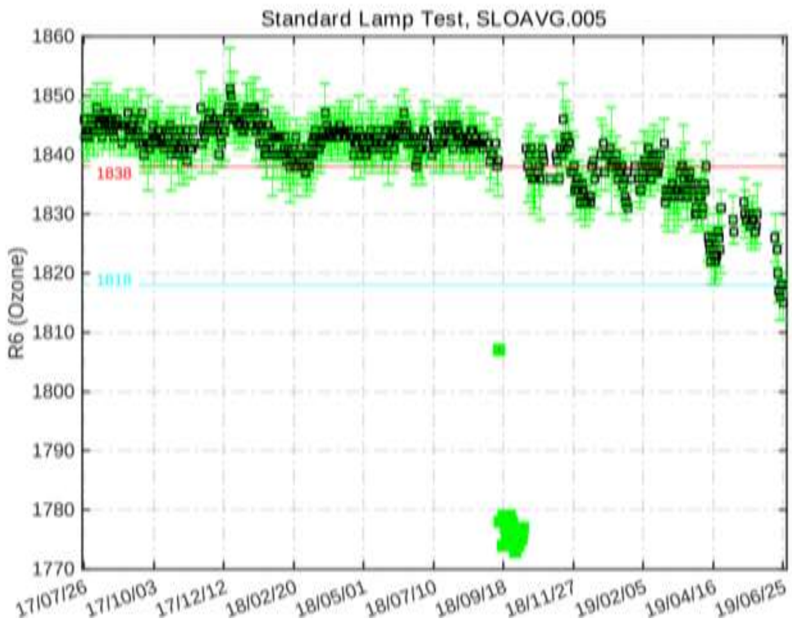


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

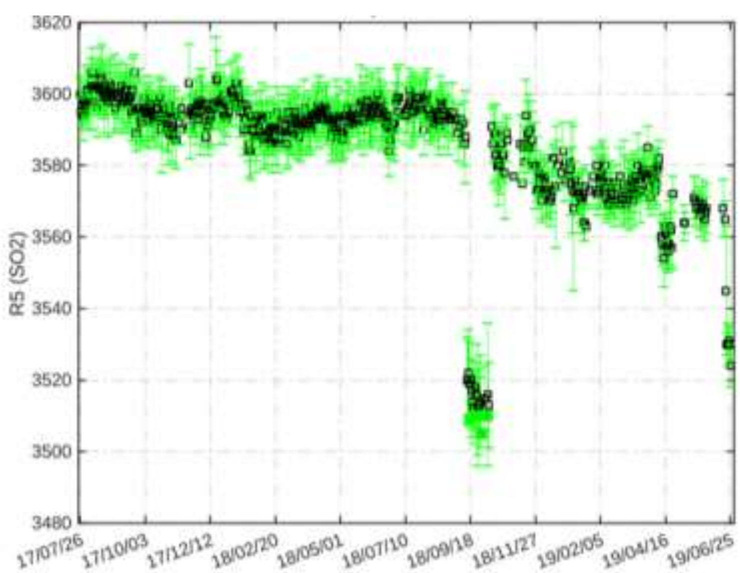


Figure 4. Standard lamp test R5 (sulphur dioxide) ratios

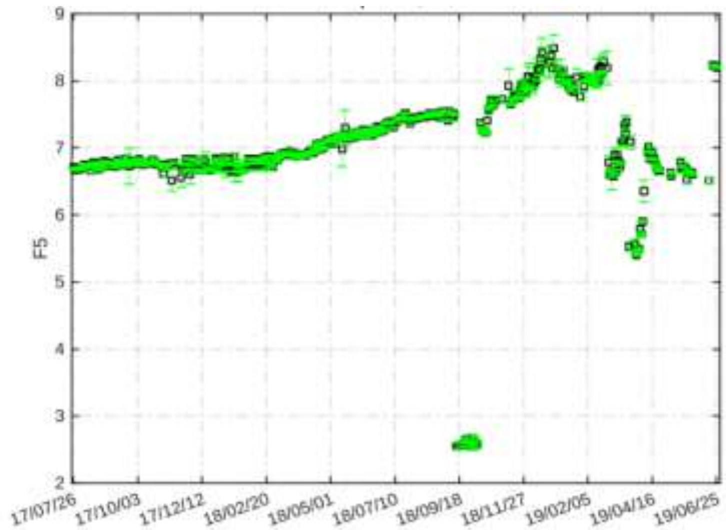


Figure 5. SL intensity for slit five

4.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 6). Note that the Hg slit is noisier that the others but inside of the normal tolerance range for this slit.

As shown in Figure 7, the results of the DT tests are quite noisy. The current DT reference value of $3.8 \cdot 10^{-8}$ seconds is slightly larger than the value recorded during the calibration period ($3.7 \cdot 10^{-8}$ s). Taking into account a ±1 ns error, we suggest keeping the current value.

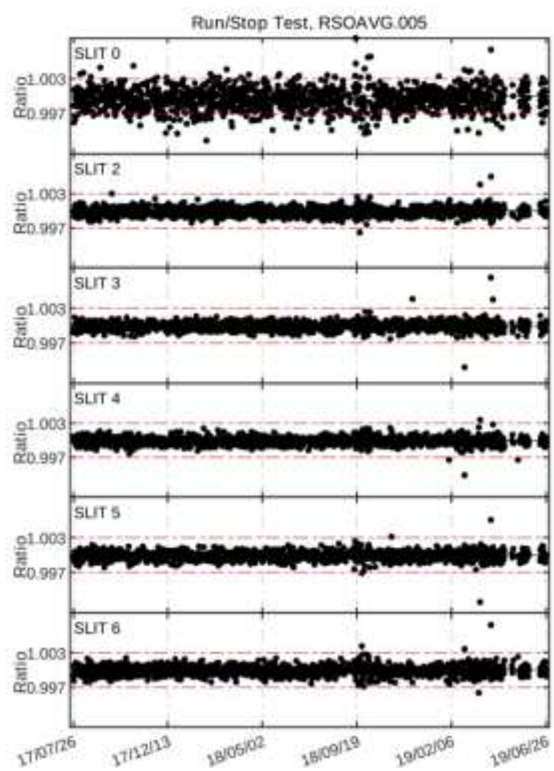


Figure 6. Run/stop test

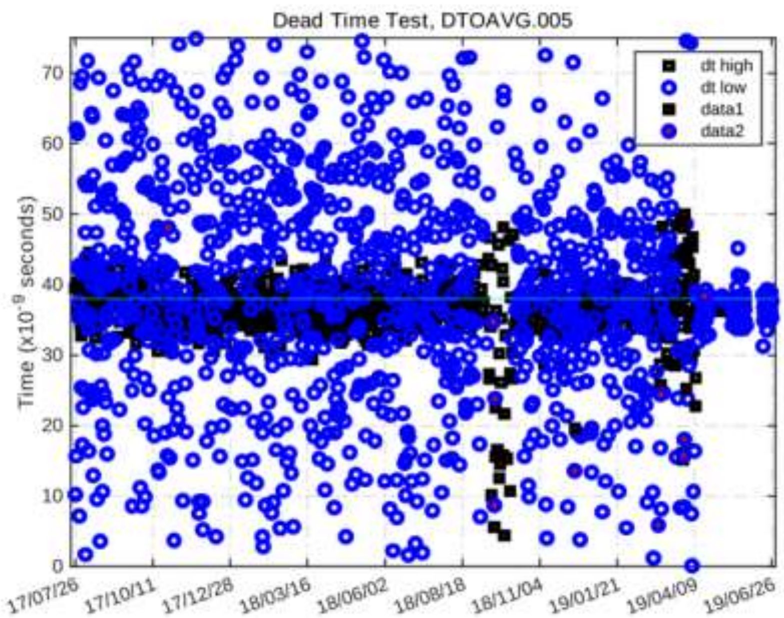


Figure 7. Dead time test. The horizontal line marks the current value, which we suggest keeping in the final ICF for the present campaign.

4.2.3. Analogue test

Figure 8 shows that the +5 voltage is very close to the lower tolerance limit and is also quite noisy. The SL current also shows some noise.

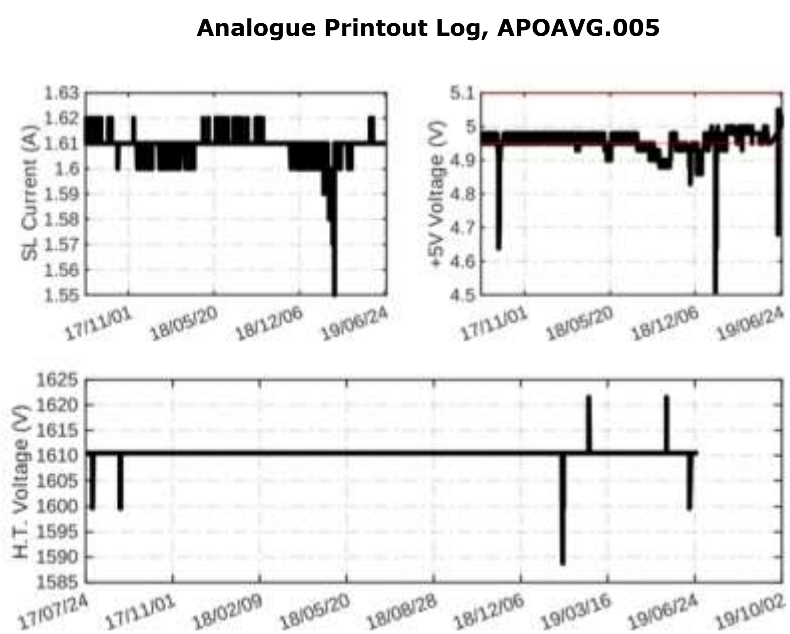


Figure 8. Analogue voltages and intensity

4.2.4. Mercury lamp test

The internal mercury lamp intensity also shows the noise and change in November 2018 already mentioned, see Figure 9. There is a correlation between the lamp intensity and the temperature up to the beginning of 2018, but not afterwards.

HgOut Test, HGOAVG.005

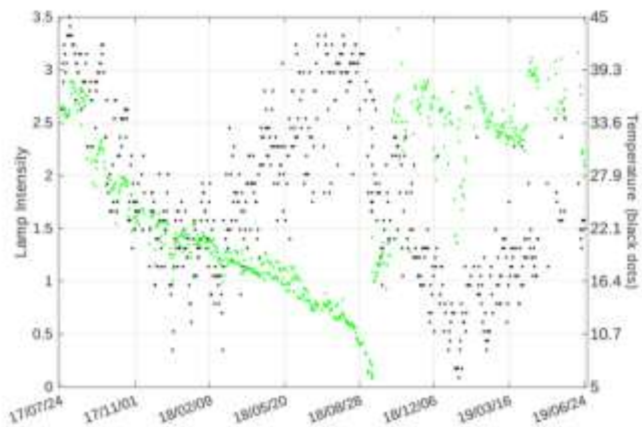


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

4.2.5. CZ scan on mercury lamp

We analysed the scans performed on the 296.728 nm mercury line in order to check both the wavelength settings and the slit function width. As a reference, the calculated scan peak in wavelength units should be within 0.013 nm of the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of CZ scans performed on Brewer TSK#005 during the campaign shows that the peak of the calculated scans is outside the accepted tolerance range. Regarding the slit function width, results are good with a Full Width at Half Maximum (FWHM) parameter lower than 0.65 nm.

HS scan on 2967.28 line. Brw#005

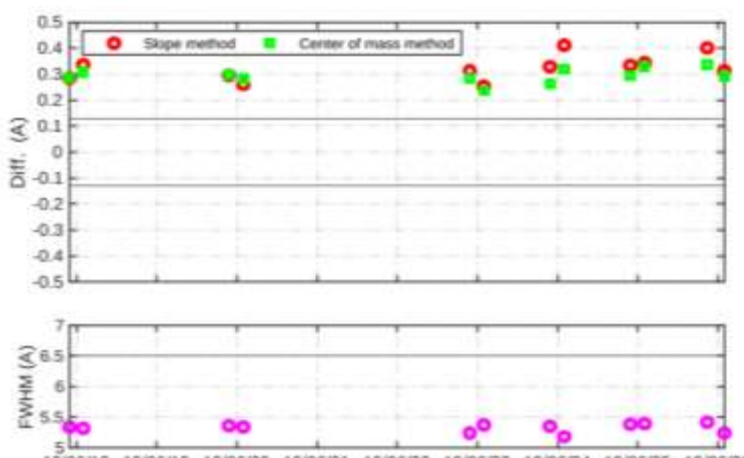


Figure 10. CZ scan on 296.728 nm Hg line. Upper figure shows differences with respect to the reference line (solid lines represent the limit ±0.013 nm) as computed by two different methods: slopes method (red circles) and centre of mass method (green squares). Lower figure shows a Full Width at Half Maximum value for each scan performed. Solid line represents the limit 0.65 nm.

4.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer TSK#005 CI scans performed during the campaign relative to the scan CI16819.005. As can be observed, there was a noticeable change on day 171 (20 June), which might be related to the maintenance carried out on the housing of the standard lamp. The results of this test are therefore inconclusive.

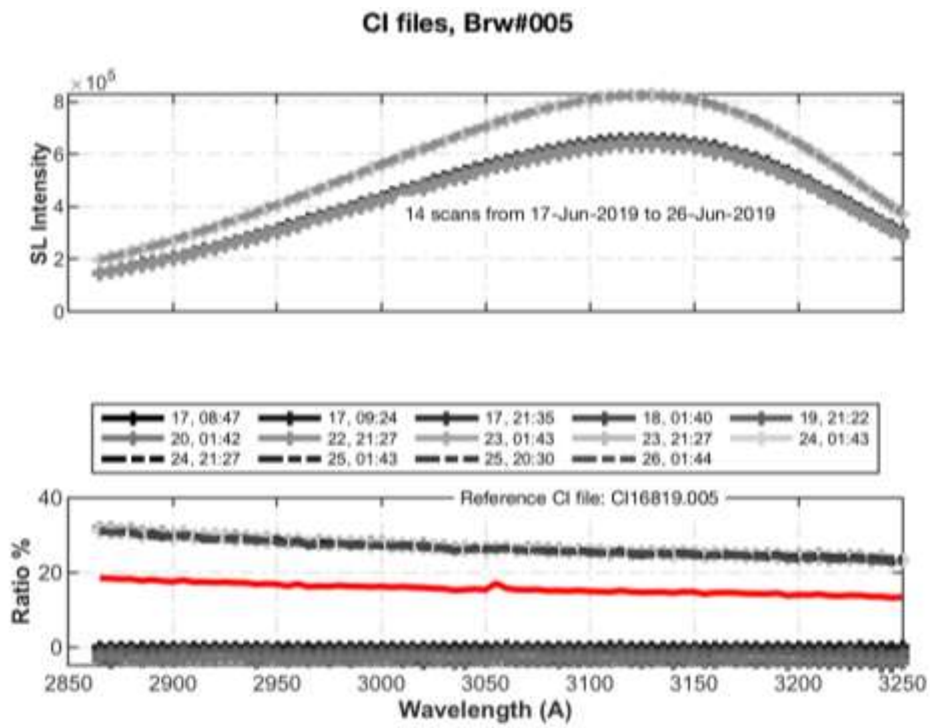


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

4.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this, we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

As shown in Figure 12 (temperature range from 19 °C to 34 °C), the current coefficients do an excellent job at reducing the temperature dependence, performing on a similar level as the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 13 and 14, the current and new coefficients seem to perform similarly. The data however is rather noisy, making it difficult to draw clear conclusions. In the end, we suggest keeping the current temperature coefficients.

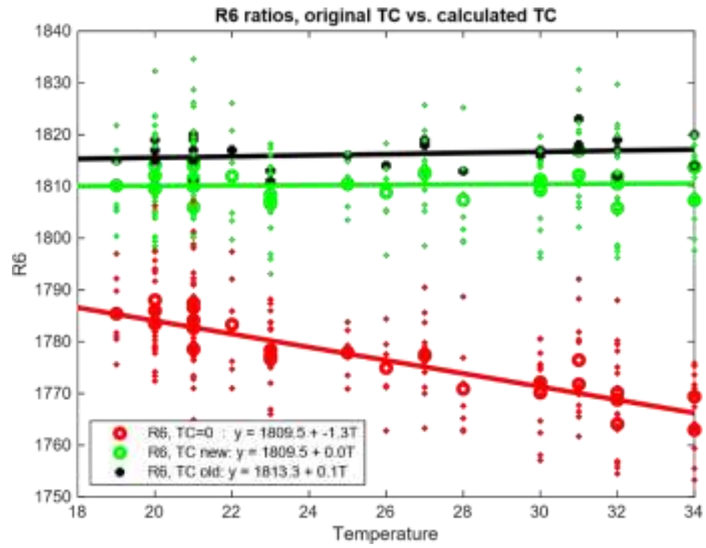


Figure 12. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown corresponds to the present campaign.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2.

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	−0.6400	−1.4000	−2.0600	−3.5500
Calculated	0.0000	−0.4500	−0.9900	−1.6200	−2.8900
Final	0.0000	−0.6400	−1.4000	−2.0600	−3.5500

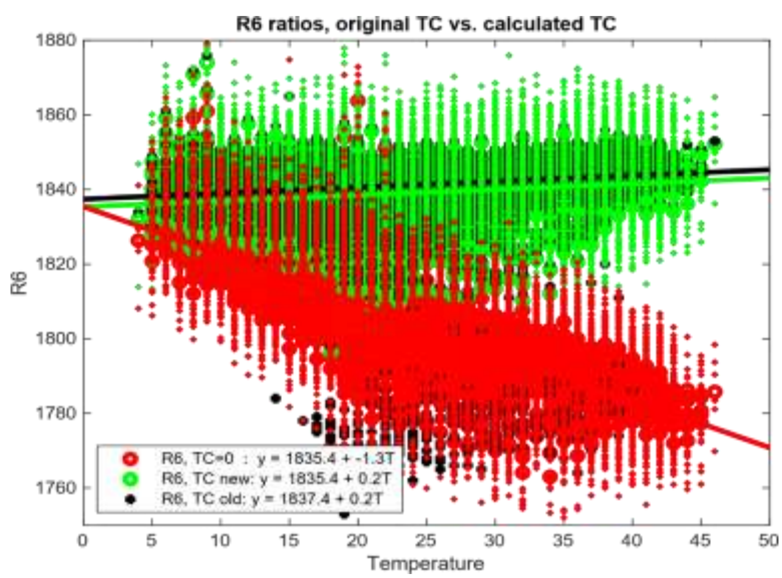


Figure 13. Same as Figure 12 but for the whole period between calibration campaigns

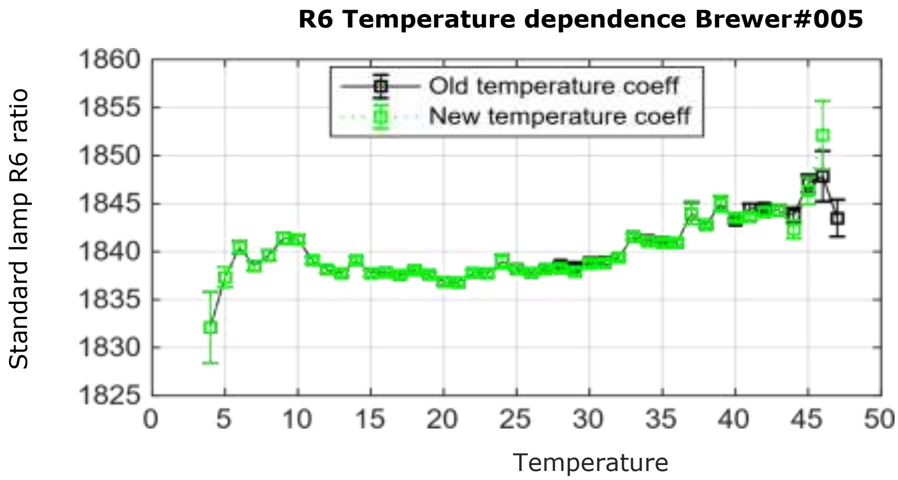


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

4.4. ATTENUATION FILTER CHARACTERIZATION

4.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 27 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

27 FI tests is a low number of measurements and the differences between the mean and median values, as well as the large confidence intervals, show that the data is also noisy. Taking into account the relative ozone difference with respect to the reference Brewer IZO#185, we suggest not applying any filter corrections.

Table 2. ETC correction due to filter non-linearity. Median value mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-1	-2	-10	4	-3
ETC Filt. Corr. (mean)	-0.9	0.4	-8.6	1	-3.4
ETC Filt. Corr. (mean 95% CI)	[-11.7 7.1]	[-6.6 7.3]	[-15.4 -1.3]	[-6.2 7.4]	[-13.4 5.9]

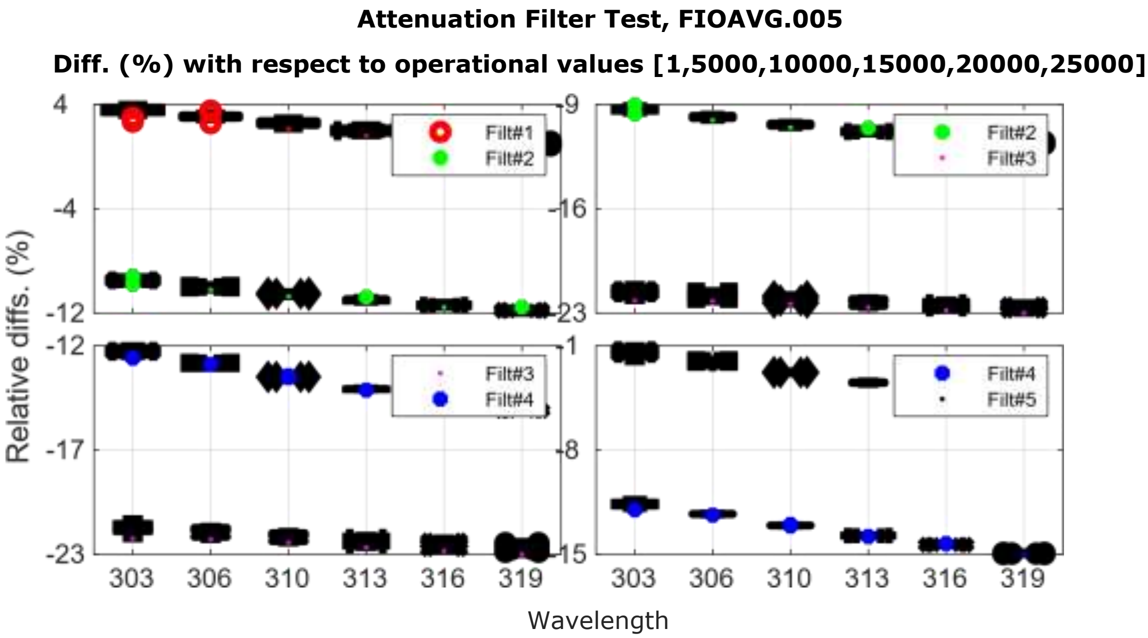


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

4.5. WAVELENGTH CALIBRATION

4.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to ensure that the correct wavelength setting is used during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts (≈ ± 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

During the campaign, sun scan (SC) tests covering an ozone slant path range from 400 to 1000 DU were carried out (see Figure 4). Within an error of ±1 step, the calculated cal step number (CSN) was the same as in the current configuration (159). SC tests performed at the station before the campaign also confirm the current cal step. No update of the cal step is thus necessary.

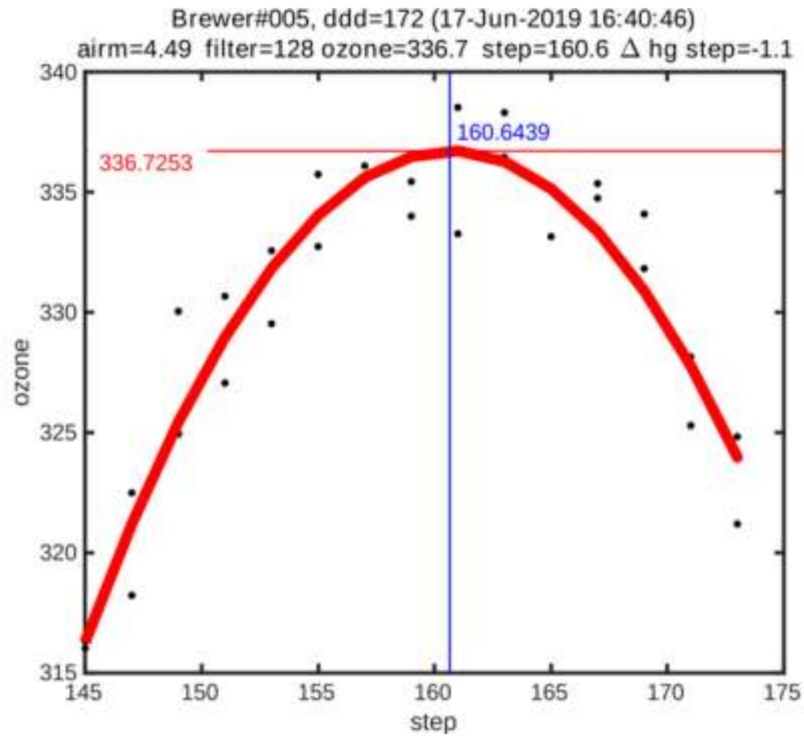


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

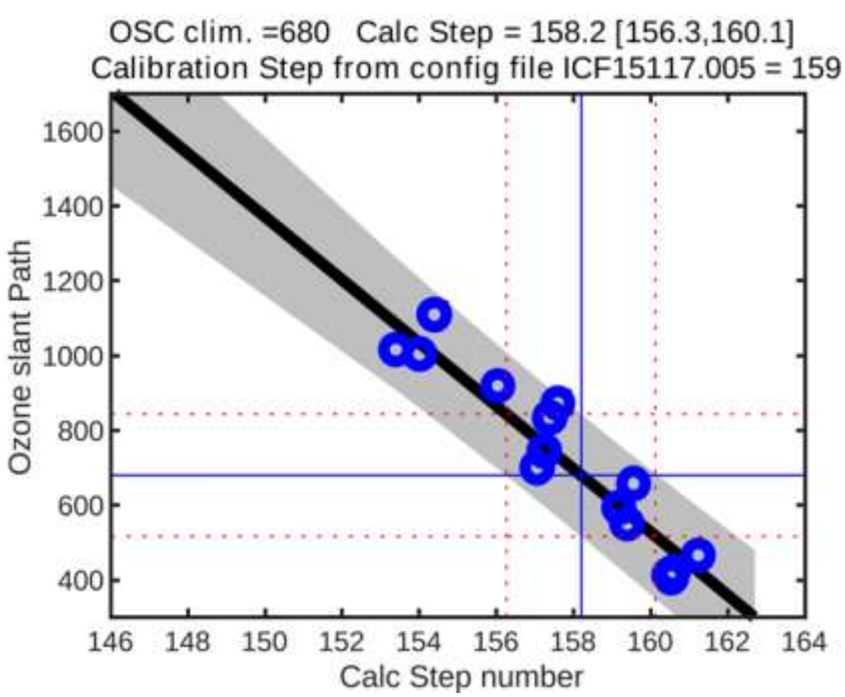


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 (horizontal solid line). The blue area represents a 95% confidence interval.

4.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

Regarding the current campaign, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ±1 step.

With no changes to the cal step, we suggest retaining the current ozone absorption coefficient of 0.3336 in the final ICF (ICF17219.005) for the present campaign. As shown in the next section, this value of the ozone absorption coefficient produces a good comparison with the reference instrument during the present campaign.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	159	0.3336	2.4400	1.1065
30 May 2015	159	0.3427	3.1047	1.1505
02 Jun 2017	159	0.3394	3.1704	1.1445
07 Jun 2017	159	0.3411	3.1343	1.1490
23 Jun 2019	159	0.3401	3.1736	1.1458
Final	159	0.3336	2.4400	1.1065

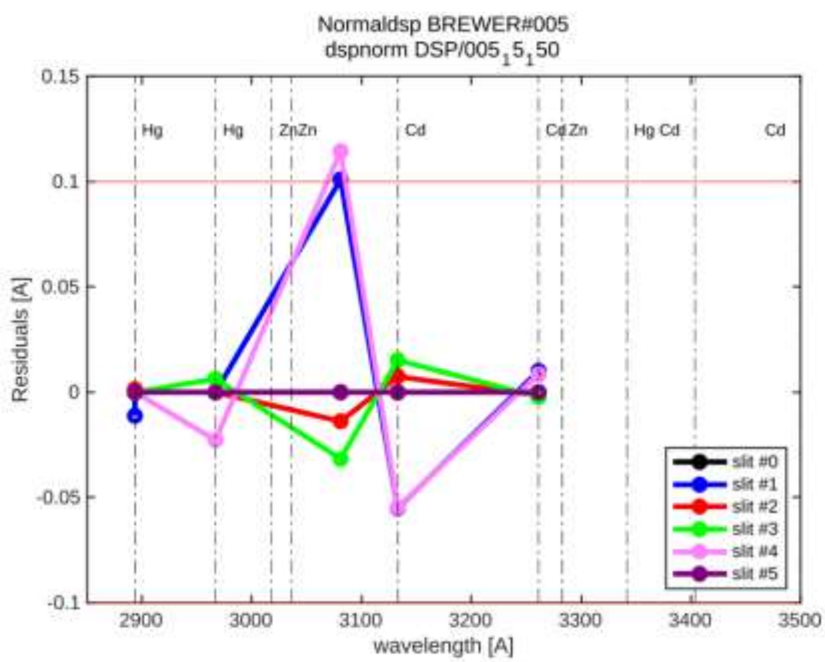


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 158	*slit#0*	*Slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3022.64	3062.9	3100.48	3134.95	3168	3200.08
Res(A)	3.8526	5.3419	5.2972	5.4348	5.4317	5.2308
O3abs(1/cm)	3.0677	1.7833	1.0051	0.6774	0.37492	0.29386
Ray abs(1/cm)	0.51182	0.4833	0.45848	0.43714	0.41785	0.40016
SO2abs(1/cm)	8.3819	5.6436	2.4008	1.9101	1.0551	0.60972
step= 159	slit#0	Slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3022.71	3062.97	3100.55	3135.02	3168.07	3200.15
Res(A)	3.8527	5.3418	5.2971	5.4347	5.4316	5.2307
O3abs(1/cm)	3.0642	1.7818	1.0049	0.6771	0.37499	0.2934
Ray abs(1/cm)	0.51177	0.48325	0.45844	0.4371	0.41782	0.40013
SO2abs(1/cm)	8.3646	5.6656	2.4082	1.8987	1.0562	0.60756
step= 160	slit#0	Slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3022.78	3063.04	3100.62	3135.09	3168.13	3200.21
Res(A)	3.8527	5.3417	5.297	5.4346	5.4316	5.2306
O3abs(1/cm)	3.0605	1.7804	1.0046	0.67675	0.37505	0.2929
Ray abs(1/cm)	0.51172	0.4832	0.4584	0.43706	0.41778	0.40009
SO2abs(1/cm)	8.3459	5.6863	2.4159	1.8875	1.0574	0.60532
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
158	0.34118	9.0984	3.1635	1.149	0.3523	0.34356
159	0.34014	9.0962	3.1736	1.1458	0.35132	0.34254
160	0.33907	9.0939	3.1824	1.1425	0.3503	0.3415

4.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as slit #1 at the Umkehr setting. The Umkehr offset calculated was 1640. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 159	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3023	3063	3101	3135	3168	3200
Res(A)	3.8527	5.3418	5.2971	5.4347	5.4316	5.2307
O3abs(1/cm)	3.0642	1.7818	1.0049	0.6771	0.37499	0.2934
Ray abs(1/cm)	0.51177	0.48325	0.45844	0.4371	0.41782	0.40013
step= 1640	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3125	3164	3200	3233	3265	3296
Res(A)	3.9432	5.2082	5.16	5.2961	5.3267	5.0844
O3abs(1/cm)	0.69606	0.39464	0.29371	0.12119	0.06075	0.033331
Ray abs(1/cm)	0.44333	0.42025	0.40013	0.38275	0.36708	0.35265

4.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where *F* are the measured double ratios corrected for Rayleigh effects, *α* is the ozone absorption coefficient, *μ* is the ozone air mass factor, and *ETC* is the extraterrestrial constant. The *F*, *α* and *ETC* parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of Equation 1, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light. In this case, the ETC distribution (see Figure 41) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content by air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column.

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and *k* and *s* are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

4.6.1. Initial calibration

For the evaluation of the initial status of Brewer TSK#005, we used the period from days 166 to 171 which correspond with 112 near-simultaneous direct sun ozone measurements. As shown in Figure 19, the initial calibration constants produce an ozone value approx. 1% lower than those of the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results are improved (see Table 6).

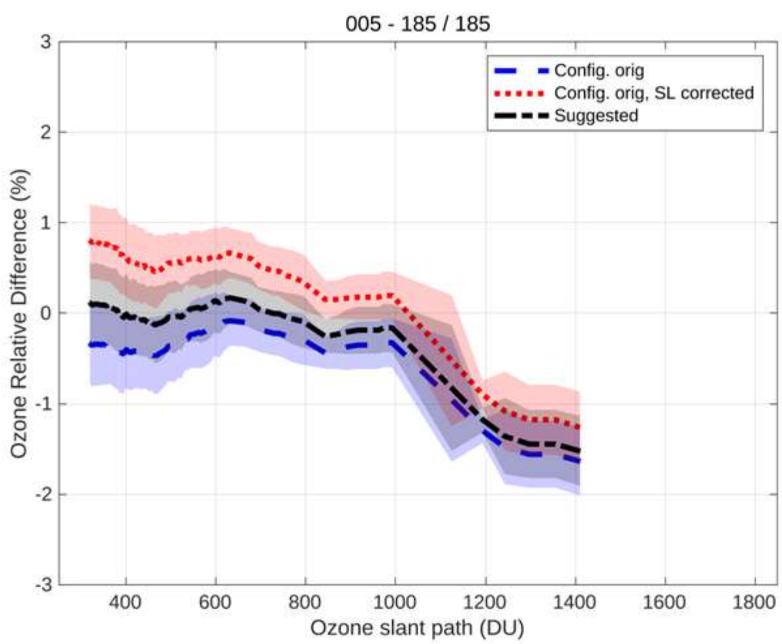


Figure 19. Mean direct sun ozone column percentage difference between Brewer TSK#005 and Brewer IZO#185 as a function of ozone slant path

Table 6. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration.

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#005*	*O3 std*	*% (005–185) /185*	*O3(*) #005*	*O3std*	*(*)%(005–185)/185*
17 Jun 2019	168	314	0.9	15	311.5	0.7	-0.8	312.8	0.7	-0.4
19 Jun 2019	170	325.2	3.1	80	324.3	3.5	-0.3	325.6	3.4	0.1
20 Jun 2019	171	330.5	4.1	17	328.7	4	-0.5	329.8	4.3	-0.2

4.6.2. Final calibration

After the maintenance on day 171, a new ETC value was calculated (see Figure 20). For the final calibration, we used 376 simultaneous direct sun measurements from days 172 to 177. The new value of 3020 is 15 units lower than the current ETC value of 3030. We therefore recommend using this new ETC, together with the new proposed standard lamp reference ratios (1818 for R6). We updated the new calibration constants in the ICF17219.005 file provided.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 7, the agreement between the 1P and 2P methods is excellent in the stray light-free OSC range.

Mean daily total ozone values for the original and the final configurations are shown in Table 8, as well as relative differences with respect to IZO#185.

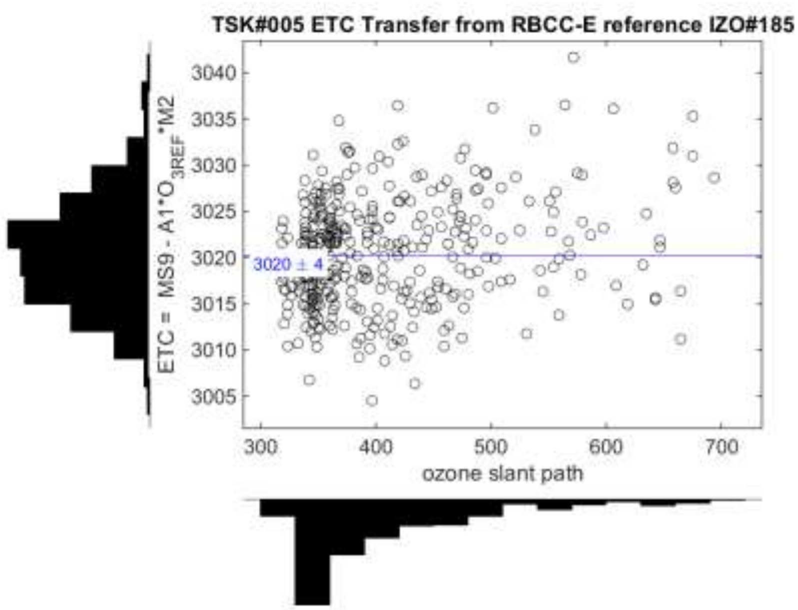


Figure 20. Mean direct sun ozone column percentage difference between Brewer TSK#005 and Brewer IZO#185 as a function of ozone slant path

Table 7. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=700	3020	3020	3336	3335
full OSC range	3020	3034	3336	3299

Table 8. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#005*	*O3 std*	*% (005–185) /185*	*O3(*) #005*	*O3std*	*(*)% (005–185) /185*
20 Jun 2019	171	336.1	0.7	52	334	1.3	-0.6	336.3	1	0.1
21 Jun 2019	172	338.6	2.2	70	336.5	1.9	-0.6	339	2.2	0.1
22 Jun 2019	173	329.8	2	67	326.9	2.3	-0.9	329.5	2.5	-0.1
23 Jun 2019	174	323.8	3.6	118	321.4	3.7	-0.7	323.4	4.1	-0.1
25 Jun 2019	176	308.7	2.1	116	306.2	2.3	-0.8	308.3	2.7	-0.1
26 Jun 2019	177	NaN	NaN	0	305.8	0.9	NaN	307.8	1.2	NaN

4.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and almost no underestimation at 800 OSC, which is very good for a single Brewer. However, this result can be improved. The empirical stray model fits quite well with coefficient values: $k = a = -6.4$, $s = b = 8.72$, and ETC=3021. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

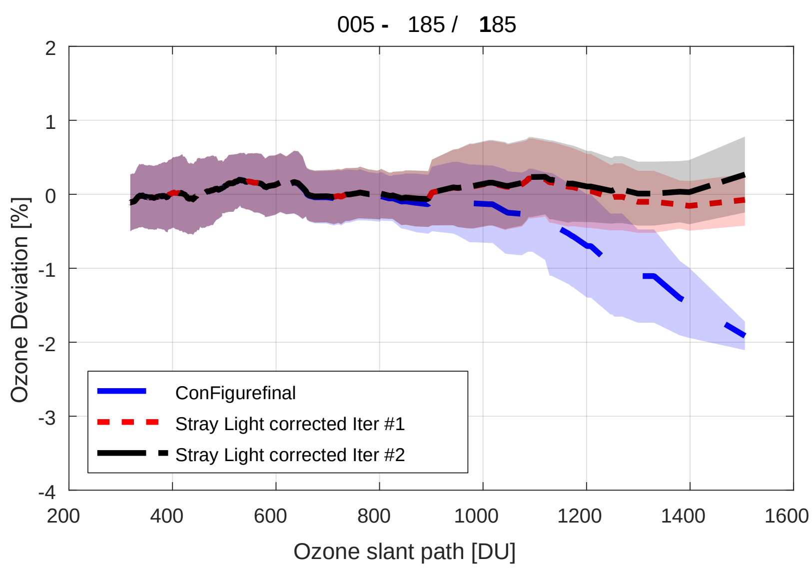


Figure 21. Ratio respect to the reference when final constants are applied and stray light correction is applied

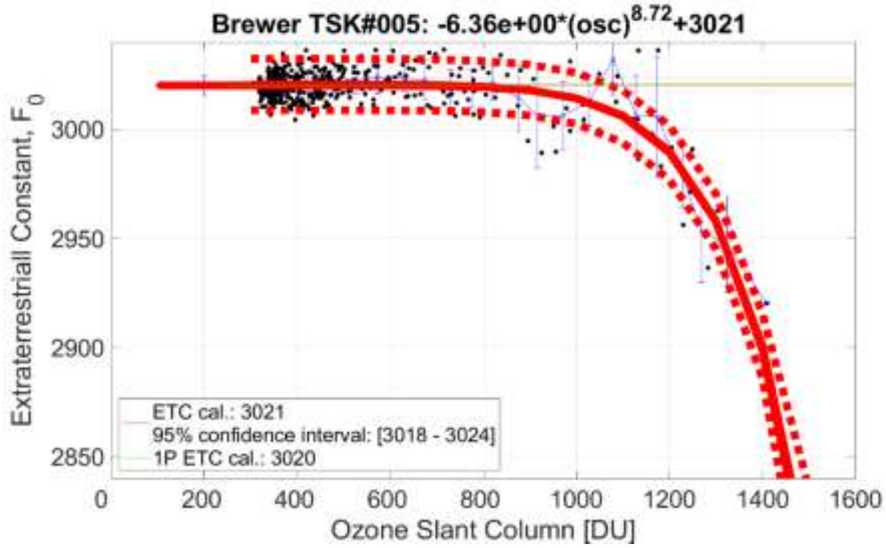


Figure 22. Stray light empirical model determination

4.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1818 for R6 (Figure 23) and 3530 for R5 (Figure 24).

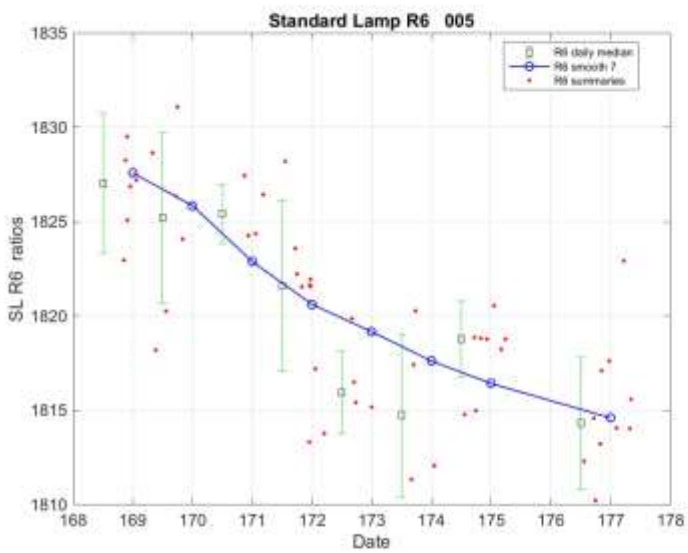


Figure 23. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

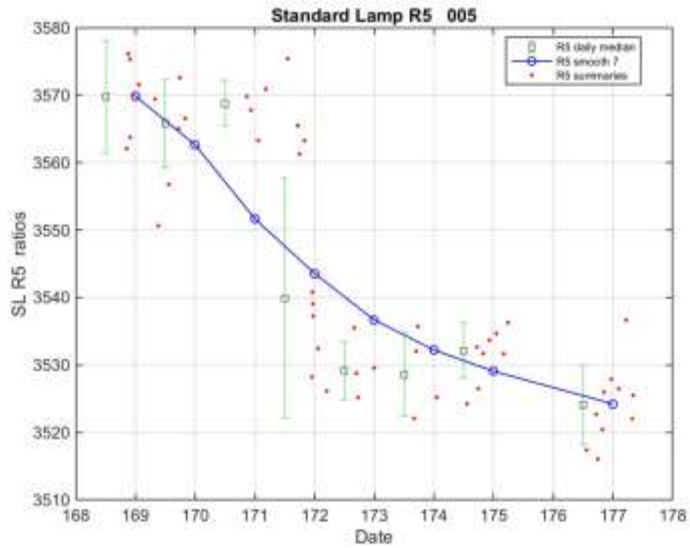


Figure 24. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

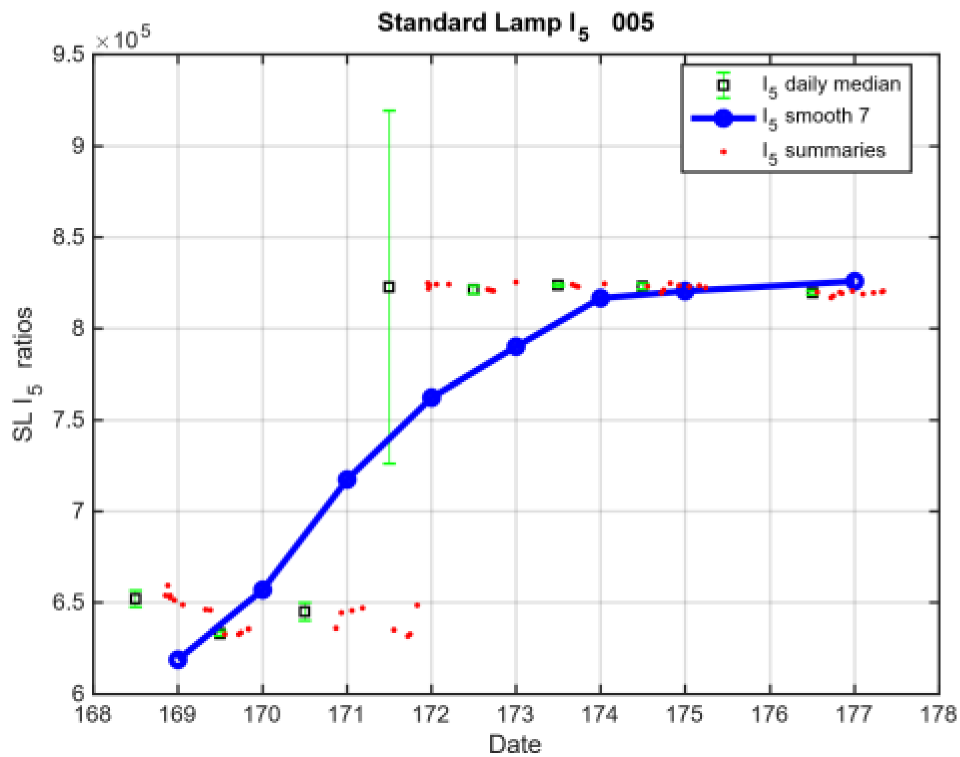


Figure 25. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

4.7. CONFIGURATION

4.7.1. Instrument constant file

	Initial (ICF15117.005)	*Final (ICF17219.005)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.64	-0.64
o3 Temp coef 3	-1.4	-1.4
o3 Temp coef 4	-2.06	-2.06
o3 Temp coef 5	-3.55	-3.55
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3336	0.3336
SO2 on SO2 Ratio	2.44	2.44
O3 on SO2 Ratio	1.1065	1.1065
ETC on O3 Ratio	3030	3020
ETC on SO2 Ratio	3200	3200
Dead time (sec)	3.8e-08	3.8e-08
WL cal step number	159	159
Slitmask motor delay	70	70
Umkehr Offset	1637	1637
ND filter 0	0	0
ND filter 1	5000	5000
ND filter 2	10000	10000
ND filter 3	15000	15000
ND filter 4	20000	20000
ND filter 5	25000	25000
Zenith steps/rev	2816	2816
Brewer Type	2	2
COM Port #	2	2
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	2546	2546
Mic #2 Offset	0	0
O3 FW #3 Offset	0	0
NO2 absn Coeff	0	0
NO2 ds etc	0	0
NO2 zs etc	0	0
NO2 Mic #1 Offset	0	0
NO2 FW #3 Offset	0	0
NO2/O3 Mode Change	0	0
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	4269	4269
Iris Open Steps	75	75
Buffer Delay (s)	0.1	0.1
NO2 FW#1 Pos	0	0

	Initial (ICF15117.005)	*Final (ICF17219.005)*
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	120	120
Zenith UVB Position	2112	2112

4.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk).

Day	osc range	O3#185	O3std	N	O3#005	O3 std	%diff	(*)O3#005	O3 std	(*)%diff
168	700> osc> 400	313	1.0	12	314	1.6	0.3	312	1.6	-0.1
168	osc< 400	312	1.3	42	314	0.9	0.6	312	0.9	0.1
170	700> osc> 400	326	3.4	27	328	4.2	0.5	326	4.2	0.0
170	osc< 400	324	2.7	47	328	2.8	0.9	326	2.8	0.3
171	1500> osc> 1000	322	0.3	5	319	1.8	-1.0	318	1.8	-1.3
171	1000> osc> 700	332	6.0	8	333	6.5	0.4	332	6.4	0.0
171	700> osc> 400	333	4.1	30	335	4.4	0.5	332	4.2	-0.1
171	osc< 400	336	0.8	29	338	1.1	0.7	335	1.1	-0.3
172	1500> osc> 1000	336	0.1	3	334	1.3	-0.4	334	1.2	-0.7
172	1000> osc> 700	335	0.7	3	337	0.5	0.8	336	0.3	0.3
172	700> osc> 400	338	2.5	20	341	2.2	0.9	338	2.0	0.1
172	osc< 400	340	1.6	41	343	1.4	1.1	340	1.5	0.1
173	1500> osc> 1000	325	0.5	3	325	0.7	-0.2	324	0.6	-0.5
173	700> osc> 400	328	2.3	16	332	2.9	1.0	329	2.8	0.1
173	osc< 400	330	1.4	41	334	1.9	1.2	330	2.0	0.1
174	1500> osc> 1000	319	4.6	11	318	6.8	-0.1	318	6.7	-0.3
174	1000> osc> 700	320	3.6	13	320	4.6	0.2	319	4.5	-0.1
174	700> osc> 400	323	2.0	44	325	2.3	0.6	323	2.2	0.0
174	osc< 400	326	1.3	46	329	2.0	0.6	326	1.9	-0.2
176	1500> osc> 1000	307	2.1	10	306	4.6	-0.5	304	4.5	-0.9

Day	osc range	O3#185	O3std	N	O3#005	O3 std	%diff	(*)O3#005	O3 std	(*)%diff
176	1000> osc> 700	307	2.3	13	308	3.0	0.3	306	3.0	-0.2
176	700> osc> 400	308	1.5	29	310	2.0	0.9	308	1.9	0.1
176	osc< 400	310	1.4	42	314	1.1	1.1	310	1.1	-0.1
177	1000> osc> 700	306	0.7	5	NaN	NaN	NaN	306	0.2	-0.1
177	700> osc> 400	308	0.9	14	NaN	NaN	NaN	308	1.1	0.1
177	osc< 400	309	0.8	6	NaN	NaN	NaN	308	1.1	-0.2

4.9. APPENDIX: SUMMARY PLOTS

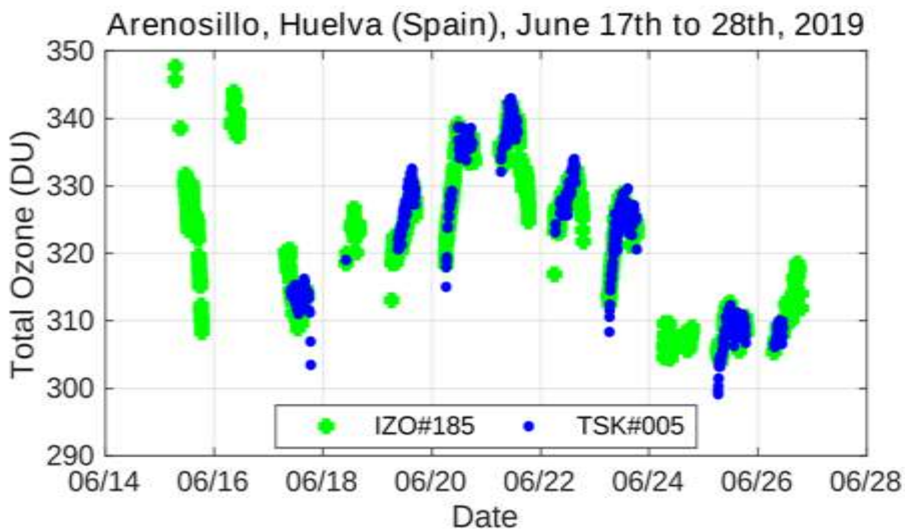
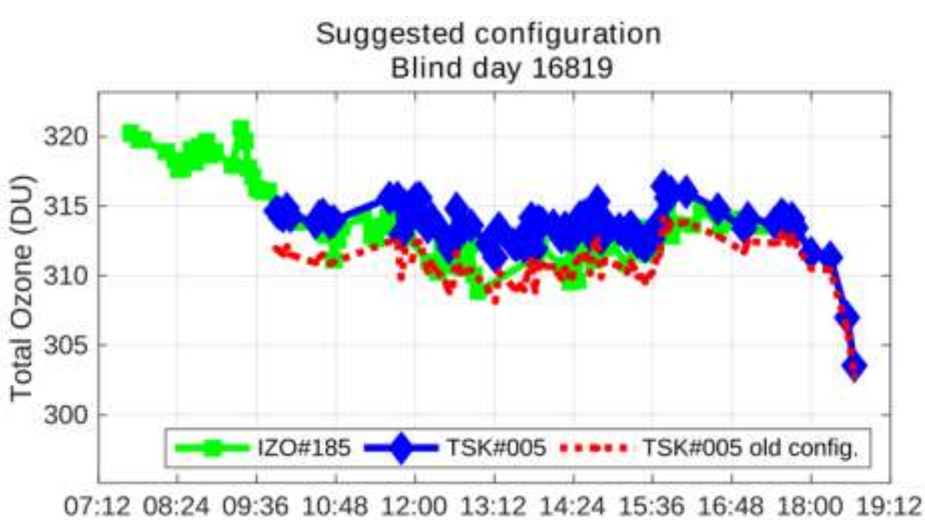
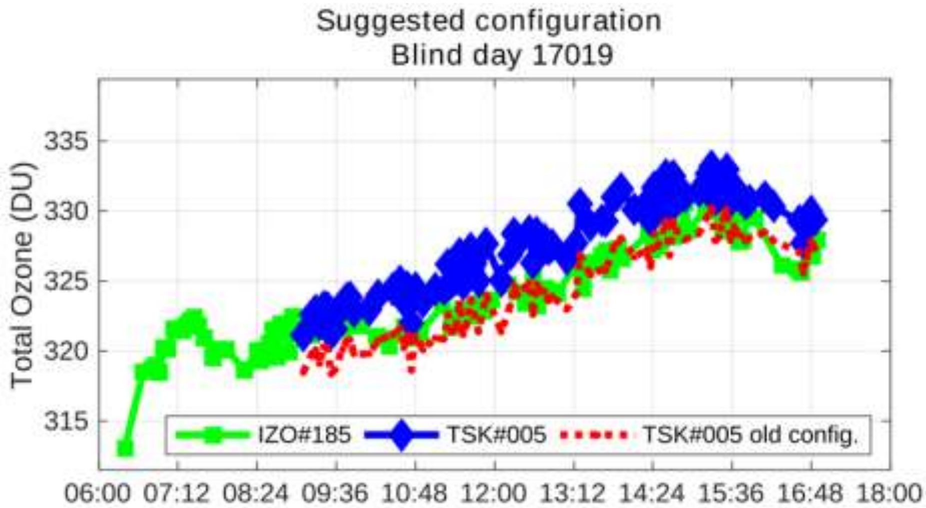
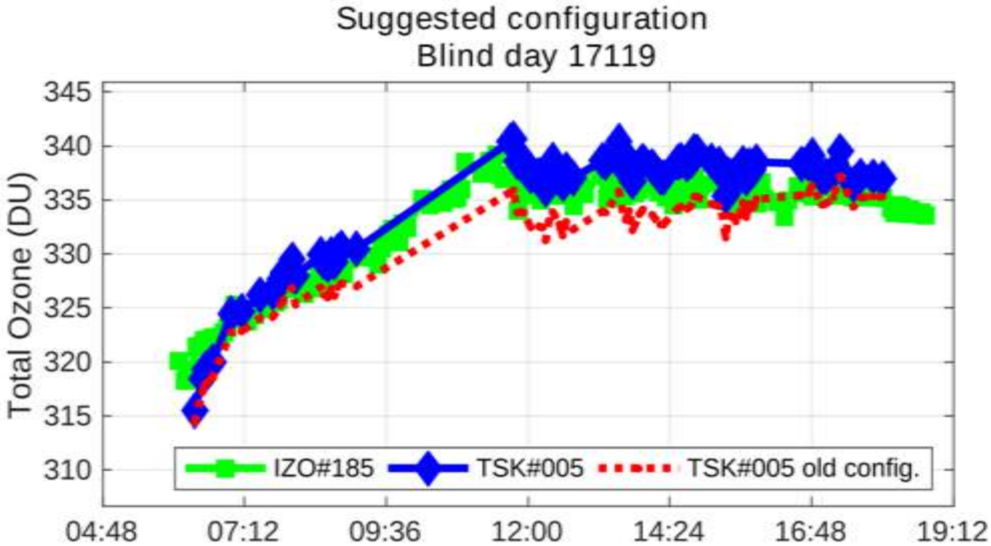
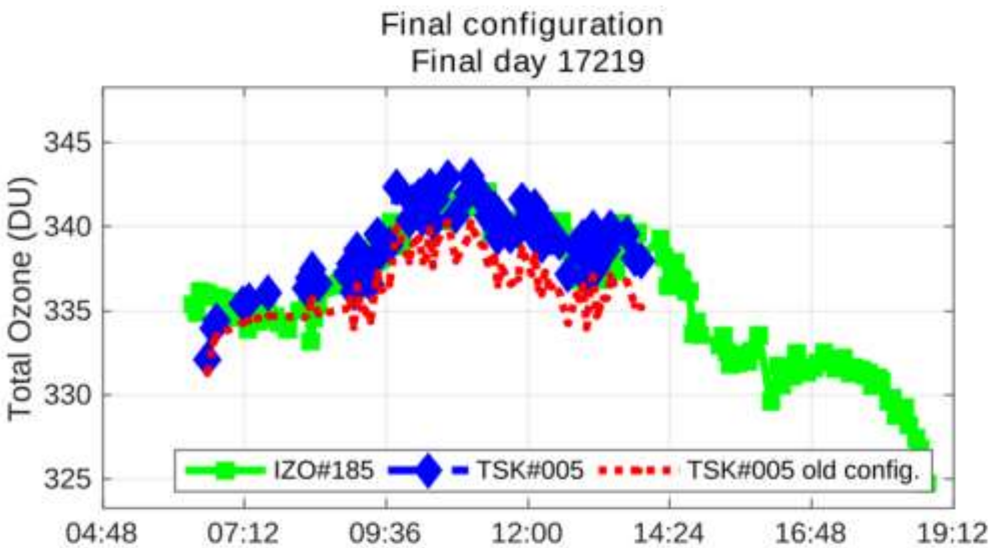


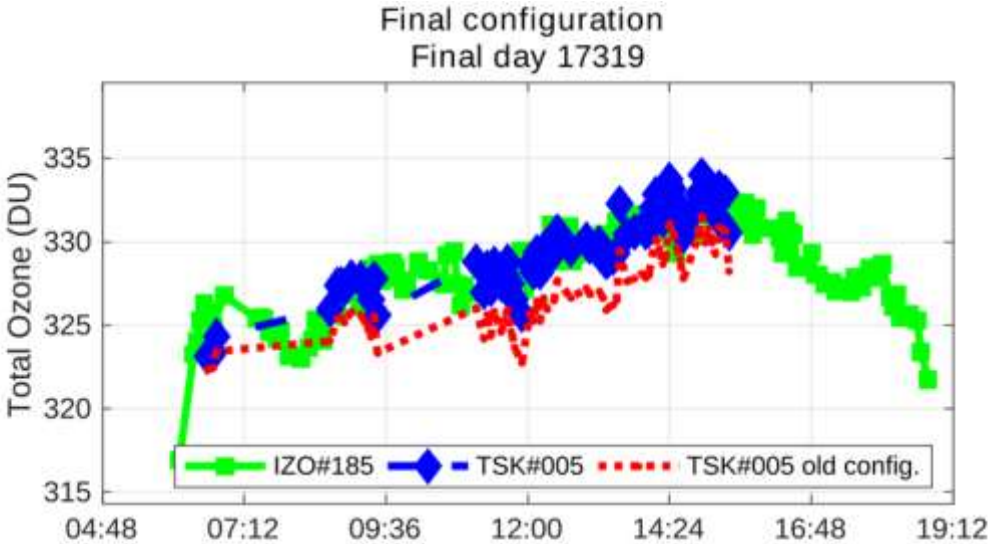
Figure 26. Overview of the intercomparison. Brewer TSK#005 data were evaluated using final constants (blue circles)

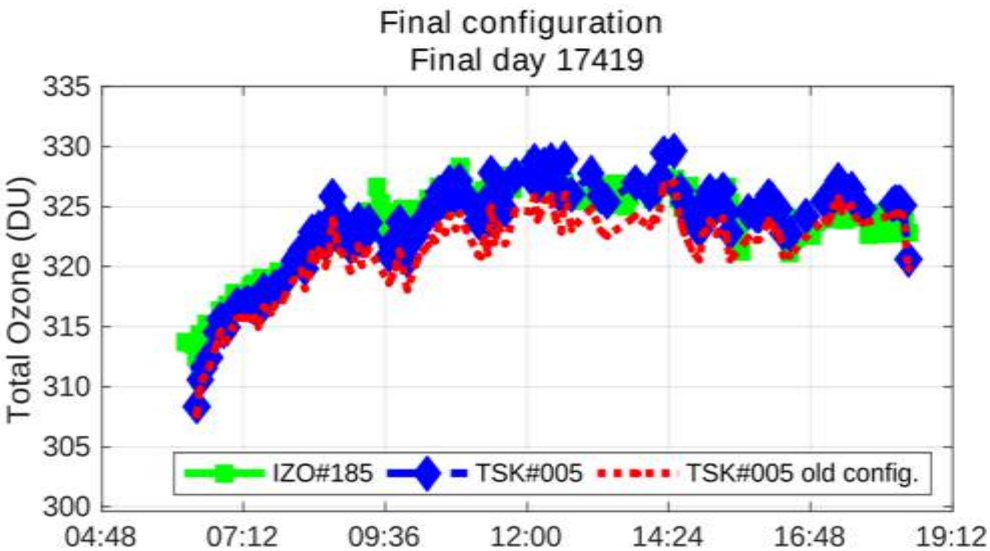


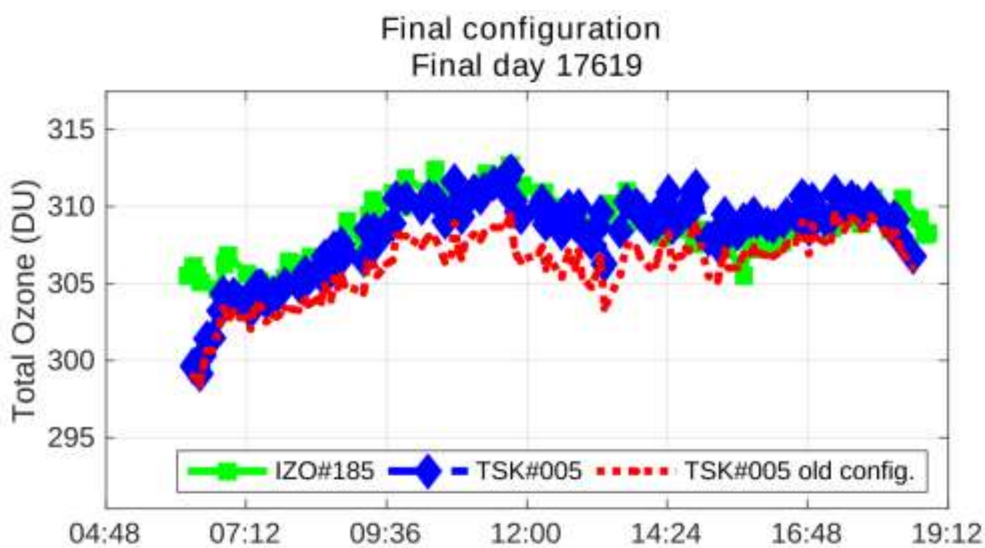

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
IZO#185
TSK#005
TSK#005 old config.
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00

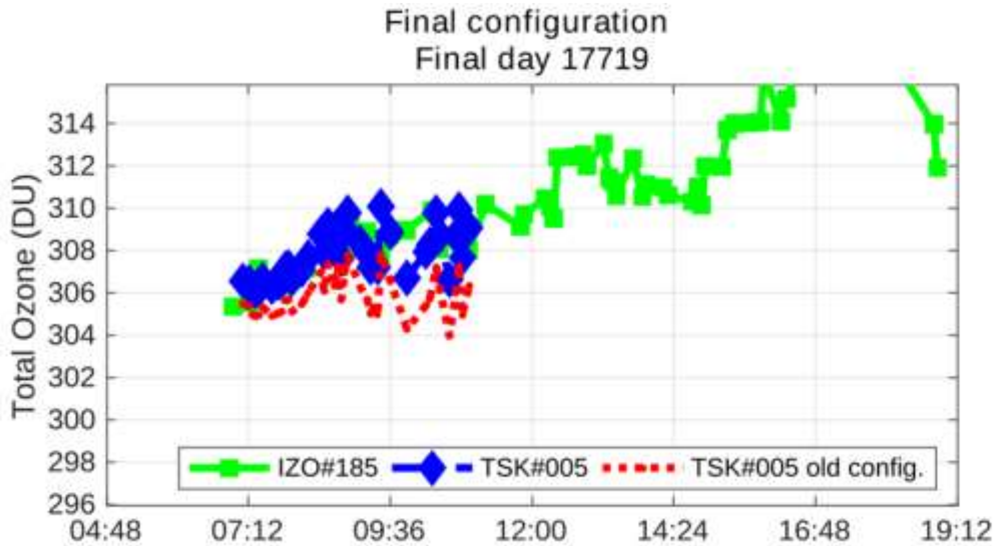

Suggested configuration
Blind day 17119
Total Ozone (DU)
345
340
335
330
325
320
315
310
IZO#185
TSK#005
TSK#005 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12


Final configuration
Final day 17219
Total Ozone (DU)
345
340
335
330
325
IZO#185
TSK#005
TSK#005 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12


Final configuration
Final day 17319
Total Ozone (DU)
335
330
325
320
315
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TSK#005
TSK#005 old config.


Final configuration
Final day 17419
Total Ozone (DU)
335
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TSK#005
TSK#005 old config.


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TSK#005
TSK#005 old config.



Final configuration
Final day 17719
Total Ozone (DU)
314
312
310
308
306
304
302
300
298
296
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TSK#005
TSK#005 old config.

5. BREWER IOS#017

5.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer IOS#017 participated in the campaign during the period from 17 to 27 June. The campaign days of Brewer IOS#017 correspond to Julian days 166–178.

The instrument did not require maintenance so we used the same data set both to evaluate the initial status of the instrument and for final calibration purposes: 407 simultaneous DS ozone measurements taken from day 166 to 178.

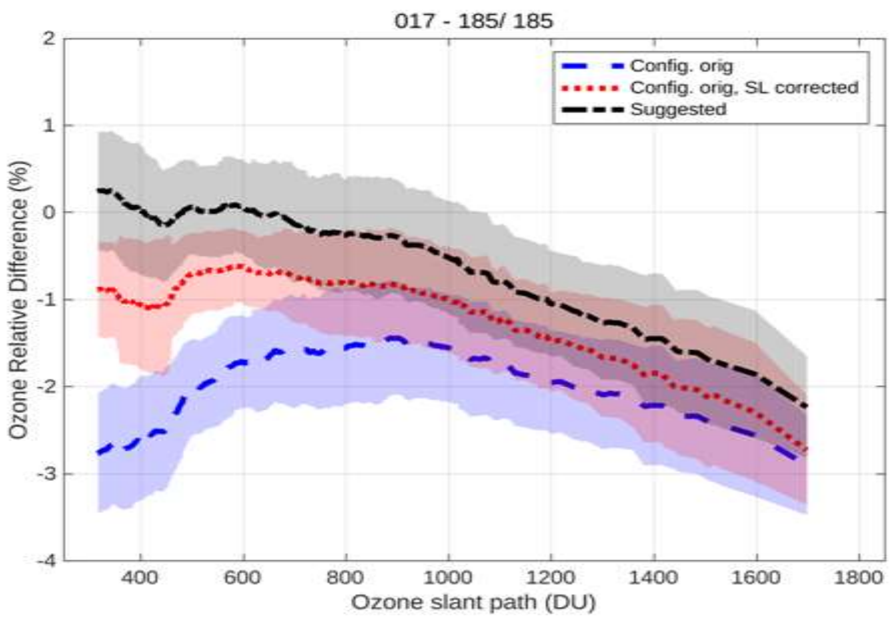


Figure 5–1. Mean DS ozone column percentage difference between Brewer IOS#017 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current configuration are show in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the whole campaign.

As shown in Figure 5–1, the current ICF (ICF14919.017, blue dashed line) produces ozone values with an average difference with respect to the reference instrument and is approx. 2.5% at OSC values lower than 1000 DU. The SL correction (Figure 1, red dotted line) improves the comparison, reducing the difference to approx. 1%.

As a Mk. II model, Brewer IOS#017 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 0.5.6).

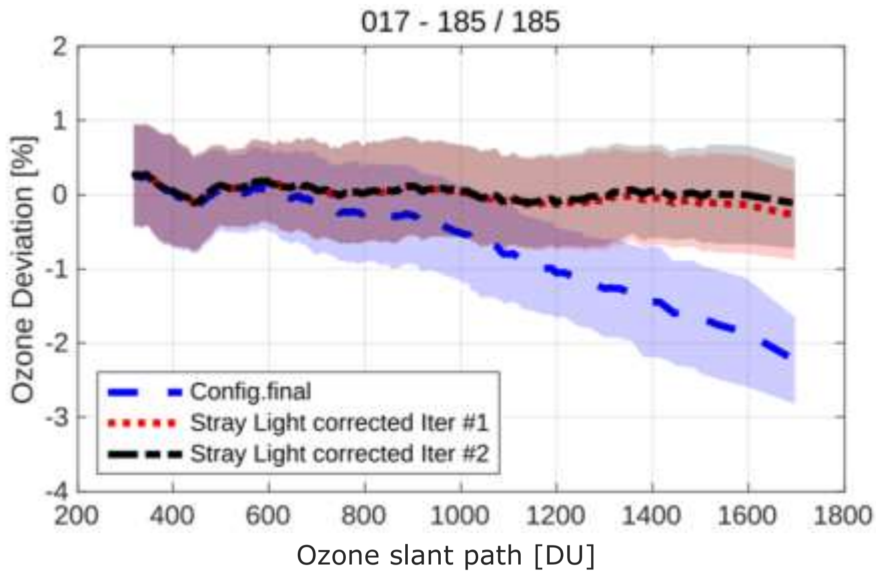


Figure 2. Mean DS ozone column percentage difference between Brewer IOS#017 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are show in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the whole campaign.

The lamp test results from Brewer IOS#017 presents a stable period from September 2018 to March 2019 but are otherwise quite noisy. During campaign days, the standard lamp ratios stabilized around values 1651 and 2898 for R6 and R5 respectively (Figures 22 and 23).
The noise of the standard lamp measurements makes the evaluation of the temperature coefficients difficult. In any case, the present temperature coefficients seem to perform reasonably well.

The neutral density filters do not show any large nonlinearity in the attenuation's spectral characteristics. We do not suggest the application of filter corrections.

Sun scan tests during the campaign confirm the current cal step value (860, within a step error of ±1). We do not have results from sun scan tests performed before the campaign.
We do not suggest changing the ozone absorption coefficient, retaining its current value of 0.3416.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CI files, dead time, and so forth) show reasonable results.

Taking this into account, we suggest very few changes to the configuration of Brewer IOS#017.

5.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer IOS#017 have been quite noisy for the last two years. The old R6 reference value was 1680 and it could be updated to 1651.
2. We suggest a new R5 reference value of 2898.

3. For Brewer IOS#017, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -19.2$, and $s = b = 4.09$.
4. In the final ICF for the present campaign, ICF16819.017, we suggest updating the ETC value from 2912 to 2877.
5. Finally, the instrument performed very well after the calibration constants were applied, with minimal ozone deviations when stray light correction is used. We recommend the use of stray light correction.

5.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/017/ICF16819.017

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid= 2062893846

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/017/html/cal_report_017a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/017/html/cal_report_017a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/017/html/cal_report_017b.html ETC transfer
http://rbcce.aemet.es/svn/campaigns/aro2019/latex/017/html/cal_report_017c.html

5.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

5.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp tests were quite noisy in the period before the campaign. The only stable period was from September 2018 to March 2019, and the SL R6 value was completely different to other dates. During the campaign, we found values of 1651 and 2898 for R6 and R5, respectively. The changes in R6 and R5 can be associated with variations of the lamp's intensity shown in Figure 5.

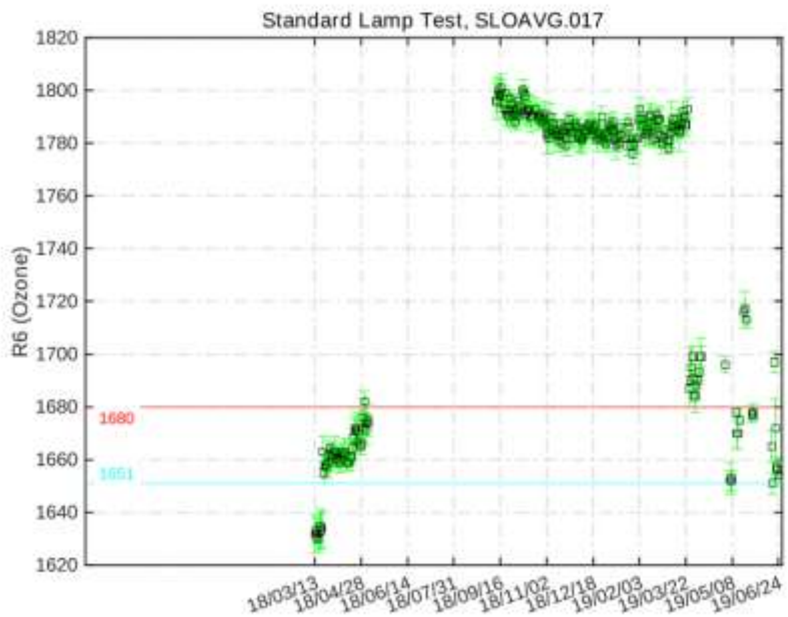


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

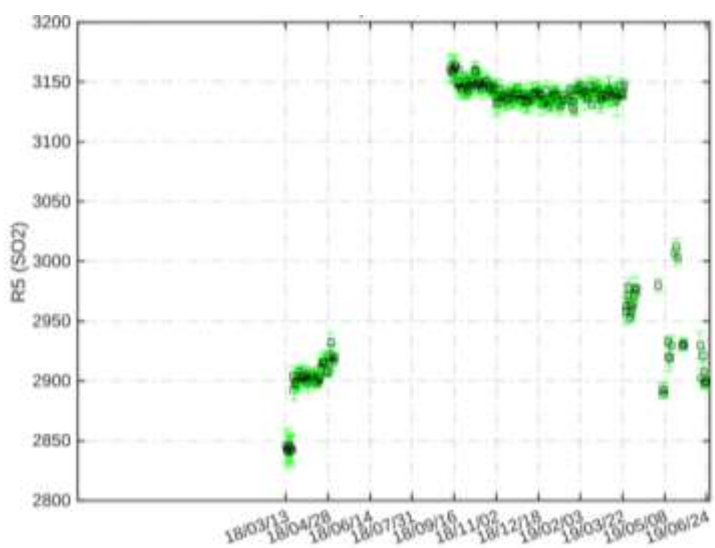


Figure 4. Standard lamp test R5 (sulfur dioxide) ratio

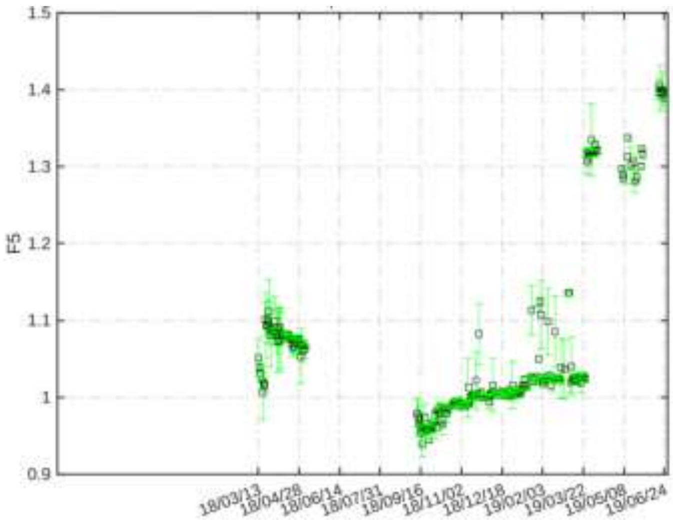


Figure 5. SL intensity for slit five

5.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 6). The Hg slit is noisier but still inside of the normal range for this slit.

As shown in Figure 7, results from the dead time tests are quite noisy. Regardless, the reference value of $4.5\cdot10^{-8}$ seconds from the present configuration seems reasonable for the campaign. Therefore, the value of $4.5\cdot10^{-8}$ s has been used in the new ICF.

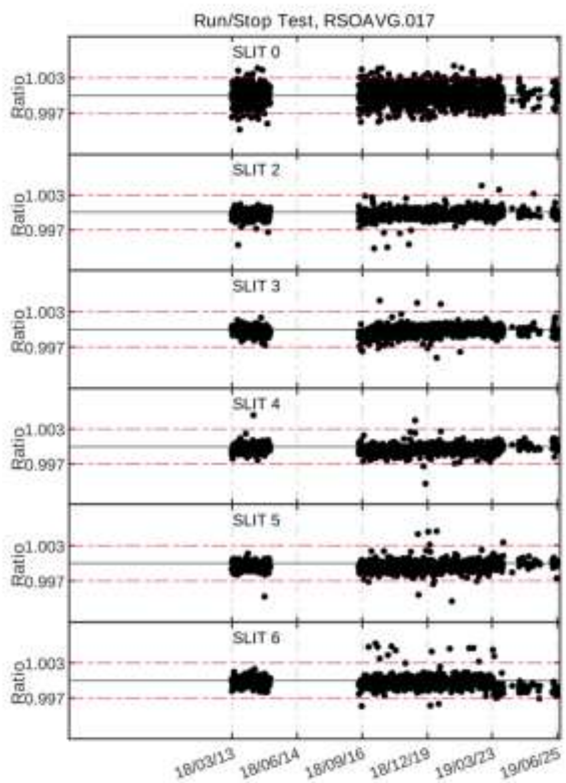


Figure 6. Run/stop test

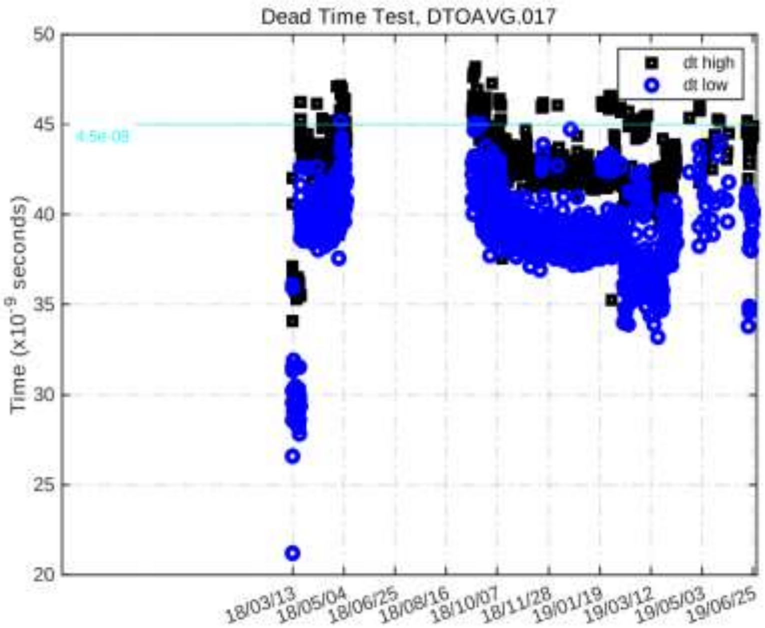


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

5.2.3. Analogue test

Figure 8 shows that the high and +5 voltages have been quite noisy over the last two years. Nevertheless, the analogue test values are within tolerance ranges.

Analogue Printout Log, APOAVG.017

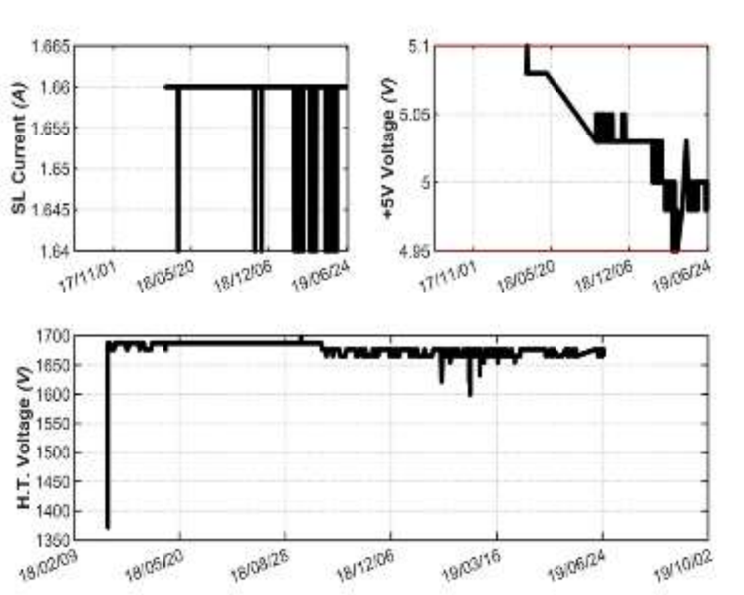


Figure 8. Analogue voltages and intensity

5.2.4. Mercury lamp test

As in previous cases, the results of the Hg lamp tests were also noisy, see Figure 9, but some temperature dependence could be identified.

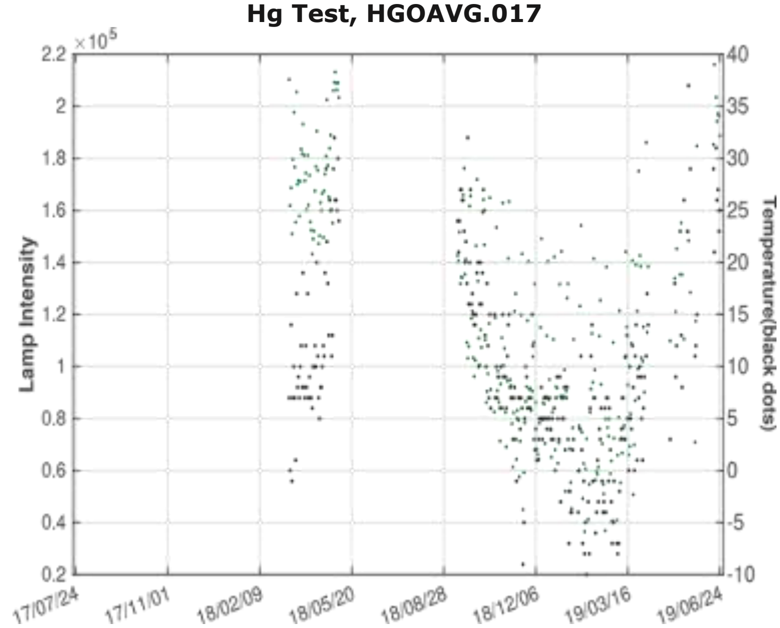


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

5.2.5. CZ scan on mercury lamp

We usually analyse the scans performed on the 296.728 nm mercury line in order to check both the wavelength settings and the slit function width. The calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Unfortunately, we do not have CZ files for Brewer IOS#017.

5.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer IOS#017 CI scans performed during the campaign relative to the scan CI17819.017. As can be observed, the lamp intensity varied with respect to the reference spectrum by around 2%. This behaviour is normal for an SL lamp.

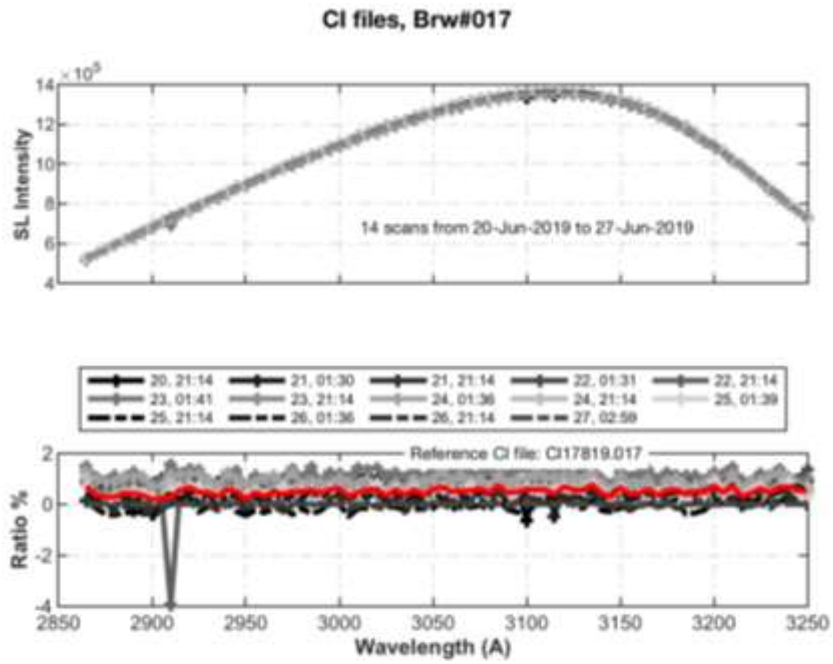


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

5.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature – the slopes then represent the instrument's temperature coefficients. From this we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature from 19 °C to 35 °C) the current coefficients do a good job at reducing the temperature dependence, performing on par with the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As we have discussed in previous sections, the data between campaigns is quite noisy. Nevertheless, as shown in Figures 12 and 13, the current and new coefficients perform similarly. For this reason, we have used the current coefficients in the final ICF.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.0514	-0.3046	-1.0856	-2.4081
Calculated	0.0000	-0.2100	-0.4200	-1.0900	-2.3400
Final	0.0000	-0.0514	-0.3046	-1.0856	-2.4081

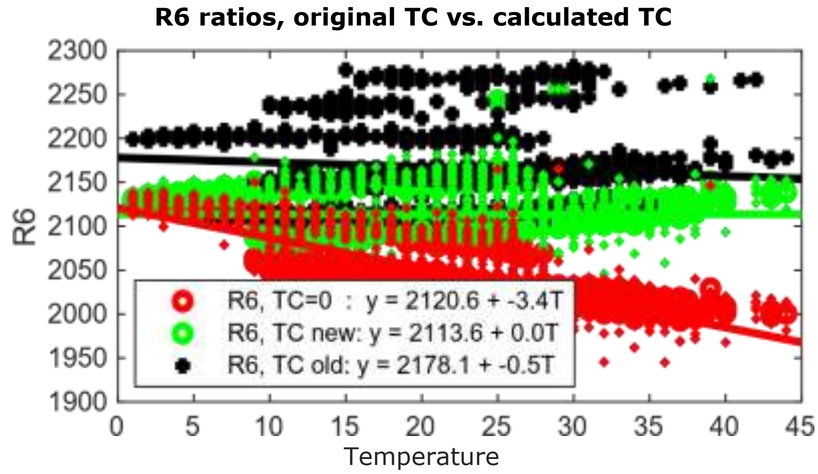


Figure 11. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

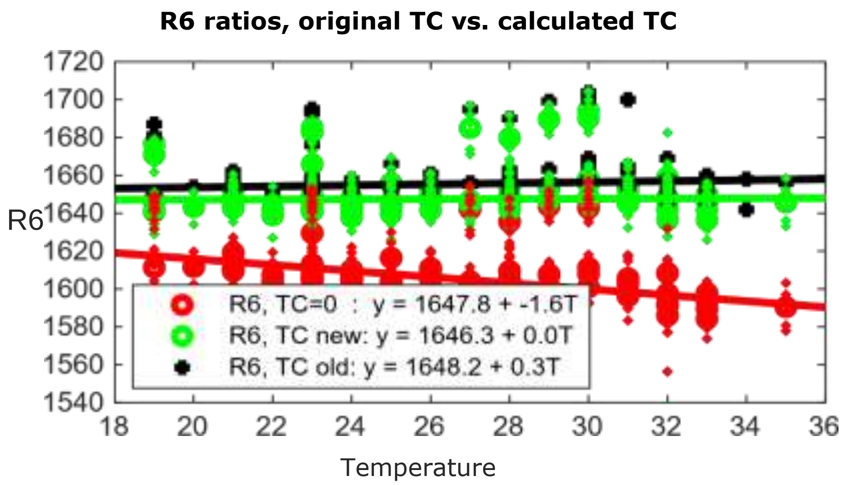


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

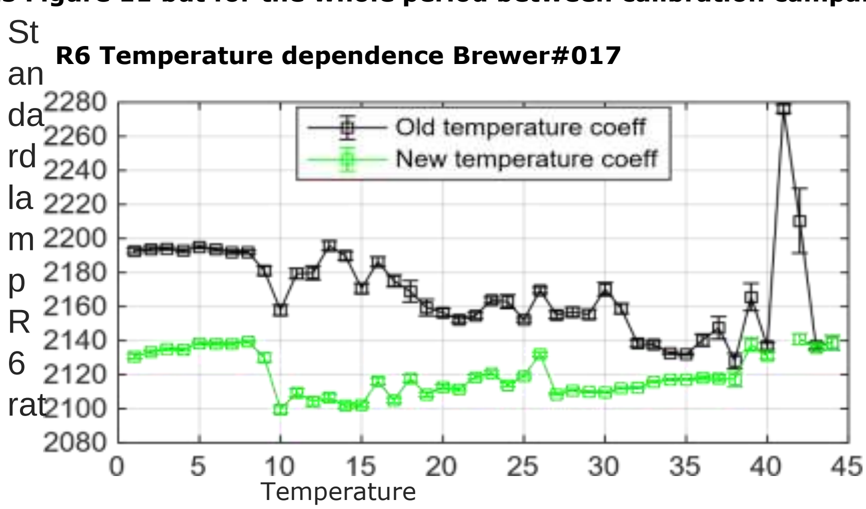


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

5.4. ATTENUATION FILTER CHARACTERIZATION

5.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 72 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Figure 14 also shows that in most cases the difference of filter changes is below 10%. Table 2 shows differences below 5 units at most filter changes, except in the case of changes from filter #4 to #5. However, even in the latter case the difference is just 7 units. All this points to filter corrections not being necessary for Brewer IOS#017.

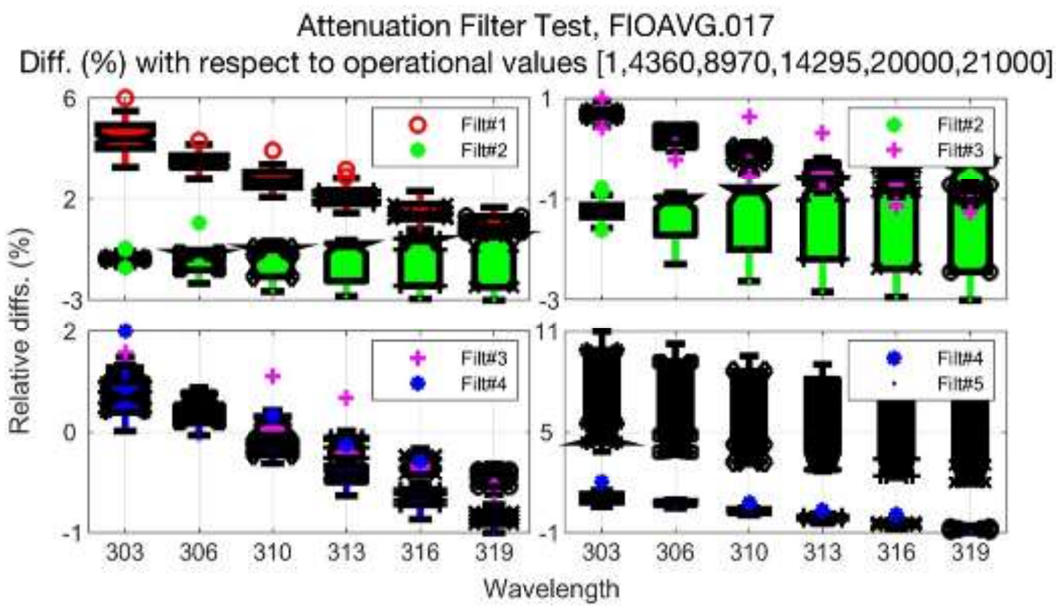


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. For each subplot, we show relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-7	-4	-8	-13	-20
ETC Filt. Corr. (mean)	-5.4	-8.3	-14.9	-12.7	-13.5
ETC Filt. Corr. (mean 95% CI)	[-11.7 0.4]	[-14.6 -3.4]	[-21.3 -10.7]	[-19.2 -8.1]	[-19.1 -9.4]

5.5. WAVELENGTH CALIBRATION

5.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts (≈ ± 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan, see Figure 15.

During the campaign, sun scan (SC) tests covering an ozone slant path range from 500 to 1000 DU were carried out (see Figure 16). The calculated cal step number (CSN) was the same as the value in the current configuration (860). We do not have data of SC tests performed before the campaign. Taking all this into account, we suggest keeping the current CSN (860).

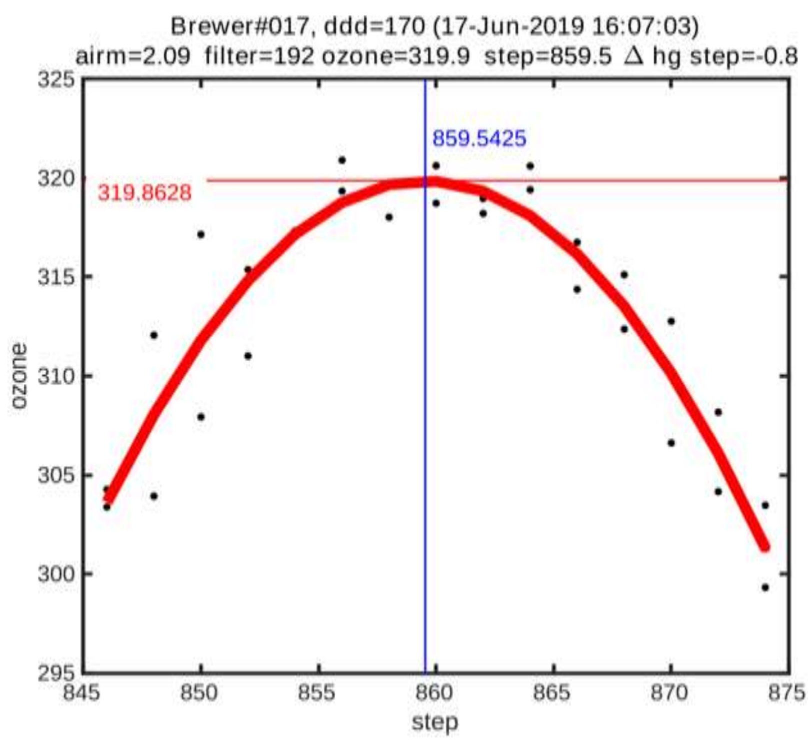


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

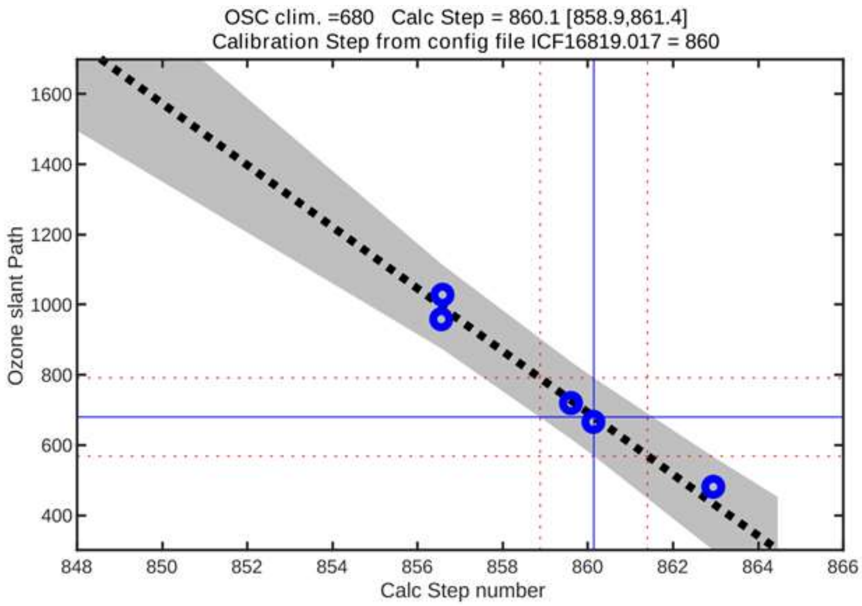


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

5.5.2. Dispersion test

We analysed the dispersion tests carried out in previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ±1 step.

Although the analysis of the dispersion tests carried out in the campaign suggest a new absorption coefficient equal to 0.3417, this is within the acceptable ±1 error from the current value of 0.3416, so no change is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	860	0.3416	2.3500	1.1400
03 Jun 2015	860	0.3414	3.2167	1.1457
23 Sep 2016	860	0.3384	3.2339	1.1360
02 Jun 2017	860	0.3406	3.2379	1.1431
23 Jun 2019	860	0.3417	3.2558	1.1456
Final	860	0.3416	2.3500	1.1400

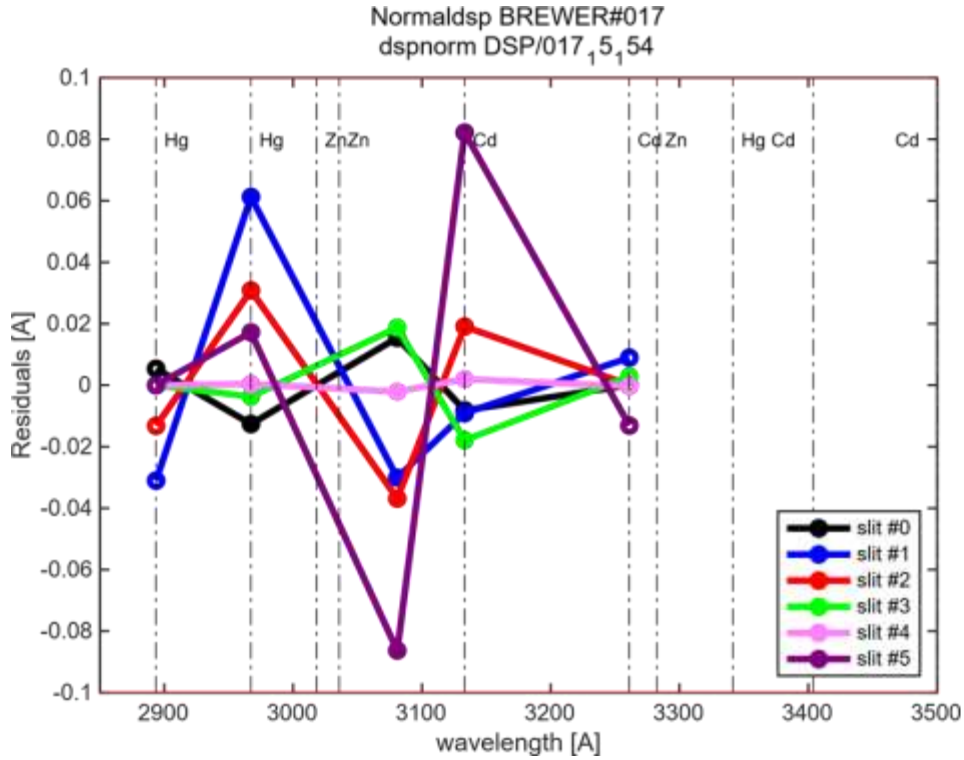


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 859	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3021.41	3063.06	3100.52	3134.96	3167.95	3199.96
Res(A)	3.5084	5.224	5.2162	5.482	5.3256	5.2847
O3abs(1/cm)	3.124	1.7805	1.0051	0.67708	0.37469	0.29446
Ray abs(1/cm)	0.51273	0.48319	0.45846	0.43713	0.41789	0.40022
SO2abs(1/cm)	8.506	5.7118	2.4024	1.9079	1.0544	0.61322
step= 860	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3021.48	3063.14	3100.6	3135.04	3168.02	3200.03
Res(A)	3.5084	5.224	5.2161	5.4819	5.3255	5.2846
O3abs(1/cm)	3.121	1.7789	1.0048	0.67672	0.37476	0.29396
Ray abs(1/cm)	0.51267	0.48314	0.45841	0.43709	0.41784	0.40019
SO2abs(1/cm)	8.5197	5.7348	2.4107	1.8957	1.0557	0.61089
step= 861	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3021.56	3063.21	3100.67	3135.11	3168.09	3200.1
Res(A)	3.5084	5.2239	5.216	5.4818	5.3254	5.2845
O3abs(1/cm)	3.1176	1.7773	1.0045	0.6763	0.37484	0.29346
Ray abs(1/cm)	0.51261	0.48309	0.45836	0.43705	0.4178	0.40015
SO2abs(1/cm)	8.5296	5.7555	2.419	1.8836	1.057	0.6086
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
859	0.34283	9.2657	3.2456	1.1491	0.35372	0.34501
860	0.34171	9.2633	3.2558	1.1456	0.35272	0.34398
861	0.34063	9.2609	3.2638	1.1421	0.35166	0.34289

5.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2221. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 860	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3021	3063	3101	3135	3168	3200
Res(A)	3.5084	5.224	5.2161	5.4819	5.3255	5.2846
O3abs(1/cm)	3.121	1.7789	1.0048	0.67672	0.37476	0.29396
Ray abs(1/cm)	0.51267	0.48314	0.45841	0.43709	0.41784	0.40019
step= 2221	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3123	3164	3200	3233	3265	3296
Res(A)	3.4964	5.1085	5.0584	5.3369	5.2108	5.1418
O3abs(1/cm)	0.71569	0.39466	0.29504	0.12328	0.060858	0.033338
Ray abs(1/cm)	0.44418	0.42025	0.40019	0.38284	0.36714	0.35271

5.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where *F* are the measured double ratios corrected for Rayleigh effects, *α* is the ozone absorption coefficient, *μ* is the ozone air mass factor, and *ETC* is the extraterrestrial constant. The *F*, *α* and *ETC* parameters are weighted functions at the operational wavelengths with weighting coefficients *w* = $[0,1, -0.5, -2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of Equation 1, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light. In this case, the ETC distribution (see Figure 51) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content by air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column.

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 13 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

5.6.1. Initial calibration

For the evaluation of the initial status of Brewer IOS#017, we used the period from days 166 to 178 which correspond to 407 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced ozone values approx. 2.5% lower than the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results improve, and the relative difference is reduced to approx. 1%.

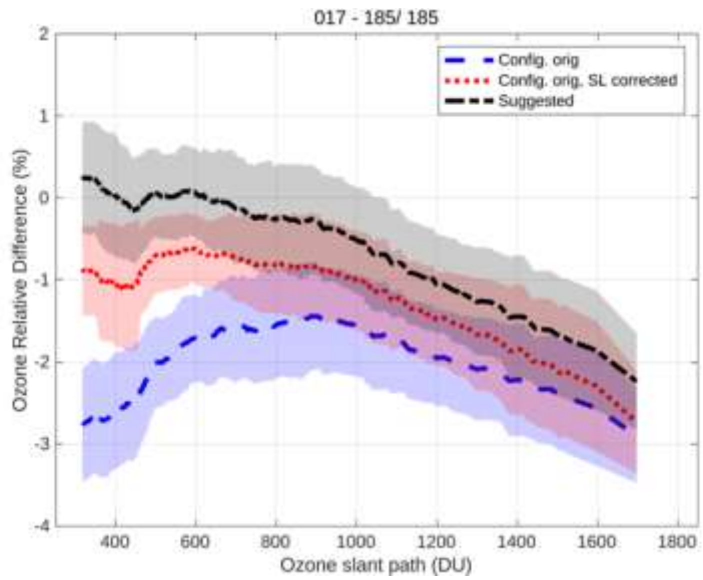


Figure 18. Mean direct sun ozone column percentage difference between Brewer IOS#017 and Brewer IZO#185 as a function of ozone slant path

5.6.2. Final calibration

A new ETC value was calculated (see Figure 19) also using the 407 simultaneous direct sun measurements from days 166 to 178. The new value (2877) is approximately 40 units lower than the current ETC value (2912). We therefore recommend using the new ETC, together with the new proposed standard lamp reference ratios (1651 for R6). We have updated these calibration constants in the new ICF provided.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 6, the agreement between the 1P and 2P methods is below the maximum tolerance limit of 10 ETCs.

Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

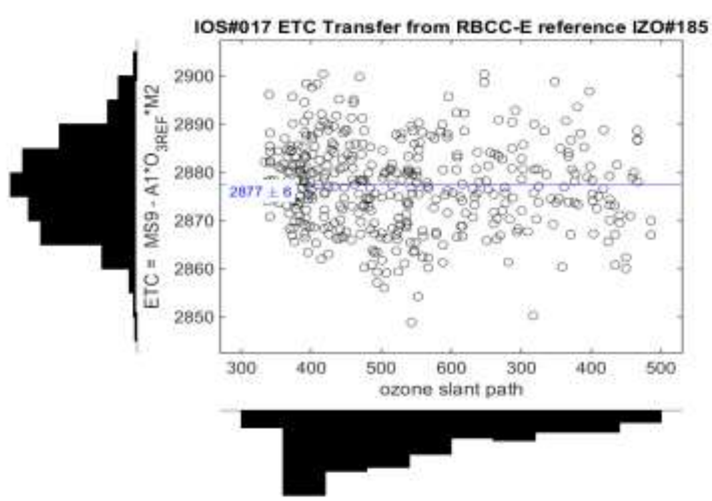


Figure 19. Mean direct sun ozone column percentage difference between Brewer IOS#017 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=600	2877	2884	3416	3400
full OSC range	2876	2881	3416	3407

Table 7. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations

	Day	*O3#185*	*O3std*	*N*	*O3#017*	*O3 std*	*% (017–185)/185*	*O3(*) #017*	*O3std*	*(*)% (017–185)/185*
17-Jun-2019	168	313.1	1.4	50	306.1	2	-2.2	314.3	1.5	0.4
18-Jun-2019	169	323.7	2.2	12	311.3	3	-3.8	320.8	3.2	-0.9
19-Jun-2019	170	320.7	1.5	32	312.5	1.9	-2.6	318.2	1.6	-0.8
20-Jun-2019	171	335.6	1.2	26	331.9	3.9	-1.1	335.9	4.5	0.1
21-Jun-2019	172	335.2	4	108	329.6	4.6	-1.7	336.2	6.2	0.3
22-Jun-2019	173	328.8	2.5	95	320.4	2.4	-2.6	327.3	3.9	-0.5
23-Jun-2019	174	323.5	3.7	120	315.6	2.8	-2.4	322.6	4.4	-0.3
24-Jun-2019	175	307.2	1.2	66	300.5	2.5	-2.2	305.9	1.9	-0.4
25-Jun-2019	176	308.5	2	119	301	1.9	-2.4	307.7	3	-0.3
26-Jun-2019	177	307.7	1.3	30	300.7	1.8	-2.3	307	1.7	-0.2
27-Jun-2019	178	NaN	NaN	0	300.2	2.3	NaN	306.3	4	NaN

5.6.3. Stray light correction

The final calibration performs well, with near zero error for low OSC and an underestimation of less than 1% at 800 OSC, which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = -19.2$, $s = 4.09$, and ETC=2878. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used (Equation 6).

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

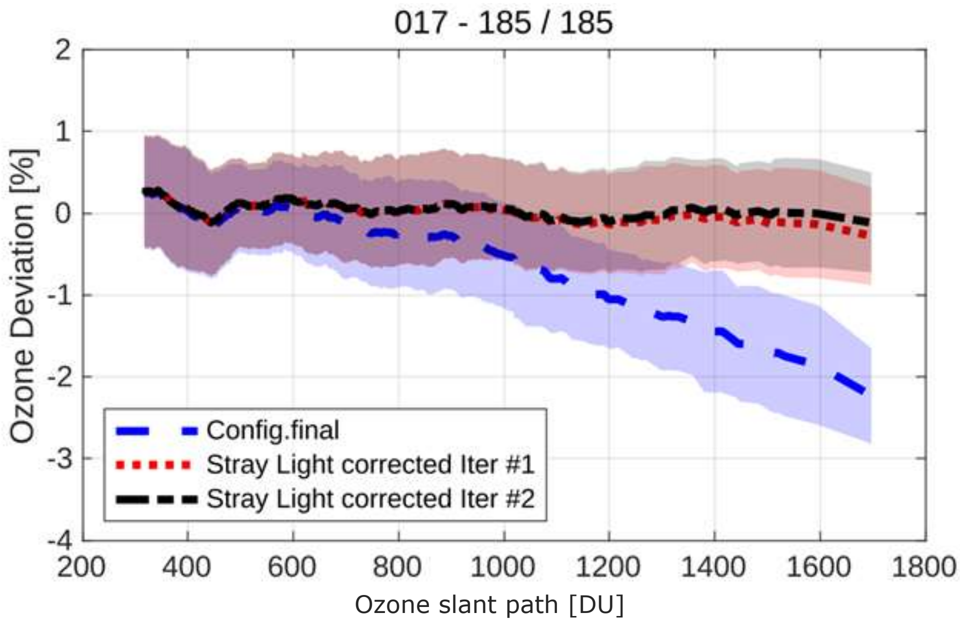


Figure 20. Ratio respect to the reference when final constants are applied and stray light correction is applied

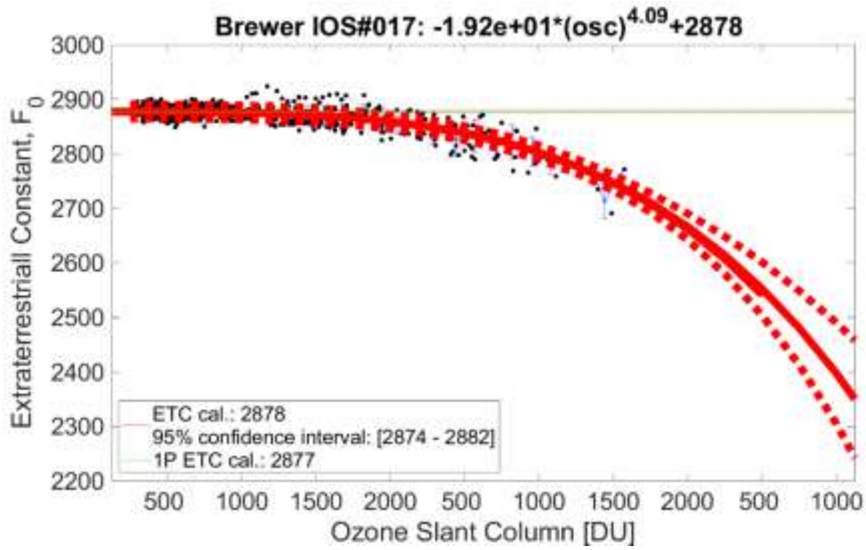


Figure 21. Stray light empirical model determination

5.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1651 for R6 (Figure 22) and 2898 for R5 (Figure 23).

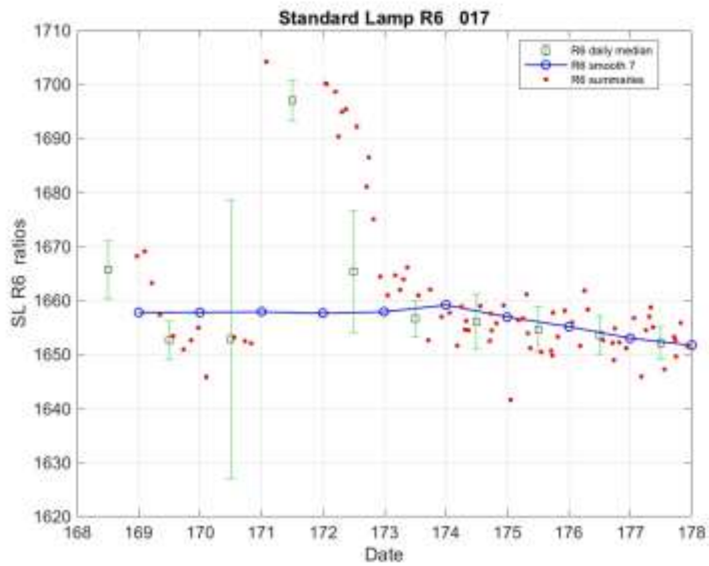


Figure 22. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

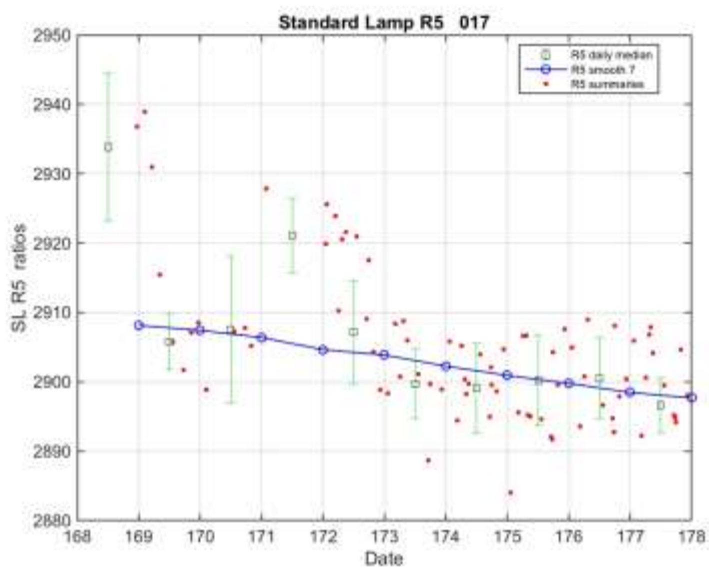


Figure 23. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

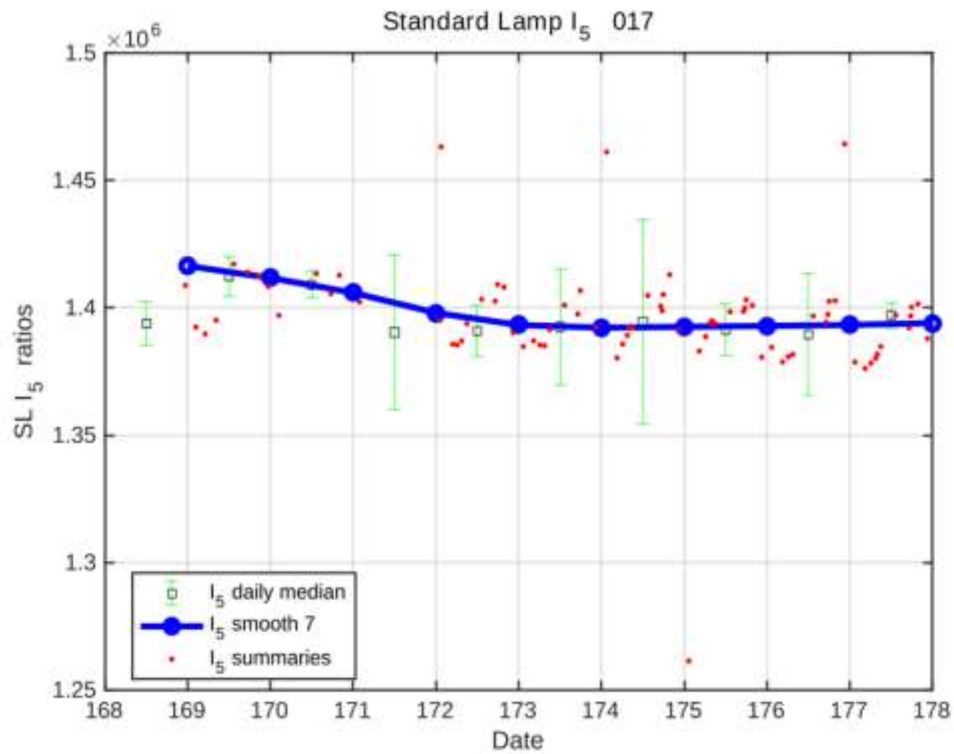


Figure 24. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

5.7. CONFIGURATION

5.7.1. Instrument constant file

	Initial (ICF14919.017)	*Final (ICF16819.017)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.0514	-0.0514
o3 Temp coef 3	-0.3046	-0.3046
o3 Temp coef 4	-1.0856	-1.0856
o3 Temp coef 5	-2.4081	-2.4081
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3416	0.3416
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.14	1.14
ETC on O3 Ratio	2912	2877
ETC on SO2 Ratio	2460	2460
Dead time (sec)	4.5e-08	4.5e-08

	Initial (ICF14919.017)	*Final (ICF16819.017)*
WL cal step number	860	860
Slitmask motor delay	76	76
Umkehr Offset	2228	2228
ND filter 0	0	0
ND filter 1	4360	4360
ND filter 2	8970	8970
ND filter 3	14295	14295
ND filter 4	20000	20000
ND filter 5	21000	21000
Zenith steps/rev	2816	2816
Brewer Type	2	2
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	3640	3640
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	1	1
NO2 ds etc	0	0
NO2 zs etc	0	0
NO2 Mic #1 Offset	0	0
NO2 FW #3 Offset	0	0
NO2/O3 Mode Change	78	78
Grating Slope	0	0
Grating Intercept	0	0

	Initial (ICF14919.017)	*Final (ICF16819.017)*
Micrometre Zero	2469	2469
Iris Open Steps	250	250
Buffer Delay (s)	0	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	55	55
Zenith UVB Position	2112	2112

5.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#017*	*O3 std*	*%diff*	*(*)O3#017*	*O3 std*	*(*)%diff*
168	700> osc> 400	314	1.0	18	310	1.5	-1.1	314	1.2	0.1
168	osc< 400	312	1.4	26	309	1.7	-0.9	314	1.6	0.9
169	osc< 400	323	2.6	9	319	3.4	-1.2	321	3.5	-0.6
170	1500> osc> 1000	319	0.1	4	314	0.8	-1.3	315	0.8	-1.1
170	1000> osc> 700	321	1.5	7	318	1.6	-0.8	319	1.7	-0.6
170	700> osc> 400	321	1.2	20	317	1.0	-1.2	318	0.9	-0.8
171	osc> 1500	334	0.0	1	323	0.0	-3.1	327	0.0	-2.1
171	1500> osc> 1000	334	0.3	6	326	2.1	-2.2	330	2.6	-1.1
171	1000> osc> 700	336	0.7	13	331	0.7	-1.4	338	1.1	0.4
171	700> osc> 400	336	0.7	5	330	6.2	-1.7	339	4.0	0.8
172	1500> osc> 1000	332	3.9	17	328	6.2	-1.4	329	6.3	-0.9
172	1000> osc> 700	333	1.7	19	330	4.5	-0.7	333	4.5	0.0
172	700> osc> 400	335	3.6	41	332	4.1	-0.7	336	4.4	0.5
172	osc< 400	339	1.7	29	336	3.0	-0.9	342	3.2	0.8
173	osc> 1500	317	0.0	1	310	0.0	-2.1	311	0.0	-1.9
173	1500> osc> 1000	325	1.3	14	320	3.1	-1.7	321	3.2	-1.4
173	1000> osc> 700	328	0.9	13	323	1.1	-1.4	324	1.1	-1.0
173	700> osc> 400	329	2.0	29	326	1.2	-0.9	329	1.4	-0.2
173	osc< 400	329	1.5	36	326	2.2	-0.9	329	2.2	0.0
174	osc> 1500	314	0.0	2	305	3.7	-2.8	306	3.8	-2.6

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#017*	*O3 std*	*%diff*	*(*)O3#017*	*O3 std*	*(*)%diff*
174	1500> osc> 1000	319	4.9	10	314	4.2	-1.5	315	4.3	-1.2
174	1000> osc> 700	320	3.5	20	318	2.8	-0.7	320	2.9	-0.3
174	700> osc> 400	323	1.9	45	321	1.9	-0.6	324	2.1	0.0
174	osc< 400	326	0.9	44	322	1.4	-1.3	325	1.5	-0.4
175	1500> osc> 1000	307	1.6	9	303	1.0	-1.2	304	1.0	-1.0
175	1000> osc> 700	308	1.2	18	306	2.6	-0.7	307	2.5	-0.3
175	700> osc> 400	307	1.1	34	304	1.5	-0.9	306	1.5	-0.3
175	osc< 400	307	0.4	3	303	1.8	-1.2	305	2.1	-0.4
176	osc> 1500	306	0.0	2	298	1.7	-2.4	299	1.7	-2.3
176	1500> osc> 1000	307	2.3	11	303	1.5	-1.5	303	1.6	-1.3
176	1000> osc> 700	307	2.2	14	305	1.0	-0.6	306	1.0	-0.3
176	700> osc> 400	308	1.5	31	306	1.4	-0.7	307	1.4	-0.2
176	osc< 400	310	1.4	40	308	2.0	-0.6	310	2.1	0.1
177	1000> osc> 700	306	0.8	7	304	1.3	-0.5	305	1.3	-0.3
177	700> osc> 400	308	1.0	13	306	1.5	-0.7	307	1.4	-0.3
177	osc< 400	309	1.0	3	306	1.5	-1.0	308	1.5	-0.4
178	1500> osc> 1000	302	1.5	6	NaN	NaN	NaN	298	2.8	-1.5
178	700> osc> 400	307	0.8	14	NaN	NaN	NaN	308	1.4	0.1
178	osc< 400	308	0.2	4	NaN	NaN	NaN	308	0.7	0.1

5.9. APPENDIX: SUMMARY PLOTS

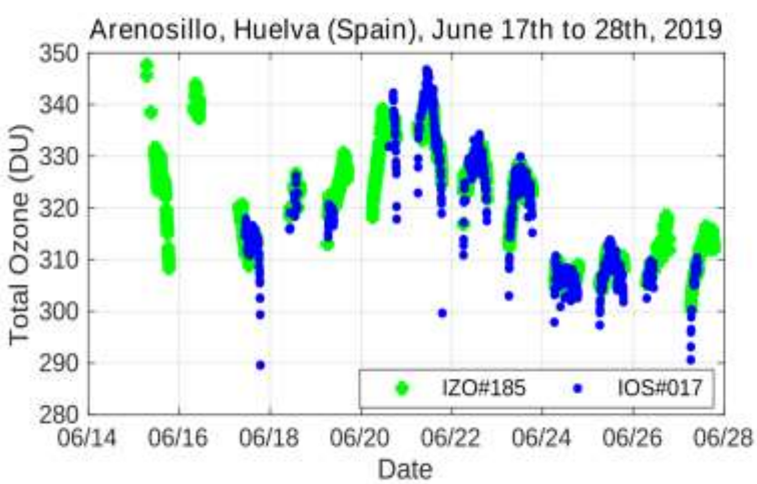
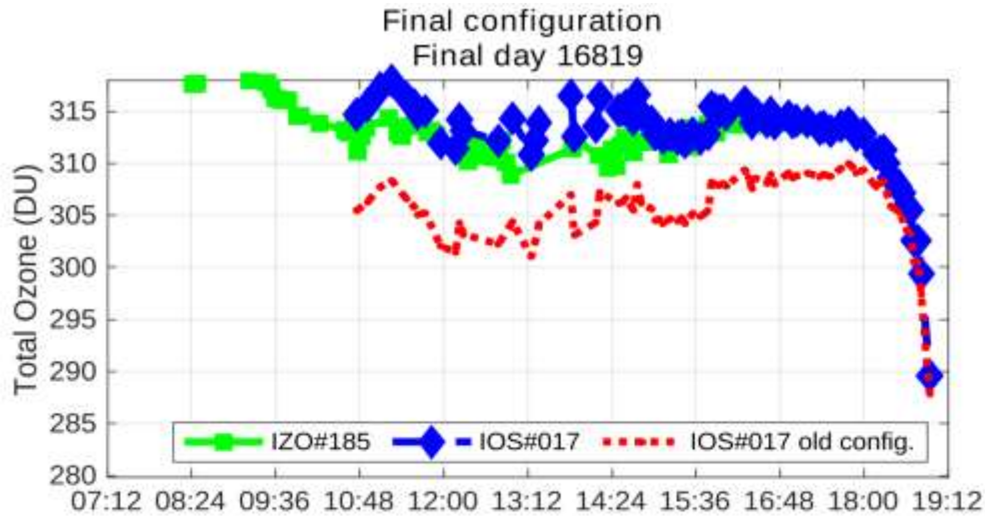
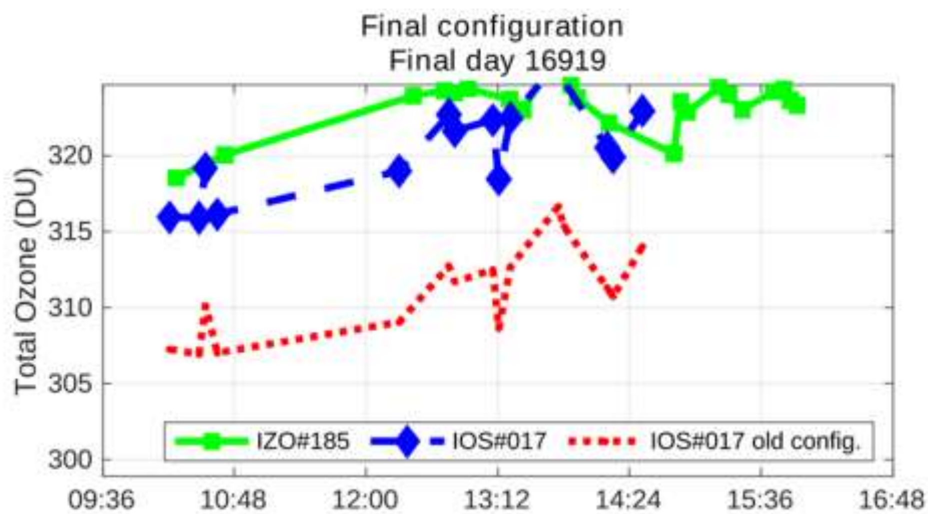
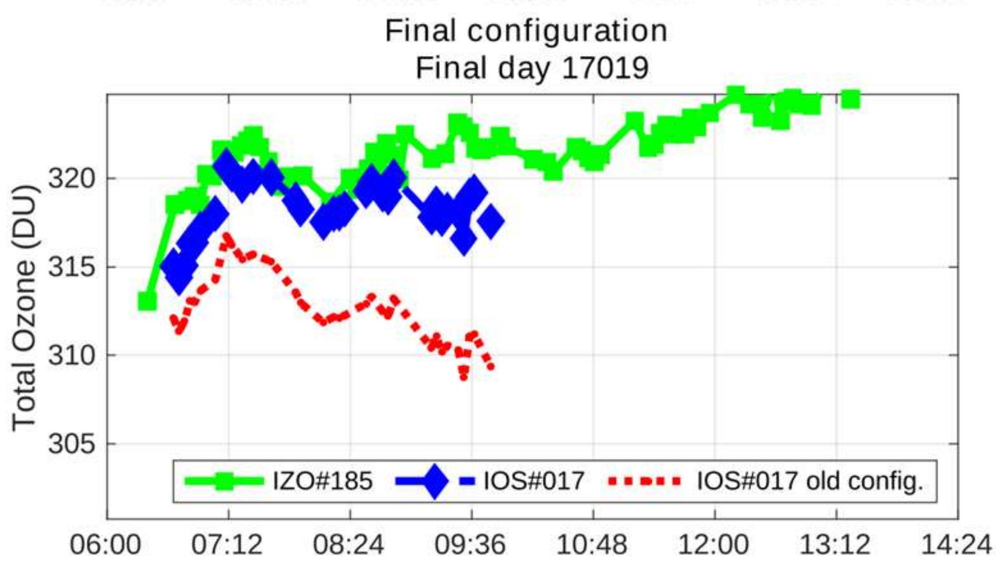
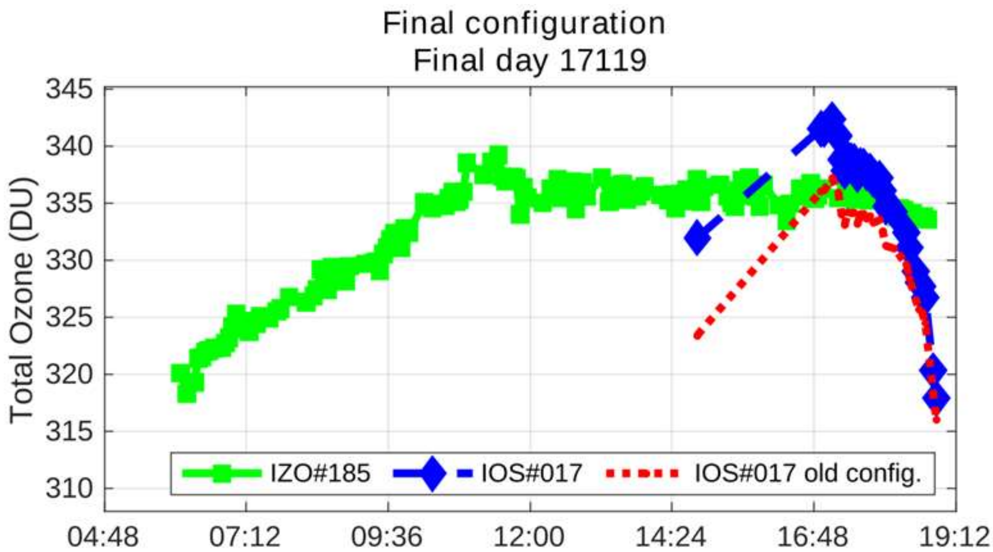


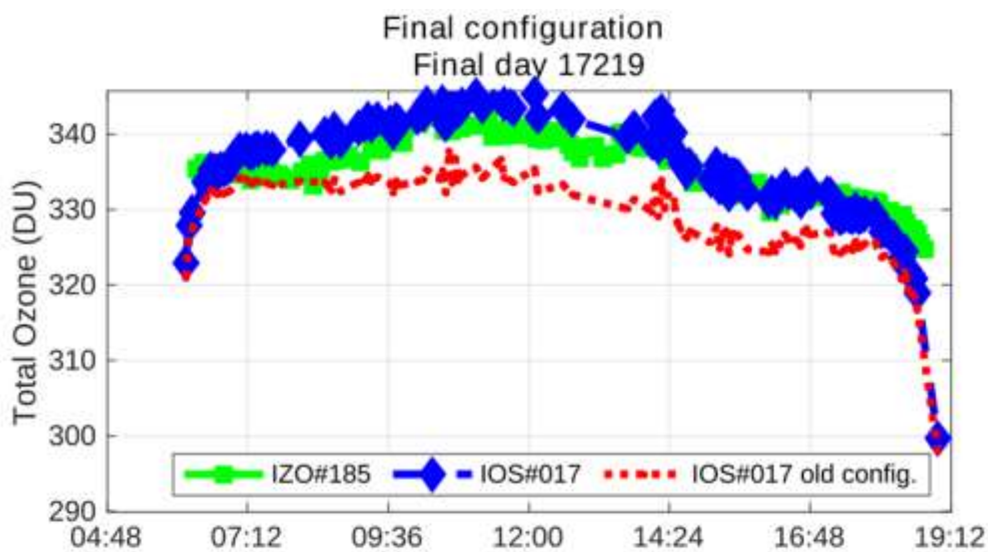
Figure 25. Overview of the intercomparison. Brewer IOS#017 data were evaluated using final constants (blue circles)

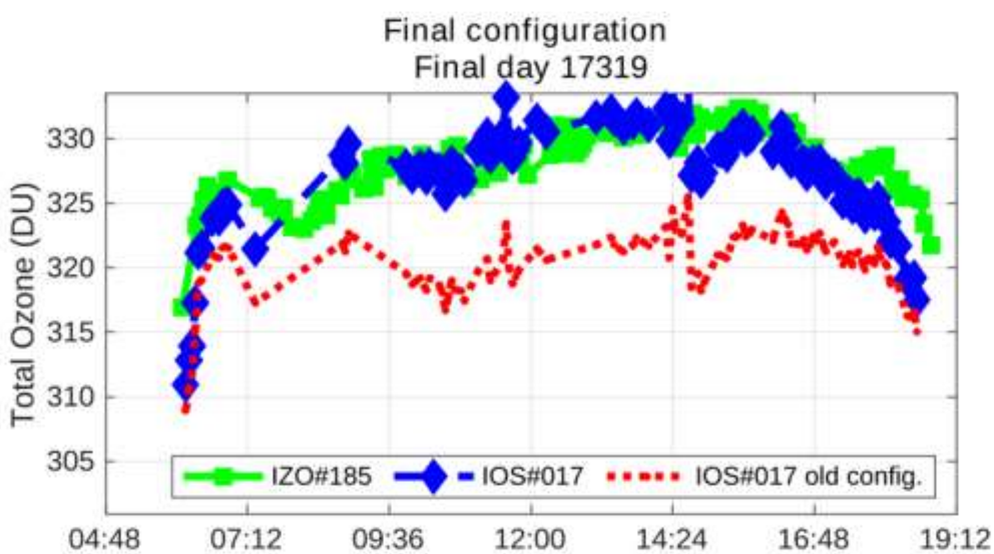

Final configuration
Final day 16819
Total Ozone (DU)
IZO#185
IOS#017
IOS#017 old config.
07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00 19:12

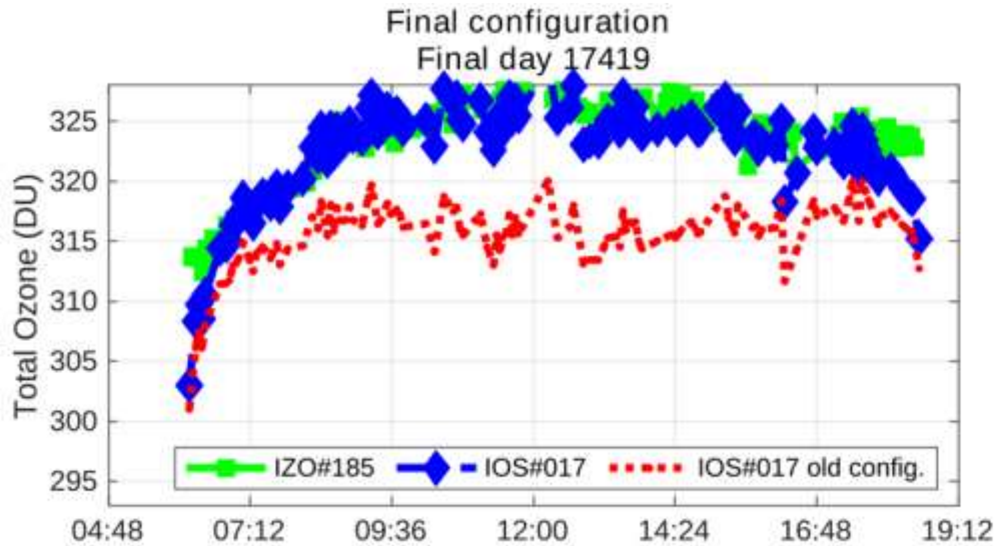

Final configuration
Final day 16919
Total Ozone (DU)
IZO#185
IOS#017
IOS#017 old config.
09:36 10:48 12:00 13:12 14:24 15:36 16:48

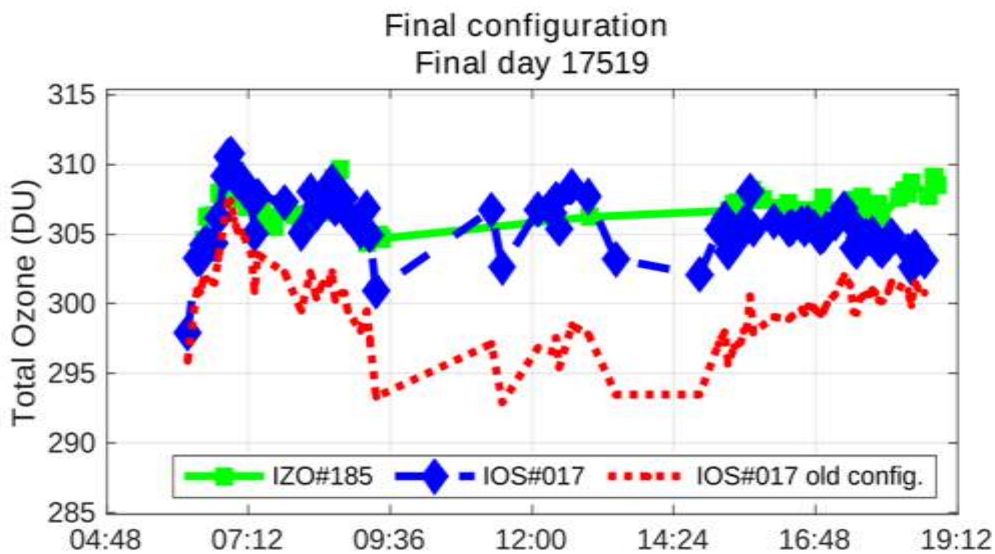

Final configuration
Final day 17019
Total Ozone (DU)
IZO#185
IOS#017
IOS#017 old config.
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24

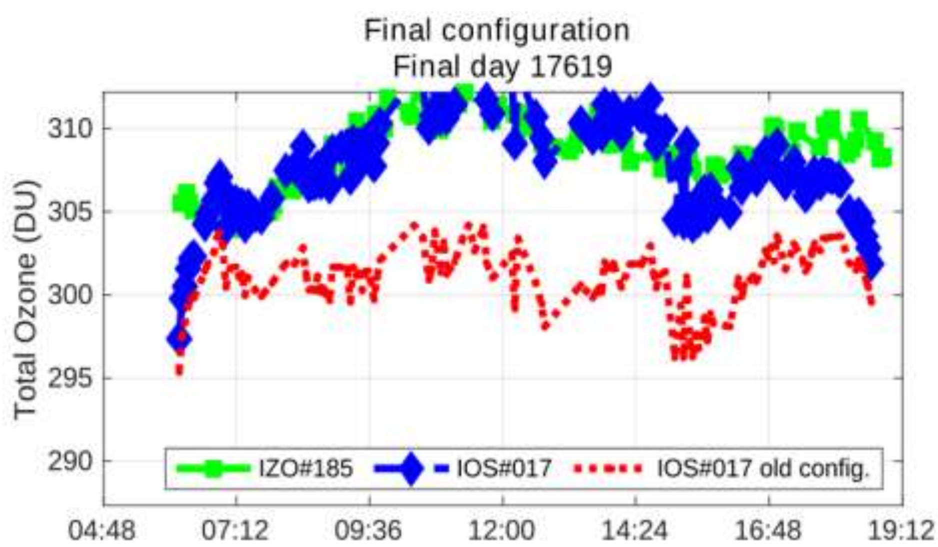

Final configuration
Final day 17119
Total Ozone (DU)
345
340
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.

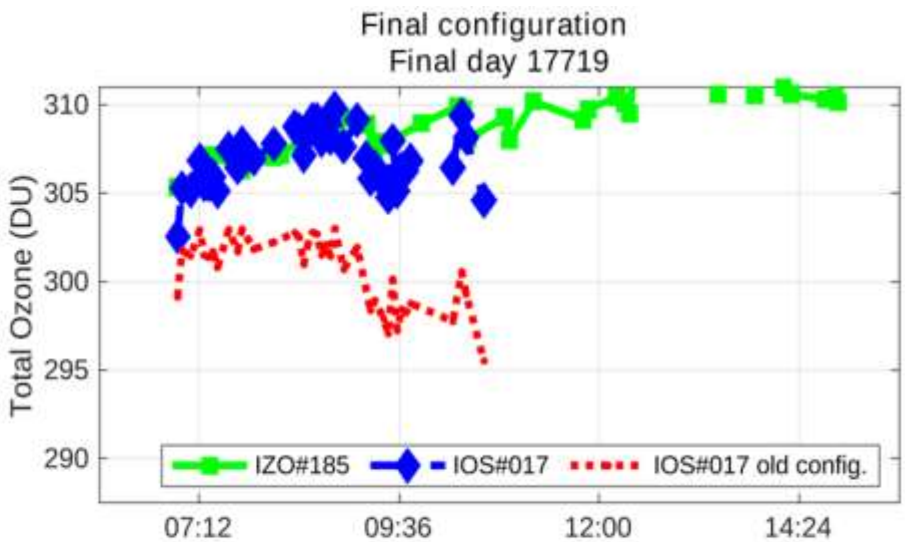

Final configuration
Final day 17219
Total Ozone (DU)
340
330
320
310
300
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.

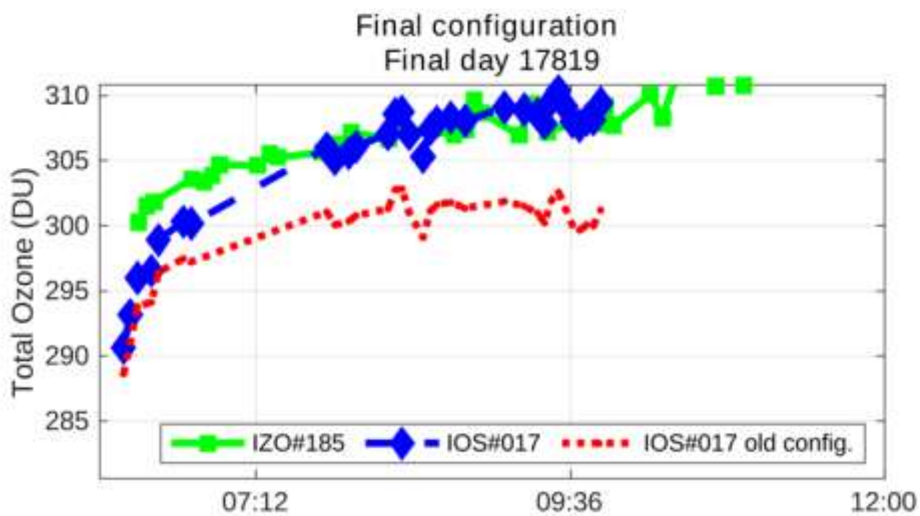

Final configuration
Final day 17319
Total Ozone (DU)
330
325
320
315
310
305
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.


Final configuration
Final day 17419
Total Ozone (DU)
325
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.


Final configuration
Final day 17519
Total Ozone (DU)
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.


Final configuration
Final day 17619
Total Ozone (DU)
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
IOS#017
IOS#017 old config.


Final configuration
Final day 17719
Total Ozone (DU)
310
305
300
295
290
07:12
09:36
12:00
14:24
IZO#185
IOS#017
IOS#017 old config.


Final configuration
Final day 17819
Total Ozone (DU)
310
305
300
295
290
285
07:12
09:36
12:00
IZO#185
IOS#017
IOS#017 old config.

6. BREWER SCO#033

6.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 18 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer SCO#033 participated in the campaign from 17 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer SCO#033 correspond to Julian days 168 – 178.

For the evaluation of the initial status, we used 141 simultaneous direct sun (DS) ozone measurements from days 168 to 172. For final calibration purposes, we used 250 simultaneous DS ozone measurements taken from day 173 to 178.

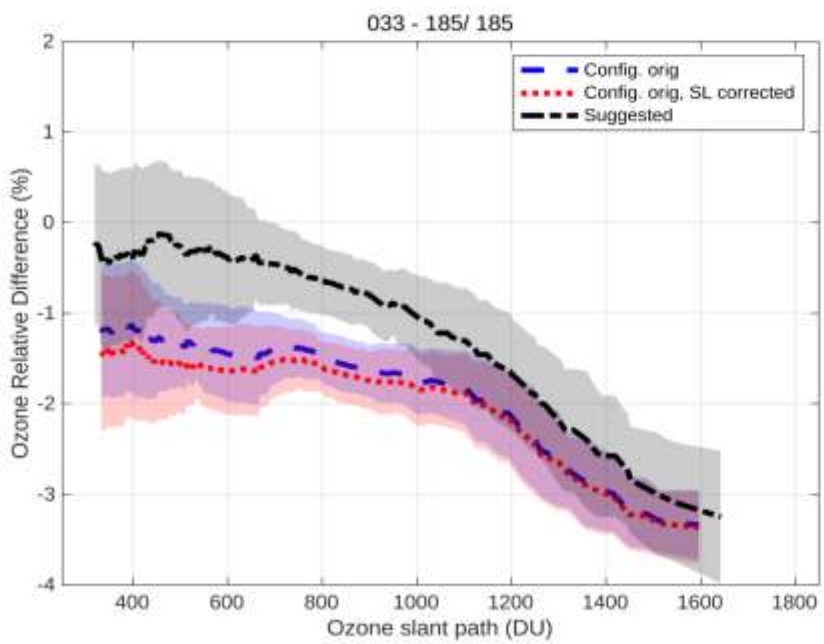


Figure 1. Mean DS ozone column percentage difference between Brewer SCO#033 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15617.033, blue dashed line) produces ozone values with an average difference of more than 1% with respect to the reference instrument. The SL correction (Figure 1, red dotted line) is thus not necessary and does not improve the comparison with Brewer IZO#185.

As a Mk. II model, Brewer SCO#033 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method, see Sec. 1.6.

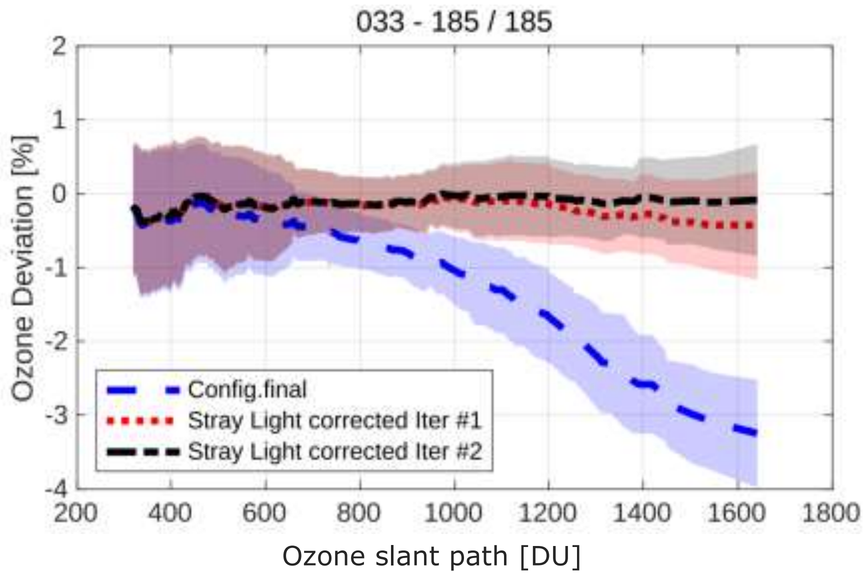


Figure 2. Mean DS ozone column percentage difference between Brewer SCO#033 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

During the intercomparison campaign period, the lamp test results from Brewer SCO#033 were quite stable, although some seasonal dependence can be observed in Figures 3 to 5. During campaign days, there was a noticeable change caused by the maintenance work carried out on day 172 (see Figures 23 and 24). However, by the end of the campaign, the standard lamp ratios stabilized around values 2324 and 4344 for R6 and R5, respectively. The value for R6 is virtually the same as the current reference value (2325).

The CZ tests on the mercury lamp shows that the peak of the 2967.28 nm line is slightly outside tolerance limits, and RS tests for slit 0 are somewhat noisy. All the other parameters analysed show reasonable results.

Concerning the performance of the filters, Filter#3 shows some non-linearity issues and we suggest the application of an ETC filter correction with a value of 10 units for this filter. Results of the FI tests for Filter#4 are quite noisy, precluding us from making any conclusion on its performance at this time, so we recommend performing further checks at the station.

The sun scan tests (SC) during the campaign confirm the current cal step number (CSN) within a step error of ± 1 . SC tests carried out at the station before the campaign provided a slightly larger difference, but these tests were somewhat noisy. We suggest retaining the current CSN, 914.

The analysis of the dispersion tests suggests an ozone absorption coefficient with 0.002 units (2 steps) more than the current one, 0.339. This is a rather small difference and, since the CSN has not been changed, we suggest retaining the current value.

Taking this into account, we suggest very few changes to the configuration of Brewer SCO#033.

6.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer SCO#033 have been very stable over the last 2 years and, despite the maintenance work carried out during the campaign, the current reference value, 2325, still seems good.
2. We suggest an R5 reference value of 4344.
3. We suggest the application of an ETC correction of 10 units for Filter#3. Furthermore, we suggest performing further checks on Filter#4 at the instrument's station.
4. For Brewer SCO#033, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -33.4$, and $s = b = 3.95$.
5. Finally, we suggest updating the ETC value from 3620 to 3601.

6.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/033/ICF17219.033

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=749793390

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/033/html/cal_report_033a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/033/html/cal_report_033a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/033/html/cal_report_033b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/033/html/cal_report_033c.html

6.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

6.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance has been quite stable since July 2017, with mean values around 2325 and 4340 for R6 and R5, respectively. The current R6 value is virtually the same as provided in the previous intercomparison campaign. Some seasonal dependence can be identified, especially in the lamp's intensity as shown in Figure 5.

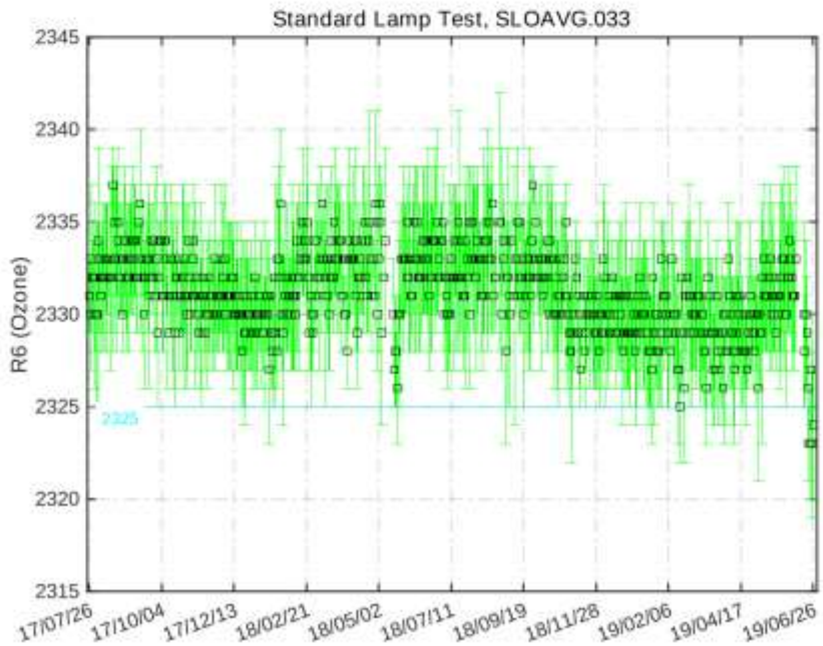


Figure 3. Standard lamp test R6 ozone ratios. The horizontal line is labelled with the original reference value, which is the same as the final one.

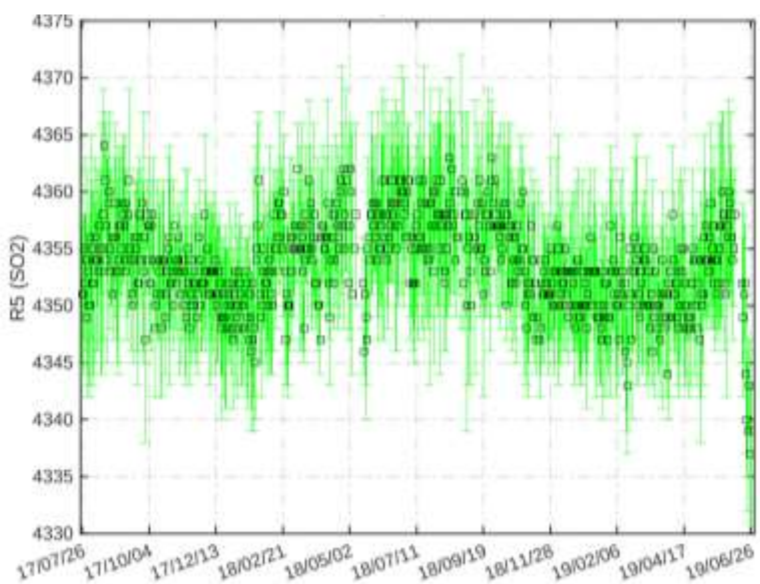


Figure 4. Standard lamp test R5 sulphur dioxide ratios

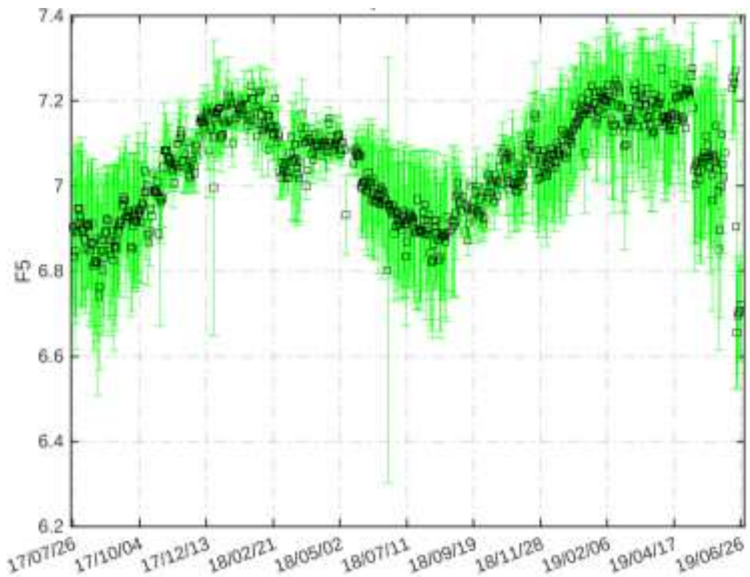


Figure 5. SL intensity for slit five

6.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 6). Note that the Hg slit (number #0) is noisier than the others, but it is still mostly within tolerance limits.

As shown in Figure 7, DT data were quite stable over the last two years. The current DT reference value of $4 \cdot 10^{-8}$ seconds still seems good at the present time.

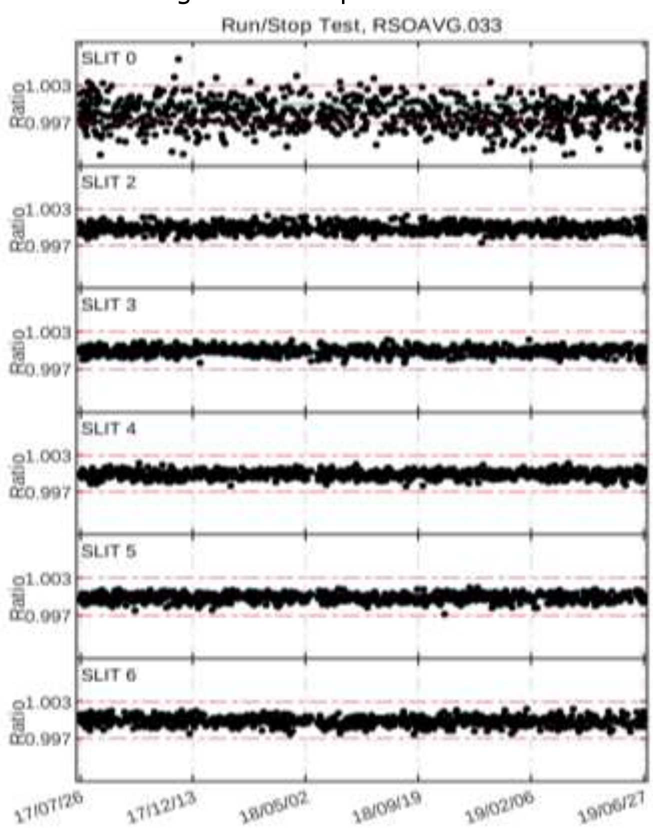


Figure 6. Run/stop test

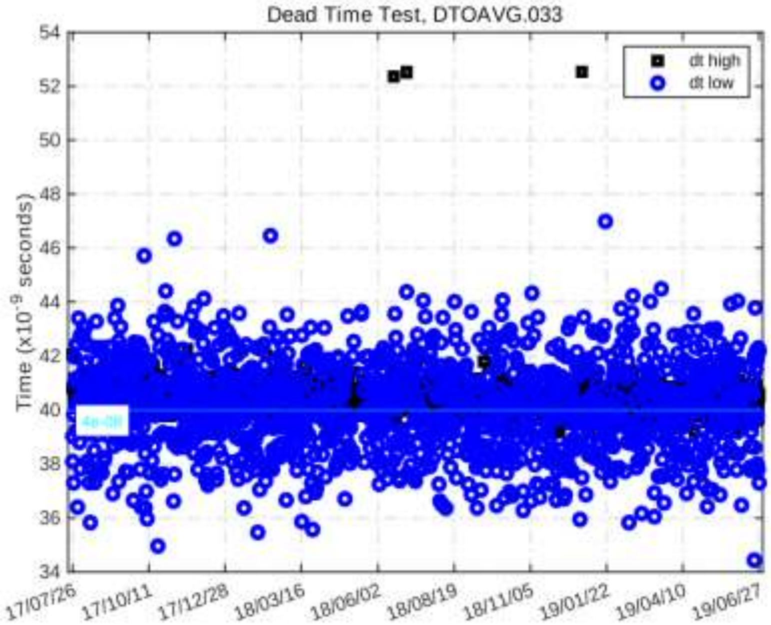


Figure 7. Dead time test. The horizontal line is labelled with the current value, which is the same as the final one.

6.2.3. Analogue test

Figure 8 shows that the +5 voltage was slightly outside tolerance limits until maintenance work was carried out at the present campaign.

Analogue Printout Log, APOAVG.033

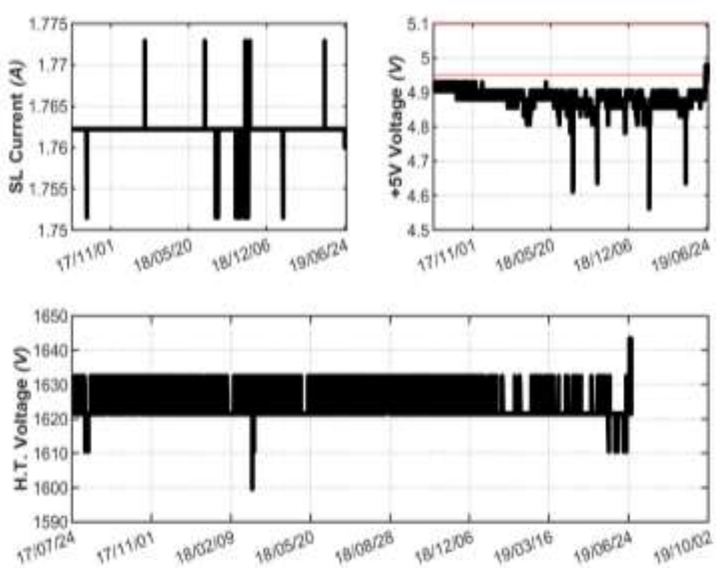


Figure 8. Analogue voltages and intensity

6.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events have been observed during the campaign (see Figure 9). Similarly, there is no clear correlation between the intensity of the Hg lamp and the instrument's temperature.

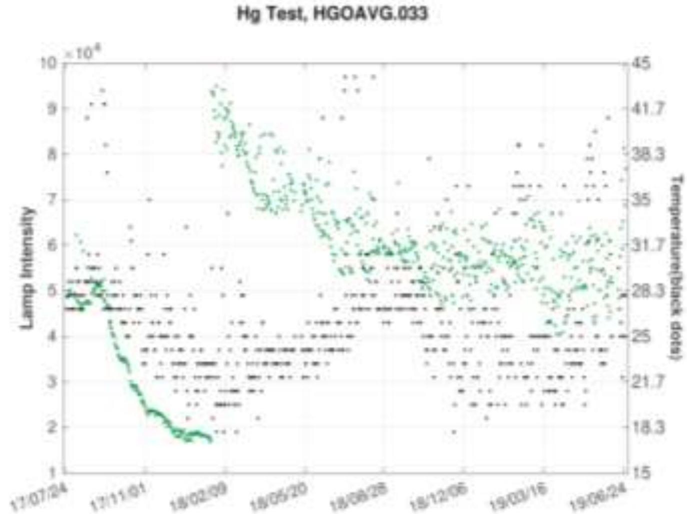


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

6.2.5. CZ scan on mercury lamp

We analysed the scans performed on the 296.728 nm mercury line, in order to check both the wavelength settings and the slit function width. As a reference, the calculated scan peak, in wavelength units, should be within ± 0.013 *nm* from the nominal value, whereas the calculated slit function width should be no more than 0.65 *nm*. Analysis of CZ scans performed on Brewer SCO#033 during the campaign shows that the peak is slightly above the tolerance limit. Regarding the slit function width, results are good, with a FWHM parameter lower than 0.65 nm.

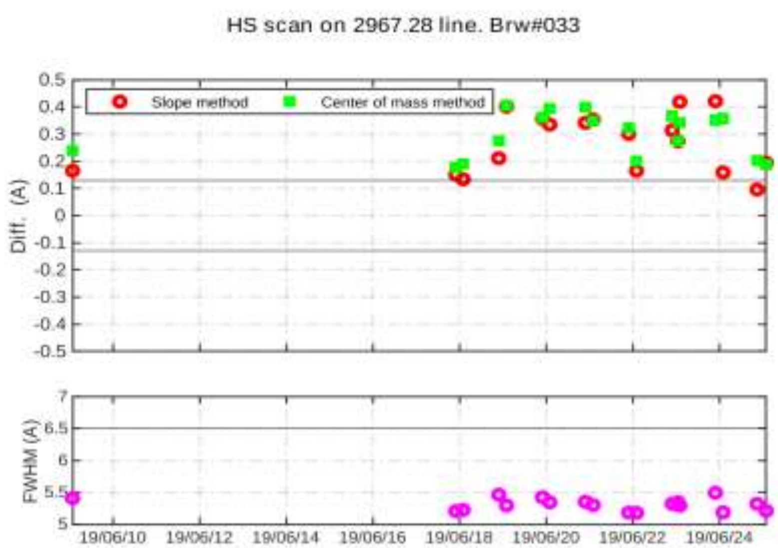


Figure 10. CZ scan on 296.728 nm Hg line. Upper figure shows differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by two different methods: slopes method (red circles) and centre of mass method (green squares). Lower figure

shows Full Width at Half Maximum value for each scan performed. Solid line represents the 0.65 nm limit

6.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer SCO#033 CI scans performed during the campaign relative to the CI17319.033 scan. As can be observed, there are two groups of results: before and after the maintenance work carried out on day 172. In both groups, the lamp intensity does not change more than 5%.

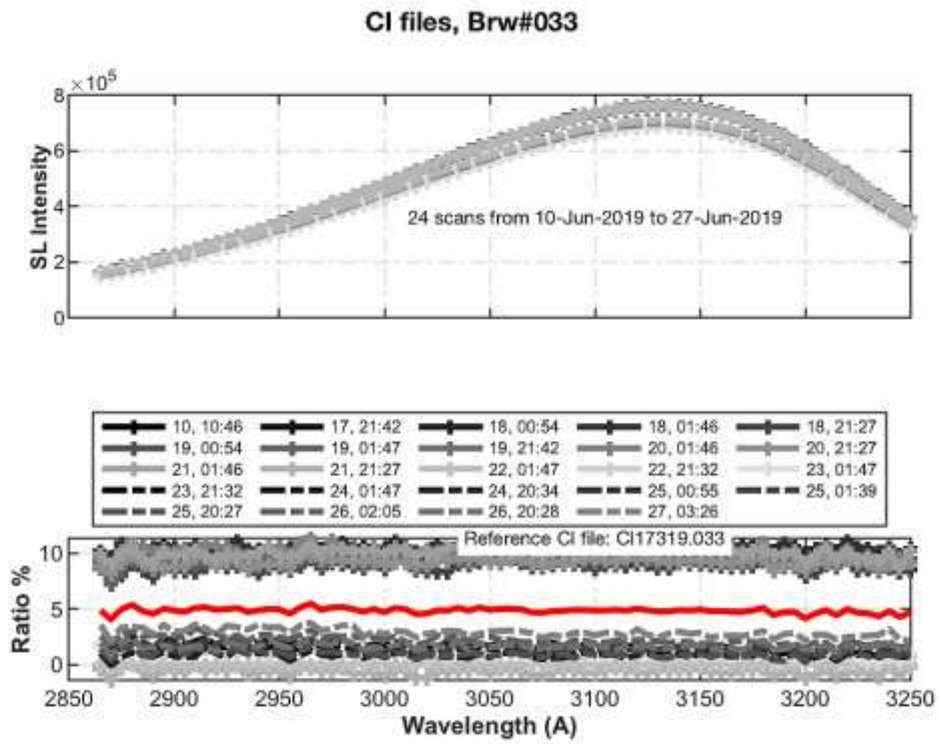


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

6.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

As shown in Figure 12 (temperature range from 21 °C to 38 °C), the current coefficients do an excellent job at reducing the temperature dependence, performing on par with the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 13 and 14, the current and new coefficients perform similarly. For this reason, we have retained the current coefficients in the final ICF.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	0.0629	0.0931	-0.7138	-2.0641
Calculated	0.0000	-0.1000	-0.4000	-1.3000	-2.9000
Final	0.0000	0.0629	0.0931	-0.7138	-2.0641

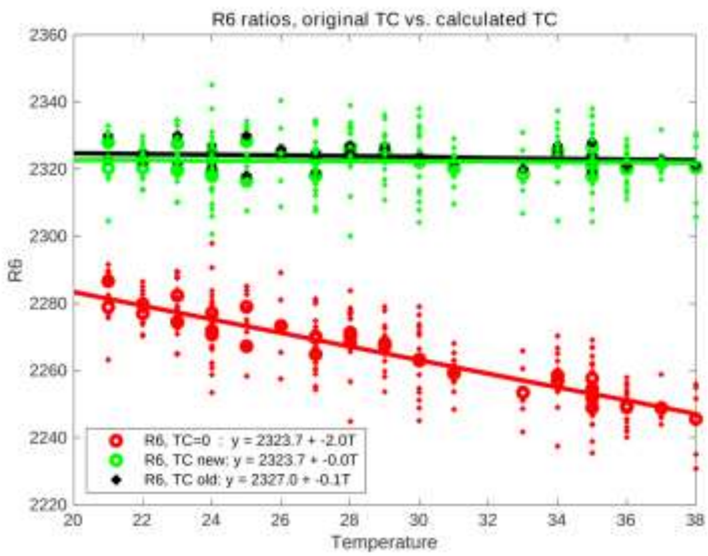


Figure 12. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

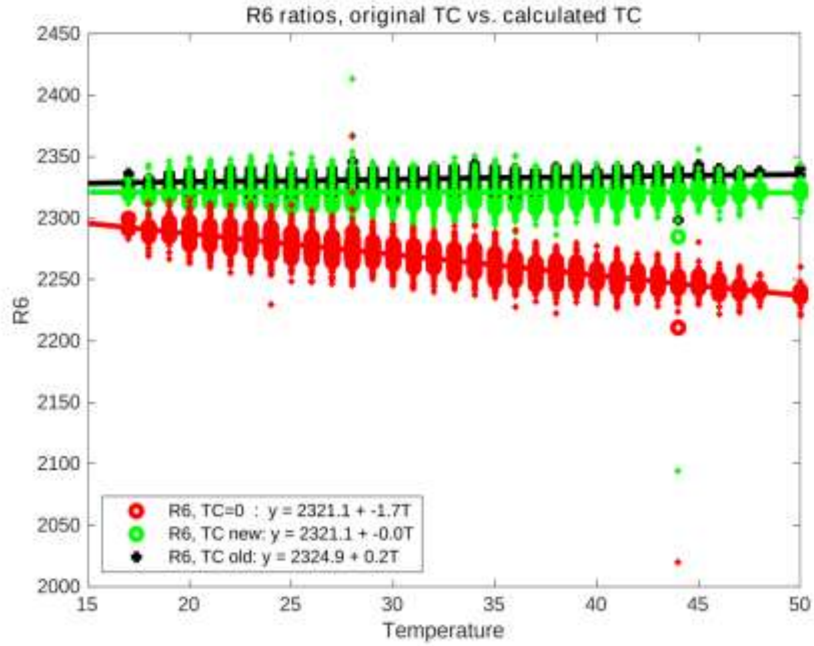


Figure 13. Same as Figure 12 but for the whole period between calibration campaigns

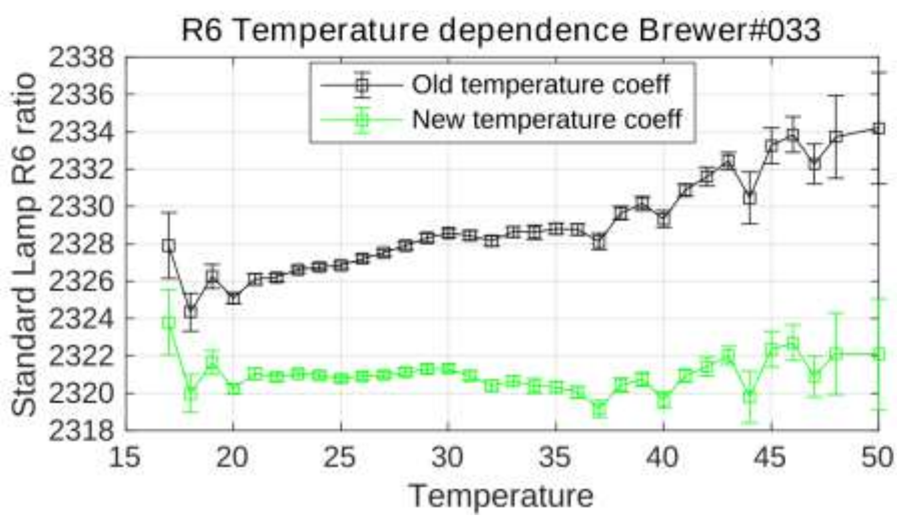


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

6.4. ATTENUATION FILTER CHARACTERIZATION

6.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 80 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Results of the FI test were rather noisy, with large confidence intervals and noticeable differences between the mean and median values of the filter corrections. Also, taking into account the comparison with reference Brewer IZO#185, we suggest applying an ETC correction of 10 units to the measurements taken with Filter #3. We also suggest performing more tests on Filter #4 at the station.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-5	-14	-15	-4	-12
ETC Filt. Corr. (mean)	-3	-9.3	-17	-0.8	-17.5
ETC Filt. Corr. (mean 95% CI)	[-7.8 2]	[-15.1 -3]	[-22.6 -11.6]	[-8.1 7.9]	[-27.8 -7.1]

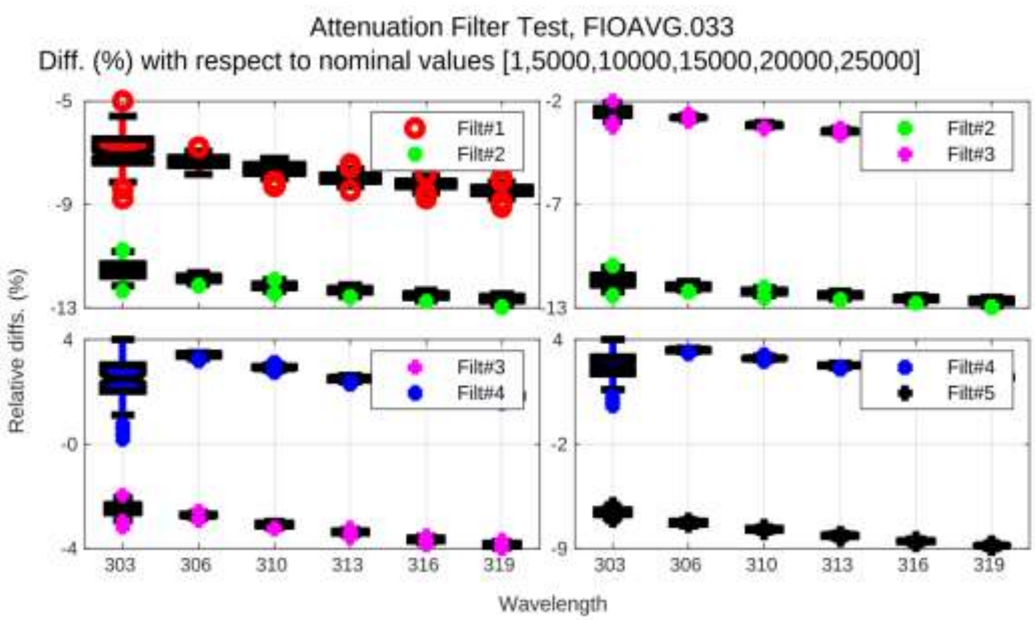


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

6.5. WAVELENGTH CALIBRATION

6.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is

required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

During the campaign, 6 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1200 DU were carried out (see Figure 17). The calculated cal step number (CSN) was 1 step higher than the value in the current configuration: 915 vs. 914. A difference of 1 step is within the tolerance limits. SC tests performed at the station before the campaign provide a CSN of 916, but these tests seem rather noisy. Taking all this into account, we suggest keeping the current CSN of 914.

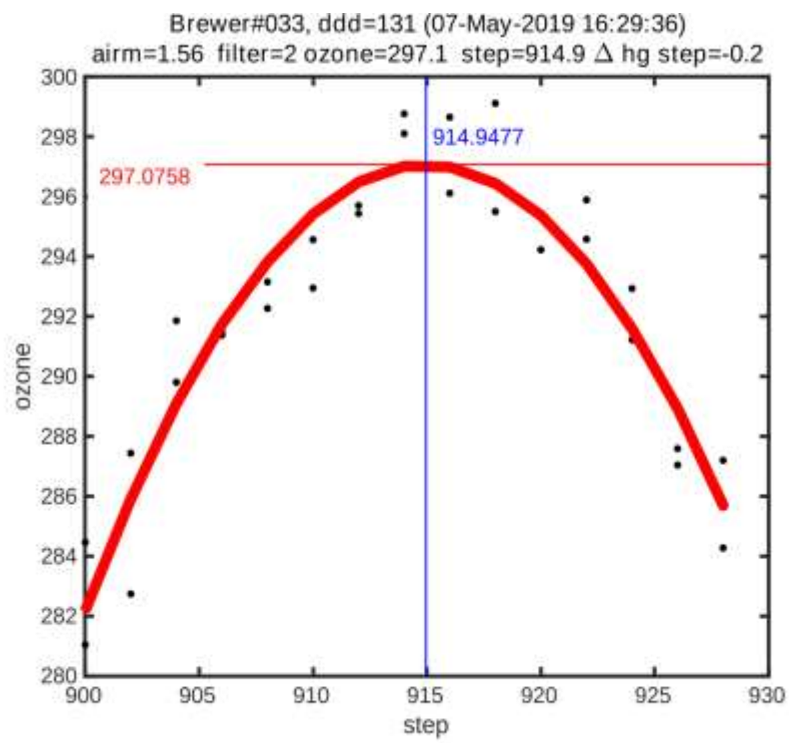


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

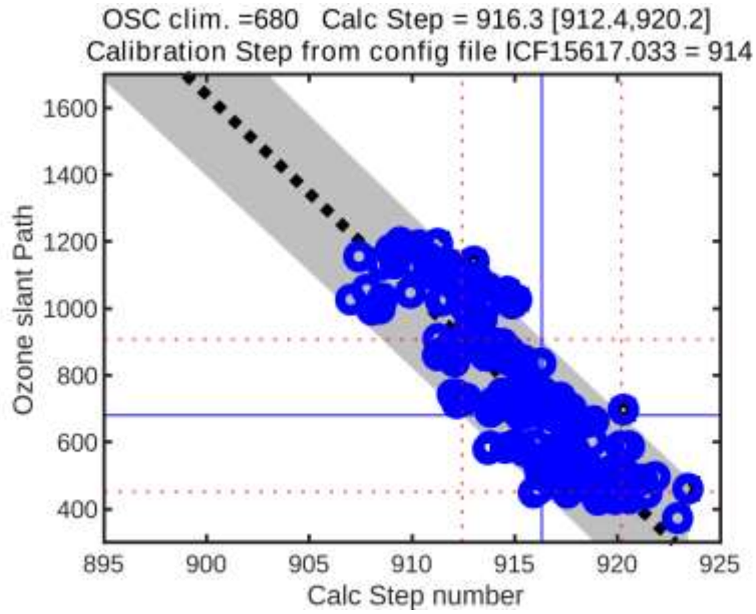


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

6.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

Although the dispersion tests carried out in the present campaign suggest a new absorption coefficient equal to 0.3415, the difference with the current value of 0.339, is rather small (0.002 units, or 2 cal steps). Since the CSN has not been changed, we suggest keeping the current Ozone absorption coefficient in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	914	0.3390	2.3500	1.1362
05-Jun-2013	914	0.3426	3.1024	1.1559
02-Jun-2015	914	0.3426	3.0715	1.1570
01-Jun-2017	914	0.3396	3.1971	1.1422
23-Jun-2019	914	0.3415	3.1404	1.1509
Final	914	0.3390	2.3500	1.1362

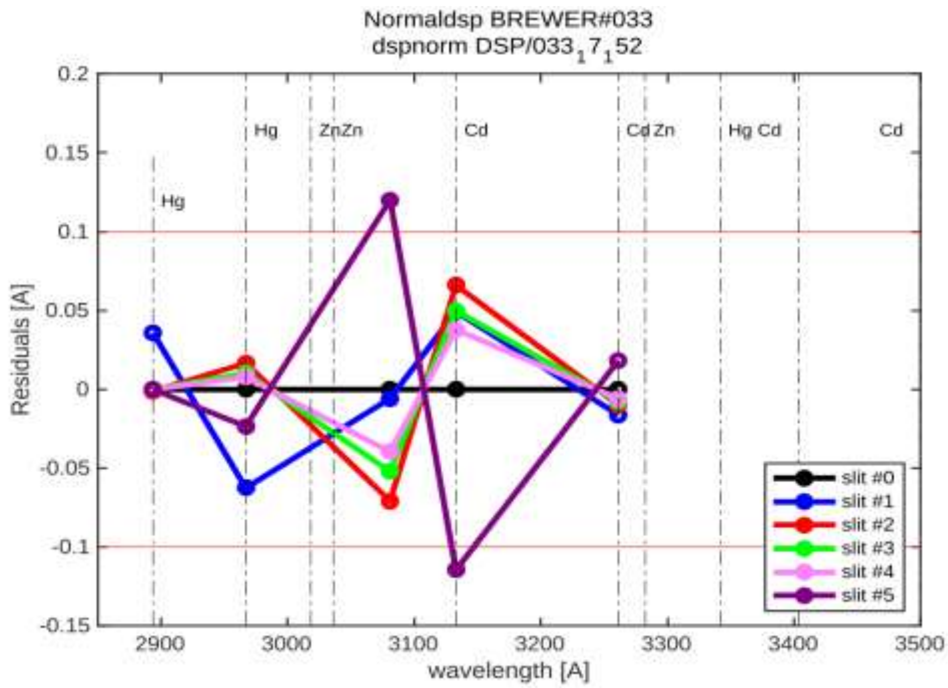


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 913	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3020.89	3062.77	3100.45	3134.99	3168.03	3200.04
Res(A)	3.5817	5.2894	5.2266	5.3913	5.3583	5.1692
O3abs(1/cm)	3.1448	1.7864	1.0054	0.67747	0.37484	0.29444
Ray abs(1/cm)	0.51311	0.48339	0.45851	0.43712	0.41784	0.40018
SO2abs(1/cm)	8.3399	5.6062	2.3945	1.9035	1.0559	0.61149
step= 914	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3020.96	3062.84	3100.52	3135.06	3168.1	3200.11
Res(A)	3.5817	5.2893	5.2266	5.3912	5.3582	5.1691
O3abs(1/cm)	3.1421	1.7849	1.0051	0.67716	0.37491	0.29396
Ray abs(1/cm)	0.51306	0.48334	0.45846	0.43708	0.4178	0.40015
SO2abs(1/cm)	8.3669	5.6303	2.4021	1.8924	1.057	0.60927
step= 915	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3021.03	3062.91	3100.59	3135.13	3168.17	3200.17
Res(A)	3.5817	5.2893	5.2266	5.3911	5.3581	5.169
O3abs(1/cm)	3.139	1.7834	1.0049	0.67682	0.37498	0.29348
Ray abs(1/cm)	0.51301	0.48329	0.45842	0.43704	0.41776	0.40011
SO2abs(1/cm)	8.3907	5.6536	2.4097	1.8811	1.0582	0.60706
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
913	0.34253	10.2065	3.1284	1.1543	0.35364	0.34489
914	0.34146	10.2036	3.1404	1.1509	0.35267	0.34389
915	0.34041	10.2007	3.1517	1.1477	0.35166	0.34285

6.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2392. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 914	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3021	3063	3101	3135	3168	3200
Res(A)	3.5817	5.2893	5.2266	5.3912	5.3582	5.1691
O3abs(1/cm)	3.1421	1.7849	1.0051	0.67716	0.37491	0.29396
Ray abs(1/cm)	0.51306	0.48334	0.45846	0.43708	0.4178	0.40015
step= 2392	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3123	3164	3200	3233	3265	3296
Res(A)	3.597	5.2398	5.2024	5.2601	5.2492	4.9738
O3abs(1/cm)	0.71742	0.39523	0.29381	0.12153	0.060516	0.033333
Ray abs(1/cm)	0.44425	0.42028	0.40015	0.38277	0.36705	0.35257

6.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F, α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.
For single monochromator Brewers, the ETC distribution (see Figure1) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

6.6.1. Initial calibration

For the evaluation of the initial status of Brewer SCO#033, we used the period from days 168 to 172 which corresponds to 141 near-simultaneous direct sun ozone measurements. As shown in Figure 19, at OSC values lower than 1000, the initial calibration constants produced ozone values quite lower (more than 1%) than the reference instrument. Because of the stray light effect, this difference increases with the OSC. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

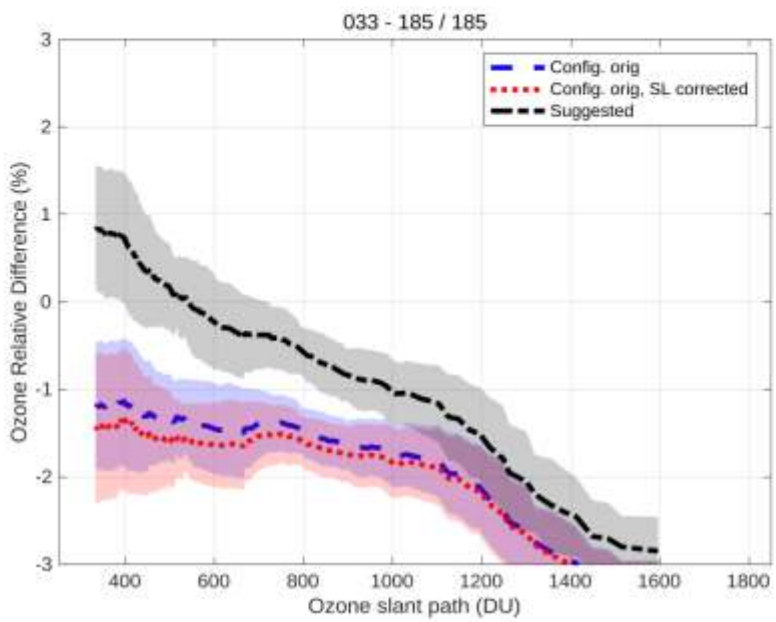


Figure 19. Mean direct sun ozone column percentage difference between Brewer SCO#033 and Brewer IZO#185 as a function of the ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=600	3596	3590	3390	3404
full OSC range	3595	3615	3390	3343

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3 std*	*N*	*O3#033*	*O3 std*	*%(033–185)/185*	*O3(*)#033*	*O3 std*	*(*)%(033–185)/185*
19 Jun 2019	170	324.8	3.4	59	318.7	2.9	-1.9	324.4	2.8	-0.1
20 Jun 2019	171	334.8	2.9	59	328.1	2.5	-2	333.9	2.7	-0.3
21 Jun 2019	172	340.1	1.2	23	336.2	1.6	-1.1	342.4	1.8	0.7

6.6.2 Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 20). For the final calibration, we used 250 simultaneous direct sun measurements from days 173 to 178. The new value of 3601 is approximately 20 units lower than the current ETC of 3620. Therefore, we recommend using this new ETC. Note that the R6 reference value remains unchanged with respect to the present value of 2325.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, in the lower OSC range, the agreement between the 1P and 2P ETCs is only slightly above the maximum tolerance limit of 10 units.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

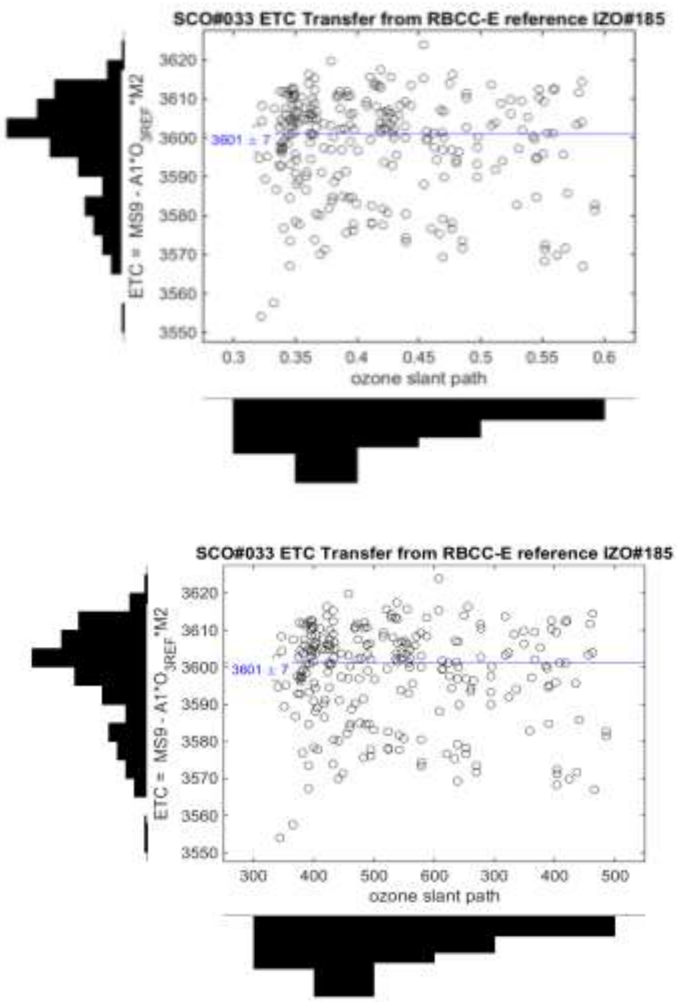


Figure 20. Mean direct sun ozone column percentage difference between Brewer SCO#033 and Brewer IZO#185 as a function of the ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=600	3601	3613	3390	3352
full OSC range	3598	3627	3390	3320

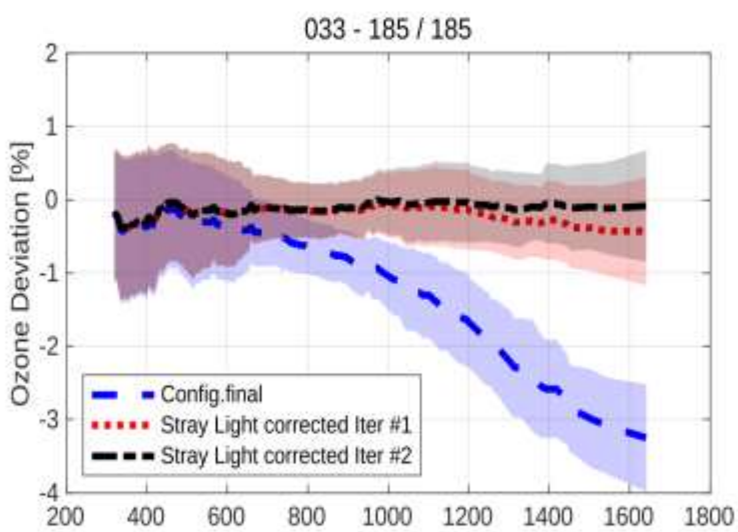
Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

	Day	*O3#185*	*O3std*	*N*	*O3#033*	*O3 std*	*%(033–185)/185*	*O3(*)#033*	*O3std*	*(*)%(03–185)/185*
21 Jun 2019	172	334	4.2	42	329.3	6.8	-1.4	331.7	7.1	-0.7
22 Jun 2019	173	328.6	2.7	97	322	2.8	-2	324.7	3.3	-1.2
23 Jun 2019	174	323.1	4	89	319.5	5.2	-1.1	322.6	5.9	-0.2
24 Jun 2019	175	307.5	1	37	301.8	3.1	-1.9	304.2	3.2	-1.1
25 Jun 2019	176	308.3	2.1	87	304.2	4.2	-1.3	306.7	4.4	-0.5
26 Jun 2019	177	307.6	1.2	25	303.2	3.4	-1.4	306.2	3.5	-0.5
27 Jun 2019	178	NaN	NaN	0	304.1	3.6	NaN	307.6	4.7	NaN

6.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and an underestimation of -1.5% at 1000 DU OSC. The empirical stray model fits with coefficient values: $k = a = -33.4$, $s = b = 3.95$, and ETC=3598. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$



Ozone slant path [DU]

Figure 21. Ratio respect to the reference when final constants are applied and stray light correction is applied

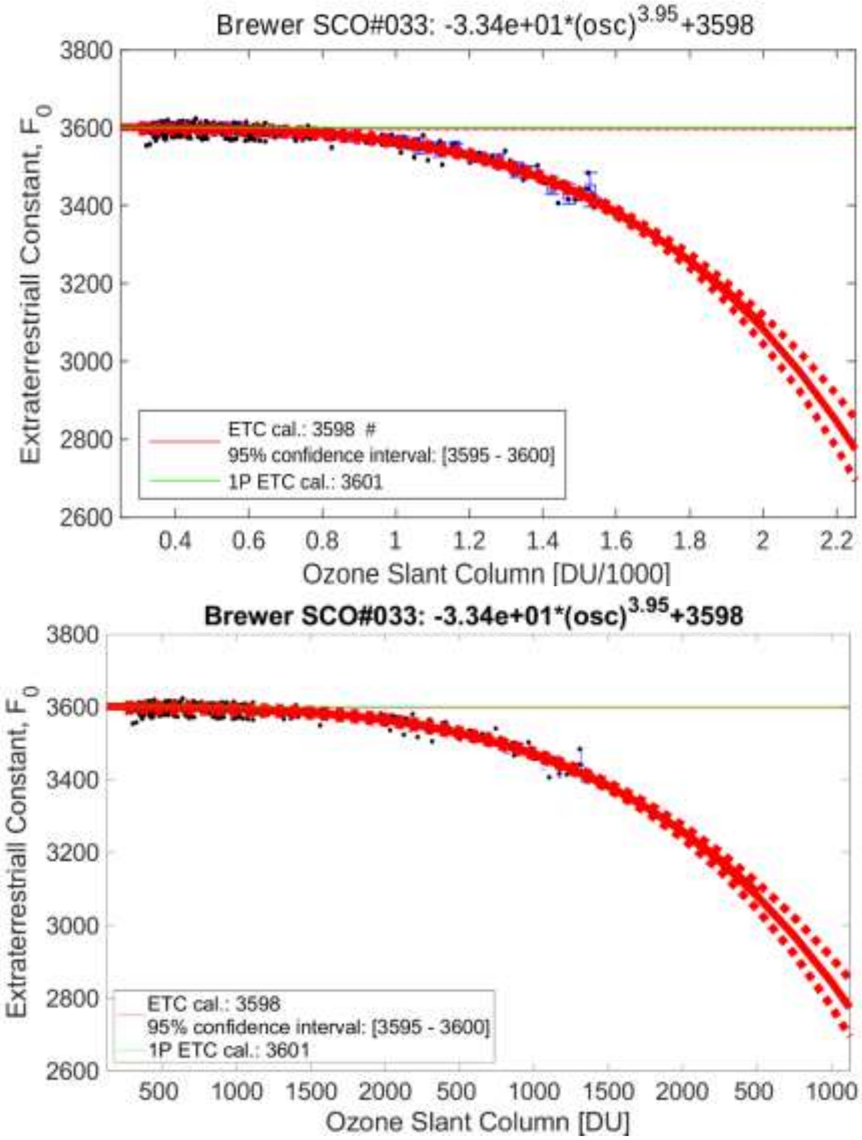


Figure 22. Stray light empirical model determination

6.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 2325 for R6 (Figure 23) and 4334 for R5 (Figure 24).

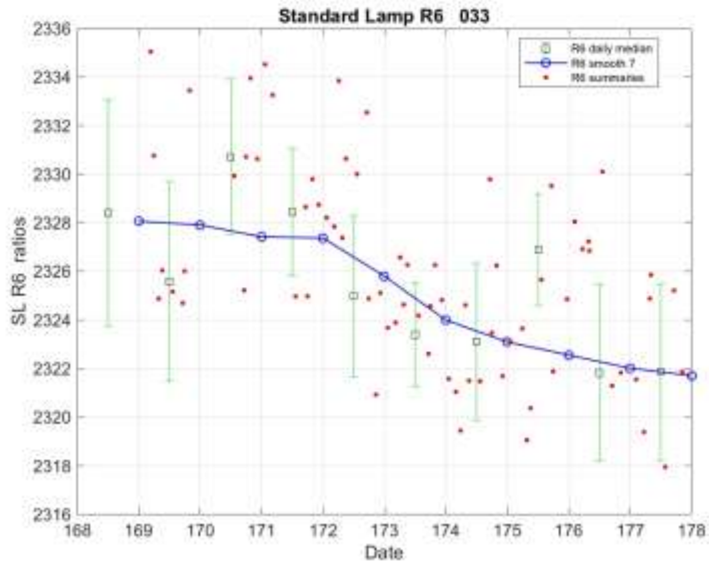


Figure 23. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

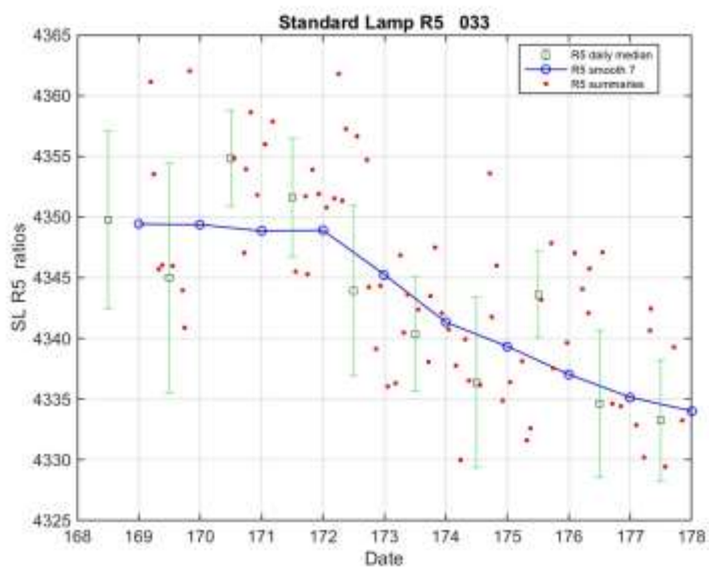


Figure 24. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

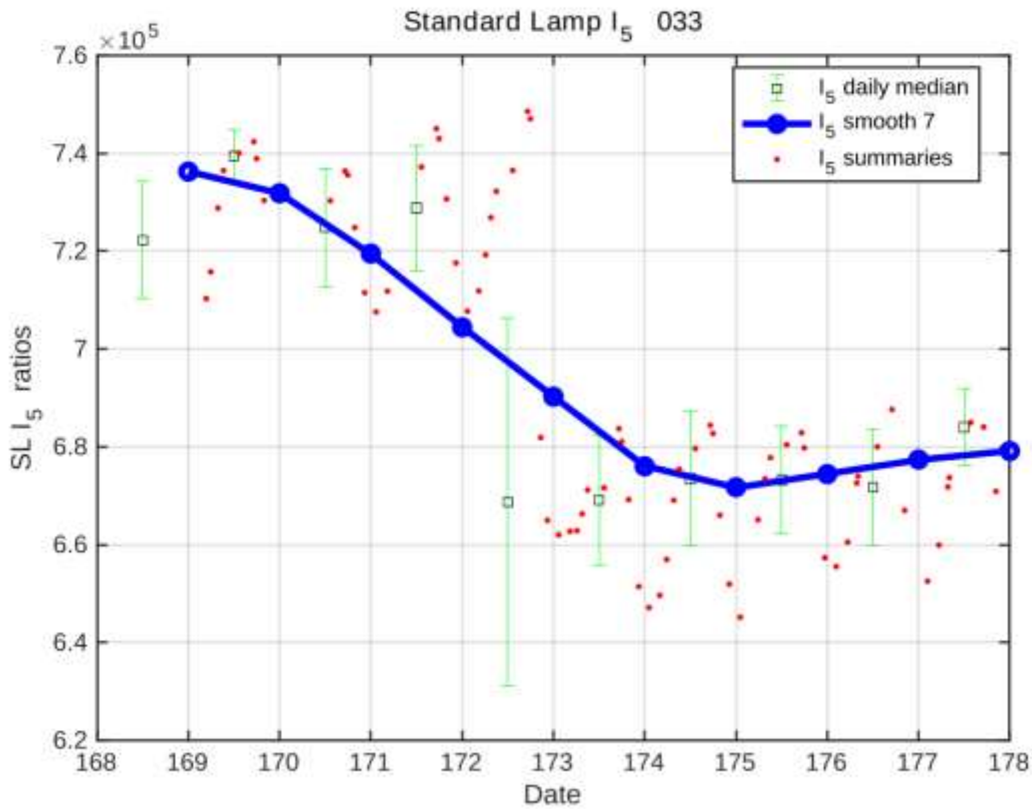


Figure 25. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

6.7. CONFIGURATION

6.7.1. Instrument constant file

	Initial (ICF15617.033)	*Final (ICF17219.033)*
o3 Temp coef 1	0	0
o3 Temp coef 2	0.0629	0.0629
o3 Temp coef 3	0.0931	0.0931
o3 Temp coef 4	-0.7138	-0.7138
o3 Temp coef 5	-2.0641	-2.0641
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.339	0.339
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1362	1.1362
ETC on O3 Ratio	3620	3601
ETC on SO2 Ratio	3960	3960
Dead time (sec)	4e-08	4e-08
WL cal step number	914	914
Slitmask motor delay	80	80
Umkehr Offset	2392	2392
ND filter 0	0	0
ND filter 1	4565	4565
ND filter 2	8822	8822
ND filter 3	14361	14361
ND filter 4	20339	20339
ND filter 5	25000	25000
Zenith steps/rev	2816	2816
Brewer Type	2	2

	Initial (ICF15617.033)	*Final (ICF17219.033)*
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	2666	2666
Mic #2 Offset	0	0
O3 FW #3 Offset	0	0
NO2 absn Coeff	1	1
NO2 ds etc	0	0
NO2 zs etc	0	0
NO2 Mic #1 Offset	0	0
NO2 FW #3 Offset	0	0
NO2/O3 Mode Change	2639	2639
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	2687	2687
Iris Open Steps	250	250
Buffer Delay (s)	0.2	0.2
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	45	45
Zenith UVB Position	2107	2107

6.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#033*	*O3 std*	*%diff*	*(*)O3#033*	*O3 std*	*(*)%diff*
170	1500> osc> 1000	319	0.1	4	310	0.8	-2.6	313	1.0	-1.8
170	1000> osc> 700	321	1.3	9	315	1.8	-1.9	318	2.1	-0.9
170	700> osc> 400	324	3.9	35	318	2.5	-1.8	324	2.9	0.0
170	osc< 400	325	2.8	31	319	3.1	-1.8	325	2.9	-0.2
171	osc> 1500	334	0.0	1	320	0.0	-4.1	322	0.0	-3.5
171	1500> osc> 1000	328	6.7	11	320	7.5	-2.6	322	7.7	-2.0
171	1000> osc> 700	334	5.0	15	328	4.6	-1.6	332	4.8	-0.6
171	700> osc> 400	333	4.0	42	328	3.3	-1.6	333	3.4	0.0
171	osc< 400	336	1.0	30	330	2.4	-1.8	335	2.4	-0.4
172	osc> 1500	325	0.6	2	310	7.0	-4.8	311	7.0	-4.4
172	1500> osc> 1000	332	3.8	13	324	4.4	-2.3	326	4.5	-1.7
172	1000> osc> 700	331	0.6	8	326	0.9	-1.6	329	1.2	-0.7
172	700> osc> 400	337	3.9	15	333	6.2	-1.1	337	6.3	0.1
172	osc< 400	339	2.0	35	337	3.7	-0.7	341	3.8	0.5

Day	osc range	O3#185	O3std	N	O3#033	O3 std	%diff	(*)O3#033	O3 std	(*)%diff
173	1500> osc> 1000	325	1.3	14	317	3.7	-2.4	319	3.8	-2.0
173	1000> osc> 700	327	1.4	12	322	1.2	-1.4	325	1.2	-0.7
173	700> osc> 400	329	3.0	38	324	1.7	-1.6	327	1.9	-0.6
173	osc< 400	329	1.7	28	323	1.4	-2.0	325	1.4	-1.4
174	1500> osc> 1000	318	4.7	11	311	6.4	-2.0	313	6.5	-1.6
174	1000> osc> 700	320	3.8	16	316	2.9	-1.4	318	3.1	-0.7
174	700> osc> 400	323	2.0	31	321	2.1	-0.7	324	2.6	0.3
174	osc< 400	327	1.3	29	324	2.3	-0.7	327	1.7	0.2
175	1500> osc> 1000	307	1.2	9	299	2.1	-2.8	300	2.2	-2.2
175	1000> osc> 700	308	1.4	9	304	0.9	-1.5	306	0.7	-0.8
175	700> osc> 400	307	0.5	14	301	3.1	-1.9	305	2.9	-0.7
175	osc< 400	307	0.0	2	306	0.8	-0.3	308	0.8	0.6
176	osc> 1500	307	1.6	4	295	3.5	-3.8	296	3.5	-3.5
176	1500> osc> 1000	308	2.2	9	301	3.3	-2.0	303	3.4	-1.6
176	1000> osc> 700	307	2.4	10	304	1.9	-1.2	305	1.9	-0.6
176	700> osc> 400	308	1.6	28	305	2.7	-1.0	307	2.6	-0.2
176	osc< 400	310	1.2	15	310	1.9	-0.3	311	1.9	0.2
177	1000> osc> 700	306	0.8	5	301	0.5	-1.6	303	0.5	-1.0
177	700> osc> 400	308	1.0	12	304	3.2	-1.4	306	3.3	-0.5
177	osc< 400	309	0.7	4	308	2.6	-0.1	311	1.4	0.6
178	1500> osc> 1000	302	1.1	3	NaN	NaN	NaN	296	3.6	-1.9
178	1000> osc> 700	305	0.8	6	NaN	NaN	NaN	303	1.5	-0.6
178	700> osc> 400	308	1.3	16	NaN	NaN	NaN	308	2.1	0.3
178	osc< 400	310	1.8	13	NaN	NaN	NaN	311	1.4	0.4

6.9. APPENDIX: SUMMARY PLOTS

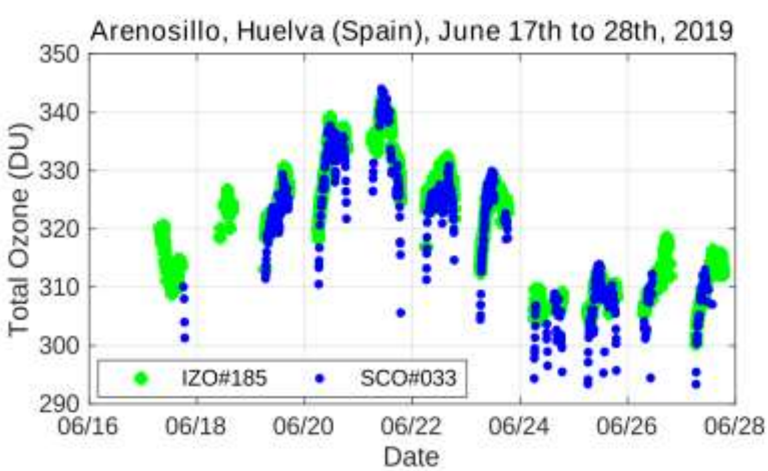
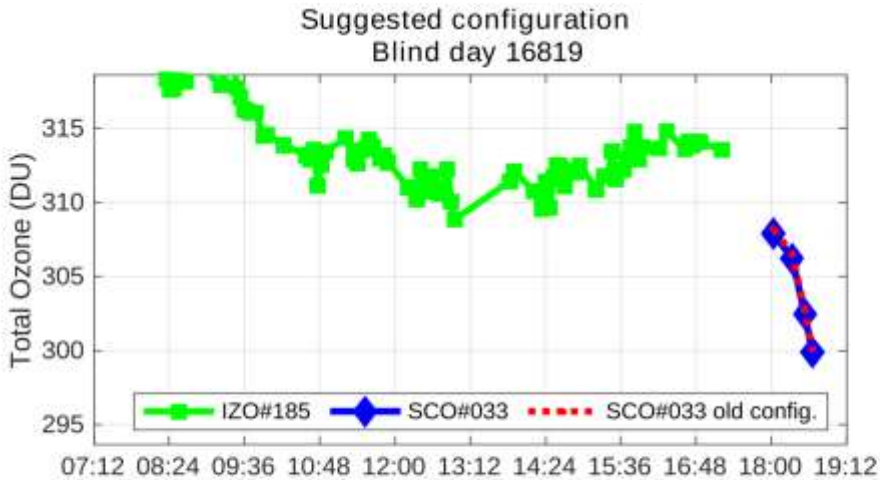
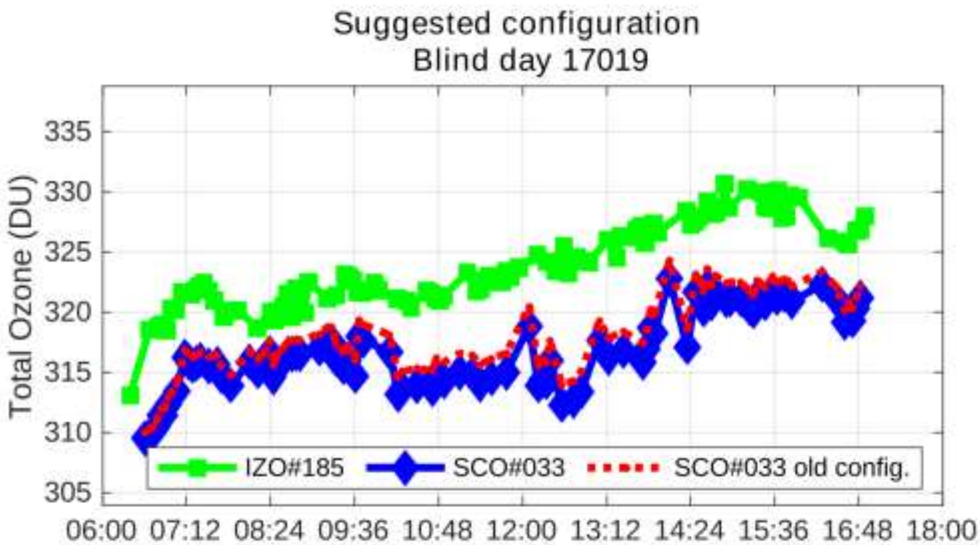
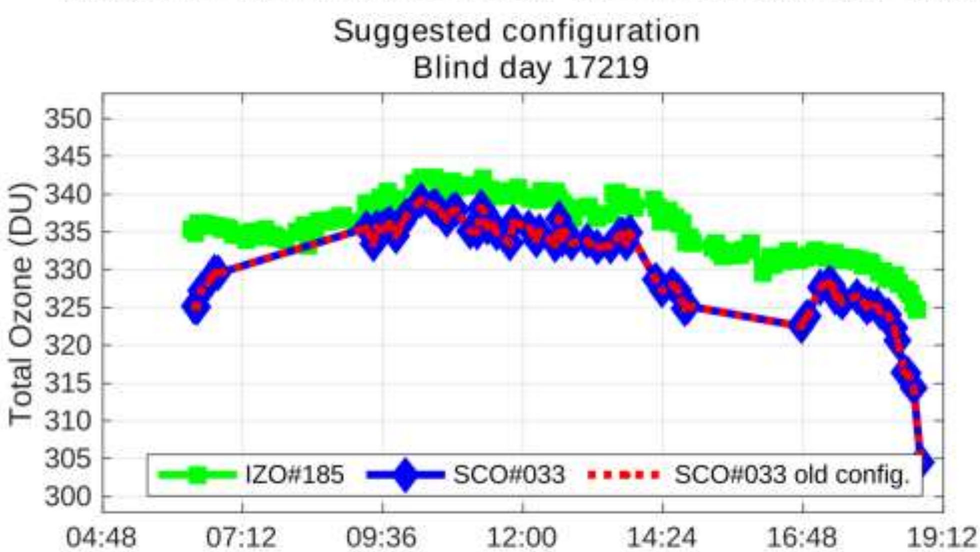
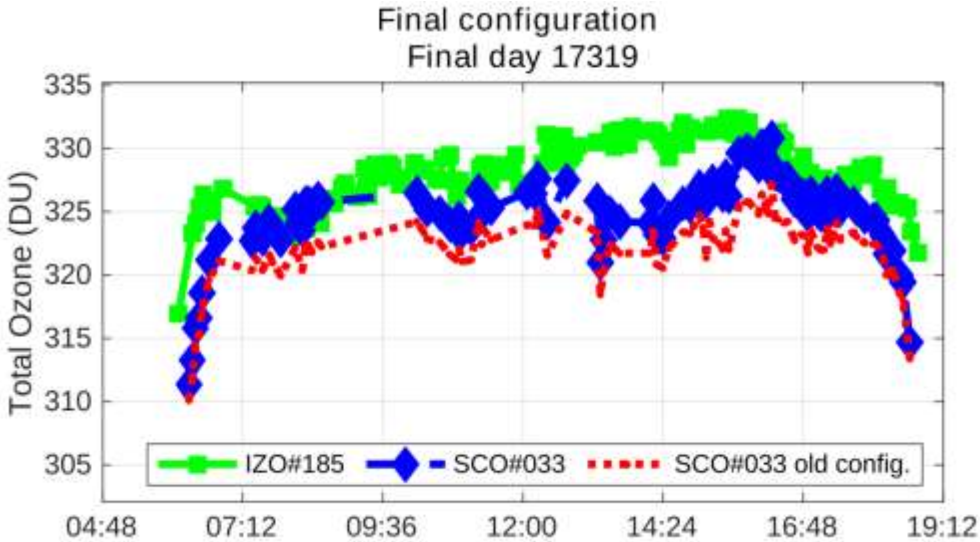


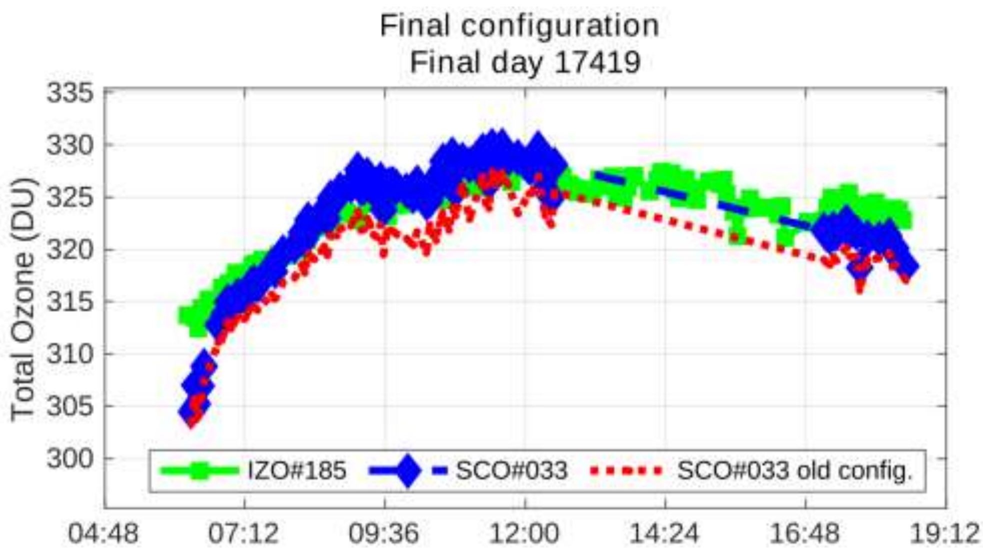
Figure 26. Overview of the intercomparison. Brewer SCO#033 data were evaluated using final constants (blue circles)

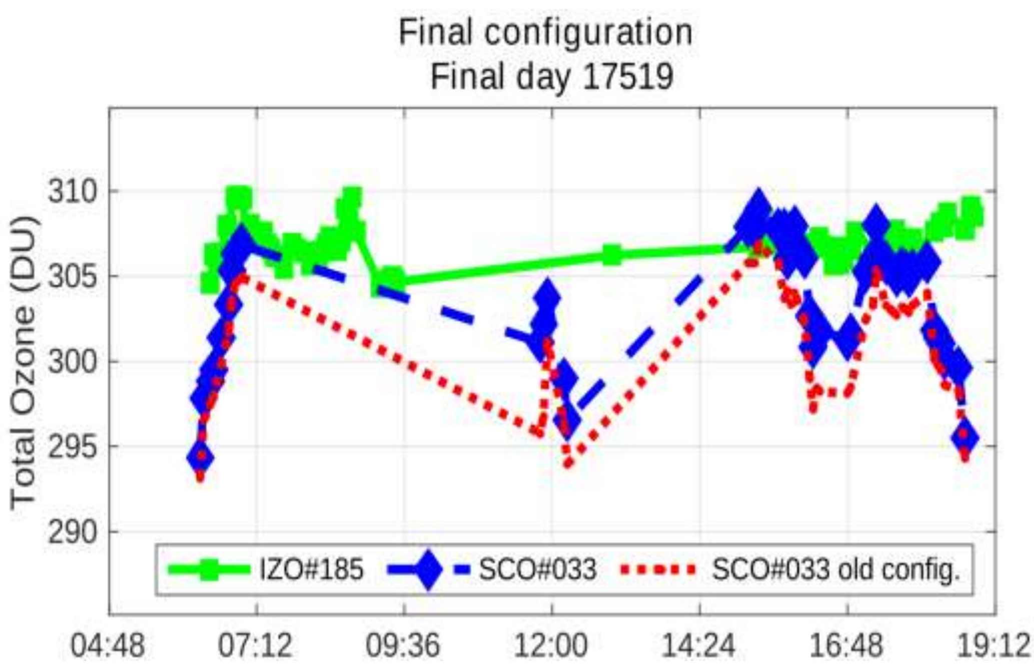

Suggested configuration
Blind day 16819
Total Ozone (DU)
315
310
305
300
295
IZO#185
SCO#033
SCO#033 old config.
07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00 19:12

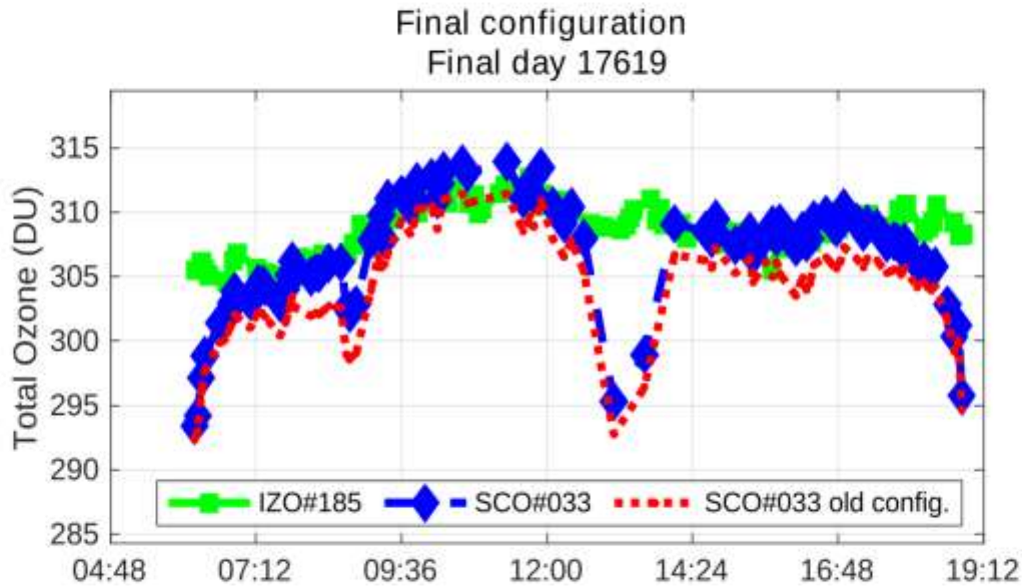

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
310
305
IZO#185
SCO#033
SCO#033 old config.
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00

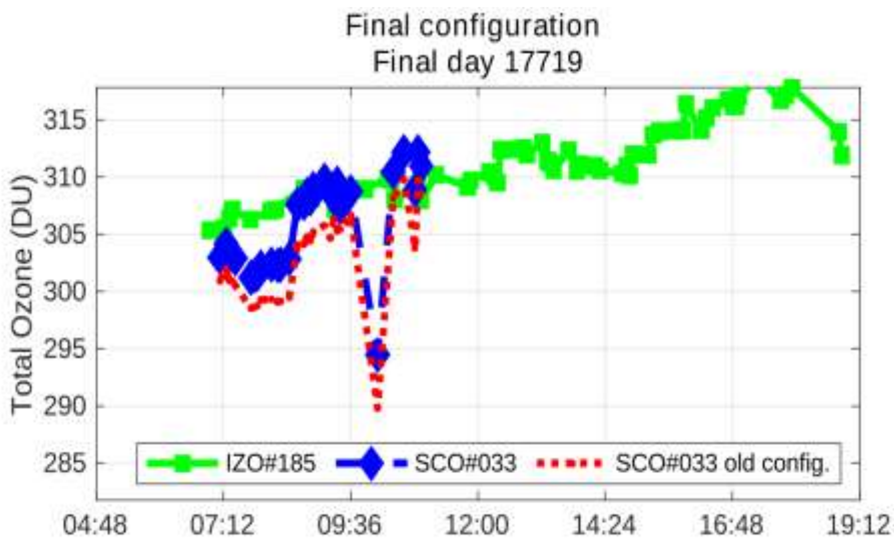

Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
320
315
310
305
300
IZO#185
SCO#033
SCO#033 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12

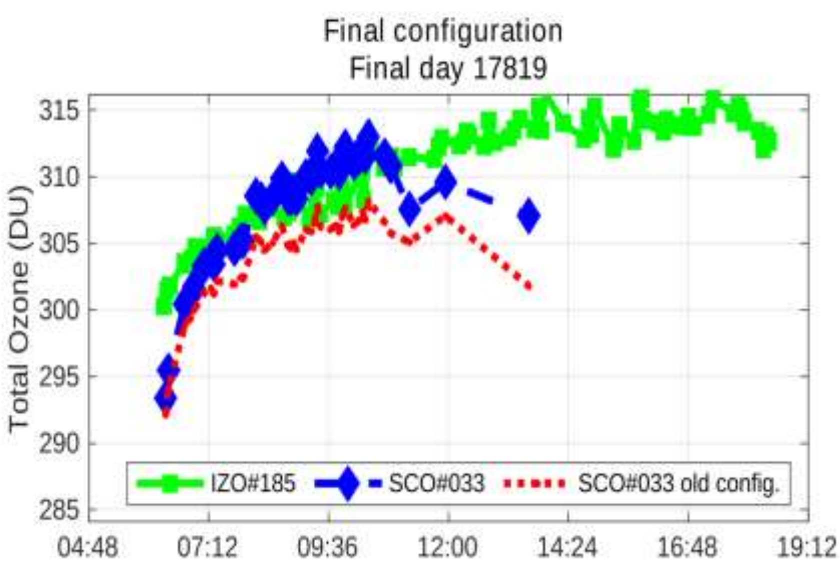

Final configuration
Final day 17319
Total Ozone (DU)
IZO#185
SCO#033
SCO#033 old config.


Final configuration
Final day 17419
Total Ozone (DU)
IZO#185
SCO#033
SCO#033 old config.


Final configuration
Final day 17519
Total Ozone (DU)
IZO#185
SCO#033
SCO#033 old config.


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
SCO#033
SCO#033 old config.


Final configuration
Final day 17719
Total Ozone (DU)
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
SCO#033
SCO#033 old config.


Final configuration
Final day 17819
Total Ozone (DU)
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
SCO#033
SCO#033 old config.

7. BREWER MAD#070

7.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer MAD#070 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer MAD#070 correspond to Julian days 168 – 178.

For the evaluation of the initial status, we used 177 simultaneous direct sun (DS) ozone measurements from days 168 to 172. For final calibration purposes, we used 446 simultaneous DS ozone measurements taken from day 173 to 178.

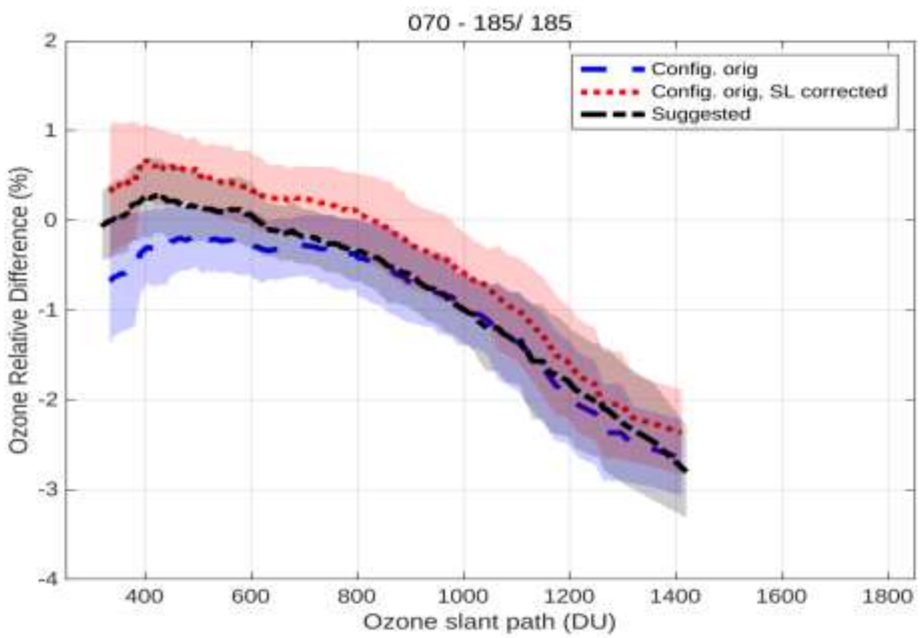


Figure 1. Mean DS ozone column percentage difference between Brewer MAD#070 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (IOS15617.070, blue dashed line) produces ozone values with an average difference of around 0.5% with respect to the reference instrument. This is a rather small difference and highlights the stability of Brewer MAD#070. This is confirmed by the stability of the R6 standard lamp measurements (see Figure 3). The SL correction (Figure 1, red dotted line) is thus not necessary and does not improve the comparison with Brewer IZO#185.

As a Mk. IV model, Brewer MAD#070 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 1.6).

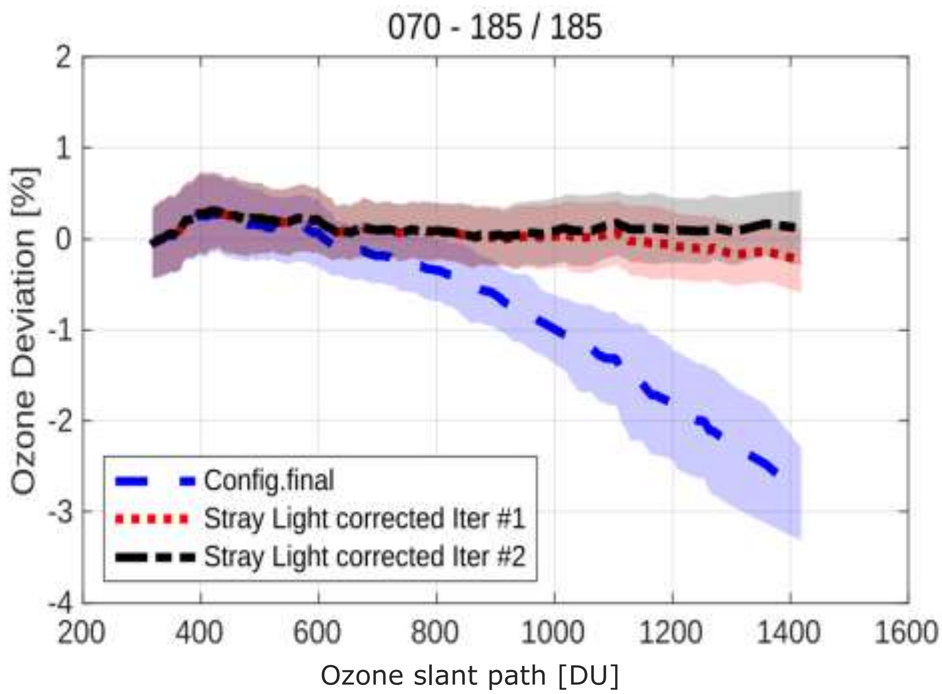


Figure 2. Mean DS ozone column percentage difference between Brewer MAD#070 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

All the other parameters analysed (DT, run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) show reasonably good results which confirms the good performance on the instrument.

Concerning the filter's performance, we suggest using a -15 ETC units' correction for filter #4.

The sun scan tests (SC) at the instrument's station before the campaign and those performed during the first days of the intercomparison, confirm the current cal step value (286, within a step error of ± 1).

We do not suggest changing the ozone absorption coefficient, retaining its current value of 0.3365.

Taking this into account, we suggest very few (if any) changes to the configuration of Brewer MAD#070.

7.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer MAD#070 have been very stable over the last 2 years but with seasonality now corrected with the new temperature coefficients. With these new coefficients, R6 reference is set to 1685.
2. We suggest a new R5 reference value of 3085.

3. We suggest using a -15 ETC unit correction for filter #4.
4. For Brewer MAD#070, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -35.2$, and $s = b = 4.88$.
5. Finally, we suggest updating the ETC value from 2950 to 2955.

7.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/070/ICF17319.070

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=436132229

Calibration reports detailed
Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/070/html/cal_report_070a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/070/html/cal_report_070a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/070/html/cal_report_070b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/070/html/cal_report_070c.html

7.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

7.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test since 2017 shows a seasonality. During the campaign, we found values of 1673 and 3063 for R6 and R5, respectively. The current R6 value is near to the reference value given in the previous intercomparison campaign (1685).

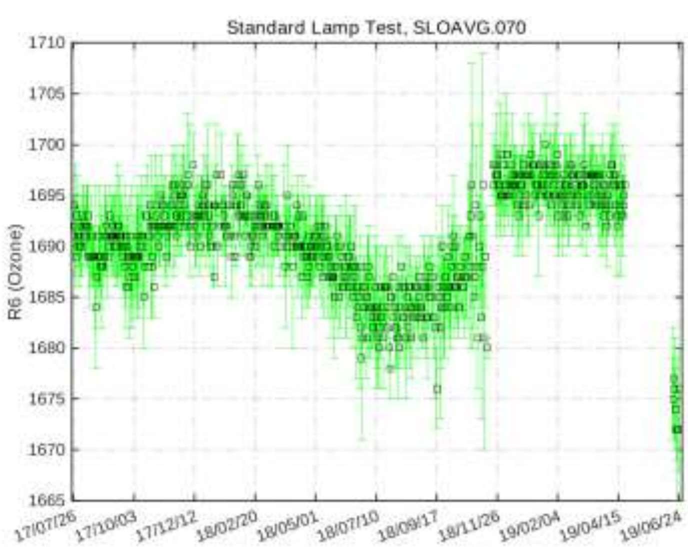


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

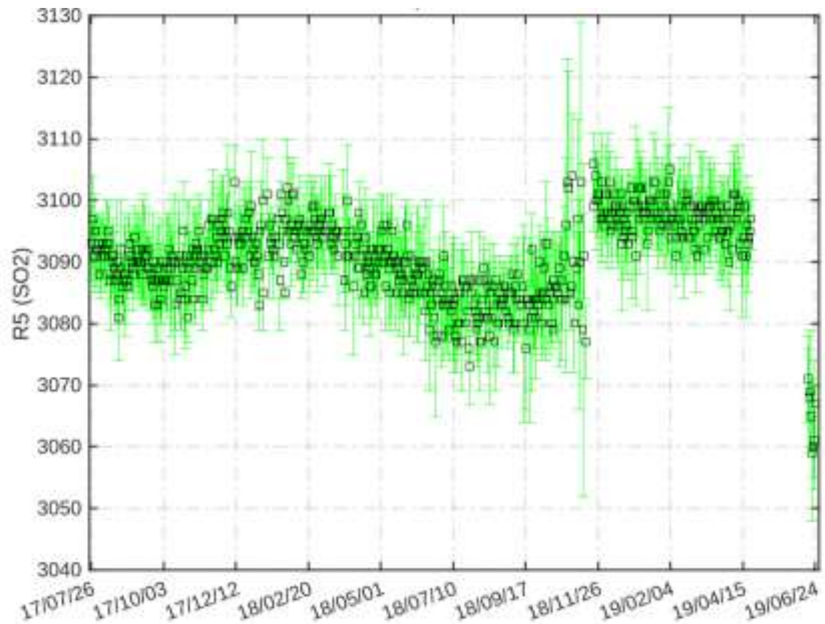


Figure 4. Standard lamp test R5 sulphur dioxide ratios

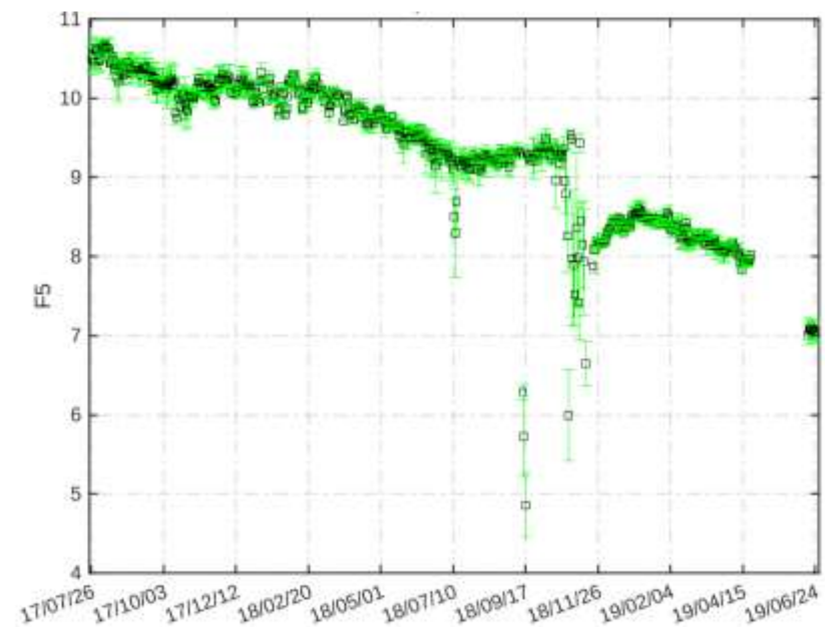


Figure 5. SL intensity for slit five

7.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits, see Figure 6.

As shown in Figure 7, the current DT reference value of $4.1 \cdot 10^{-8}$ s is confirmed.

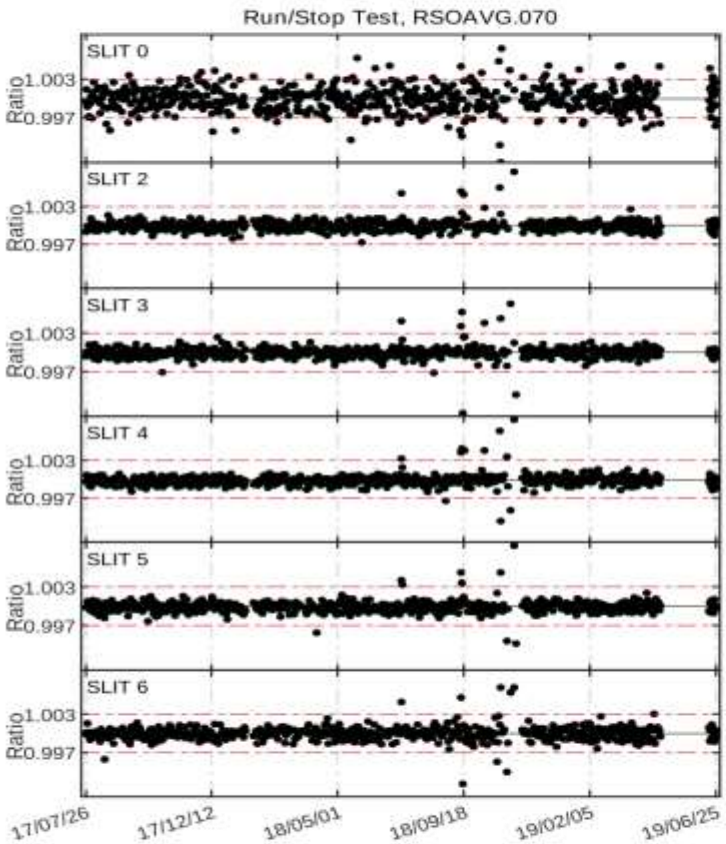


Figure 6. Run/stop test

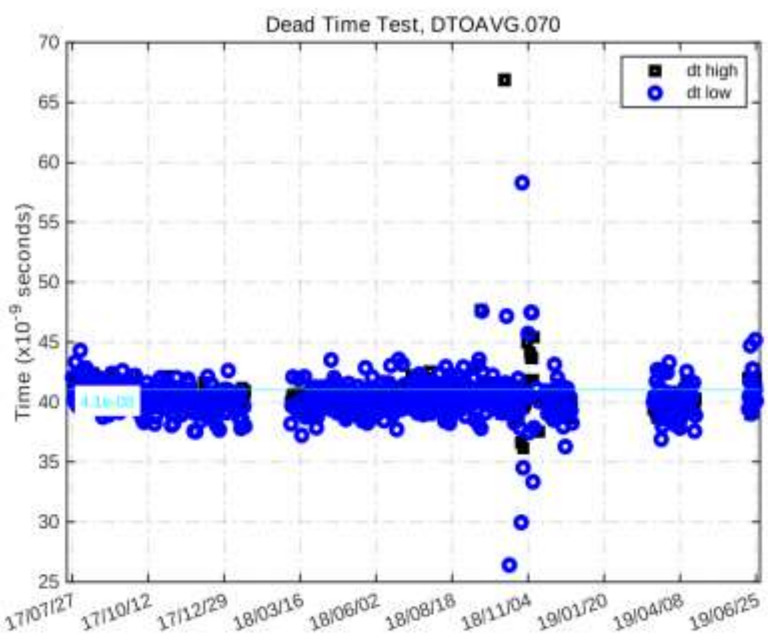


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

7.2.3. Analogue test

Figure 8 shows that the high voltage has remained constant at around 1560 over the last two years. Furthermore, analogue test values were within the test tolerance range.

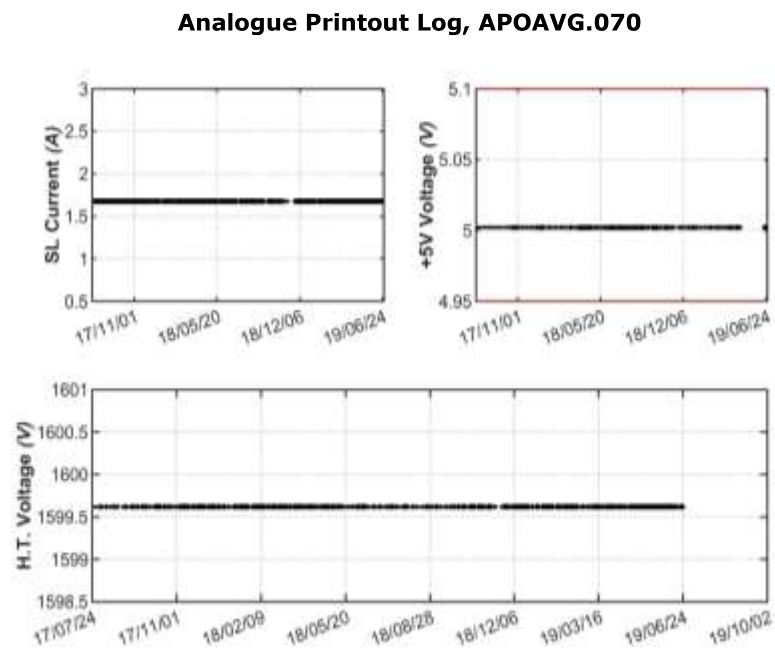


Figure 8. Analogue voltages and intensity

7.2.4. Mercury lamp test

The internal mercury lamp intensity shows two changes in October 2017 and November 2018 (see Figure 9). There is no clear correlation between the Hg intensity and the instrument's temperature.

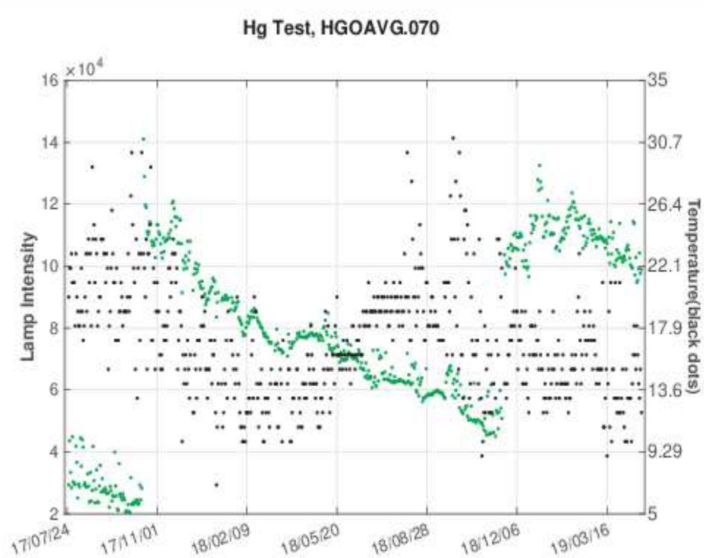


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

7.2.5. CZ scan on mercury lamp

We analysed the scans performed on the 296.728 nm mercury line, in order to check both the wavelength settings and the slit function width. As a reference, the calculated scan peak in wavelength units should be within $0.013nm$ from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. As shown in Figure 10, analysis of HS scans performed on Brewer MAD#070 during the campaign shows quite nice results for the centre of mass method, with the peak of the calculated scans within the accepted tolerance range but the slope method is generally outside the tolerance. Regarding the slit function width, results were good, with FWHM parameter lower than 0.65 nm.

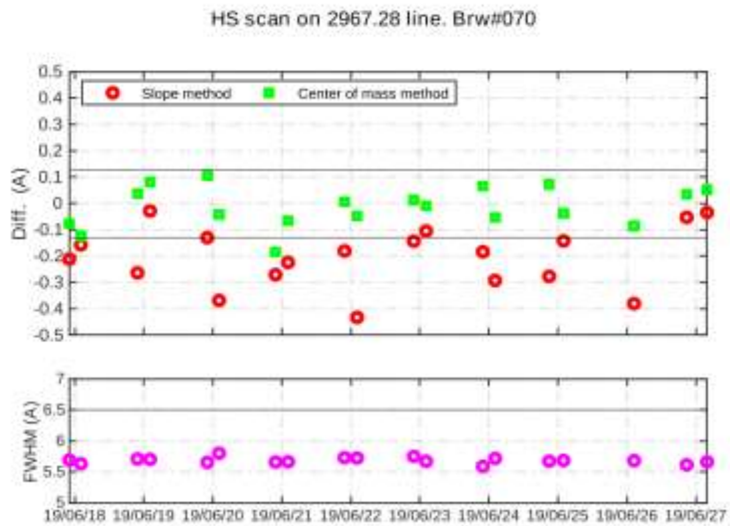


Figure 10. CZ scan on 296.728 nm Hg line. Upper figure shows differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by two different methods: slopes method (red circles) and center of mass method (green squares). Lower figure shows a Full Width at Half Maximum value for each scan performed. Solid line represents the 0.65 nm limit

7.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer MAD#070 CI scans performed during the campaign relative to the scan CI16819.070. As can be observed, the lamp intensity varied with respect to the reference spectrum by around 5%. Similar variations were observed in the daily R6 and R5 values. This behaviour is normal for an SL lamp.

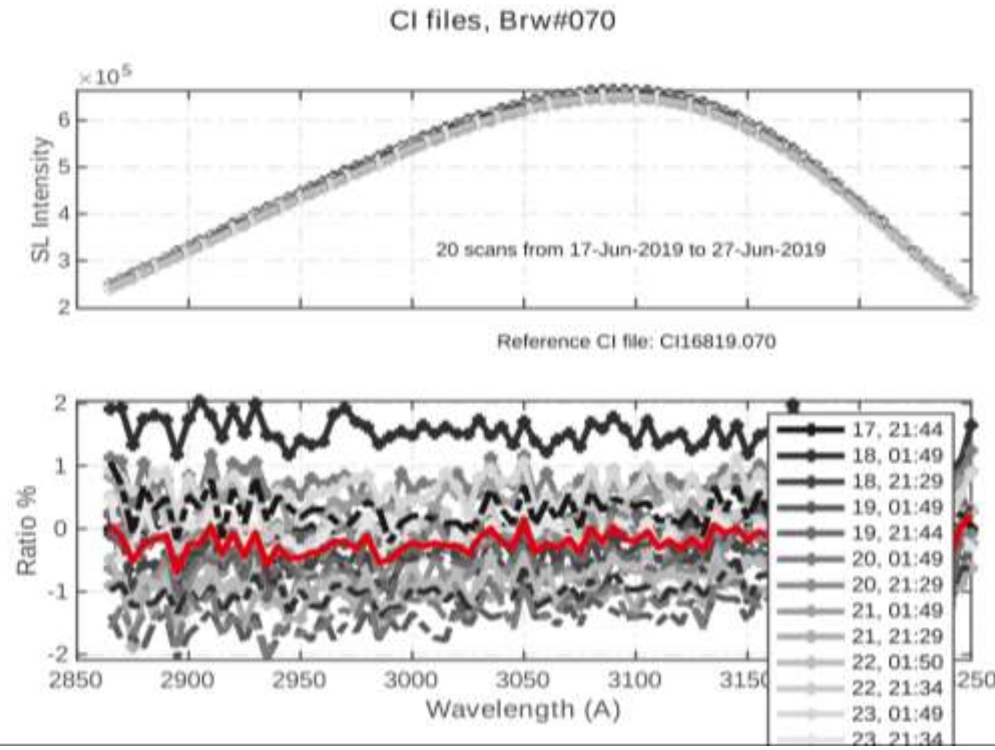


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

7.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

The current coefficients present a bad agreement as we see on the seasonality of R6. Therefore, a new set of coefficients was calculated as the Figure 12 shown (temperature range from 16 ˚C to 30 ˚C). The results obtained are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign (Figure 13). As shown in Figure 14, the current and new coefficients improved the temperature dependence.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.4009	-1.0721	-1.9735	-3.4170
Campaign	0.0000	-0.6000	-1.4000	-2.7000	-4.7000
Calculated	0.0000	-0.6000	-1.4000	-2.7400	-4.6500

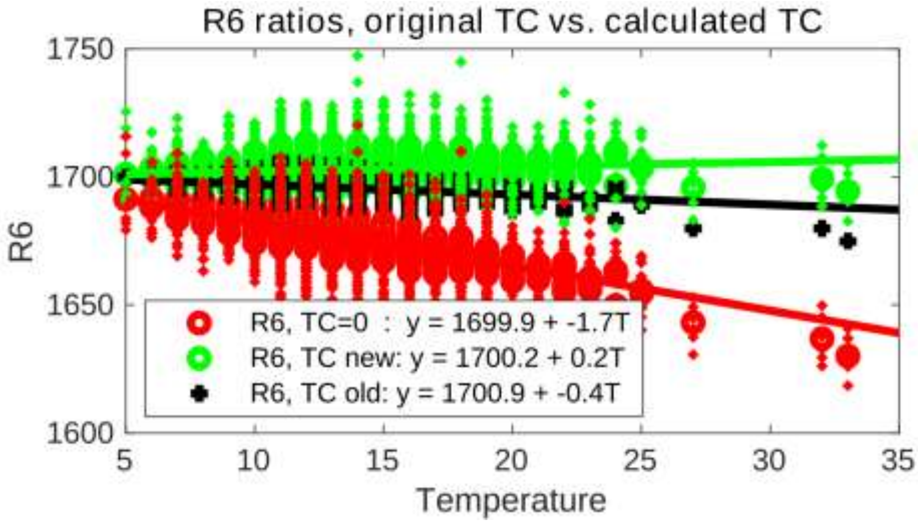


Figure 12. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

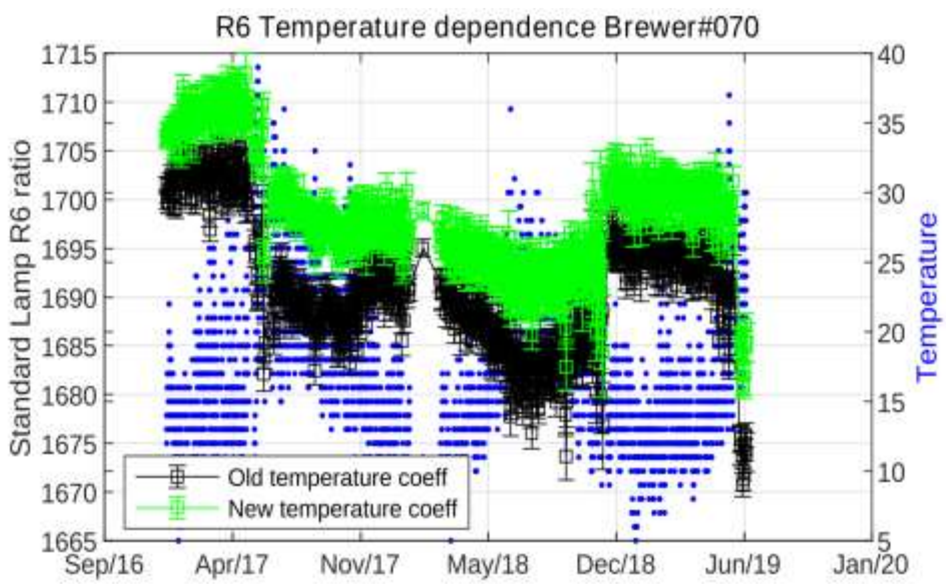


Figure 13. Standard lamp R6 (MS9) ratio recalculated with the original (black) and the new (green) temperature coefficients, where blue dots show the recorded temperature

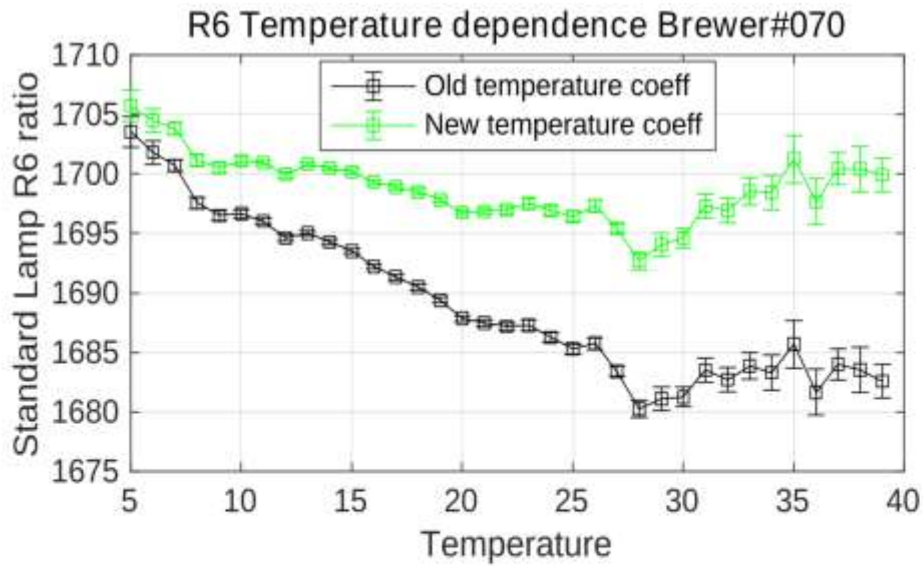


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

7.4. ATTENUATION FILTER CHARACTERIZATION

7.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 41 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter. Also, taking into account the relative ozone difference with respect to reference Brewer IZO#185, we suggest applying an ETC correction of -15 units for measurements taken with filter #4.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-10	-17	-31	13	-66
ETC Filt. Corr. (mean)	-6.9	-8	-20.2	8.9	-107.5
ETC Filt. Corr. (mean 95% CI)	[-17.9 4]	[-18 1.9]	[-28.7 -7.2]	[-4.9 23.8]	[-173.6 -45.5]

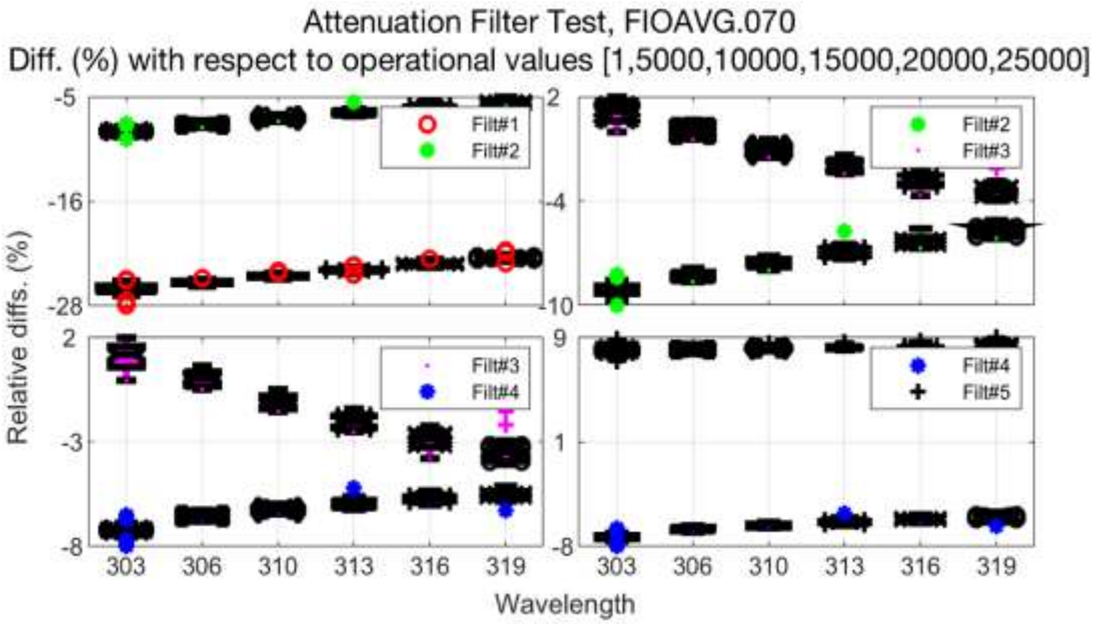


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

Calculated mean attenuation values for every filter are compared with operational values (see Figure 15), updating them (ICF file) where necessary. Individual values for every wavelength and every filter should be used for aerosol optical depth calculations. The calculated mean attenuation values for every filter (Table 3) are quite different to the operational attenuations (nominal values). In addition to that, differences greater than 10% are observable when changing filters. We have updated attenuations in ICF file provided.

Table 3. Filter attenuation by wavelength

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
slit#0	3704	9120	15133	18631	26880
slit#1	3745	9206	14977	18764	26898
slit#2	3782	9278	14815	18819	26942
slit#3	3813	9341	14691	18869	26945
slit#4	3844	9392	14581	18918	26956
slit#5	3877	9454	14494	18954	27000
mean	3794	9298	14781	18825	26936

7.5. WAVELENGTH CALIBRATION

7.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is

required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan, see Figure 16.

During the campaign, 6 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out, see Figure 17. The calculated cal step number (CSN) was 1 step lower than the value in the current configuration: 161 vs. 162. SC tests performed at the station before the campaign provide a CSN of 161. Taking all this into account, we suggest keeping the current CSN of 162.

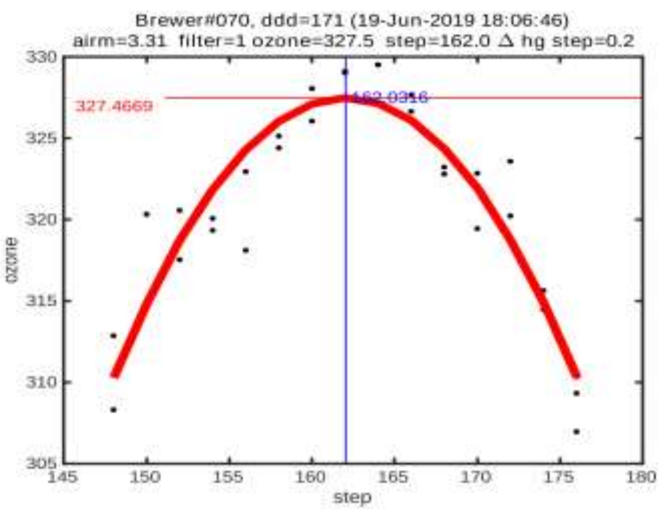


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

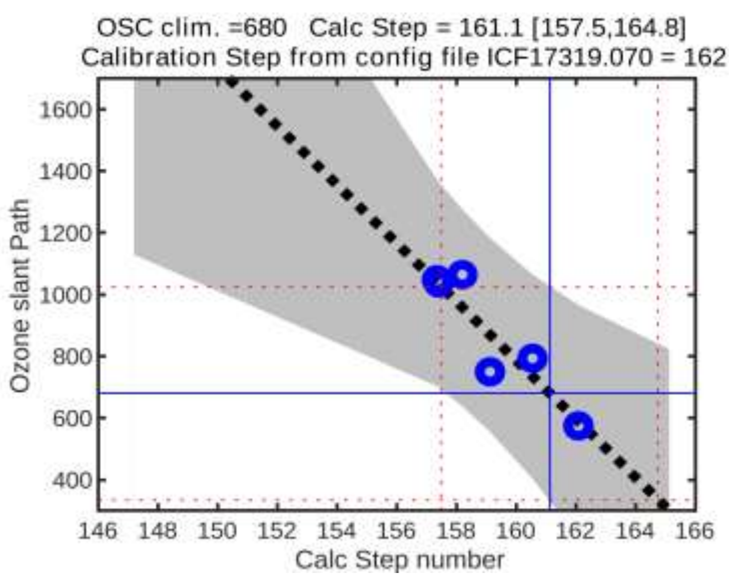


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

7.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 4.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 5 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.3365 is suggested in the final configuration.

Table 4. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	162	0.3365	2.3500	1.1322
09-Jul-2011	162	0.3343	3.1749	1.1269
14-Jun-2013	162	0.3387	3.1300	1.1411
01-Jun-2015	162	0.3384	3.1502	1.1372
01-Jun-2017	162	0.3382	3.1964	1.1364
23-Jun-2019	162	0.3361	3.1884	1.1328
Final	162	0.3365	2.3500	1.1322

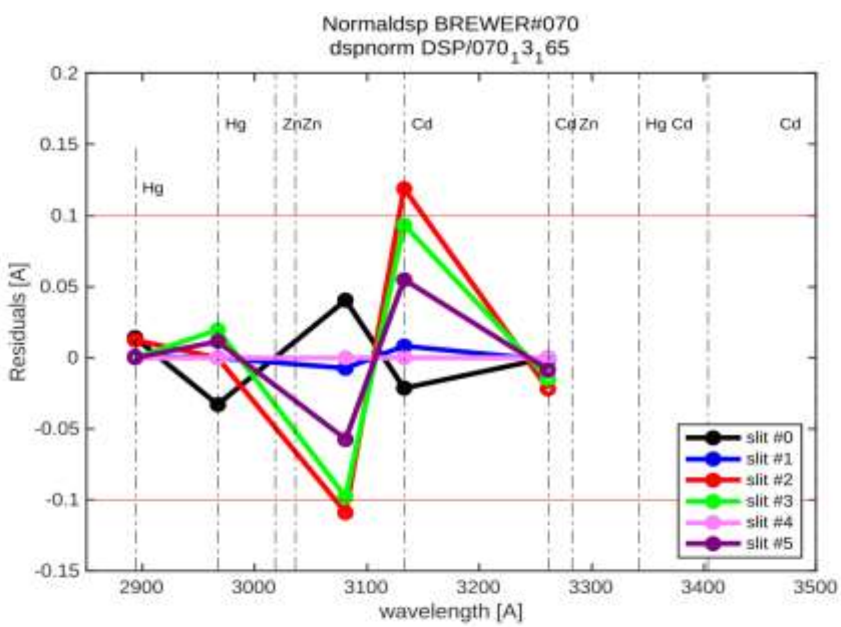


Figure 18. 2019 Residuals of quadratic fit

Table 5. 2019 Dispersion derived constants

step= 161	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3022.87	3063.02	3100.53	3135.16	3168.09	3200.18
Res(A)	3.7401	5.5914	5.3622	5.568	5.4841	5.3326
O3abs(1/cm)	3.0563	1.7795	1.0049	0.6755	0.37509	0.29272
Ray abs(1/cm)	0.51165	0.48321	0.45845	0.43702	0.4178	0.40011
SO2abs(1/cm)	8.3395	5.6412	2.4086	1.8762	1.0565	0.6057
step= 162	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3022.94	3063.09	3100.6	3135.22	3168.16	3200.25
Res(A)	3.7402	5.5914	5.3621	5.568	5.484	5.3325
O3abs(1/cm)	3.0529	1.7779	1.0046	0.67513	0.37515	0.29216
Ray abs(1/cm)	0.5116	0.48317	0.45841	0.43698	0.41776	0.40007
SO2abs(1/cm)	8.3187	5.6611	2.4164	1.8652	1.0576	0.60344
step= 163	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3023.01	3063.16	3100.67	3135.29	3168.22	3200.31
Res(A)	3.7402	5.5913	5.3621	5.5679	5.4839	5.3324
O3abs(1/cm)	3.0495	1.7765	1.0044	0.67472	0.37523	0.29159
Ray abs(1/cm)	0.51155	0.48312	0.45837	0.43694	0.41773	0.40004
SO2abs(1/cm)	8.2934	5.6806	2.4244	1.8543	1.0587	0.60119
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
161	0.33954	9.6148	3.1421	1.1409	0.35044	0.34171
162	0.33838	9.6129	3.1502	1.1372	0.34943	0.34068
163	0.3372	9.611	3.1578	1.1336	0.34839	0.33961

7.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1662. Table 6 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 6. 2019 Umkehr dispersion constants

step= 162	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3023	3063	3101	3135	3168	3200
Res(A)	3.7083	5.4785	5.3766	5.5292	5.4625	5.3353
O3abs(1/cm)	3.0513	1.776	1.0038	0.6754	0.37516	0.29139
Ray abs(1/cm)	0.51157	0.48309	0.45829	0.43698	0.41774	0.40003
step= 1662	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3125	3164	3200	3234	3265	3296
Res(A)	3.6959	5.4252	5.2922	5.4655	5.3425	5.1945
O3abs(1/cm)	0.69158	0.3928	0.29161	0.11951	0.060578	0.03336
Ray abs(1/cm)	0.44314	0.42013	0.40003	0.38266	0.36703	0.35268

7.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F, α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.
For single monochromator Brewers, the ETC distribution (see Figure 1) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

7.6.1. Initial calibration

For the evaluation of the initial status of Brewer MAD#070, we used the period from days 168 to 172 which correspond with 177 near-simultaneous direct sun ozone measurements. As shown in Figure 19, the initial calibration constants produced ozone values slightly lower than the reference instrument (0.4%). When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 7 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 8, as well as relative differences with respect to IZO#185 .

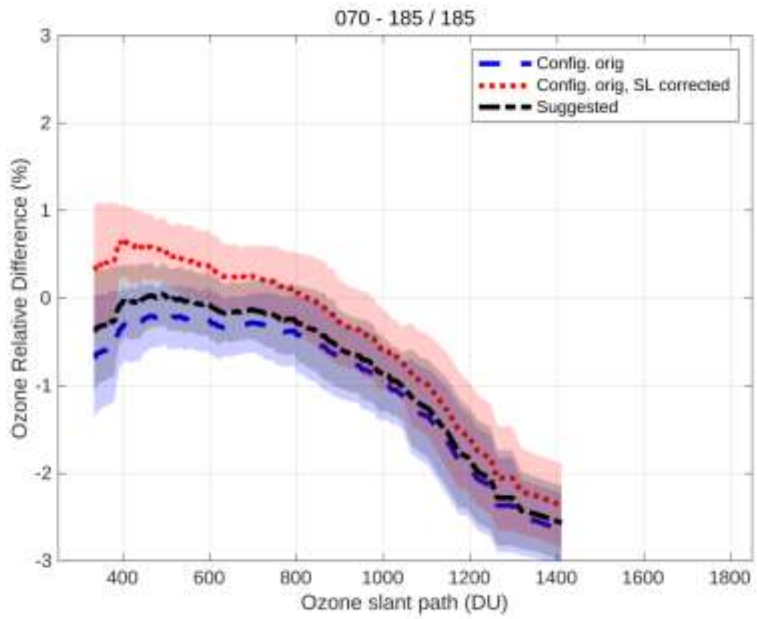


Figure 19. Mean direct sun ozone column percentage difference between Brewer MAD#070 and Brewer IZO#185 as a function of the ozone slant path

Table 7. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=800	2946	2949	3365	3360
full OSC range	2946	2955	3365	3343

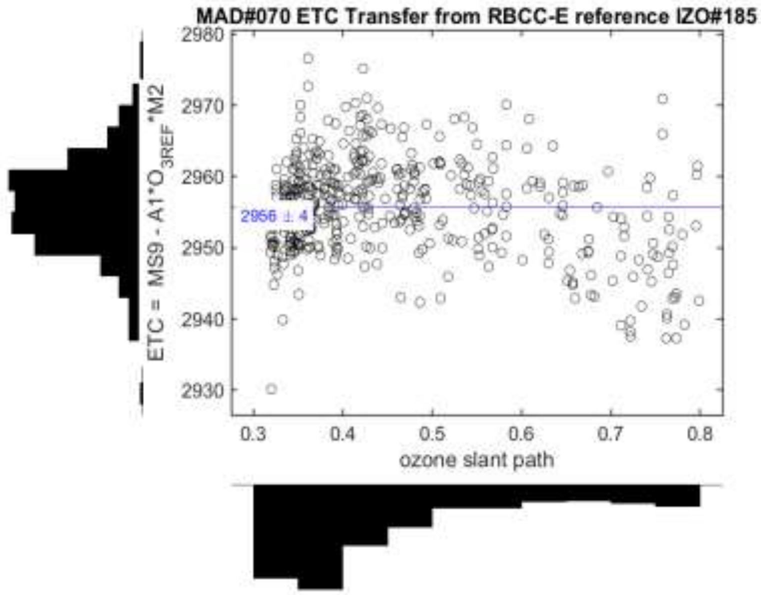
Table 8. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

	Day	*O3#185*	*O3std*	*N*	*O3#070*	*O3 std*	*%(070–185)/185*	*O3(*) #070*	*O3std*	*(*)%(070 – 185)/185*
18-Jun-2019	169	324.2	2.7	9	322.7	2.6	-0.5	323.6	2.6	-0.2
19-Jun-2019	170	323.9	3.1	65	322.7	3.1	-0.4	323.6	3.1	-0.1
20-Jun-2019	171	335	3	79	334.2	2.9	-0.2	335.1	3	0
21-Jun-2019	172	340.2	2	24	338.5	1.3	-0.5	339.4	1.4	-0.2

7.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 20). For the final calibration, we used 446 simultaneous direct sun measurements from days 173 to 178. The new value (2955) is only 5 units higher than the current ETC value (2950) due to the new temperature coefficients. Therefore, we recommend using this new ETC value, together with the new proposed standard lamp reference ratios (1685 for R6). We updated the new calibration constants in the ICF provided. The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 9, the agreement between the 1P and 2P ETCs is very good.

Mean daily total ozone values for the original and the final configurations are shown in Table 10, as well as relative differences with respect to IZO#185.



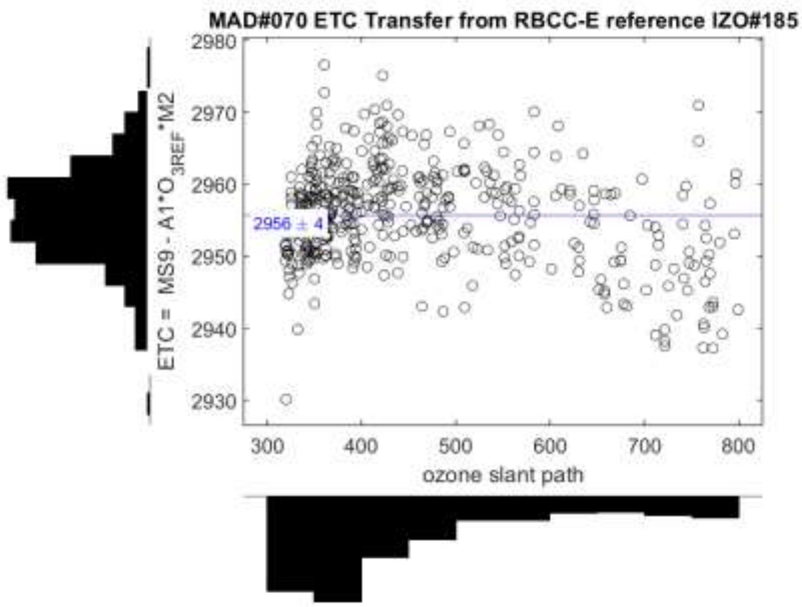


Figure 20. Mean direct sun ozone column percentage difference between Brewer MAD#070 and Brewer IZO#185 as a function of the ozone slant path

Table 9. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=800	2956	2957	3365	3363
full OSC range	2956	2972	3365	3326

Table 10. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	Day	O3#185	O3std	N	O3#070	O3 std	%(070–185)/185	O3(*)#070	O3std	(*)%(070–185)/185
21-Jun-2019	172	334.5	3.6	79	332.6	3.8	-0.6	334.1	4.3	-0.1
22-Jun-2019	173	327.6	1.7	63	324.3	4.6	-1	325.7	5.2	-0.6
23-Jun-2019	174	324.2	3.2	143	322.2	3.6	-0.6	323.8	4.2	-0.1
24-Jun-2019	175	307.1	1.3	60	305	1.9	-0.7	306.1	2.1	-0.3
25-Jun-2019	176	308.4	2.1	82	305.7	2.6	-0.9	308.3	2	0
26-Jun-2019	177	311.4	3.5	78	308.8	4.1	-0.8	311.2	3.3	-0.1
27-Jun-2019	178	307.9	2.9	49	306.5	4.6	-0.5	307.8	5.2	0

7.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and an underestimation of 1% at 800 DU OSC which is very good for a single Brewer. The empirical stray model fits well with coefficient values: $k = a = -35.2$, $s = b = 4.88$, and ETC=2957. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

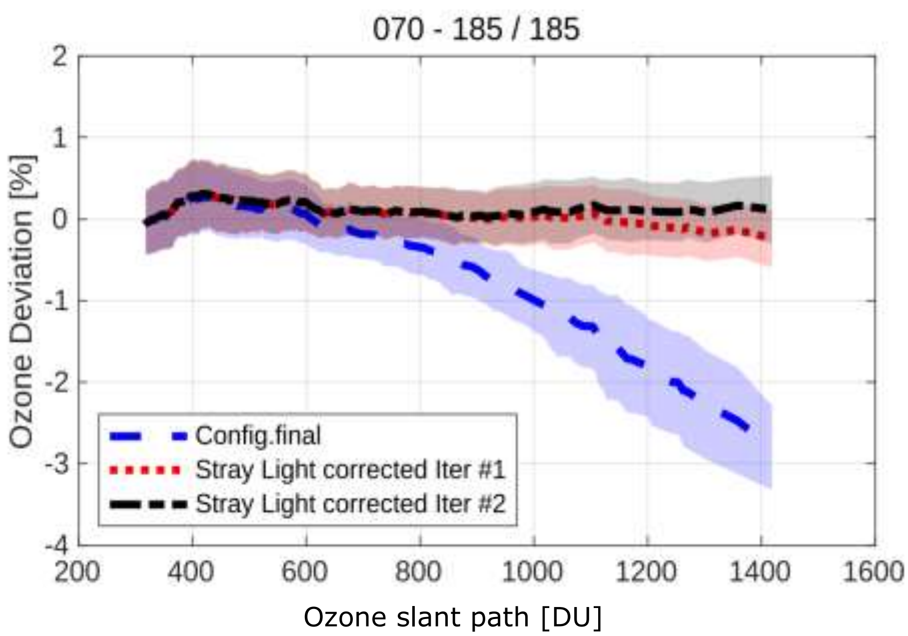


Figure 21. Ratio respect to the reference when final constants are applied and stray light correction is applied

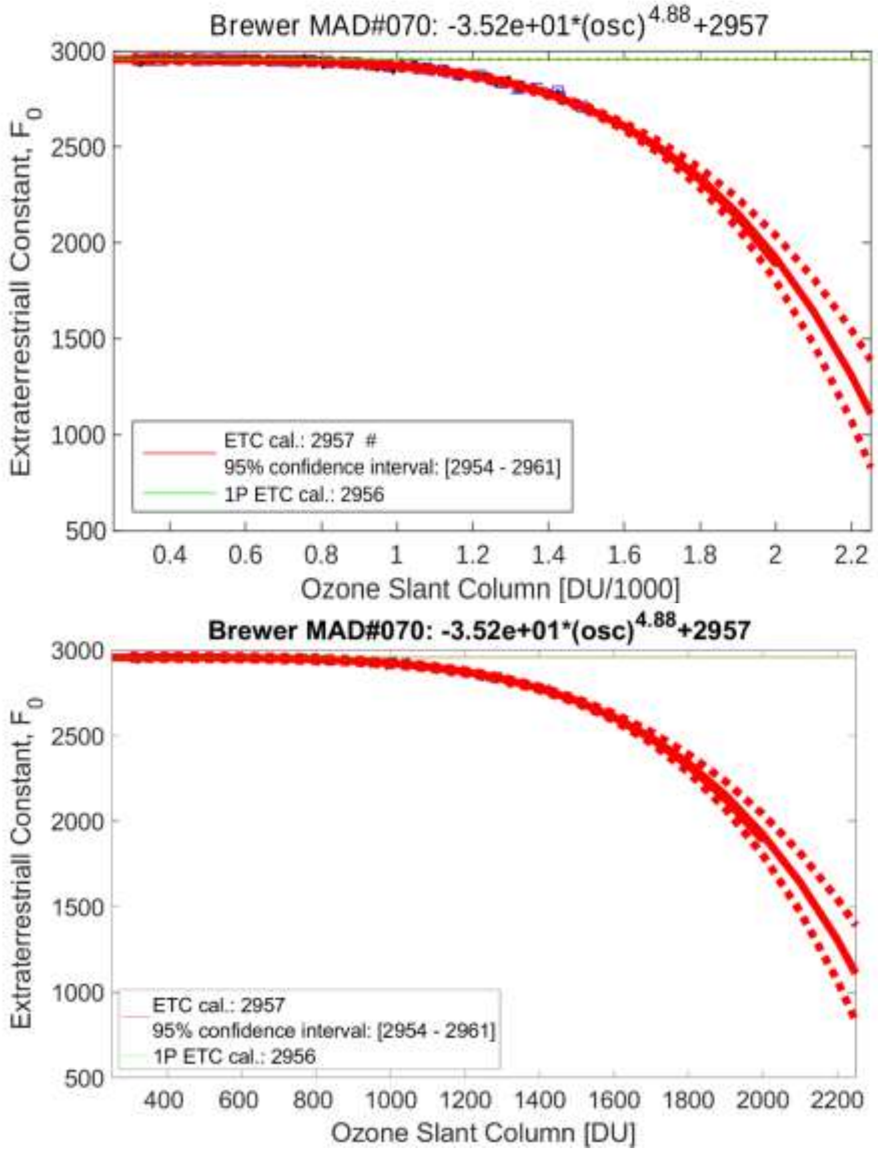


Figure 22. Stray light empirical model determination

7.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1685 for R6 (Figure 24) and 3085 for R5 (Figure 25).

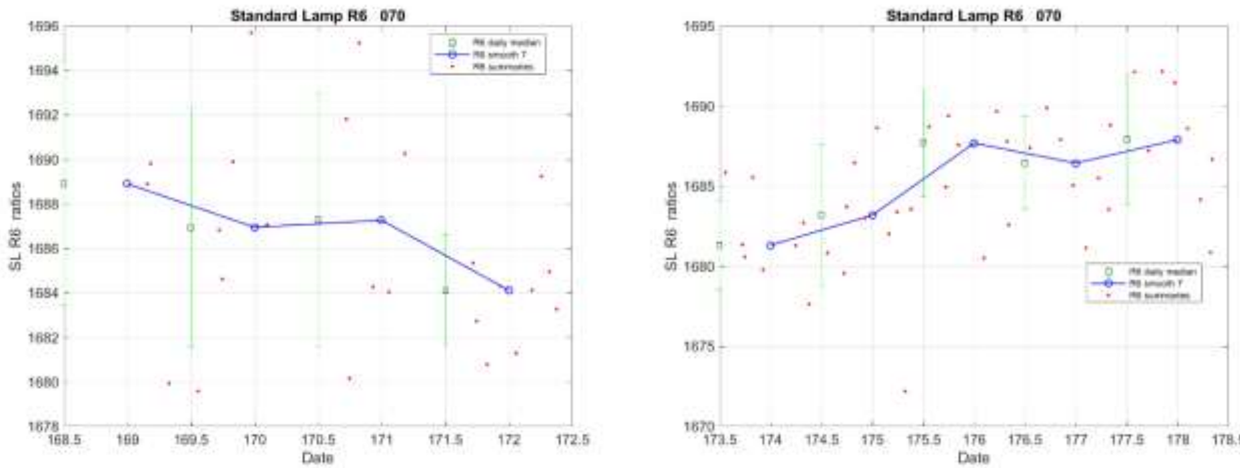


Figure 24. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

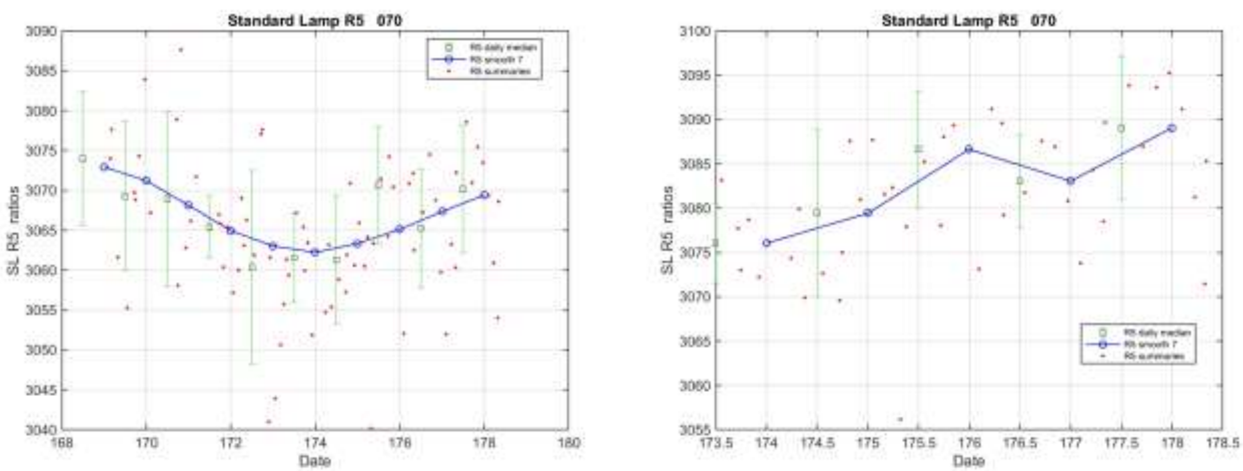


Figure 25. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

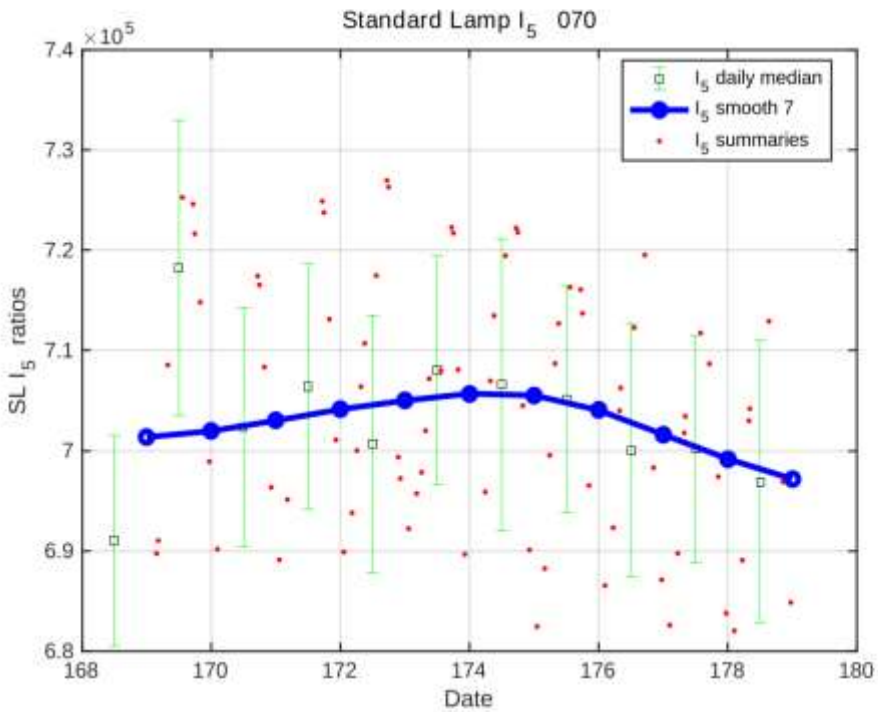


Figure 26. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

7.7. CONFIGURATION

7.7.1. Instrument constant file

	Initial (IOS15617.070)	*Final (ICF17319.070)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.4009	-0.6
o3 Temp coef 3	-1.0721	-1.4
o3 Temp coef 4	-1.9735	-2.74
o3 Temp coef 5	-3.417	-4.65
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3365	0.3365
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1322	1.1322
ETC on O3 Ratio	2950	2955
ETC on SO2 Ratio	2790	2790
Dead time (sec)	4.1e-08	4.1e-08
WL cal step number	162	162

	Initial (IOS15617.070)	*Final (ICF17319.070)*
Slitmask motor delay	74	74
Umkehr Offset	1688	1688
ND filter 0	0	0
ND filter 1	5000	3800
ND filter 2	10000	9300
ND filter 3	15000	14800
ND filter 4	20000	18820
ND filter 5	25000	26940
Zenith steps/rev	2972	2972
Brewer Type	0	0
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	2579	2579
Mic #2 Offset	0	0
O3 FW #3 Offset	240	240
NO2 absn Coeff	-3	-3
NO2 ds etc	650	650
NO2 zs etc	595	595
NO2 Mic #1 Offset	5252	5252
NO2 FW #3 Offset	176	176
NO2/O3 Mode Change	2700	2700
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	3469	3469
Iris Open Steps	75	75

	Initial (IOS15617.070)	*Final (ICF17319.070)*
Buffer Delay (s)	0.2	0.2
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	56	56
Zenith UVB Position	2216	2216

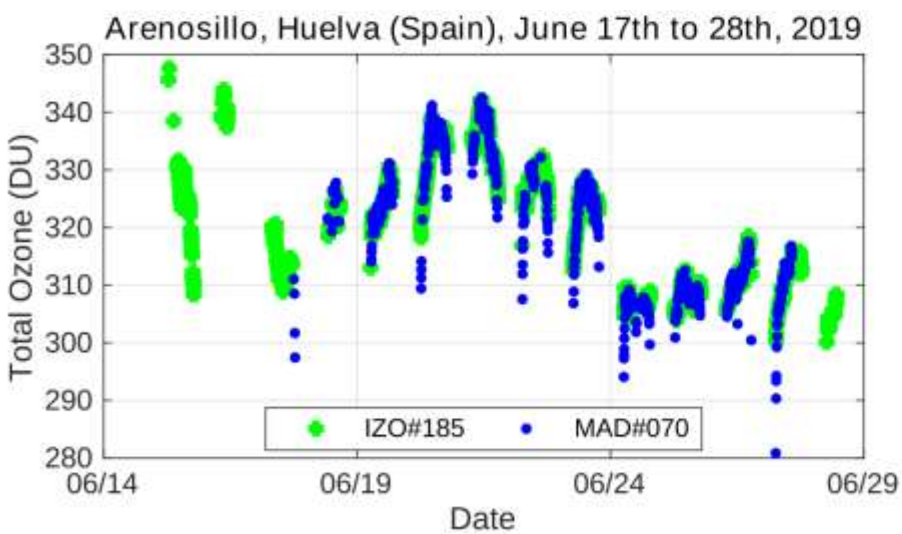
7.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

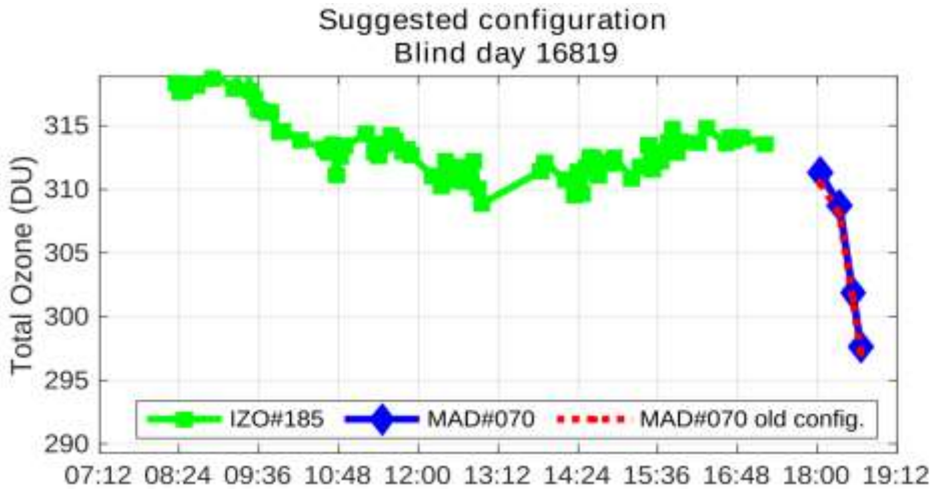
Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#070*	*O3 std*	*%diff*	*(*)O3#070*	*O3 std*	*(*)%diff*
169	osc< 400	324	2.7	9	324	2.6	0.2	324	2.6	0.0
170	1500> osc> 1000	319	0.1	3	315	0.9	-1.0	315	0.9	-1.2
170	1000> osc> 700	321	1.4	8	321	2.5	-0.1	320	2.4	-0.3
170	700> osc> 400	324	3.9	43	325	3.8	0.3	324	3.8	-0.1
170	osc< 400	323	2.0	27	322	2.0	-0.2	323	2.2	0.0
171	1500> osc> 1000	328	7.0	8	321	8.9	-2.1	320	8.9	-2.3
171	1000> osc> 700	334	4.9	16	332	4.2	-0.4	332	4.1	-0.7
171	700> osc> 400	333	3.7	41	335	3.6	0.5	333	3.5	0.1
171	osc< 400	336	1.1	43	339	1.6	0.7	336	1.6	0.1
172	1500> osc> 1000	333	3.6	9	329	4.4	-1.0	328	4.4	-1.3
172	1000> osc> 700	333	1.8	21	333	2.9	0.0	331	2.9	-0.5
172	700> osc> 400	334	3.4	33	336	3.7	0.7	333	3.4	-0.1
172	osc< 400	339	2.0	53	341	1.8	0.7	338	1.8	-0.3
173	1500> osc> 1000	325	1.2	14	318	4.4	-2.2	318	4.4	-2.4
173	1000> osc> 700	327	1.3	15	326	1.2	-0.3	326	1.2	-0.5
173	700> osc> 400	327	1.6	5	330	2.8	0.8	328	2.7	0.5
173	osc< 400	328	1.0	27	331	1.2	0.7	329	1.2	0.3
174	1500> osc> 1000	320	4.2	9	315	5.0	-1.4	315	5.1	-1.6
174	1000> osc> 700	320	3.6	18	319	3.3	-0.3	318	3.3	-0.6
174	700> osc> 400	324	2.0	51	325	2.4	0.5	324	2.3	0.2
174	osc< 400	326	1.1	55	328	1.3	0.4	327	1.2	0.0
175	1500> osc> 1000	307	1.4	9	302	2.4	-1.4	302	2.5	-1.5

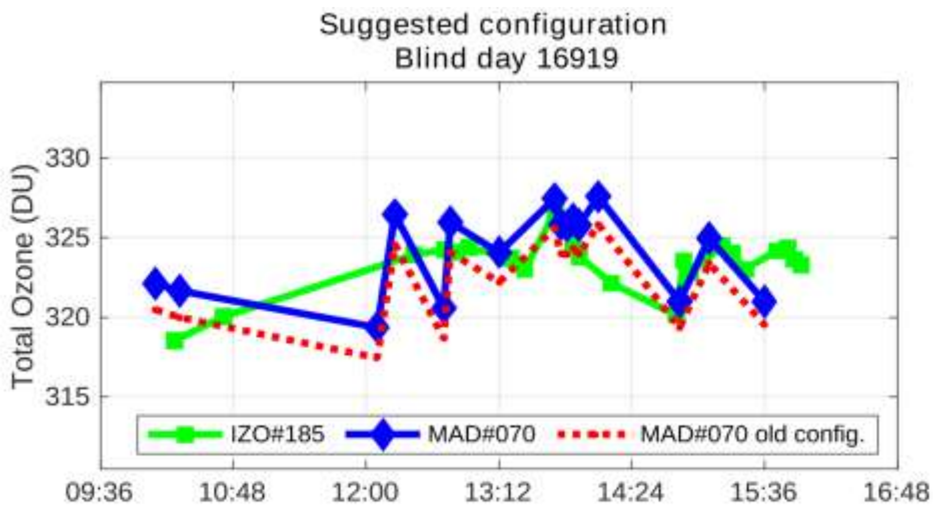
Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#070*	*O3 std*	*%diff*	*(*)O3#070*	*O3 std*	*(*)%diff*
175	1000> osc> 700	308	1.3	14	306	1.0	-0.4	306	0.9	-0.5
175	700> osc> 400	307	1.1	32	307	1.1	0.2	307	1.1	0.1
176	1500> osc> 1000	307	2.2	6	305	0.8	-0.7	305	0.9	-0.8
176	1000> osc> 700	307	2.6	10	307	1.7	0.0	307	1.8	-0.2
176	700> osc> 400	308	1.6	26	309	1.4	0.4	308	1.4	0.2
176	osc< 400	310	1.2	23	307	3.1	-0.9	310	1.4	-0.2
177	1000> osc> 700	312	5.8	8	311	5.1	-0.2	311	5.2	-0.3
177	700> osc> 400	312	4.1	28	312	3.3	0.1	312	3.4	0.0
177	osc< 400	311	1.2	24	309	2.6	-0.7	311	1.6	-0.1
178	1500> osc> 1000	302	0.9	4	295	3.7	-2.5	294	3.7	-2.6
178	1000> osc> 700	305	0.6	8	305	1.6	0.0	304	1.6	-0.2
178	700> osc> 400	308	1.4	13	308	1.8	0.3	308	1.9	0.1
178	osc< 400	312	1.9	28	313	1.9	0.5	313	2.0	0.4

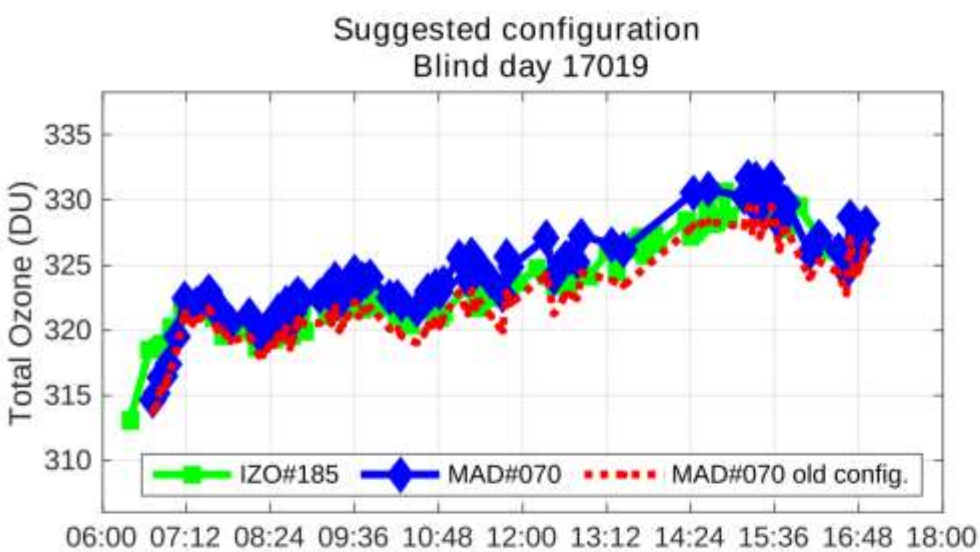
7.9. APPENDIX: SUMMARY PLOTS

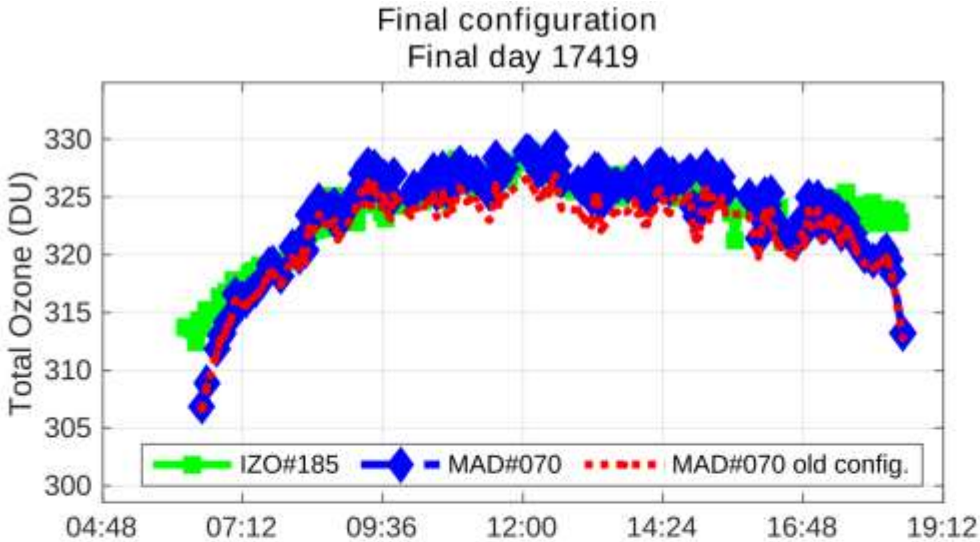


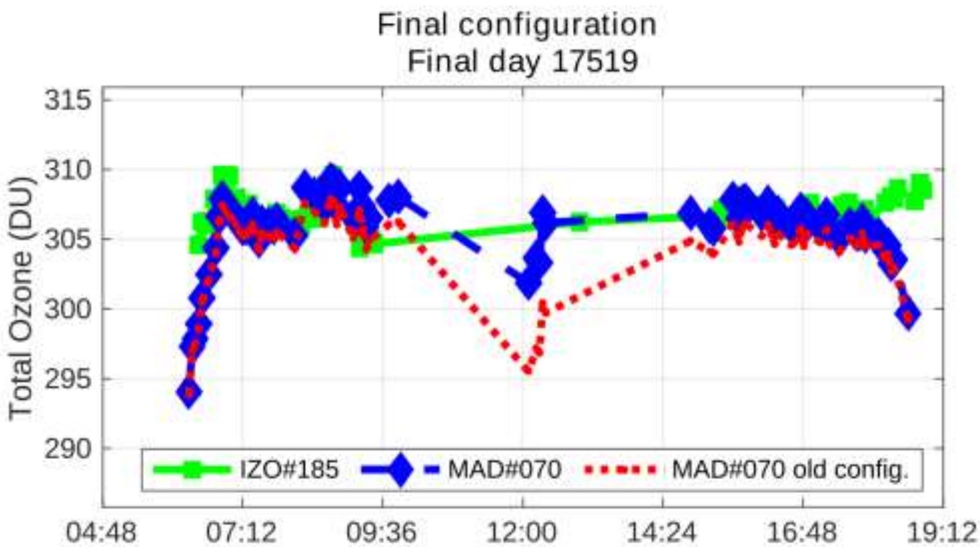
Overview of the intercomparison. Brewer MAD#070 data were evaluated using final constants (blue circles)

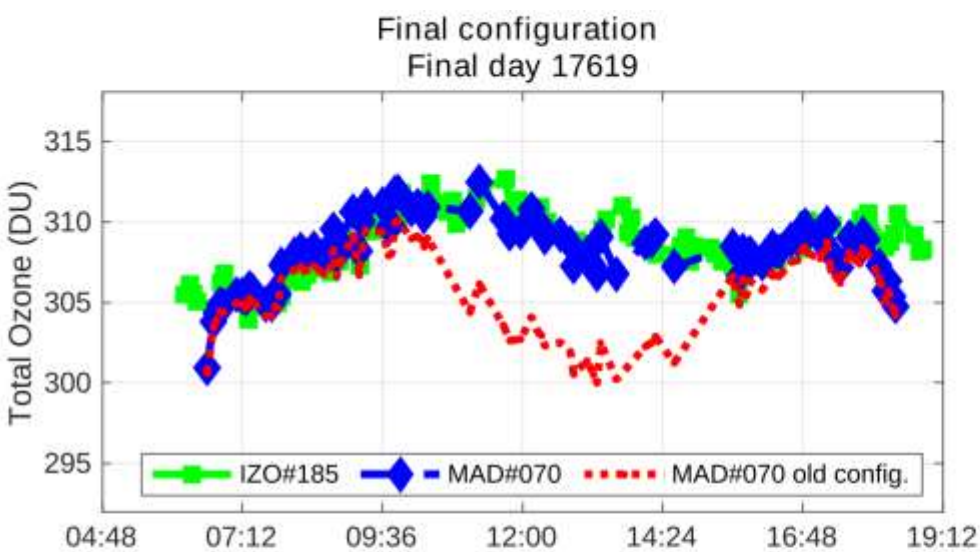

Suggested configuration
Blind day 16819
Total Ozone (DU)
315
310
305
300
295
290
07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00 19:12
IZO#185
MAD#070
MAD#070 old config.

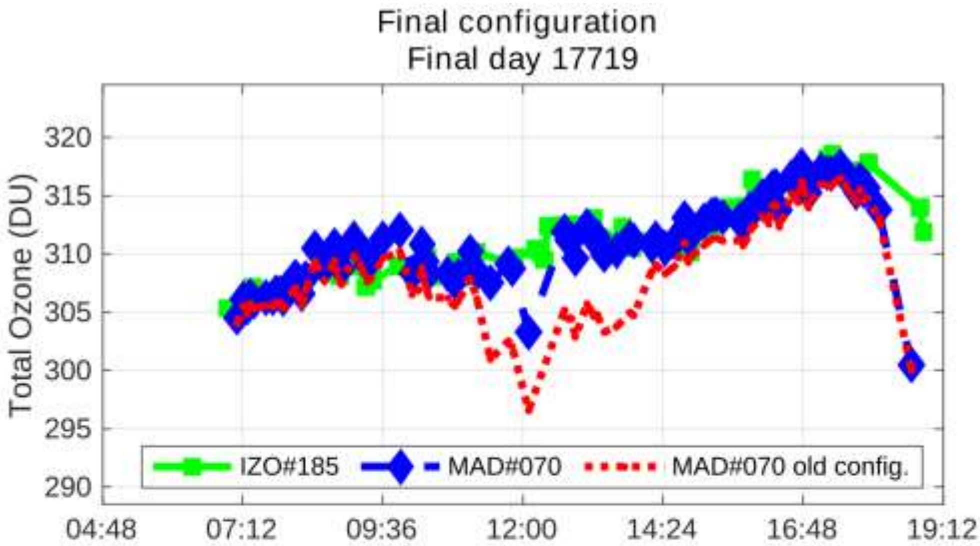

Suggested configuration
Blind day 16919
Total Ozone (DU)
330
325
320
315
09:36 10:48 12:00 13:12 14:24 15:36 16:48
IZO#185
MAD#070
MAD#070 old config.

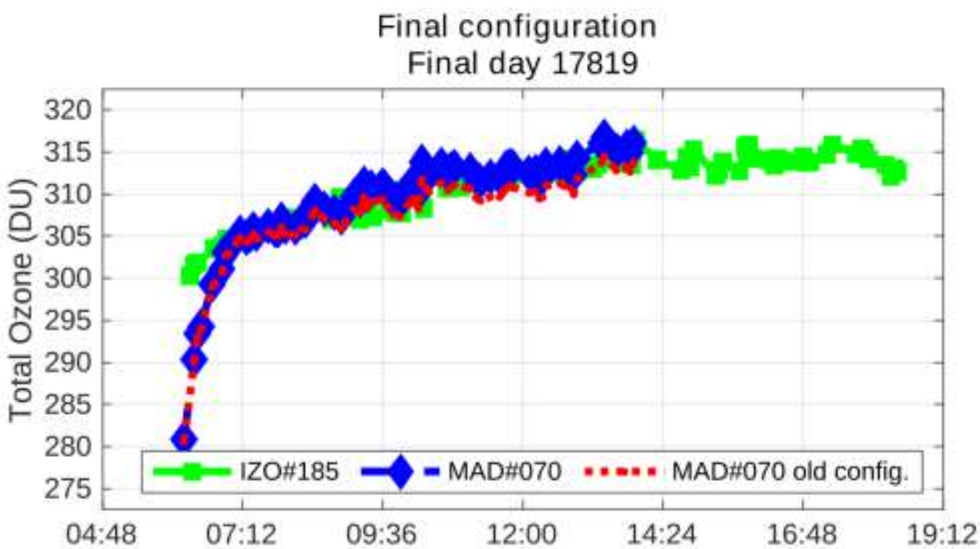

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
310
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00
IZO#185
MAD#070
MAD#070 old config.


Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#070
MAD#070 old config.


Final configuration
Final day 17519
Total Ozone (DU)
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#070
MAD#070 old config.


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#070
MAD#070 old config.


Final configuration
Final day 17719
Total Ozone (DU)
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#070
MAD#070 old config.


Final configuration
Final day 17819
Total Ozone (DU)
320
315
310
305
300
295
290
285
280
275
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#070
MAD#070 old config.

8. BREWER UK #075

8.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer UK#075 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer UK #075 correspond to Julian days 166–178.

For the evaluation of the initial status, we used 14 simultaneous direct sun (DS) ozone measurements from days 168 to 169. For final calibration purposes, we used 228 simultaneous DS ozone measurements taken from day 174 to 178. Maintenance work, especially focused on the filters, was carried out in the days between these two periods.

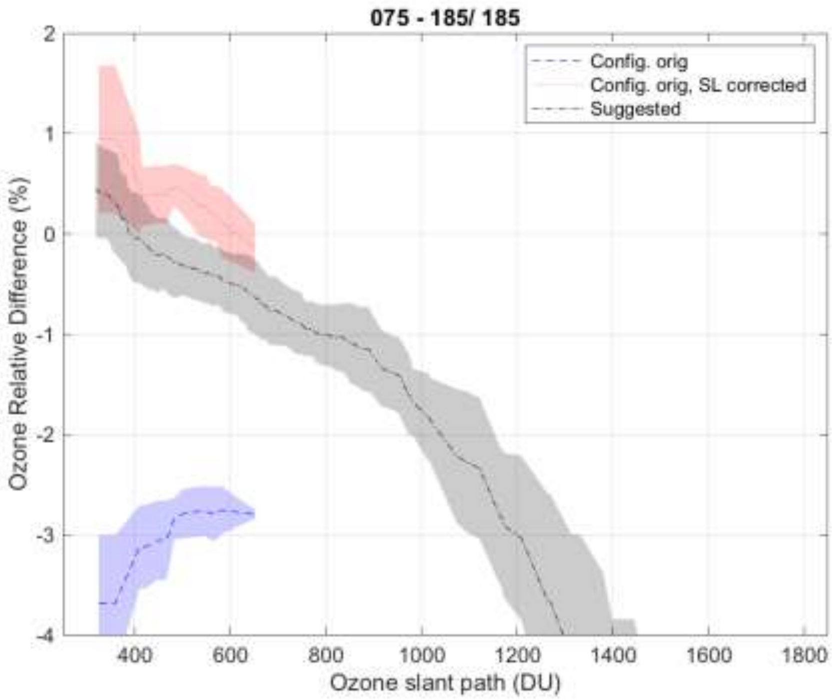


Figure 1. Mean DS ozone column percentage difference between Brewer UK #075 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the black line corresponds to results obtained with the updated configuration proposed in the current campaign without the stray light correction. The shadowed areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15017.075, blue dashed line) produces ozone values with a large difference with respect to the reference instrument IZO#185. The R6 standard lamp measurements in Figure 3 show a large change during the campaign, likely caused by the maintenance work. This makes a new calibration an absolute necessity.

As a Mk. IV model, Brewer UK #075 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer References allows us to correct the effect of the stray light using a recently developed method, see Sec. 1.6.

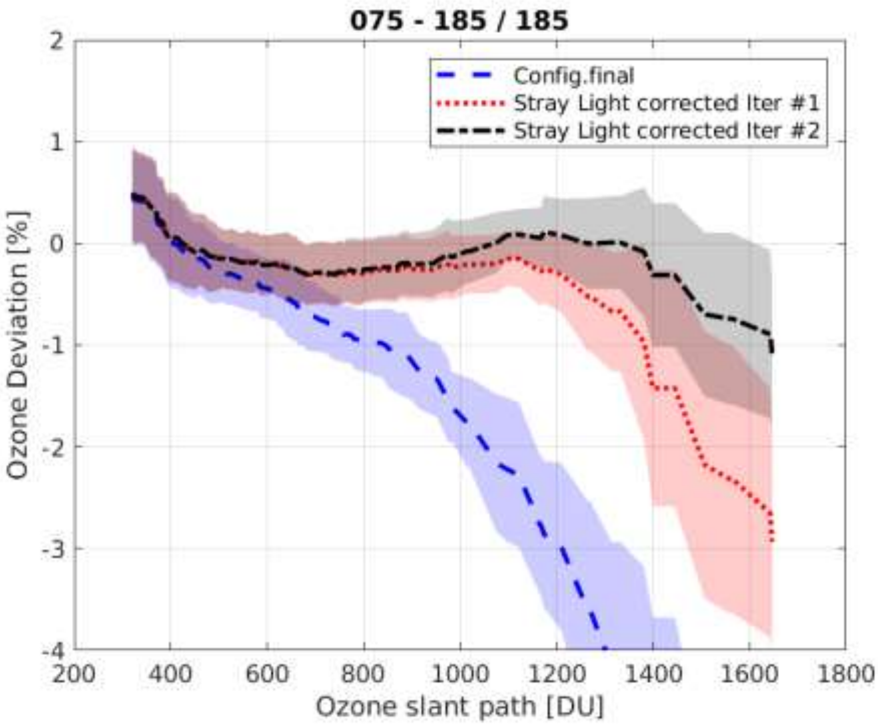


Figure 2. Mean DS ozone column percentage difference between Brewer UK #075 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) show reasonable results. Dead time (DT) shows 2ns difference between the current and campaign, with its value changing from $3.2 \cdot 10^{-8}$ s to $3 \cdot 10^{-8}$ s. This is a significant change for single Brewers.

Concerning the filter’s performance, we suggest using the following ETC corrections: 15 units for measurements taken with Filter#3, and 20 for those taken with Filter#4.

The sun scan tests (SC), both at the instrument’s station before the campaign and during the first days of the intercomparison, confirm the current cal step value (291, within a step error of ± 1). We do not suggest changing the ozone absorption coefficient, retaining its current value of 0.34.

Taking this into account, we suggest the following changes to the configuration of Brewer UK #075.

8.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer UK#075 show a large change during the initial calibration campaign. The old R6 reference value was 1714 and it should be updated to 1576.
2. We suggest a new R5 reference value of 3020.
3. We suggest updating the DT to $3 \cdot 10^{-8}$ seconds, which is two units less than the value proposed in the last intercomparison.
4. We suggest the application of an ETC correction of 15 units for filter#3, and 20 units for filter#4.
5. For Brewer UK #075, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -56.1$, and $s = b = 4.66$.
6. Finally, we suggest updating the ETC value from 2925 to 2770.

8.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/075/ICF17419.075

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1466211107

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/075/html/cal_report_075a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/075/html/cal_report_075a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/075/html/cal_report_075b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/075/html/cal_report_075c.html

8.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

8.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance has been reasonably stable since July 2017 up to the present campaign, with a change of some 50 units in this period. However, maintenance work carried out during the present campaign is likely responsible for large changes in R6 and R5. In this way, the R6 reference value changes from 1714 to 1576, and the R5 reference, from approx. 3300 to 3020. Note also that seasonal variations can be identified in Figure 5.

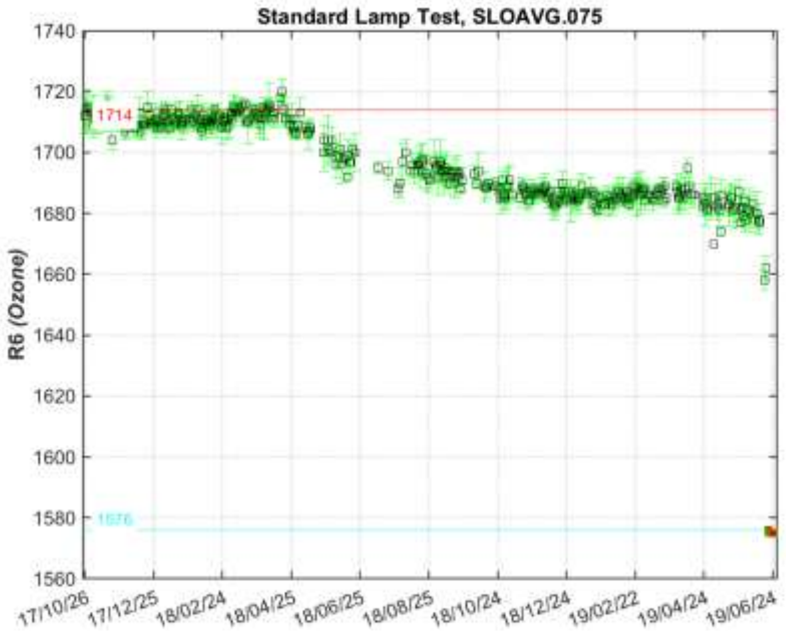


Figure 3. Standard lamp test R6 zone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

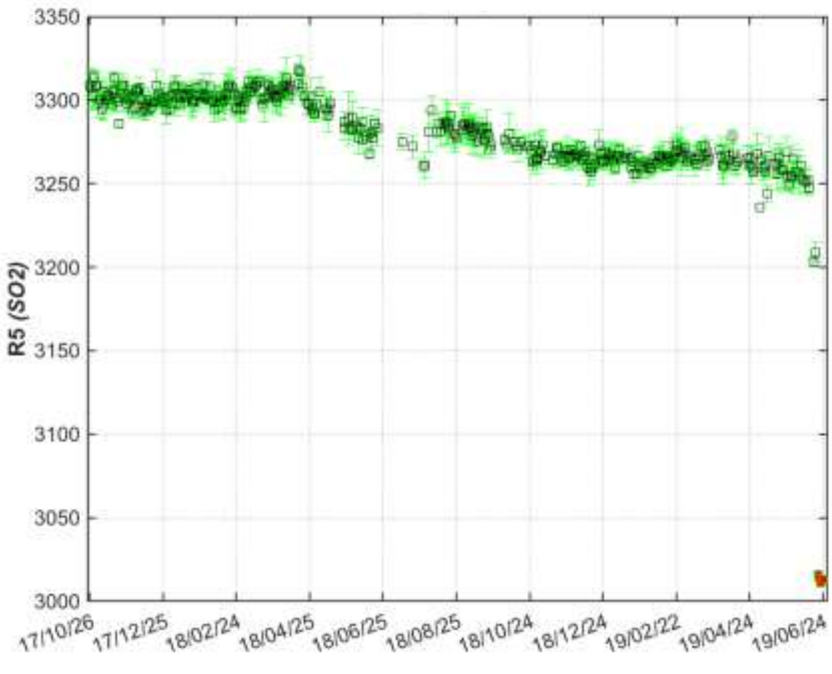
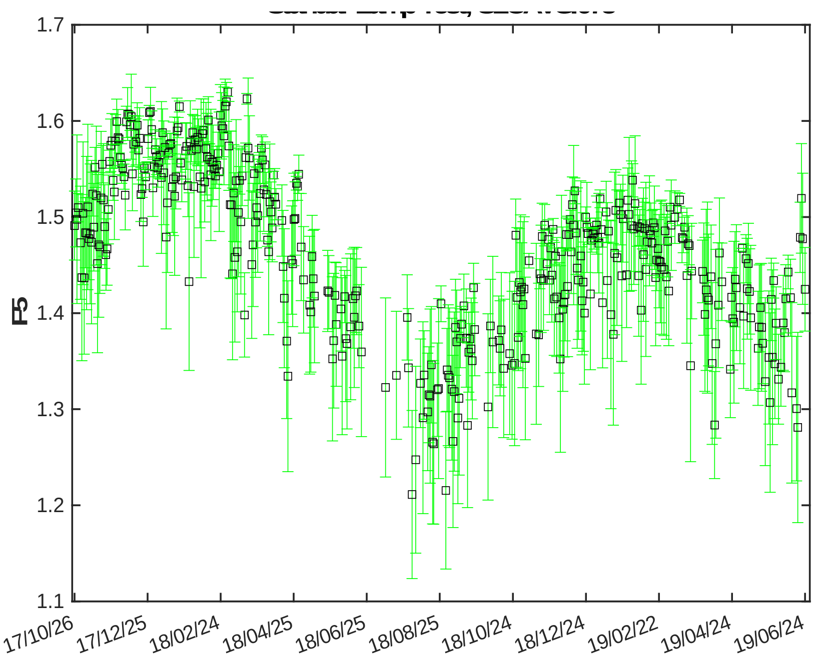


Figure 4. Standard lamp test R5 (sulfur dioxide) ratios



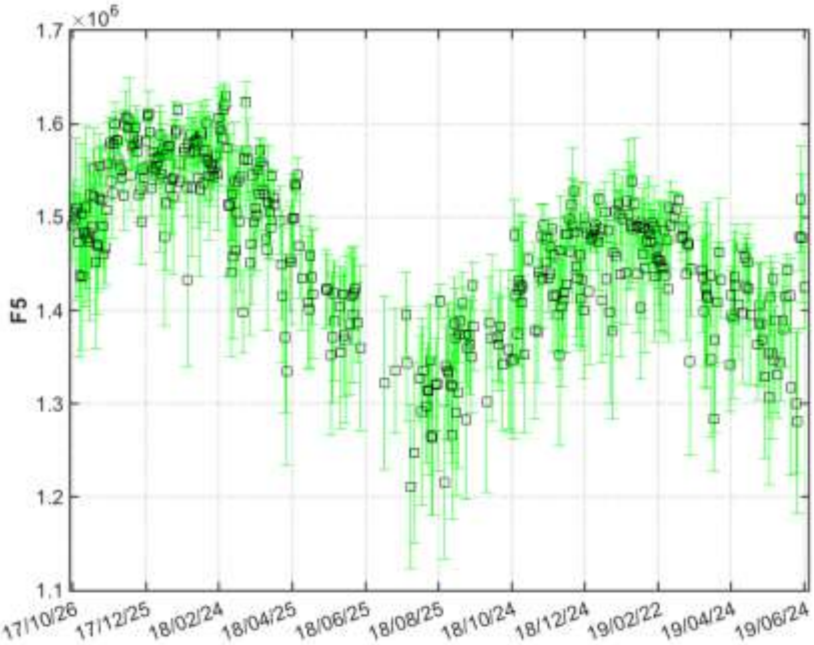


Figure 5. SL intensity for slit five

8.2.2. Run/Stop and dead time

Run/stop tests' values were within the test tolerance limits (see Figure 6).

As shown in Figure 7, the current DT reference value of $3.2 \cdot 10^{-8}$ seconds is 2 ns higher than the value recorded during the calibration period, $3 \cdot 10^{-8}$ s. Therefore, this new value has been used in the new ICF.

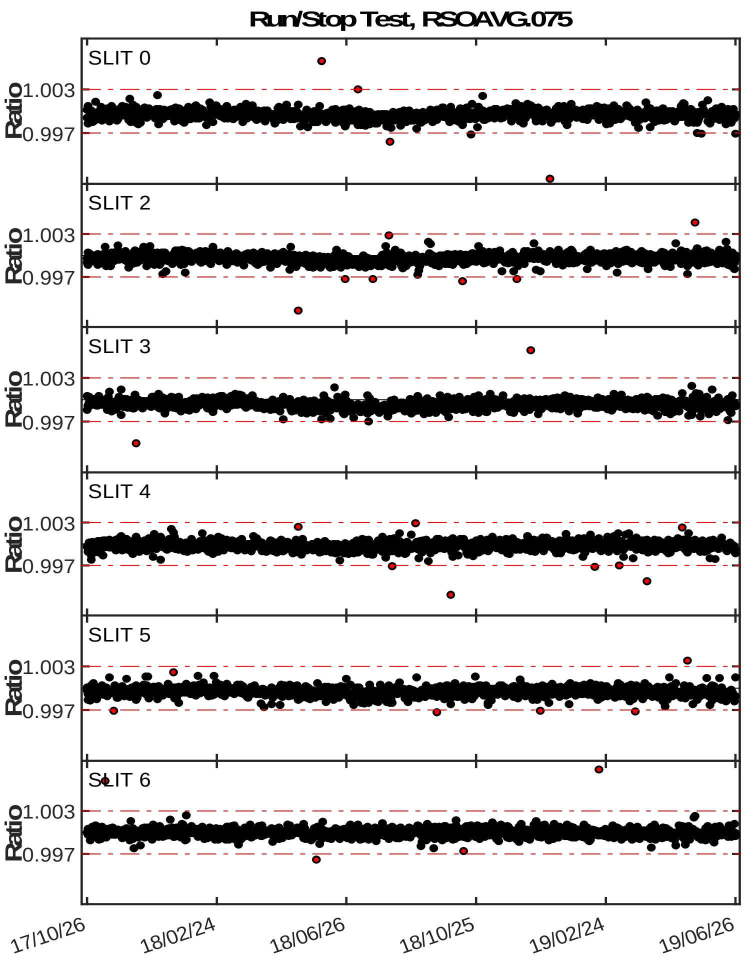


Figure 6. Run/stop test

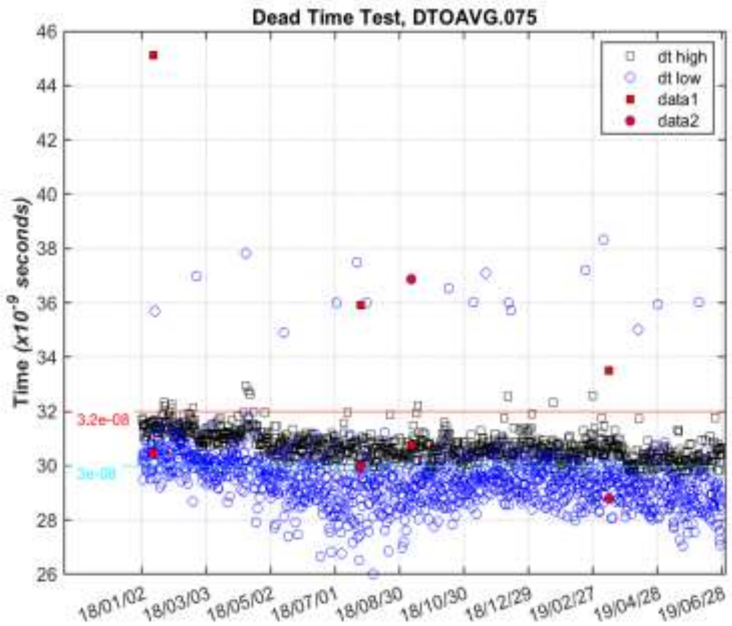


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

8.2.3. Analogue test

Figure 8 shows that the high voltage has remained almost constant at approx. 1545 over the last two years. Furthermore, analogue test values were within the test tolerance range.

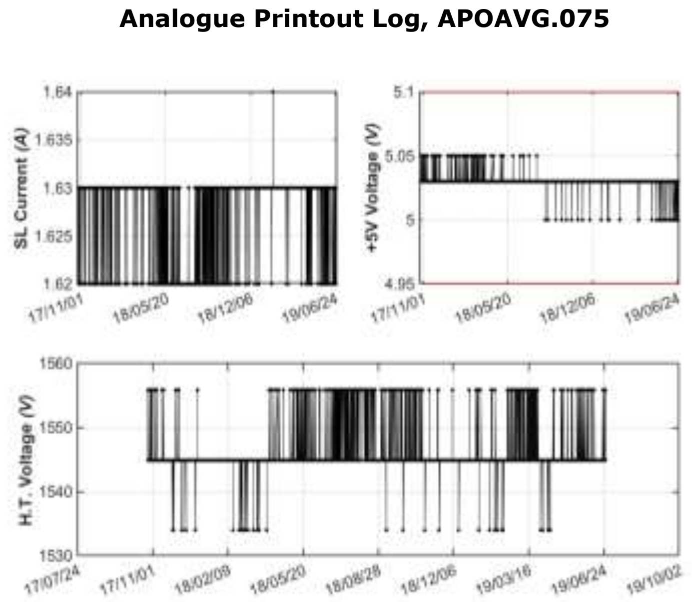


Figure 8. Analogue voltages and intensity

8.2.4. Mercury lamp test

A very noticeable internal mercury lamp intensity event can be observed in the fall of 2018 (see Figure 9). However, no large changes were observed during the present campaign.

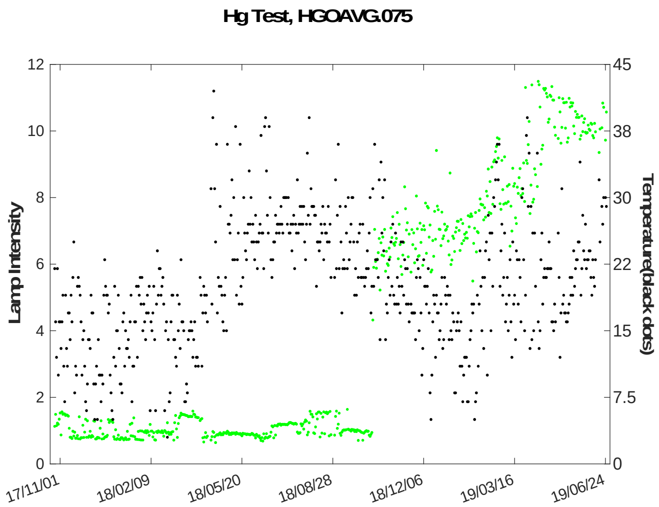


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

8.2.5. CZ scan on mercury lamp

We analysed the scans performed on the 296.728 nm mercury line, in order to check both the wavelength settings and the slit function width. As a reference, the calculated scan peak in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of CZ scans performed on Brewer UK #075 during the campaign show reasonable results, with the peak of the calculated scans slightly above the accepted tolerance range. Regarding the slit function width, results are good, with FWHM parameter lower than 0.65 nm.

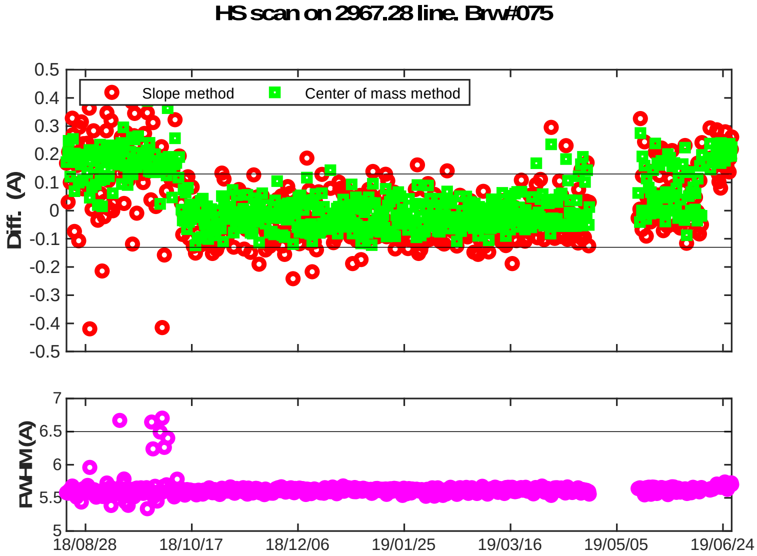


Figure 10. CZ scan on 296.728 nm Hg line. Upper figure shows differences with respect to the reference line (solid lines represent the limit ±0.013 nm) as computed by two different methods: slopes method (red circles) and centre of mass method (green squares). Lower figure shows Full Width at Half Maximum value for each scan performed. Solid line represents the 0.65 nm limit

8.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer UK #075 CI scans performed during the campaign relative to the CI10019.075 scan. As can be observed, on average the relative difference of the lamp intensity remains constant at approx. 10% up to 315.0 nm. At this wavelength, the most recent scans show a large increase in the relative difference, reaching up to 60%.

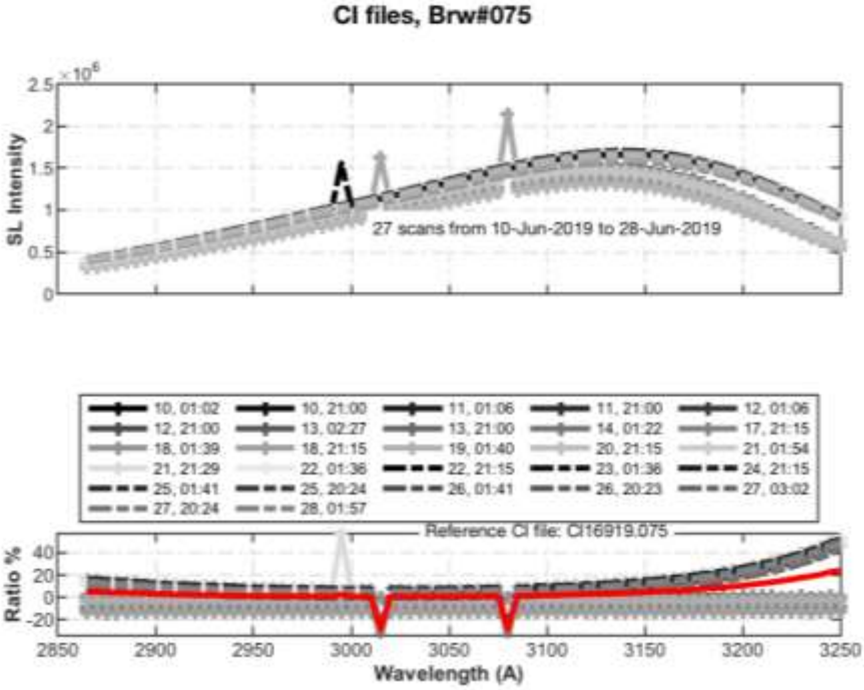


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

8.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

As shown in Figure 12 (temperature range from 23˚C to 42˚C), the current coefficients do an excellent job at reducing the temperature dependence, performing even better than the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 13 and 14, the current and new coefficients perform similarly, the current coefficients being slightly better. For this reason, in the final ICF we have used the current coefficients.

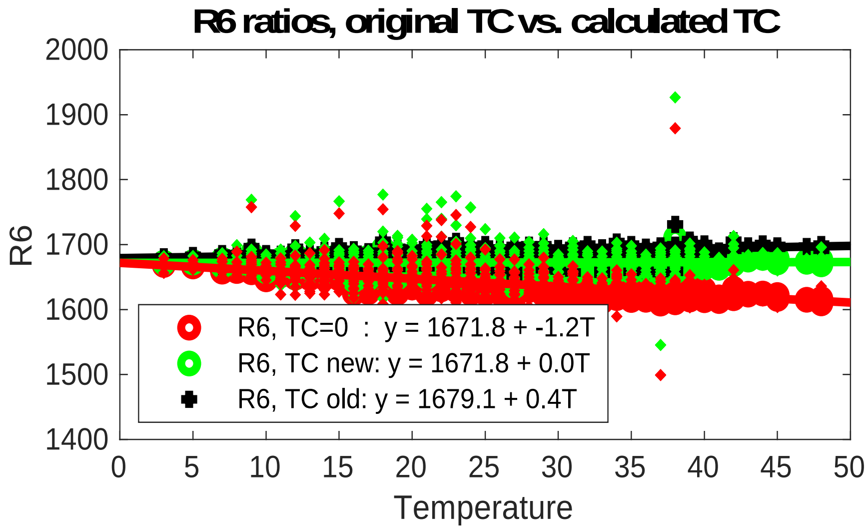


Figure 12. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.1800	-0.8600	-2.0200	-3.4300
Calculated	0.0000	5.1000	4.0000	2.5000	1.1000
Final	0.0000	-0.1800	-0.8600	-2.0200	-3.4300

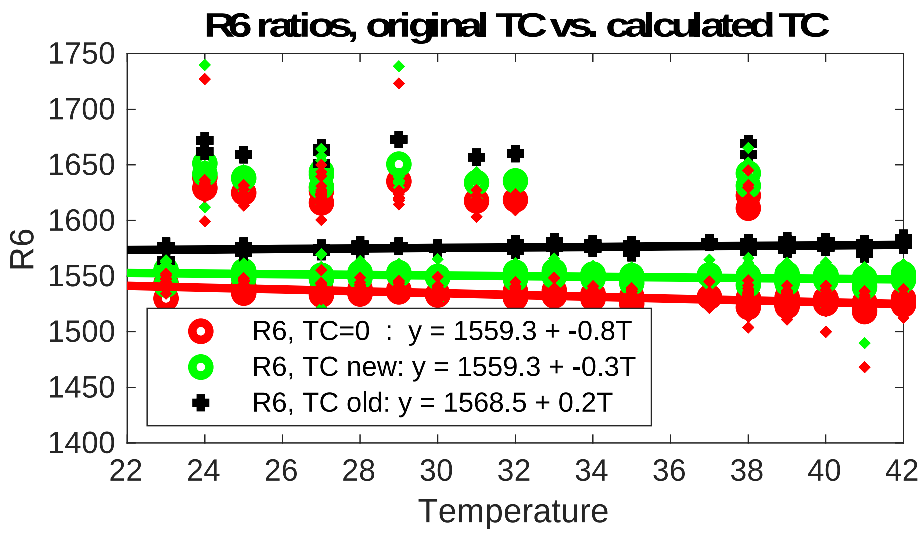


Figure 13. Same as Figure 12 but for the whole period between calibration campaigns

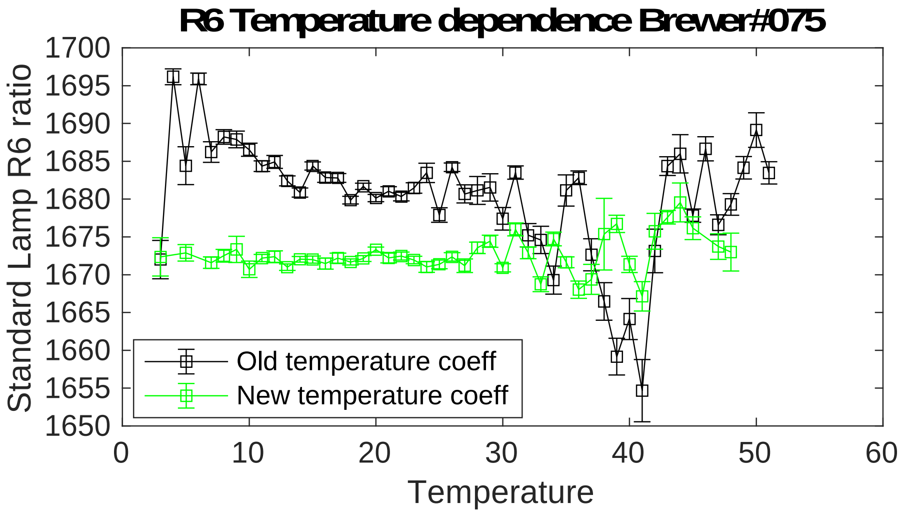


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

8.4. ATTENUATION FILTER CHARACTERIZATION

8.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 105 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Also, taking into account the relative ozone difference with respect to the reference Brewer IZO#185, we suggest applying an ETC correction of 15 units for measurements taken with filter #3, and 20 for those taken with filter #4.

ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	Filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	4	14	-8	-11	41
ETC Filt. Corr. (mean)	3.5	10	-8.7	-12.5	38.6
ETC Filt. Corr. (mean 95% CI)	[1 6.1]	[6.5 13.1]	[-11.3 - 6.2]	[-15.2 - 9.9]	[34.2 42.7]

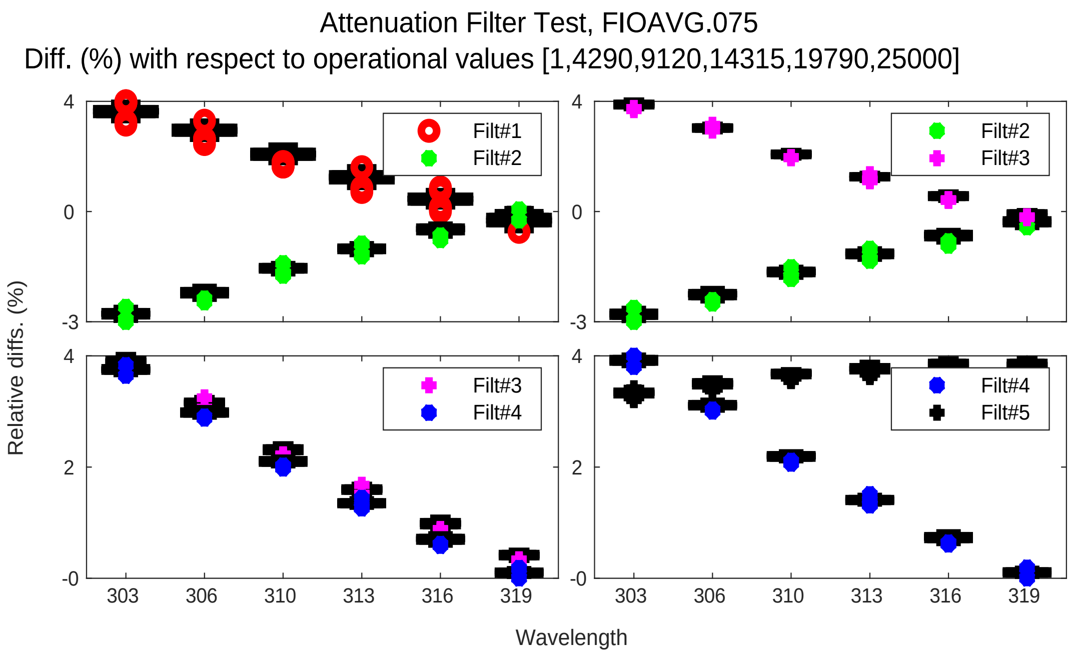


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

8.5. WAVELENGTH CALIBRATION

8.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

During the campaign, sun scan (SC) tests covering an ozone slant path range from 400 to 1000 DU were carried out (see Figure 17). The calculated cal step number (CSN) was almost 1 step higher than the value in the current configuration: 291.9 *vs.* 291. This difference is however within the margin of error of ± 1 step, so we suggest keeping the current CSN of 291.

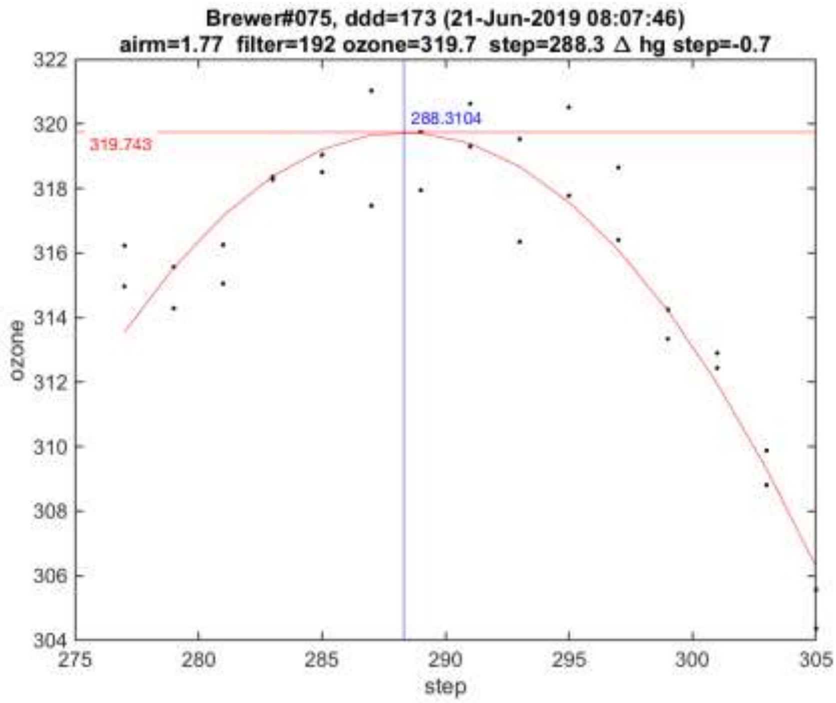


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

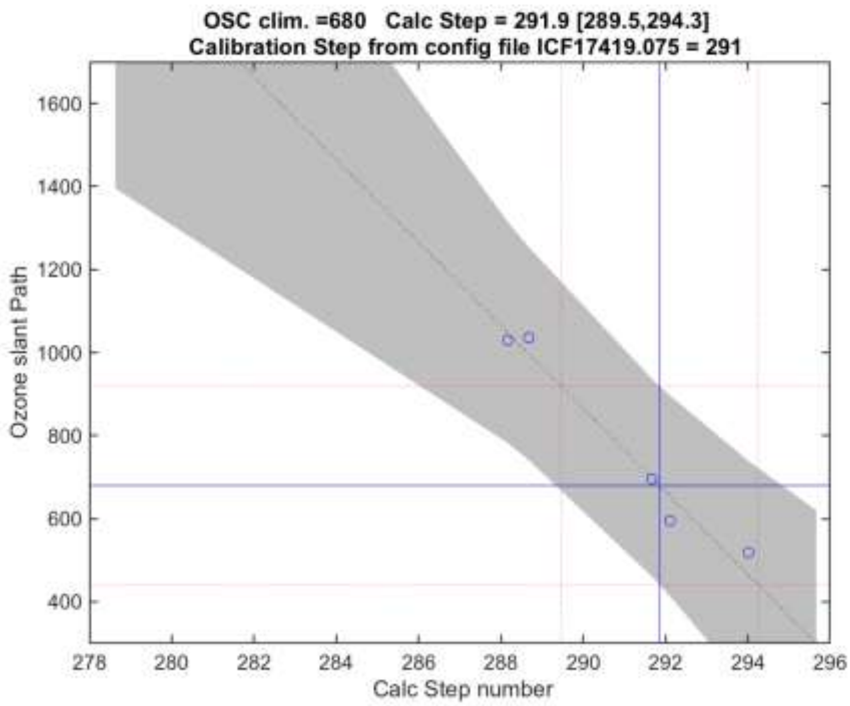


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

8.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

We suggest keeping the current absorption coefficient of 0.3400.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	291	0.3400	2.3500	1.1390
15 Jun-2013	291	0.3420	3.1699	1.1496
01-Jun-2015	291	0.3414	3.1186	1.1509
02-Jun-2017	291	0.3382	3.1407	1.1410
23-Jun-2019	291	0.3405	3.1079	1.1489
Final	291	0.3400	2.3500	1.1390

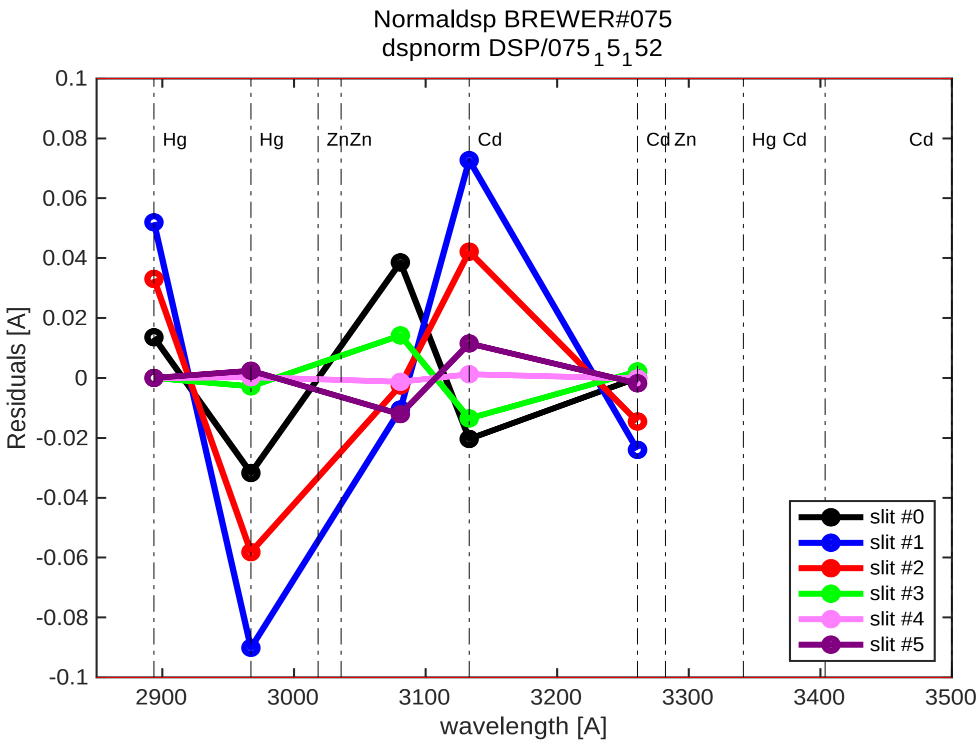


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 290	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.83	3062.73	3100.5	3134.93	3167.91	3199.95
Res(A)	5.5324	5.5343	5.478	5.6165	5.5362	5.3978
O3abs(1/cm)	2.6014	1.786	1.0048	0.67637	0.37505	0.29407
Ray abs(1/cm)	0.50512	0.48341	0.45847	0.43715	0.41791	0.40023
SO2abs(1/cm)	3.4465	5.5572	2.4094	1.9126	1.0531	0.61293
step= 291	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.9	3062.8	3100.57	3135	3167.97	3200.01
Res(A)	5.5323	5.5342	5.4779	5.6164	5.5361	5.3977
O3abs(1/cm)	2.5989	1.7846	1.0046	0.67603	0.37507	0.29363
Ray abs(1/cm)	0.50507	0.48337	0.45843	0.43711	0.41787	0.4002
SO2abs(1/cm)	3.4303	5.581	2.4171	1.9019	1.0542	0.61084
step= 292	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.97	3062.87	3100.64	3135.07	3168.04	3200.08
Res(A)	5.5322	5.5341	5.4778	5.6163	5.5361	5.3976
O3abs(1/cm)	2.5965	1.7832	1.0043	0.67569	0.37511	0.29319
Ray abs(1/cm)	0.50502	0.48332	0.45839	0.43707	0.41783	0.40016
SO2abs(1/cm)	3.4151	5.6037	2.4248	1.8911	1.0554	0.60867
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
290	0.34145	8.937	3.0956	1.1518	0.35208	0.34345
291	0.34054	8.9352	3.1079	1.1489	0.35118	0.34252
292	0.33961	8.9333	3.1189	1.1459	0.35024	0.34156

8.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1768. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 291	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.5323	5.5342	5.4779	5.6164	5.5361	5.3977
O3abs(1/cm)	2.5989	1.7846	1.0046	0.67603	0.37507	0.29363
Ray abs(1/cm)	0.50507	0.48337	0.45843	0.43711	0.41787	0.4002
step= 1768	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3133	3164	3200	3233	3265	3296
Res(A)	5.3965	5.4347	5.3421	5.4676	5.4315	5.2492
O3abs(1/cm)	0.67859	0.39743	0.29386	0.12465	0.061588	0.033364
Ray abs(1/cm)	0.43809	0.42038	0.4002	0.38289	0.36723	0.35285

8.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F, α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients *w=0, 1, −0.5,−2.2,1.7* for slits 1 to 5, with nominal wavelengths equal to *306.3,310.1,313.5,316.8,320.1* nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light. In this case, the ETC distribution shows (see Figure1) a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column.

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 5 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

8.6.1. Initial calibration

For the evaluation of the initial status of Brewer UK #075, we used the period from day 168 to 169 in which 14 near-simultaneous DS ozone measurements were taken. As shown in Figure 19, without the standard lamp correction, the initial calibration constants produced ozone values which are 3%–4% below those of reference Brewer IZO#185. Adding the standard lamp correction does not improve the results, which are now overestimated by 2%–3%.

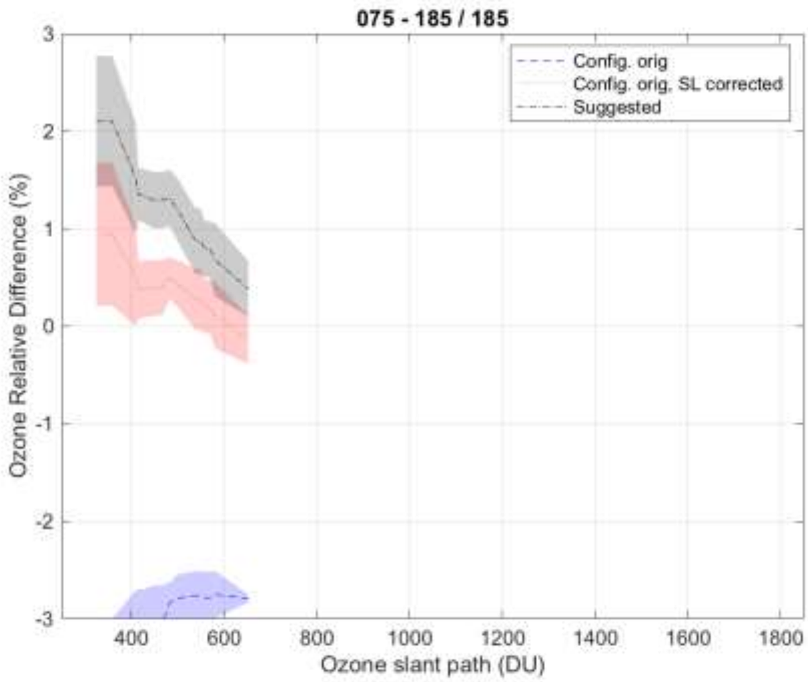


Figure 19. Mean direct sun ozone column percentage difference between Brewer UK #075 and Brewer IZO#185 as a function of ozone slant path

8.6.2. Final calibration

Using data after the end of the maintenance on day 170, a new ETC value was calculated (see Figure 20). For the final calibration, we used 228 simultaneous direct sun measurements from days 174 to 178. Because of the important effect of the stray light on Brewer UK #075, we only included measurements up to an ozone slant column value of 600 DU in this data set.

The new value is 2770, approximately 160 units lower than the current ETC value of 2925. This is a very large change, and we strongly recommend using the new configuration suggested in this report. This new configuration includes not only a change to the ETC, but also to the standard lamp R6 reference ratios (with a new value of 1576), and the dead time ($3 \cdot 10^{-8}\,s$).

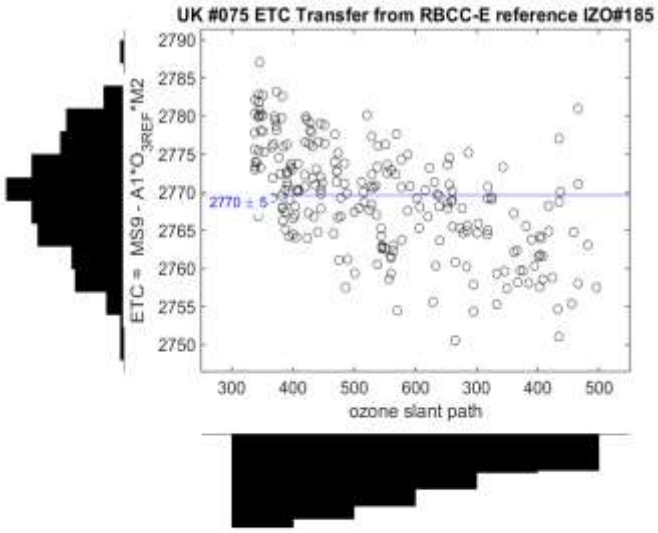


Figure 20. Mean direct sun ozone column percentage difference between Brewer UK #075 and Brewer IZO#185 as a function of ozone slant path

8.6.3. Stray light correction

The final calibration performed well with near zero error for low OSC and an underestimation of 1.7% at 1000 DU OSC, which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = a = -56.1$, $s = b = 4.66$, and ETC=2767. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

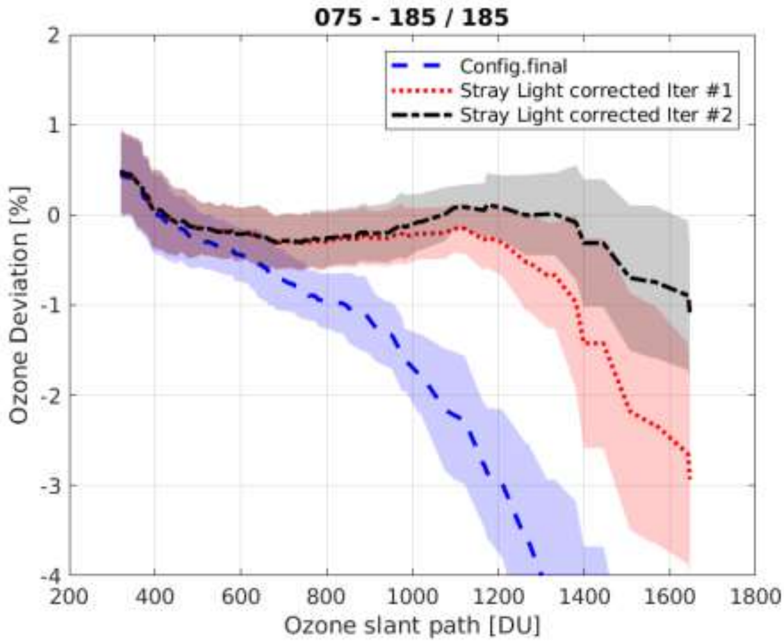


Figure 21. Ratio respect to the reference when final constants are applied and the stray light correction from empirical model is applied.

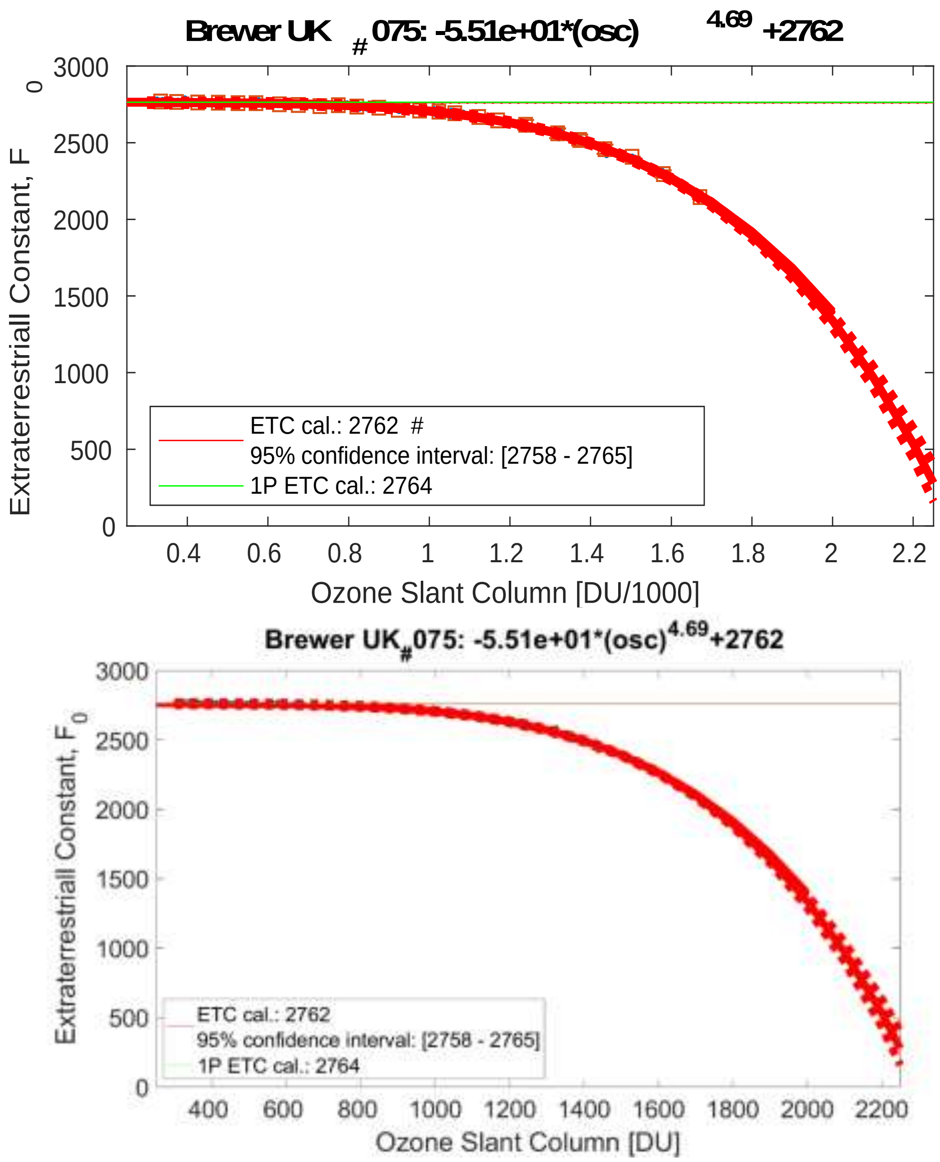


Figure 22. Stray light empirical model determination

8.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1576 for R6 (Figure 23) and 3020 for R5 (Figure 24).

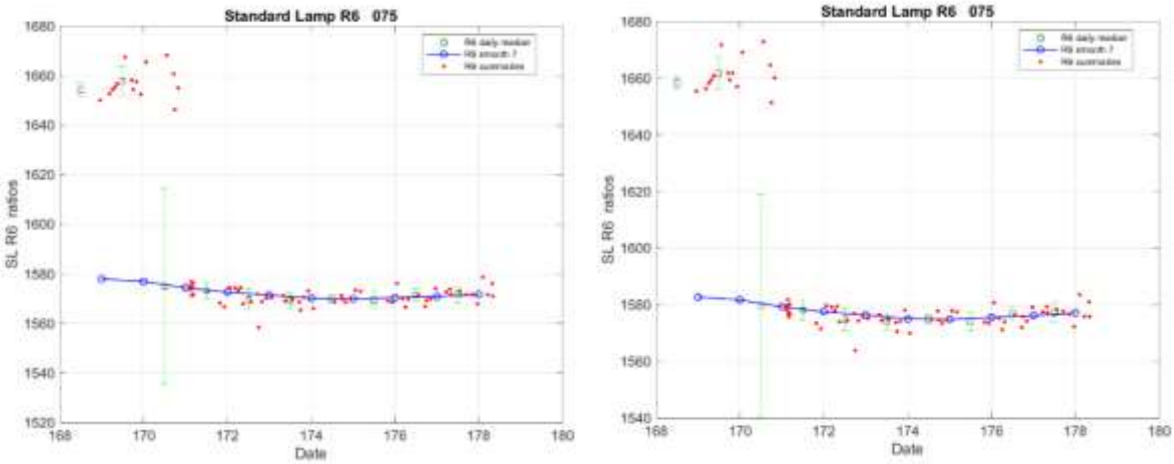


Figure 23. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

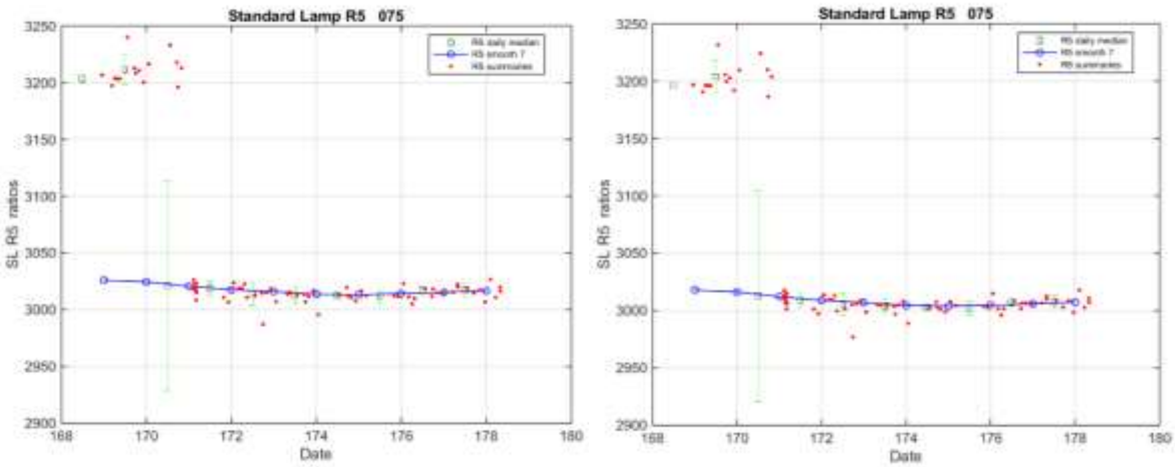


Figure 24. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

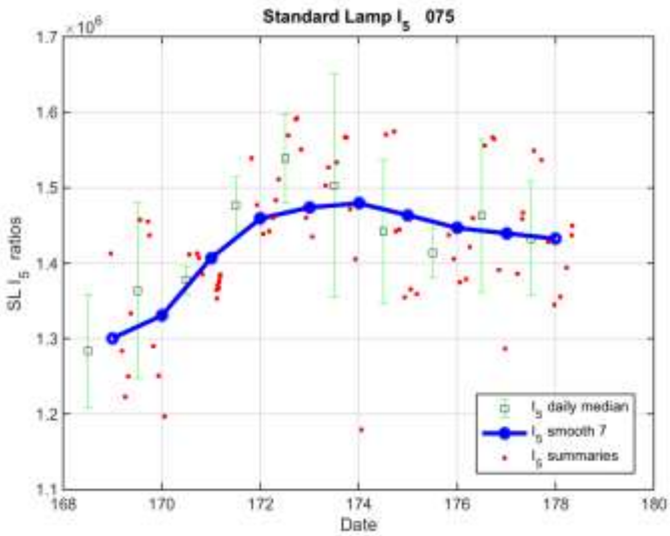


Figure 25. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

8.7. CONFIGURATION

8.7.1. Instrument constant file

	Initial (ICF15017.075)	Final (ICF17419.075)
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.18	-0.18
o3 Temp coef 3	-0.86	-0.86
o3 Temp coef 4	-2.02	-2.02
o3 Temp coef 5	-3.43	-3.43
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.34	0.34
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.139	1.139
ETC on O3 Ratio	2925	2770
ETC on SO2 Ratio	3160	3160
Dead time (sec)	3.2e-08	3e-08
WL cal step number	291	291
Slitmask motor delay	76	76
Umkehr Offset	1766	1766
ND filter 0	0	0
ND filter 1	4290	4290
ND filter 2	9120	9120
ND filter 3	14315	14315
ND filter 4	19790	19790
ND filter 5	25000	25000
Zenith steps/rev	2816	2816
Brewer Type	0	0
COM Port #	2	2
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	15	15
n2 Temp coef 3	20	20
n2 Temp coef 4	22	22
n2 Temp coef 5	0	0
O3 Mic #1 Offset	2984	2984
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	772	772
NO2 zs etc	770	770
NO2 Mic #1 Offset	5642	5642
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2650	2650
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	3469	3469
Iris Open Steps	75	75
Buffer Delay (s)	0	0
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	52	52
Zenith UVB Position	2112	2112

8.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk).

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#075*	*O3 std*	*%diff*	*(*)O3#075*	*O3 std*	*(*)%diff*
168	700> osc> 400	314	0.4	11	314	1.0	0.2	312	0.8	-0.6
168	osc< 400	313	0.0	1	318	0.0	1.6	312	0.0	-0.2
169	700> osc> 400	324	0.3	5	325	1.0	0.4	325	1.0	0.4
169	osc< 400	323	2.3	7	324	4.2	0.3	322	1.8	-0.4
174	1500> osc> 1000	314	1.5	5	303	6.5	-3.6	304	6.6	-3.3
174	1000> osc> 700	320	3.4	15	315	3.4	-1.6	317	3.5	-1.1
174	700> osc> 400	323	2.1	45	323	3.3	-0.1	323	2.7	-0.3
174	osc< 400	327	1.0	32	329	1.7	0.7	327	1.6	0.2
175	osc> 1500	309	0.4	2	277	4.1	-10.4	278	4.2	-10.1
175	1500> osc> 1000	308	0.4	5	296	5.0	-3.9	297	5.1	-3.5
175	1000> osc> 700	307	0.4	8	304	0.7	-1.0	304	0.4	-0.9
175	700> osc> 400	307	0.6	27	306	1.7	-0.2	306	1.3	-0.4
175	osc< 400	307	0.0	1	309	0.0	0.6	307	0.0	0.0
176	osc> 1500	308	1.4	4	278	8.2	-9.6	279	8.2	-9.3
176	1500> osc> 1000	308	2.0	10	296	6.3	-4.0	297	6.4	-3.5
176	1000> osc> 700	307	2.2	10	303	2.8	-1.4	304	2.5	-1.1
176	700> osc> 400	308	1.4	32	307	1.6	-0.3	306	1.4	-0.5
176	osc< 400	310	1.4	26	313	2.2	0.8	311	2.1	0.3
177	1000> osc> 700	311	5.7	11	307	5.7	-1.3	308	6.1	-0.9
177	700> osc> 400	312	4.2	28	312	4.2	0.0	312	4.2	-0.2
177	osc< 400	311	1.3	23	314	2.3	0.9	312	2.2	0.5
178	1500> osc> 1000	306	6.1	7	NaN	NaN	NaN	294	10.9	-4.2
178	1000> osc> 700	306	3.7	8	NaN	NaN	NaN	302	4.7	-1.3
178	700> osc> 400	311	3.4	30	NaN	NaN	NaN	310	4.4	-0.1
178	osc< 400	312	2.4	24	NaN	NaN	NaN	313	2.8	0.5

8.9. APPENDIX: SUMMARY PLOTS

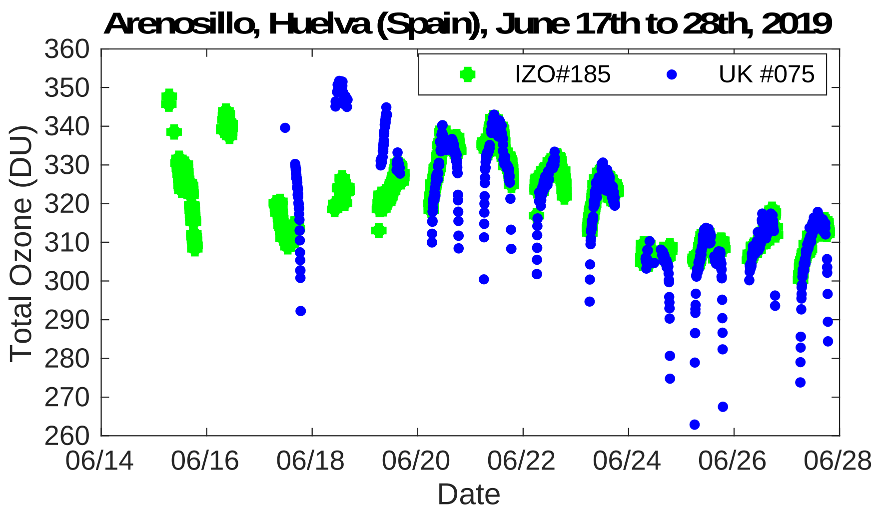
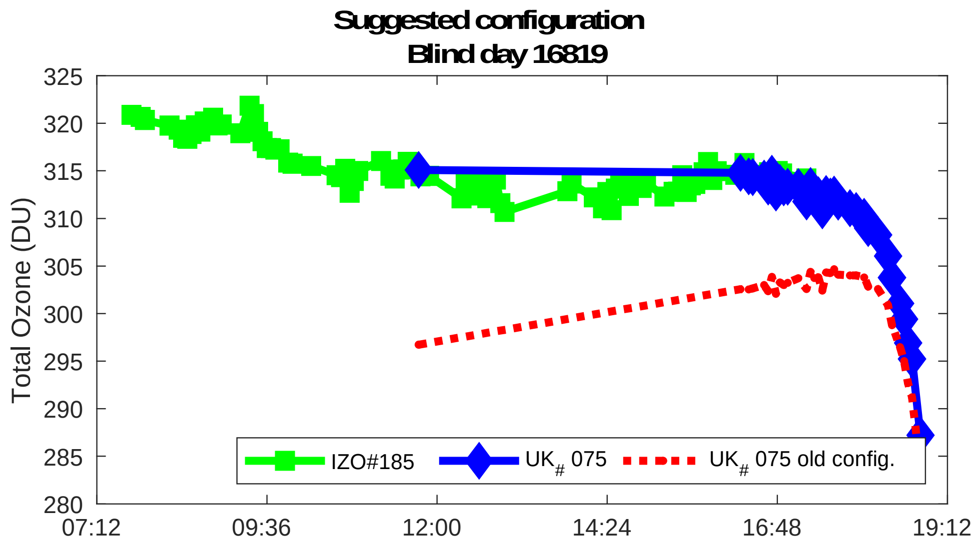
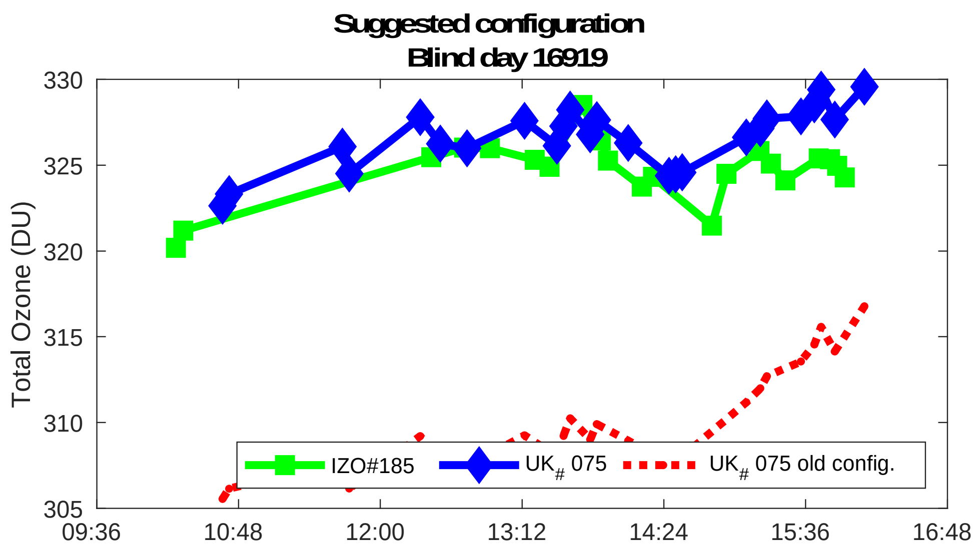
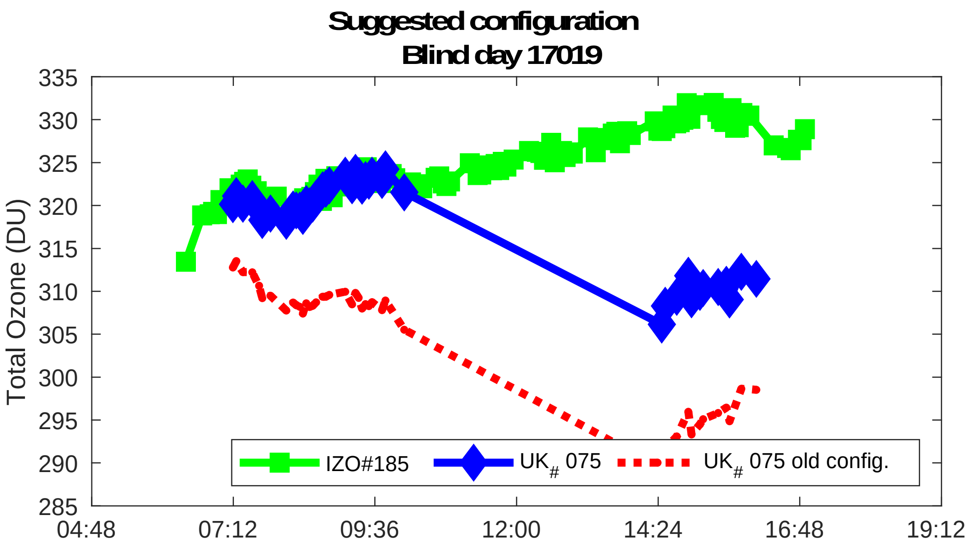
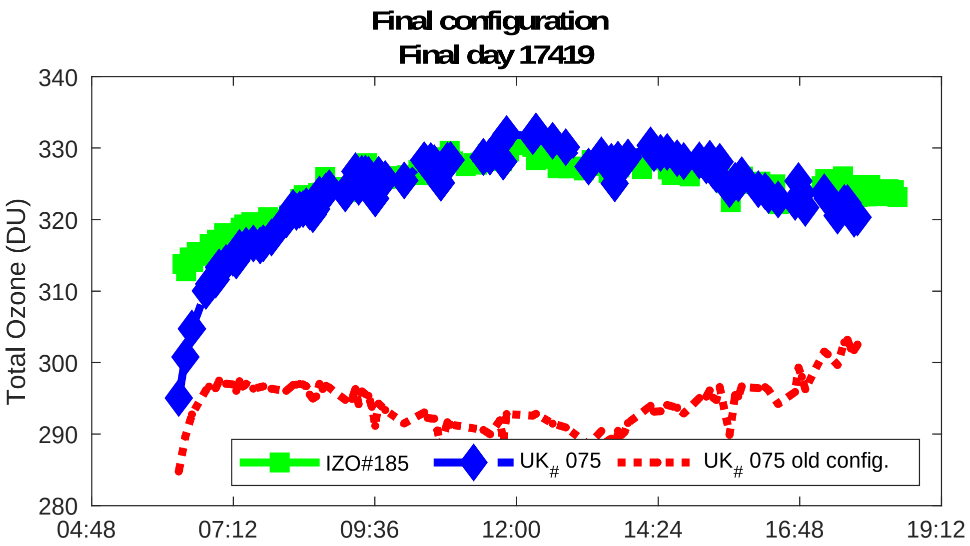


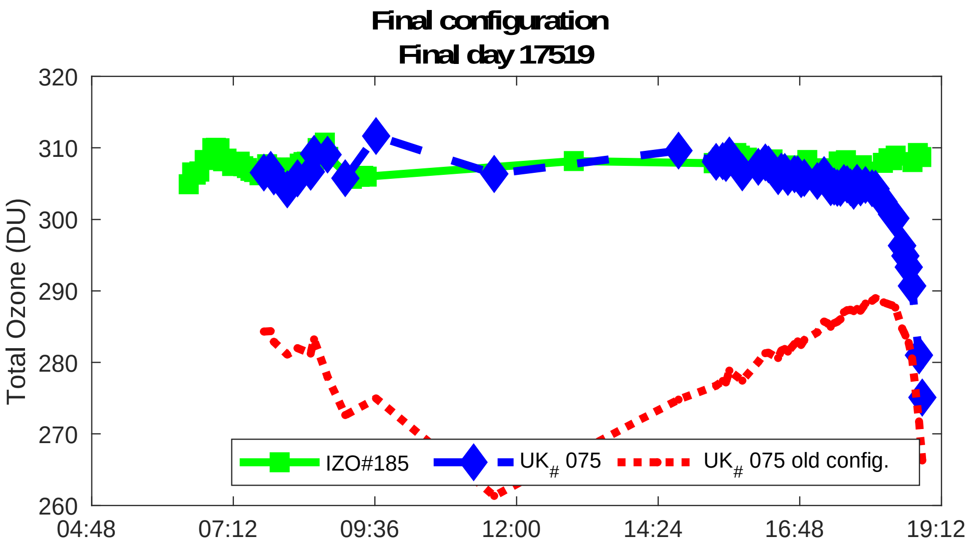
Figure 26. Overview of the intercomparison. Brewer UK #075 data were evaluated using final constants (blue circles)

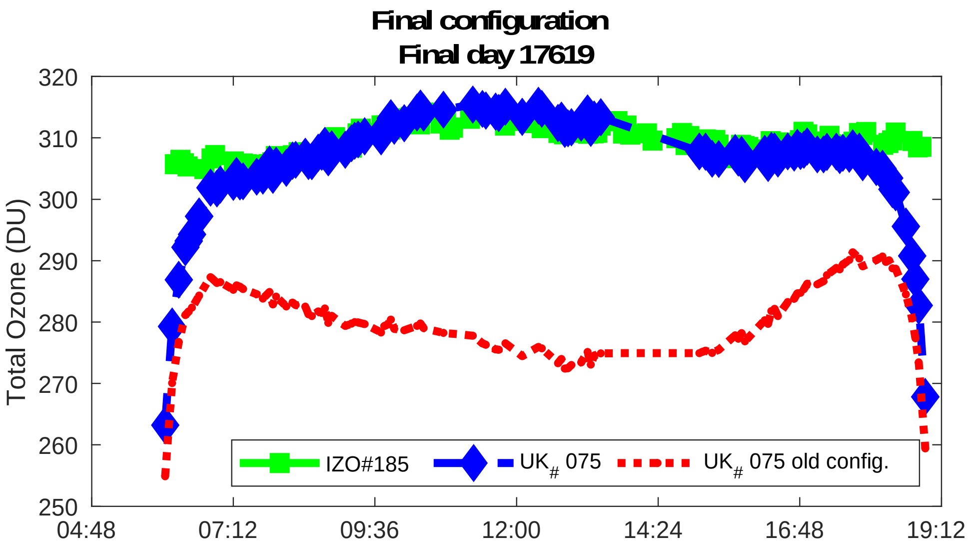


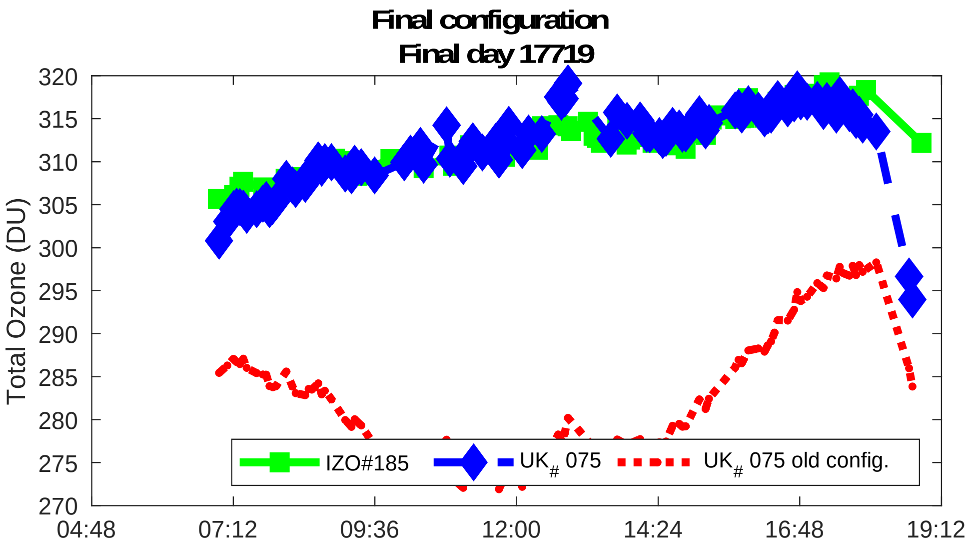


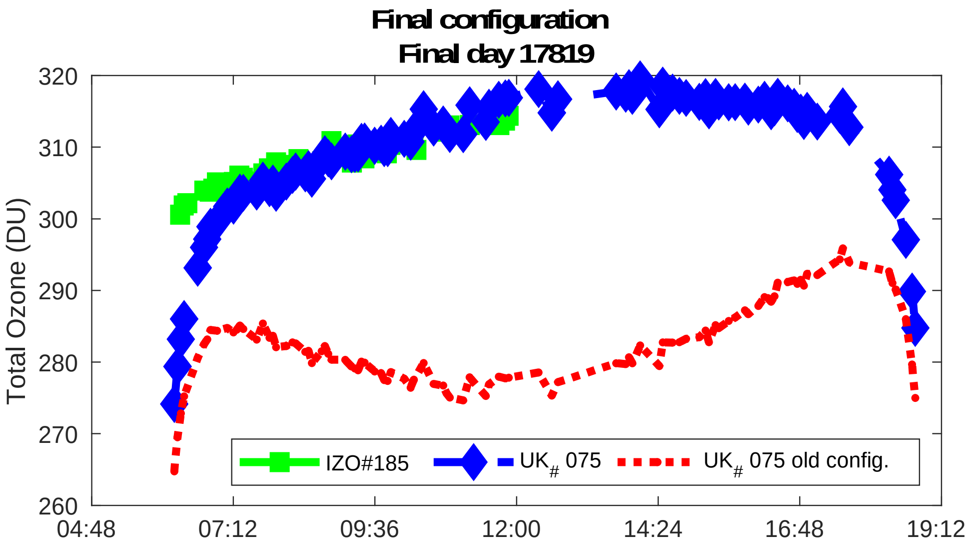

Suggested configuration
Blind day 17019
Total Ozone (DU)
IZO#185
UK# 075
UK# 075 old config.


Final configuration
Final day 17419
Total Ozone (DU)
IZO#185
UK# 075
UK# 075 old config.


Final configuration
Final day 17519
Total Ozone (DU)
IZO#185
UK# 075
UK# 075 old config.


Final configuration
Final day 17619
Total Ozone (DU)
320
310
300
290
280
270
260
250
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK# 075
UK# 075 old config.


Final configuration
Final day 17719
Total Ozone (DU)
320
315
310
305
300
295
290
285
280
275
270
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK# 075
UK# 075 old config.


Final configuration
Final day 17819
Total Ozone (DU)
320
310
300
290
280
270
260
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK# 075
UK# 075 old config.

9. BREWER MUR#117

9.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer MUR#117 participated in the campaign from 17 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer MUR#117 correspond to Julian days 168 – 178.

For the evaluation of the initial status, we used 78 simultaneous direct sun (DS) ozone measurements from days 168 to 171. For final calibration purposes, we used 110 simultaneous DS ozone measurements taken from day 173 to 177.

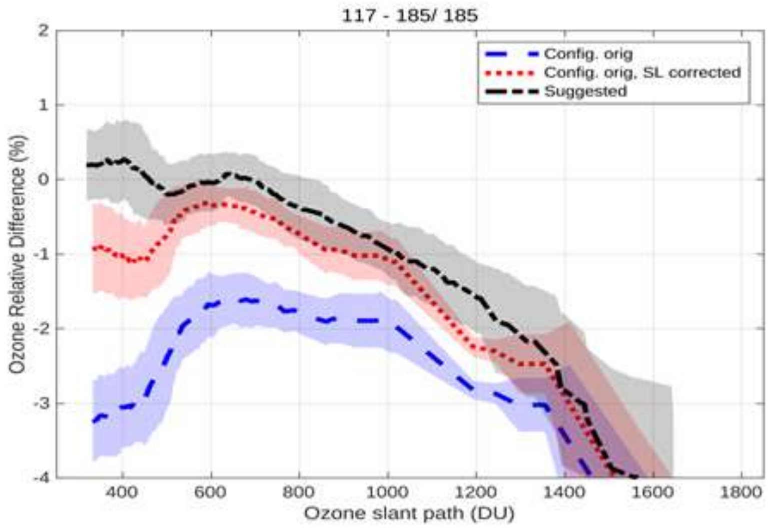


Figure 1. Mean DS ozone column percentage difference between Brewer MUR#117 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (IOS15517.117, blue dashed line) produces ozone values with an average difference of approx. 2.5% with respect to the reference instrument Brewer IZO#185 . The SL correction (Figure 1, red dotted line) improves the comparison, lowering the difference to approx. 0.5% in the lower ozone slant path range, up to approx. 600 DU.

As a Mk. IV model, Brewer MUR#117 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 1.6).

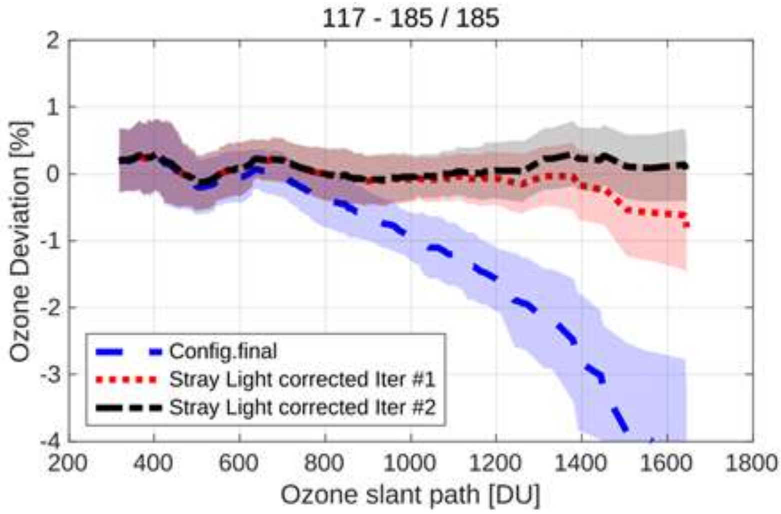


Figure 2. Mean DS ozone column percentage difference between Brewer MUR#117 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in the figures, the instrument at short OSC overestimated the ozone. This can be partially compensated with the correction for filter #3 but the characterization is not conclusive. The FIAVG test suggests a correction of 20 +/- 3 for this filter and the comparison with the reference suggests a correction of 9 ETC units but none of these corrections are confirmed when we analyse past simultaneous observations. Also, the slope of the ratio of the measurements of filter #3 with the reference suggests that it is related with the DT correction. Considering this, we performed the calibration without considering the short OSC region and suggest a correction of filter #3 of 9 units that have to be validated with the observations after the campaign.

The lamp test results from Brewer MUR#117 have been reasonably stable over the last 2 years. The maintenance work carried out on day 172 resulted in a large change in the standard lamp ratios, but by the end of the campaign their values were stable at approx. 1685 and 3100, for R6 and R5 respectively (see Figures 24 and 26).

Dead time (DT) also changed as a result of the maintenance on day 172, showing a large increase of 8 units, from $2.7 \cdot 10^{-8}$ s to $3.5 \cdot 10^{-8}$ s. Results of the analogue tests in the APOAVG.117 file also show noticeable changes on day 172. Further changes were also made on day 178, but apparently, they were made only at software level. We have therefore not used the data of day 178 in our calibration.

The other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) show reasonable results.

Although the current temperature coefficients do not completely remove the temperature dependence of the instrument, their performance is within tolerance limits, so we have not updated them. Changes in the standard lamp ratios during the campaign also make it difficult to suggest new and reliable coefficients.

FI tests to detect the filters' nonlinear effects with wavelengths were quite noisy. Nevertheless, taking also into account the data from the comparison with Brewer IZO#185, we are able to suggest a filter correction of 9 units for ND#3.

The sun scan (SC) tests both at the instrument's station before the campaign and carried out during the campaign confirmed the current cal step number (CSN), with those performed during the first days of the intercomparison confirming the current cal step value of 286 within a step error of ± 1 .

Dispersion tests carried out during the campaign suggest a new ozone absorption coefficient of 0.3411. This is approx. 2 steps (0.002 units) higher than the current value of 0.3394. This is a rather small difference and since the CSN has not changed, we suggest keeping the current value.

Taking this into account, we suggest the following changes to the configuration of Brewer MUR#117.

9.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer MUR#117 have been quite stable during the last 2 years, but maintenance work during the campaign produced a large change. The old R6 reference value was 1620 and the new suggested value is 1685.
2. We suggest a new R5 reference value of 3100.
3. Maintenance work during the campaign introduced a large change on the DT of the instrument, its value increasing in 8 units up to $3.5 \cdot 10^{-8}$ seconds.
4. We suggest the application of an ETC correction of 9 units for filter#3.
5. We recommend performing frequent measurements of the filter attenuation (FI.RTN) and compare the observations performed with filter#3 to validate previous correction.
6. For Brewer MUR#117 stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -29.3$, and $s = b = 4.87$.
7. Finally, we suggest updating the ETC value from 2830 to 2881.

9.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/117/ICF17319.117

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=787554647

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/117/html/cal_report_117a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/117/html/cal_report_117a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/117/html/cal_report_117b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/117/html/cal_report_117c.html

9.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

9.2.1. Standard lamp test

As shown in Figure 3 and 4, the standard lamp test performance has been quite stable since July 2017. However, maintenance on day 172 during the present campaign caused a large change. By the end of the campaign, the ratios stabilized at values of approx. 1685 and 3100 for R6 and R5, respectively. The current R6 value is 65 units higher than the present one, a very noticeable change. Small seasonal variations can be identified in the lamp's intensity as shown in Figure 5, with maxima in December.

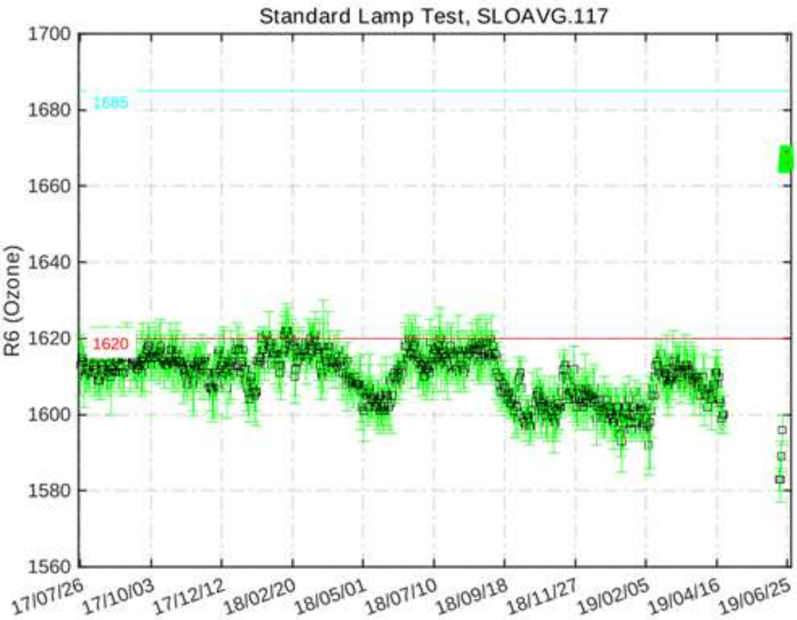


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

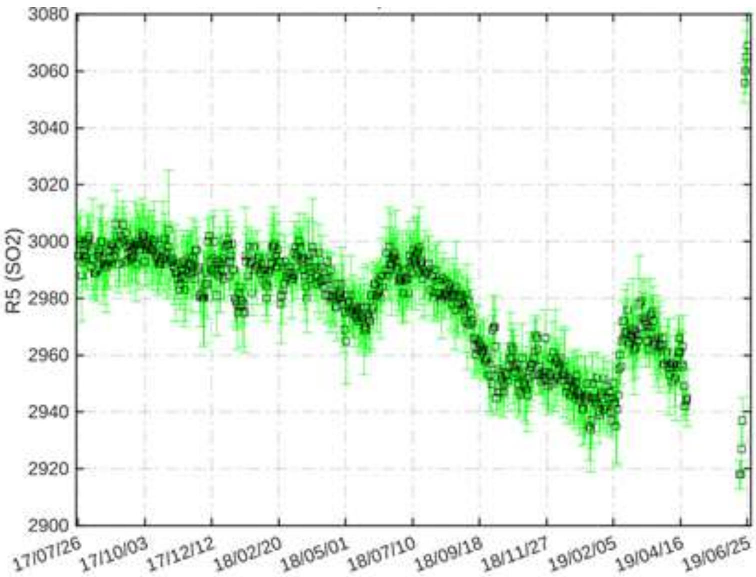


Figure 4. Standard lamp test R5 sulphur dioxide ratios

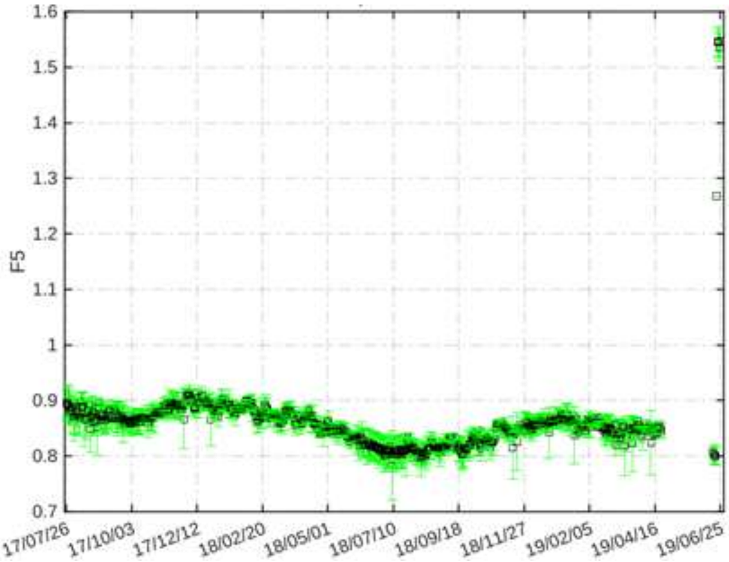


Figure 5. SL intensity for slit five

9.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 6).

As shown in Figure 7, the current DT reference value of $2.7\cdot 10^{-8}$ seconds is 8 ns lower than the value recorded during the calibration period after maintenance was performed on day 172 of $3.5\cdot 10^{-8}$ s. This is a very important change and this new value has been used in the new ICF issued in the present campaign (ICF17319.117).

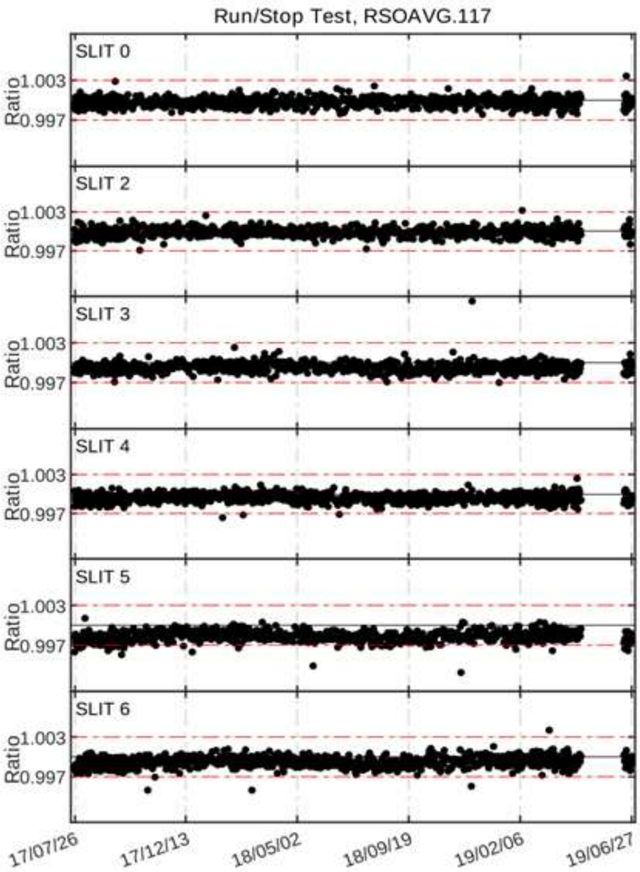


Figure 6. Run/stop test

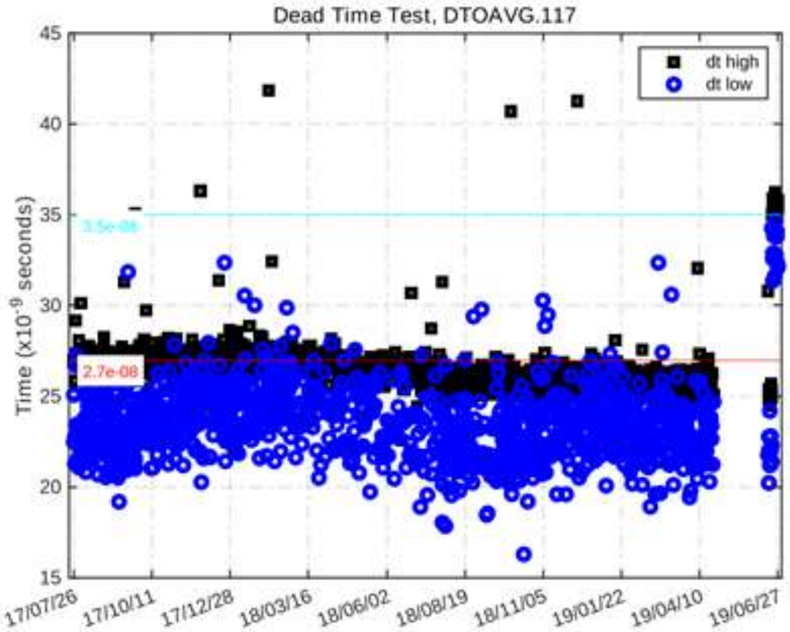


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

9.2.3. Analogue test

Figure 8 shows that the SL current and +5 Voltage have not been stable during the intercampaign period. Maintenance carried out on day 172 during the campaign noticeably improved the +5V output. Further changes were performed on the instrument, apparently just at software level, on day 178. Unfortunately, we cannot really analyse the stability of the instrument after all these changes because we have no data for the instrument after the campaign.

Analogue Printout Log, APOAVG.075

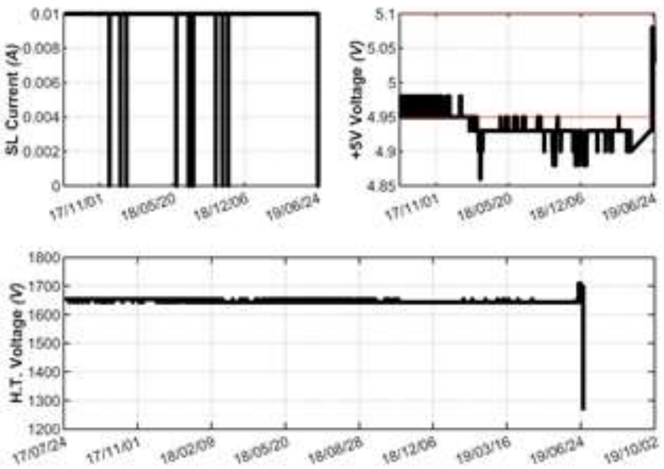


Figure 8. Analogue voltages and intensity

9.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign (see Figure 9). There is no clear correlation between the Hg intensity and the instrument's temperature.

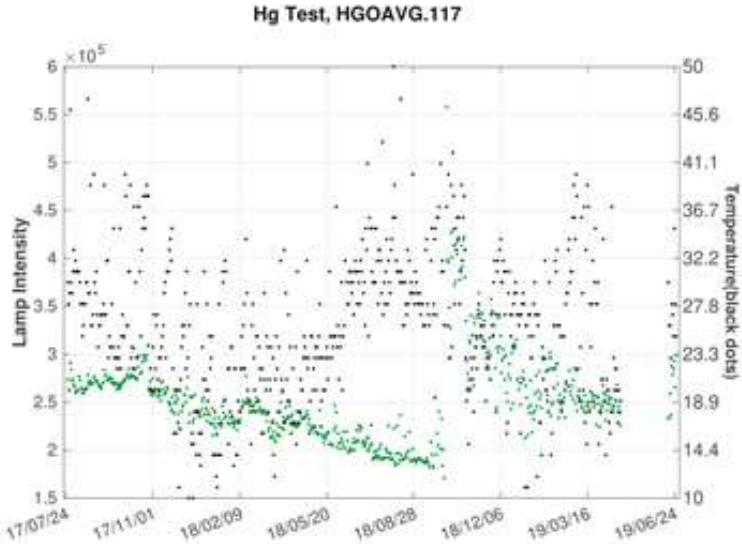


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

9.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm and 334.148 nm mercury lines (see Figure 11 and Figure 10). As a reference, the calculated scan peak in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer MUR#117 during the campaign show reasonable results for the 296.728 nm line and worse ones for 334.148 nm, with the peak of the calculated scans outside the tolerance range.

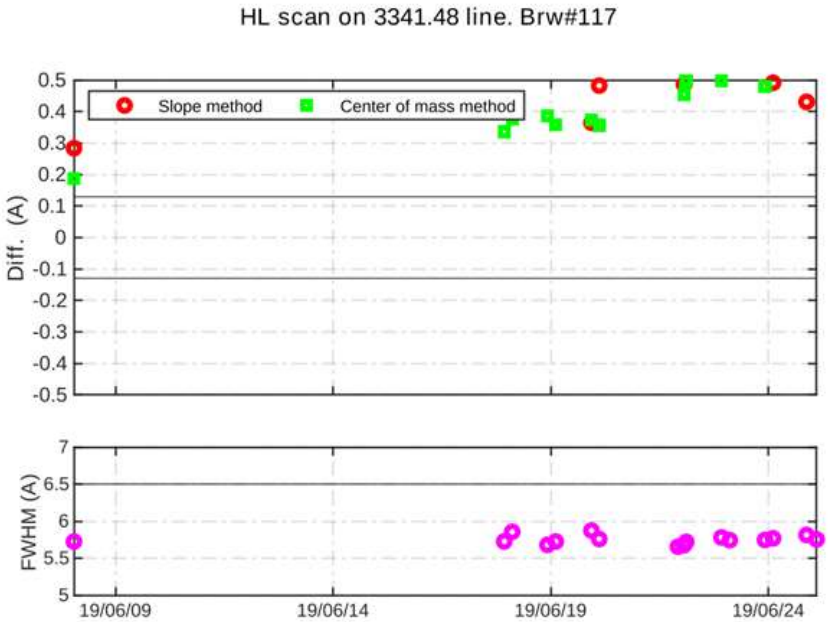


Figure 10. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

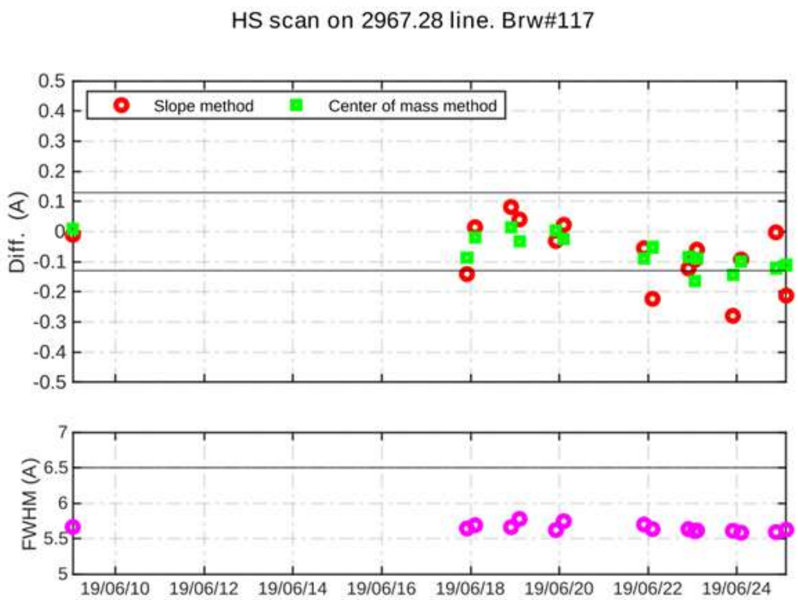


Figure 11. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

9.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 12, we show percentage ratios of the Brewer MUR#117 CI scans performed during the campaign (after the maintenance of day 172) relative to scan CI17819.117. As can be observed, the lamp intensity varies with respect to the reference spectrum by less than 4%. This behaviour is normal for a SL lamp.

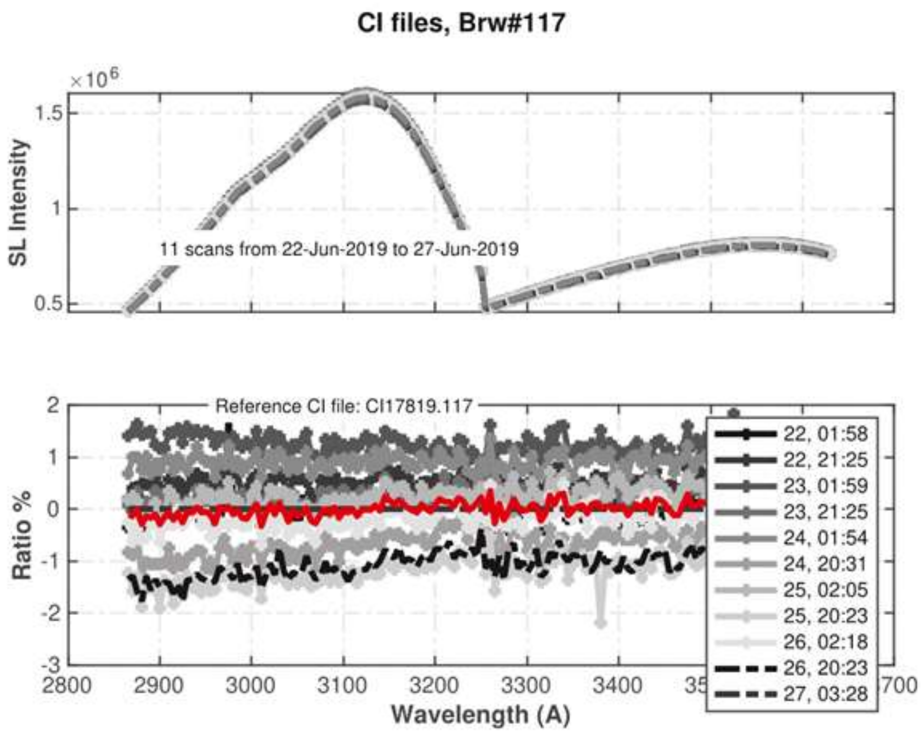


Figure 12. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

9.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected *R6* and *R5* ratios to analyse the new temperature coefficients' performance.

As shown in Figure 13 (temperature range from 21 °C to 35 °C) the current coefficients do a reasonable job at reducing the temperature dependence, although the coefficients calculated using the data from the present campaign perform better. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figure 14, new temperature coefficients calculated for this longer period perform slightly better than the current ones. Figure 15, further shows the R6 values calculated using both the current coefficients and those obtained in the present campaign and both datasets have approx. the same temperature dependence.

Overall, there is no clear advantage in updating the temperature coefficients and considering the changes that the instrument has undergone during maintenance, as regards the final ICF for the present campaign, we suggest retaining the present coefficients after new observations are available.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	0.1248	0.0766	-0.3592	-1.8928
Calculated	0.0000	-0.1000	-0.7000	-1.0000	-2.5000
Final	0.0000	0.1248	0.0766	-0.3592	-1.8928

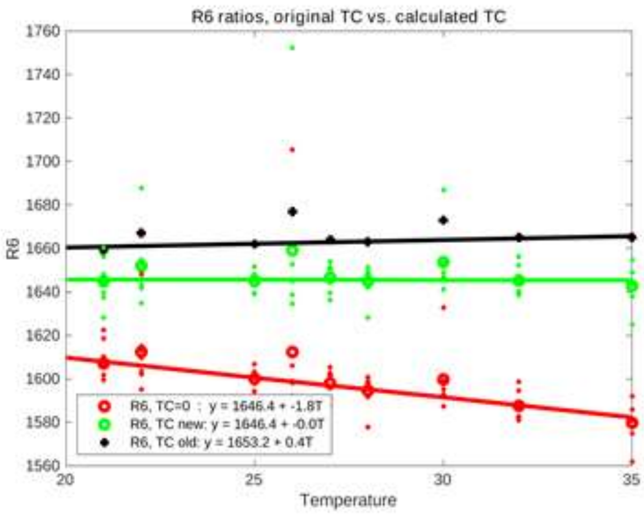


Figure 13. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

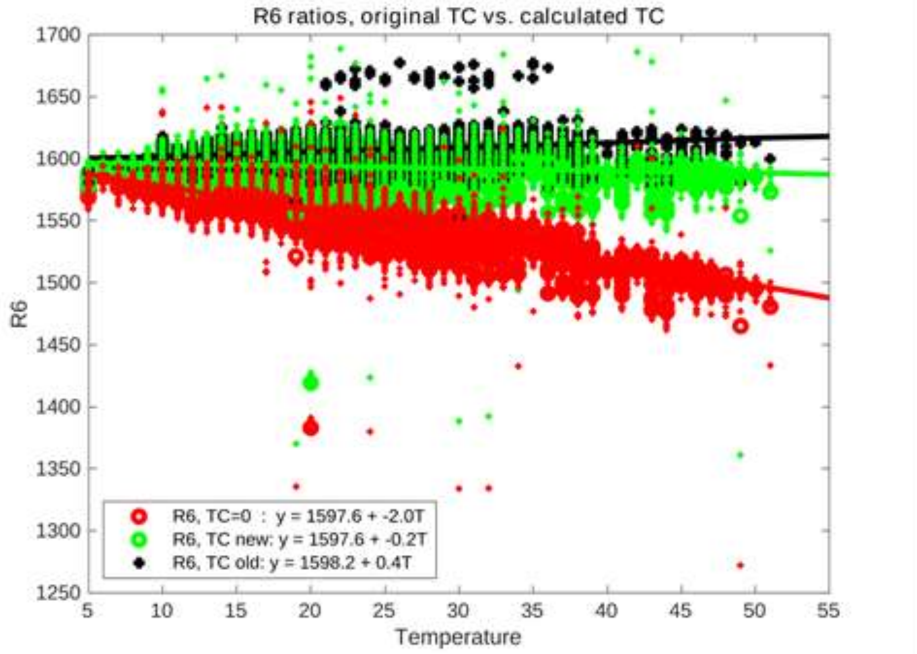


Figure 14. Same as Figure 13 but for the whole period between calibration campaigns

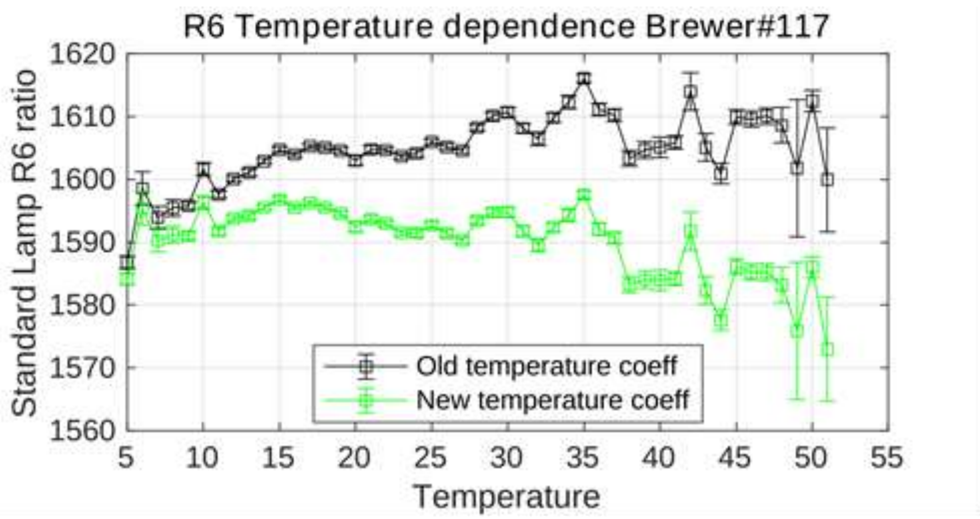


Figure 15. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

9.4. ATTENUATION FILTER CHARACTERIZATION

9.4.1 Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 36 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 16 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Results in Table 2 show a noticeable spread, with large confidence intervals in most cases, making these results of little use. The reason for the spread of data might be the small number of FI tests performed. Looking at the data from the ozone comparison with reference instrument IZO#185, we can however suggest a filter correction of 9 units for filter 3.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-11	10	-15	-17	5
ETC Filt. Corr. (mean)	-12.1	-2.2	-15.3	-16	34.4
ETC Filt. Corr. (mean 95% CI)	[-21.7 - 3.1]	[-10.9 8.2]	[-24.1 - 4.3]	[-30.5 1.9]	[-2.6 71.9]

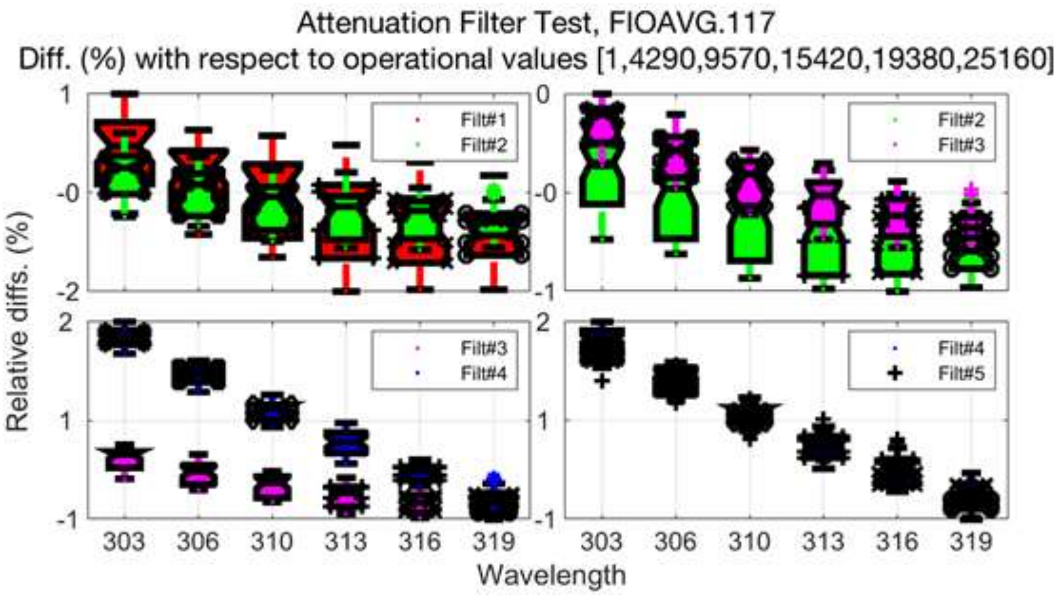


Figure 16. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

9.5. WAVELENGTH CALIBRATION

9.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 17).

During the campaign, 11 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1200 DU were carried out (see Figure 18). The calculated cal step number (CSN) was 1 step higher than the value in the current configuration: 287 *vs.* 286. SC tests performed at the station before the campaign provide the same CSN found during the campaign of 287.

A difference on 1 step is within the acceptable tolerance limit, so we suggest keeping the current CSN of 286.

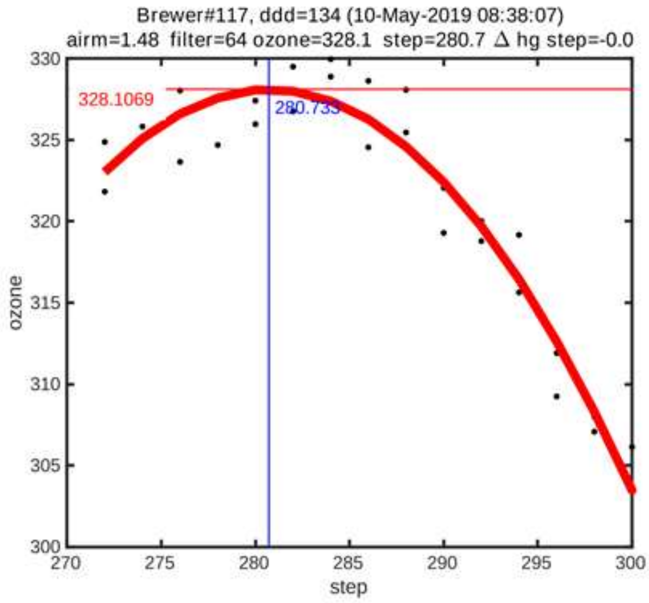


Figure 17. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

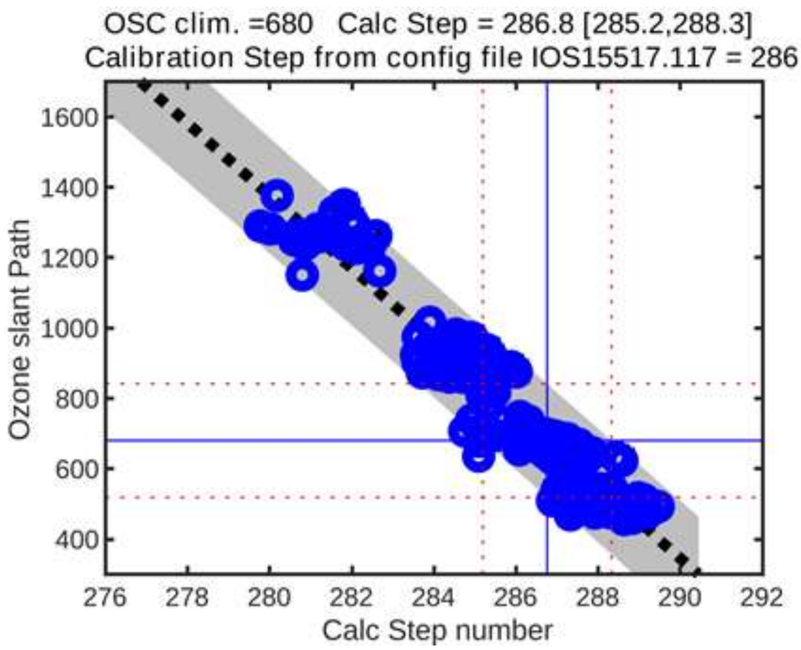


Figure 18. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

9.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 19 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

Dispersion tests carried out in the campaign suggest a value of 0.3411 for the absorption coefficient. This is only 0.002 units (2 steps) above the current value of 0.3394. This is a rather small difference and, since the CSN has not changed, we suggest retaining the current value.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	286	0.3394	2.3500	1.1384
14-Jun-2013	286	0.3336	3.1514	1.1247
01-Jun-2015	286	0.3389	3.2106	1.1382
02-Jun-2017	286	0.3435	3.1695	1.1495
23-Jun-2019	286	0.3411	3.1778	1.1437
Final	286	0.3394	2.3500	1.1384

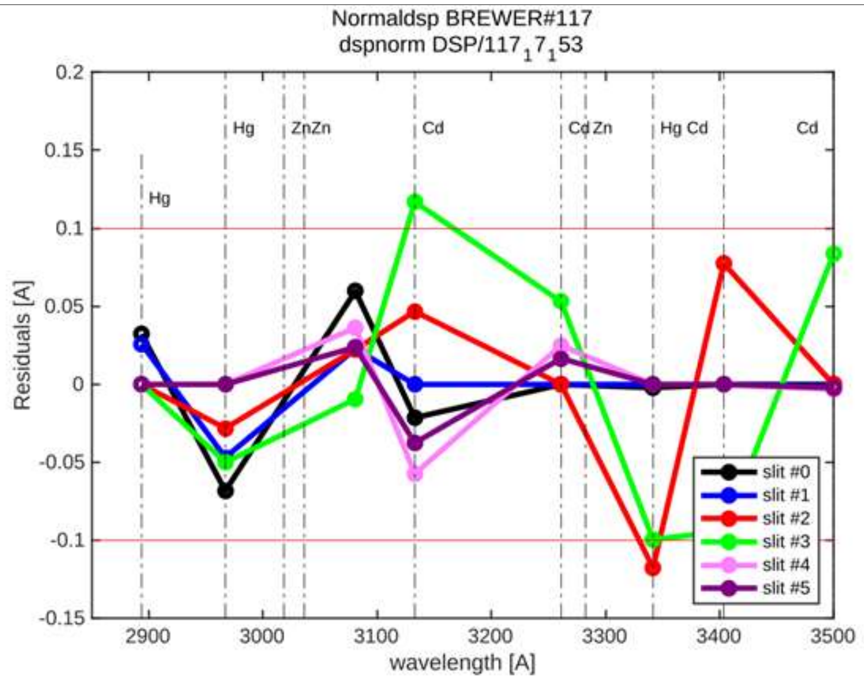


Figure 19. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 285	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032.2	3063	3100.61	3135.1	3168.05	3199.87
Res(A)	5.58	5.5799	5.4973	5.6469	5.4625	5.4367
O3abs(1/cm)	2.5888	1.7802	1.0044	0.67534	0.37502	0.29441
Ray abs(1/cm)	0.50486	0.48323	0.4584	0.43705	0.41782	0.40027
SO2abs(1/cm)	3.3755	5.6353	2.4223	1.886	1.0559	0.61494
step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.27	3063.07	3100.68	3135.17	3168.12	3199.94
Res(A)	5.5799	5.5798	5.4973	5.6468	5.4624	5.4367
O3abs(1/cm)	2.5865	1.7785	1.0041	0.67499	0.37509	0.29393
Ray abs(1/cm)	0.5048	0.48318	0.45836	0.43701	0.41778	0.40024
SO2abs(1/cm)	3.3618	5.6565	2.4304	1.8744	1.0571	0.61282
step= 287	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.34	3063.14	3100.75	3135.24	3168.19	3200.01
Res(A)	5.5799	5.5798	5.4972	5.6467	5.4624	5.4366
O3abs(1/cm)	2.5841	1.7769	1.0037	0.6746	0.37516	0.29348
Ray abs(1/cm)	0.50475	0.48313	0.45831	0.43697	0.41775	0.4002
SO2abs(1/cm)	3.3501	5.6775	2.4389	1.8628	1.0582	0.61061
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
285	0.34213	11.2601	3.1684	1.1472	0.35251	0.34388
286	0.34106	11.2564	3.1778	1.1437	0.35154	0.34289
287	0.34002	11.2527	3.1868	1.1404	0.35054	0.34186

9.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1696. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 286	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.5799	5.5798	5.4973	5.6468	5.4624	5.4367
O3abs(1/cm)	2.5865	1.7785	1.0041	0.67499	0.37509	0.29393
Ray abs(1/cm)	0.5048	0.48318	0.45836	0.43701	0.41778	0.40024
step= 1696	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3133	3163	3200	3233	3265	3295
Res(A)	5.5029	5.5061	5.4136	5.5433	5.3805	5.3727
O3abs(1/cm)	0.67845	0.40123	0.29403	0.12674	0.061925	0.033425
Ray abs(1/cm)	0.43804	0.42057	0.40024	0.38297	0.3673	0.35291

9.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

For single monochromator Brewers, the ETC distribution (see Figure 1) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column:

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, OSC up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 5 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

9.6.1. Initial calibration

For the evaluation of the initial status of Brewer MUR#117, we used the period from days 168 to 171 which correspond with 78 near-simultaneous direct sun ozone measurements. As shown in Figure 20, the initial calibration constants produce an ozone values much lower – approximately a 2.5% – than the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results improve noticeably, but the ozone is still underestimated by 1.5%. Note these differences increase with the OSC, because of the stray light effect in this Mk IV Brewer.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185 .

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=600	2783	2777	3394	3406
full OSC range	2783	2800	3394	3348

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#117*	*O3 std*	*%(117–185)/185*	*O3(*)#117*	*O3std*	*(*)%(117–185)/185*
19-Jun-2019	170	324.6	3.2	55	312.4	3.8	-3.8	324	3.6	-0.2
20-Jun-2019	171	333.4	3.7	23	323	1.3	-3.1	334.4	2.8	0.3

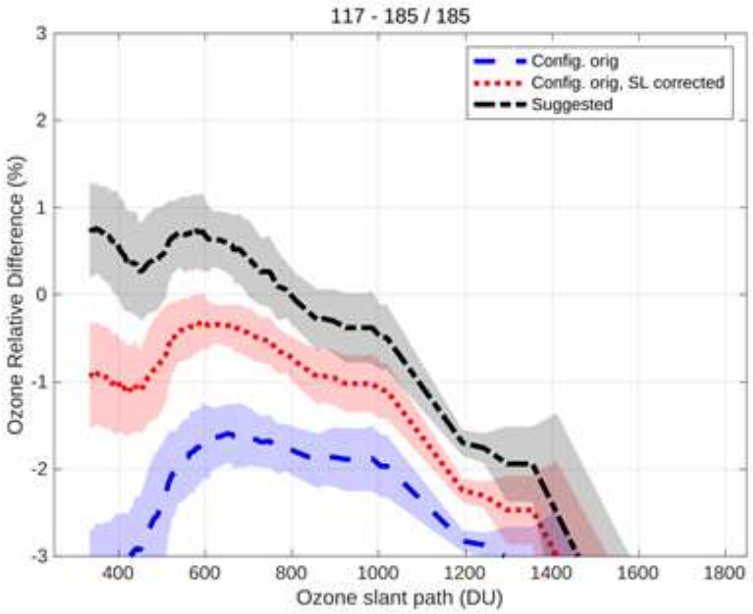


Figure 20. Mean direct sun ozone column percentage difference between Brewer MUR#117 and Brewer IZO#185 as a function of ozone slant path

9.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 21). For the final calibration, we used 110 simultaneous direct sun measurements from days 173 to 177. The new ETC value is 2881, approximately 50 units higher than the current ETC value of 2830. Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (1685 for R6). We updated the new calibration constants in the ICF17319.117 provided. Of course, the new ETC has been calculated taking into account the new suggested dead time of $3.5 \cdot 10^{-8}$ s.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is not within the maximum tolerance limit of 10 units.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185 .

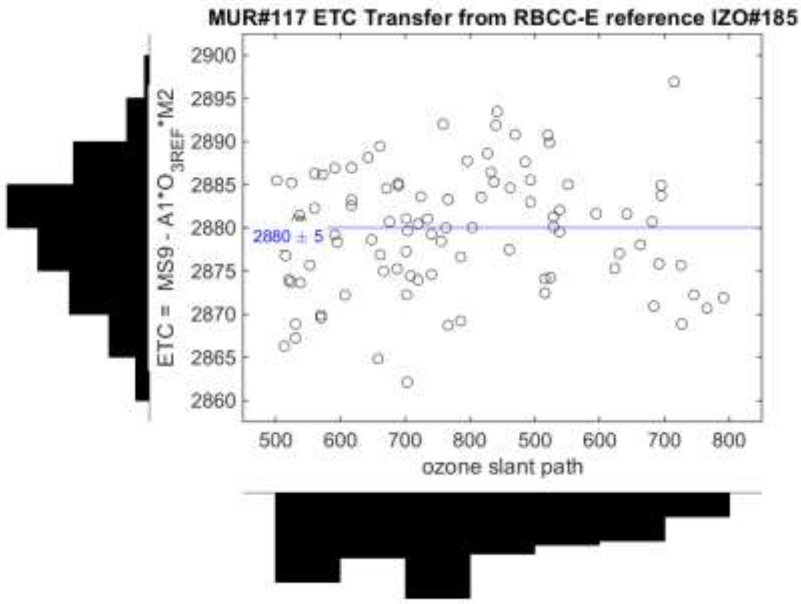


Figure 21. Mean direct sun ozone column percentage difference between Brewer MUR#117 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=420 800	2880	2881	3394	3388
full OSC range	2880	2893	3394	3369

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#117*	*O3 std*	*%(117–185)/185*	*O3(*) #117*	*O3std*	*(*)%(117 –185)/185*
22-Jun-2019	173	328	2.4	109	331.4	7.6	1	325.6	4.9	-0.7
23-Jun-2019	174	322.5	4.3	70	328	8.7	1.7	321.5	5.9	-0.3
24-Jun-2019	175	307.3	1.2	46	310.4	5.1	1	305.3	3.8	-0.7
25-Jun-2019	176	308.4	2	76	314.1	7.7	1.8	307.1	5.2	-0.4
26-Jun-2019	177	308.1	1.3	21	314.6	5.7	2.1	307.9	1.9	-0.1

9.6.3. Stray light correction

The final calibration performed well with near zero error for low OSC and an underestimation of 1% at 800 OSC which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = a = -29.3$, $s = b = 4.87$, and ETC=2881. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

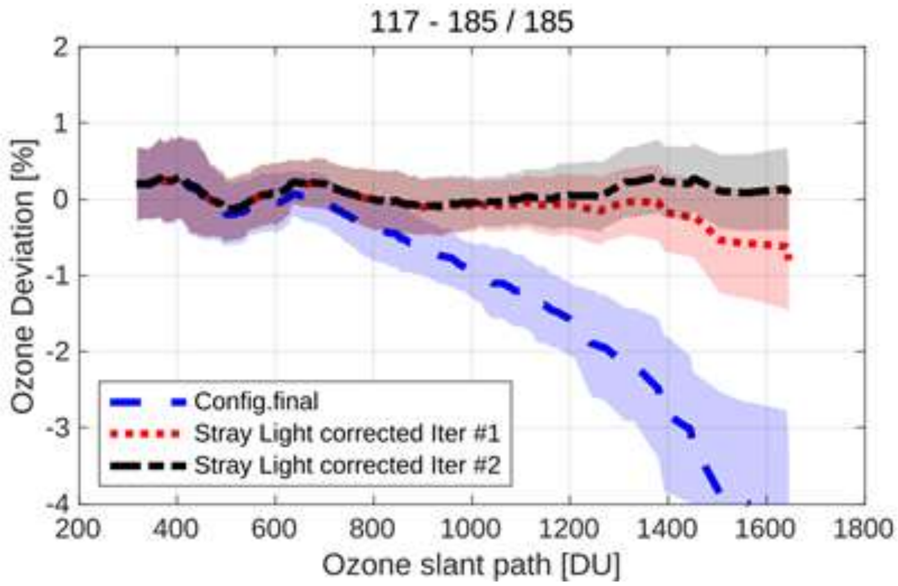


Figure 22. Ratio respect to the reference when the final constants and the stray light correction are applied

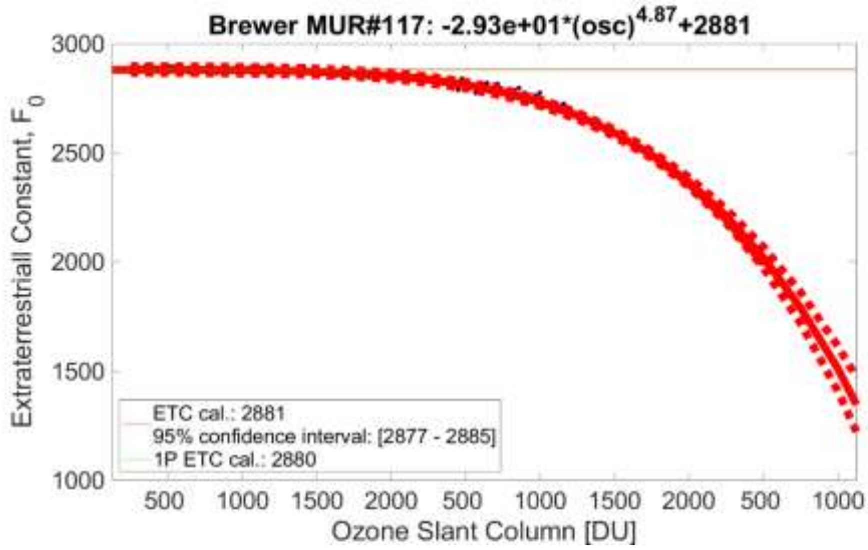


Figure 23. Stray light empirical model determination

9.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1685 for R6 (Figure 24) and 3100 for R5 (see Figure 25). This figure also shows quite clearly the effect of maintenance on day 172.

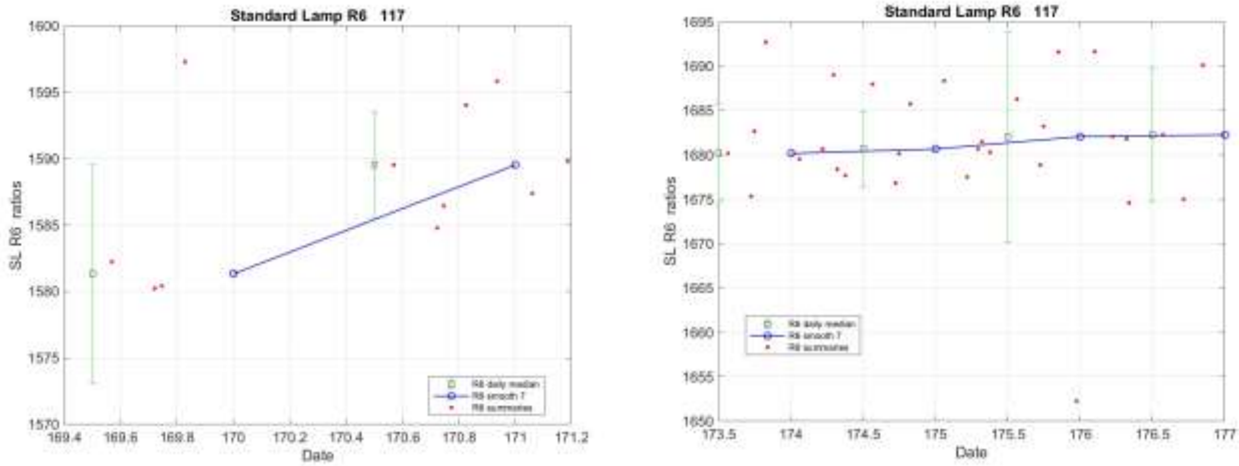


Figure 24. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

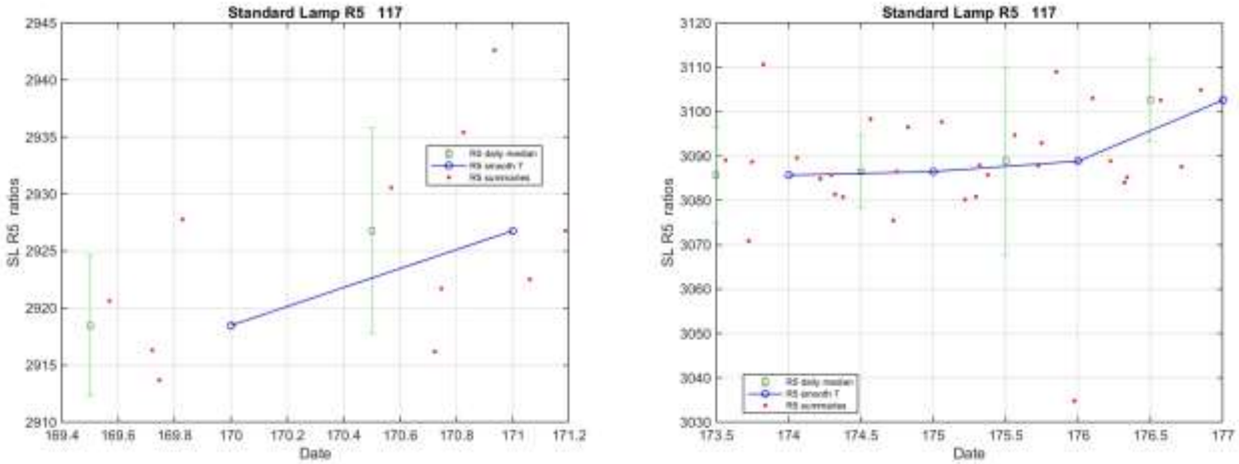


Figure 25. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

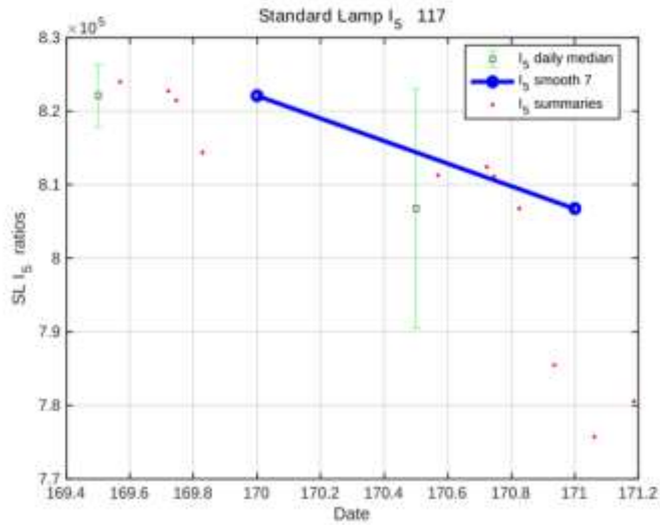


Figure 26. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

9.7. CONFIGURATION

9.7.1. Instrument constant file

	Initial (IOS15517.117)	*Final (ICF17319.117)*
o3 Temp coef 1	0	0
o3 Temp coef 2	0.12475	0.12475
o3 Temp coef 3	0.07659	0.07659
o3 Temp coef 4	-0.35919	-0.35919
o3 Temp coef 5	-1.8928	-1.8928
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3394	0.3394
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1384	1.1384
ETC on O3 Ratio	2830	2881
ETC on SO2 Ratio	2680	2680
Dead time (sec)	2.7e-08	3.5e-08
WL cal step number	286	286
Slitmask motor delay	92	92
Umkehr Offset	1692	1692
ND filter 0	0	0
ND filter 1	4290	4290
ND filter 2	9570	9570
ND filter 3	15420	15420
ND filter 4	19380	19380
ND filter 5	25160	25160
Zenith steps/rev	2816	2816
Brewer Type	0	0
COM Port #	2	2
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0

	Initial (IOS15517.117)	*Final (ICF17319.117)*
n2 Temp coef 5	0	0
O3 Mic #1 Offset	5715	5715
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	670	670
NO2 zs etc	615	615
NO2 Mic #1 Offset	8231	8231
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2536	2536
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	2669	2669
Iris Open Steps	250	250
Buffer Delay (s)	0.4	0.4
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	35	35
Zenith UVB Position	2112	2112

9.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#117*	*O3std*	*%diff*	*(*)O3#117*	*O3std*	*(*)%diff*
170	1500> osc> 1000	319	0.0	2	314	0.2	-1.4	314	0.2	-1.4
170	1000> osc> 700	321	1.4	10	318	2.1	-0.9	318	2.1	-0.9
170	700> osc> 400	324	4.0	31	321	3.6	-0.9	320	3.7	-1.2
170	osc< 400	325	2.5	31	322	3.5	-0.7	320	3.5	-1.4

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#117*	*O3std*	*%diff*	*(*)O3#117*	*O3std*	*(*)%diff*
171	osc> 1500	318	0.0	1	303	0.0	-4.9	303	0.0	-4.9
171	1500> osc> 1000	321	1.3	5	313	2.2	-2.5	313	2.2	-2.5
171	1000> osc> 700	328	7.9	3	325	6.7	-0.9	325	6.7	-0.9
171	700> osc> 400	333	3.7	33	331	3.5	-0.6	330	3.7	-0.8
171	osc< 400	336	1.1	33	332	1.6	-1.2	330	1.6	-1.9
173	1500> osc> 1000	325	1.2	16	318	3.3	-2.2	318	3.5	-2.2
173	1000> osc> 700	328	0.9	10	324	1.7	-1.0	326	1.2	-0.5
173	700> osc> 400	326	2.4	24	322	2.9	-1.3	326	2.2	-0.2
173	osc< 400	330	1.0	14	329	1.1	-0.3	331	1.1	0.1
174	1500> osc> 1000	318	4.8	13	314	5.8	-1.5	314	5.8	-1.4
174	1000> osc> 700	320	3.4	14	316	3.4	-1.0	318	2.9	-0.5
174	700> osc> 400	323	2.6	23	321	3.4	-0.7	324	2.9	0.1
174	osc< 400	327	1.1	18	325	2.8	-0.4	327	1.7	0.1
175	osc> 1500	309	0.4	2	292	5.4	-5.6	291	5.4	-5.6
175	1500> osc> 1000	307	1.4	11	303	1.6	-1.4	303	2.0	-1.3
175	1000> osc> 700	308	1.3	10	305	1.6	-0.9	306	1.3	-0.4
175	700> osc> 400	306	1.1	22	304	2.1	-0.8	306	1.4	0.0
175	osc< 400	307	0.3	2	309	1.7	0.6	310	1.8	0.9
176	osc> 1500	308	1.4	4	291	3.7	-5.4	291	3.7	-5.5
176	1500> osc> 1000	308	2.2	9	302	3.3	-2.0	302	3.5	-1.9
176	1000> osc> 700	307	2.4	10	305	2.4	-0.7	306	2.2	-0.3
176	700> osc> 400	308	1.6	25	306	2.2	-0.4	308	1.6	0.1
176	osc< 400	310	1.2	27	308	1.7	-0.4	311	1.7	0.4
177	1000> osc> 700	313	6.1	5	NaN	NaN	NaN	311	5.9	-0.5

Day	osc range	O3#185	O3std	N	O3#117	O3std	%diff	(*)O3#117	O3std	(*)%diff
177	700> osc> 400	313	3.9	26	NaN	NaN	NaN	313	4.4	0.0
177	osc< 400	311	1.4	25	NaN	NaN	NaN	311	1.9	0.1

9.9. APPENDIX: SUMMARY PLOTS

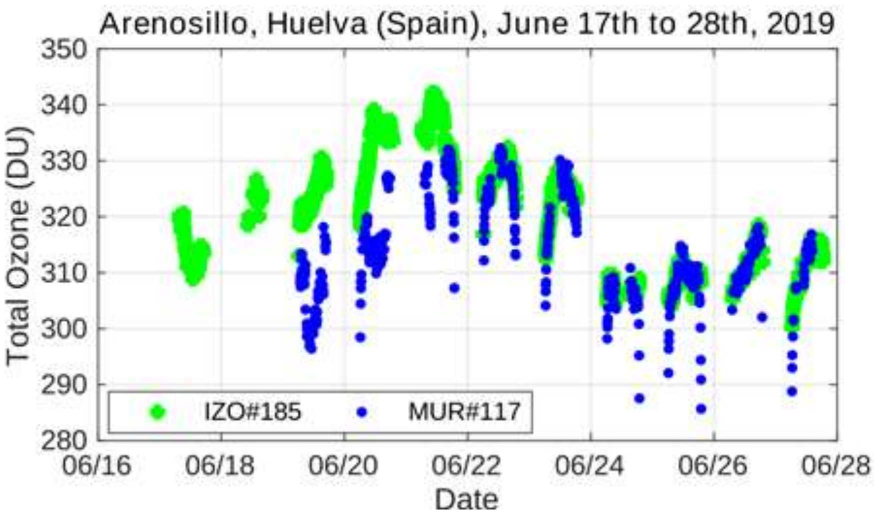
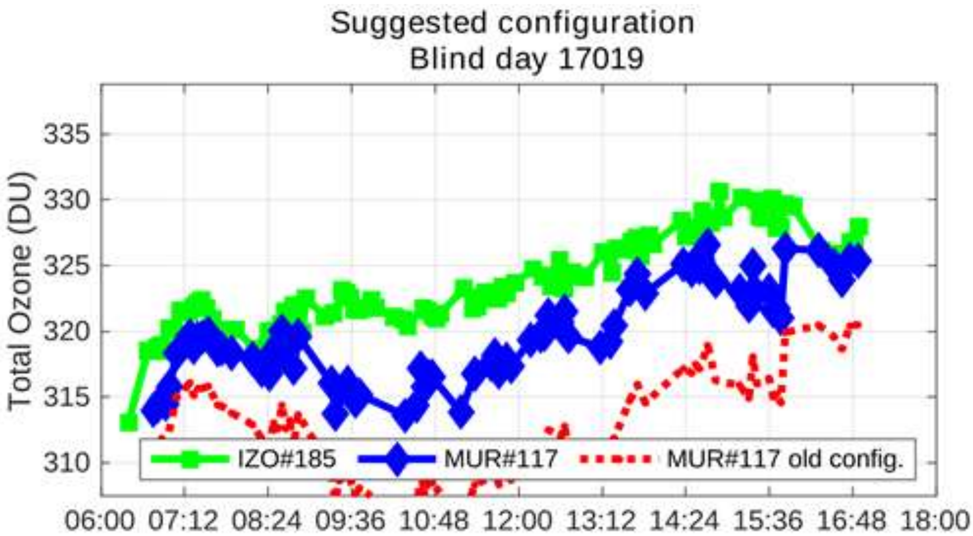
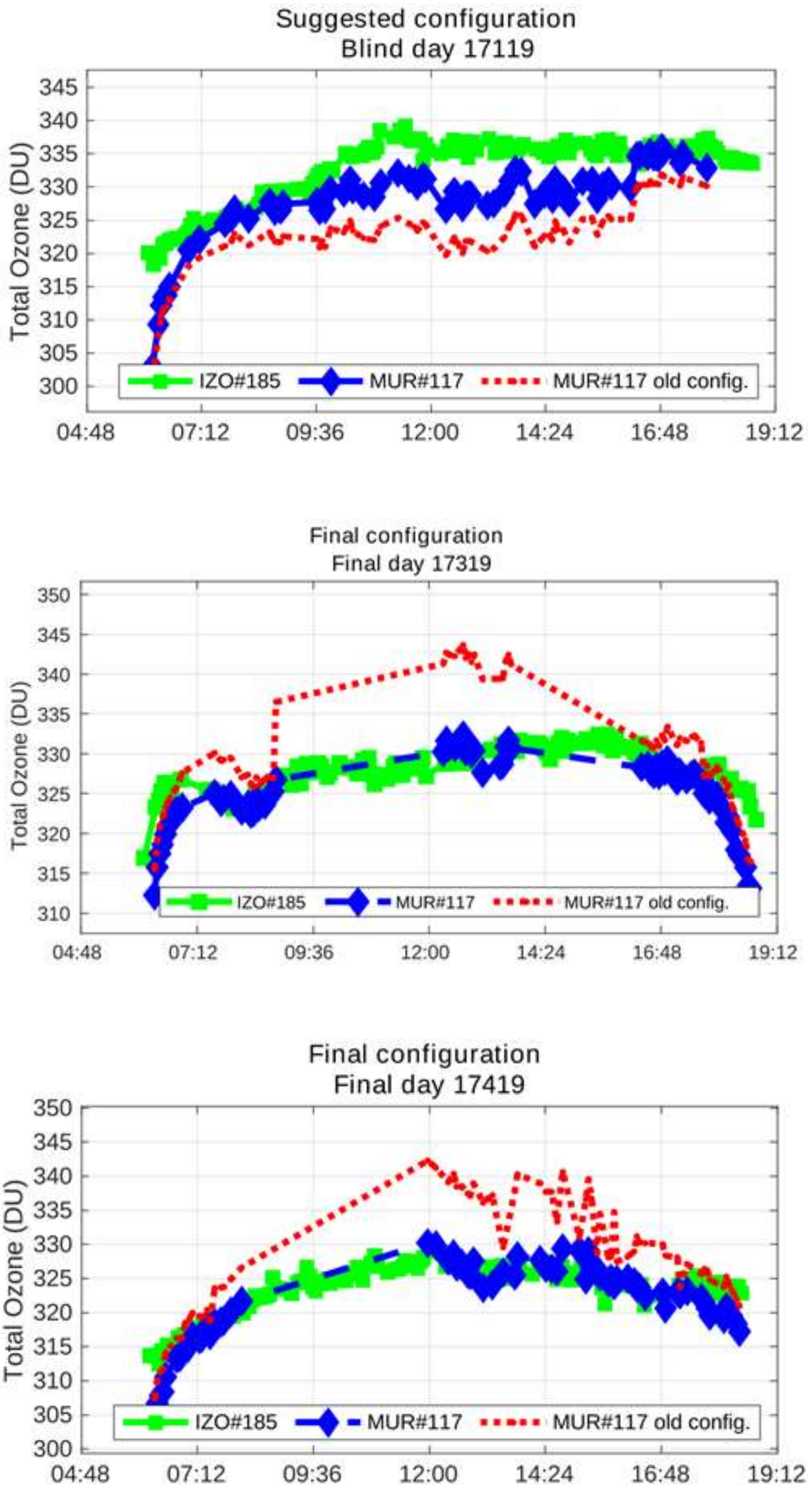
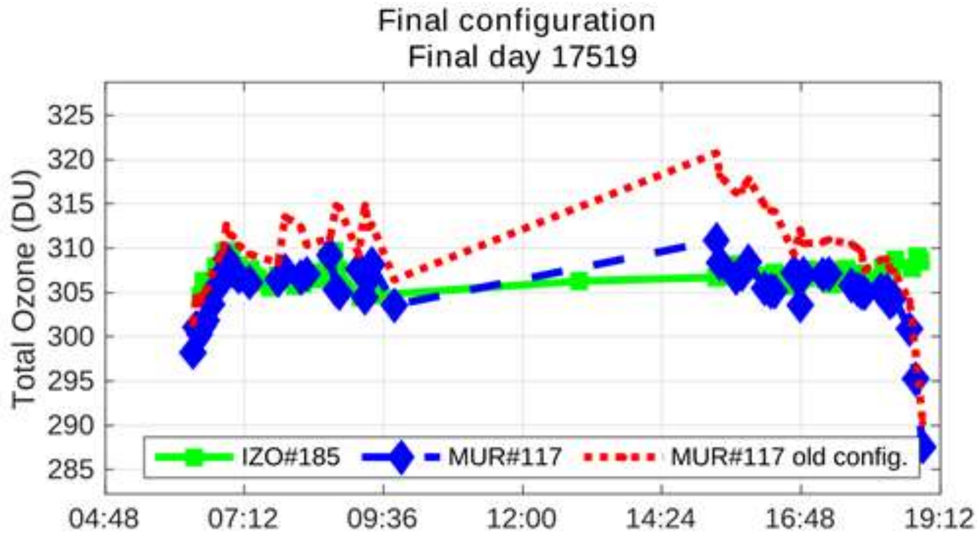
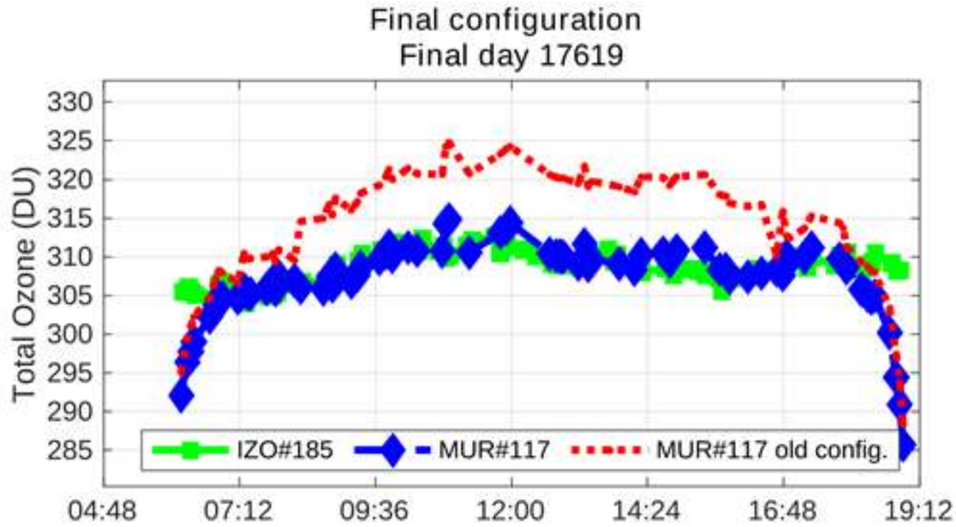


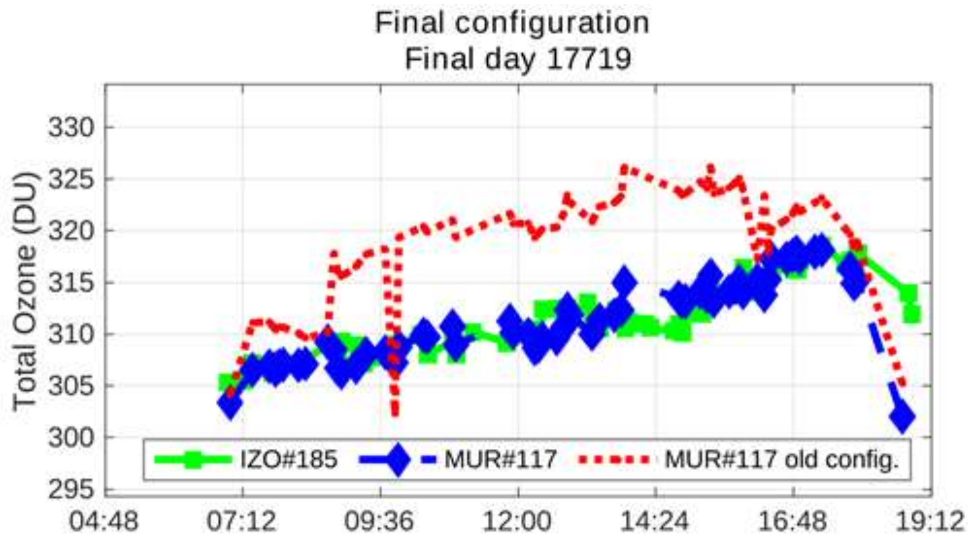
Figure 29. Overview of the intercomparison. Brewer MUR#117 data were evaluated using final constants (blue circles)




Suggested configuration
Blind day 17119
Total Ozone (DU)
345
340
335
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MUR#117
MUR#117 old config.
Final configuration
Final day 17319
350
345
340
335
330
325
320
315
310
Final configuration
Final day 17419


Final configuration
Final day 17519
Total Ozone (DU)
325
320
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MUR#117
MUR#117 old config.


Final configuration
Final day 17619
Total Ozone (DU)
330
325
320
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MUR#117
MUR#117 old config.


Final configuration
Final day 17719
Total Ozone (DU)
330
325
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MUR#117
MUR#117 old config.

10. BREWER UK #126

10.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer UK #126 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer UK #126 correspond to Julian days 166 – 178.

For the evaluation of the initial status, we used 203 simultaneous direct sun (DS) ozone measurements from days 170 to 173. For final calibration purposes, we used 384 simultaneous DS ozone measurements taken from day 174 to 178.

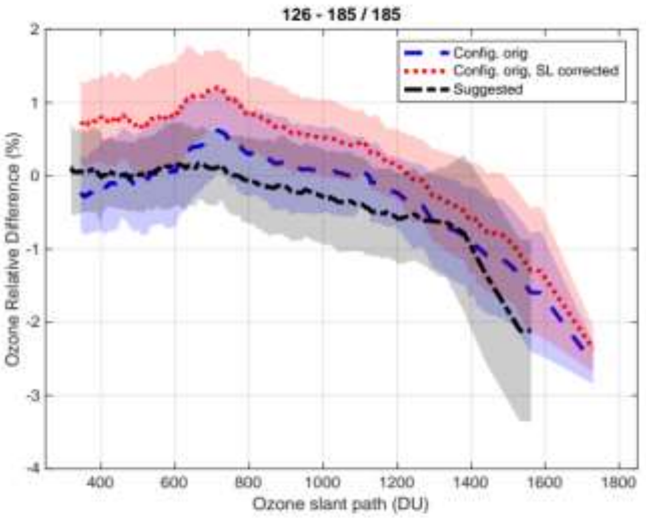


Figure 1. Mean DS ozone column percentage difference between Brewer UK #126 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadowed areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, up to an ozone slant column value of 1200, the current ICF (ICF15517.126, blue dashed line) produces ozone values with an average difference of around 0.5% with respect to the reference instrument, and thus very close to the new calibration suggested as the result of the present calibration campaign. Brewer UK #126 has largely been inoperative since the last campaign so we have no data to analyse the stability of the instrument in this two-year period. Below, we suggest changes to the configuration which improve the comparison to the reference instrument, Brewer IZO#185, using data obtained from the present calibration campaign.

As a single-spectrometer instrument, Brewer UK #126 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the double-spectrometer Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 1.6).

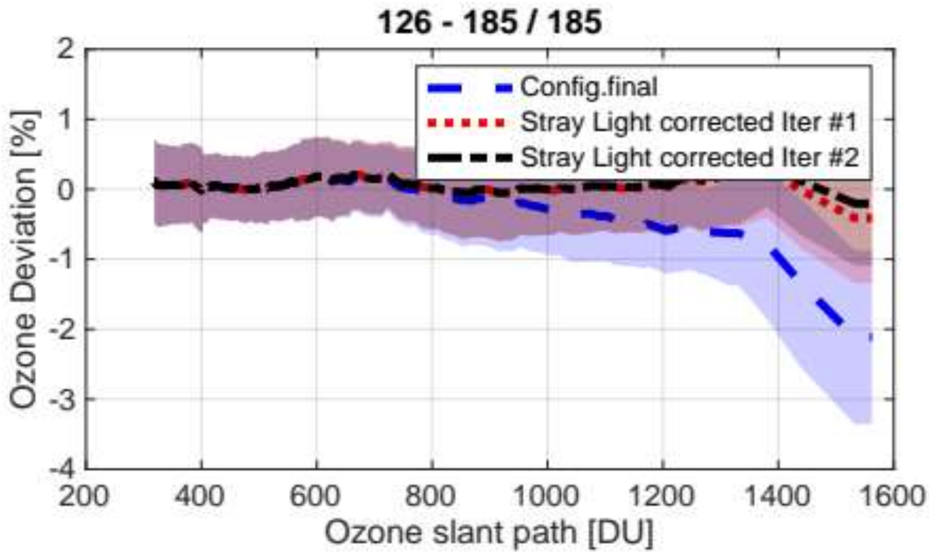


Figure 2. Mean DS ozone column percentage difference between Brewer UK #126 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

The lack of measurements in the two-year period before this calibration campaign obviously precludes the analysis of the standard lamp stability. However, looking at the results of this calibration campaign (see Figure 22), we suggest updating the R6 reference value from 2075 to 2057. A new R5 reference value of 4445 is also recommended.

Dead time (DT) shows a small difference between the current and campaign values of around 3 ns, with its value changing from $3.6 \cdot 10^{-8}$ s to $3.3 \cdot 10^{-8}$ s. This is a significant change for single Brewers. All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) show reasonable results.

We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients in previous calibrations.

Although filters #3 and #4 show small nonlinear effects, we do not recommend the application of any ETC filter correction.

The sun scan tests performed during the campaign suggested that a change in cal step number was needed, and it was therefore updated from 286 to 291 on day 174 (23 June).

According to our analysis of the campaign's data, the change in the cal step is accompanied by a small change in the ozone absorption coefficient, from 0.3435 to 0.3419.

Taking this into account, we suggest the following changes to the configuration of Brewer UK #126.

10.1.1. Recommendations and remarks

1. The R6 reference proposed in the last calibration campaign was 2075, and we recommend updating it to 2057.
2. We suggest using a R5 reference value of 4445.
3. We suggest updating the DT to $3.3 \cdot 10^{-8}$ seconds. This is 3 ns less than the value proposed in the previous calibration campaign, a rather significant change.
4. Despite some small non-linearity effects observed in filters #3 and #4, we do not recommend the application of any ETC filter corrections.
5. Sun scan tests during the campaign suggested updating the cal step number from 286 to 291, and this change was implemented on day 174 (23 June).
6. For Brewer UK #126, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters: $k = a = -9$, and $s = b = 6.19$.
7. We suggest updating the ETC value from 3225 to 3241.
8. Finally, we suggest performing periodic checks on the instrument at the station so that its stability can be tracked during the inter-campaign period.

10.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/126/ICF17419.126

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1613812319

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/126/html/cal_report_126a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/126/html/cal_report_126a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/126/html/cal_report_126b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/126/html/cal_report_126c.html

10.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

10.2.1. Standard lamp test

Brewer UK #126 has largely been inoperative since the last campaign, so we have no data to analyse the stability of the instrument in this period of two years. From the data collected in the present campaign (see Figures 3 and 4), we suggest using 2057 and 4445 for the reference values of R6 and R5, respectively. The current R6 value (2075) is approx. 20 units higher than the new suggested value. Very little can be said about the stability of R6, R5 and F5 (Figure 5) from the data of this campaign alone, so we recommend performing some tests at the station.

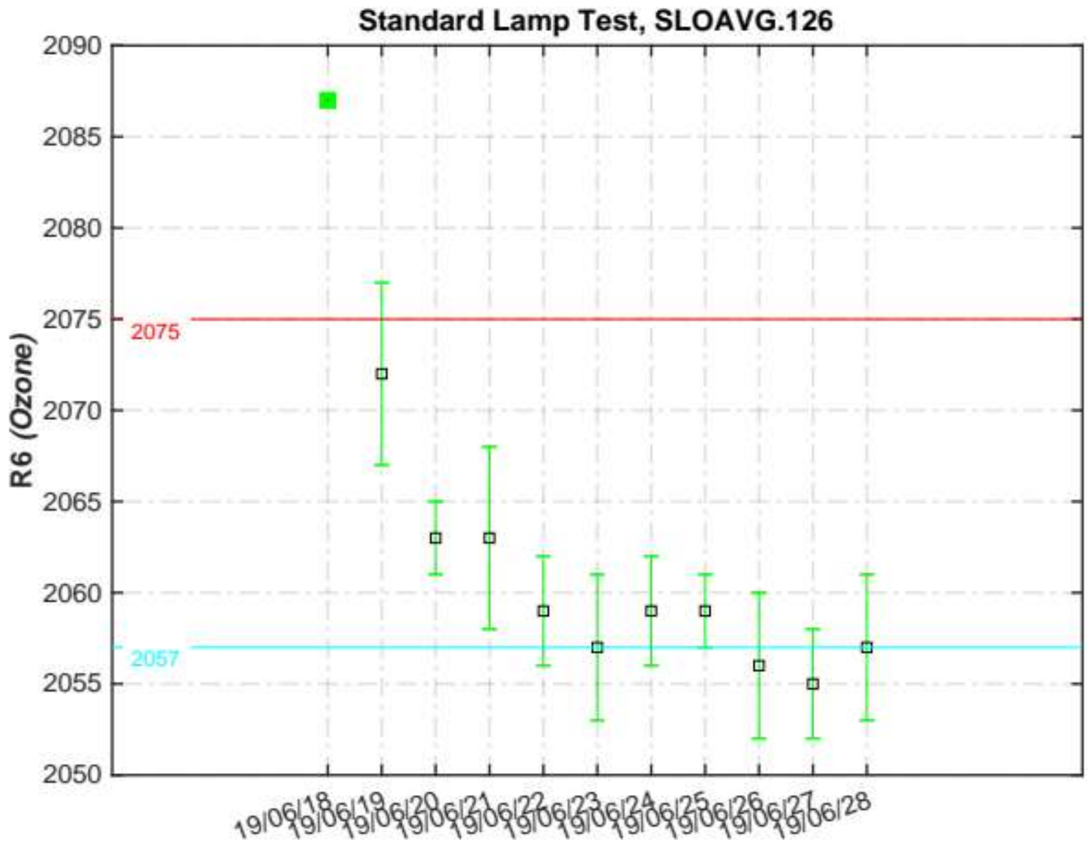


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

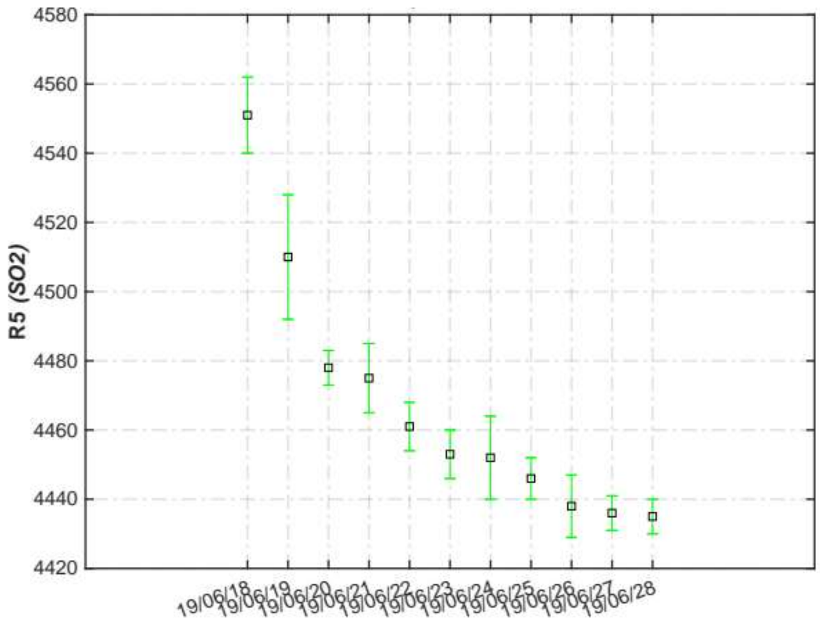


Figure 4. Standard lamp test R5 sulphur dioxide ratios

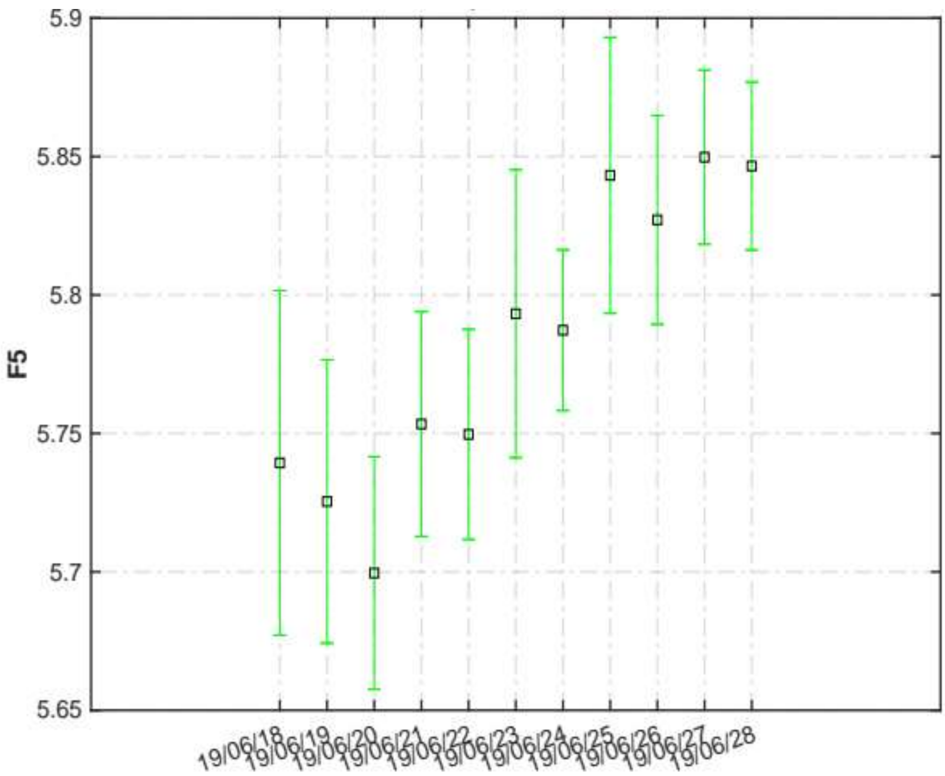


Figure 5. SL intensity for slit five

10.2.2. Run/Stop and dead time

From the data obtained during the present campaign, run/stop test values were within the test tolerance limits (see Figure 6).

As shown in Figure 7, the current DT reference value of $3.6 \cdot 10^{-8}$ seconds is 3 ns higher than the value recorded during the calibration period of $3.3 \cdot 10^{-8}$ s. Therefore, this new value has been used in the new ICF.

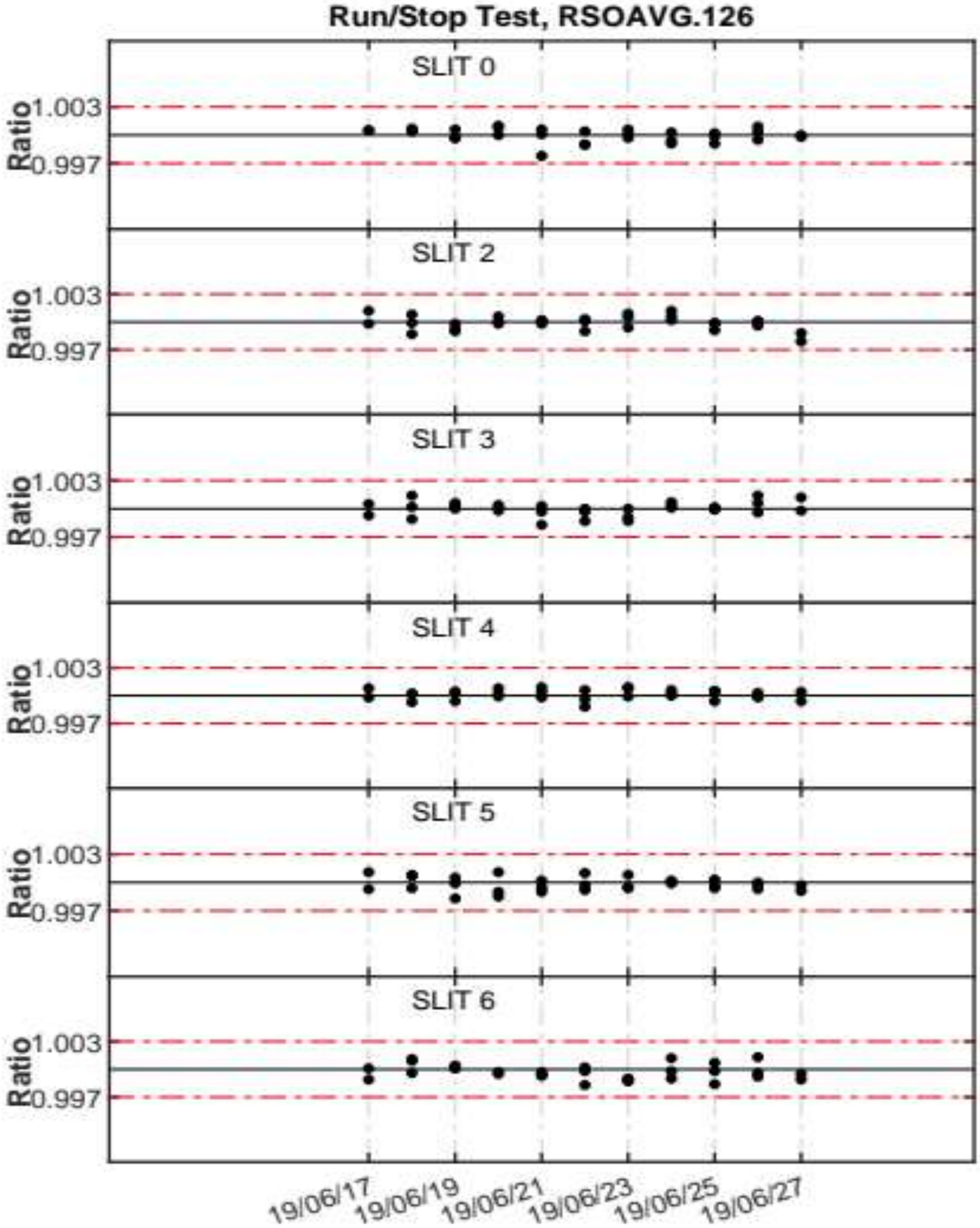


Figure 6. Run/stop test

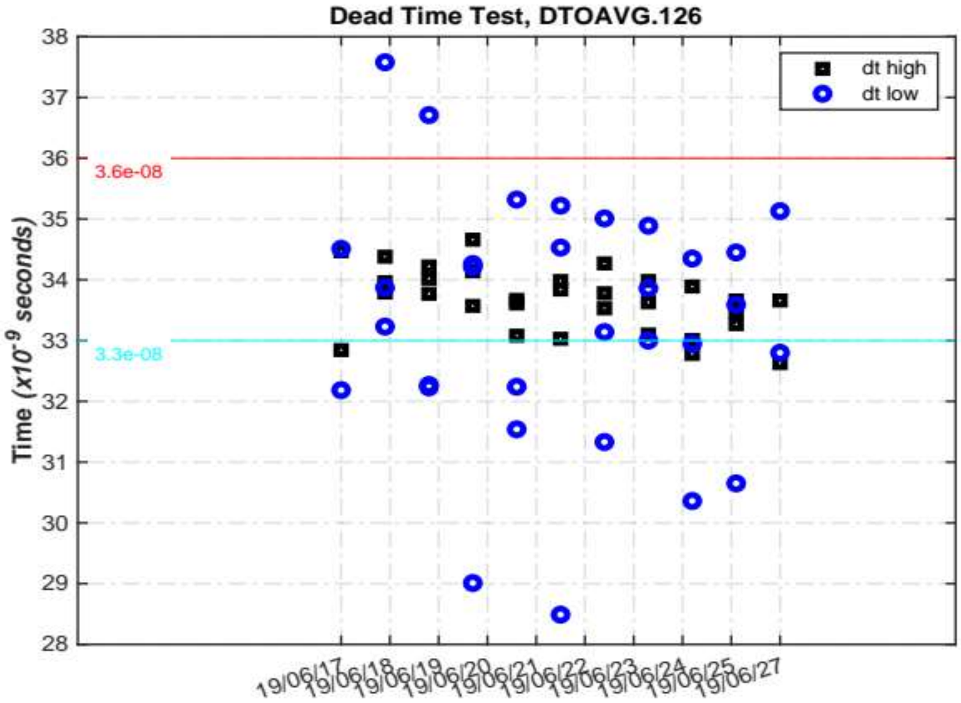


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

10.2.3. Analogue test

Results from the analogue tests (Figure 8) show quite stable values within the tolerance range.

Analogue Printout Log, APOAVG.075

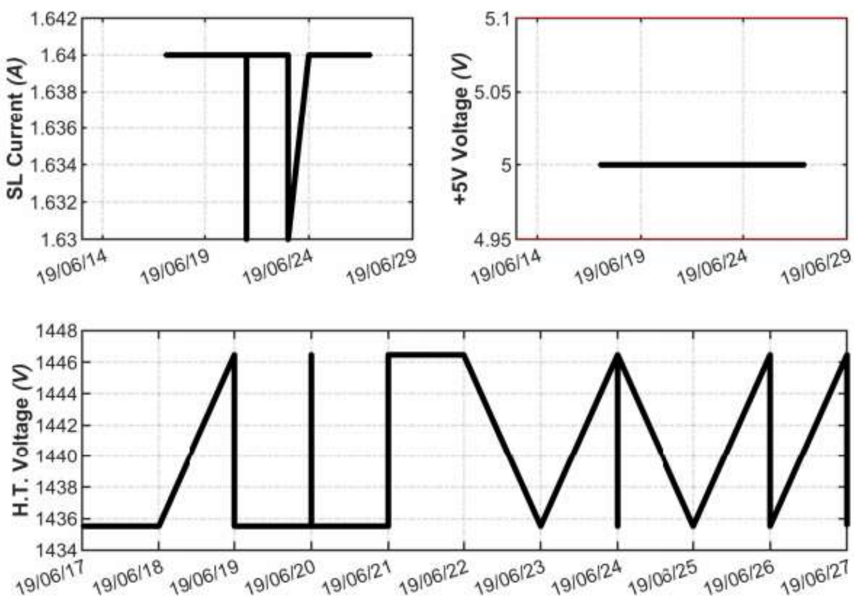


Figure 8. Analogue voltages and intensity

10.2.4. Mercury lamp test

Very little data is available from the internal Hg tests (Figure 9), but its values seem stable.

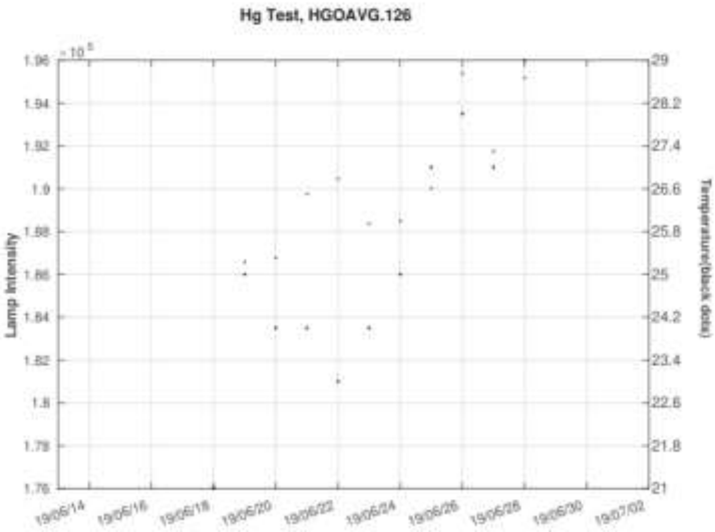


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

10.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm mercury line. As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of CZ scans performed on Brewer UK #126 during the campaign (Figure 10) show reasonable results, with the peak of the calculated scans within the accepted tolerance range. Regarding the slit function width, results are good, with a FWHM parameter lower than 0.65 nm.

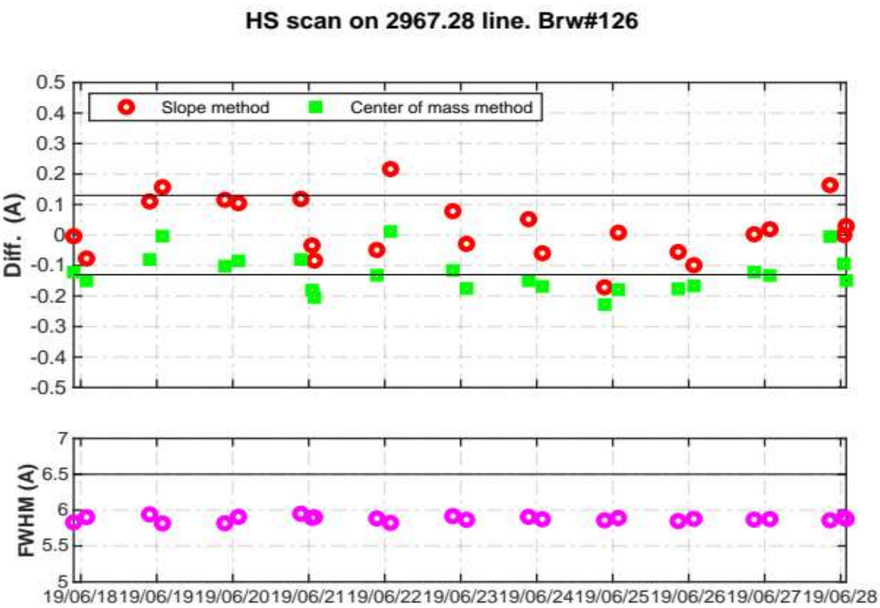


Figure 10. CZ scan on the 296.728 nm Hg line. Upper figure shows differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by two different methods: slopes method (red circles) and centre of mass method (green squares). Lower figure shows the Full Width at Half Maximum value for each scan performed. Solid line represents the 0.65 nm limit

10.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer UK #126 CI scans performed during the campaign relative to the scan CI16819.126. As can be observed, the lamp intensity varied with respect to the reference spectrum by approx. 5% on average. This is within the usual range.

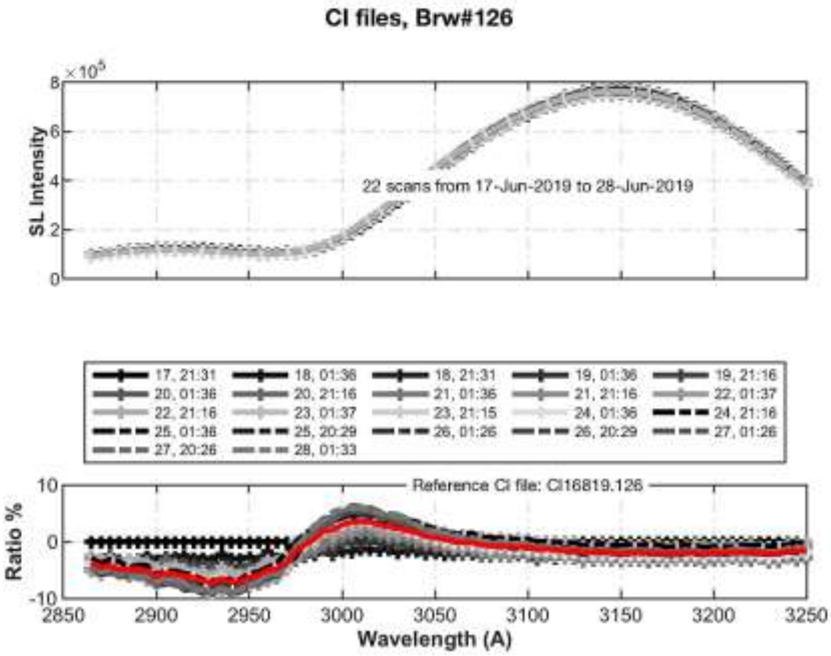


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

10.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figures 12 and 13 (temperature range from 21 °C to 38°C), the current coefficients do an excellent job at reducing the temperature dependence, performing at the same level as the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1. No change to the temperature coefficients seems necessary from analysis of the campaign data.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	0.5518	0.3869	-0.1935	-1.3538
Calculated	0.0000	2.5400	2.7400	2.3000	1.2400
Final	0.0000	0.5518	0.3869	-0.1935	-1.3538

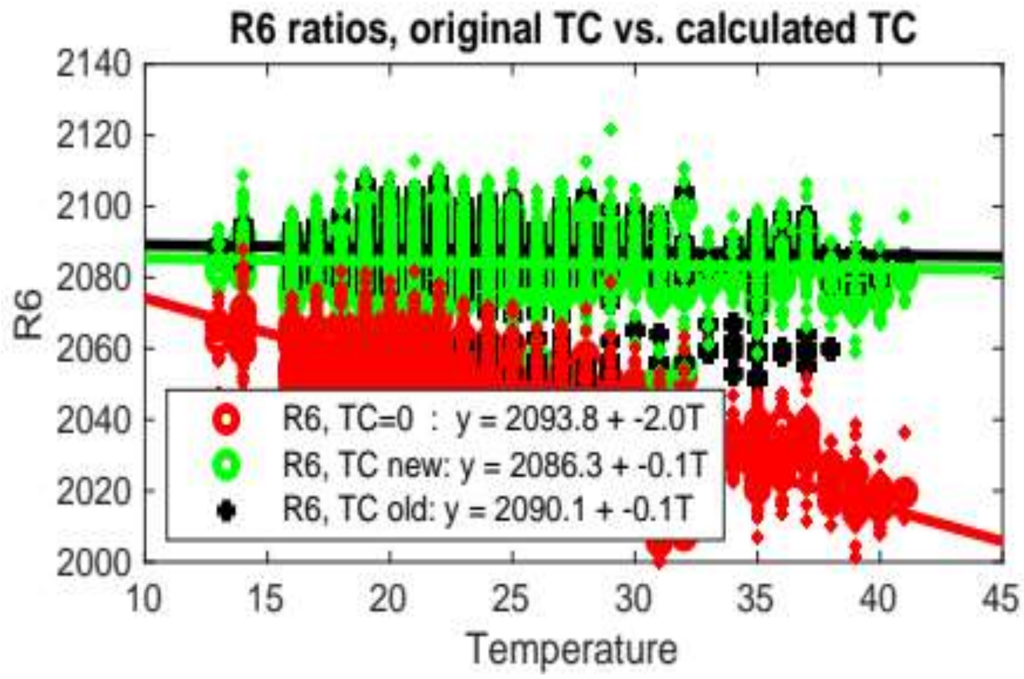


Figure 12. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

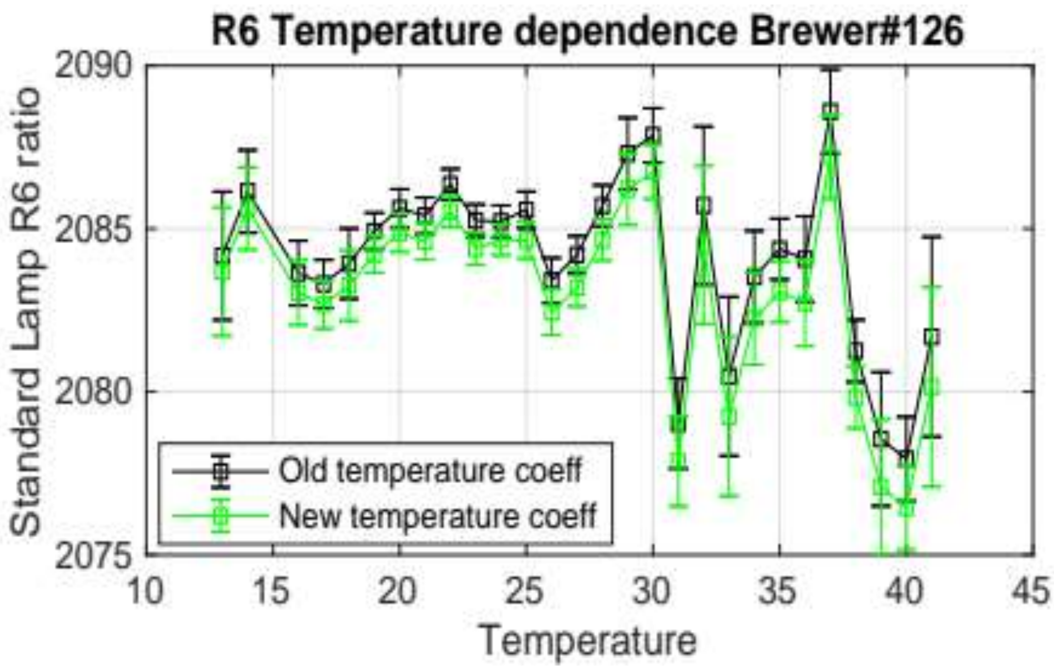


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

10.4. ATTENUATION FILTER CHARACTERIZATION

10.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 169 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Filters #3 and #4 show some non-linearity, however the suggested ETC corrections are quite small so we do not recommend their application.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-2	-4	2	8	-1
ETC Filt. Corr. (mean)	-2.3	-1.9	0	5.7	3.7
ETC Filt. Corr. (mean 95% CI)	[-5.3 0.6]	[-5 1.3]	[-3 2.9]	[2.1 9.4]	[-2.3 9.1]

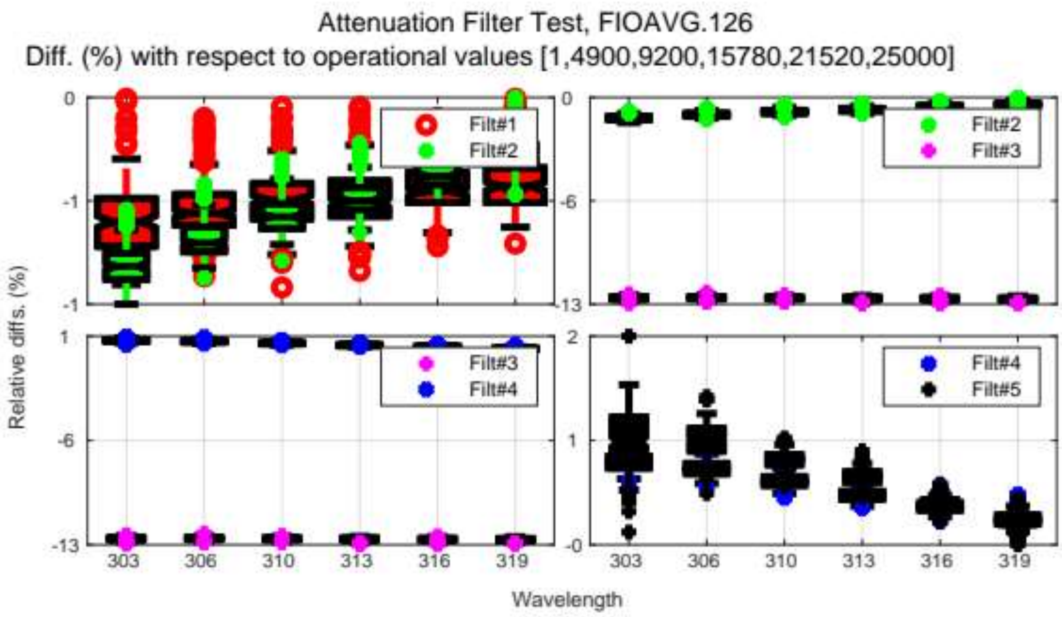


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

10.5. WAVELENGTH CALIBRATION

10.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, sun scan (SC) tests covering an ozone slant path range from 500 to 1600 DU were carried out (see Figure 16). The calculated cal step number (CSN) was 5 steps lower than the value in the current configuration: 286 *vs.* 291. Unfortunately, we have no data from SC tests carried out before the campaign at the station, so we cannot verify the present result. Nevertheless, the cal step number was changed to 291 on 26 June (day 174).

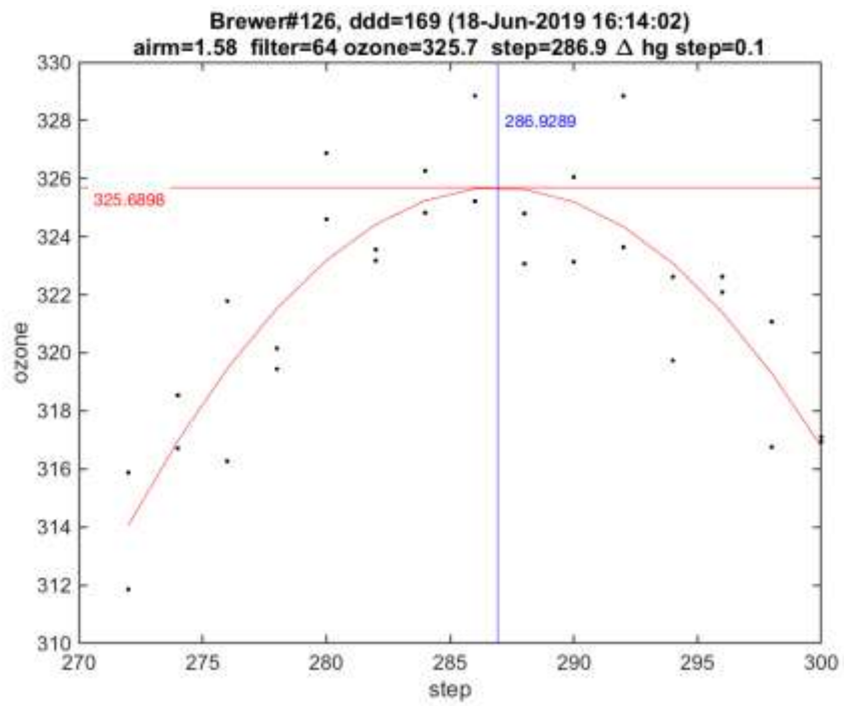


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

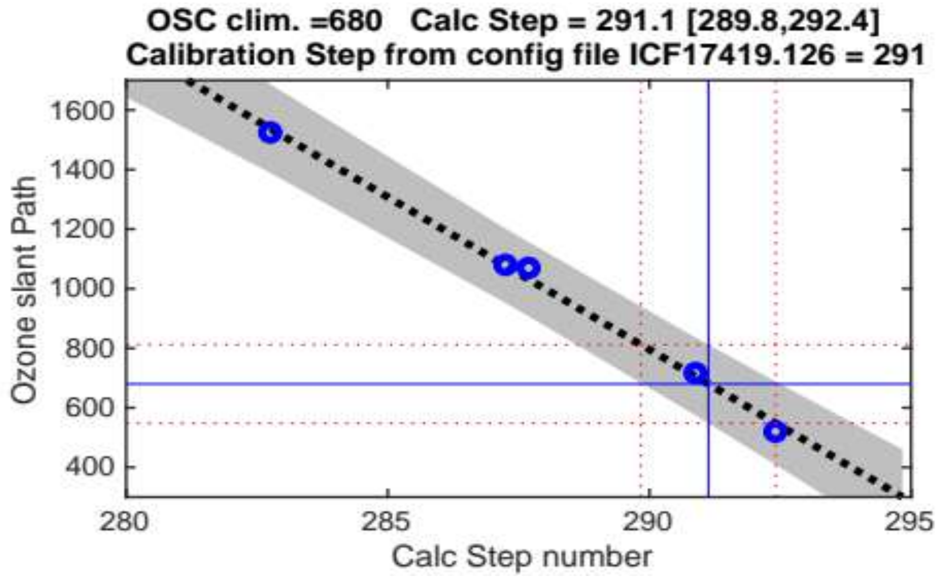


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

10.5.2 Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.3419 is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	286	0.3435	2.3500	1.1514
15-Jun-2013	286	0.3483	3.1068	1.1631
01-Jun-2015	286	0.3435	3.1108	1.1533
02-Jun-2017	286	0.3409	3.1357	1.1461
19-Jun-2019	286	0.3467	3.1239	1.1587
19-Jun-2019	291	0.3419	3.1749	1.1435
Final	291	0.3419	2.3500	1.1514

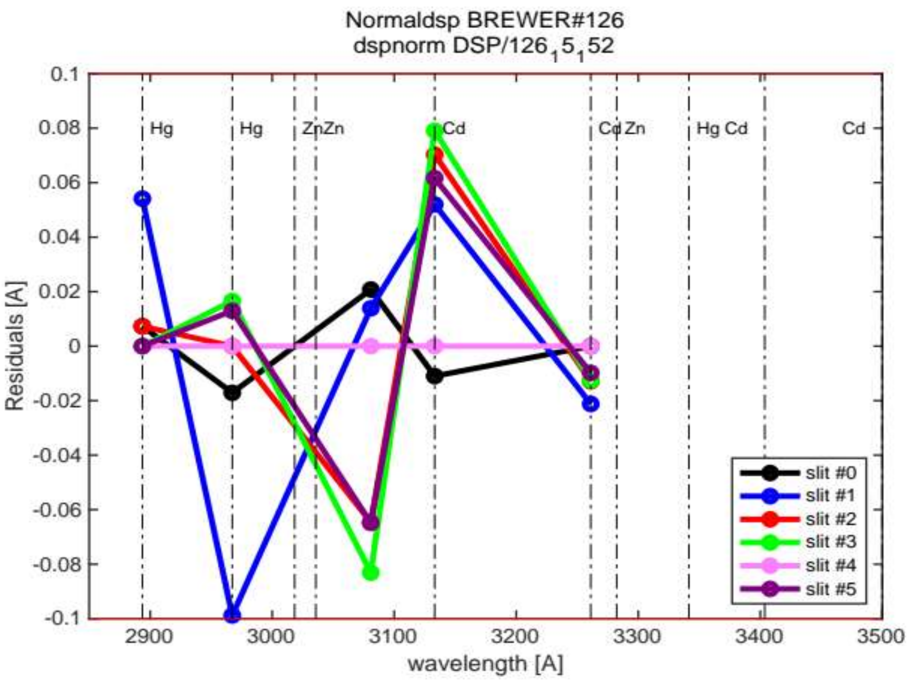


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 290	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.91	3063	3100.48	3134.96	3167.97	3199.93
Res(A)	5.5583	5.6194	5.4336	5.833	5.5347	5.3458
O3abs(1/cm)	2.5989	1.7799	1.005	0.67488	0.37507	0.29438
Ray abs(1/cm)	0.50507	0.48323	0.45849	0.43713	0.41787	0.40024
SO2abs(1/cm)	3.4318	5.6299	2.4047	1.9066	1.0542	0.61374
step= 291	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.98	3063.07	3100.54	3135.03	3168.04	3200
Res(A)	5.5583	5.6192	5.4335	5.8329	5.5346	5.3457
O3abs(1/cm)	2.5964	1.7783	1.0047	0.67456	0.3751	0.29393
Ray abs(1/cm)	0.50502	0.48318	0.45844	0.43709	0.41783	0.4002
SO2abs(1/cm)	3.4163	5.6502	2.4126	1.8957	1.0553	0.6116
step= 292	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.05	3063.14	3100.61	3135.1	3168.1	3200.07
Res(A)	5.5582	5.6191	5.4335	5.8328	5.5345	5.3455
O3abs(1/cm)	2.5938	1.7767	1.0045	0.67424	0.37517	0.29348
Ray abs(1/cm)	0.50497	0.48314	0.4584	0.43705	0.4178	0.40017
SO2abs(1/cm)	3.4026	5.6699	2.4204	1.8848	1.0565	0.60947
Step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
290	0.34283	10.1384	3.1663	1.1466	0.35331	0.34466
291	0.34192	10.1358	3.1749	1.1435	0.35241	0.34374
292	0.34089	10.1333	3.1829	1.1402	0.35147	0.34277

10.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1756. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 291	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.5583	5.6192	5.4335	5.8329	5.5346	5.3457
O3abs(1/cm)	2.5964	1.7783	1.0047	0.67456	0.3751	0.29393
Ray abs(1/cm)	0.50502	0.48318	0.45844	0.43709	0.41783	0.4002
step= 1756	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.4574	5.4279	5.3148	5.6992	5.4497	5.1472
O3abs(1/cm)	0.67895	0.39486	0.29407	0.12486	0.061564	0.033338
Ray abs(1/cm)	0.43794	0.42024	0.4002	0.38288	0.36722	0.35284

10.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone airmass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light. In this case, the ETC distribution shows (see Figure 1) a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column:

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison (Figure 21). These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 5 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

10.6.1. Initial calibration

For the evaluation of the initial status of Brewer UK #126, we used the period from days 170 to 173 which corresponds with 203 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced ozone values slightly lower than the reference instrument (0.5%). When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

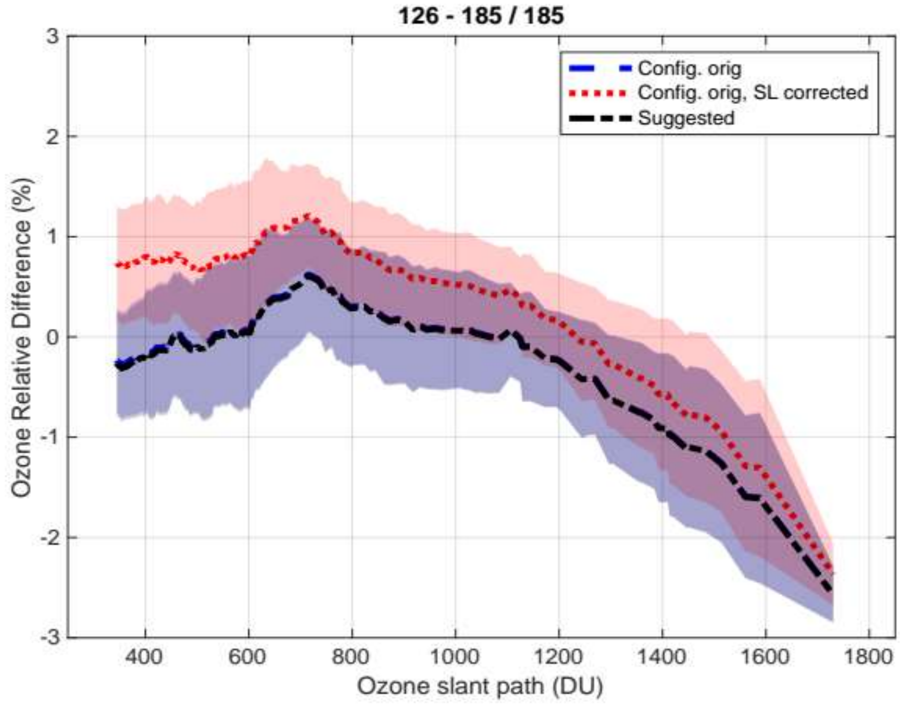
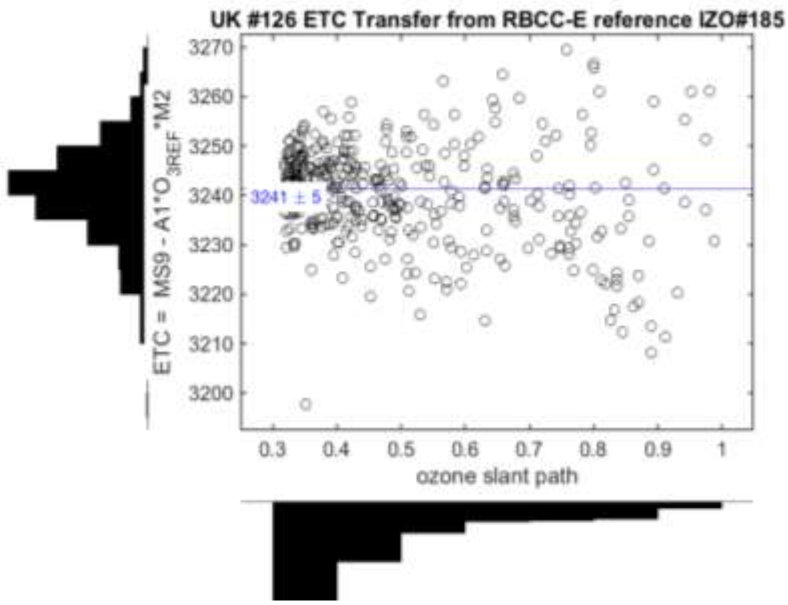


Figure 18. Mean direct sun ozone column percentage difference between Brewer UK #126 and Brewer IZO#185 as a function of ozone slant path

10.6.2. Final calibration

After the change of the cal step number on day 174, a new ETC value was calculated (see Figure 19). For the final calibration, we used 384 simultaneous direct sun measurements from days 174 to 178. The new value of the ETC is 3241, approximately 10 units higher than the current ETC value of 3225. Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratio (2057 for R6). We updated the new calibration constants in the ICF provided. Of course, the new ETC has been calculated taking into account the new suggested dead time of $3.3 \cdot 10^{-8}$ s.



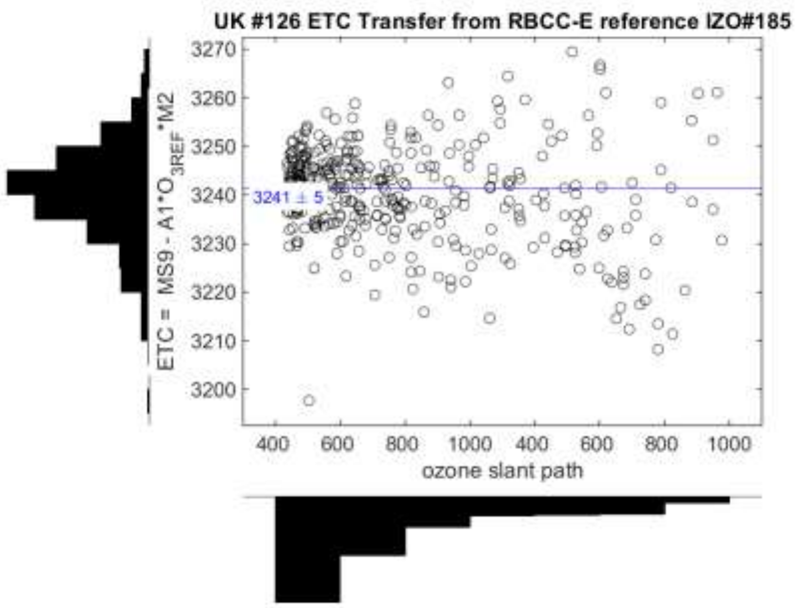


Figure 19. Mean direct sun ozone column percentage difference between Brewer UK #126 and Brewer IZO#185 as a function of ozone slant path

10.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and a 0.2% underestimation at 1000 OSC, which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = a = -9$, $s = b = 6.19$, and ETC=3241. These parameters give a much better agreement with the reference for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Mean daily total ozone values for the original and the final configurations are shown in Table 6, as well as relative differences with respect to IZO#185.

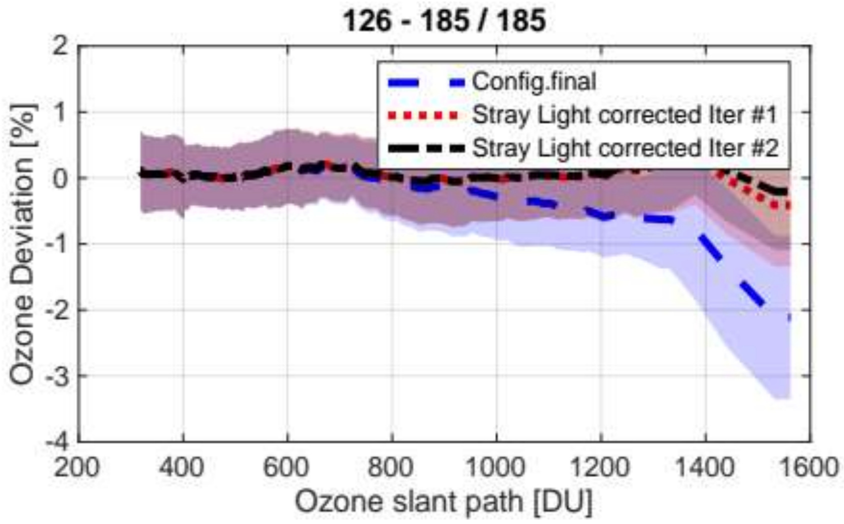


Figure 20. Ratio respect to the reference when final constants are applied and stray light correction introduced from empirical model is applied

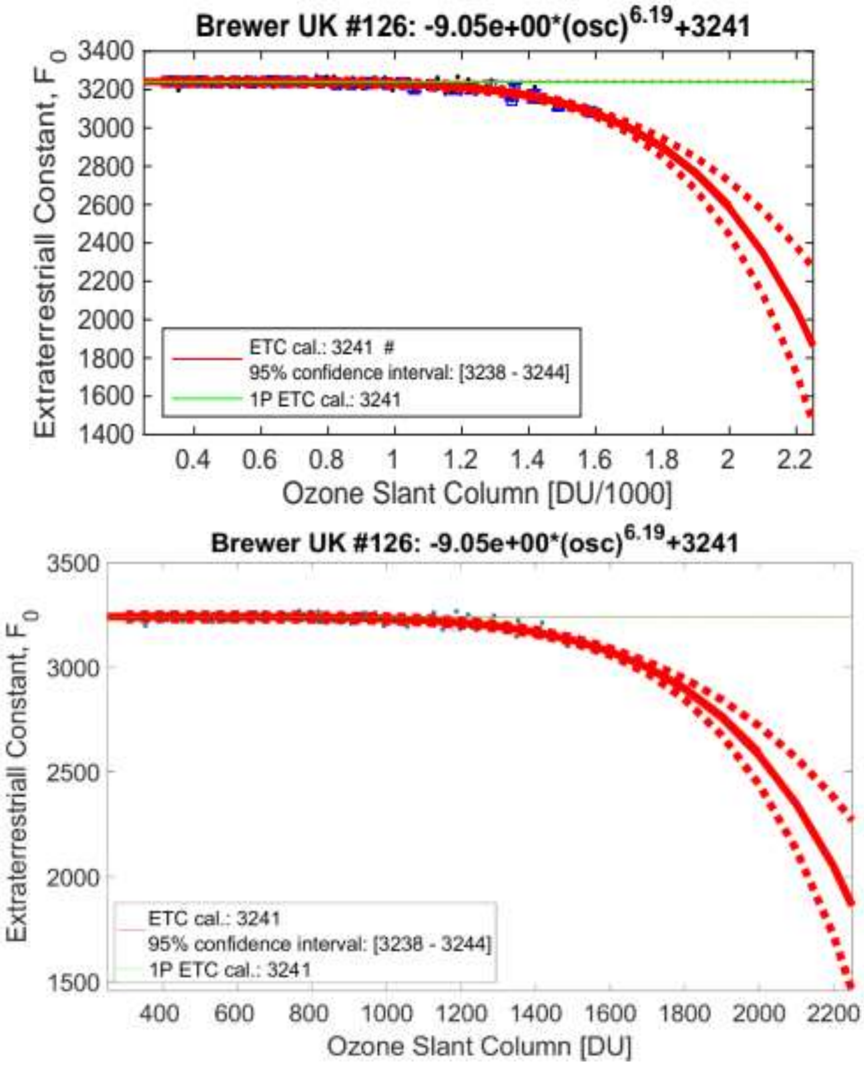


Figure 21. Stray light empirical model determination

Table 6. Daily mean ozone processed with original and final (*) calibration. Final Days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#126*	*O3 std*	*%(126–185)/185*	*O3(*) #126*	*O3std*	*(*)%(126–185)/185*
22-Jun-2019	173	327.8	1.7	33	326.2	3.3	-0.5	324.9	2.6	-0.9
23-Jun-2019	174	323.6	3.9	100	327.2	6.4	1.1	324.1	4.6	0.2
24-Jun-2019	175	307.2	1.2	72	308.4	2.4	0.4	306.3	1.9	-0.3
25-Jun-2019	176	308.9	2	113	312.6	3.6	1.2	308.5	1.7	-0.1
26-Jun-2019	177	311.5	3.5	98	315.2	3.4	1.2	311.2	3	-0.1
27-Jun-2019	178	NaN	NaN	0	312.5	7	NaN	309	5.2	NaN

10.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 2057 for R6 (see Figure 22) and 4445 for R5 (see Figure 23).

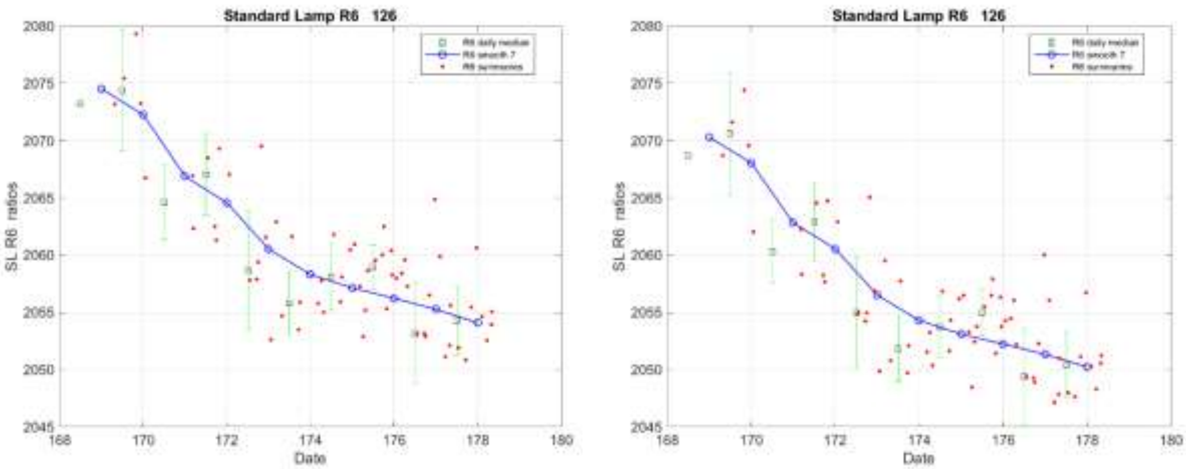


Figure 22. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

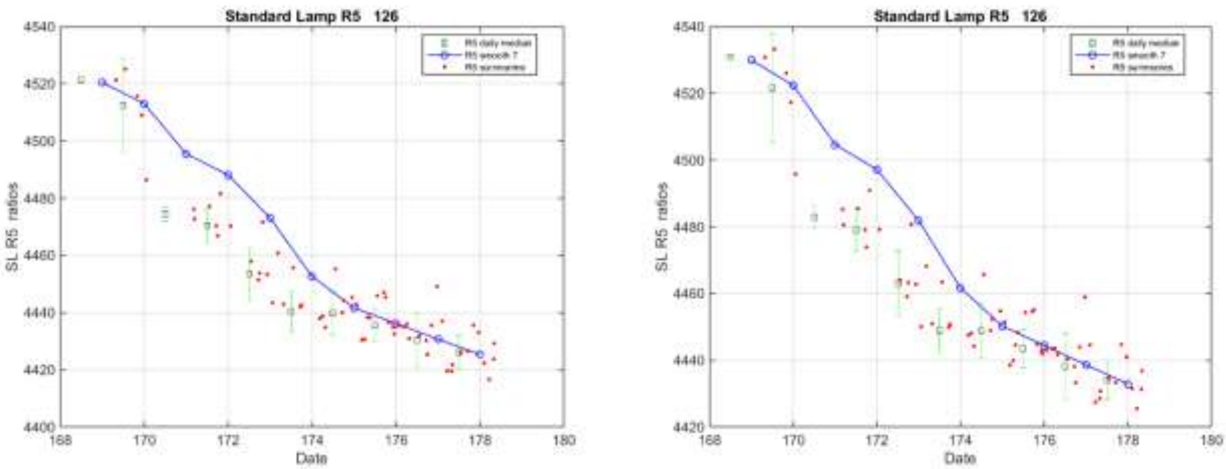


Figure 23. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

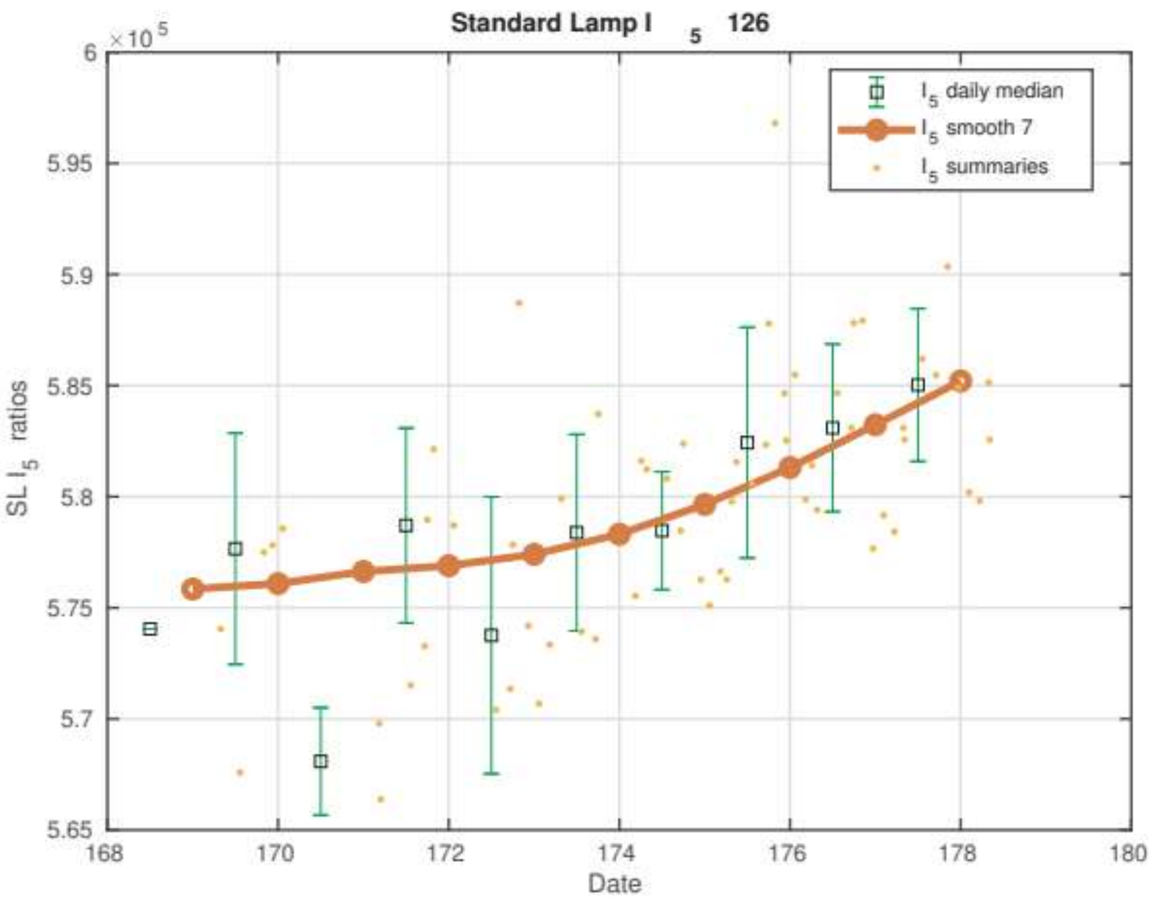


Figure 24. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

10.7. CONFIGURATION

10.7.1. Instrument constant file

	Initial (ICF15517.126)	*Final (ICF17419.126)*
o3 Temp coef 1	0	0
o3 Temp coef 2	0.5518	0.5518
o3 Temp coef 3	0.3869	0.3869
o3 Temp coef 4	-0.1935	-0.1935
o3 Temp coef 5	-1.3538	-1.3538
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3435	0.3419
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1514	1.1514
ETC on O3 Ratio	3225	3241
ETC on SO2 Ratio	4020	4020
Dead time (sec)	3.6e-08	3.3e-08
WL cal step number	286	291
Slitmask motor delay	92	92
Umkehr Offset	1757	1757
ND filter 0	0	0
ND filter 1	4900	4900
ND filter 2	9200	9200
ND filter 3	15780	15780
ND filter 4	21520	21520
ND filter 5	25000	25000
Zenith steps/rev	2816	2816
Brewer Type	2	2
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0

	Initial (ICF15517.126)	*Final (ICF17419.126)*
n2 Temp coef 5	0	0
O3 Mic #1 Offset	2925	2901
Mic #2 Offset	0	0
O3 FW #3 Offset	0	0
NO2 absn Coeff	1	1
NO2 ds etc	0	0
NO2 zs etc	0	0
NO2 Mic #1 Offset	0	0
NO2 FW #3 Offset	0	0
NO2/O3 Mode Change	2546	2546
Grating Slope	0.99262	0.9926
Grating Intercept	25.4761	25.4761
Micrometre Zero	3469	3469
Iris Open Steps	250	250
Buffer Delay (s)	0.4	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	31	31
Zenith UVB Position	2110	2110

10.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#126*	*O3 std*	*%diff*	*(*)O3#126*	*O3 std*	*(*)%diff*
170	700>osc>400	327	0.1	2	329	0.5	0.8	328	0.5	0.3
171	osc>1500	318	0.0	1	311	0.0	-2.2	311	0.0	-2.3
171	1500>osc>1000	321	1.3	9	322	3.0	0.2	321	2.9	0.0
171	1000>osc>700	324	0.8	8	328	0.7	1.1	327	0.7	0.8
171	700>osc>400	332	3.7	40	334	2.8	0.8	332	2.7	0.2
171	osc<400	336	1.2	51	338	1.3	0.4	336	1.3	-0.2
172	osc>1500	325	0.6	2	319	1.6	-2.0	318	1.5	-2.3
172	1500>osc>1000	334	3.3	12	334	5.5	-0.2	332	5.4	-0.6

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#126*	*O3 std*	*%diff*	*(*)O3#126*	*O3 std*	*(*)%diff*
172	1000>osc>700	333	1.8	13	336	3.8	0.9	334	3.8	0.3
172	700>osc>400	335	3.2	51	338	5.0	1.0	335	4.9	0.0
172	osc<400	339	1.9	45	342	3.6	0.9	338	3.6	-0.4
173	1500>osc>1000	325	1.4	15	325	3.9	-0.2	323	3.7	-0.6
173	1000>osc>700	328	0.6	12	329	1.0	0.4	327	0.9	-0.3
173	700>osc>400	329	1.2	14	332	0.9	0.9	328	0.7	-0.1
174	osc>1500	314	0.0	1	305	0.0	-2.7	305	0.0	-2.9
174	1500>osc>1000	318	4.6	12	319	4.0	0.2	317	3.7	-0.2
174	1000>osc>700	320	3.4	17	324	2.7	1.0	321	2.2	0.1
174	700>osc>400	324	1.4	28	331	2.3	2.1	325	1.3	0.3
174	osc<400	326	0.9	41	337	2.5	3.3	327	2.5	0.3
175	1500>osc>1000	307	1.2	11	305	2.7	-0.6	304	2.4	-1.0
175	1000>osc>700	308	1.3	17	310	1.8	0.8	307	2.0	-0.1
175	700>osc>400	307	1.1	41	312	1.8	1.7	306	1.4	-0.1
175	osc<400	307	0.3	2	314	0.2	2.3	306	0.0	-0.3
176	1500>osc>1000	308	2.4	8	307	2.1	-0.1	305	1.8	-0.7
176	1000>osc>700	308	2.4	11	311	1.0	1.0	308	1.0	0.0
176	700>osc>400	308	1.5	34	314	1.8	2.2	308	1.0	0.1
176	osc<400	310	1.3	57	321	2.0	3.6	310	1.2	-0.1
177	1000>osc>700	312	5.7	11	314	4.4	0.7	311	4.5	-0.4
177	700>osc>400	313	4.0	39	319	3.1	2.0	312	3.3	-0.2
177	osc<400	311	1.3	38	322	2.5	3.7	311	1.9	0.0
178	1500>osc>1000	306	5.4	9	NaN	NaN	NaN	302	6.4	-1.2
178	1000>osc>700	313	5.2	5	NaN	NaN	NaN	312	5.1	-0.4
178	700>osc4>00	312	3.1	28	NaN	NaN	NaN	313	2.7	0.2
178	osc<400	312	2.1	43	NaN	NaN	NaN	313	1.7	0.3

10.9. APPENDIX: SUMMARY PLOTS

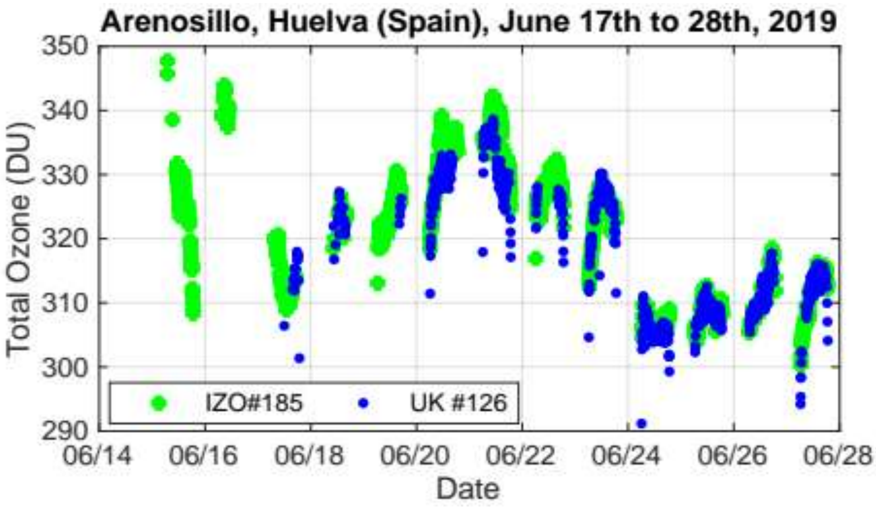
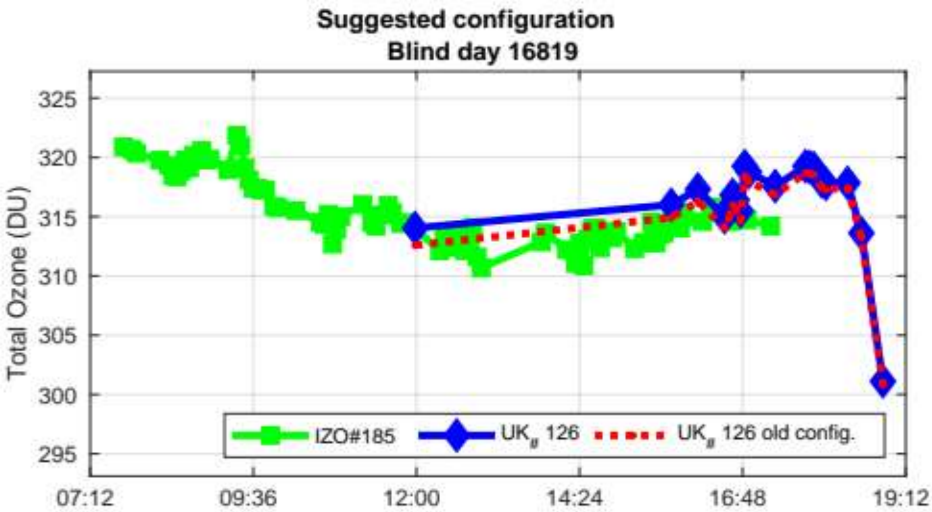
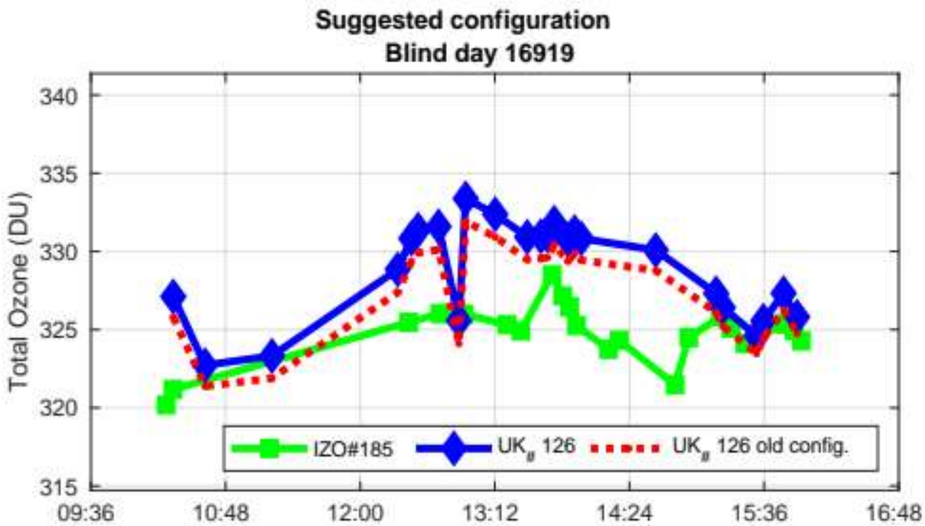
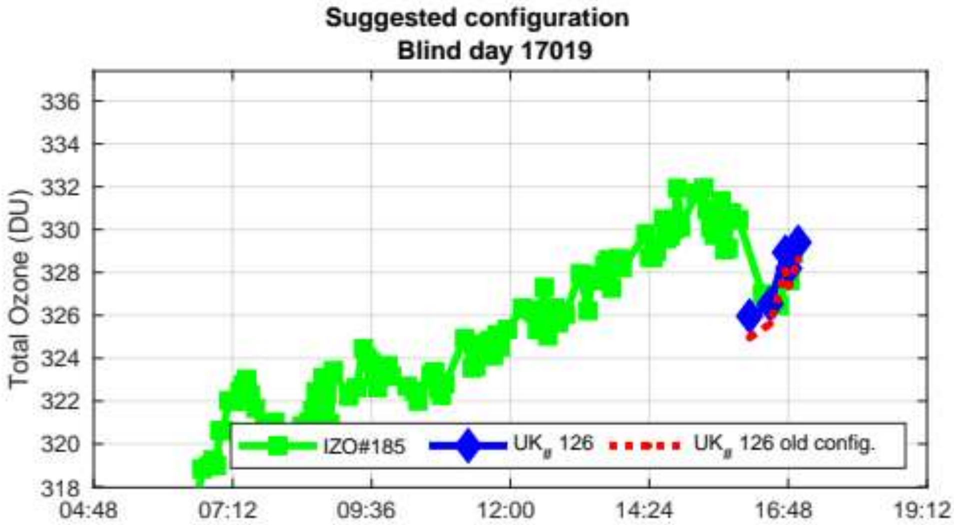
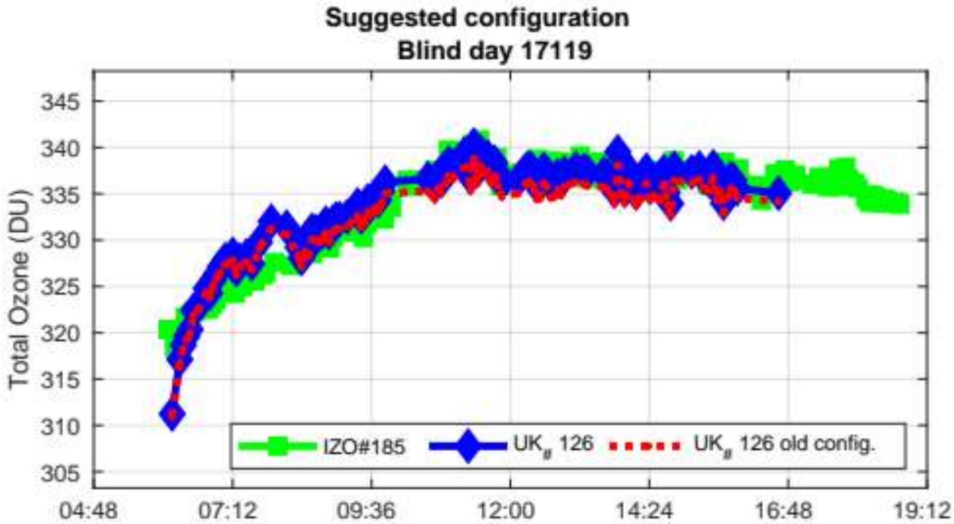


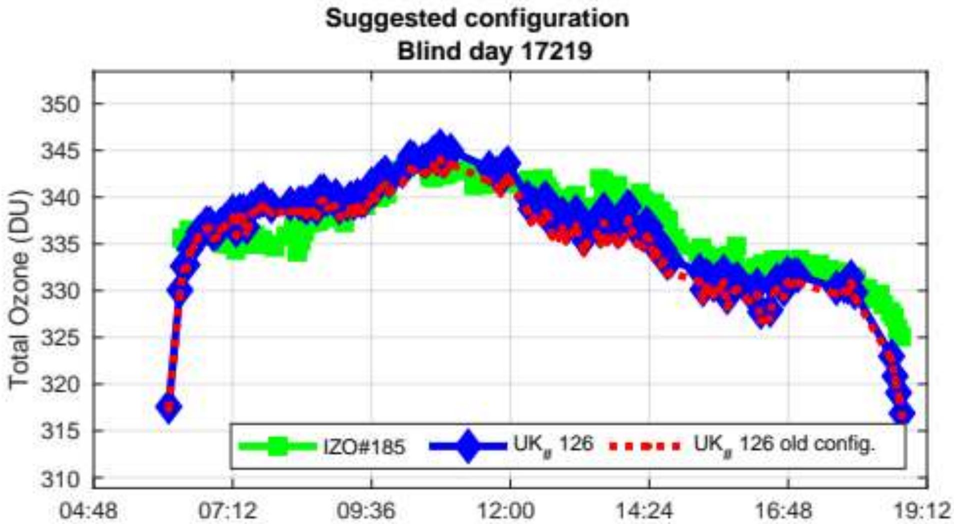
Figure 25. Overview of the intercomparison. Brewer UK #126 data were evaluated using final constants (blue circles)

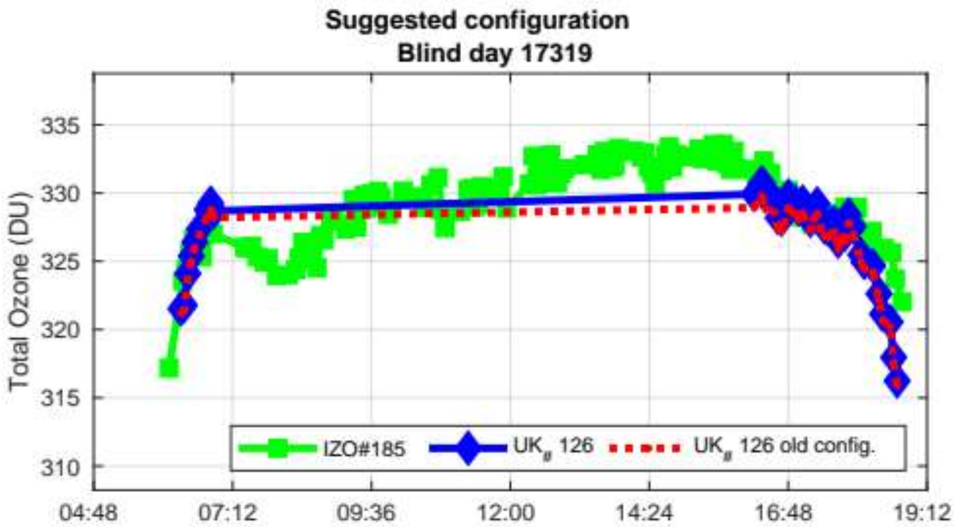


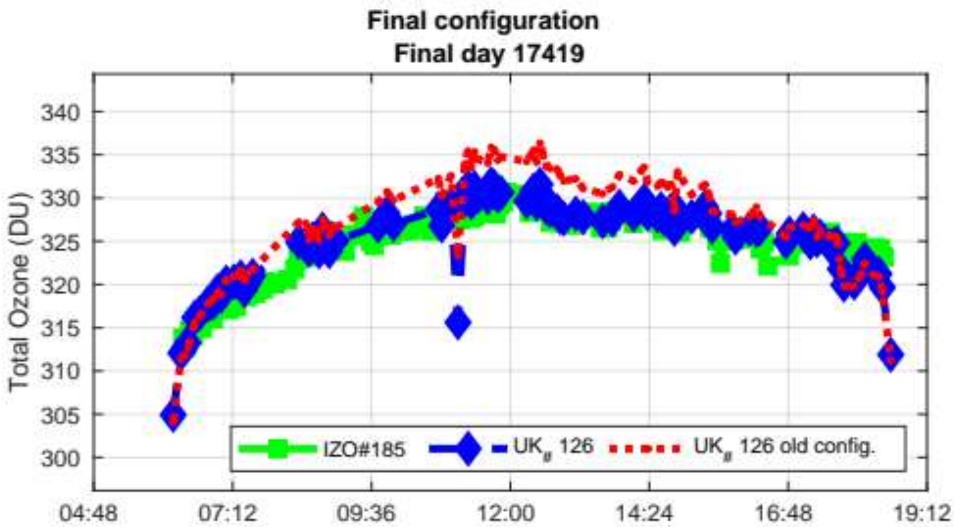


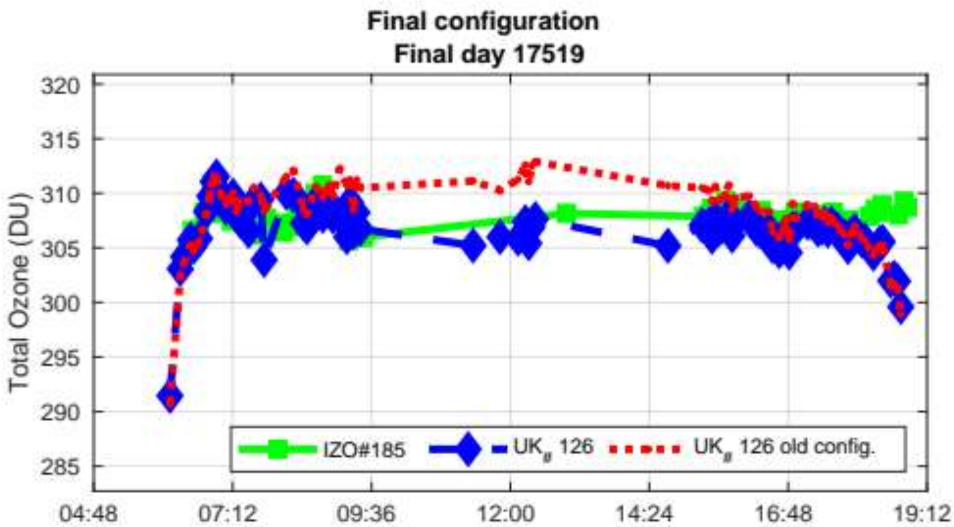

Suggested configuration
Blind day 17019
Total Ozone (DU)
IZO#185
UK$_g$ 126
UK$_g$ 126 old config.

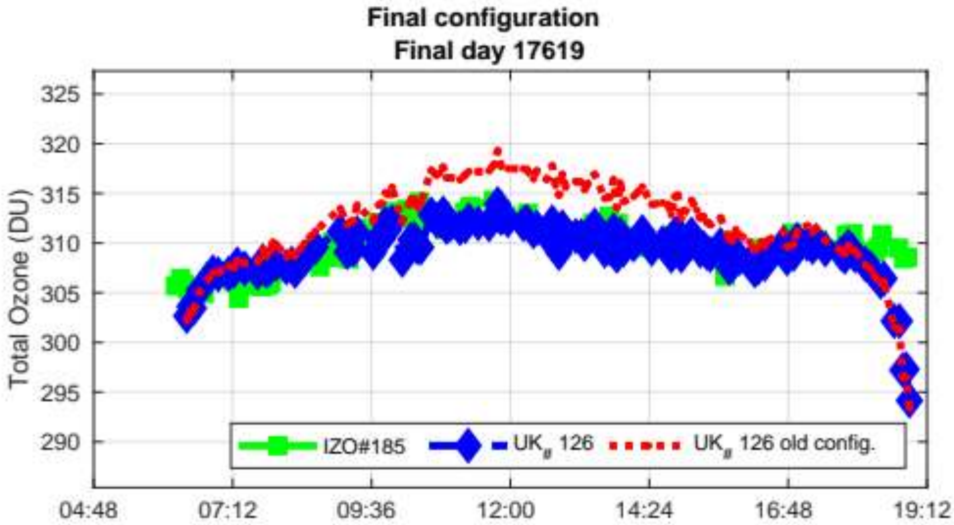

Suggested configuration
Blind day 17119
Total Ozone (DU)
IZO#185
UK$_g$ 126
UK$_g$ 126 old config.

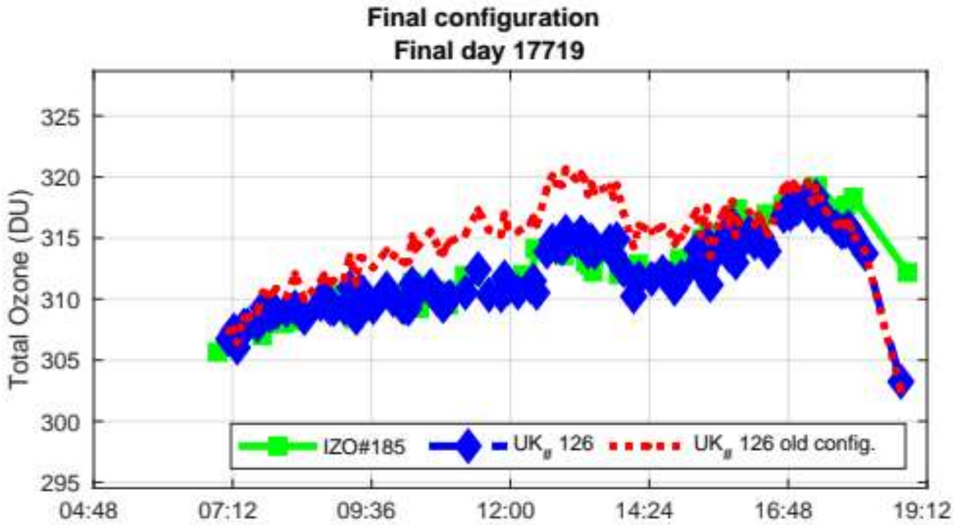

Suggested configuration
Blind day 17219
Total Ozone (DU)
IZO#185
UK$_g$ 126
UK$_g$ 126 old config.

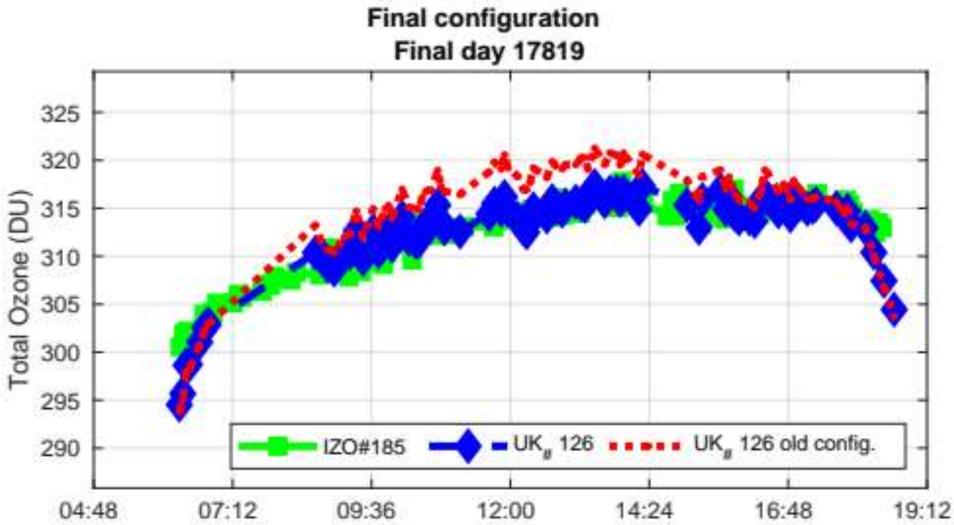

Suggested configuration
Blind day 17319
Total Ozone (DU)
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_g 126
UK_g 126 old config.


Final configuration
Final day 17419
Total Ozone (DU)
340
335
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_g 126
UK_g 126 old config.


Final configuration
Final day 17519
Total Ozone (DU)
320
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_g 126
UK_g 126 old config.


Final configuration
Final day 17619
Total Ozone (DU)
325
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_B 126
UK_B 126 old config.


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_B 126
UK_B 126 old config.


Final configuration
Final day 17819
Total Ozone (DU)
325
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK_B 126
UK_B 126 old config.

11. BREWER ARE#150

11.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer ARE#150 participated in the campaign from 17 to 28 June. The campaign days of Brewer ARE#150 correspond to Julian days 166 – 179.

For the evaluation of the initial status, we used 65 simultaneous direct sun (DS) ozone measurements from days 166 to 169.5. During days 170 and 171, the instrument was operated with the Fore optics of Brewer #017 during the maintenance. For final calibration purposes, we used 221 simultaneous DS ozone measurements taken from day 171.3 to 179.

As shown in Figures 1 and 2, the current ICF (ICF15617.150, blue dashed line) produces ozone values with an average difference of around -0.5% with respect to the reference instrument. This is a rather small difference, however the comparison is very noisy in contrast with the stability of the R6 standard lamp measurements (see Figure 3). The SL correction (Figure 2, red dotted line) is thus not necessary and slightly improve the comparison with Brewer IZO#185. The new calibration provided from the observations during the campaign is not optimal. Figure 2 shows an important dependence with the OSC. The instrument underestimates at low OSC and overestimates at high OSC, in mean the agreement is reasonable. There are several reasons that may explain this effect:

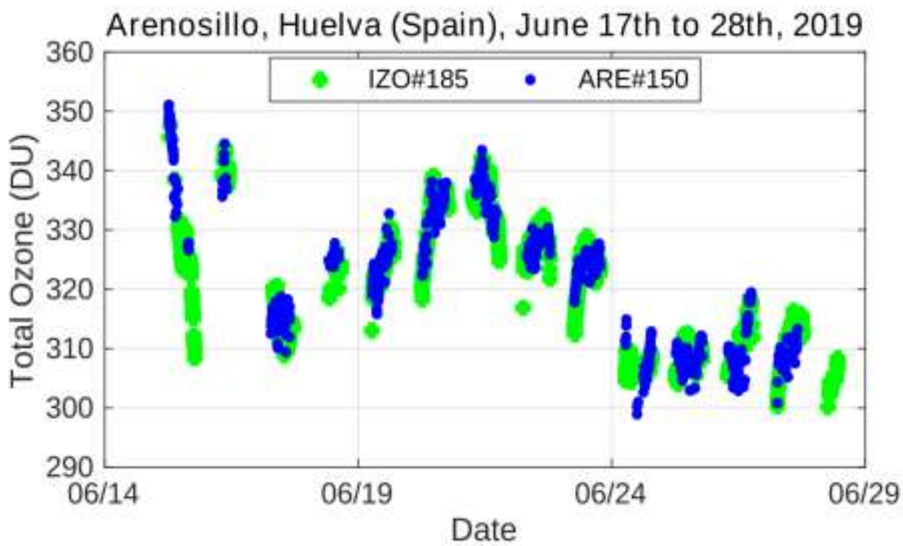


Figure 1. Overview of the intercomparison. Brewer ARE#150 data were evaluated using final constants (blue circles)

A wrong wavelength calibration can give a bias on the ETC, in fact this effect disappears if we used the 2P calibration. For these reasons the wavelength calibration was repeated after the campaign confirming the current wavelength calibration. Using the mean of the last 4 campaigns, the ozone absorption coefficient only changed from 0.3405 to 0.341, very far from the value suggested by the 2P calibration of 0.3481 (Table 8).

A nonlinearity of filter attenuation can also produce this effect. In fact a correction of filter #4 of 20 units also corrects this effect. However, this correction is not in agreement with what we observed in the filter analysis (see filter section). Therefore we analysed the simultaneous measurements from 2017–2020 which confirmed the small corrections of the filters.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) show reasonable results with the exception of dead time (DT) which is decreasing since the last calibration from $3.2 \cdot 10^{-8}$ s to $2.9 \cdot 10^{-8}$ s, in a double Brewer the effect of this change in DT is small.

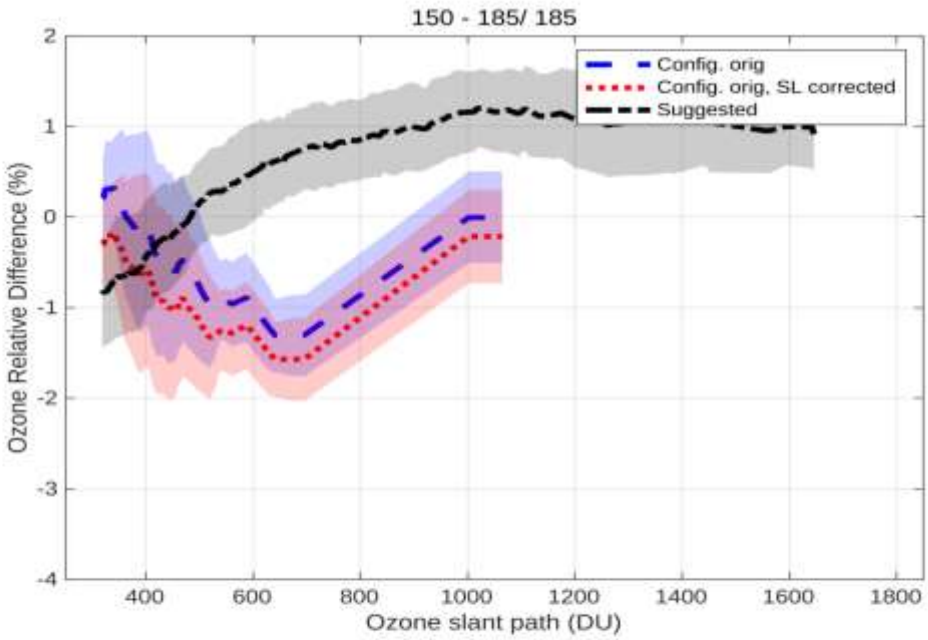


Figure 2. Mean DS ozone column percentage difference between Brewer ARE#150 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

We wish to highlight several issues during the operation of this Brewer:

- There were a lot of missing observations during the middle of the day, with filtered due standard deviation above 2.5.
- The ozone measurements of the instrument were noisy especially at midday. Some of this could be due to focus problems of the instrument.

Taking this into account, we suggest small changes to the configuration of Brewer ARE#150, due to unreliability. Put simply, we updated the ETC to reflect the changes during maintenance. These changes are in agreement with the SL change during the campaign and overall, the instrument performed well.

11.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer ARE#150 have been very stable during the last 2 years. The old R6 reference value was 322 and could be updated to 315.
2. We suggest a new R5 reference value of 669.
3. We suggest updating the DT to $2.9 \cdot 10^{-8}$ seconds, which is one unit less than the value proposed in the last intercomparison.
4. The neutral density filters show the same behaviour as in the previous campaign and we suggest retaining the same correction factors.
5. We suggest updating the ETC value from 1580 to 1570.
6. Finally, due to the unexplained solar zenith angle (sza) dependence, a further investigation is needed for this instrument. A comparison with collocated total ozone instruments could help to determine the described behaviour of this Brewer.

11.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/150/ICF17519.150

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=355711255

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/150/html/cal_report_150a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/150/html/cal_report_150a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/150/html/cal_report_150b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/are2019/latex/150/html/cal_report_150c.html

11.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

11.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance has been quite stable since August 2017, with mean values of around 315 and 669 for R6 and R5 respectively, after the campaign. Figures 4 and 5 show small seasonal variations.

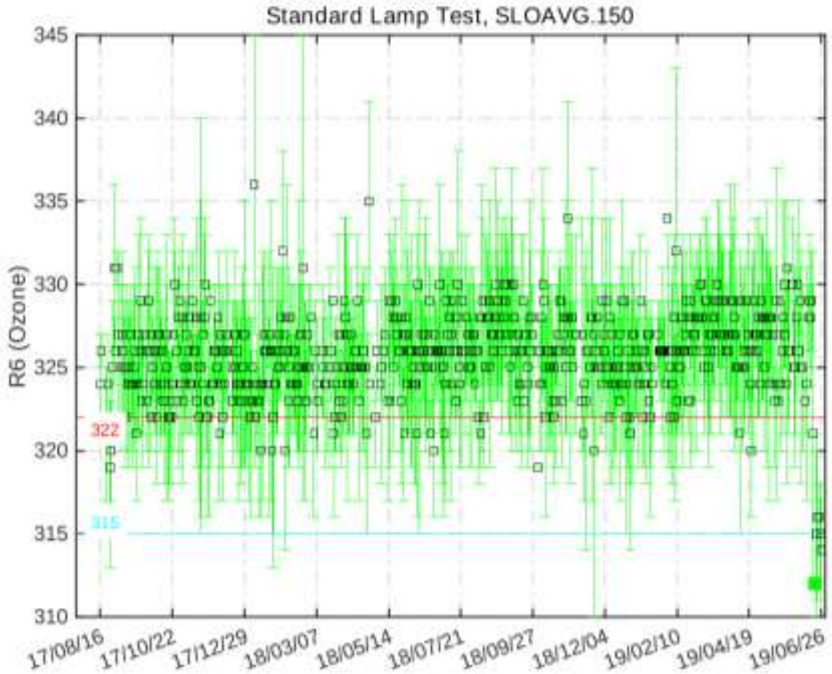


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

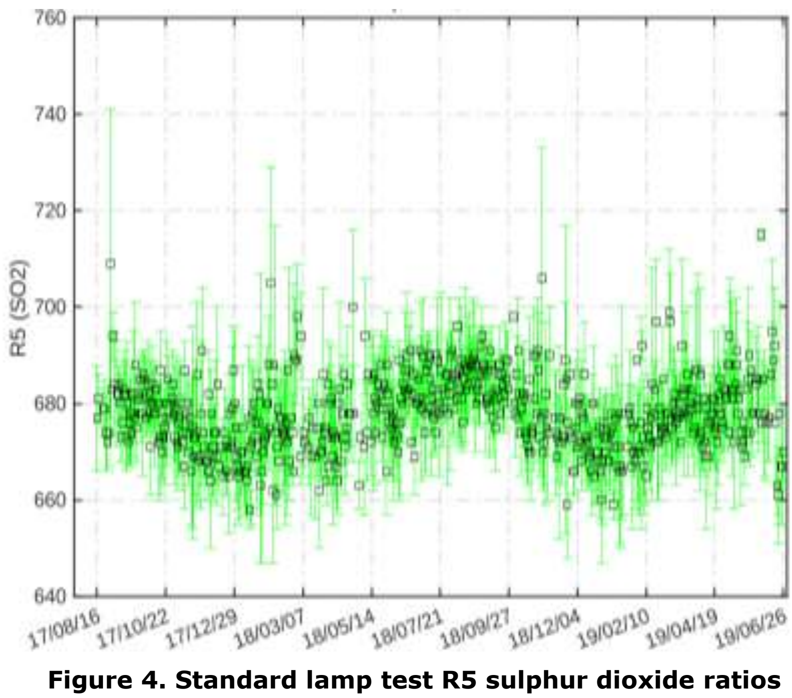


Figure 4. Standard lamp test R5 sulphur dioxide ratios

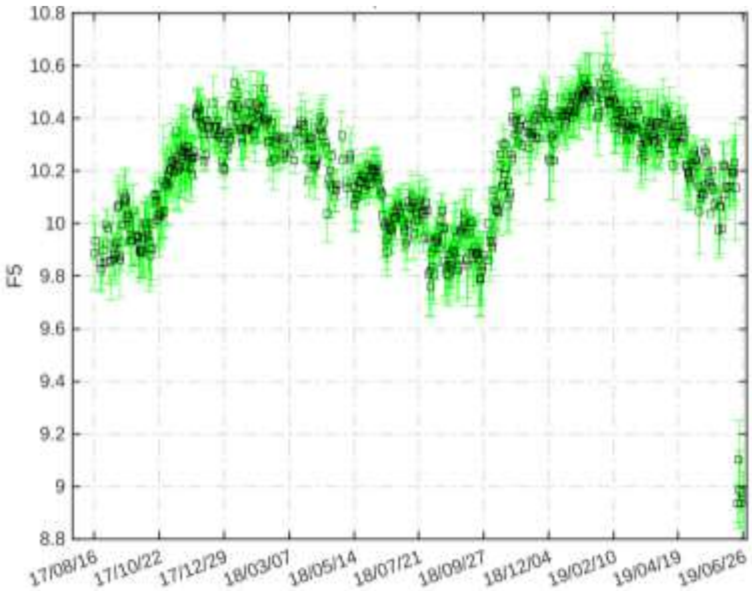


Figure 5. SL intensity for slit five

11.2.3. Run/Stop and dead time

Run/stop test values were within the test tolerance limits,(see Figure 6).

As shown in Figure 7, the current DT reference value of $3.2 \cdot 10^{-8}$ seconds is slightly larger than the value recorded during the calibration period ($2.9 \cdot 10^{-8}$ s). Therefore, this new value has been used in the new ICF.

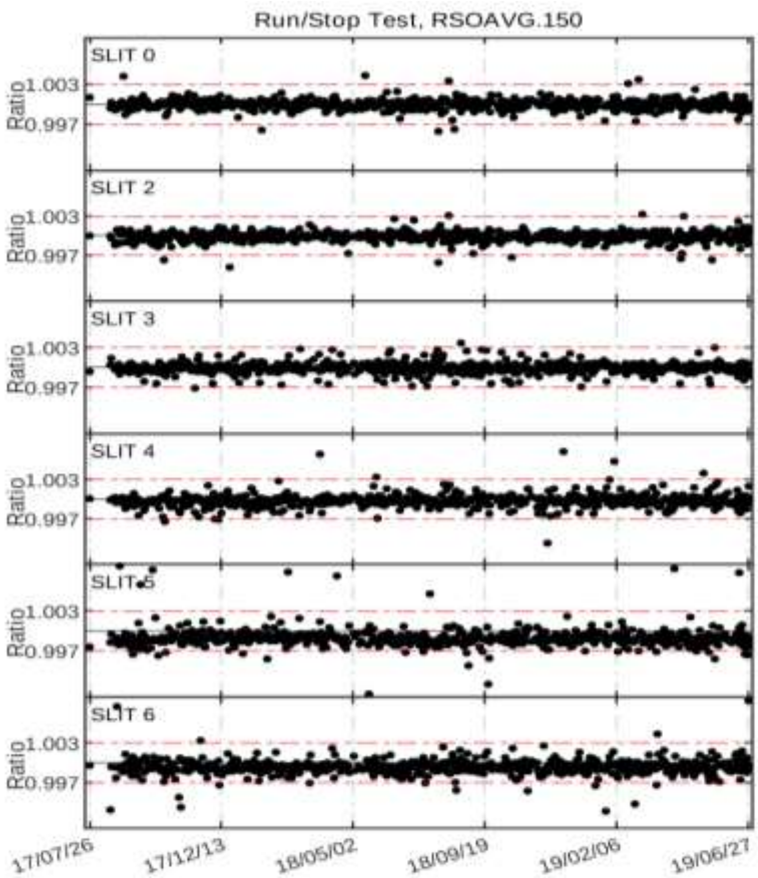


Figure 6. Run/stop test

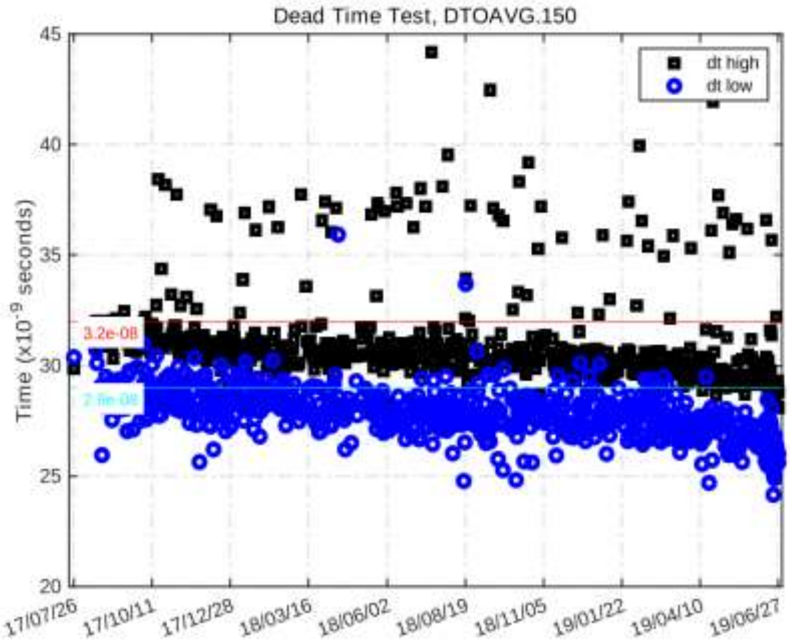


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

11.2.4. Analogue test

Figure 8 shows that high voltage has remained almost constant at around 1171 over the last two years. Furthermore, analogue test values were within the test tolerance range.

Analogue Printout Log, APOAVG.150

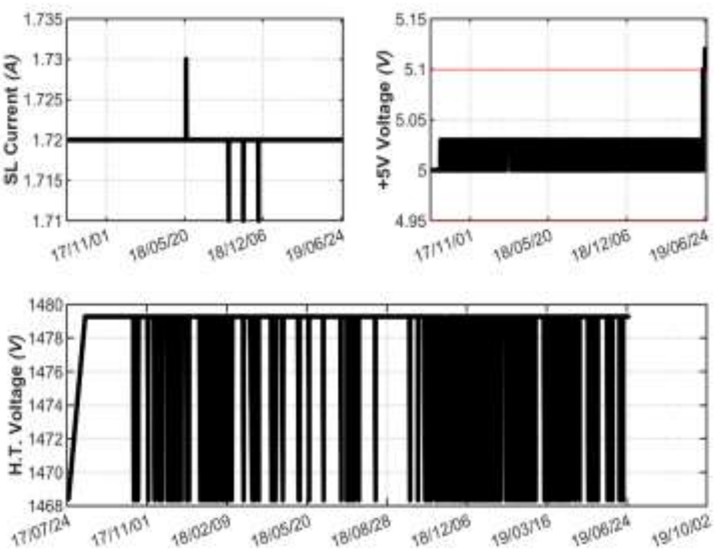


Figure 8. Analogue voltages and intensity

11.2.5. Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign, see Figure 9.

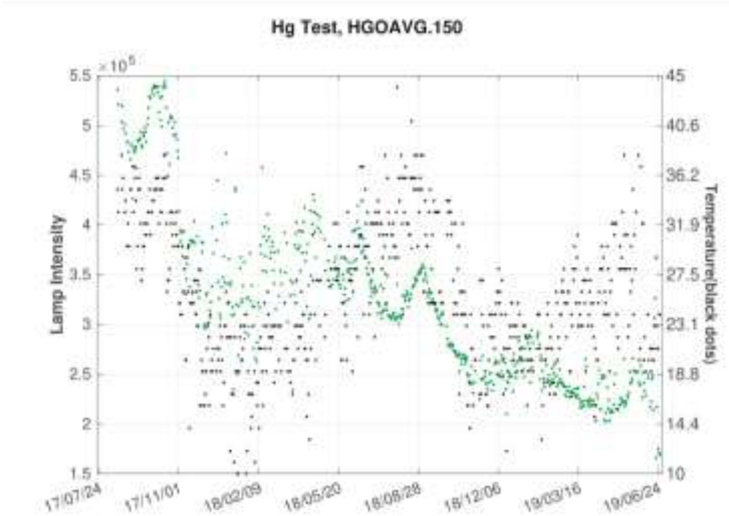


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

11.2.6. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 10). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer ARE#150 during the campaign show reasonable results, with the peak of the calculated scans close to, although slightly above, the accepted tolerance range. Regarding the slit function width, results are good, with a FWHM value lower than 0.65 nm.

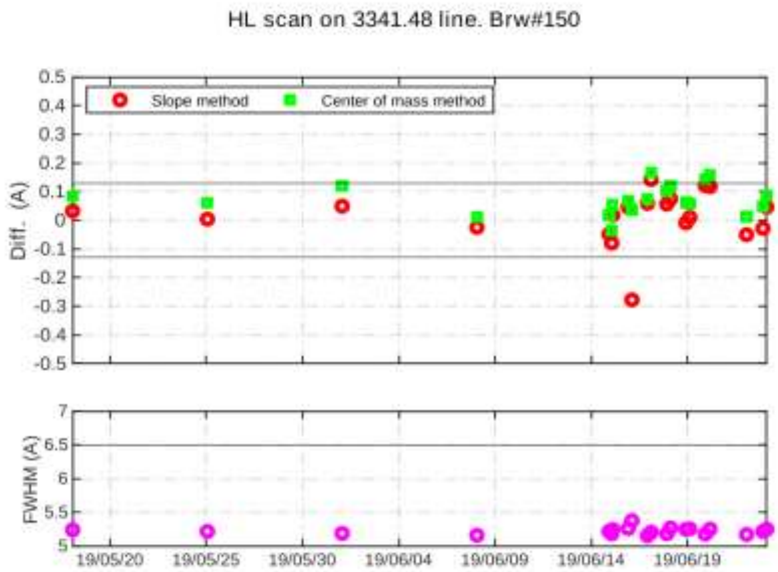


Figure 10. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

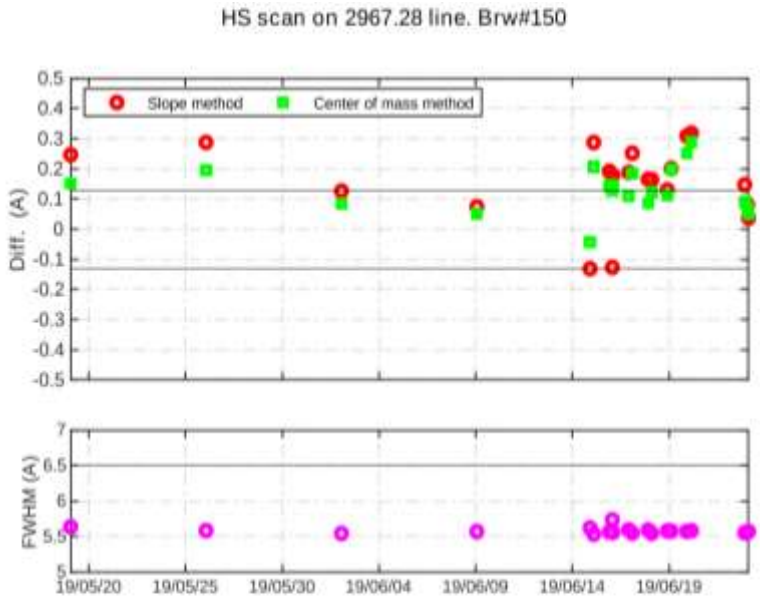


Figure 11. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

11.2.7. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 12, we show percentage ratios of the Brewer ARE#150 CI scans performed during the campaign relative to scan CI17217.150. As can be observed, the lamp intensity varied with respect to the reference spectrum by around 5%. Similar variations have been observed in the daily R6 and R5 values. This behaviour is normal for a SL lamp.

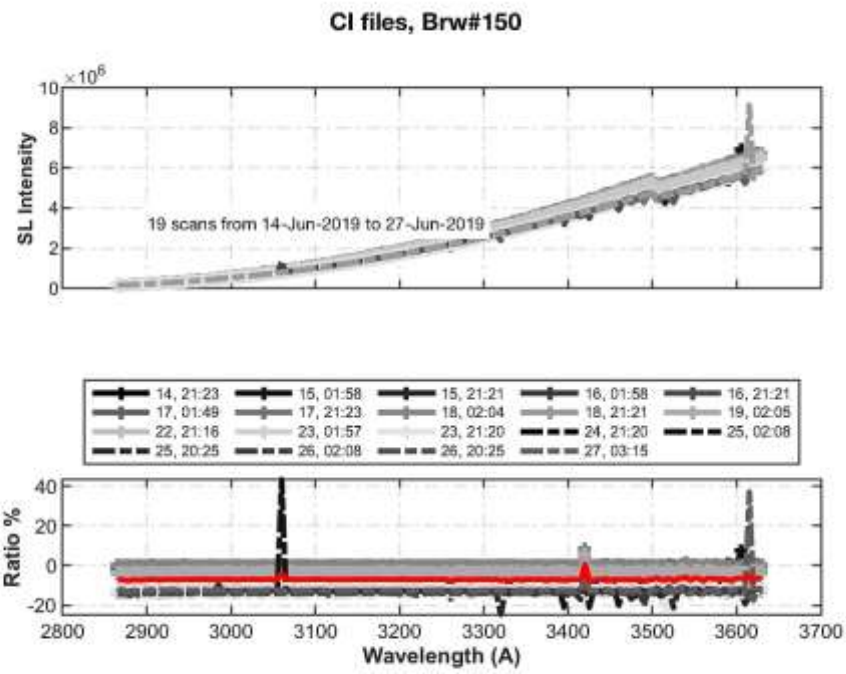


Figure 12. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

11.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 13 (temperature range from 16˚C to 33˚C), the current coefficients do an excellent job at reducing the temperature dependence, performing even better that the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 14 and 15, the current and new coefficients perform similarly, with the current coefficients being slightly better. For this reason, in the final ICF we have used the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	1.3100	1.9300	2.1300	2.0100
Calculated	0.0000	0.4000	0.6000	0.9000	0.4000
Final	0.0000	1.3100	1.9300	2.1300	2.0100

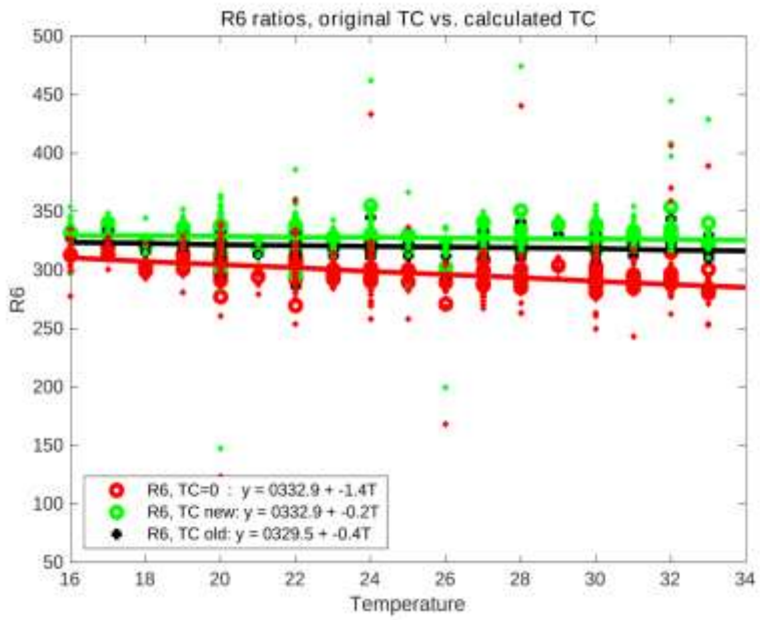


Figure 13. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

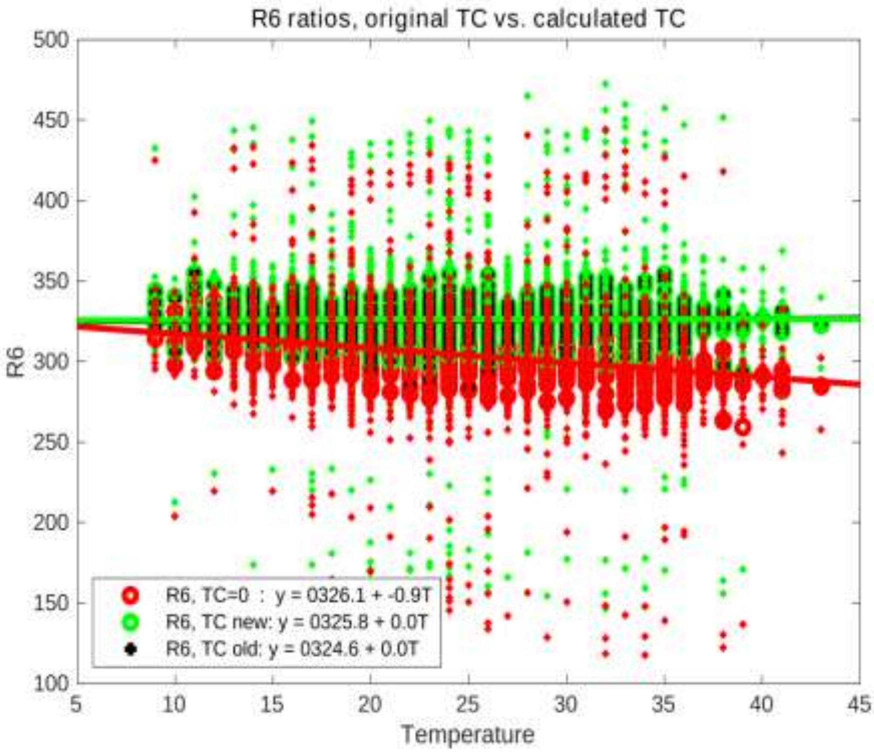


Figure 14. Same as Figure 13 but for the whole period between calibration campaigns

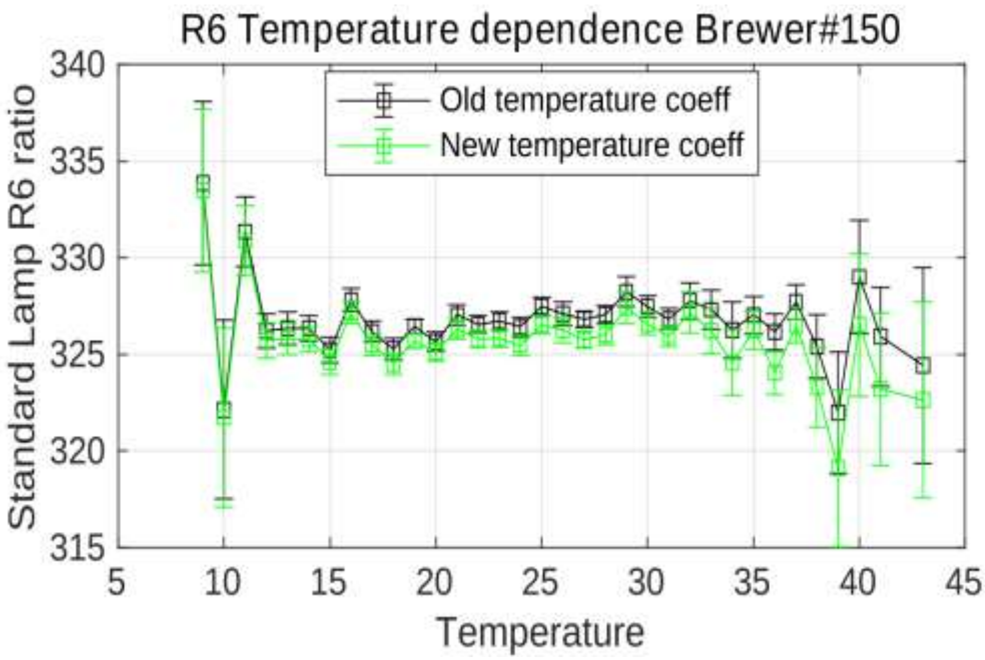


Figure 15. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

11.4. ATTENUATION FILTER CHARACTERIZATION

11.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

A total of 182 FI tests were analysed to calculate the attenuation for every filter and slit. Figures 16 and 17 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

The filter corrections are very similar on the higher filters and no correction is suggested.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	0	-4	-8	-4	-3
ETC Filt. Corr. (mean)	-0.7	-3.8	-6.9	-3.9	-3.8
ETC Filt. Corr. (mean 95% CI)	[-3.3 1.8]	[-6 -1.6]	[-9.4 -4.7]	[-6.3 -1.6]	[-6.5 -1.1]

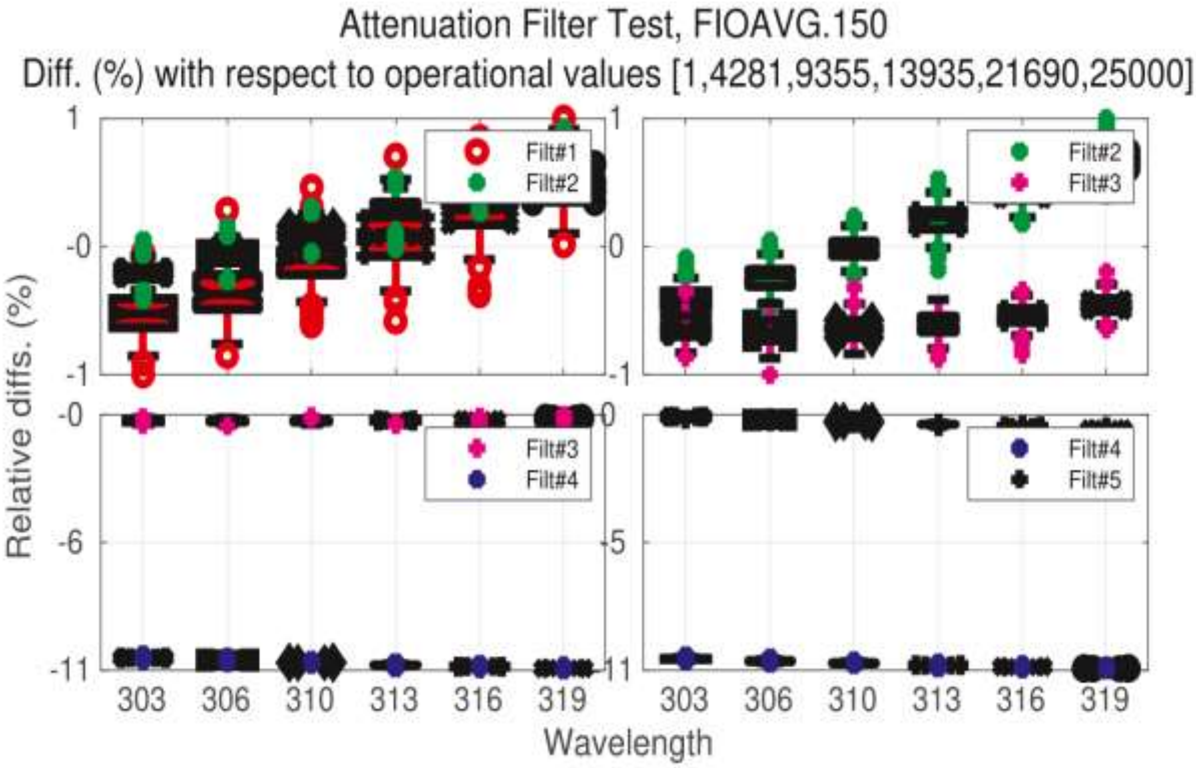


Figure 16. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

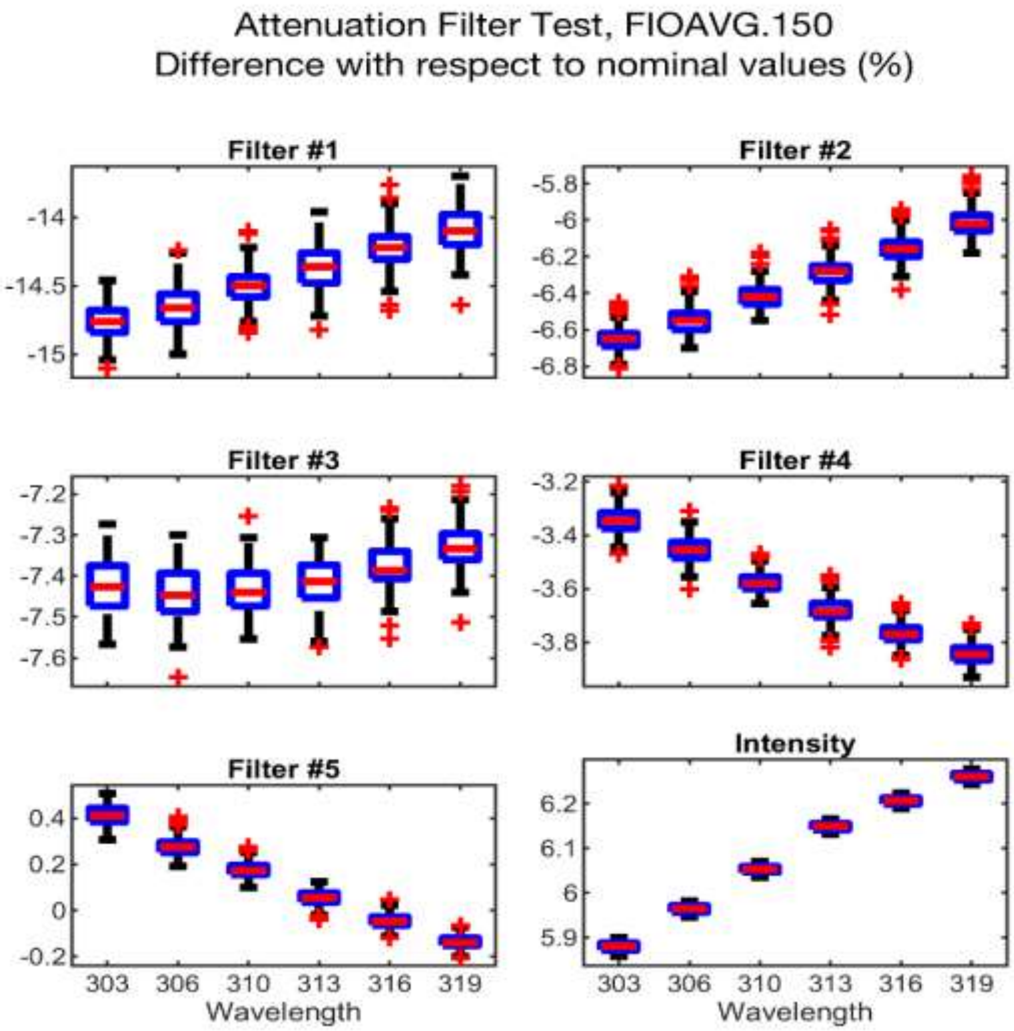


Figure 17. Boxplot for the calculated attenuation relative differences of neutral density filters with respect to nominal values. Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 2 times larger than the interquartile range is defined as an outlier (red cross).

11.5. WAVELENGTH CALIBRATION

11.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 18).

During the campaign, 29 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out (see Figure 19). The calculated cal step number (CSN) was 1 step higher than the value in the current configuration (1032 vs. 1031). Taking all this into account, we suggest keeping the current CSN of 1031.

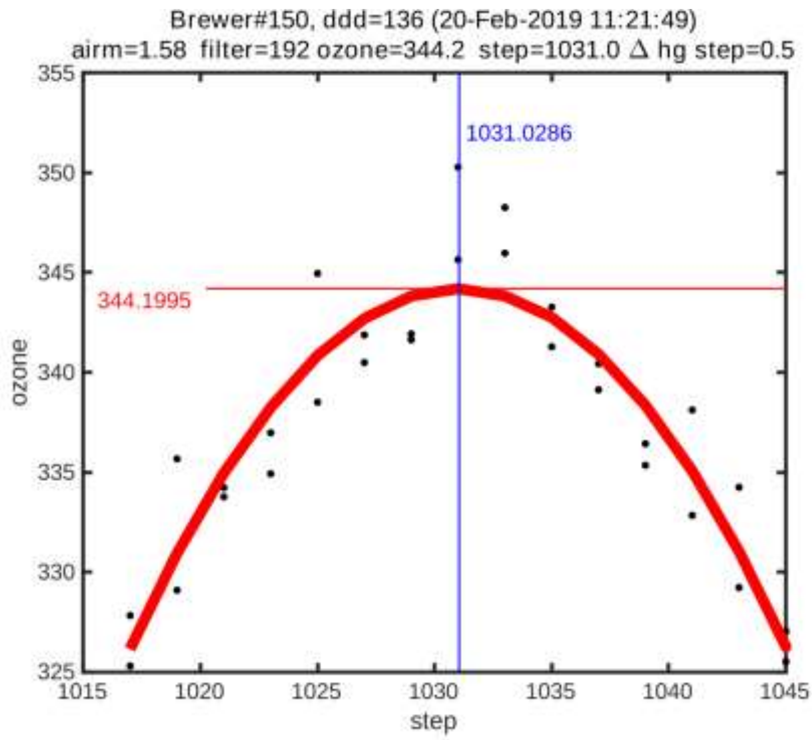


Figure 18. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

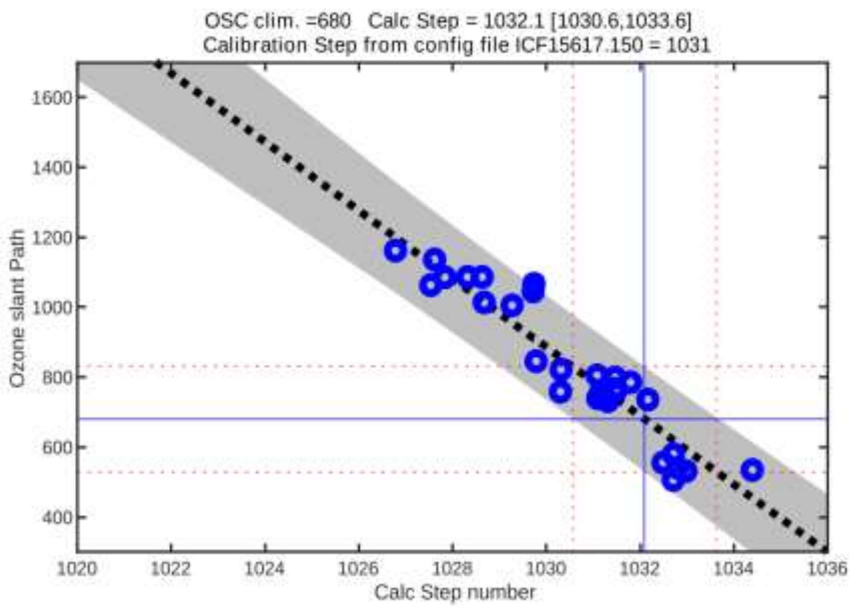


Figure 19. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

11.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 20 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.341 is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	1031	0.3405	2.3500	1.1420
27-May-2015	1031	0.3400	3.1777	1.1412
11-Sep-2015	1031	0.3407	3.1530	1.1456
01-Jun-2017	1031	0.3410	3.1950	1.1441
23-Jun-2019	1031	0.3394	3.1516	1.1423
25-Oct-2019	1031	0.3418	3.1814	1.1462
Final	1031	0.3410	2.3500	1.1420

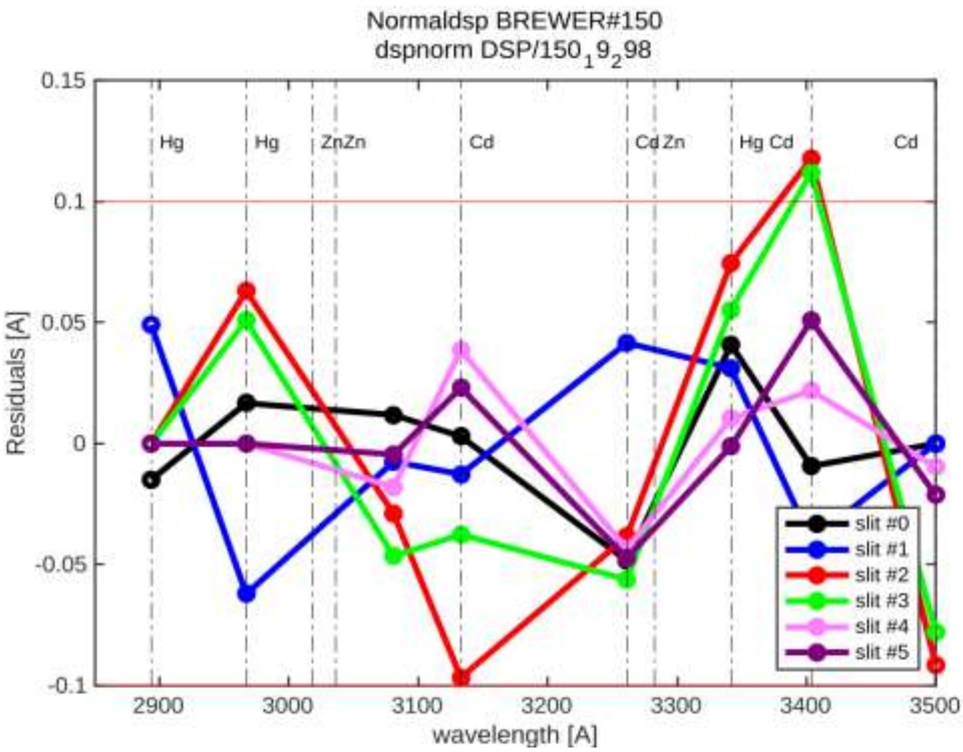


Figure 20. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 1030	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.84	3062.99	3100.47	3134.91	3167.87	3199.88
Res(A)	5.6529	5.5367	5.5071	5.6003	5.5335	5.4366
O3abs(1/cm)	2.6019	1.7806	1.0049	0.6766	0.37503	0.29434
Ray abs(1/cm)	0.50512	0.48324	0.4585	0.43717	0.41793	0.40027
SO2abs(1/cm)	3.4576	5.6391	2.4065	1.9164	1.0525	0.61463
step= 1031	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.91	3063.06	3100.54	3134.98	3167.94	3199.95
Res(A)	5.6528	5.5366	5.507	5.6002	5.5334	5.4365
O3abs(1/cm)	2.5993	1.779	1.0046	0.67624	0.37506	0.29387
Ray abs(1/cm)	0.50506	0.48319	0.45845	0.43712	0.41789	0.40023
SO2abs(1/cm)	3.4417	5.6607	2.4145	1.9051	1.0537	0.61249
step= 1032	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.98	3063.13	3100.61	3135.05	3168.01	3200.02
Res(A)	5.6527	5.5365	5.5069	5.6001	5.5333	5.4364
O3abs(1/cm)	2.5967	1.7774	1.0043	0.67588	0.37508	0.29341
Ray abs(1/cm)	0.50501	0.48314	0.4584	0.43708	0.41785	0.40019
SO2abs(1/cm)	3.4259	5.6823	2.4225	1.8938	1.0549	0.61027
Step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
1030	0.34195	9.272	3.1853	1.1474	0.3525	0.3439
1031	0.34096	9.2696	3.195	1.1441	0.35158	0.34295
1032	0.34002	9.2671	3.2045	1.141	0.35061	0.34195

11.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2447. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 1031	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.6538	5.5934	5.5314	5.5902	5.497	5.4245
O3abs(1/cm)	2.6008	1.7807	1.0046	0.67642	0.37501	0.29373
Ray abs(1/cm)	0.5051	0.48325	0.45845	0.43714	0.41786	0.40022
step= 2447	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.5314	5.4607	5.4039	5.4937	5.3639	5.303
O3abs(1/cm)	0.67846	0.39628	0.29382	0.12394	0.061168	0.033384
Ray abs(1/cm)	0.43801	0.42032	0.40022	0.38285	0.36716	0.35274

11.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 9 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

11.6.1. Initial calibration

For the evaluation of initial status of Brewer ARE#150, we used the period from days 166 to 169.5 which corresponds to 65 near-simultaneous direct sun ozone measurements. As shown in Figure 21, the initial calibration constants produced ozone values slightly lower than the reference instrument (0.5%). When the ETC is corrected, taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

As we explain in the summary, the calibration of the blind days confirms the calibration of the instrument (1P) and the agreement that the reference is inside of 1% but the instrument is noisy with day-to-day differences varying from +0.7% to -0.9%, non-uniform OSC dependence with big differences among 1P and 2P calibration.

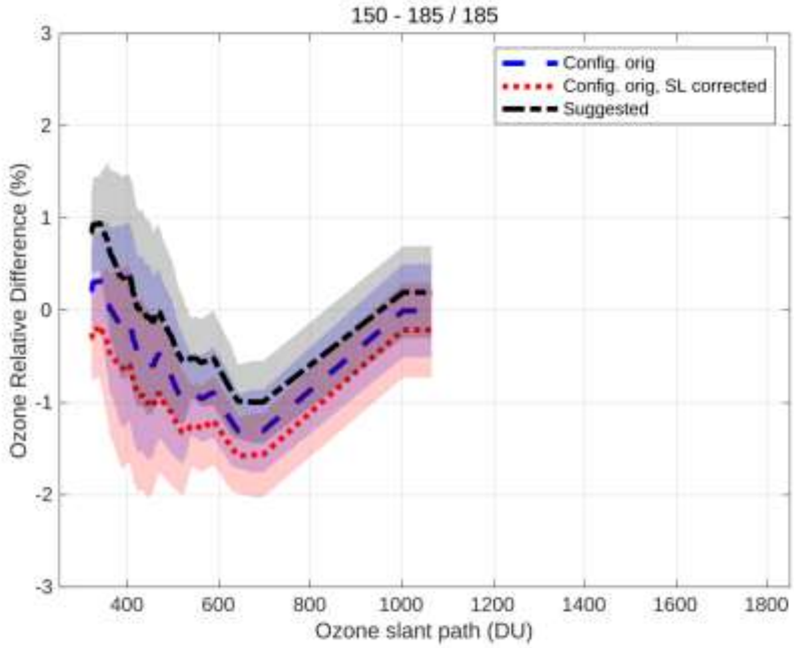


Figure 21. Mean direct sun ozone column percentage difference between Brewer ARE#150 and Brewer IZO#185 as a function of the ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=1000	1573	1600	3405	3343
full OSC range	1576	1603	3405	3336

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3 std*	*N*	*O3#150*	*O3 std*	*%(150–185)/185*	*O3(*)#150*	*O3 std*	*(*)%(150–185)/185*
15-Jun-2019	166	326.7	5.3	7	326.4	2	-0.1	327.9	2	0.4
16-Jun-2019	167	341.3	1.5	11	337.6	2.8	-1.1	338.9	2.8	-0.7
17-Jun-2019	168	315.7	3.2	39	313.3	2.4	-0.8	314.9	2.3	-0.3
18-Jun-2019	169	322.4	2.1	8	323.5	1.5	0.3	325.5	1.5	1

11.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 22). For the final calibration, we used 221 simultaneous direct sun measurements from days 171.3 to 179. The new value is approximately 10 units lower than the current ETC value (1580). Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios of 315 for R6. We updated the new calibration constants in the ICF provided. Of course, the new ETC has been calculated taking into account the new suggested dead time of $2.9 \cdot 10^{-8}$ s.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is bad as we explain in the summary.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

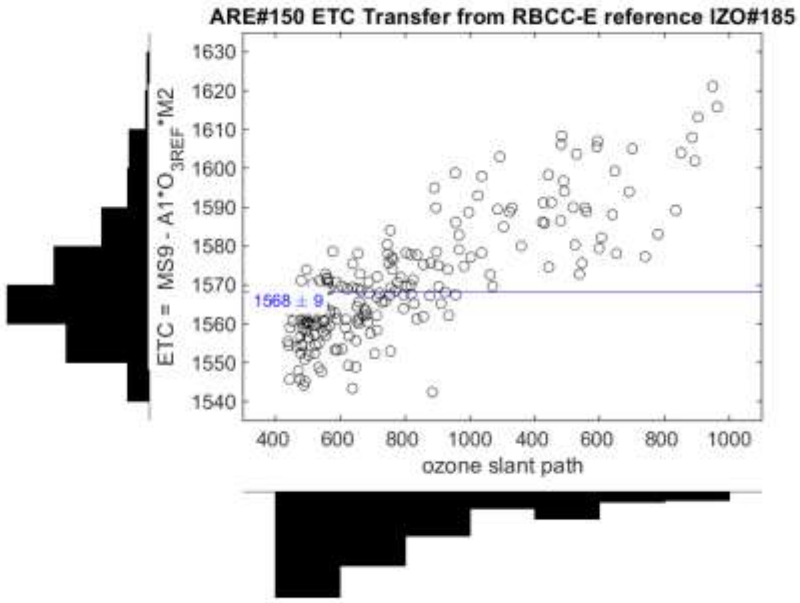


Figure 22. Mean direct sun ozone column percentage difference between Brewer ARE#150 and Brewer IZO#185 as a function of the ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days.

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1568	1533	3405	3485
full OSC range	1568	1536	3405	3477

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#150*	*O3 std*	*%(150–185)/185*	*O3(*) #150*	*O3std*	*(*)%(150–185)/185*
20-Jun-2019	171	333.8	4.2	50	331.4	3.4	-0.7	333	3.5	-0.2
21-Jun-2019	172	334.7	3.2	23	332.6	3.2	-0.6	334.2	3.2	-0.1
22-Jun-2019	173	329	2.2	13	325.7	1.9	-1	327.4	1.8	-0.5
23-Jun-2019	174	323	3.3	33	322.7	1.8	-0.1	324	1.8	0.3

24-Jun-2019	175	307.2	0.6	12	304.8	1.5	-0.8	306.2	1.4	-0.3
25-Jun-2019	176	308.5	2	37	306.4	2.2	-0.7	307.8	1.9	-0.2
26-Jun-2019	177	311.8	3.4	25	308.7	5.4	-1	310.3	5.1	-0.5
27-Jun-2019	178	309.9	3.5	28	307.5	1.8	-0.8	309.1	1.8	-0.3

11.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 315 for R6 (Figure 23) and 669 for R5 (Figure 24).

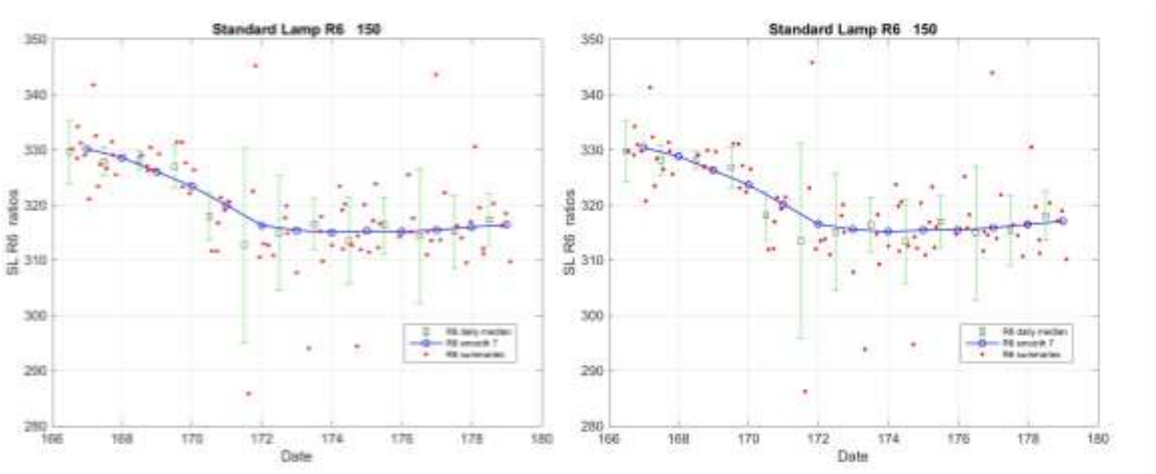


Figure 23. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

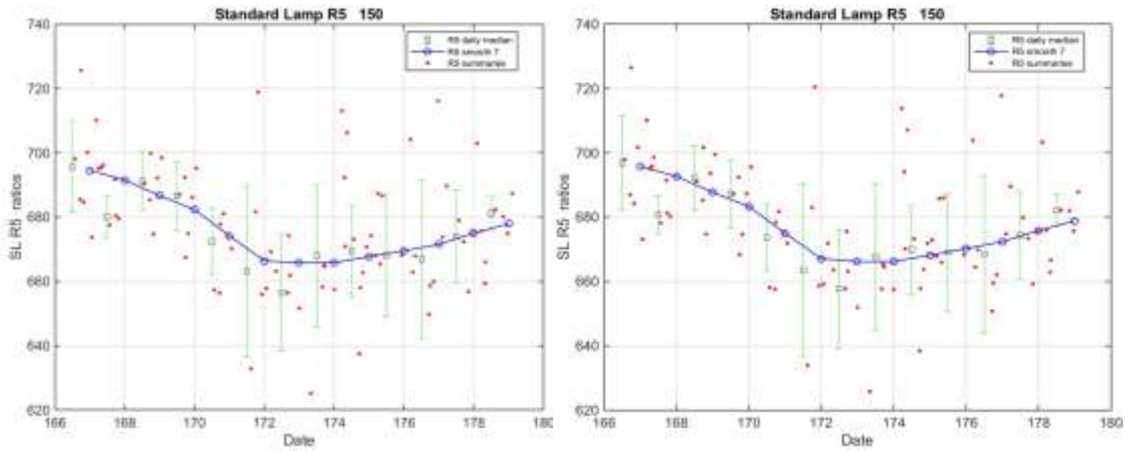


Figure 24. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

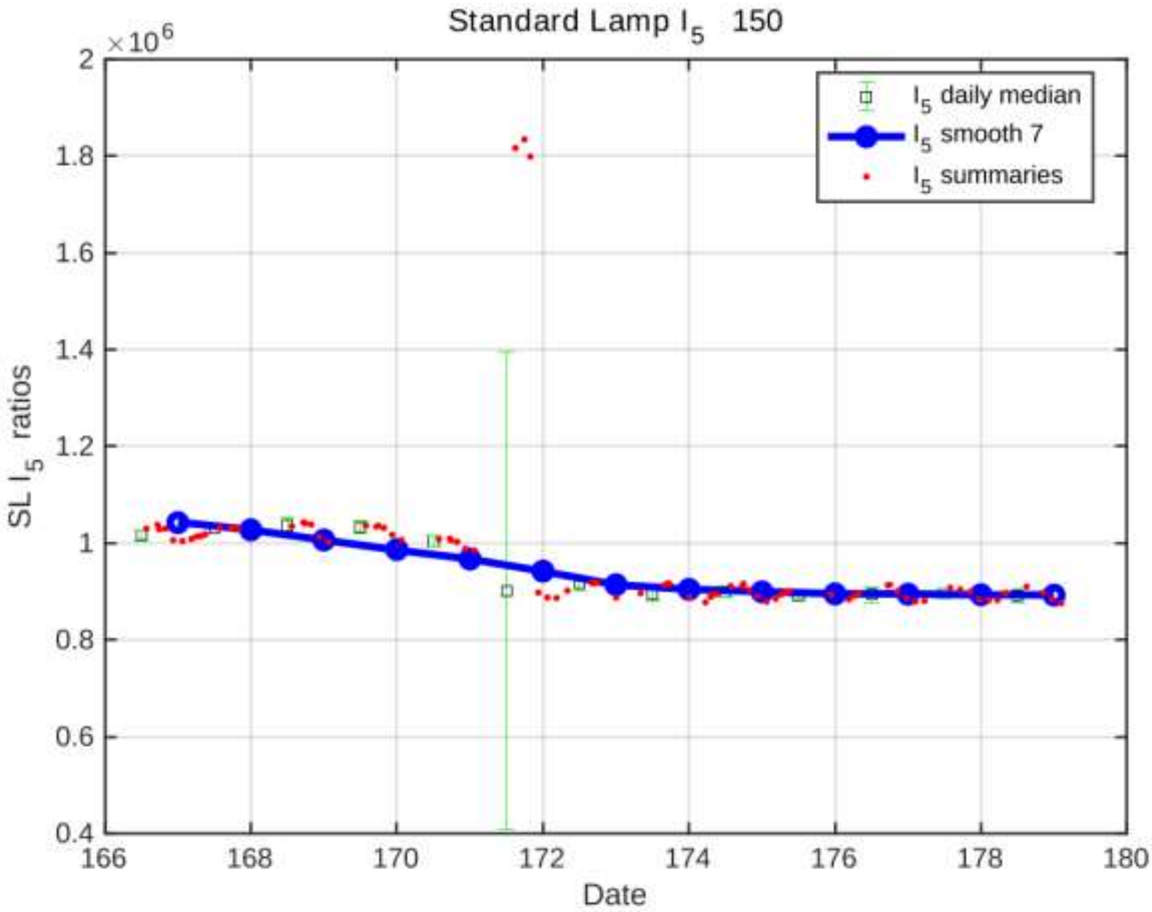


Figure 25. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

11.7. CONFIGURATION

11.7.1. Instrument constant file

	Initial (ICF15617.150)	*Final (ICF17519.150)*
o3 Temp coef 1	0	0
o3 Temp coef 2	1.31	1.31
o3 Temp coef 3	1.93	1.93
o3 Temp coef 4	2.13	2.13
o3 Temp coef 5	2.01	2.01
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3405	0.341
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.142	1.142
ETC on O3 Ratio	1580	1570

	Initial (ICF15617.150)	*Final (ICF17519.150)*
ETC on SO2 Ratio	140	140
Dead time (sec)	3.2e-08	2.9e-08
WL cal step number	1031	1031
Slitmask motor delay	94	94
Umkehr Offset	2452	2452
ND filter 0	0	0
ND filter 1	4281	4281
ND filter 2	9355	9355
ND filter 3	13935	13935
ND filter 4	21690	21690
ND filter 5	25000	25000
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	7122	7122
Mic #2 Offset	6487	6487
O3 FW #3 Offset	178	178
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2525	2525
Grating Slope	1.0009	1.0009
Grating Intercept	-12.8	-12.8
Micrometre Zero	1728	1728

	Initial (ICF15617.150)	*Final (ICF17519.150)*
Iris Open Steps	250	250
Buffer Delay (s)	0	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	33	33
Zenith UVB Position	2228	2228

11.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#150*	*O3 std*	*%diff*	*(*)O3#150*	*O3 std*	*(*)%diff*
166	1500> osc> 1000	346	1.1	5	347	0.9	0.1	347	0.9	0.1
166	700> osc> 400	325	0.7	6	324	0.5	-0.2	324	0.5	-0.2
167	700> osc> 400	341	1.6	10	336	2.8	-1.5	336	2.8	-1.5
168	700> osc> 400	317	3.0	17	313	1.8	-1.3	313	1.8	-1.3
168	osc< 400	313	1.6	18	311	2.5	-0.6	311	2.5	-0.6
169	osc< 400	322	2.0	6	322	1.5	-0.1	322	1.5	-0.1
171	1500> osc> 1000	322	0.4	6	323	1.1	0.4	323	1.0	0.3
171	1000> osc> 700	326	3.8	10	328	3.8	0.7	328	3.7	0.7
171	700> osc> 400	334	3.6	25	334	3.8	0.2	334	3.9	0.0
171	osc< 400	336	0.9	23	334	2.0	-0.5	334	2.0	-0.7
172	1000> osc> 700	334	1.3	3	337	3.3	0.9	337	3.3	0.9
172	700> osc> 400	335	3.2	33	335	3.7	0.0	335	3.7	0.1
172	osc< 400	340	2.0	25	338	2.9	-0.5	338	2.9	-0.5
173	1500> osc> 1000	325	1.2	9	328	0.8	0.7	328	0.8	0.7
173	1000> osc> 700	328	0.5	9	329	0.7	0.3	329	0.7	0.3
173	700> osc> 400	326	1.6	19	326	1.1	-0.1	326	1.1	0.0
173	osc< 400	329	1.4	21	326	1.7	-0.8	327	1.8	-0.6
174	1500> osc> 1000	318	4.6	12	322	3.5	1.2	322	3.5	1.1
174	1000> osc> 700	321	3.6	20	324	2.7	0.9	324	2.6	0.9
174	700> osc> 400	323	1.8	28	324	1.1	0.3	324	1.1	0.2
174	osc< 400	327	1.0	19	325	1.8	-0.6	324	1.8	-0.7
175	osc> 1500	309	0.4	2	311	1.8	0.8	311	1.8	0.8

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#150*	*O3 std*	*%diff*	*(*)O3#150*	*O3 std*	*(*)%diff*
175	1500> osc> 1000	307	1.3	11	312	0.9	1.4	312	0.9	1.4
175	1000> osc> 700	307	1.2	10	309	2.7	0.6	310	2.8	0.7
175	700> osc> 400	307	0.6	17	306	1.4	-0.3	306	1.4	-0.2
175	osc< 400	307	0.3	2	305	1.5	-0.5	306	1.5	-0.4
176	osc> 1500	308	0.1	2	310	1.7	0.6	310	1.7	0.6
176	1500> osc> 1000	307	2.3	9	311	1.3	1.1	311	1.3	1.1
176	1000> osc> 700	307	2.2	10	310	1.1	1.1	310	1.1	1.1
176	700> osc> 400	308	1.6	22	308	1.7	-0.1	308	1.6	-0.1
176	osc< 400	310	1.3	18	307	1.9	-1.1	307	1.9	-1.2
177	1000> osc> 700	311	5.9	9	314	4.7	0.8	314	4.7	0.9
177	700> osc> 400	313	3.9	20	312	4.7	-0.2	312	4.7	-0.1
177	osc< 400	310	1.3	16	306	2.1	-1.4	306	2.0	-1.4
178	1500> osc> 1000	302	1.7	3	304	3.1	0.7	304	3.3	0.8
178	1000> osc> 700	305	0.6	5	308	0.5	1.2	309	0.4	1.3
178	700> osc> 400	309	2.9	17	308	1.9	-0.1	309	1.9	0.1
178	osc< 400	312	2.5	17	308	1.7	-1.0	309	1.7	-0.8

11.9. APPENDIX: SUMMARY PLOTS

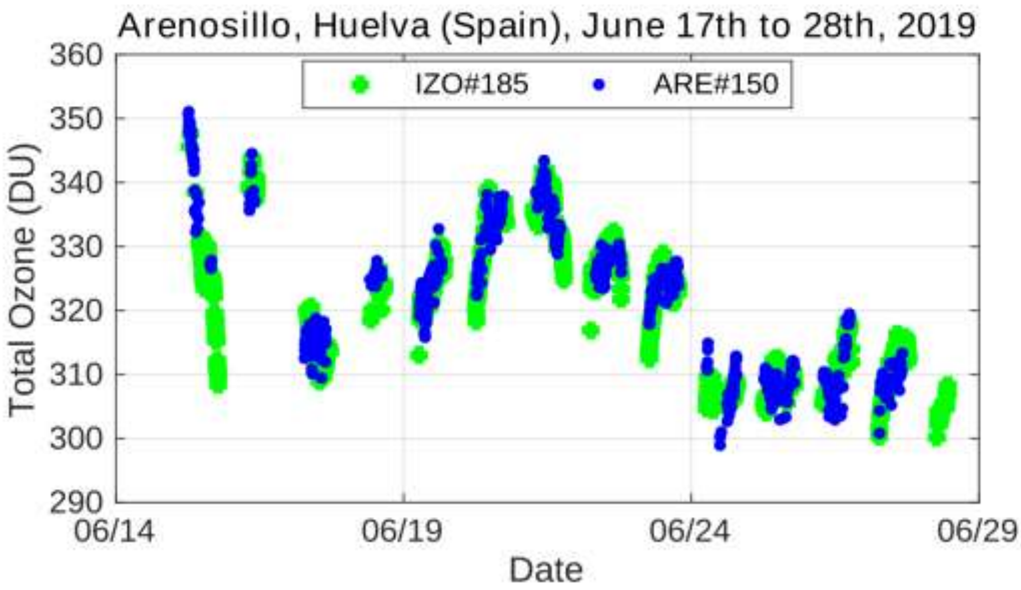
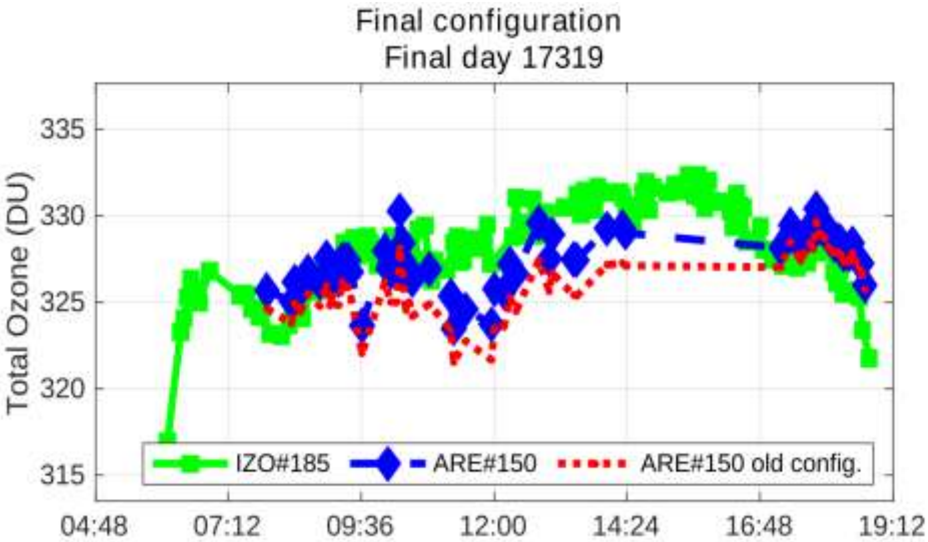
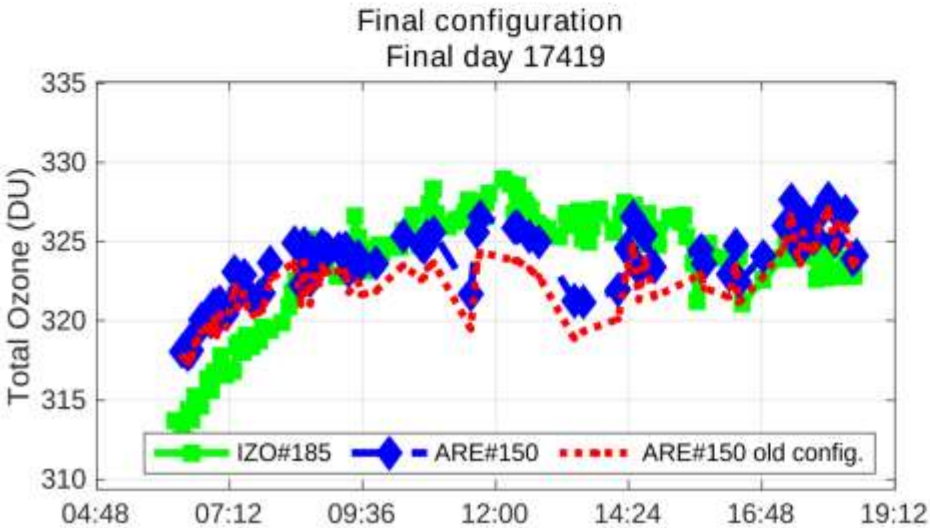
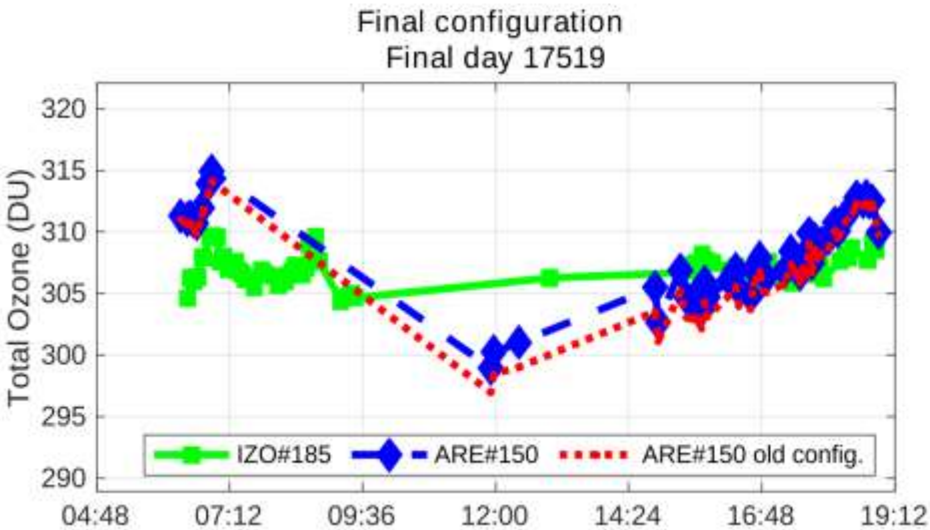
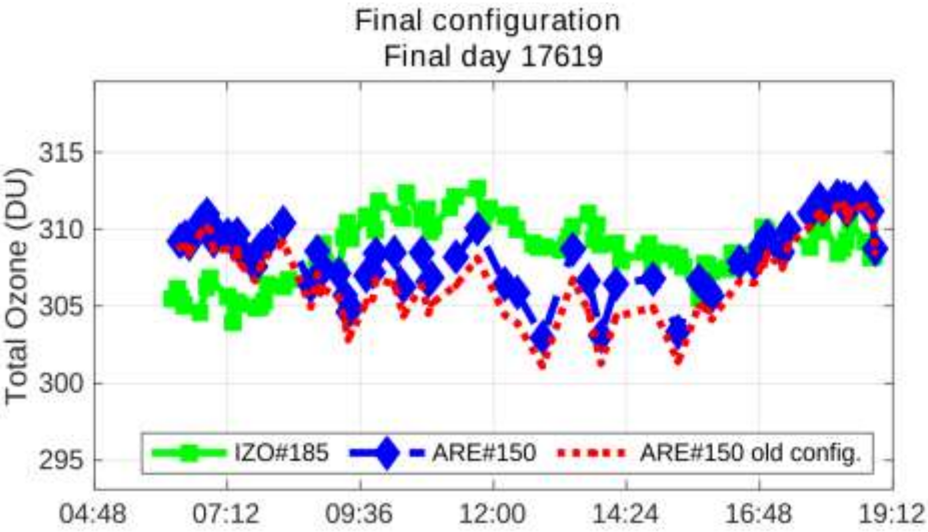


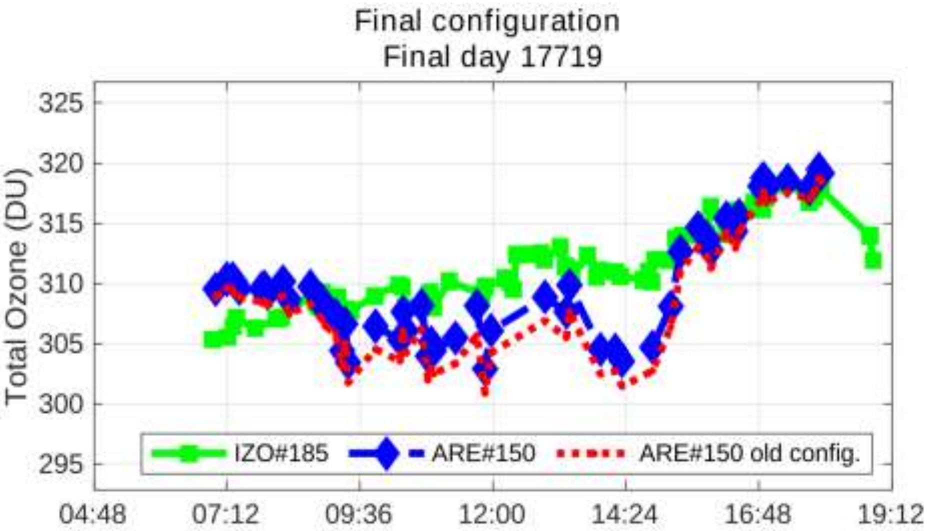
Figure 26. Overview of the intercomparison. Brewer ARE#150 data were evaluated using final constants (blue circles)

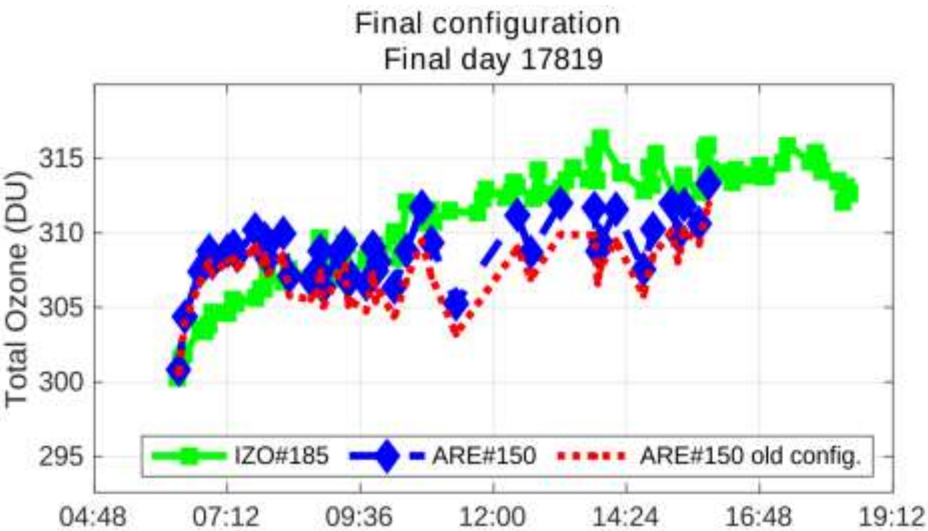

Final configuration
Final day 17319
Total Ozone (DU)
335
330
325
320
315
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
ARE#150
ARE#150 old config.


Final configuration
Final day 17419
Total Ozone (DU)
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
ARE#150
ARE#150 old config.


Final configuration
Final day 17519
Total Ozone (DU)
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
ARE#150
ARE#150 old config.


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
IZO#185
ARE#150
ARE#150 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
295
IZO#185
ARE#150
ARE#150 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17819
Total Ozone (DU)
315
310
305
300
295
IZO#185
ARE#150
ARE#150 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12

12. BREWER COR#151

12.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer COR#151 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer COR#151 correspond to Julian days 166 – 178.

For the evaluation of the initial status, we used 185 simultaneous direct sun (DS) ozone measurements from days 166 to 173. For final calibration purposes, we used 205 simultaneous DS ozone measurements taken from day 174 to 178.

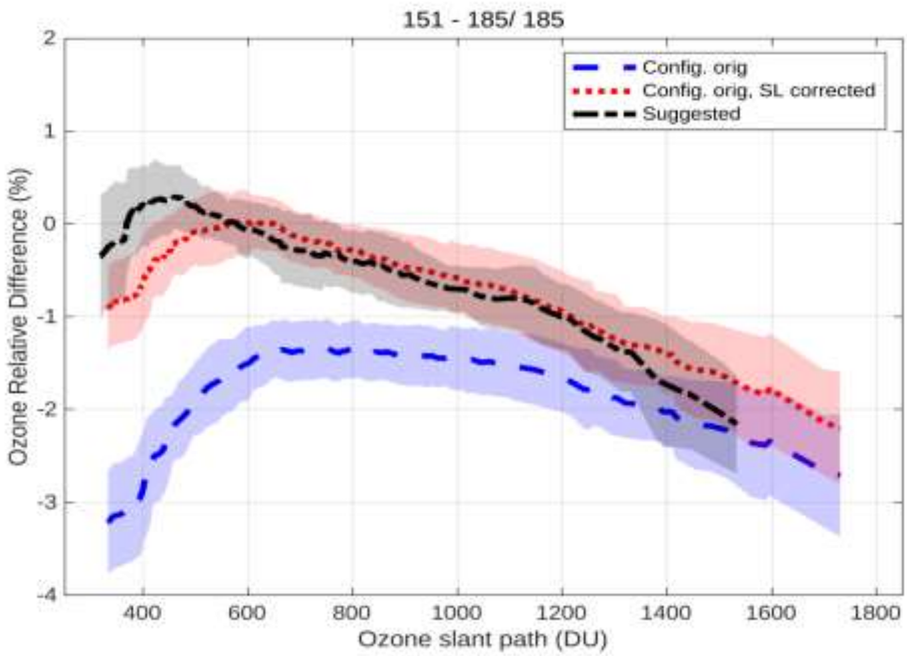


Figure 1. Mean DS ozone column percentage difference between Brewer COR#151 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15317.151, blue dashed line) produces ozone values with an average difference of around 1.5% with respect to the reference instrument. The SL correction (Figure 1, red dotted line) greatly improves the comparison and is recommended to process the observations between the calibrations.

As a Mk. IV model, Brewer COR#151 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 1.6).

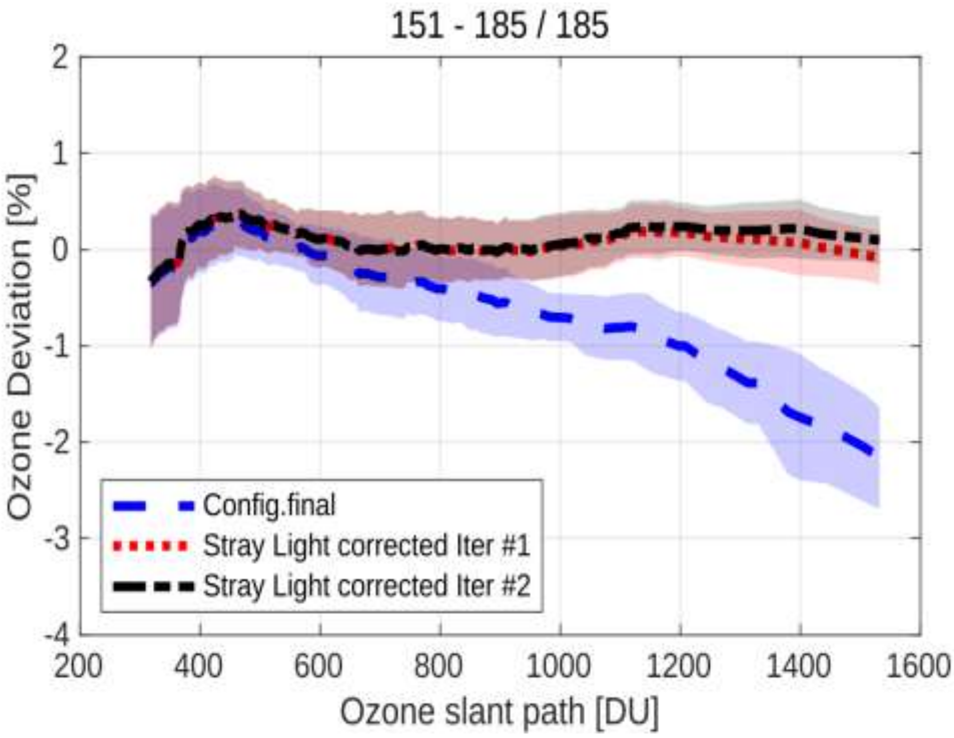


Figure 2. Mean DS ozone column percentage difference between Brewer COR#151 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) show reasonable results, with the exception of the dead time (DT) which shows a big oscillation on the lower intensity value. During the maintenance its value changed from $3.4 \cdot 10^{-8}$ s to $3.6 \cdot 10^{-8}$ s. This is a significant change for single Brewers.

Concerning filter performance, we suggest the use of a correction factor of -15 for Filter#4 and performing regular filter tests (FI.RTN).

The sun scan tests (SC) at the instrument’s station before the campaign and those performed during the first days of the intercomparison, confirm the current cal step value (288, within a step error of ± 1).

We do not suggest changing the ozone absorption coefficient, retaining its current value of 0.3417.

Taking this into account, we suggest very few (if any) changes to the configuration of Brewer COR#151.

12.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer COR#151 have been very stable over the last 2 years. The old R6 reference value was 1880 and, although the difference is almost within the acceptable error of ± 5 , it could be updated to 1870.
2. We suggest a new R5 reference value of 3460.
3. We suggest updating the DT to $3.6 \cdot 10^{-8}$ seconds and follow the evolution of the DT test.
4. We suggest the application of an ETC correction of 15 units for filter#4, performed regularly to enable the filter test to monitor the nonlinearity of the filters.
5. We suggest looking carefully at the power supply performance and the results of the DT test in the future.
6. 6. For Brewer COR#151, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -26.5$, and $s = b = 3.84$.
7. Finally, we suggest updating the ETC value from 3120 to 3118.

12.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/151/ICF17419.151

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=401824256

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/151/html/cal_report_151a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/151/html/cal_report_151a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/151/html/cal_report_151b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/151/html/cal_report_151c.html

12.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

12.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance shows a seasonal behaviour with mean values around 1856 25 units less than the reported reference 1880. The R5 does not show the seasonality with a mean value of 3442. The Intensity of the lamp also shows this dependence 5.

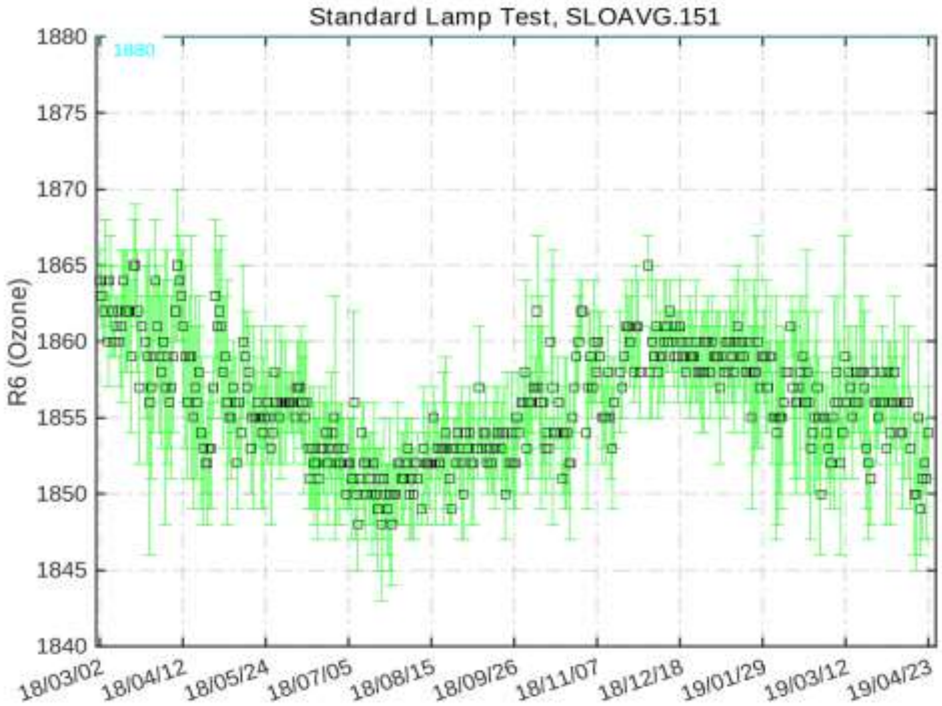


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

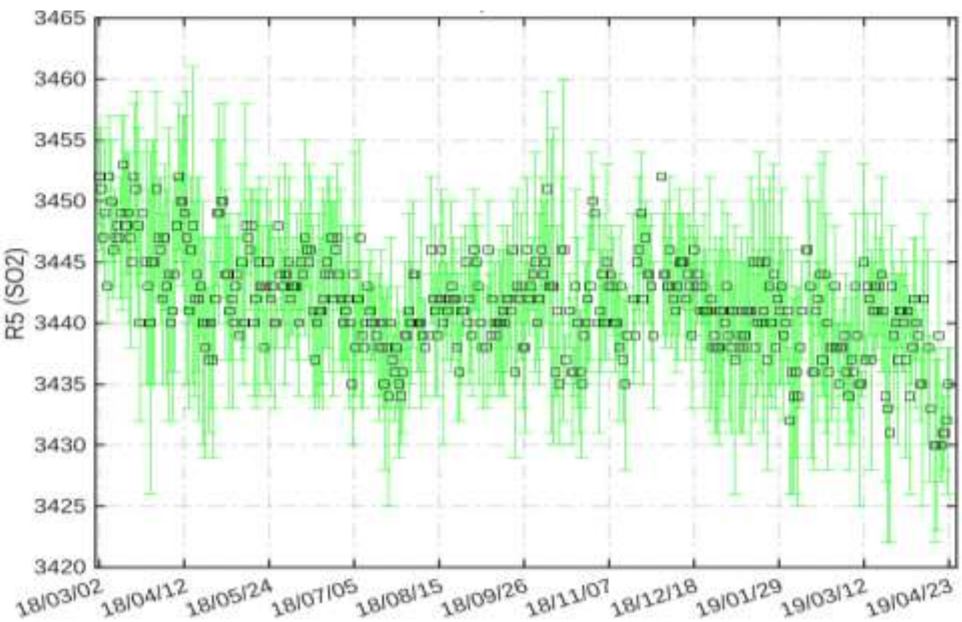


Figure 4. Standard lamp test R5 sulphur dioxide ratios

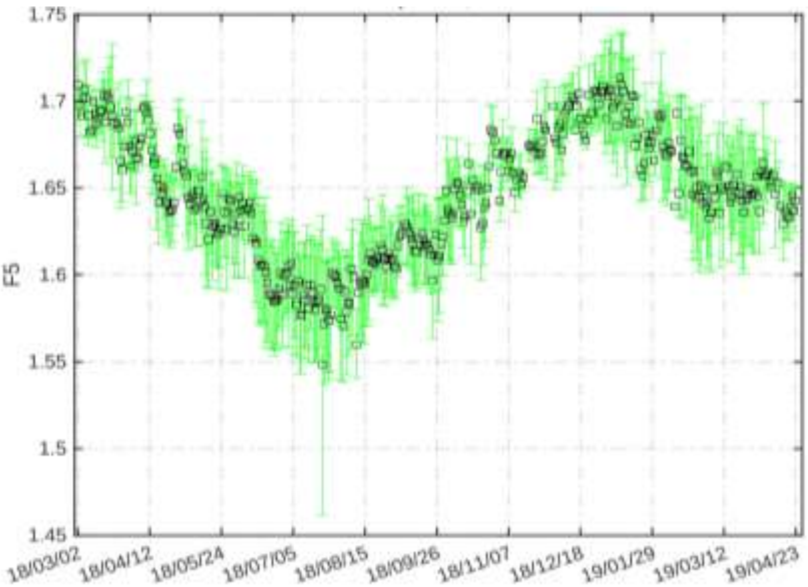


Figure 5. SL intensity for slit five

12.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits, see Figure 6.

As shown in Figure 7, the current DT reference value of $3.4 \cdot 10^{-8}$ seconds is lower than the value recorded during the calibration period of $3.7 \cdot 10^{-8}$ s. The record of low intensity value is quite different from the high intensity and shows huge seasonality, probably related to the anomalies also detected in the analogue test. Therefore, this new value has been used in the new ICF and we recommend looking carefully at the power supply performance and the results of DT test in the future.

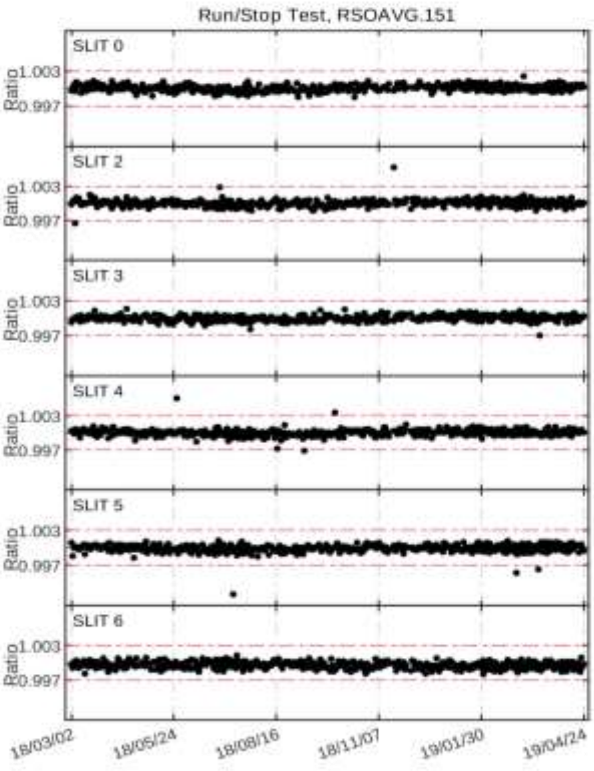


Figure 6. Run/stop test

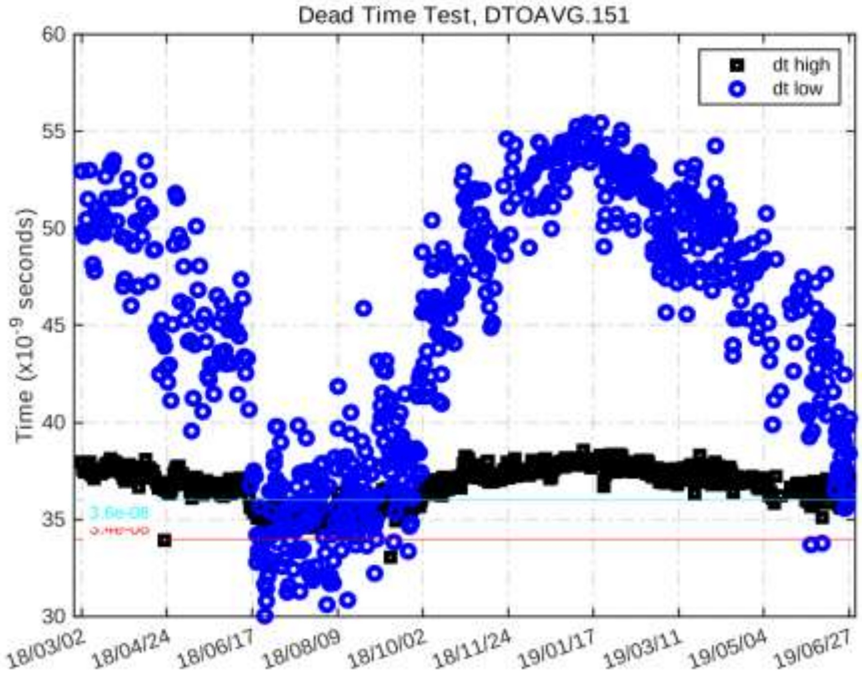


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

12.2.3. Analogue test

Figure 8 shows that high voltage has remained almost constant at around 1400 over the last two years but with periods of anomalous high values also reflected on the lamp current and voltage records.

Analogue Printout Log, APOAVG.151

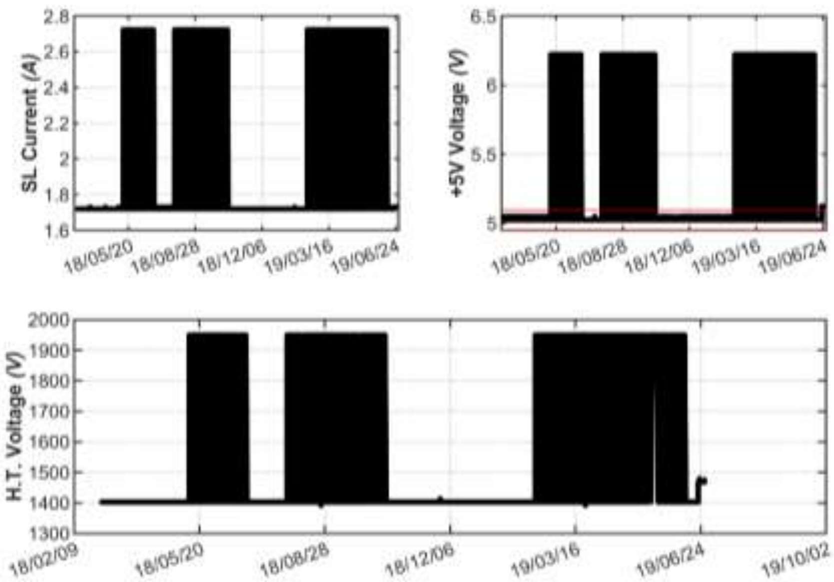


Figure 8. Analogue voltages and intensity

12.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events have been observed during the campaign (see Figure 9).

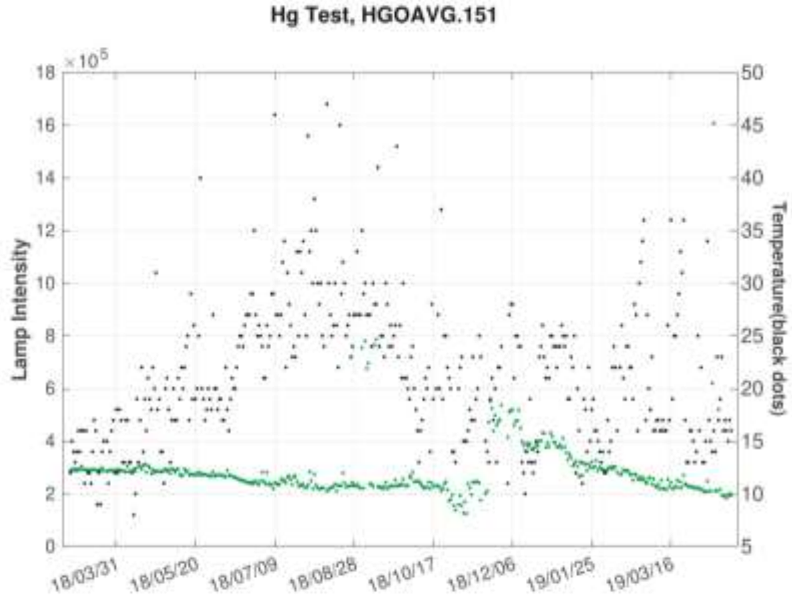


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

12.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 10). As a reference, the calculated scan peak in wavelength units should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer COR#151 during the campaign showed reasonable results, with the peak of the calculated scans close to, although slightly below, the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM value lower than 0.65 nm.

Analysis of CZ scans performed on Brewer COR#151 during the campaign shows a discrepancy between the calculated line peak and the nominal value just slightly above the upper tolerance limit (see Figure 10).

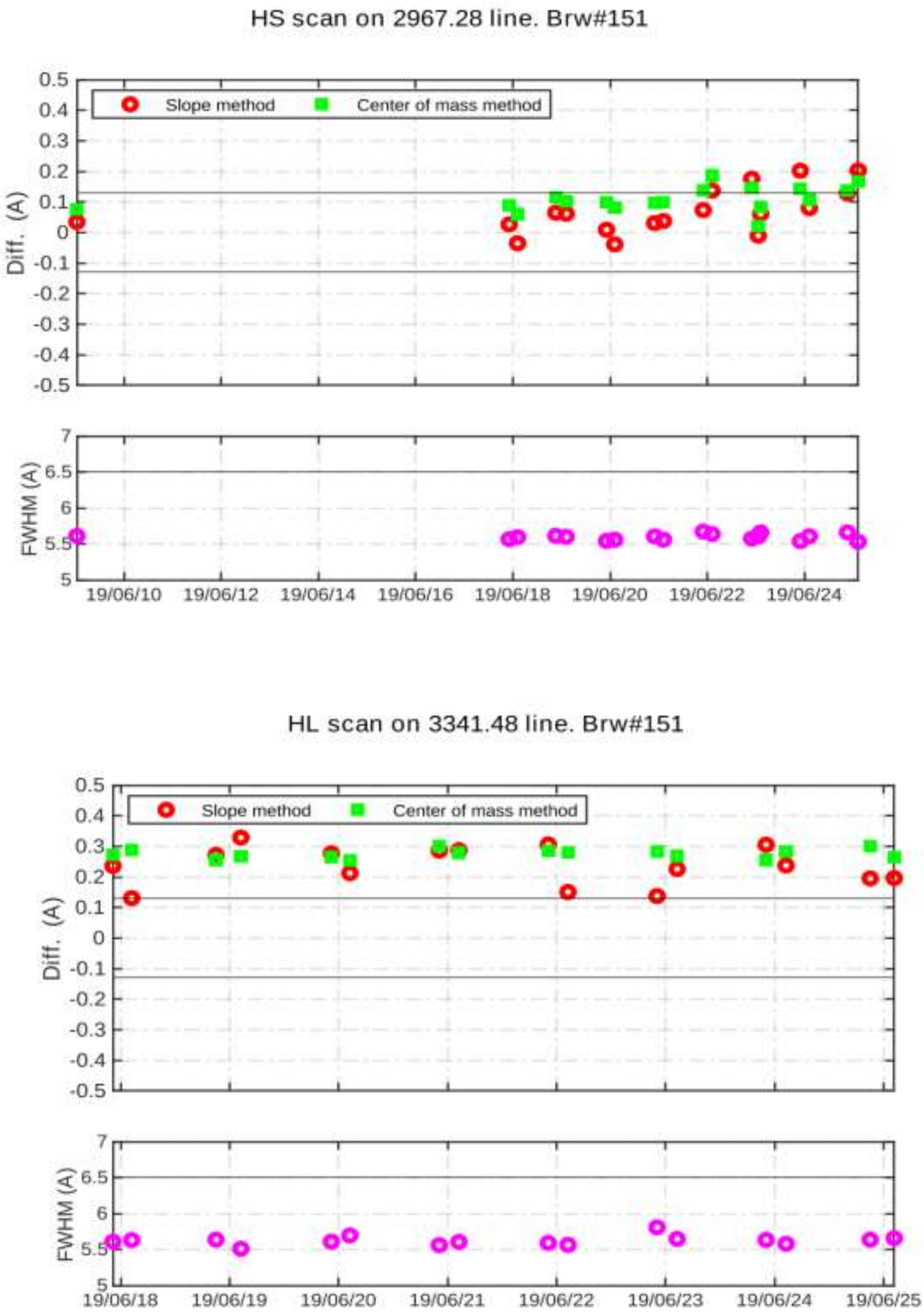


Figure 10. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

12.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer COR#151 CI scans performed during the campaign relative to the scan CI17217.151. As can be observed, lamp intensity varied with respect to the reference spectrum by around 10% during maintenance.

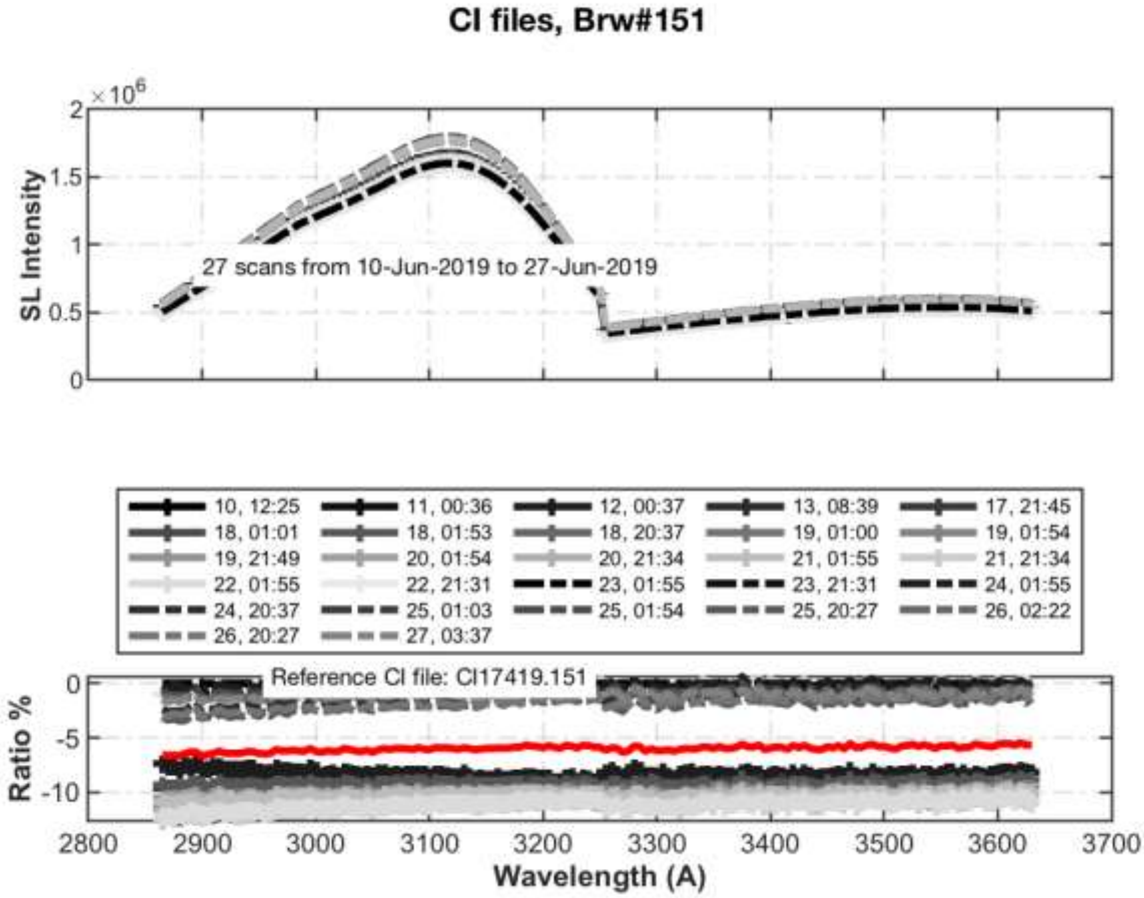


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

12.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 12 (temperature range from 19° C to 38° C), the current temperature coefficients give a good correction. The values of the coefficients are summarized in Table 1. However, due the seasonality on R6 record, a new set of temperature coefficients are calculated (Figure 13) which improves the temperature dependence observed (14) and is used on the final configuration.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2.

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.9600	-2.5000	-4.3430	-6.6470
Campaign	0.0000	-0.6000	-1.1000	-1.6000	-2.7000
Calculated	0.0000	-0.6400	-1.1000	-1.6500	-3.1400

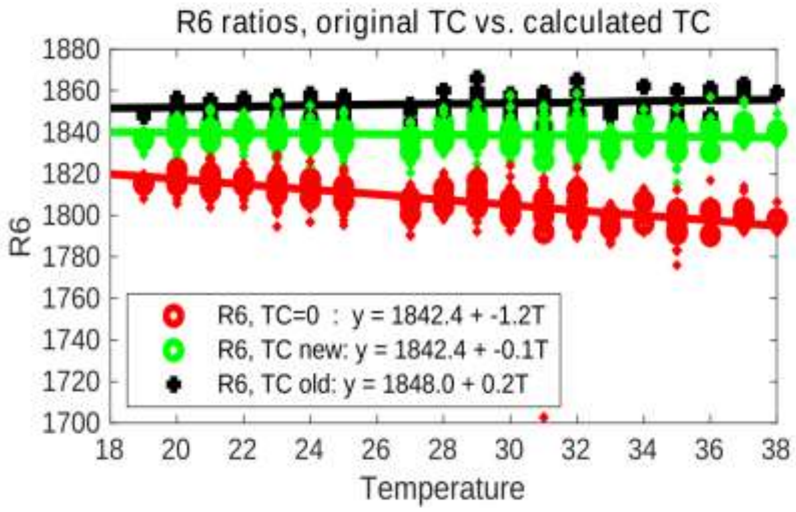


Figure 12. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

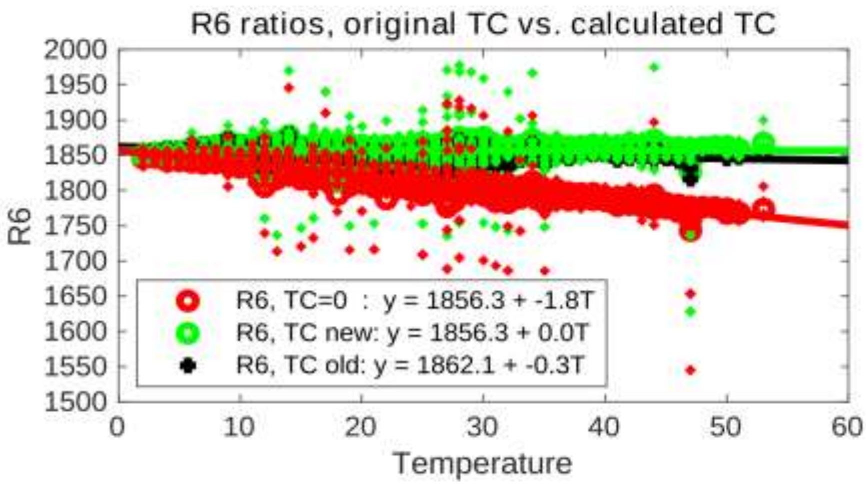


Figure 13. Same as Figure 12 but for the whole period between calibration campaigns

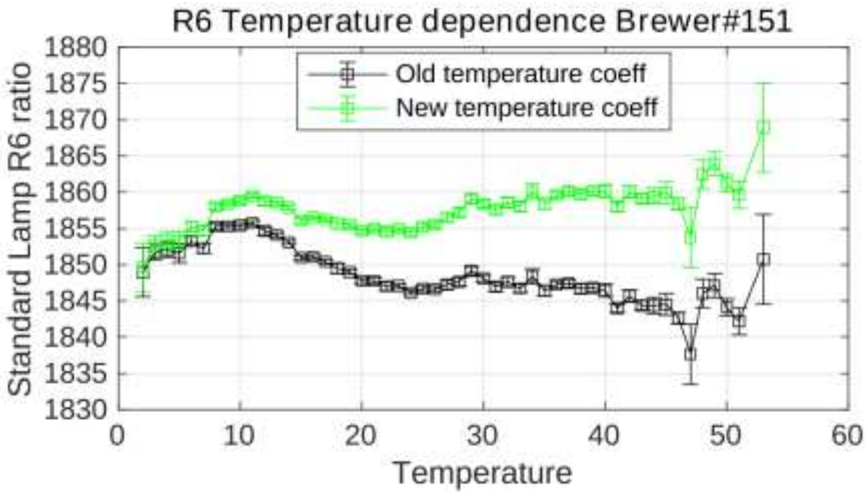


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

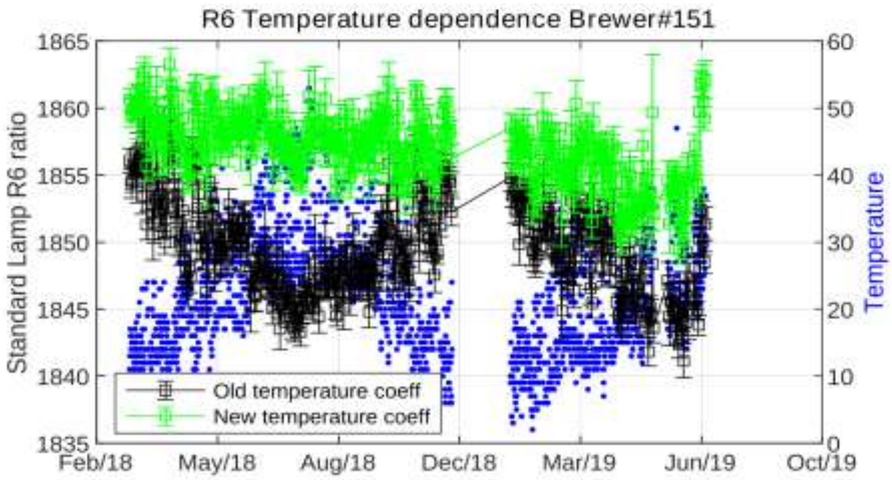


Figure 15. Standard lamp R6 (MS9) ratio and temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

12.4. ATTENUATION FILTER CHARACTERIZATION

12.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 28 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 16 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

There were not many tests and none of the filter corrections calculated were significative. However, the measurements with filter ND#4 clearly need correction (see blind days plots which are not corrected in section 2).

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-7	2	0	2	9
ETC Filt. Corr. (mean)	-8.6	-12.3	-15.8	0.3	-30
ETC Filt. Corr. (mean 95% CI)	[-22.9 1.7]	[-33.8 0.8]	[-33.5 -3.5]	[-22.8 22.1]	[-56.6 -7.5]

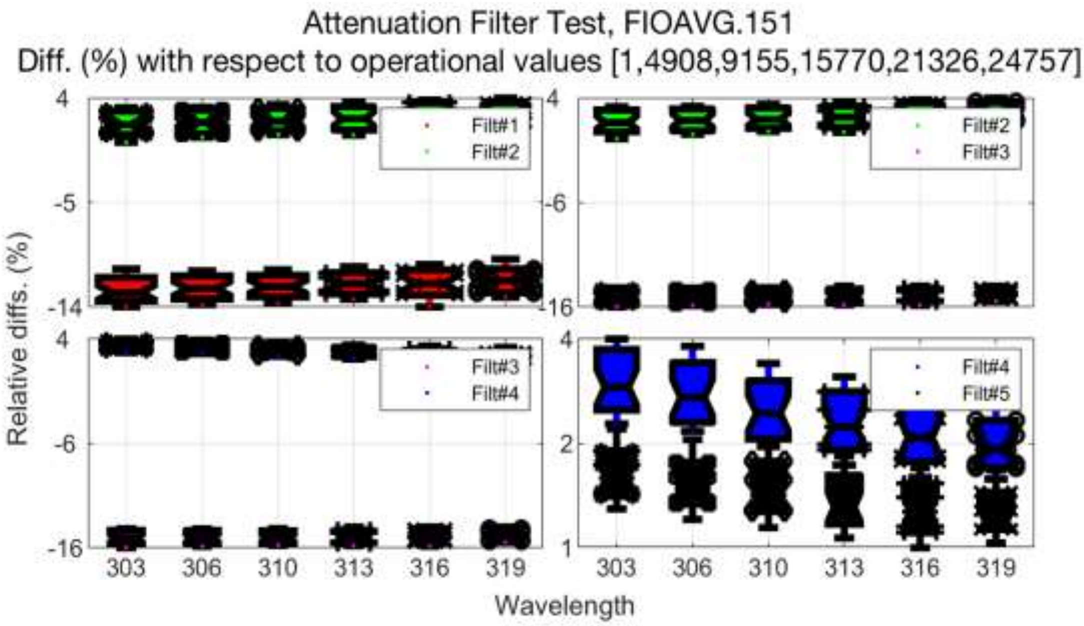


Figure 16. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

Calculated mean attenuation values for every filter are compared with operational values (see Table 3 and Figure 16), updating them (ICF file) when necessary. Individual values for every wavelength and every filter should be used for aerosol optical depth calculations. In the case of Brewer COR#151, the calculated mean attenuation values for every filter are similar to the operational values (relative percentage differences on the order of 5%), whereas the observed transitions between successive filters are much higher (20%) than recommended (relative percentage differences lower than 10% when changing filter).

Table 3. Filter attenuation by wavelength

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
slit#0	4277	9278	13451	21939	25137
slit#1	4294	9296	13454	21907	25096
slit#2	4301	9305	13456	21857	25076
slit#3	4313	9324	13466	21815	25032
slit#4	4315	9338	13477	21781	25015
slit#5	4327	9352	13486	21745	24979
mean	4304	9315	13465	21840	25055

12.5. WAVELENGTH CALIBRATION

12.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 17).

During the campaign, 9 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out (see Figure 18). The calculated cal step number (CSN) at the campaign and at the station confirm the current CSN of 288.

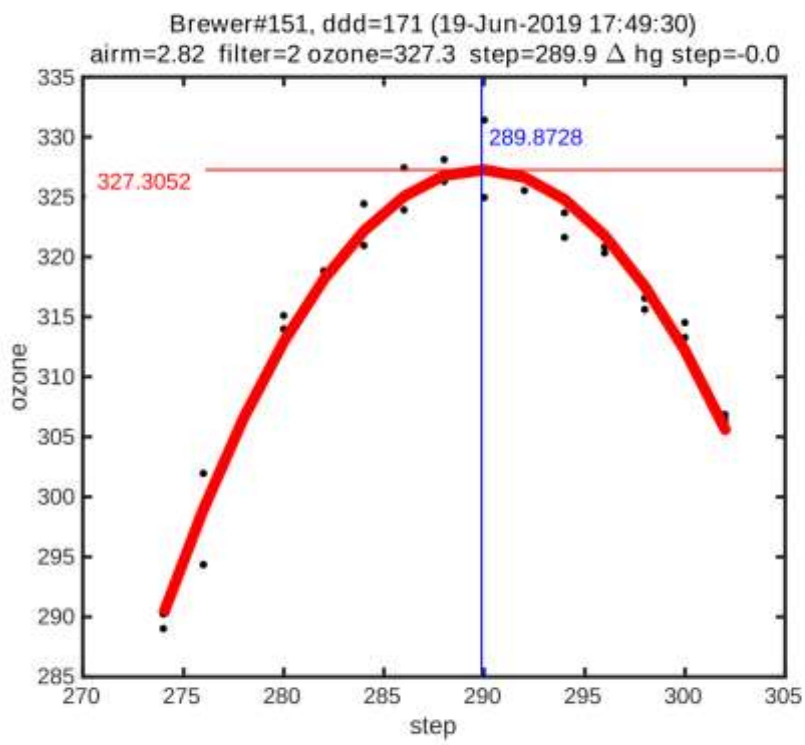


Figure 17. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

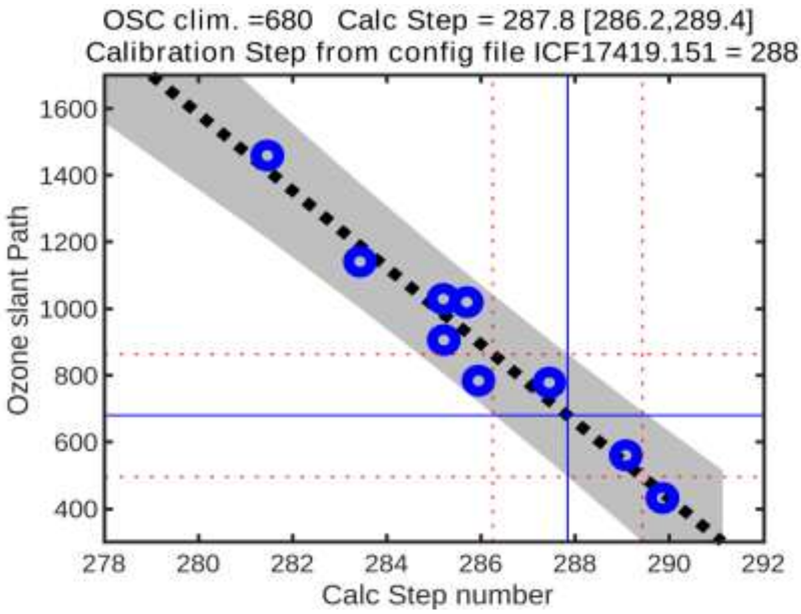


Figure 18. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

12.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 4.

For the current campaign in particular, Figure 19 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 5 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

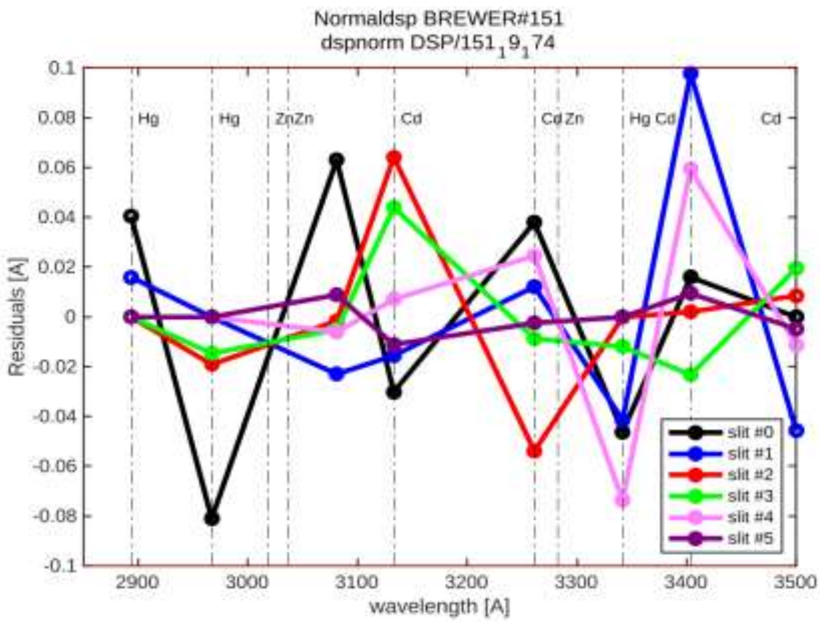


Figure 19. 2019 Residuals of quadratic fit

The dispersion tests confirm the current setting and the absorption coefficient equal to 0.3417 is suggested in the final configuration.

Table 4. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	288	0.3417	2.3500	1.1428
09-Jul-2011	288	0.3409	3.1981	1.1426
14-Jun-2013	288	0.3431	3.1860	1.1502
02-Jun-2015	288	0.3428	3.1935	1.1479
01-Jun-2017	288	0.3404	3.1903	1.1438
23-Jun-2019	288	0.3426	3.1935	1.1469
Final	288	0.3417	2.3500	1.1428

Table 5. 2019 Dispersion derived constants

step= 287	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.92	3062.96	3100.4	3134.9	3167.94	3199.8
Res(A)	5.6121	5.5212	5.4231	5.542	5.458	5.367
O3abs(1/cm)	2.5989	1.7813	1.0053	0.67699	0.3749	0.29519
Ray abs(1/cm)	0.50506	0.48326	0.45854	0.43717	0.41789	0.40031
SO2abs(1/cm)	3.4357	5.6334	2.3959	1.9186	1.0539	0.61766
step= 288	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.99	3063.03	3100.47	3134.97	3168.01	3199.87
Res(A)	5.612	5.5211	5.423	5.5419	5.4579	5.367
O3abs(1/cm)	2.5962	1.7797	1.005	0.67669	0.37496	0.2947
Ray abs(1/cm)	0.50501	0.48321	0.45849	0.43713	0.41785	0.40027
SO2abs(1/cm)	3.4197	5.6552	2.4033	1.907	1.0551	0.61553
step= 289	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.06	3063.1	3100.54	3135.04	3168.08	3199.94
Res(A)	5.6119	5.521	5.4229	5.5418	5.4578	5.3669
O3abs(1/cm)	2.5936	1.7781	1.0048	0.67632	0.37503	0.29424
Ray abs(1/cm)	0.50496	0.48316	0.45845	0.43709	0.41781	0.40024
SO2abs(1/cm)	3.4052	5.6769	2.4114	1.8955	1.0563	0.61334
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
287	0.34384	11.2348	3.1837	1.1514	0.35428	0.34566
288	0.34275	11.2328	3.1935	1.1479	0.35336	0.34471
289	0.34175	11.2308	3.2031	1.1445	0.35241	0.34373

12.5.3 Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1703. Table 6 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 6. 2019 Umkehr dispersion constants

step= 288	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.551	5.5244	5.418	5.5081	5.4684	5.4065
O3abs(1/cm)	2.595	1.7812	1.0052	0.67709	0.37489	0.29483
Ray abs(1/cm)	0.50499	0.48326	0.45852	0.43716	0.41793	0.4003
step= 1704	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.4497	5.4119	5.3087	5.4118	5.344	5.2714
O3abs(1/cm)	0.679	0.39632	0.29526	0.12432	0.061456	0.033363
Ray abs(1/cm)	0.43793	0.42032	0.4003	0.38288	0.36722	0.35281

12.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

For single monochromator Brewers, the ETC distribution shows (see Figure 1) a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content by airmass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column.

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 5 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

12.6.1. Initial calibration

For the evaluation of the initial status of Brewer COR#151, we used the period from days 166 to 173 which corresponds with 185 near-simultaneous direct sun ozone measurements. As shown in Figure 20, the initial calibration constants produced ozone values 2% lower than the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results improve and the ozone is around 1% lower (see Table 8).

Table 7 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 8, as well as relative differences with respect to IZO#185.

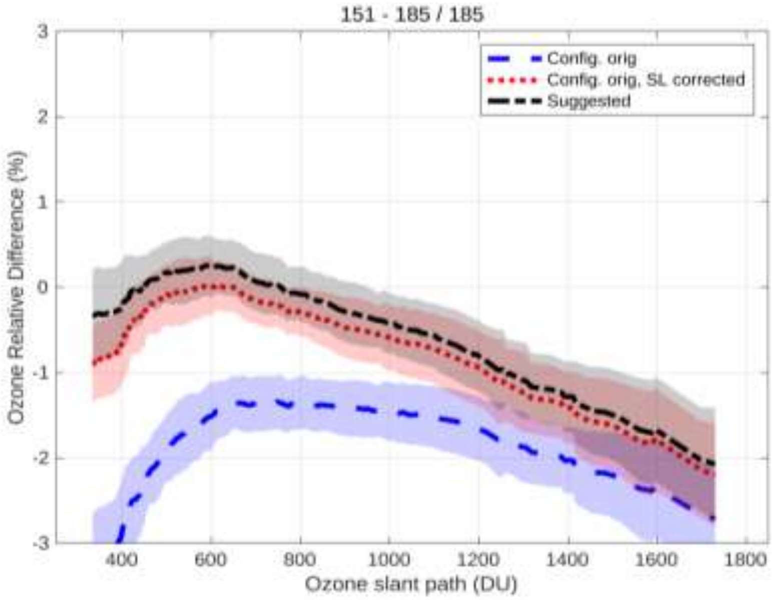


Figure 20. Mean direct sun ozone column percentage difference between Brewer COR#151 and Brewer IZO#185 as a function of the ozone slant path

Table 7. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=600	3085	3079	3417	3432
full OSC range	3085	3097	3417	3390

Table 8. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#151*	*O3 std*	*%(151–185)/185*	*O3(*)#151*	*O3std*	*(*)%(151–185)/185*
19-Jun-2019	170	324.3	3.2	59	316.4	3.9	-2.4	324.5	3.6	0.1
20-Jun-2019	171	335.1	2.9	52	326.7	2.9	-2.5	335	3.1	0
21-Jun-2019	172	336.7	3.3	60	328.1	2.8	-2.6	336.2	3	-0.1
22-Jun-2019	173	328.7	0.9	14	321.3	2.2	-2.3	330.6	2.1	0.6

12.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 21). For the final calibration, we used 205 simultaneous direct sun measurements from days 174 to 178. The new value is similar than the current ETC value (3120) but include the changes of the temperature coefficients and DT. Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (1870 for R6). We updated the new calibration constants in the ICF provided.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 9, the agreement between the 1P and 2P ETCs is good if we include the ND#4 correction.

Mean daily total ozone values for the original and the final configurations are shown in Table 10, as well as relative differences with respect to IZO#185.

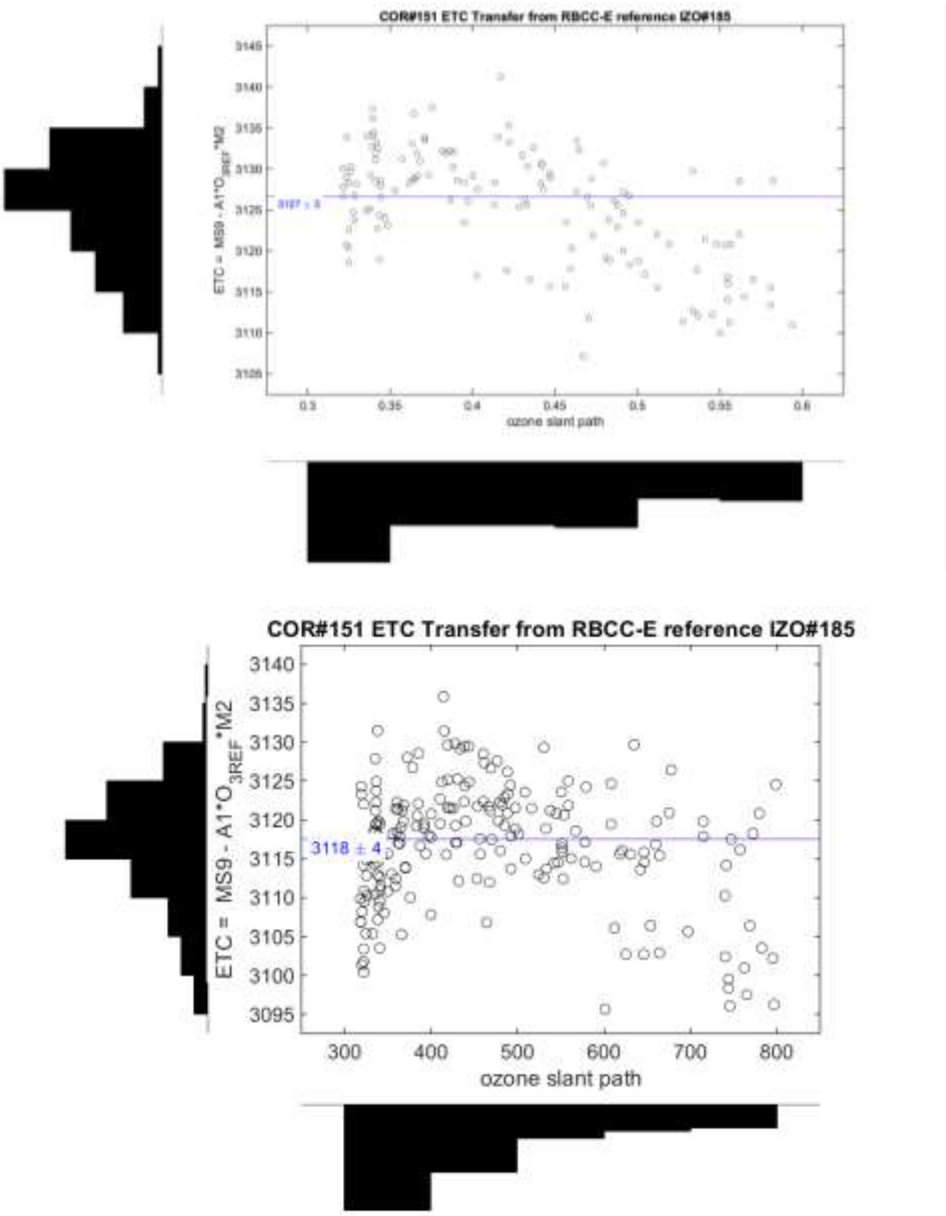


Figure 21. Mean direct sun ozone column percentage difference between Brewer COR#151 and Brewer IZO#185 as a function of the ozone slant path

Table 9. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=800	3118	3114	3417	3426
full OSC range	3115	3149	3417	3343

Table 10. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#151*	*O3 std*	*%(151−185)/185*	*O3(*)#151*	*O3std*	*(*)%(151−185)/185*
22-Jun-2019	173	328.6	2.3	38	320.9	3.1	-2.3	325.8	4.1	-0.9
23-Jun-2019	174	321.8	4.7	58	316.9	4.6	-1.5	321.2	6.7	-0.2
24-Jun-2019	175	307.3	1.2	32	303.4	1.7	-1.3	306.2	1.8	-0.4
25-Jun-2019	176	308.1	2	64	302.6	2.8	-1.8	307.2	3	-0.3
26-Jun-2019	177	311.8	3.8	53	305.7	5.7	-2	311.2	4.2	-0.2
27-Jun-2019	178	NaN	NaN	0	302	2.7	NaN	306.1	4.5	NaN

12.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and an underestimation of 1% at 1000 OSC which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = a = -26.5$, $s = b = 3.84$, and ETC=3119. These parameters produce a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone, an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

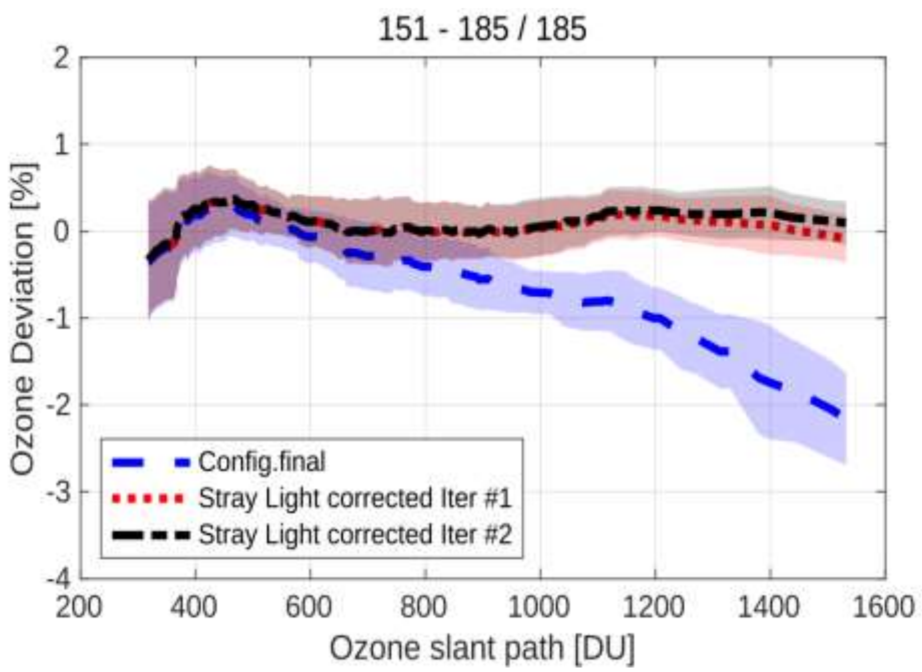


Figure 22. Ratio respect to the reference when the final constants and the stray light correction are applied

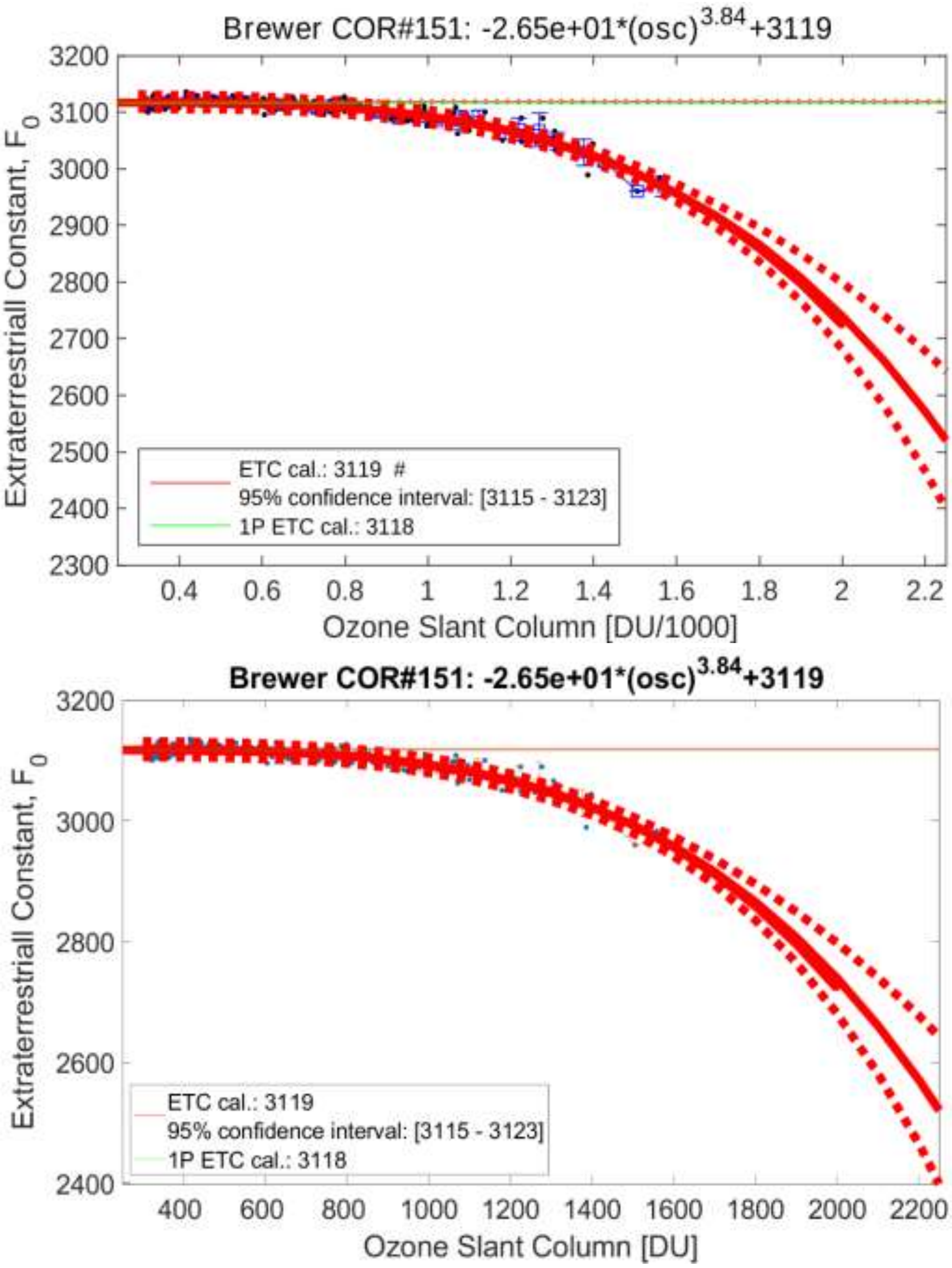


Figure 23. Stray light empirical model determination

12.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1870 for R6 (Figure 24) and 3460 for R5 (Figure 25).

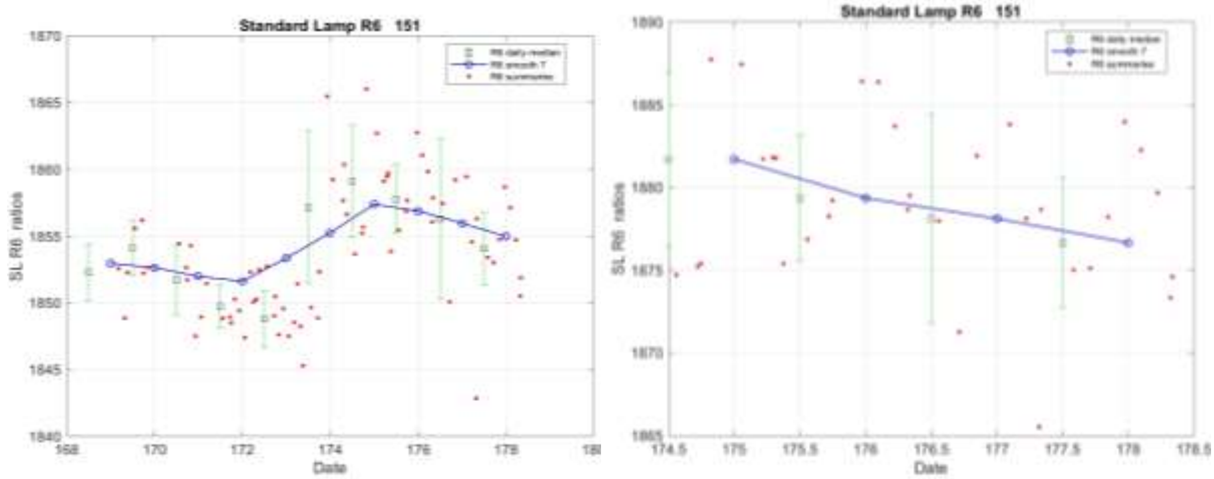


Figure 24. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

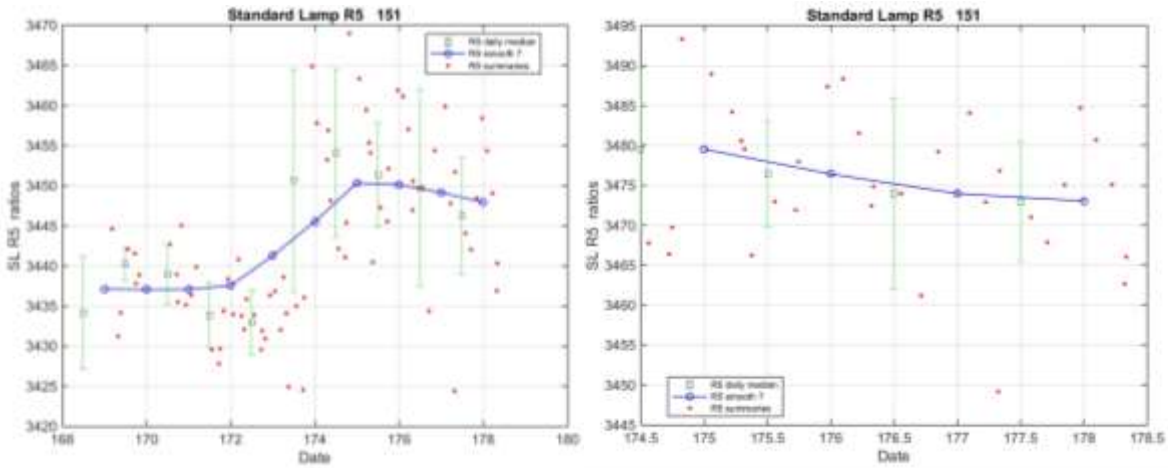


Figure 25. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

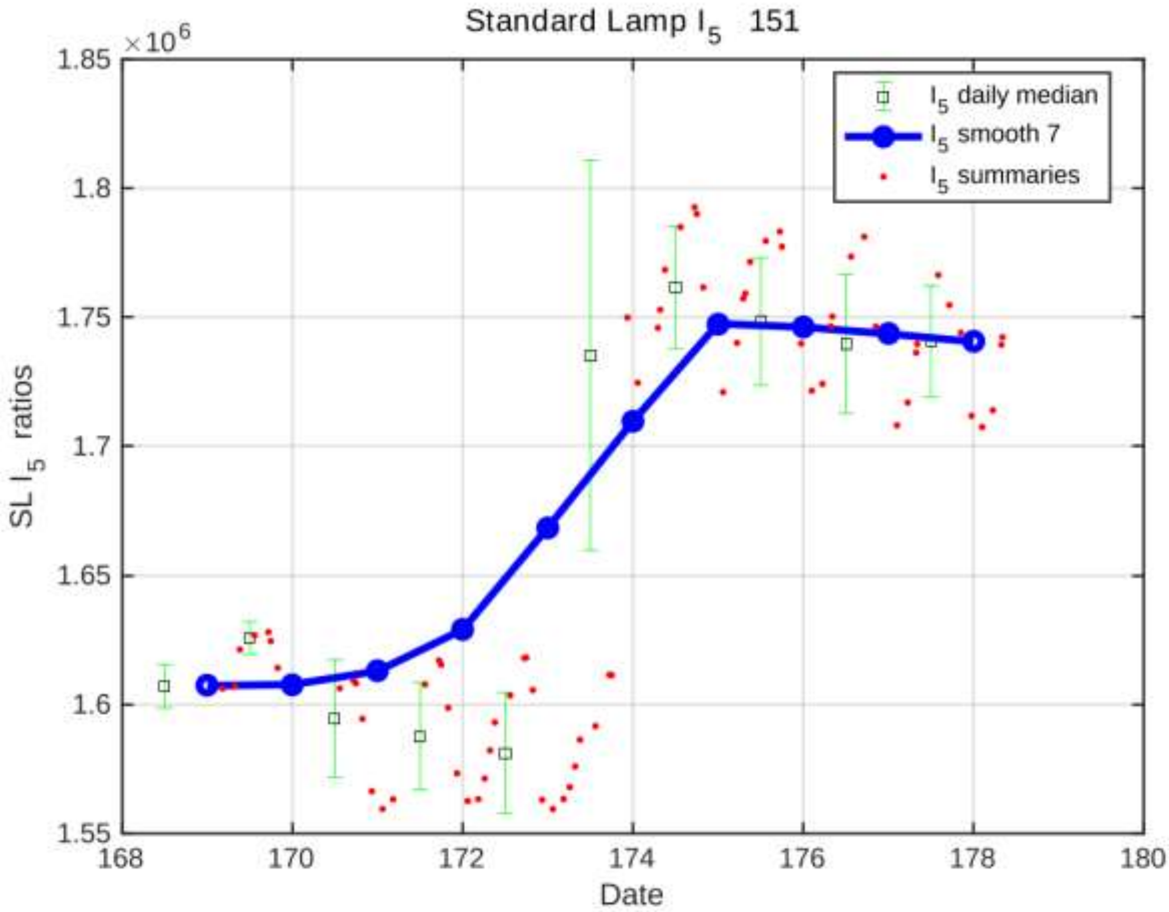


Figure 26. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

12.7. CONFIGURATION

12.7.1 Instrument constant file

	Initial (ICF15317.151)	*Final (ICF17419.151)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.96	-0.64
o3 Temp coef 3	-2.5	-1.1
o3 Temp coef 4	-4.343	-1.65
o3 Temp coef 5	-6.647	-3.14
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3417	0.3417
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1428	1.1428
ETC on O3 Ratio	3120	3118
ETC on SO2 Ratio	3054	3054

	Initial (ICF15317.151)	*Final (ICF17419.151)*
Dead time (sec)	3.4e-08	3.6e-08
WL cal step number	288	288
Slitmask motor delay	96	96
Umkehr Offset	1706	1706
ND filter 0	0	0
ND filter 1	4908	4908
ND filter 2	9155	9155
ND filter 3	15770	15770
ND filter 4	21326	21326
ND filter 5	24757	24757
Zenith steps/rev	2972	2972
Brewer Type	0	0
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	7206	7206
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	750	750
NO2 zs etc	700	700
NO2 Mic #1 Offset	9749	9749
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2540	2540
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	2669	2669

	Initial (ICF15317.151)	*Final (ICF17419.151)*
Iris Open Steps	250	250
Buffer Delay (s)	0.3	0.3
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	60	60
Zenith UVB Position	2220	2220

12.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#151*	*O3 std*	*%diff*	*(*)O3#151*	*O3 std*	*(*)%diff*
170	1500> osc> 1000	317	3.3	3	313	3.3	-1.3	313	3.3	-1.3
170	1000> osc> 700	321	1.4	9	319	2.0	-0.7	319	2.0	-0.7
170	700> osc> 400	324	3.9	34	323	4.1	-0.3	323	4.0	-0.2
170	osc< 400	324	2.6	31	322	2.9	-0.8	322	3.1	-0.5
171	osc> 1500	318	0.0	1	311	0.0	-2.2	311	0.0	-2.2
171	1500> osc> 1000	327	7.1	10	324	7.4	-1.1	324	7.4	-1.1
171	1000> osc> 700	334	4.9	16	333	4.7	-0.4	333	4.7	-0.4
171	700> osc> 400	333	3.8	32	332	3.9	-0.1	333	3.9	-0.1
171	osc< 400	336	1.3	28	334	1.5	-0.6	335	2.3	-0.4
172	osc> 1500	325	0.6	2	318	2.2	-2.2	318	2.2	-2.2
172	1500> osc> 1000	333	3.7	17	330	3.8	-1.0	330	3.8	-1.0
172	1000> osc> 700	333	1.7	21	332	1.6	-0.2	332	1.6	-0.2
172	700> osc> 400	334	3.0	42	334	2.9	-0.1	334	3.0	0.0
172	osc< 400	339	2.0	29	335	2.2	-1.1	336	2.6	-0.8
173	osc> 1500	317	0.0	1	313	0.0	-1.2	313	0.0	-1.2
173	1500> osc> 1000	325	1.3	14	320	3.2	-1.5	320	3.2	-1.5
173	1000> osc> 700	328	0.6	10	327	1.0	-0.1	327	1.0	-0.1
173	700> osc> 400	327	0.0	1	328	0.0	0.3	328	0.0	0.3
173	osc< 400	329	1.4	30	326	1.3	-0.9	328	2.4	-0.5

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#151*	*O3 std*	*%diff*	*(*)O3#151*	*O3 std*	*(*)%diff*
174	osc> 1500	314	0.0	1	305	0.0	-2.8	304	0.0	-3.0
174	1500> osc> 1000	314	1.5	7	310	2.6	-1.2	310	2.6	-1.4
174	1000> osc> 700	317	1.0	9	316	1.6	-0.5	315	1.6	-0.6
174	700> osc> 400	322	2.2	25	323	3.0	0.2	323	3.1	0.2
174	osc< 400	327	1.0	16	325	1.6	-0.6	328	1.3	0.2
175	1500> osc> 1000	307	1.4	10	305	1.7	-0.6	304	1.8	-0.8
175	1000> osc> 700	308	1.6	7	307	0.9	-0.2	307	0.9	-0.4
175	700> osc> 400	307	0.6	13	307	0.8	0.1	307	1.0	0.2
175	osc< 400	307	0.3	2	304	0.7	-0.9	306	0.9	-0.5
176	osc> 1500	306	0.0	1	298	0.0	-2.3	298	0.0	-2.5
176	1500> osc> 1000	308	2.1	9	305	2.8	-1.0	304	3.0	-1.1
176	1000> osc> 700	307	2.3	11	306	2.7	-0.3	306	2.7	-0.5
176	700> osc> 400	308	1.5	24	308	1.8	0.2	308	1.8	0.2
176	osc< 400	310	1.2	18	307	2.4	-1.0	309	2.0	-0.2
177	1000> osc> 700	314	5.7	6	313	6.9	-0.1	312	6.8	-0.4
177	700> osc> 400	313	4.1	26	313	4.0	0.2	313	3.9	0.1
177	osc< 400	311	1.4	17	308	2.4	-1.0	309	2.1	-0.5
178	1500> osc> 1000	302	1.7	3	NaN	NaN	NaN	296	2.2	-1.8
178	1000> osc> 700	305	0.9	6	NaN	NaN	NaN	302	1.4	-0.9
178	700> osc> 400	307	1.2	13	NaN	NaN	NaN	306	2.0	-0.3
178	osc< 400	311	2.2	19	NaN	NaN	NaN	311	1.5	-0.2

12.9. APPENDIX: SUMMARY PLOTS

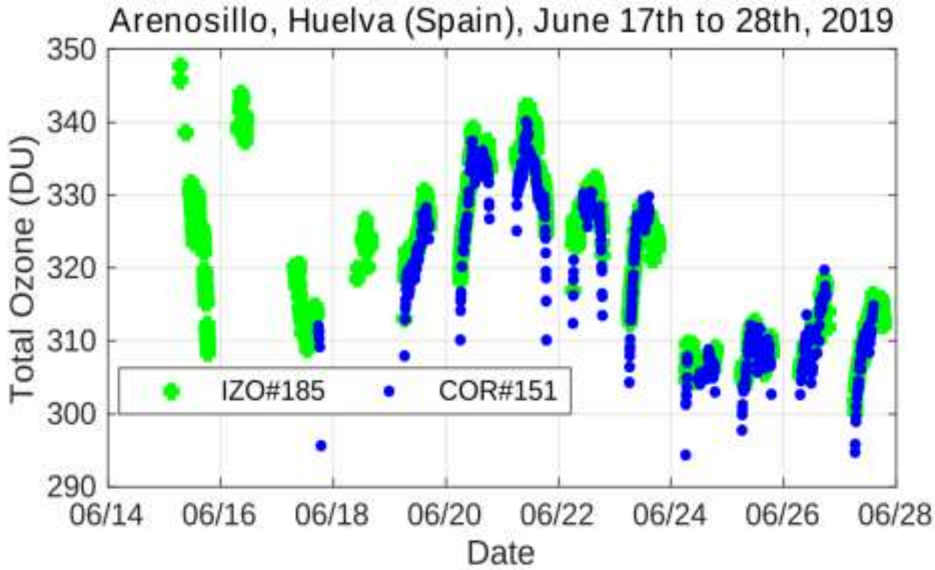
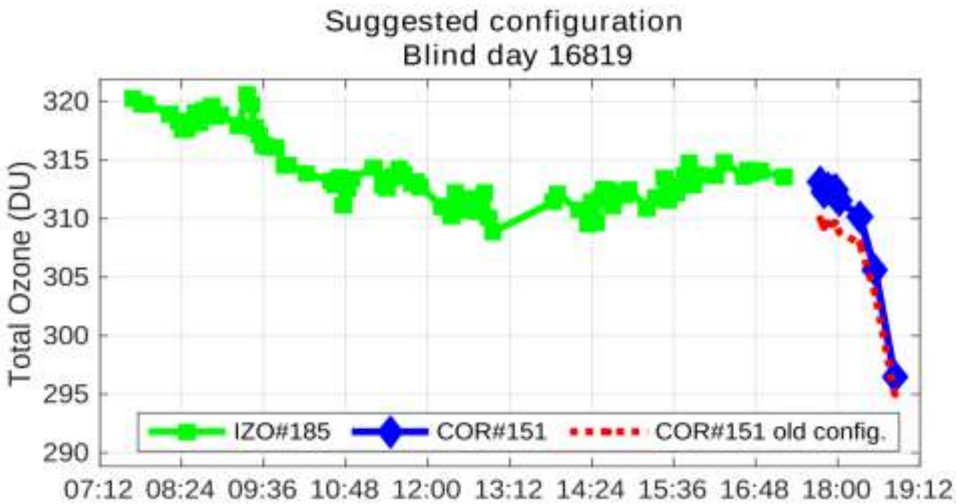
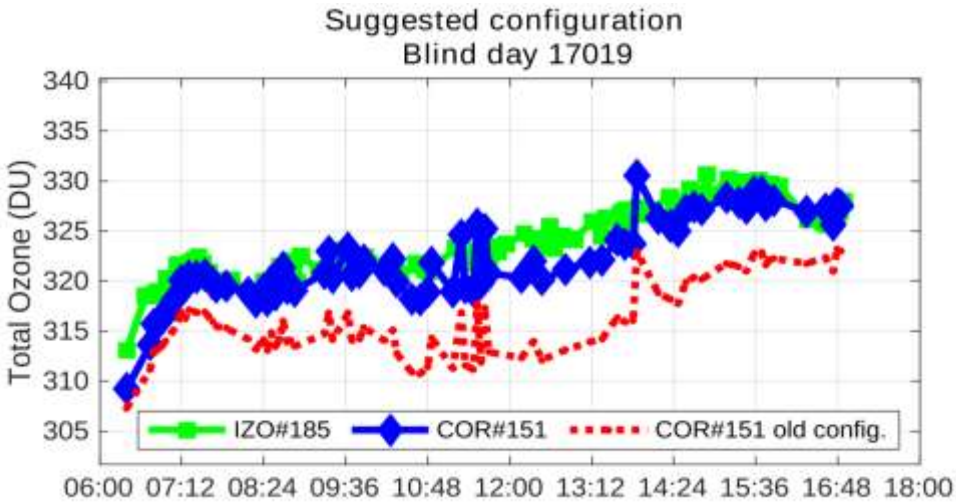
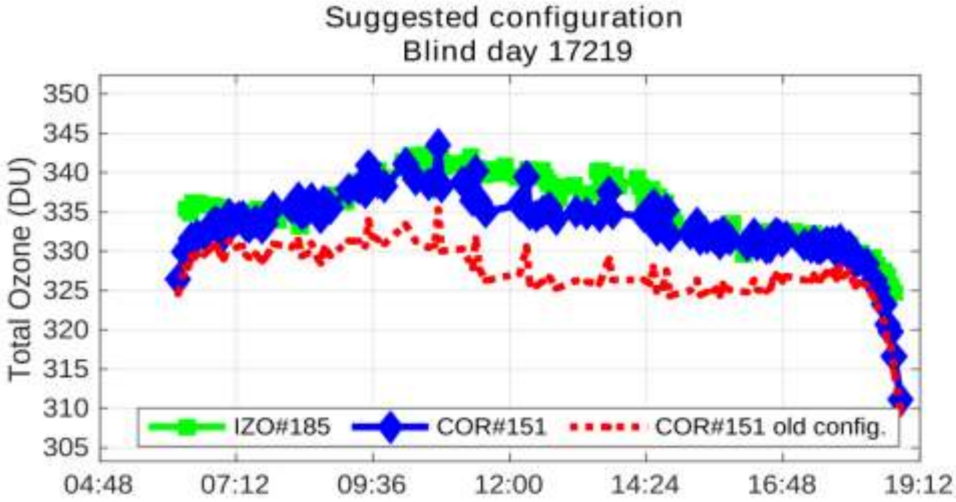


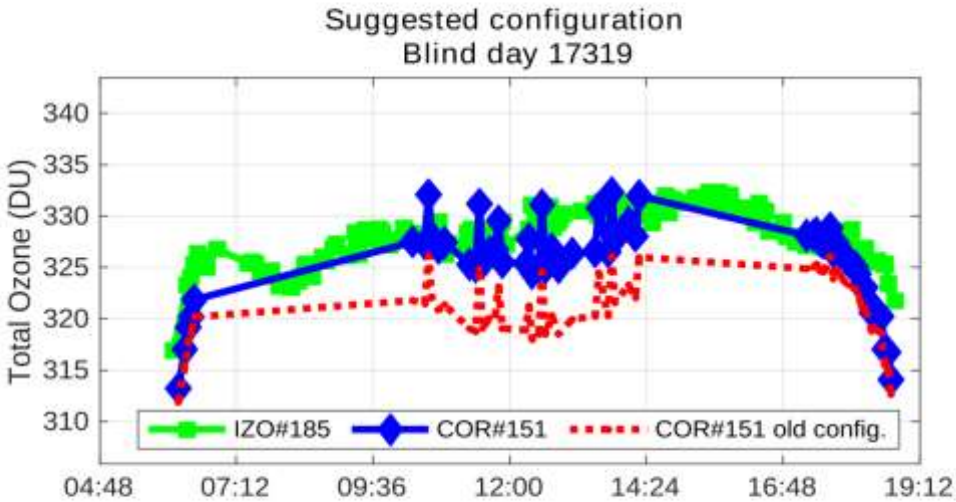
Figure 27. Overview of the intercomparison. Brewer COR#151 data were evaluated using final constants (blue circles)



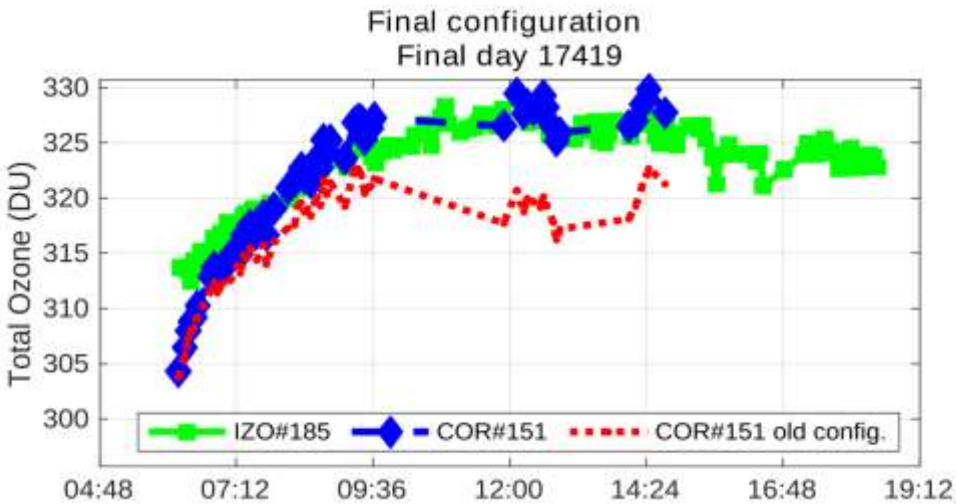




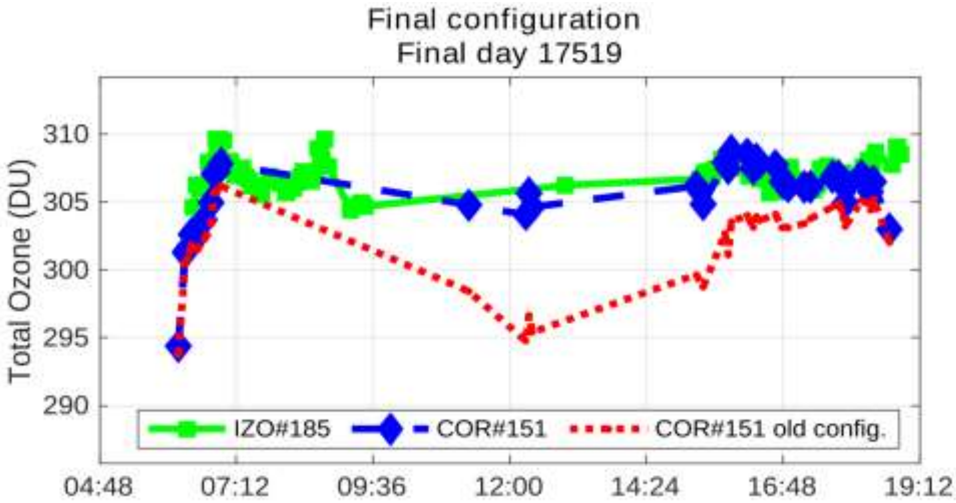
Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
320
315
310
305
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
COR#151
COR#151 old config.

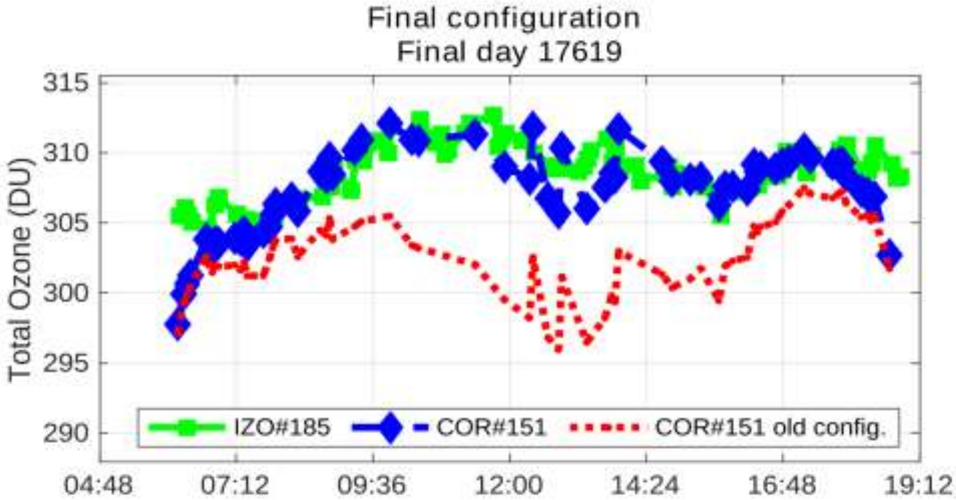


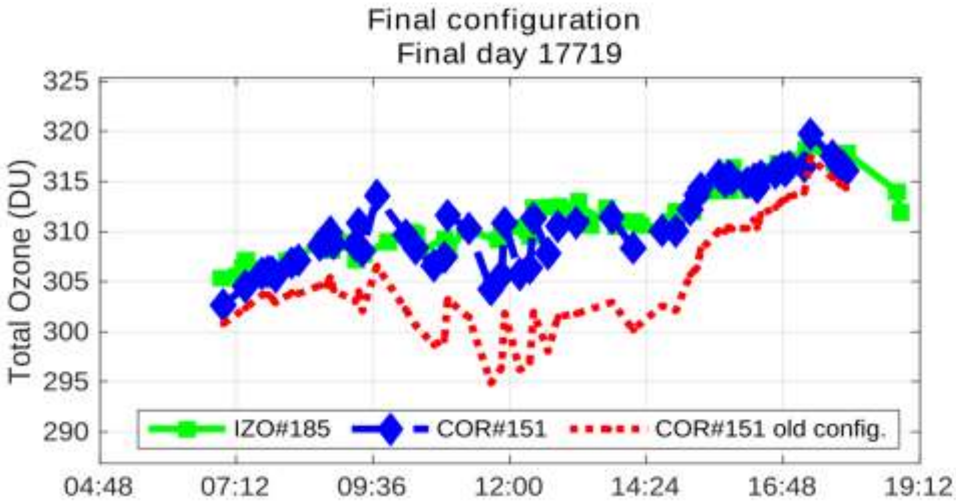
Suggested configuration
Blind day 17319
Total Ozone (DU)
340
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
COR#151
COR#151 old config.

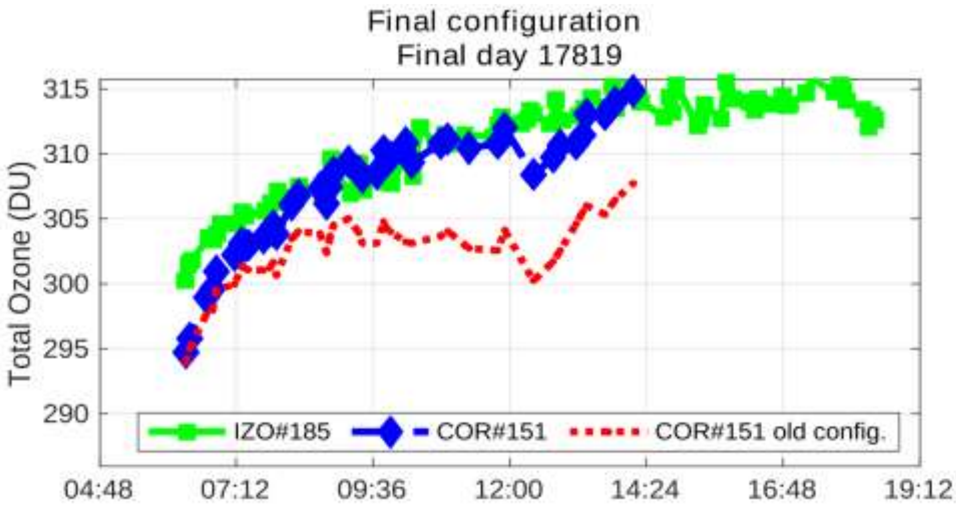


Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
COR#151
COR#151 old config.


Final configuration
Final day 17519
Total Ozone (DU)
310
305
300
295
290
IZO#185
COR#151
COR#151 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
290
IZO#185
COR#151
COR#151 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
295
290
IZO#185
COR#151
COR#151 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17819
Total Ozone (DU)
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
COR#151
COR#151 old config.

13. BREWER K&Z#158

13.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer K&Z#158 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer K&Z#158 correspond to Julian days 166 – 179.

For the evaluation of the initial status, we used 116 simultaneous direct sun (DS) ozone measurements from days 166 to 172. For final calibration purposes, we used 287 simultaneous DS ozone measurements taken from day 174 to 179.

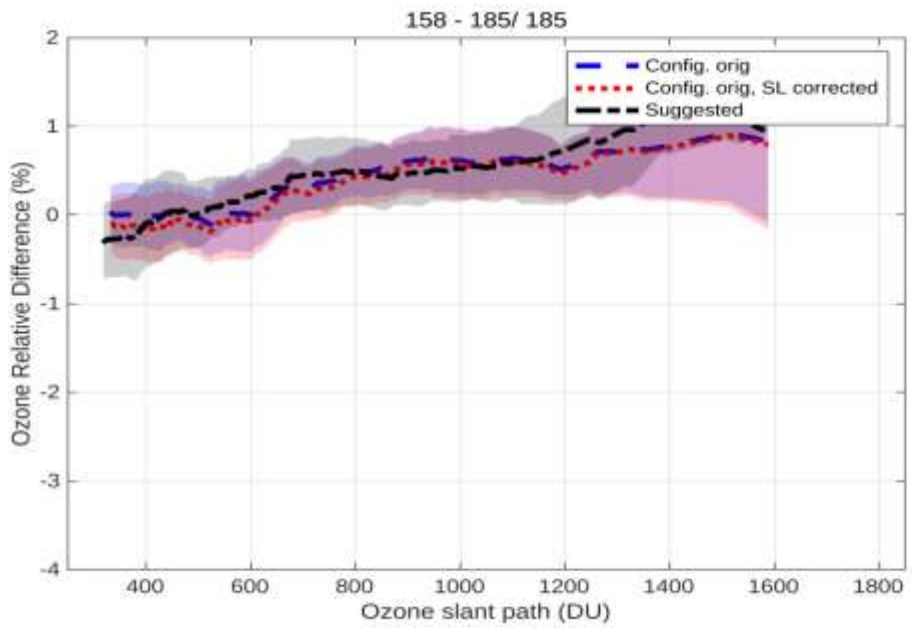


Figure 1. Mean DS ozone column percentage difference between Brewer K&Z#158 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF21218.158, blue dashed line) produces ozone values with an average difference of approx. 0.5% with respect to the reference instrument, which is a rather small difference. The SL correction (Figure 1, red dotted line) is thus not necessary and does not improve the comparison with Brewer IZO#185.

As a travelling instrument, the lamp test results from Brewer K&Z#158 (see Figure 2) show a lot of gaps. There is also a noticeable change before the campaign, however the data from the campaign itself seems quite stable (Figures 20 and 21), with values of 541 and 825 for the R6 and R5 ratios, respectively. These values were calculated taking into account new temperature coefficients calculated in this campaign.

Dead time (DT) tests were somewhat noisy and they also showed a change during the campaign, possibly related to the maintenance work carried out on day 173. In the final ICF for the present campaign, ICF17519.158, we have updated the DT value to $3 \cdot 10^{-8}$ s which is 2 ns higher than $2.8 \cdot 10^{-8}$ s which is the value in the current ICF (ICF21218.158).

There is some noise in the results of some of the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth), but their overall behaviour seems reasonable.

Concerning the performance of the filters, the FIOAVG data indicates that some corrections are needed. However, these data have large confidence intervals, so these corrections might not be reliable. We do not recommend the application of filter corrections at this time.

The sun scan tests (SC) at the instrument's station before the campaign and those performed during the first days of the intercomparison confirmed the current cal step value of 1015 within a step error of ± 1 .

Dispersion tests carried out during the campaign suggest a new value for the ozone absorption coefficient of 0.3431. The difference with the current value of 0.3414 is almost 0.002, or 2 cal steps. In the final ICF for this campaign, ICF17519.158, we used this new value, which is also closer to the value found in previous campaigns.

Taking this into account, we suggest the following changes to the configuration of Brewer K&Z#158.

13.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer K&Z#158 are quite stable by the end of the campaign, and we suggest updating the reference value to 541.
2. Similarly, we suggest a new R5 reference value of 854.
3. We have found that new temperature coefficients improve the behaviour of the instrument and include them in the final ICF for the campaign.
4. We suggest updating the DT to $3 \cdot 10^{-8}$ seconds, which is two units higher than the current value.
5. At this time, we do not propose the application of any filter correction. However, we recommend to keep checking them.
6. We recommend updating the ozone absorption coefficient to 0.3431. Even though the Cal Step has not changed, this value of the absorption coefficient is closer than the current one to those obtained in previous campaigns.
7. Finally, we suggest updating the ETC value from 1820 to 1792.

13.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/158/ICF17519.158

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=592573784

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/158/html/cal_report_158a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/158/html/cal_report_158a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/158/html/cal_report_158b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/158/html/cal_report_158c.html

13.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

13.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp data have many gaps in the last two years. This is expected for a travelling instrument. Of greater importance is the large drop in the ratios that took place at the end of April 2019. However, the instrument was again stable by the end of the campaign, as we will show in Sec. 1.6.3.

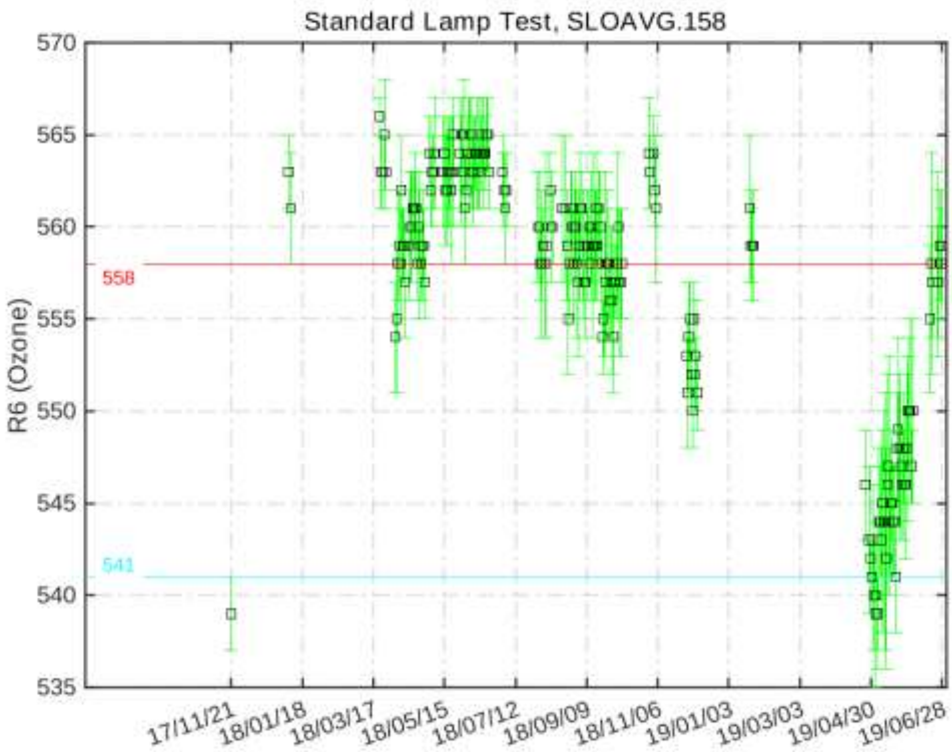


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

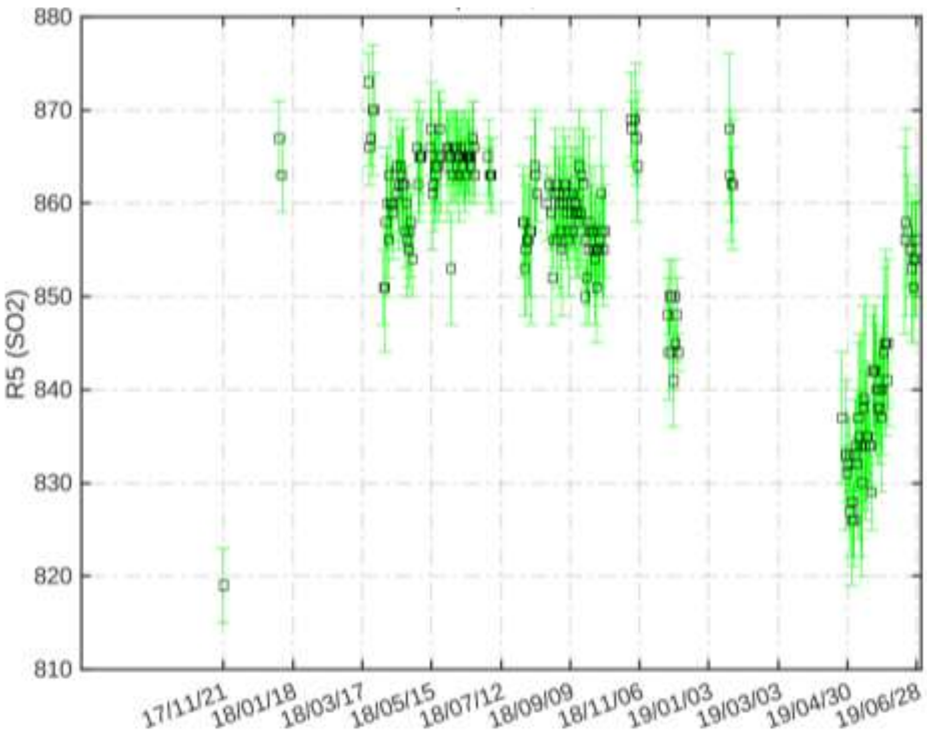


Figure 3. Standard lamp test R5 sulphur dioxide ratios

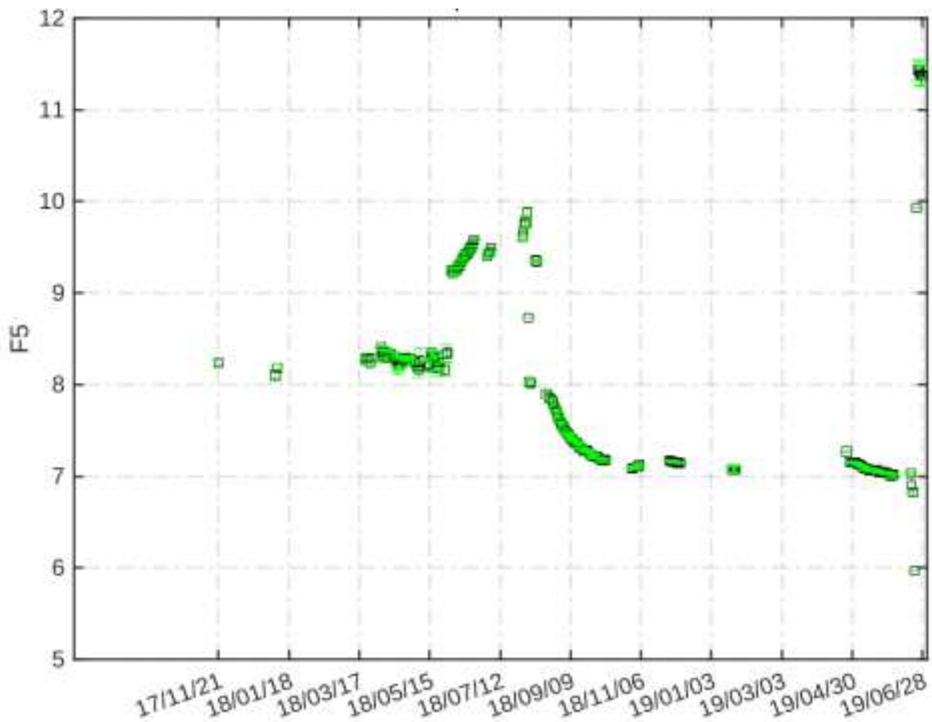


Figure 4. SL intensity for slit five

13.2.2. Run/Stop and dead time

Run/stop test values were mostly within the test tolerance limits (see Figure 5).

As shown in Figure 6, the results of the DT tests are somewhat noisy. During the campaign, a noticeable increase of 2 ns in DT took place as the result of the maintenance work carried out on day 173. Therefore, the current DT value of $2.8 \cdot 10^{-8}$ seconds increased to $3 \cdot 10^{-8}$ s by the end of the campaign. This new value has been used in the new ICF.

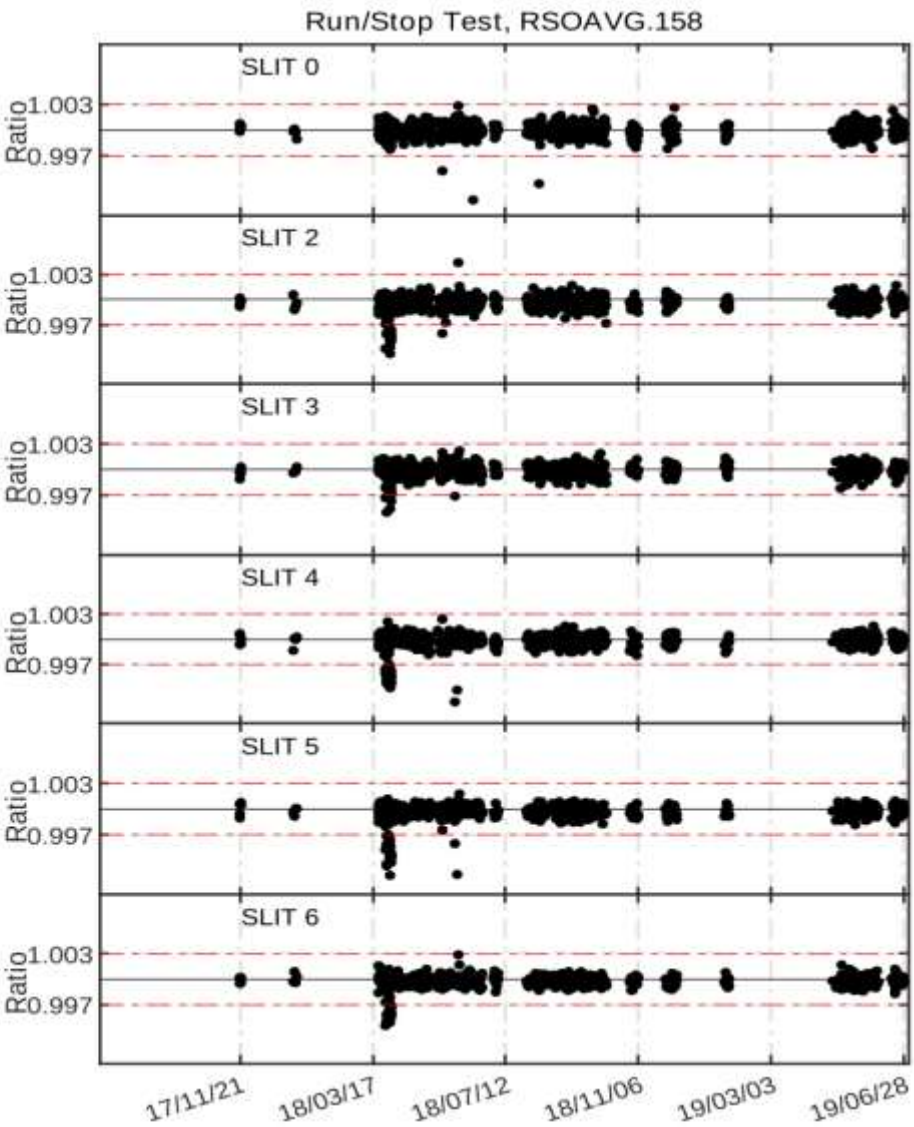


Figure 5. Run/stop test

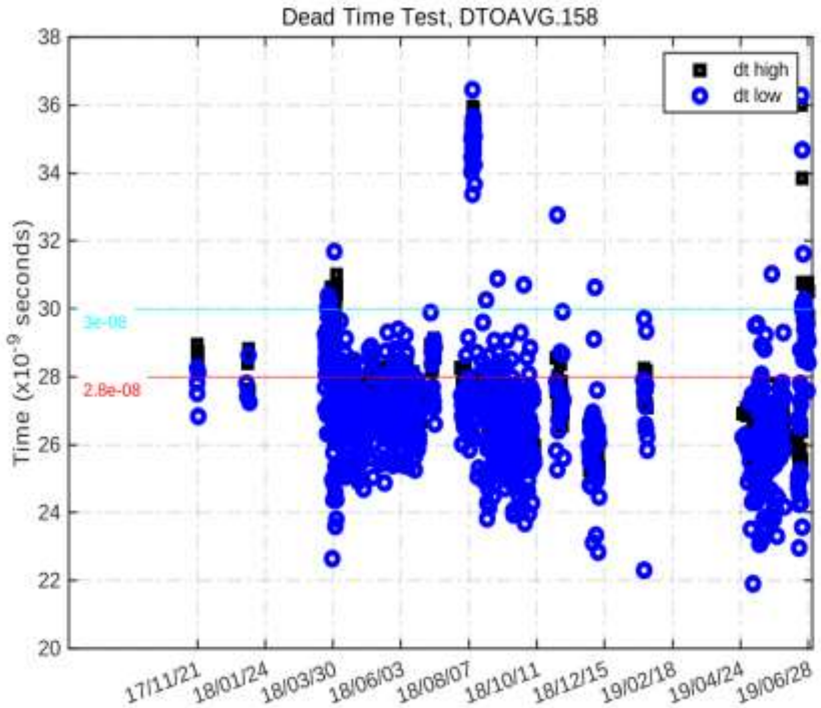


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

13.2.3. Analogue test

Figure 7 showed some noise in the analogue tests results, particularly at high voltage. Note that, as part of the maintenance work carried out on day 173, high voltage was increased from approx. 1280 to 1336.

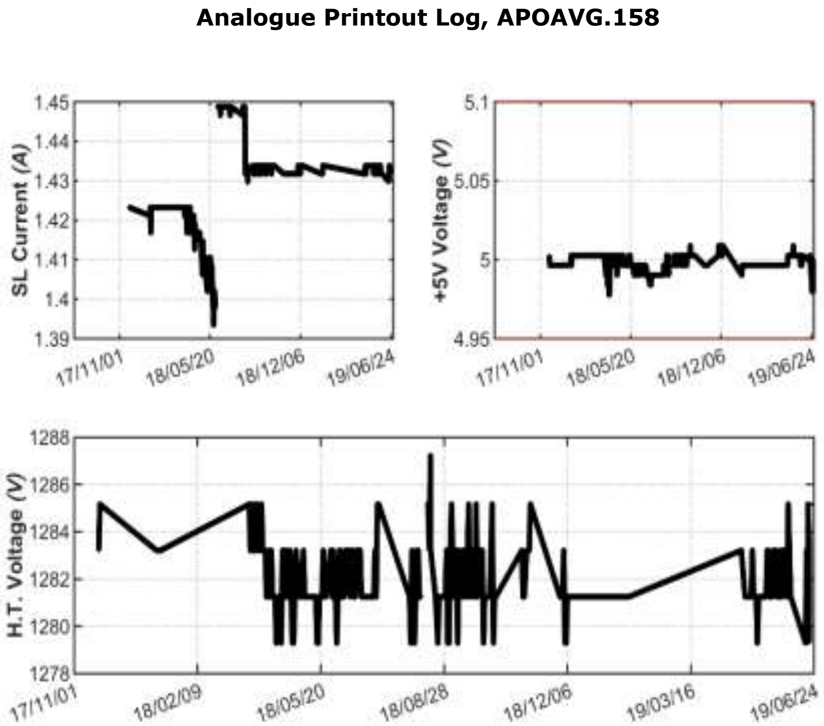


Figure 7. Analogue voltages and intensity

13.2.4. Mercury lamp test

Internal mercury lamp intensity data also presents many gaps (see Figure 8). From the available data, it is not clear if there is any temperature dependence.

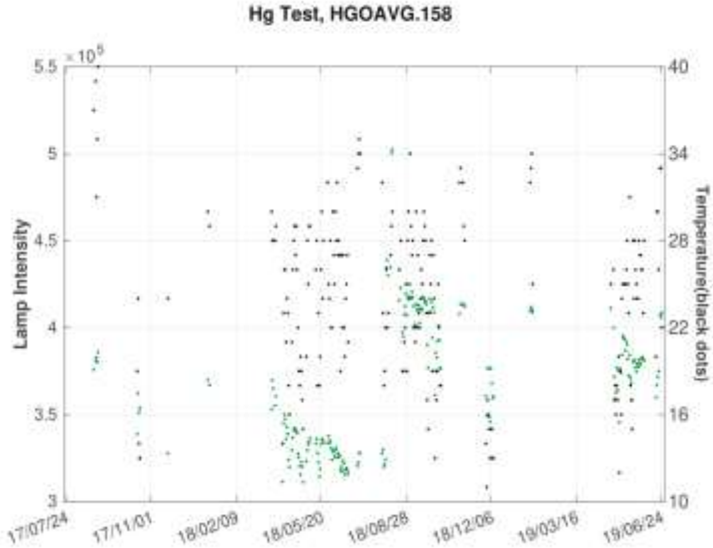
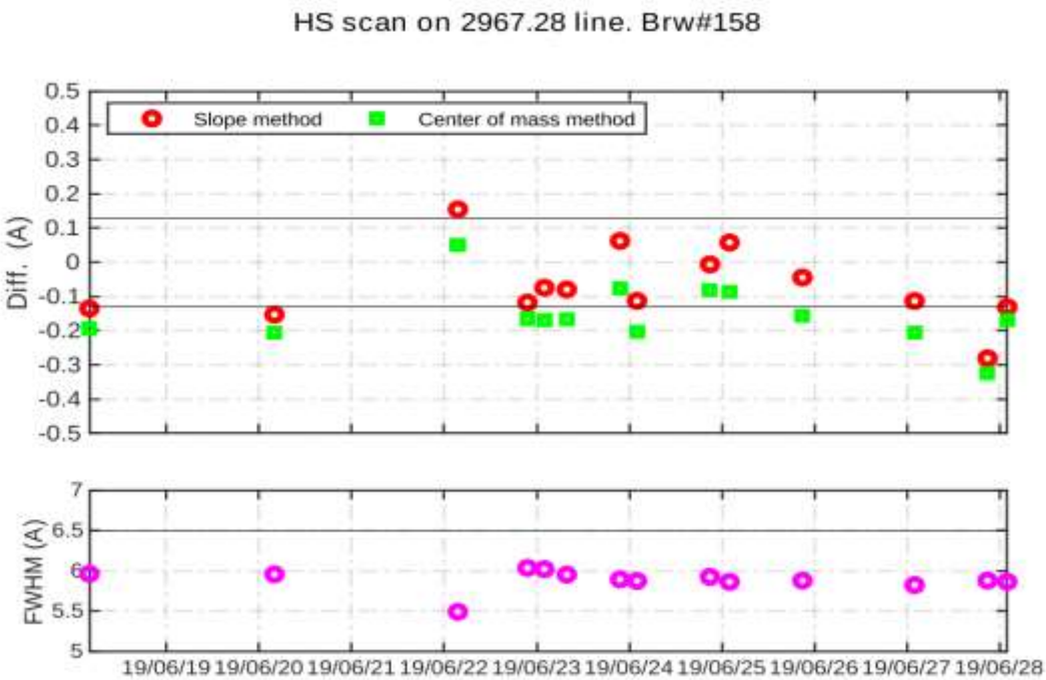


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

13.2.5 CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer K&Z#158 during the campaign showed reasonable results, with the peak of the calculated scans close to, although slightly below, the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.



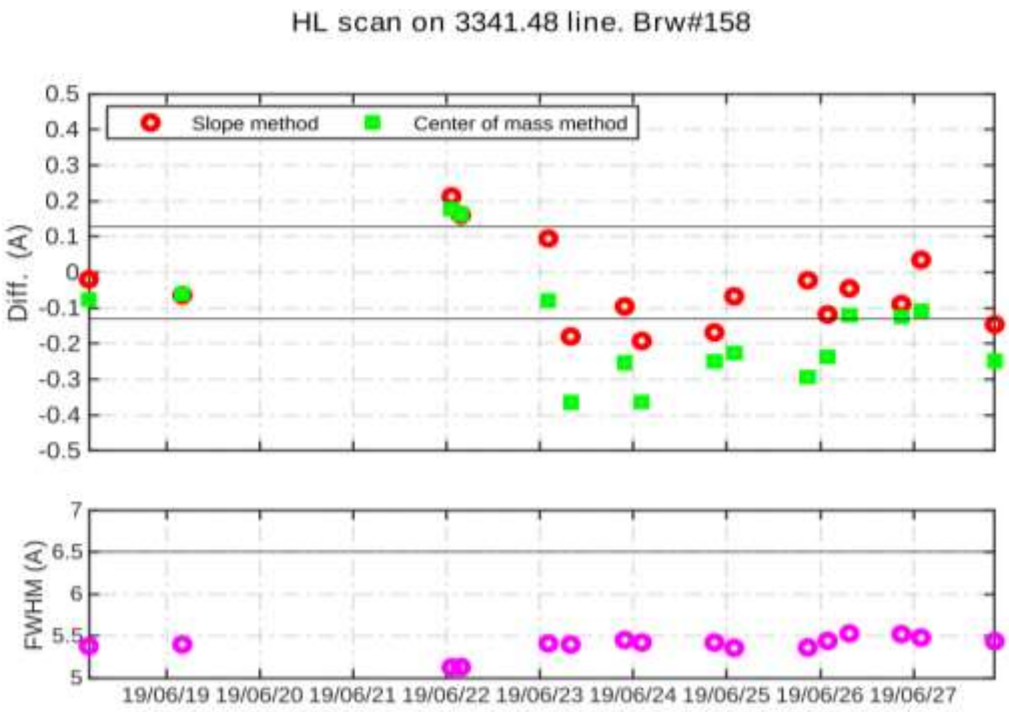


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

13.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer K&Z#158 CI scans performed during the campaign relative to the scan CI17319.158. As can be observed, lamp intensity varied with respect to the reference spectrum by around 1%.

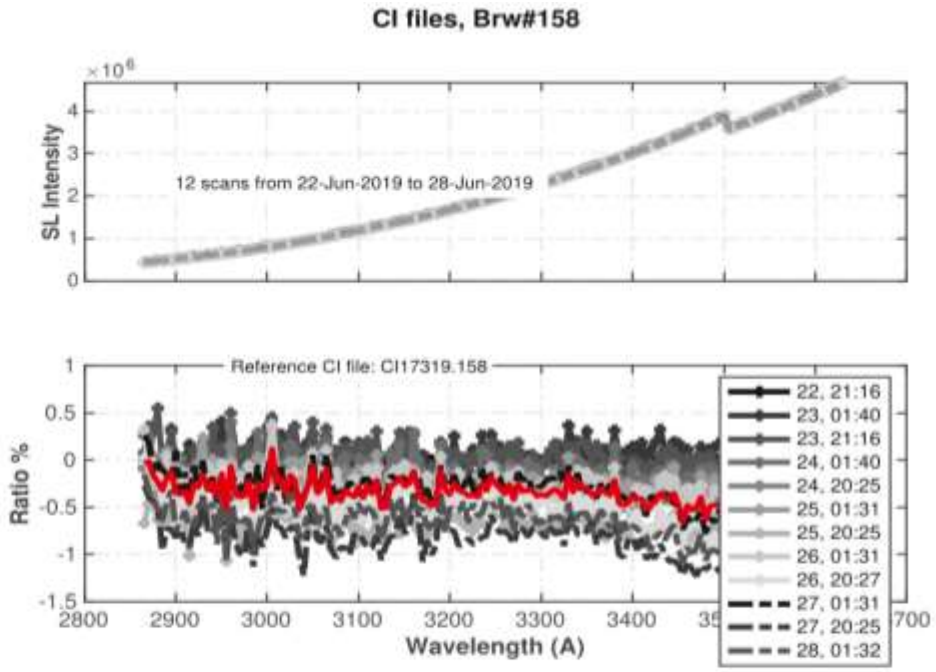


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

13.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 19 ˚C to 34 ˚C), the current coefficients do not completely remove the temperature dependence, with a slope of 6 units per 10 ˚C. New temperature coefficients calculated using the data from the present campaign reduced this dependence noticeably. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, the current coefficients perform worse than the new ones.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.1000	-0.3000	-0.8000	-1.3000
Calculated	0.0000	-0.4000	-1.0000	-1.9000	-2.4000
Final	0.0000	-0.4100	-1.0500	-1.9500	-2.4600

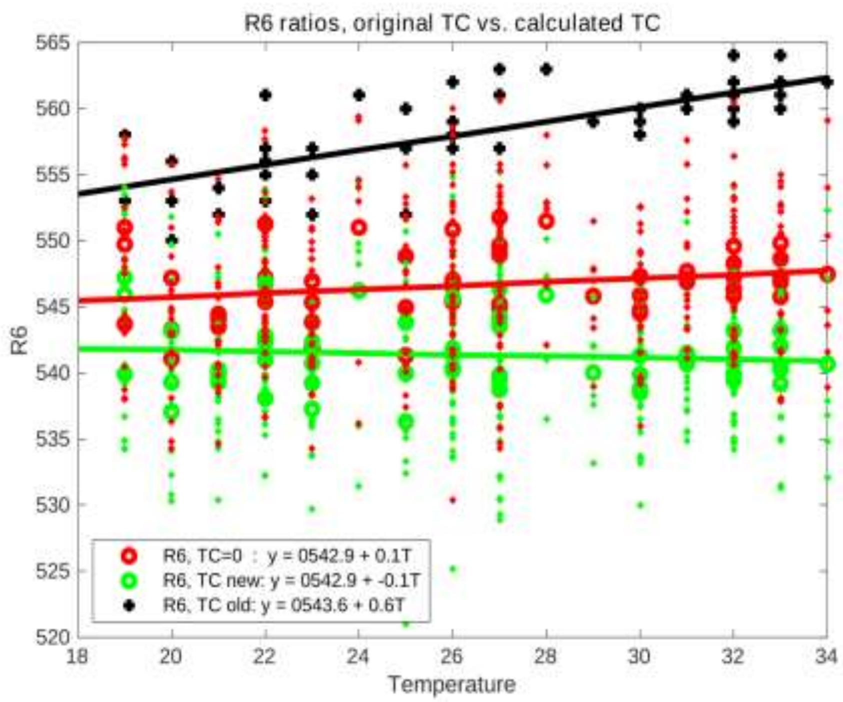


Figure 11. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

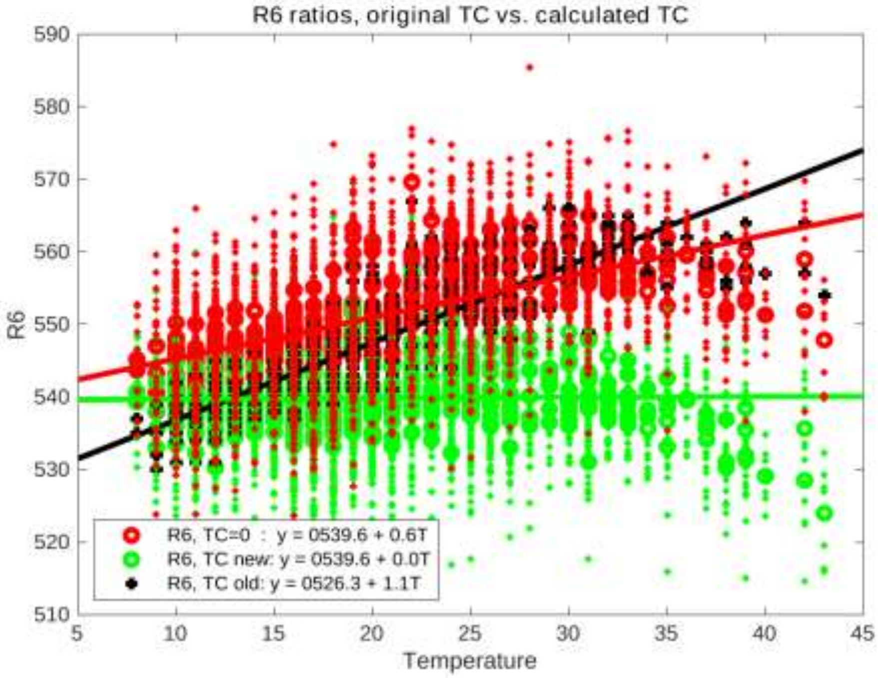


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

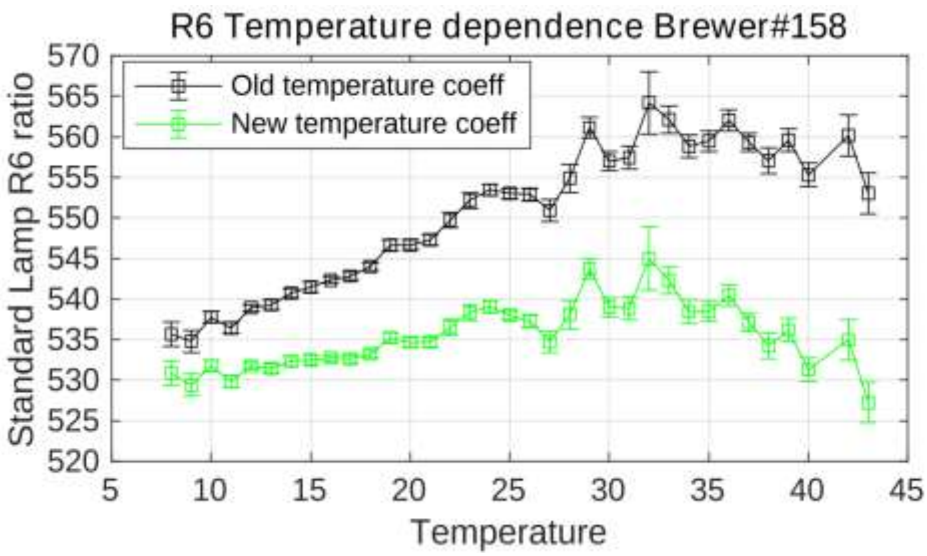


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

13.4. ATTENUATION FILTER CHARACTERIZATION

13.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 17 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter. Results in the latter Table show large confidence intervals, and large differences between means and medians, so these data are not considered reliable, probably because of the low number of measurements.

Taking also into account the relative ozone difference with respect to the reference Brewer IZO#185, we do not suggest the application of any filter correction.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-2	-2	-3	-9	9
ETC Filt. Corr. (mean)	-6.9	-2.6	-5.1	-4	16.8
ETC Filt. Corr. (mean 95% CI)	[-17.3 3.1]	[-13.7 7.1]	[-14.7 5.9]	[-12.7 6.2]	[-7.4 38.6]

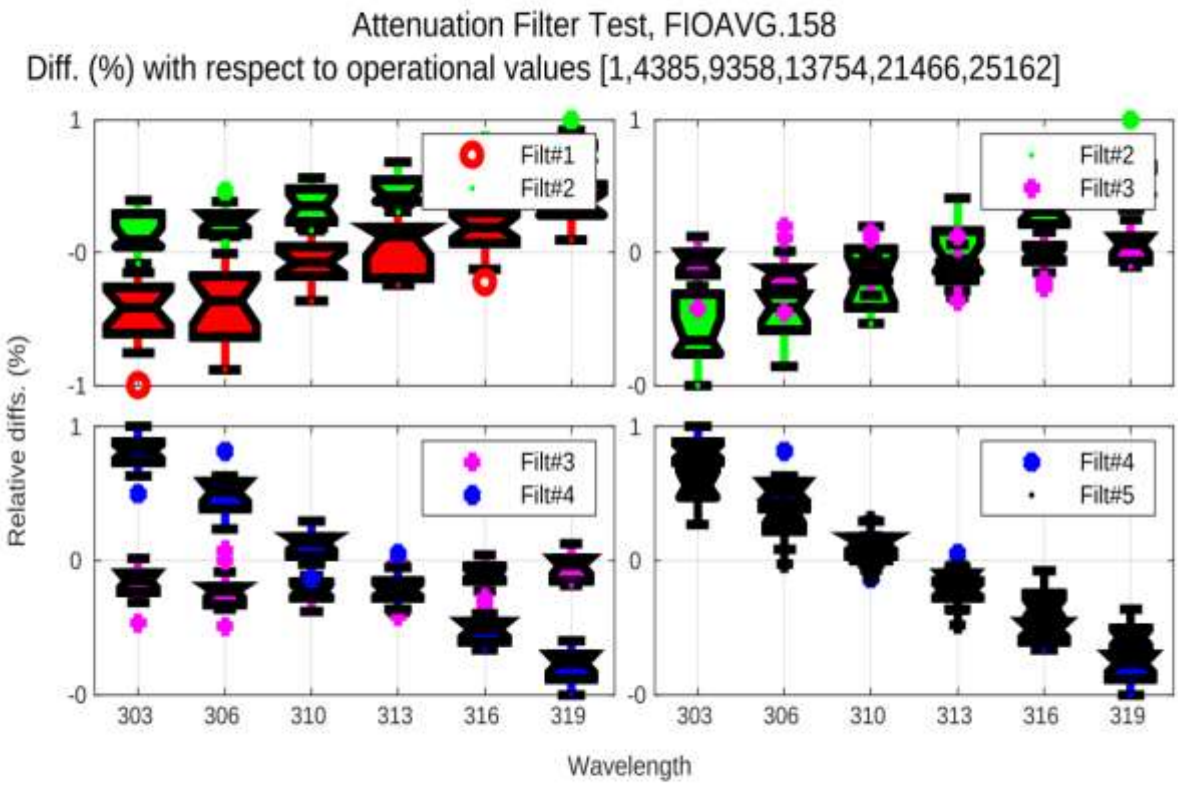


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

13.5. WAVELENGTH CALIBRATION

13.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts (≈ ± 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 16 sun scan (SC) tests covering an ozone slant path range from 400 to 1000 DU were carried out, see Figure 16. The calculated cal step number (CSN) was found to be the same as in the current configuration (1015). SC tests performed at the station also confirm a CSN of 1015, so we have kept this value in the final ICF of the present campaign (ICF17519.158).

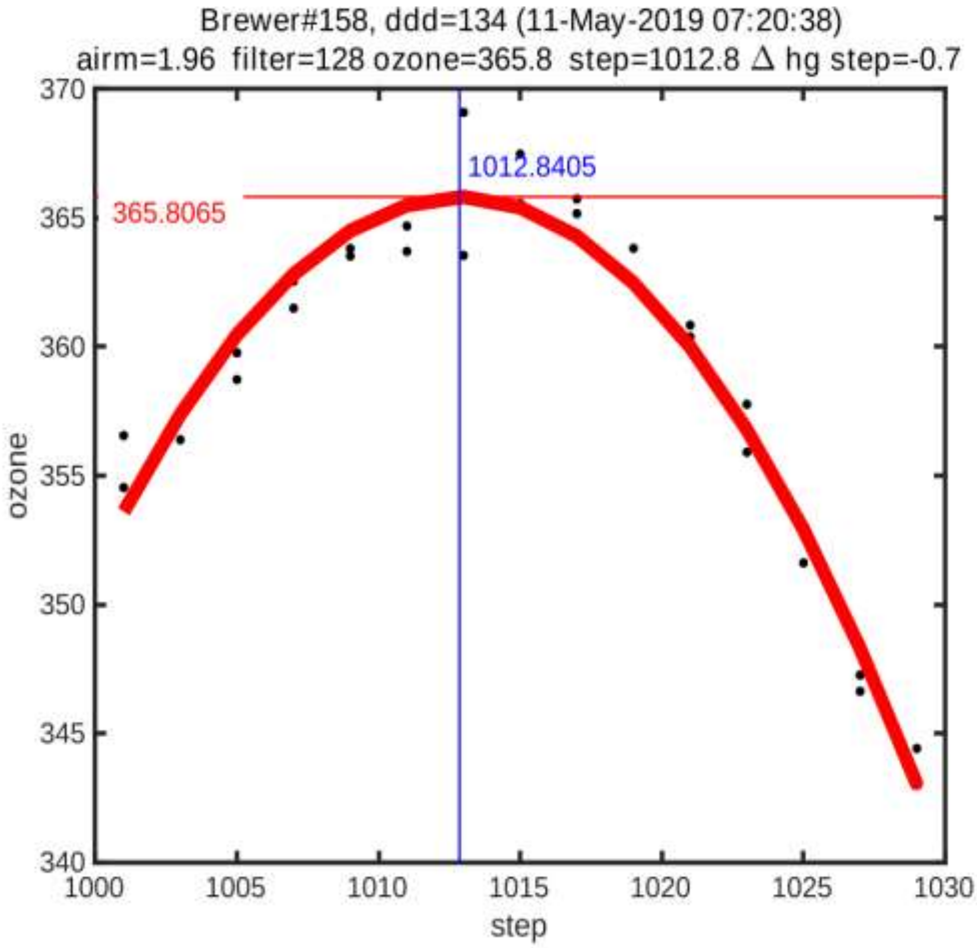


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

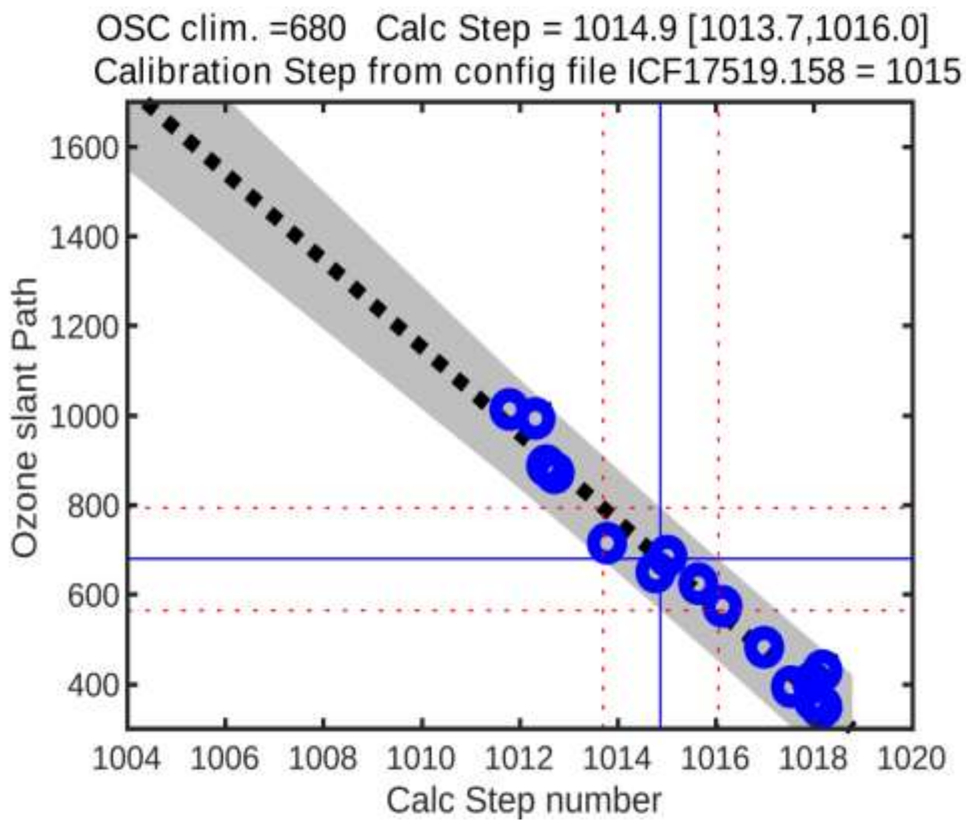


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

13.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

Although the Cal Step has not changed, the absorption coefficient calculated in the current campaign is approx. 0.002 units, or 2 steps, higher than the value in the current ICF (0.3431 vs. 0.3414). The new ozone absorption coefficient is also closer to the values obtained in previous campaigns (see Table 3), so we used this new value in the final ICF for the current campaign.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	1015	0.3414	2.3500	1.1636
17-Oct-2017	1015	0.3434	3.1989	1.1495
18-Oct-2017	1015	0.3434	3.1989	1.1495
02-Aug-2018	1015	0.3438	3.2056	1.1501
23-Jun-2019	1015	0.3431	3.1892	1.1493
Final	1015	0.3431	2.3500	1.1636

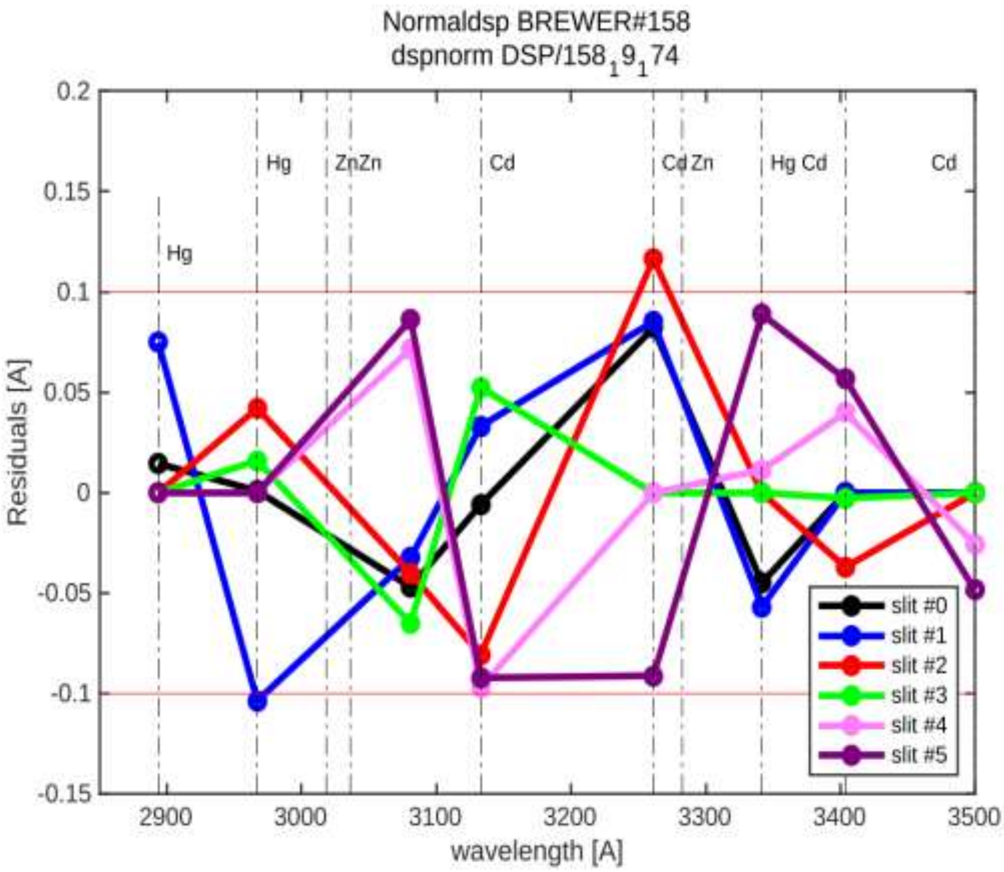


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 1014	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.82	3062.91	3100.36	3135	3167.76	3199.85
Res(A)	5.5603	5.5122	5.3718	5.4598	5.4435	5.3262
O3abs(1/cm)	2.6021	1.7824	1.0054	0.67705	0.3748	0.29507
Ray abs(1/cm)	0.50513	0.48329	0.45856	0.43711	0.41799	0.40029
SO2abs(1/cm)	3.453	5.6194	2.3908	1.902	1.0508	0.61666
step= 1015	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.89	3062.98	3100.44	3135.07	3167.83	3199.92
Res(A)	5.5602	5.5121	5.3717	5.4598	5.4434	5.3261

step= 1014	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
O3abs(1/cm)	2.5995	1.7809	1.0052	0.67667	0.37482	0.29459
Ray abs(1/cm)	0.50508	0.48324	0.45851	0.43707	0.41795	0.40025
SO2abs(1/cm)	3.436	5.6416	2.3985	1.89	1.0521	0.61446
step= 1016	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.96	3063.06	3100.51	3135.14	3167.9	3199.98
Res(A)	5.5601	5.512	5.3716	5.4597	5.4433	5.3261
O3abs(1/cm)	2.5969	1.7792	1.0049	0.67626	0.37485	0.29412
Ray abs(1/cm)	0.50503	0.48319	0.45847	0.43703	0.41791	0.40021
SO2abs(1/cm)	3.4192	5.6637	2.4062	1.8783	1.0533	0.61219
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
1014	0.34399	9.1727	3.1794	1.1525	0.35444	0.34591
1015	0.34305	9.1693	3.1892	1.1493	0.35359	0.34503
1016	0.34213	9.1659	3.1988	1.146	0.3527	0.3441

13.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340.0 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2414. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 1015	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.5602	5.5121	5.3717	5.4598	5.4434	5.3261
O3abs(1/cm)	2.5995	1.7809	1.0052	0.67667	0.37482	0.29459
Ray abs(1/cm)	0.50508	0.48324	0.45851	0.43707	0.41795	0.40025
step= 2414	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.4143	5.3979	5.2531	5.3685	5.3409	5.1995
O3abs(1/cm)	0.679	0.39612	0.29494	0.12198	0.061716	0.033348
Ray abs(1/cm)	0.43799	0.42031	0.40025	0.38278	0.36727	0.35276

13.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant.

The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

13.6.1. Initial calibration

For the evaluation of initial status of Brewer K&Z#158, we used the period from days 166 to 172 which correspond to 116 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced ozone values approx. 0.5% higher than the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185 .

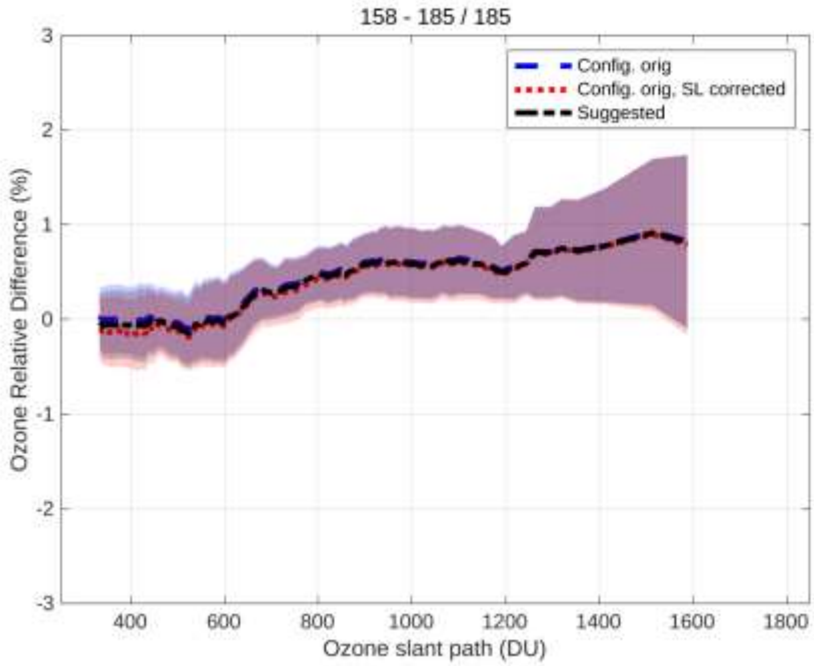


Figure 18. Mean direct sun ozone column percentage difference between Brewer K&Z#158 and Brewer IZO#185 as a function of the ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=1000	1821	1810	3414	3441
full OSC range	1821	1809	3414	3445

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	O3#185	O3std	N	O3#158	O3 std	%(158–185)/185	O3(*) #158	O3std	(*)%(158–185)/185
19-Jun-2019	170	325.3	3.2	42	325.3	2.7	0	325.1	2.7	-0.1
20-Jun-2019	171	334	4.9	28	333.9	4.8	0	333.7	4.8	-0.1
21-Jun-2019	172	339.3	2.2	46	339.9	2.4	0.2	339.7	2.4	0.1

13.6.2. Final calibration

After the maintenance on day 173, a new ETC value was calculated (see Figure 19). For the final calibration, we used 287 simultaneous direct sun measurements from days 174 to 179. The new value of 1792, is approximately 30 units lower than the current ETC value of 1820. Note this new ETC has been calculated taking into account the new suggested dead time of $3 \cdot 10^{-8}$ s.

We recommend using this new ETC, together with the new proposed standard lamp reference ratios, 541 for R6. We have updated the new calibration constants in the ICF17519.158 file provided.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P methods is above the maximum tolerance limit of 10 ETCs. Despite that, as shown in Table 9, the daily ozone differences with respect to IZO#185 are within the 0.5% limit in most cases.

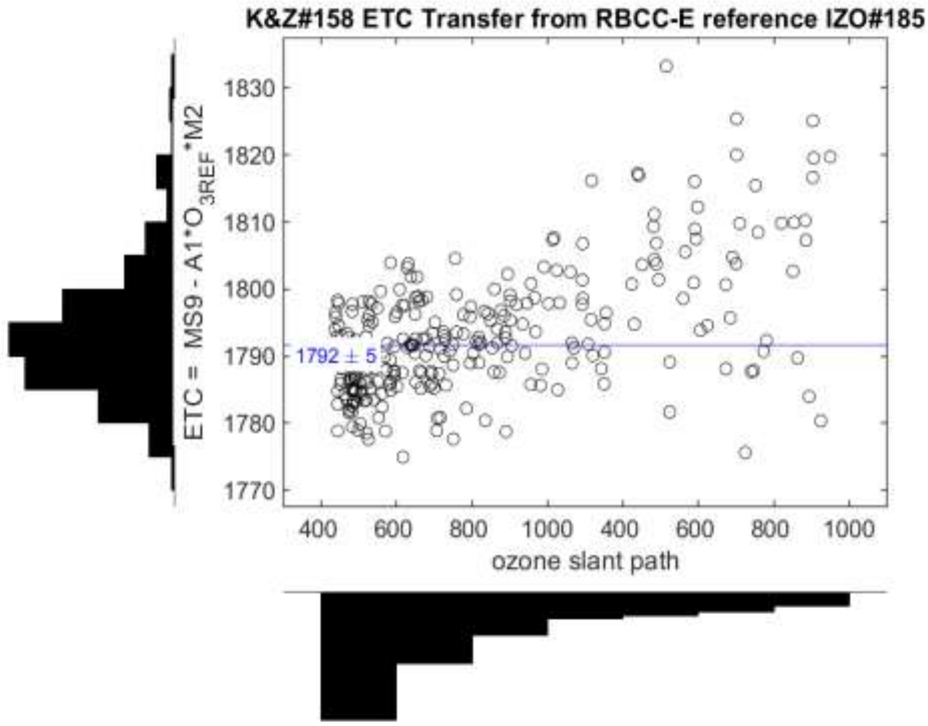


Figure 19. Mean direct sun ozone column percentage difference between Brewer K&Z#158 and Brewer IZO#185 as a function of the ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1792	1776	3431	3467
full OSC range	1791	1778	3431	3463

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#158*	*O3 std*	*%(158–185)/185*	*O3(*)#158*	*O3std*	*(*)%(158–185)/185*
22-Jun-2019	173	330	1.9	34	329.4	1.5	-0.2	329.3	1.8	-0.2
23-Jun-2019	174	324.7	2.7	95	323.6	1.6	-0.3	324	1.7	-0.2
24-Jun-2019	175	307.9	1.5	13	309	2.4	0.4	308.8	2	0.3
25-Jun-2019	176	309	1.9	46	308.9	1.3	0	309.5	1.5	0.2

Date	Day	O3#185	O3std	N	O3#158	O3 std	%(158–185)/185	O3(*)#158	O3std	(*)%(158–185)/185
26-Jun-2019	177	312.2	3.5	40	311.3	4.3	-0.3	311.8	3.7	-0.1
27-Jun-2019	178	311.3	3.4	50	311.2	3.1	0	311.6	3	0.1
28-Jun-2019	179	NaN	NaN	0	305.7	0.5	NaN	305.5	0.5	NaN

13.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 541 for R6 (Figure 20) and 825 for R5 (Figure 21). Figure 22 shows the SL counts, and the effect of the maintenance work on day 173 is clearly visible.

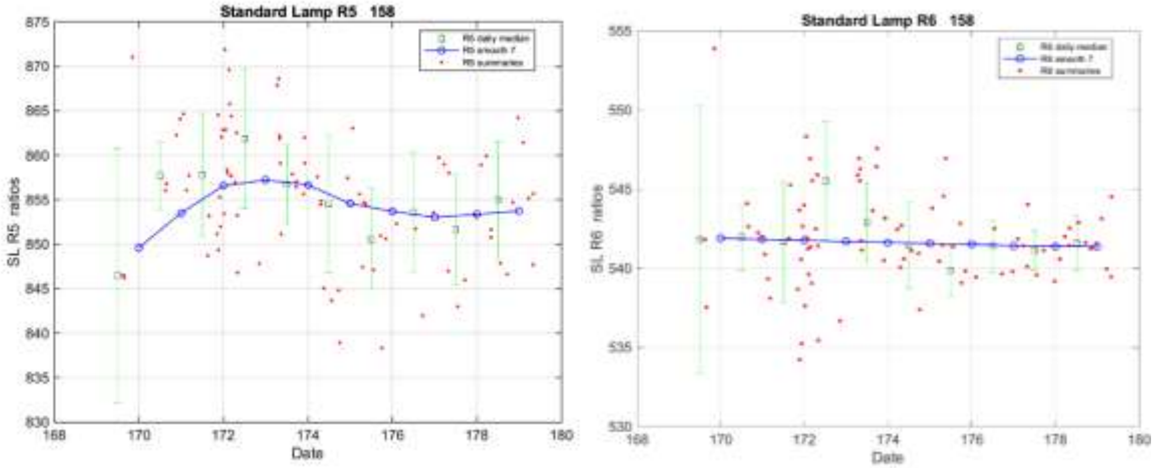


Figure 20. Standard lamp ozoneR6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

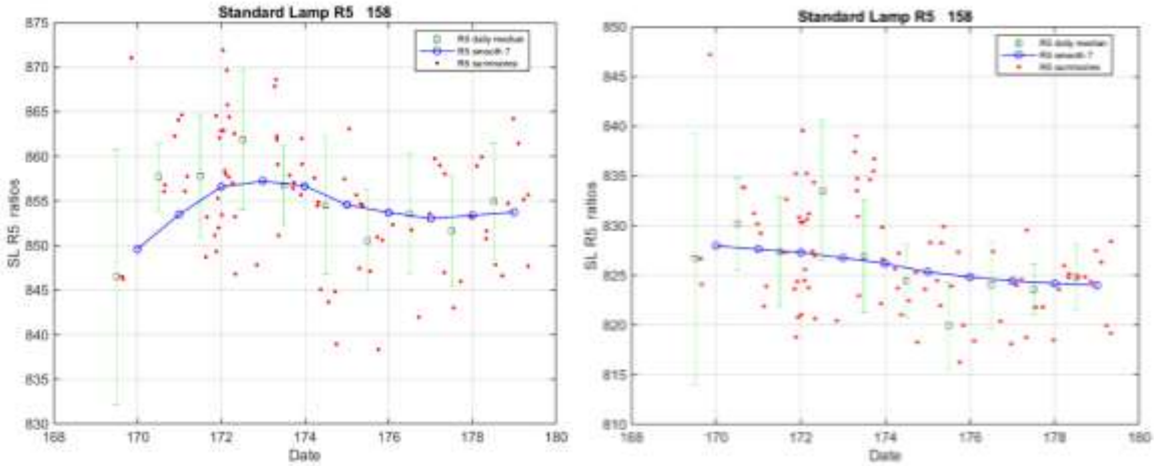


Figure 21. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

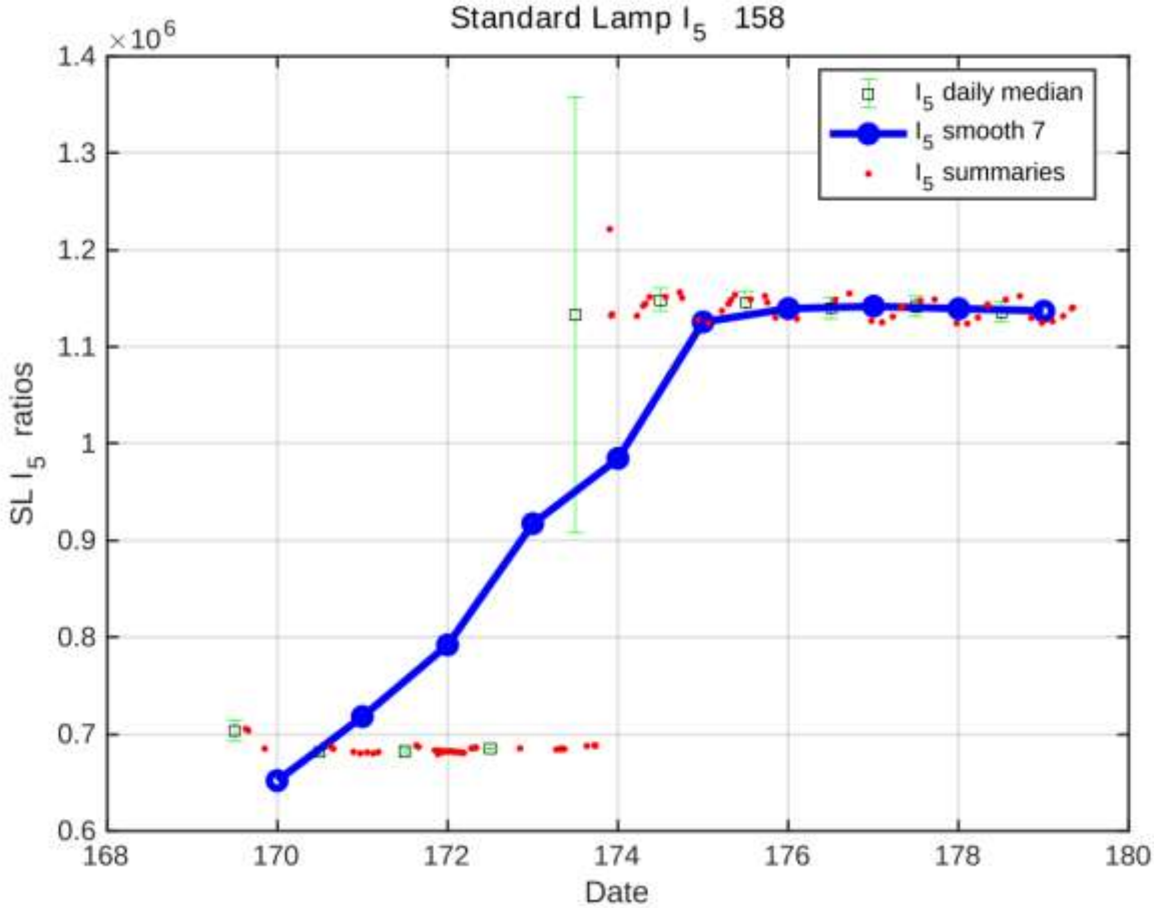


Figure 22. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

13.7. CONFIGURATION

13.7.1. Instrument constant file

	Initial (ICF21218.158)	*Final (ICF17519.158)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.1	-0.41
o3 Temp coef 3	-0.3	-1.05
o3 Temp coef 4	-0.8	-1.95
o3 Temp coef 5	-1.3	-2.46
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3414	0.3431
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1636	1.1636
ETC on O3 Ratio	1820	1792

	Initial (ICF21218.158)	*Final (ICF17519.158)*
ETC on SO2 Ratio	332	332
Dead time (sec)	2.8e-08	3e-08
WL cal step number	1015	1015
Slitmask motor delay	14	14
Umkehr Offset	2463	2463
ND filter 0	0	0
ND filter 1	4385	4385
ND filter 2	9358	9358
ND filter 3	13754	13754
ND filter 4	21466	21466
ND filter 5	25162	25162
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	0	0
Mic #2 Offset	0	0
O3 FW #3 Offset	178	178
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2497	2497
Grating Slope	0.9989	0.9989
Grating Intercept	-13.86	-13.86

	Initial (ICF21218.158)	*Final (ICF17519.158)*
Micrometre Zero	1738	1738
Iris Open Steps	250	250
Buffer Delay (s)	0	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	0	0

13.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#158*	*O3 std*	*%diff*	*(*)O3#158*	*O3 std*	*(*)%diff*
170	1000> osc> 700	320	1.3	4	322	1.2	0.8	322	1.2	0.8
170	700> osc> 400	327	3.7	12	326	3.2	-0.1	326	3.2	-0.2
170	osc< 400	325	2.3	28	325	2.3	0.0	325	2.3	-0.1
171	1500> osc> 1000	329	6.4	9	331	5.3	0.7	331	5.3	0.7
171	1000> osc> 700	328	5.9	10	330	4.9	0.6	330	4.9	0.6
171	700> osc> 400	330	4.1	16	330	4.7	0.1	330	4.7	0.1
171	osc< 400	337	1.1	14	337	1.7	-0.1	337	1.7	-0.2
172	osc> 1500	325	0.0	1	326	0.0	0.4	326	0.0	0.4
172	1500> osc> 1000	331	3.7	6	332	3.7	0.3	332	3.7	0.4
172	1000> osc> 700	333	1.8	6	334	2.4	0.3	334	2.4	0.4
172	700> osc> 400	337	2.7	30	337	2.8	-0.1	337	2.8	0.0
172	osc< 400	339	1.9	57	339	2.4	-0.2	339	2.4	0.0
174	osc> 1500	314	0.0	2	318	1.2	1.4	317	1.2	1.2
174	1500> osc> 1000	320	4.9	8	323	3.3	1.1	322	3.2	0.8
174	1000> osc> 700	321	3.6	14	322	2.3	0.5	322	2.3	0.4
174	700> osc> 400	324	1.4	37	324	1.4	0.0	324	1.4	0.0
174	osc< 400	327	1.0	42	324	1.2	-0.8	325	1.2	-0.6
175	1500> osc> 1000	306	1.2	6	311	0.6	1.5	310	0.6	1.3
175	1000> osc> 700	308	1.3	6	311	1.2	0.9	311	1.2	0.7
175	700> osc> 400	307	1.4	6	308	1.1	0.3	307	1.0	0.2

Day	osc range	O3#185	O3std	N	O3#158	O3 std	%diff	(*)O3#158	O3 std	(*)%diff
176	osc> 1500	306	0.0	1	309	0.0	1.2	308	0.0	1.0
176	1500> osc> 1000	307	2.4	6	310	0.7	0.9	309	0.6	0.6
176	1000> osc> 700	307	2.5	7	309	1.4	0.6	309	1.2	0.5
176	700> osc> 400	308	1.6	12	308	1.1	0.1	309	0.9	0.2
176	osc< 400	310	1.4	26	308	1.3	-0.4	310	1.5	0.0
177	osc> 1500	314	0.0	1	318	0.0	1.3	317	0.0	0.9
177	1000> osc> 700	317	0.5	3	319	0.6	0.6	318	0.6	0.3
177	700> osc> 400	313	4.2	17	313	3.9	0.0	313	3.6	0.0
177	osc< 400	311	1.5	18	309	2.0	-0.6	310	1.9	-0.3
178	1500> osc> 1000	311	4.7	4	312	4.6	0.6	312	4.4	0.4
178	1000> osc> 700	309	5.2	7	311	5.5	0.6	311	5.2	0.5
178	700> osc> 400	311	3.6	22	311	3.3	0.1	312	3.2	0.2
178	osc< 400	312	2.0	20	311	1.7	-0.4	312	1.7	-0.1
179	1500> osc> 1000	303	0.0	1	NaN	NaN	NaN	305	0.0	0.6
179	1000> osc> 700	303	0.9	5	NaN	NaN	NaN	306	0.6	0.8
179	700> osc> 400	304	0.4	4	NaN	NaN	NaN	306	0.5	0.5

13.9. APPENDIX: SUMMARY PLOTS

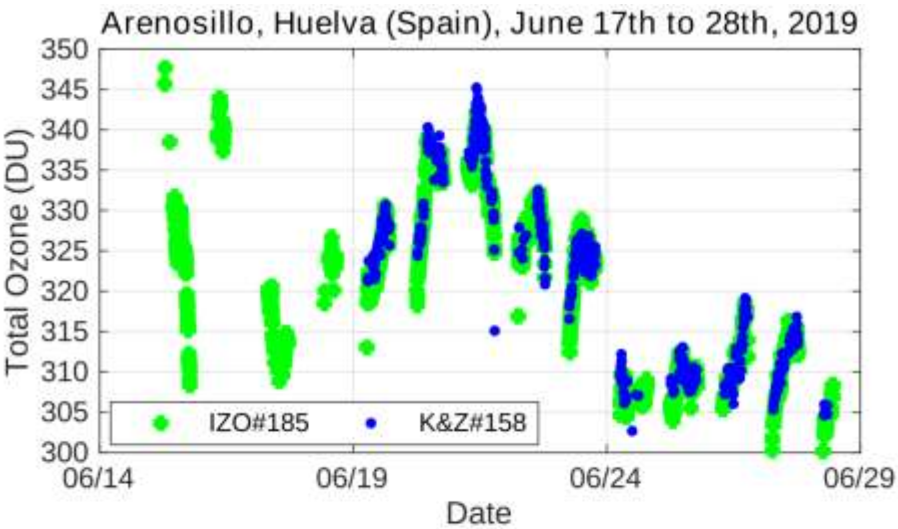
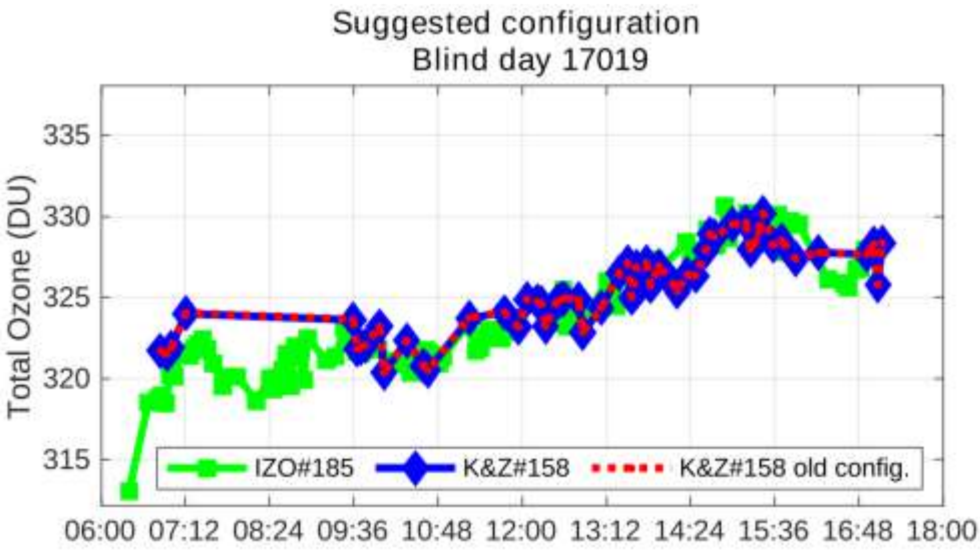
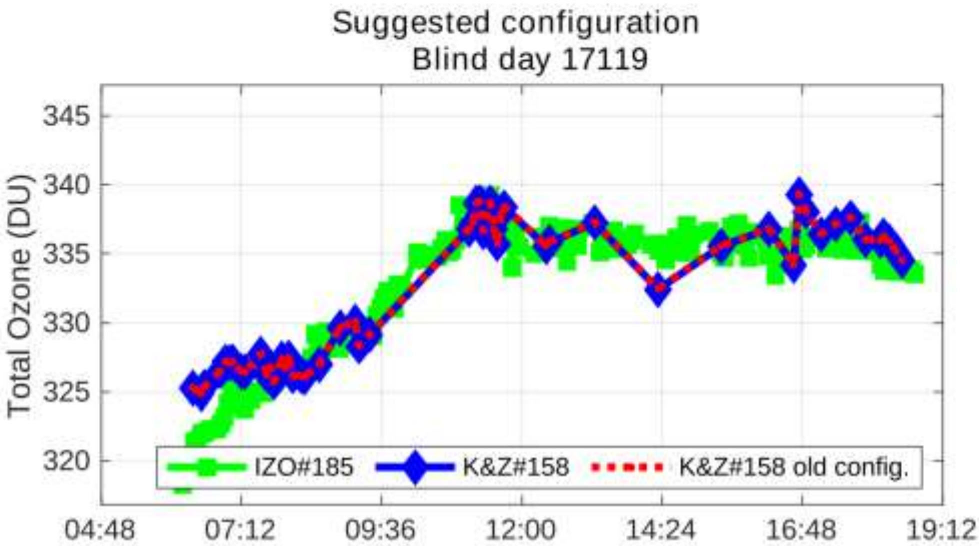
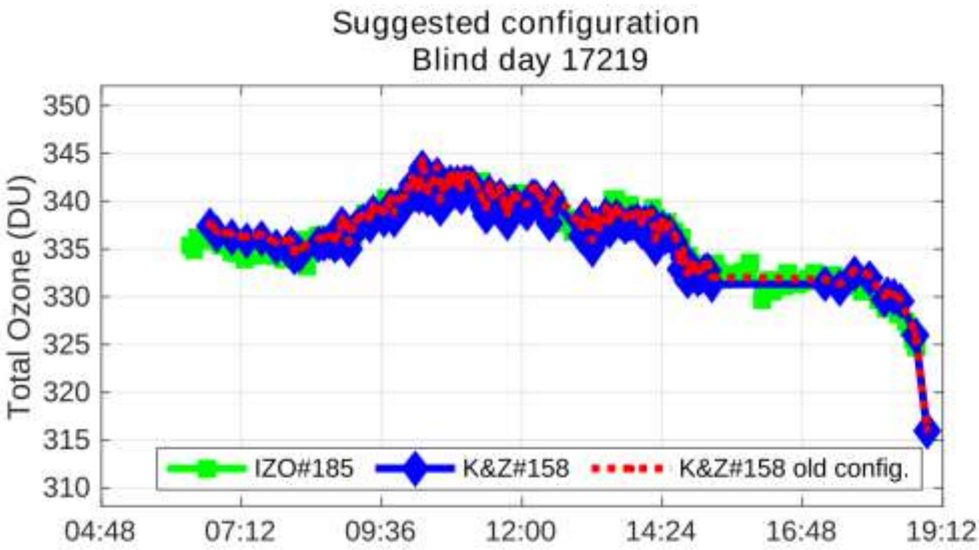
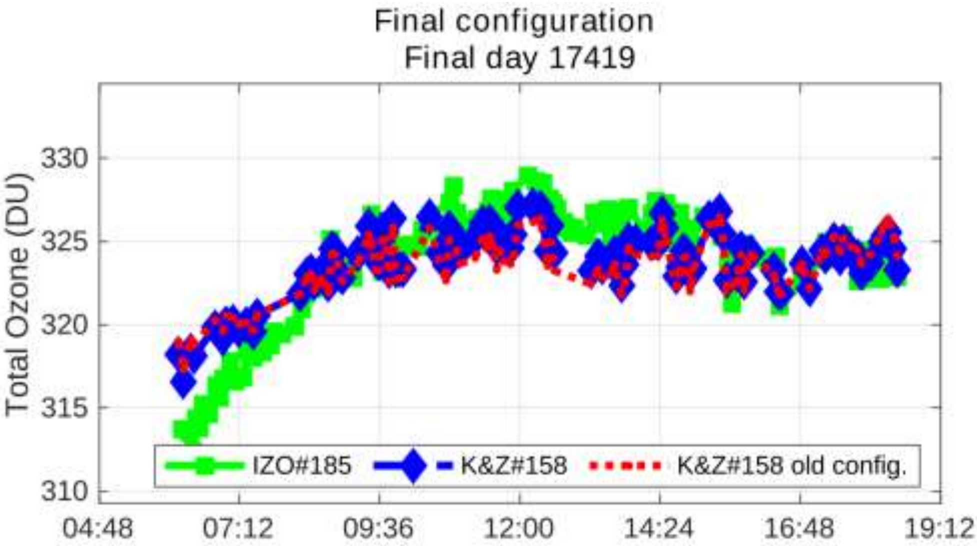


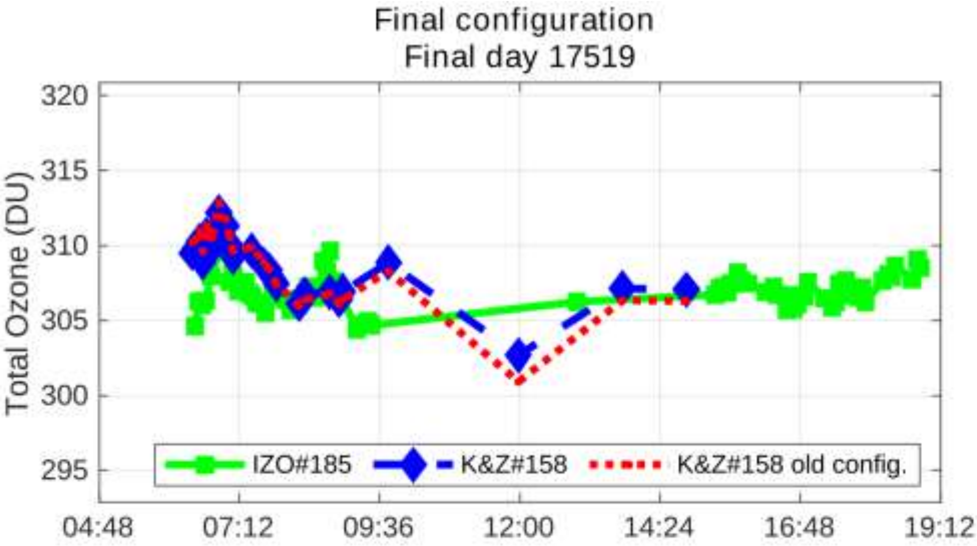
Figure 23. Overview of the intercomparison. Brewer K&Z#158 data were evaluated using final constants (blue circles)

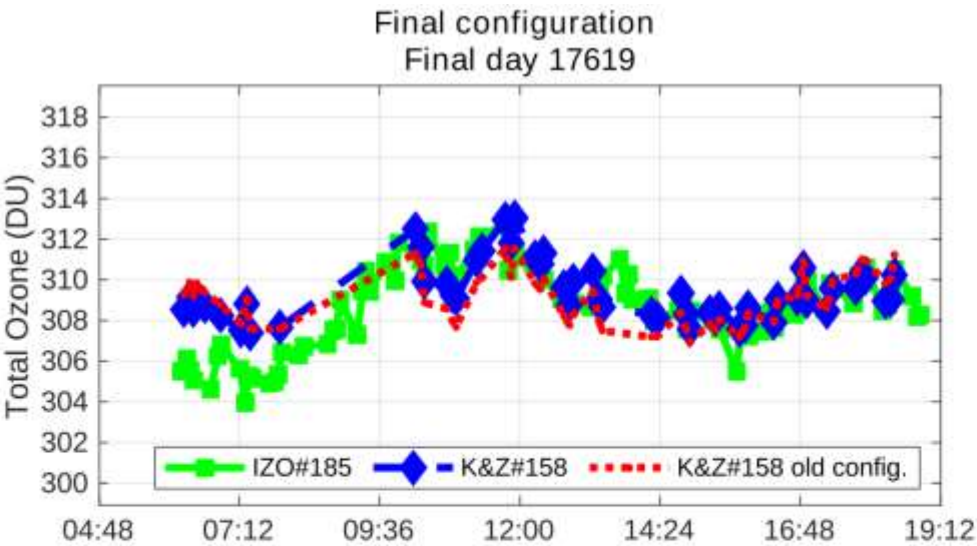

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
IZO#185
K&Z#158
K&Z#158 old config.
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00

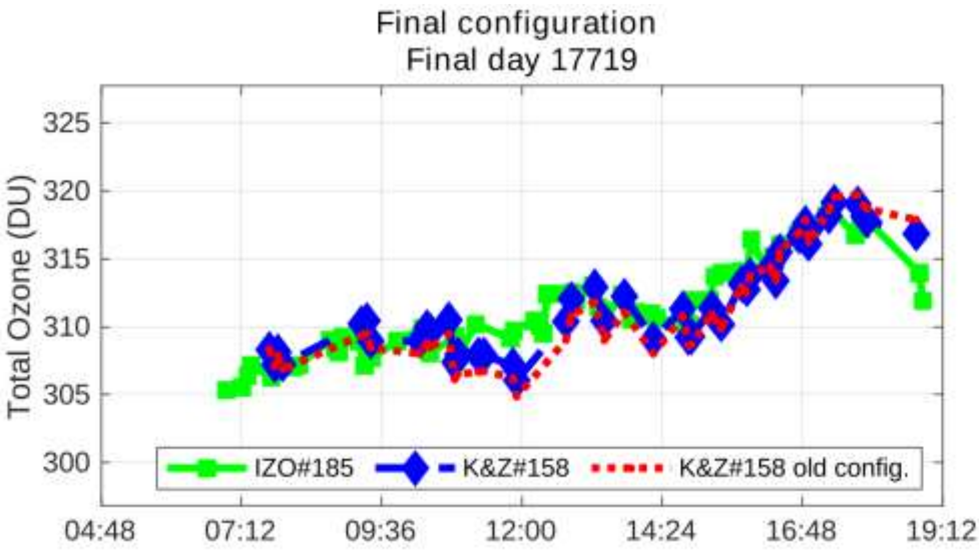

Suggested configuration
Blind day 17119
Total Ozone (DU)
345
340
335
330
325
320
IZO#185
K&Z#158
K&Z#158 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12

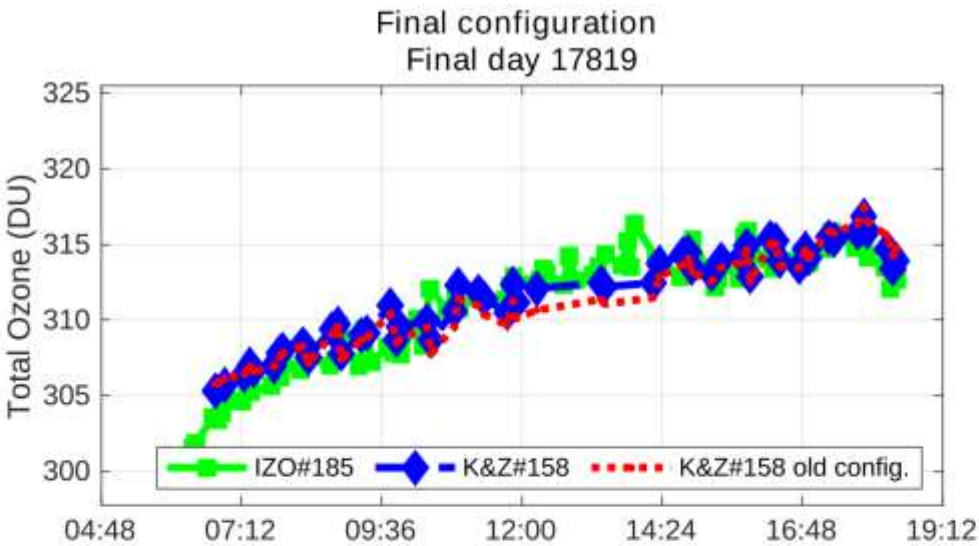

Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
320
315
310
IZO#185
K&Z#158
K&Z#158 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12

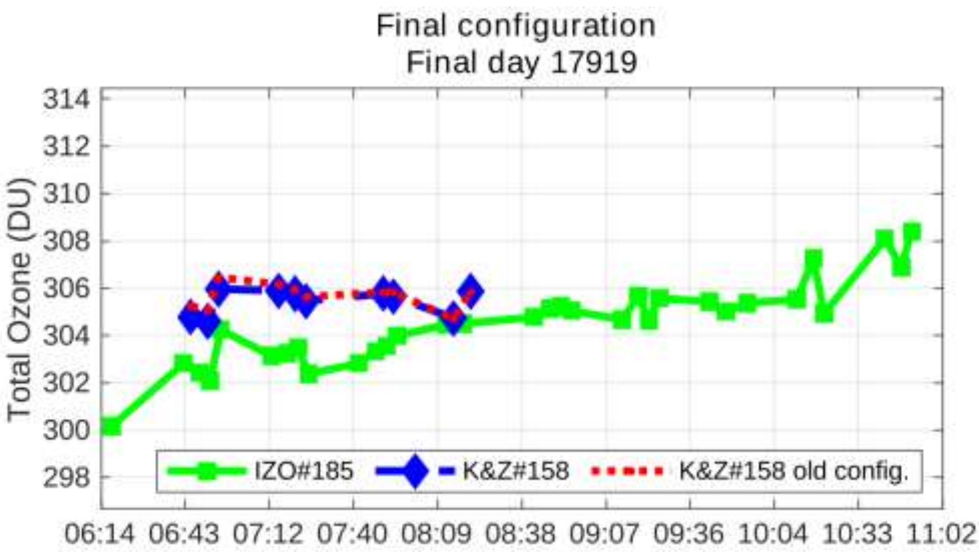

Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
K&Z#158
K&Z#158 old config.


Final configuration
Final day 17519
Total Ozone (DU)
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
K&Z#158
K&Z#158 old config.


Final configuration
Final day 17619
Total Ozone (DU)
318
316
314
312
310
308
306
304
302
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
K&Z#158
K&Z#158 old config.


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
K&Z#158
K&Z#158 old config.


Final configuration
Final day 17819
Total Ozone (DU)
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
K&Z#158
K&Z#158 old config.


Final configuration
Final day 17919
Total Ozone (DU)
314
312
310
308
306
304
302
300
298
06:14
06:43
07:12
07:40
08:09
08:38
09:07
09:36
10:04
10:33
11:02
IZO#185
K&Z#158
K&Z#158 old config.

14. BREWER WRC#163

14.1 CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer WRC#163 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer WRC#163 correspond to Julian days 166 – 179.

The instrument did not require maintenance, so we used the same data set both to evaluate the initial status of the instrument and for final calibration. However, the comparison with the reference shows a small shift of about 0.3% after day 175. We use the measurements from 166 to 179 to analyse the initial calibration (571 observations) whereas the final calibration is obtained for the most reliable period from day 170 to 175 with 472 simultaneous DS ozone measurements.

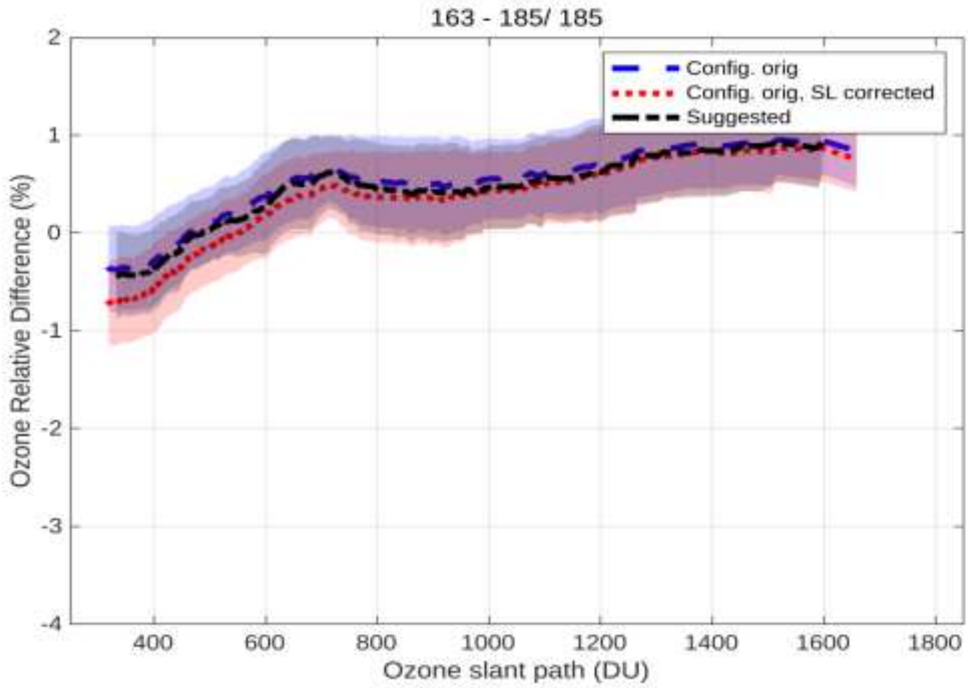


Figure 1. Mean DS ozone column percentage difference between Brewer WRC#163 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF23318.163, blue dashed line) produces ozone values with an average difference of around 0.5% with respect to the reference instrument. This is a rather small difference and highlights the stability of Brewer WRC#163. This is confirmed by the stability of the R6 standard lamp measurements (see Figure 2). The SL correction (Figure 1, red dotted line) is thus not necessary and does not improve the comparison with Brewer IZO#185. The behaviour of the instrument is not uniform. It slightly overestimates the ozone at high sza

($OSC > 600DU$) and underestimates it at noon. We cannot find an explanation for this behaviour. We have tested new temperature coefficients and filtered nonlinearity without improvement but cannot explain why this effect occurs mainly in the morning. The sitting of the instrument was not optimal, but we don't have enough FV observations to arrive at a conclusion.

Dead time (DT) shows a small difference between the current and campaign values of approx. 1 ns. This difference is within tolerance limits, so for the final configuration, we suggest $3 \cdot 10^{-8}$ s, which is the same as the original value.

We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of temperature coefficients.

The neutral density filters did not show any nonlinearity in the attenuation's spectral characteristics. We do not suggest the application of any correction to filters.

The cal step in the current ICF is 1021, which is higher than the value determined from the sun scan (SC) test performed at the station before the campaign (1019). SC tests performed during the campaign suggest yet another value for the cal step (1024). The cal step value was not updated during the campaign, but we recommend checking it at the station.

The ozone absorption coefficient in use (0.341) produces a noticeable dependence of the 1P ETC (see Sec.1.6) with the optical air mass. This behaviour can be compensated if the ozone absorption coefficient is also calculated from reference (see Sec.1.6 for details), but this would require a change of more than two micrometre steps away from the value obtained in the dispersion tests.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) show reasonable results.

Taking this into account, we suggest maintaining the current configuration. The changes on the ETC are small (1488), but the WRC#163 instrument requires further investigation into the unexplained behaviour.

14.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer WRC#163 have been quite stable during the last 2 years. The old R6 reference value was 274 and, although the difference is within the ± 5 acceptable error, it could be updated to 278.
2. We suggest a new R5 reference value of 473.
3. It might be worth checking the cal step at the station. However, in the final ICF for this campaign, we retain its current value.
4. The ozone absorption coefficient in use (0.341) produces a noticeable dependence of the 1P ETC with the optical air mass.
5. Finally, we suggest maintaining the ETC value 1490.

14.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/163/ICF17519.163

Calibration report
https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=2024243408

Calibration reports detailed
Historic and instrumental
http://rbcce.aemet.es/svn/campaigns/are2019/latex/163/html/cal_report_163a1.html

Temperature & filter
http://rbcce.aemet.es/svn/campaigns/are2019/latex/163/html/cal_report_163a2.html

Wavelength
http://rbcce.aemet.es/svn/campaigns/are2019/latex/163/html/cal_report_163b.html

ETC transfer
http://rbcce.aemet.es/svn/campaigns/are2019/latex/163/html/cal_report_163c.html

14.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

14.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp test performance has been quite stable since the end of 2017, with mean values of around 278 and 473 for R6 and R5, respectively. The current R6 value is only 4 units more that the reference value given in the previous intercomparison campaign. The small changes in R6 and R5 can be associated to changes of the lamp's intensity as shown in Figure 4.

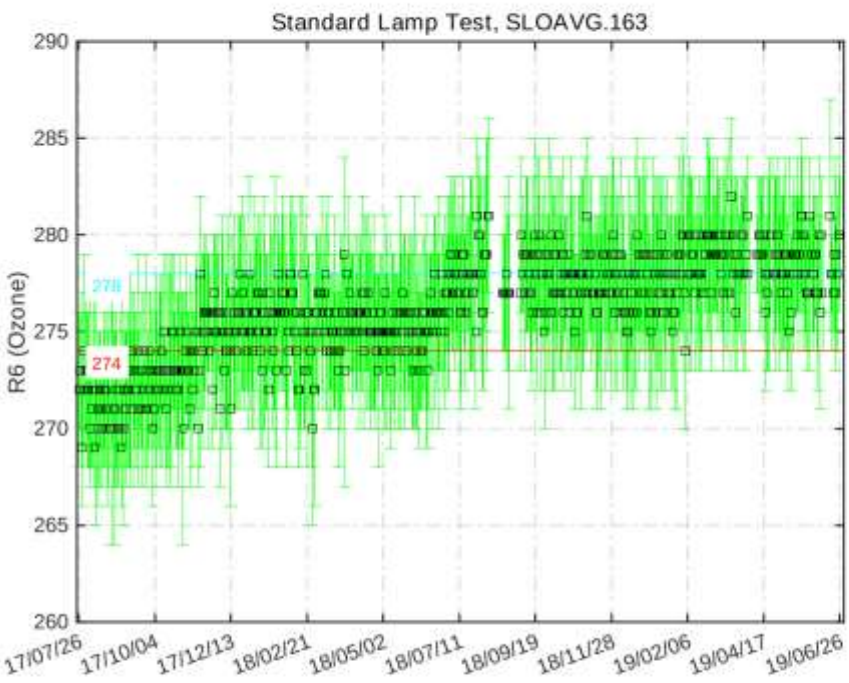


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

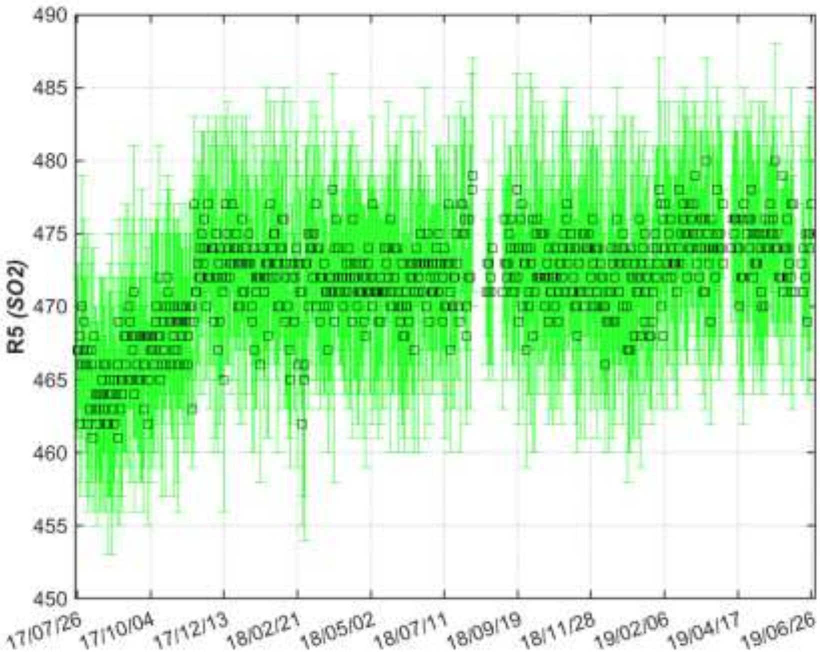


Figure 3. Standard lamp test R5 sulphur dioxide ratios

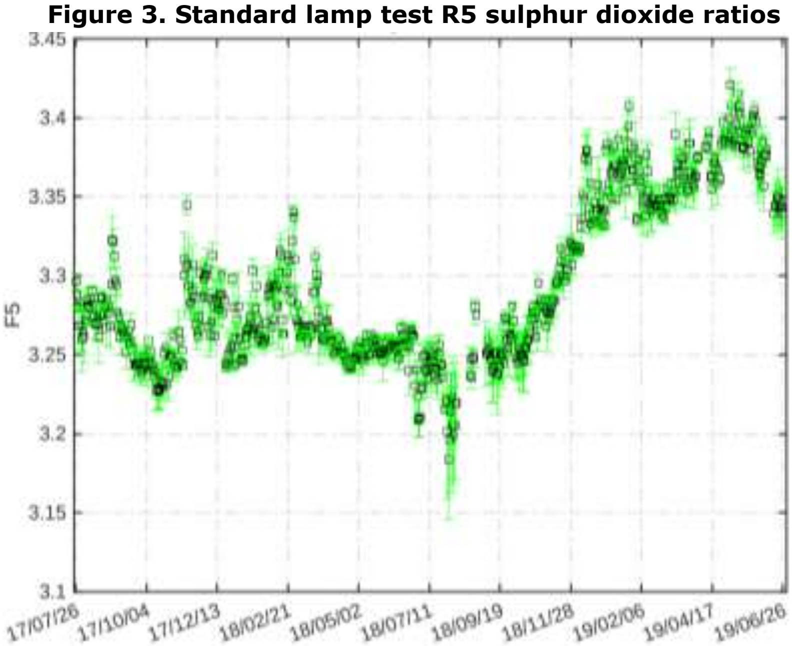


Figure 4. SL intensity for slit five

14.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, the current DT reference value of $3 \cdot 10^{-8}$ seconds is slightly larger than the value recorded during the calibration period ($2.9 \cdot 10^{-8}$ s). This difference is within the tolerance limit, so the current value of $3 \cdot 10^{-8}$ s has been retained in the new ICF (ICF17519.163).

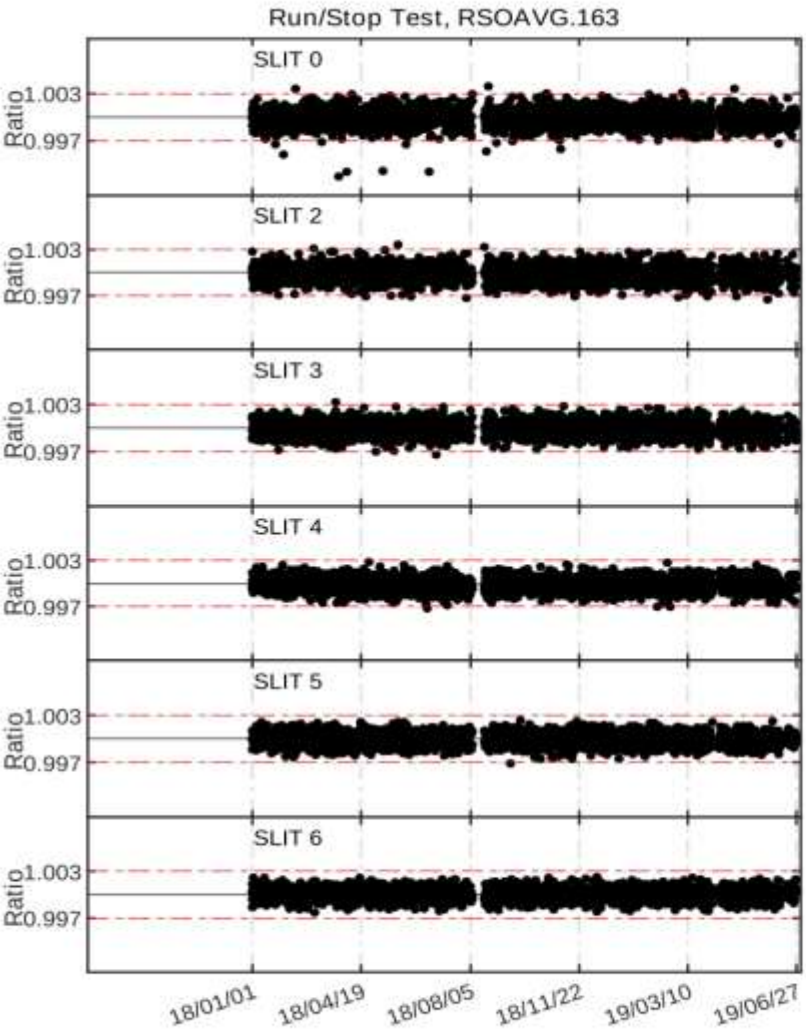


Figure 5. Run/stop test

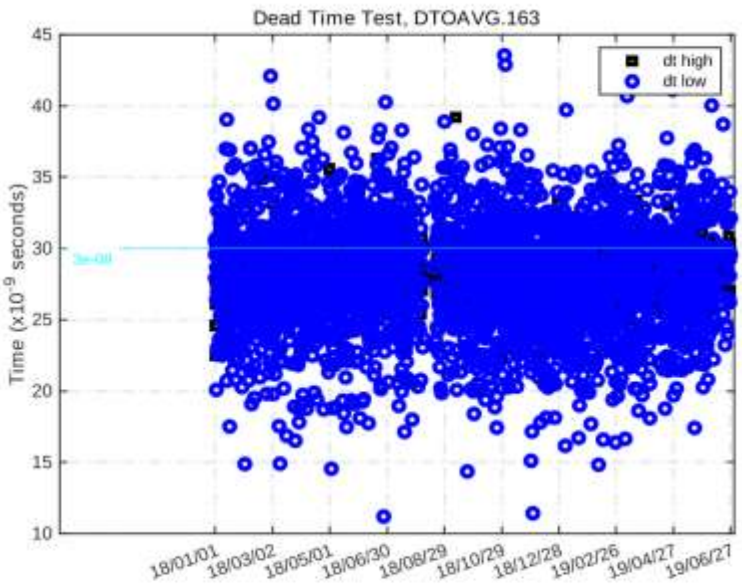


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

14.2.3. Analogue test

Figure 7 shows that the results of the analogue test are quite noisy. However, the results are overall correct.

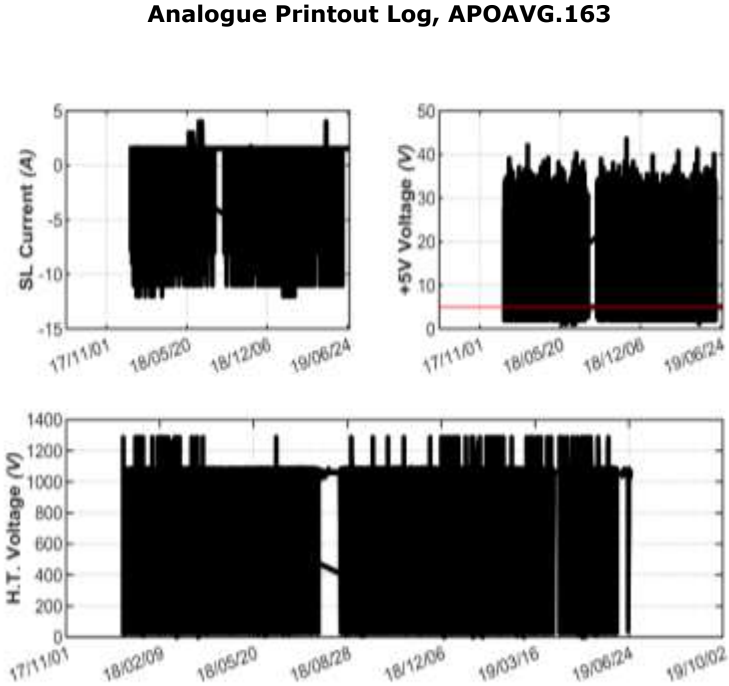


Figure 7. Analogue voltages and intensity

14.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events have been observed during the campaign, see Figure 8. A clear temperature dependence can be identified.

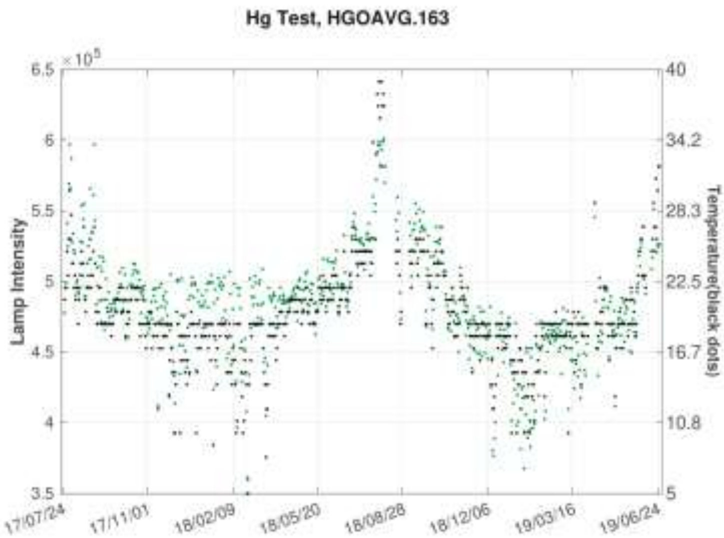


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

14.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer WRC#163 during the campaign show reasonable results, with the peak of the calculated scans within the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.

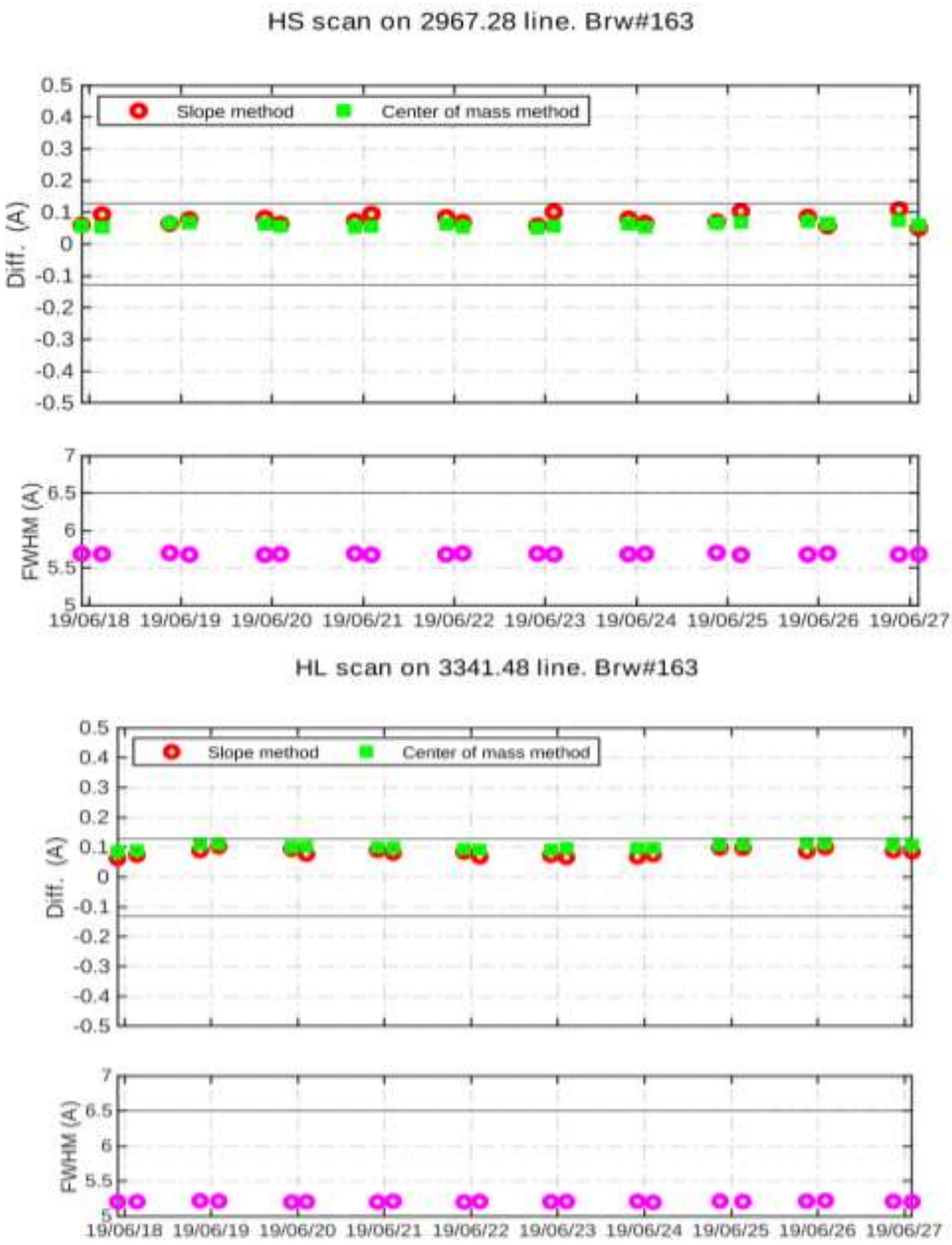


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

14.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer WRC#163 CI scans performed during the campaign relative to the scan CI16819.163. As can be observed, the lamp intensity varies below 1% with respect to the reference spectrum. This behaviour is normal for a SL lamp.

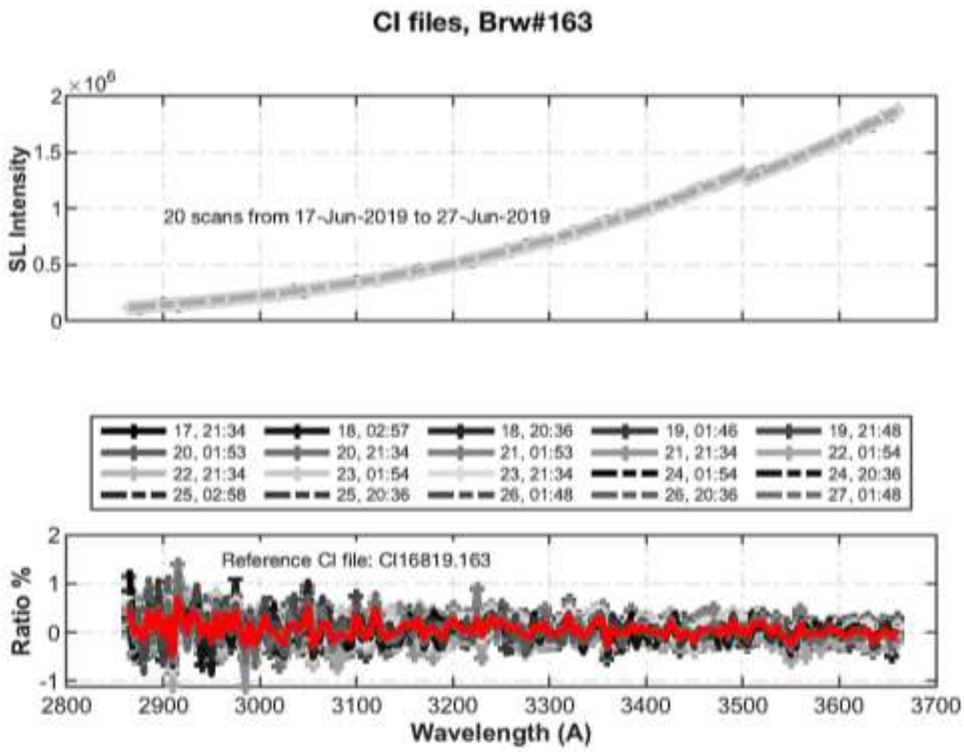


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

14.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature, with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 22 ˚C to 32 ˚C), the current coefficients do a reasonable job at reducing the temperature dependence, with a slope within the tolerance limit of 5 units per 10 ˚C. As expected, the temperature coefficients calculated using the data from the campaign completely remove the temperature dependence. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, the current and new coefficients perform similarly, the current coefficients being only slightly better. For this reason, in the final ICF we have used the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	0.1845	0.1625	0.4778	-0.4826
Calculated	0.0000	0.3200	0.0600	0.3400	-0.5200
Final	0.0000	0.1845	0.1625	0.4778	-0.4826

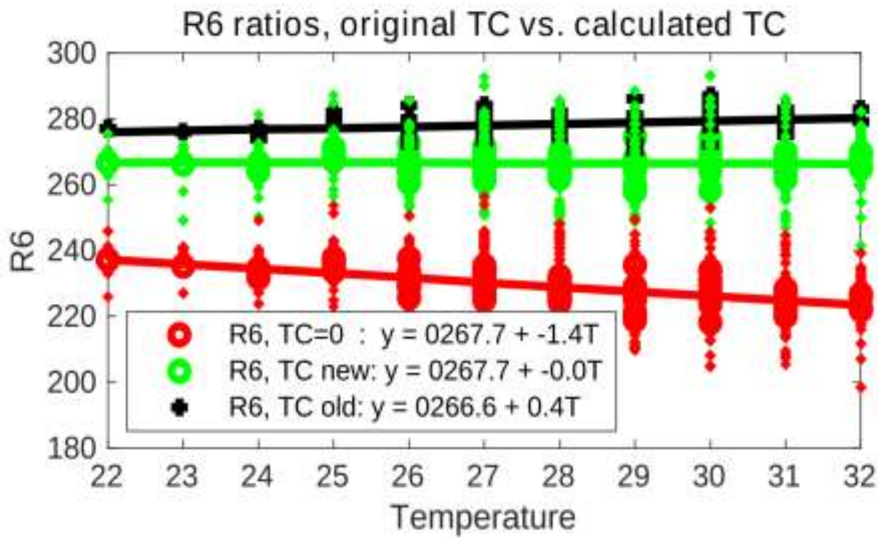


Figure 11. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

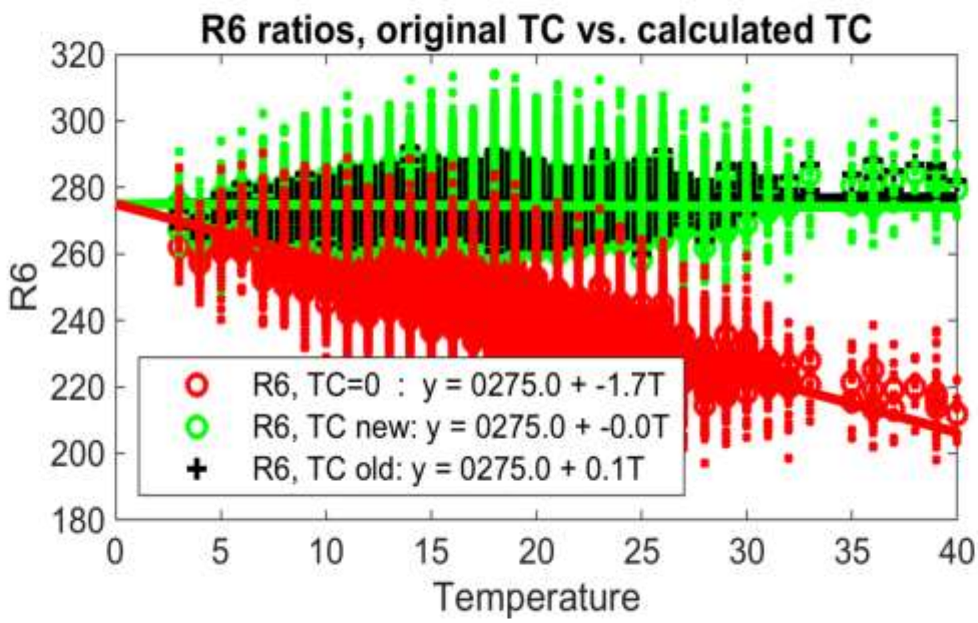


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

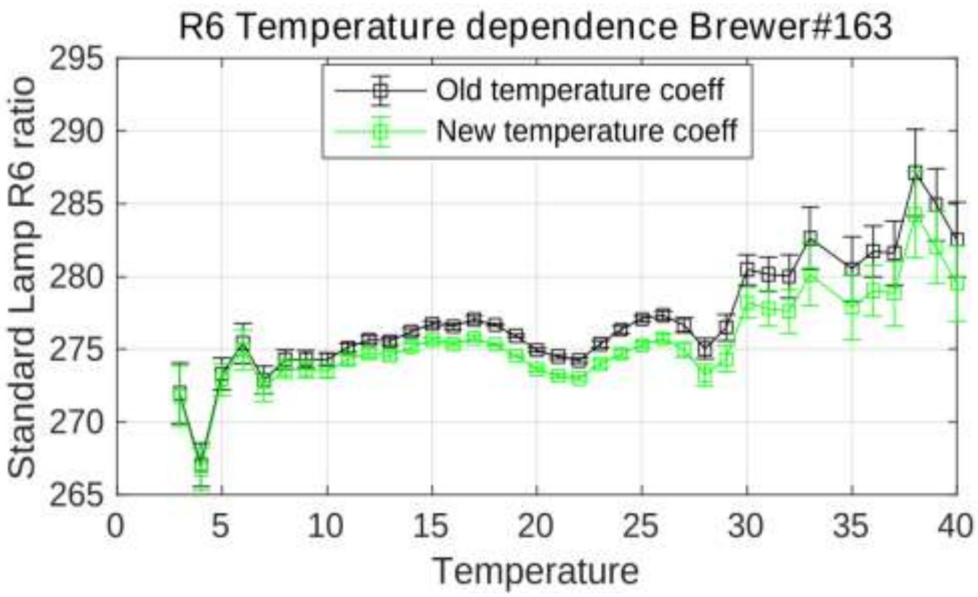


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

14.4. ATTENUATION FILTER CHARACTERIZATION

14.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 43 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

The results of the FI tests are very noisy, as shown by the difference between the median and values, and the large confidence intervals in Table 2. Taking into account the relative ozone difference with respect to the reference Brewer IZO#185, we do not suggest the application of any ETC filter correction.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	5	-7	-5	17	18
ETC Filt. Corr. (mean)	1.7	2.2	0.5	16	-7.3
ETC Filt. Corr. (mean 95% CI)	[-10.6 13.4]	[-10.4 14]	[-11.6 13.3]	[-8.7 42.5]	[-48.8 29.2]

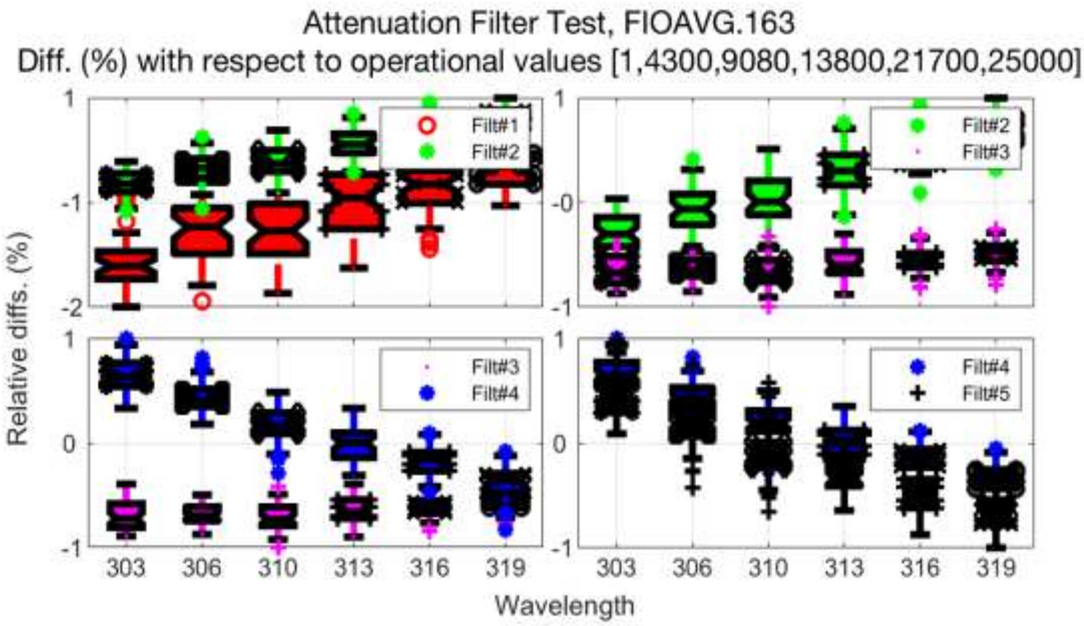


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

14.5. WAVELENGTH CALIBRATION

14.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 8 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out (see Figure 16). The calculated cal step number (CSN) was 3 steps higher than the value in the current configuration: 1024 vs. 1021. SC tests performed at the station before the campaign provide a CSN of 1019. We retain the current CSN of 1021 in the final ICF for the campaign but suggest checking the cal step at the station.

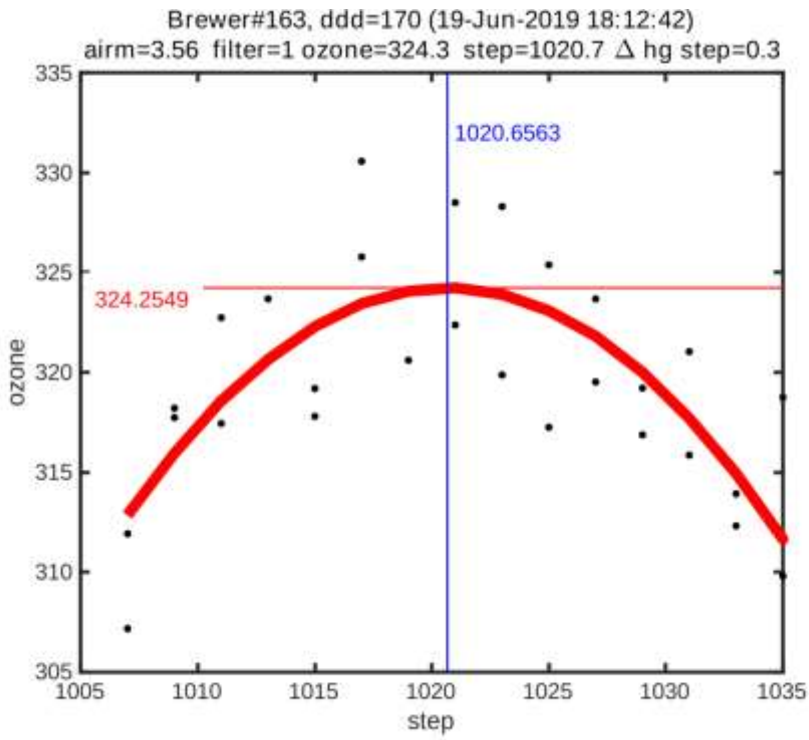


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

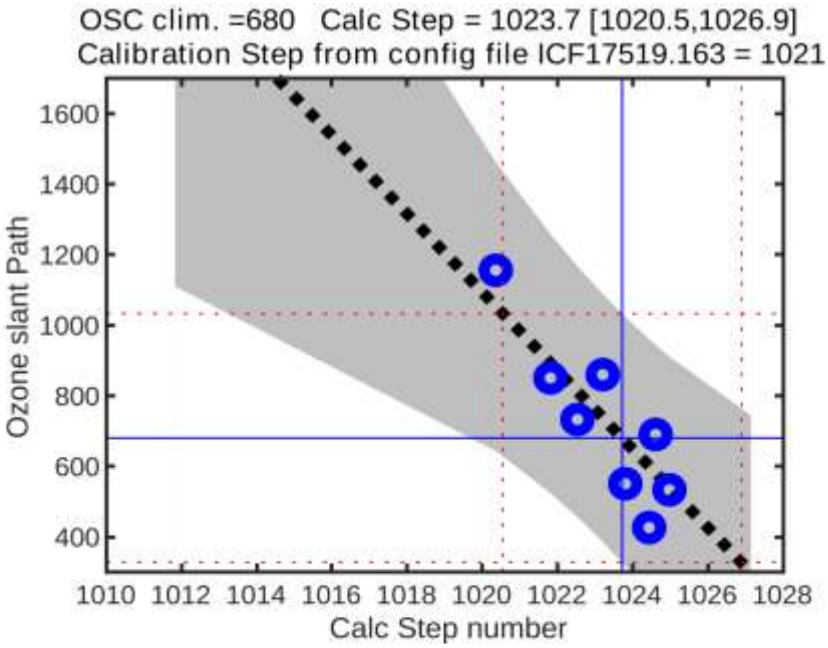


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

14.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.341 is suggested in the final configuration. This value is the same as the current one (0.341) and we have found that it introduces a dependence of the 1P ETC with the optical air mass (see Sec.1.6). Note that the value obtained from the 2P ETC transfer is 0.345.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	1021	0.3410	2.3500	1.1342
01-Jun-2017	1021	0.3399	3.1446	1.1429
02-Aug-2018	1021	0.3408	3.1632	1.1440
23-Jun-2019	1021	0.3406	3.1479	1.1454
Final	1021	0.3410	2.3500	1.1342

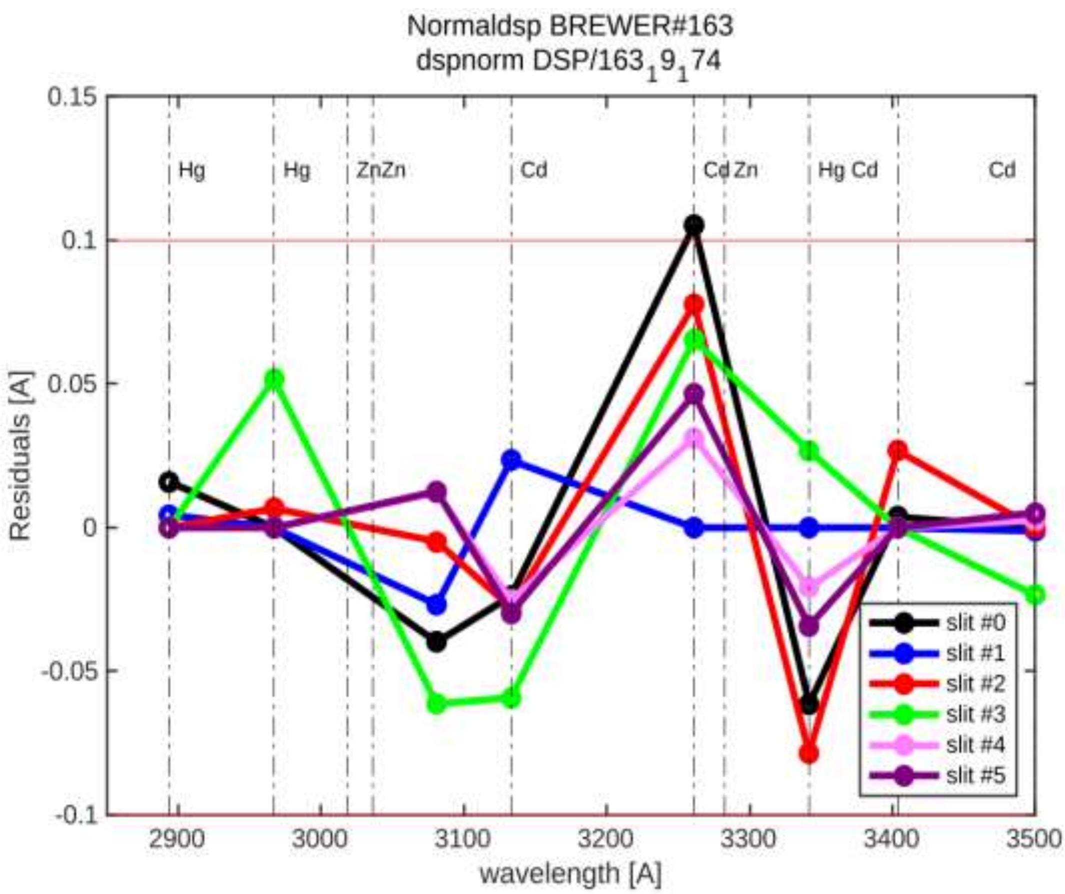


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 1020	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.83	3062.88	3100.39	3134.87	3167.87	3199.94
Res(A)	5.6662	5.5966	5.506	5.5595	5.5193	5.4205
O3abs(1/cm)	2.602	1.7827	1.0053	0.67701	0.375	0.29402
Ray abs(1/cm)	0.50512	0.48331	0.45855	0.43719	0.41793	0.40024
SO2abs(1/cm)	3.4596	5.5974	2.3976	1.9238	1.0526	0.613
step= 1021	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.91	3062.95	3100.46	3134.94	3167.94	3200.01
Res(A)	5.6661	5.5966	5.506	5.5594	5.5192	5.4204
O3abs(1/cm)	2.5994	1.7811	1.005	0.67673	0.37503	0.29356
Ray abs(1/cm)	0.50507	0.48326	0.4585	0.43715	0.41789	0.4002
SO2abs(1/cm)	3.4437	5.6193	2.4056	1.9121	1.0538	0.61077
step= 1022	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.98	3063.02	3100.53	3135.01	3168.01	3200.08
Res(A)	5.666	5.5965	5.5059	5.5593	5.5191	5.4203
O3abs(1/cm)	2.5968	1.7795	1.0047	0.67636	0.37506	0.2931
Ray abs(1/cm)	0.50501	0.48321	0.45845	0.43711	0.41785	0.40016
SO2abs(1/cm)	3.4278	5.6407	2.4136	1.9005	1.055	0.6085
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
1020	0.3416	9.1539	3.1382	1.1486	0.35244	0.34379
1021	0.3406	9.1515	3.1479	1.1454	0.35147	0.3428
1022	0.33962	9.1492	3.1569	1.1421	0.35047	0.34176

14.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2426. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 1021	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.6661	5.5966	5.506	5.5594	5.5192	5.4204
O3abs(1/cm)	2.5994	1.7811	1.005	0.67673	0.37503	0.29356
Ray abs(1/cm)	0.50507	0.48326	0.4585	0.43715	0.41789	0.4002
step= 2426	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.5532	5.48	5.3861	5.4445	5.3752	5.291
O3abs(1/cm)	0.67858	0.39426	0.2937	0.12255	0.060926	0.033395
Ray abs(1/cm)	0.43792	0.42021	0.4002	0.3828	0.3671	0.35265

14.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for Ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light. In this case, the ETC distribution (see Figure 1) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The network Brewers were calibrated using the one parameter ETC transfer method (1P) only the ozone ETC constant was transferred from the reference instrument. The so-called 'two-parameters calibration method' (2P) where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and used as a quality indicator of the calibration. We consider a good calibration when both ETC agrees in 10 ETC units and the ozone absorption coefficient calculated from dispersion and obtained by 2P agrees in +/- 2 micrometre steps or approximately +/- 0.002 $atm.cm^{-1}$. This range represents a total ozone difference of about 0.5% at air mass equal to 2 and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

14.6.1. Initial calibration

For the evaluation of initial status of Brewer WRC#163, we used the full campaign period, from days 168 to 178. As shown in Figure 18, the initial calibration constants produced ozone values within ± 0.5% of the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

The dependence with the air mass mentioned in the summary is almost compensated if we used the 2P calibration, but this requires the use of an unrealistic ozone coefficient (Table 6, Figure 19).

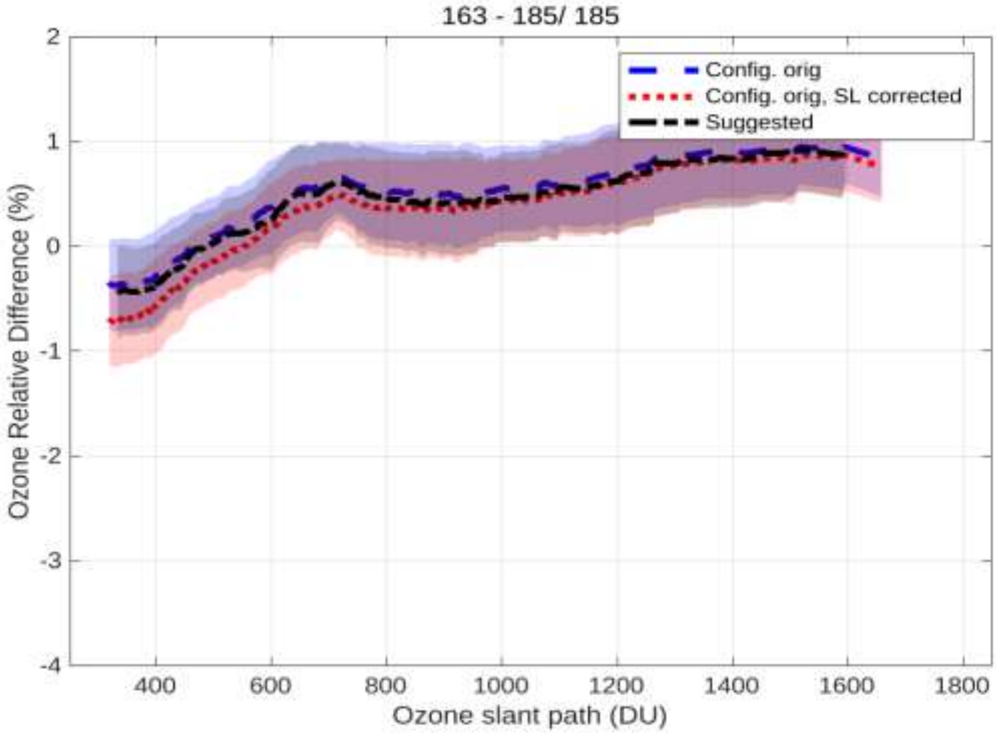


Figure 18. Mean direct sun ozone column percentage difference between Brewer WRC#163 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods. Blind period

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=700	1488	1471	3410	3451
full OSC range	1486	1472	3410	3450

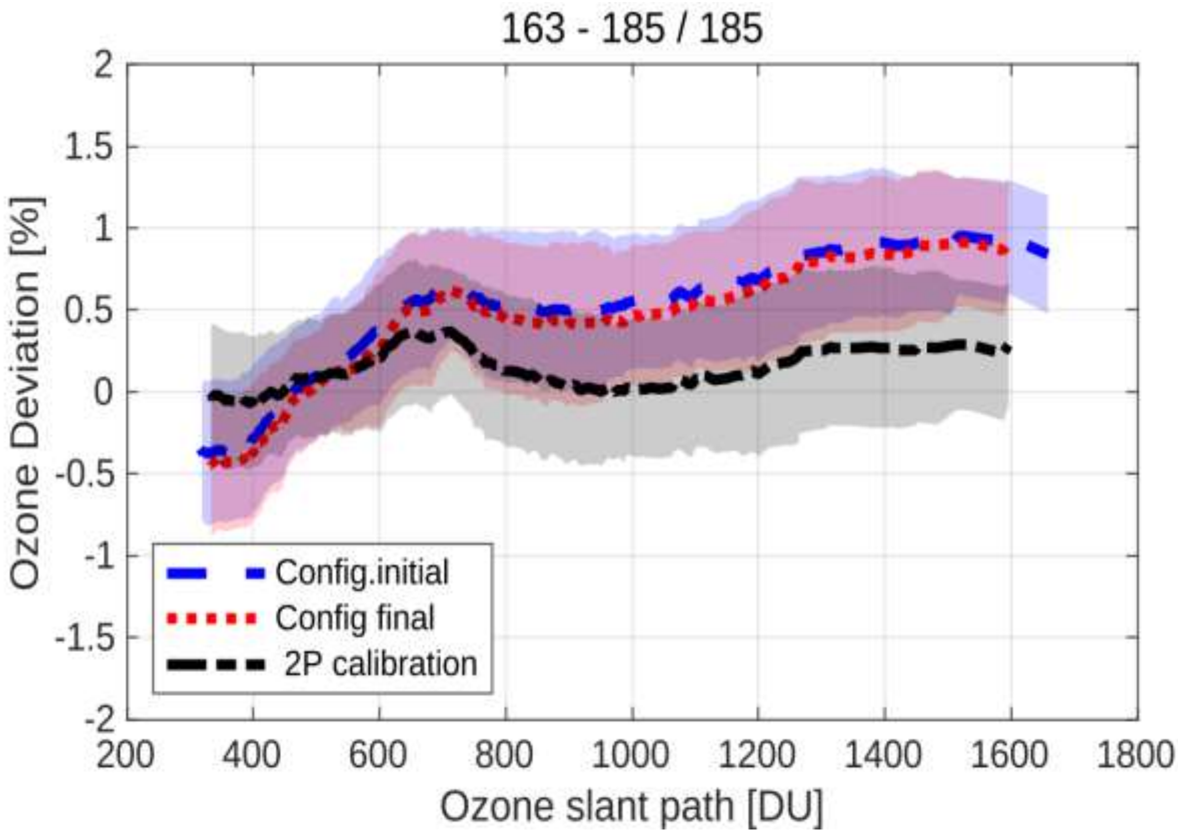


Figure 19. Mean direct sun ozone column percentage difference between Brewer WRC#163 and Brewer IZO#185 as a function of ozone slant path

14.6.2. Final calibration

A new ETC value was calculated (see Figure 20) using 472 simultaneous direct sun measurements from days 170 to 175. This is the most stable period of the campaign for this period, because there is a small shift of 0.3% on day 175. The new 1P value of 1487 is almost the same as the current one (1490). Therefore, we recommend not changing the ETC.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 7, there is a difference of approx. 13 units between the ETC of the 1P and 2P methods if we consider only the data up to an OSC value of 700. Taking into account the full OSC range, this difference decreases in half, to 7 units.

Mean daily total ozone values for the original and the final configurations are shown in Table 8, as well as relative differences with respect to IZO#185.

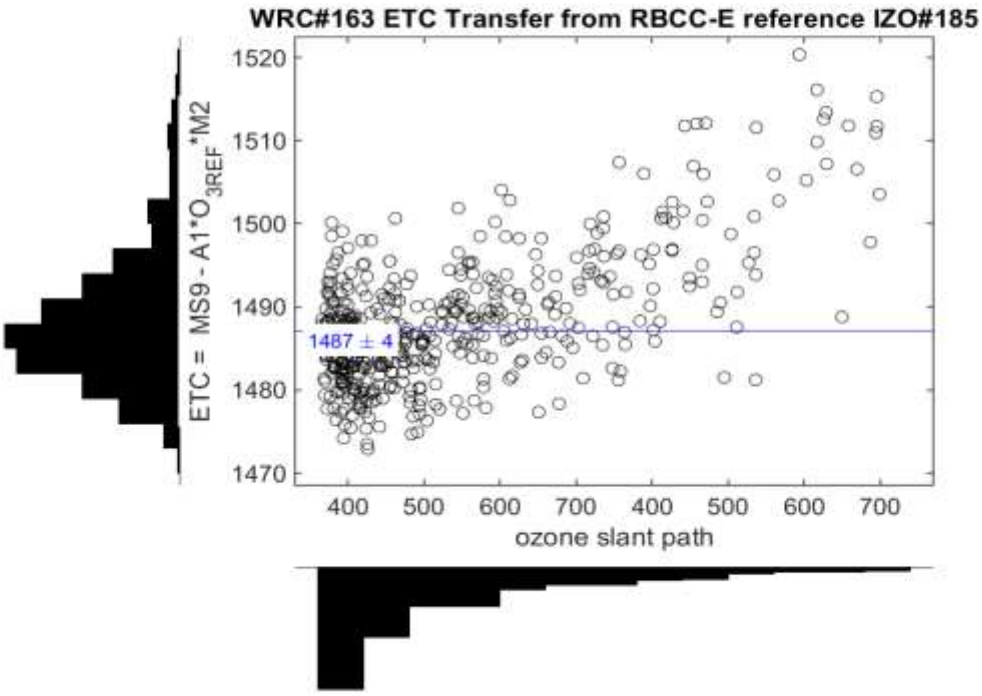


Figure 20. Mean direct sun ozone column percentage difference between Brewer WRC#163 and Brewer IZO#185 as a function of ozone slant path

Table 7. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=700	1487	1474	3410	3443
full OSC range	1487	1480	3410	3426

Table 8. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#163*	*O3 std*	*%(163–185)/185*	*O3(*) #163*	*O3std*	*(*)%(163–185)/185*
18-Jun-2019	169	323.8	1.8	13	324.2	2.1	0.1	324.2	2.1	0.1
19-Jun-2019	170	324.8	3.3	87	324.2	3.7	-0.2	324.2	3.7	-0.2
20-Jun-2019	171	334.4	3.4	94	333.3	2.8	-0.3	333.3	2.8	-0.3
21-Jun-2019	172	337.1	3.3	98	336.3	2.8	-0.2	336.3	2.8	-0.2
22-Jun-2019	173	330.2	1.5	72	328.7	1.8	-0.5	328.7	1.8	-0.5
23-Jun-2019	174	325.1	2.2	89	324.4	1.7	-0.2	324.4	1.7	-0.2
24-Jun-2019	175	306.8	1.5	19	307.5	1.4	0.2	307.5	1.4	0.2

14.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 278 for R6 (Figure 21) and 473 for R5 (Figure 22).

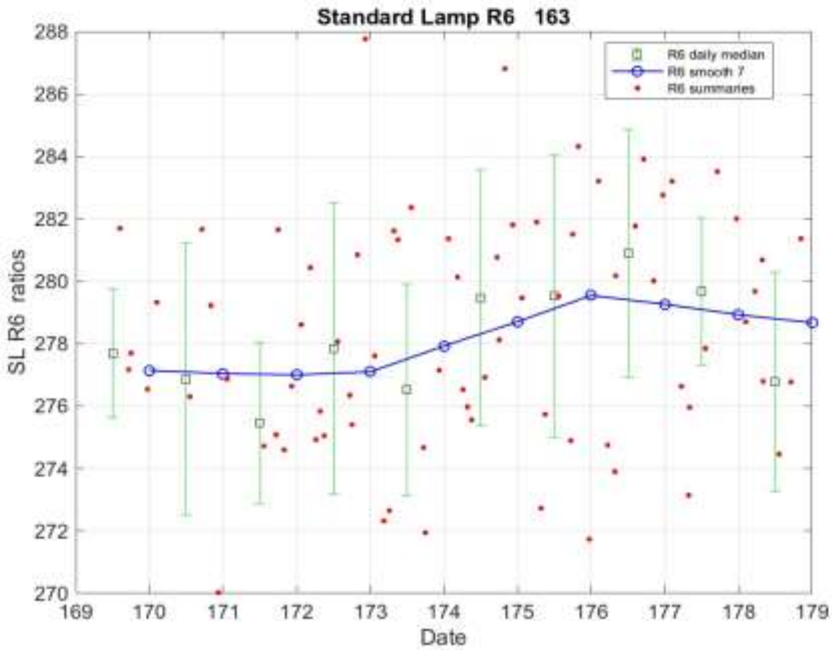


Figure 21. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

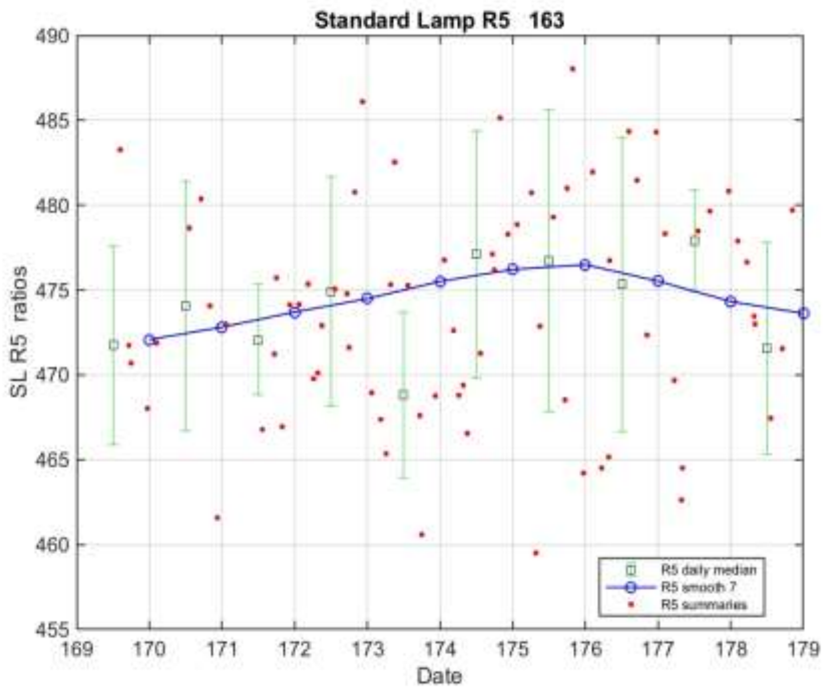


Figure 22. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

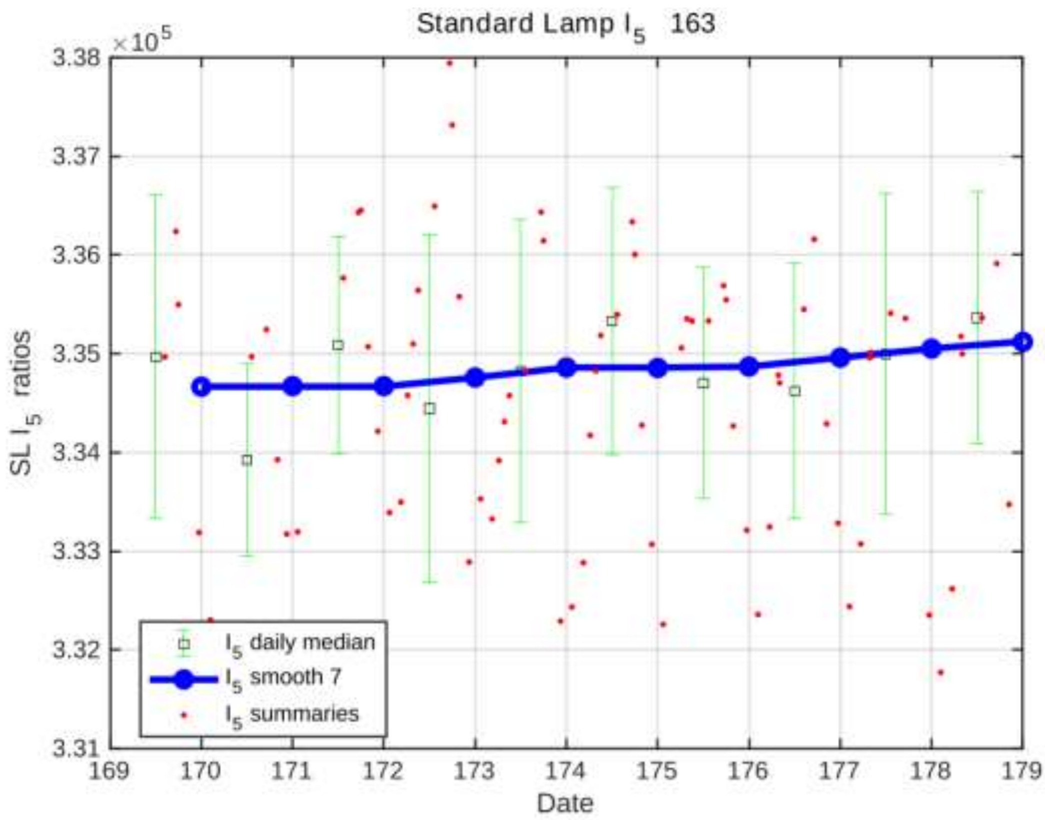


Figure 23. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

14.7. CONFIGURATION

14.7.1. Instrument constant file

	Initial (ICF23318.163)	*Final (ICF17519.163)*
o3 Temp coef 1	0	0
o3 Temp coef 2	0.1845	0.1845
o3 Temp coef 3	0.16251	0.16251
o3 Temp coef 4	0.47783	0.47783
o3 Temp coef 5	-0.48255	-0.48255
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.341	0.341
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1342	1.1342
ETC on O3 Ratio	1490	1490
ETC on SO2 Ratio	105	105
Dead time (sec)	3e-08	3e-08

	Initial (ICF23318.163)	*Final (ICF17519.163)*
WL cal step number	1021	1021
Slitmask motor delay	14	14
Umkehr Offset	1693	1693
ND filter 0	0	0
ND filter 1	4300	4300
ND filter 2	9080	9080
ND filter 3	13800	13800
ND filter 4	21700	21700
ND filter 5	25000	25000
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	2
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	-1	-1
Mic #2 Offset	-4	-4
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2503	2503
Grating Slope	0.9965	0.9965
Grating Intercept	10	10
Micrometre Zero	1738	1738
Iris Open Steps	250	250

	Initial (ICF23318.163)	*Final (ICF17519.163)*
Buffer Delay (s)	0.6	0.6
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2242	2242

14.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#163*	*O3 std*	*%diff*	*(*)O3#163*	*O3 std*	*(*)%diff*
169	700> osc> 400	324	0.7	3	324	2.1	-0.1	325	2.1	0.3
169	osc< 400	323	2.4	9	323	1.9	0.0	325	1.9	0.5
170	1500> osc> 1000	319	0.0	2	320	0.0	0.4	320	0.2	0.5
170	1000> osc> 700	321	0.9	4	322	1.3	0.2	322	1.4	0.3
170	700> osc> 400	325	4.1	58	324	4.5	-0.1	325	4.5	0.2
170	osc< 400	325	2.6	104	323	2.9	-0.5	324	3.0	-0.1
171	osc> 1500	334	0.2	4	336	0.5	0.6	336	0.5	0.6
171	1500> osc> 1000	326	6.7	20	328	5.4	0.6	328	5.4	0.6
171	1000> osc> 700	326	4.1	24	328	3.7	0.5	328	3.7	0.6
171	700> osc> 400	332	3.7	94	332	3.4	-0.1	332	3.4	0.1
171	osc< 400	336	1.1	94	334	1.5	-0.7	335	1.5	-0.4
172	osc> 1500	326	0.0	2	327	0.0	0.5	327	0.1	0.6
172	1500> osc> 1000	334	2.8	26	336	3.3	0.6	337	3.3	0.8
172	1000> osc> 700	333	1.9	30	334	3.9	0.2	334	3.9	0.4
172	700> osc> 400	335	3.1	92	334	3.0	-0.2	335	3.0	0.1
172	osc< 400	339	1.9	102	336	2.2	-0.8	338	2.2	-0.4
173	1500> osc> 1000	325	1.3	24	328	1.5	0.8	328	1.6	0.9

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#163*	*O3 std*	*%diff*	*(*)O3#163*	*O3 std*	*(*)%diff*
173	1000> osc> 700	326	1.1	12	328	0.9	0.3	328	0.9	0.5
173	700> osc> 400	330	1.7	40	330	1.5	-0.1	331	1.5	0.1
173	osc< 400	329	1.4	100	327	1.5	-0.6	328	1.5	-0.3
174	osc> 1500	314	0.0	2	318	0.0	1.3	318	0.1	1.4
174	1500> osc> 1000	316	4.1	18	319	2.8	0.9	320	2.8	1.1
174	1000> osc> 700	319	3.2	26	320	1.9	0.3	321	2.0	0.6
174	700> osc> 400	323	2.0	78	322	1.1	-0.3	324	1.2	0.1
174	osc< 400	326	1.0	94	324	1.7	-0.8	326	1.8	-0.3
175	1500> osc> 1000	307	1.4	20	309	0.8	0.8	310	0.8	1.0
175	1000> osc> 700	308	1.3	20	309	2.1	0.4	310	2.1	0.6
175	700> osc> 400	307	1.3	50	307	1.4	0.1	308	1.3	0.4
175	osc< 400	307	0.0	2	306	0.0	-0.3	308	0.4	0.2
176	osc> 1500	306	0.0	1	309	0.0	1.2	310	0.0	1.4
176	1500> osc> 1000	307	2.0	7	309	1.6	0.8	310	1.5	1.0
176	1000> osc> 700	307	2.3	10	308	1.4	0.2	309	1.3	0.6
176	700> osc> 400	308	1.6	22	308	1.3	0.0	310	1.3	0.5
176	osc< 400	310	1.3	38	307	1.1	-0.8	310	1.1	0.0
177	osc> 1500	314	0.0	1	315	0.0	0.4	316	0.0	0.5
177	1000> osc> 700	312	6.1	6	314	7.0	0.7	315	6.9	1.0
177	700> osc> 400	313	4.1	22	313	4.4	-0.1	314	4.2	0.3
177	osc< 400	311	1.3	30	308	1.6	-0.7	311	1.6	0.0
178	1500> osc> 1000	302	1.4	4	304	0.8	0.8	304	0.9	0.9
178	1000> osc> 700	305	0.8	7	306	0.6	0.5	307	0.6	0.7
178	700> osc> 400	308	1.3	14	307	0.6	-0.1	308	0.7	0.2
178	osc< 400	310	1.8	4	309	0.9	-0.2	310	0.9	0.3

14.9. APPENDIX: SUMMARY PLOTS

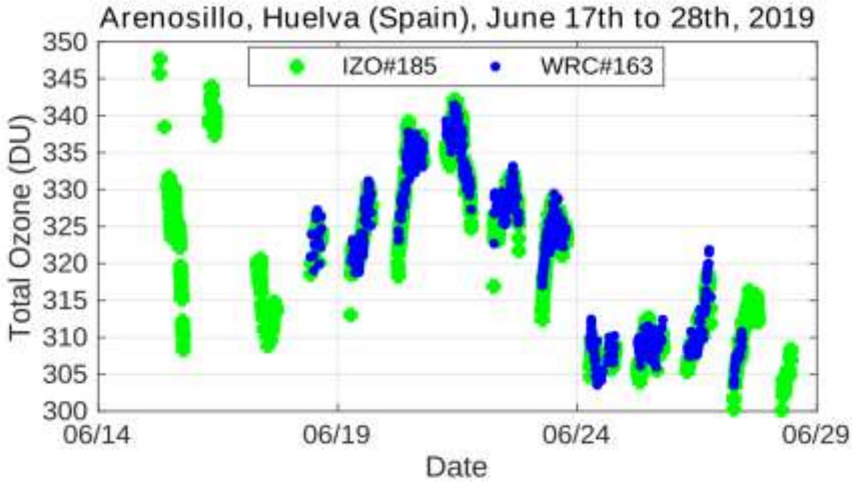
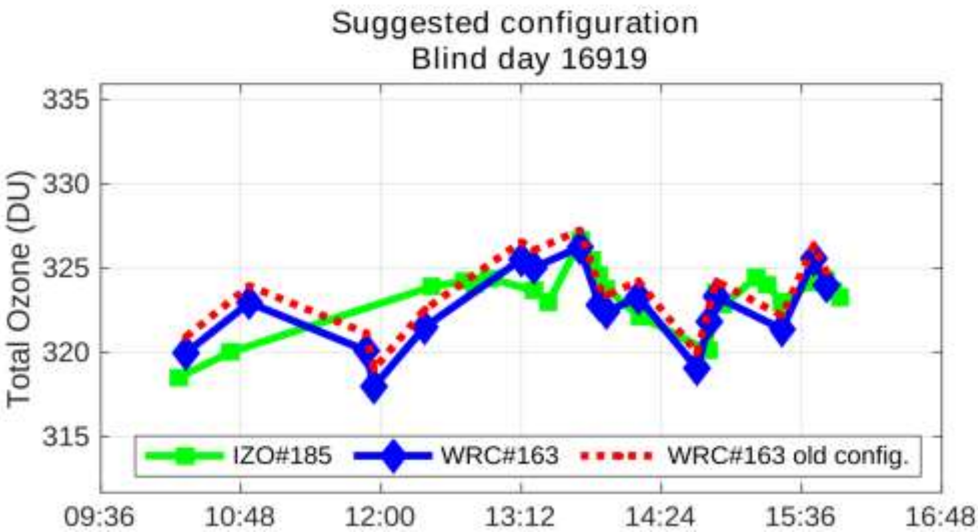
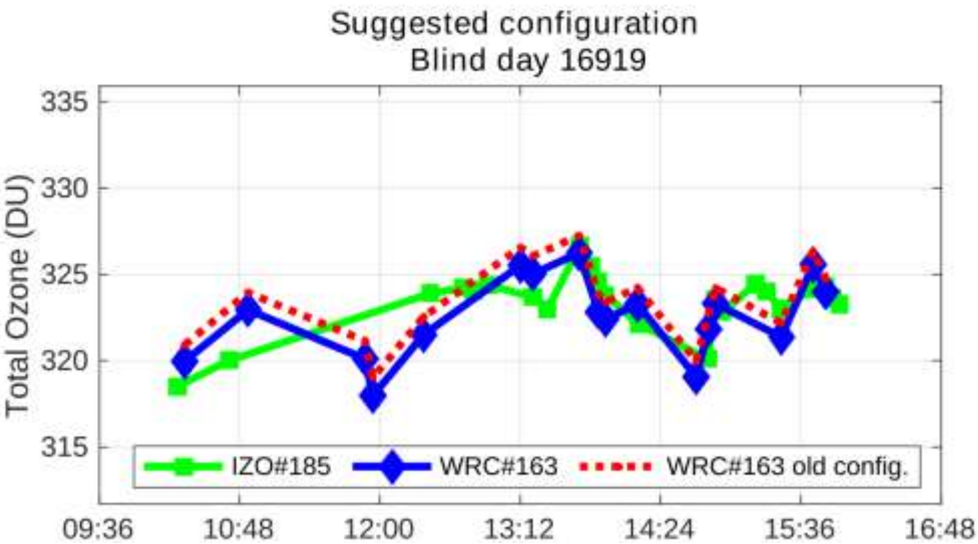
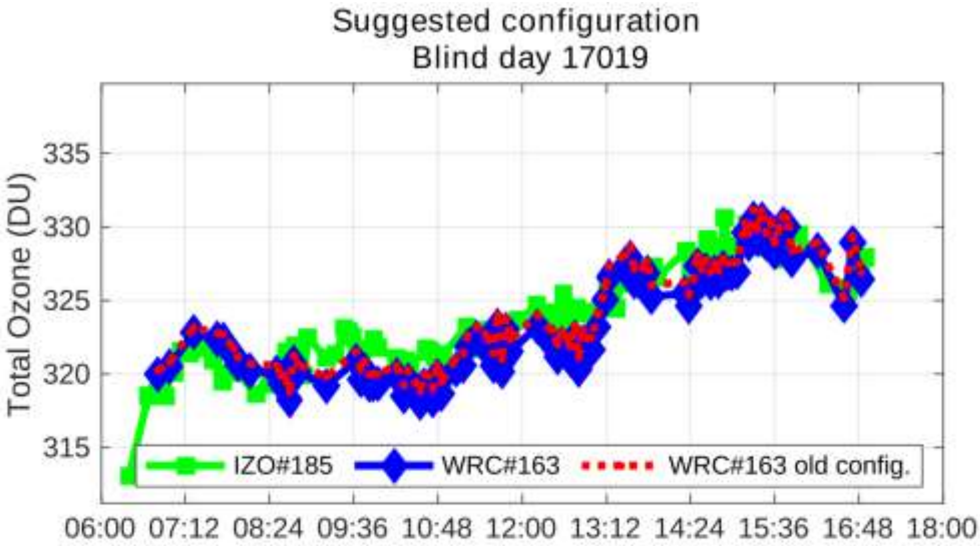
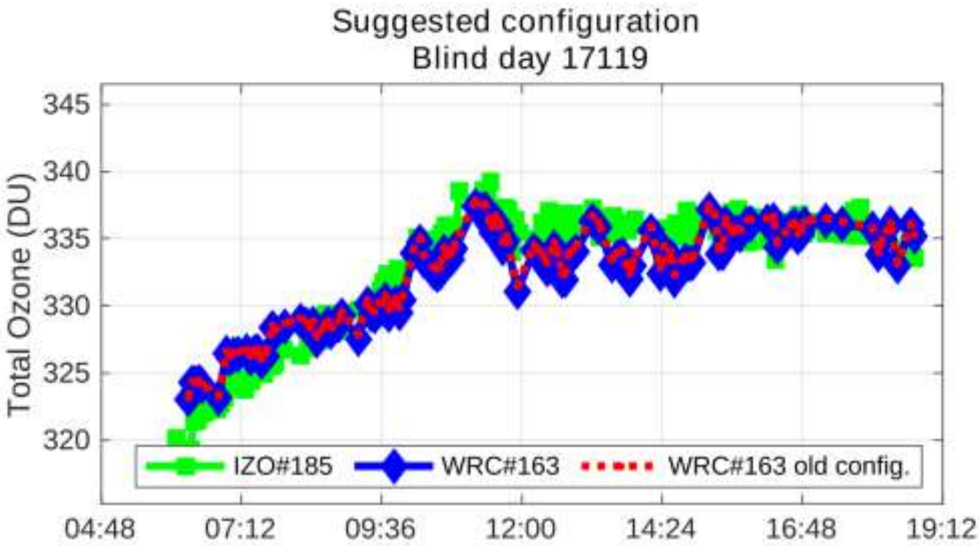


Figure 24. Overview of the intercomparison. Brewer WRC#163 data were evaluated using final constants (blue circles)






Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
IZO#185
WRC#163
WRC#163 old config.
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00


Suggested configuration
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Total Ozone (DU)
345
340
335
330
325
320
IZO#185
WRC#163
WRC#163 old config.
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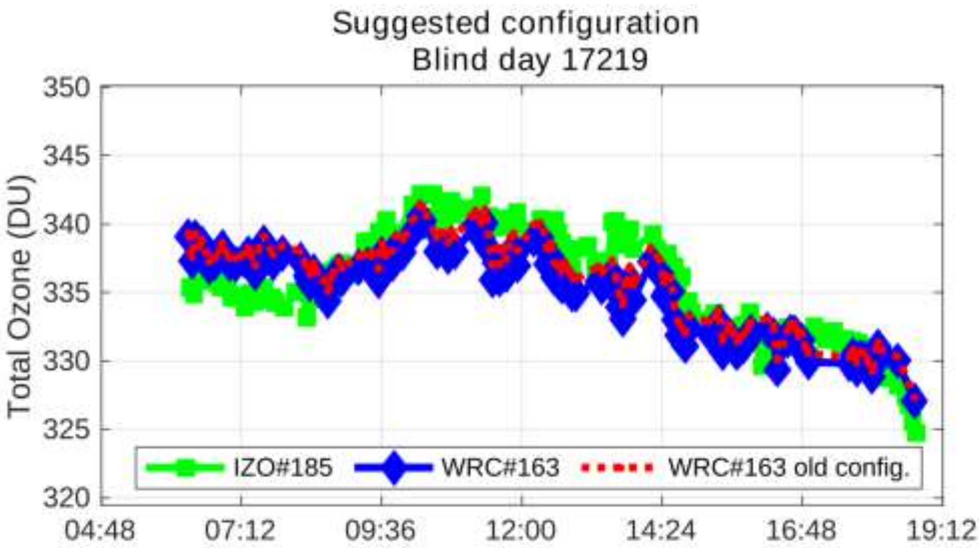
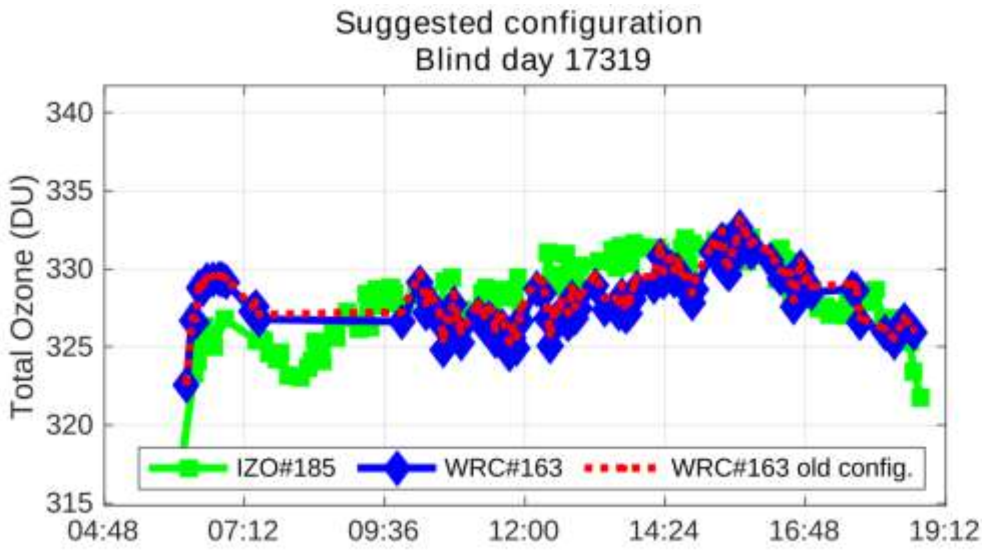

Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
320
IZO#185
WRC#163
WRC#163 old config.
04:48 07:12 09:36 12:00 14:24 16:48 19:12


Suggested configuration
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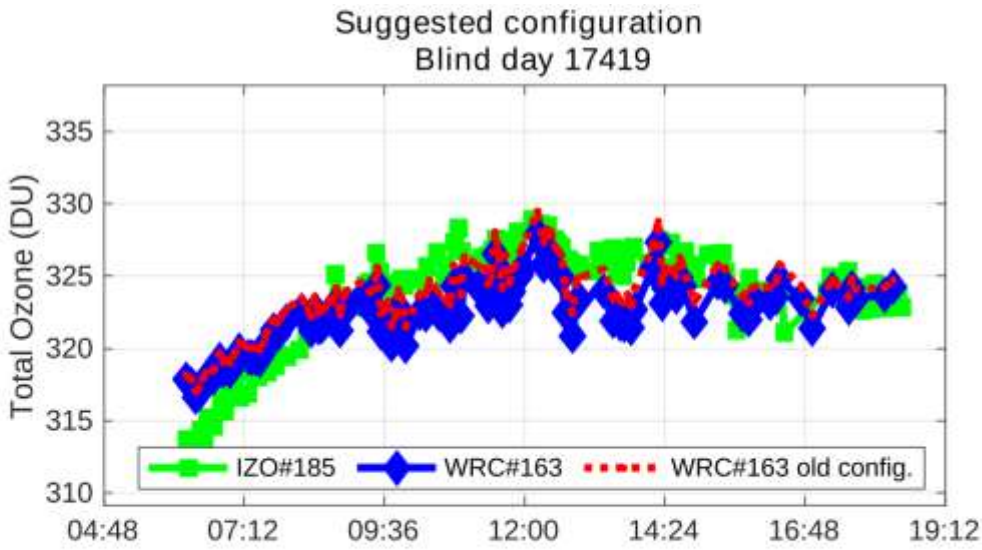
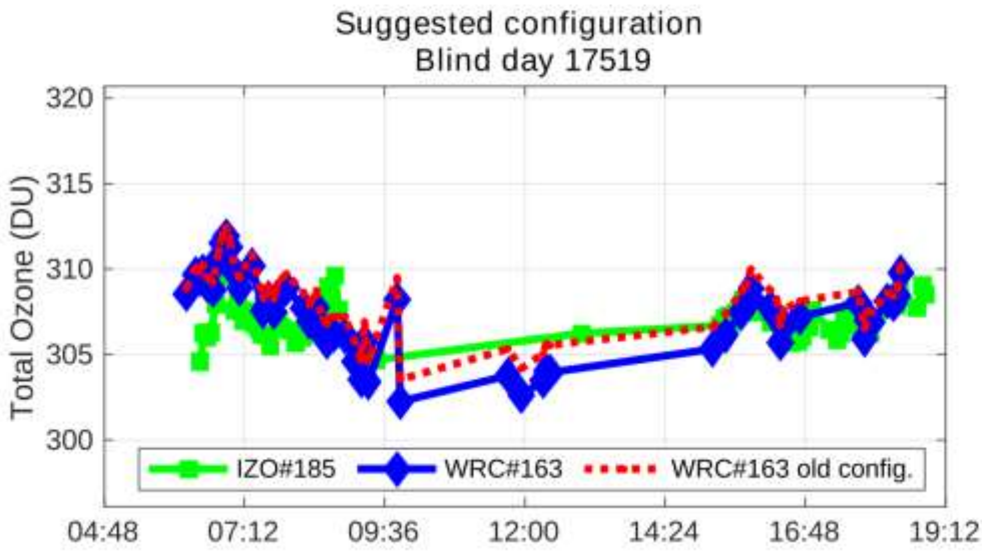
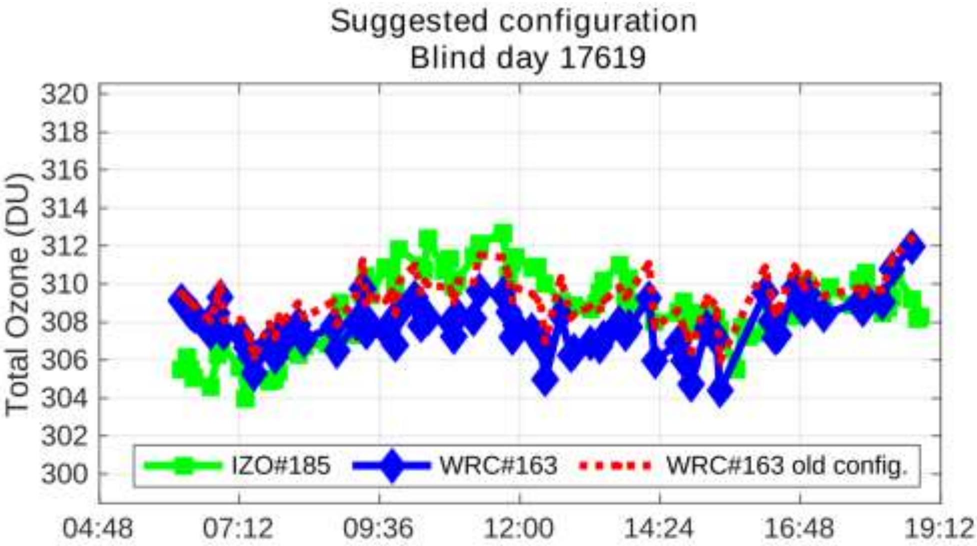
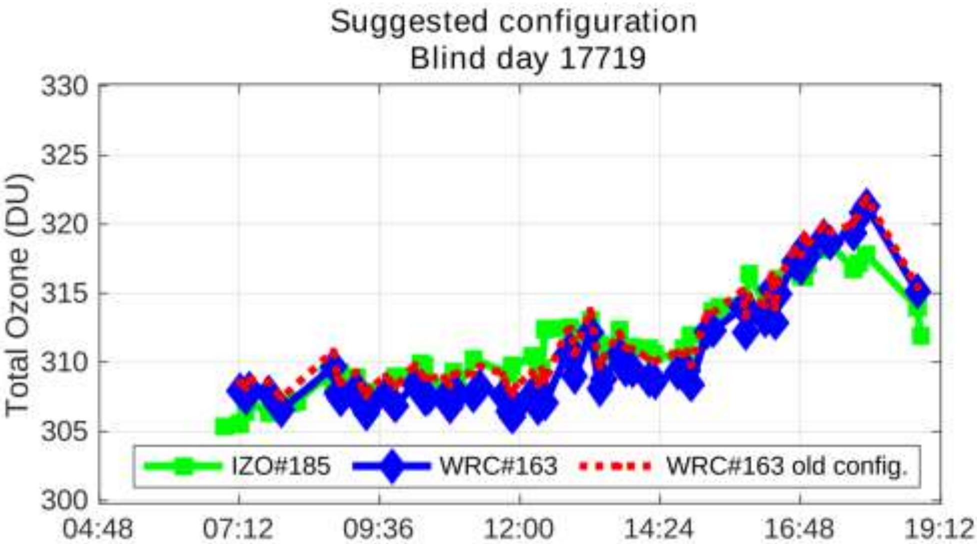
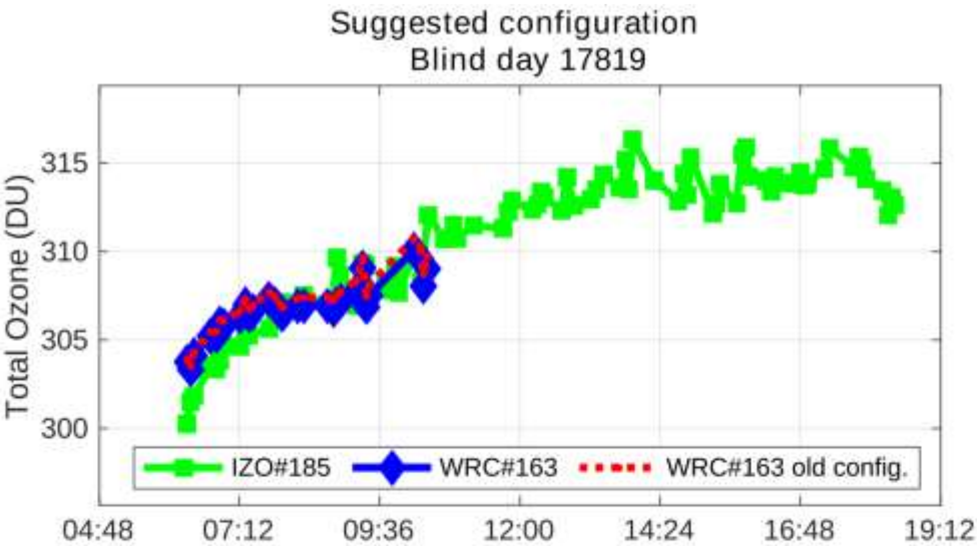
Total Ozone (DU)
340
335
330
325
320
315
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
WRC#163
WRC#163 old config.


Suggested configuration
Blind day 17419
Total Ozone (DU)
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
WRC#163
WRC#163 old config.


Suggested configuration
Blind day 17519
Total Ozone (DU)
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
WRC#163
WRC#163 old config.


Suggested configuration
Blind day 17619
Total Ozone (DU)
320
318
316
314
312
310
308
306
304
302
300
IZO#185
WRC#163
WRC#163 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Suggested configuration
Blind day 17719
Total Ozone (DU)
330
325
320
315
310
305
300
IZO#185
WRC#163
WRC#163 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Suggested configuration
Blind day 17819
Total Ozone (DU)
315
310
305
300
IZO#185
WRC#163
WRC#163 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12

15. BREWER ZAR#166

15.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer ZAR#166 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer ZAR#166 correspond to Julian days 169 – 178. Maintenance work was carried out on days 172 and 174. In the latter day, the cal step was updated.

For the evaluation of the initial status, we used 243 simultaneous direct sun (DS) ozone measurements from days 169 to 173. For final calibration purposes, we used 288 simultaneous DS ozone measurements taken from day 174 to 178.

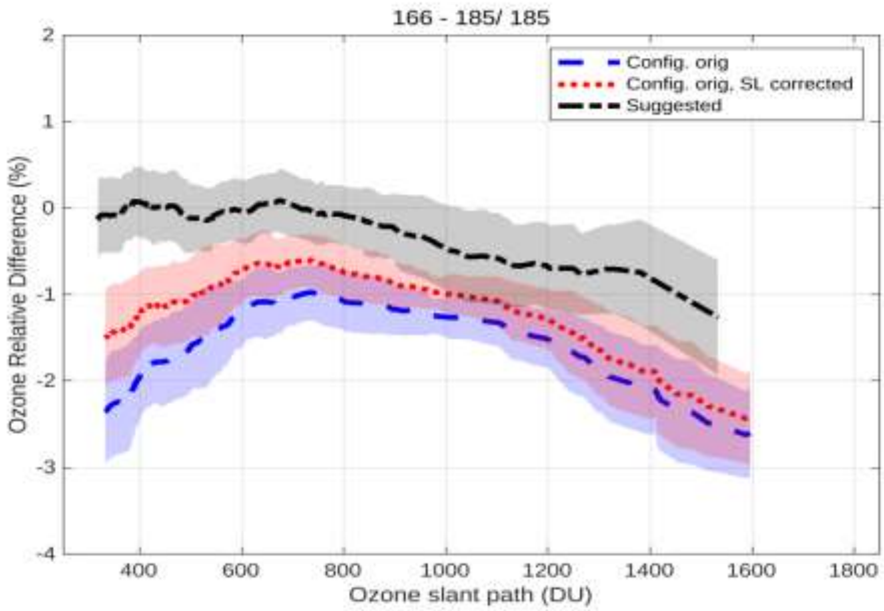


Figure 1. Mean DS ozone column percentage difference between Brewer ZAR#166 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (IOS15717.166, blue dashed line) produces ozone values with an average difference of approx. 1.5% with respect to the reference instrument. The SL correction (Figure 1, red dotted line) improves the comparison with Brewer IZO#185, but the difference is still very noticeable.

As a Mk. IV model, Brewer ZAR#166 measurements are affected by stray light. This produces the downward tail at large ozone slant path values shown in Figure 1. However, as shown in

Figure 2, the comparison with the Mk. III Brewer IZO#185 allows us to correct the effect of the stray light using a recently developed method (see Sec. 1.6).

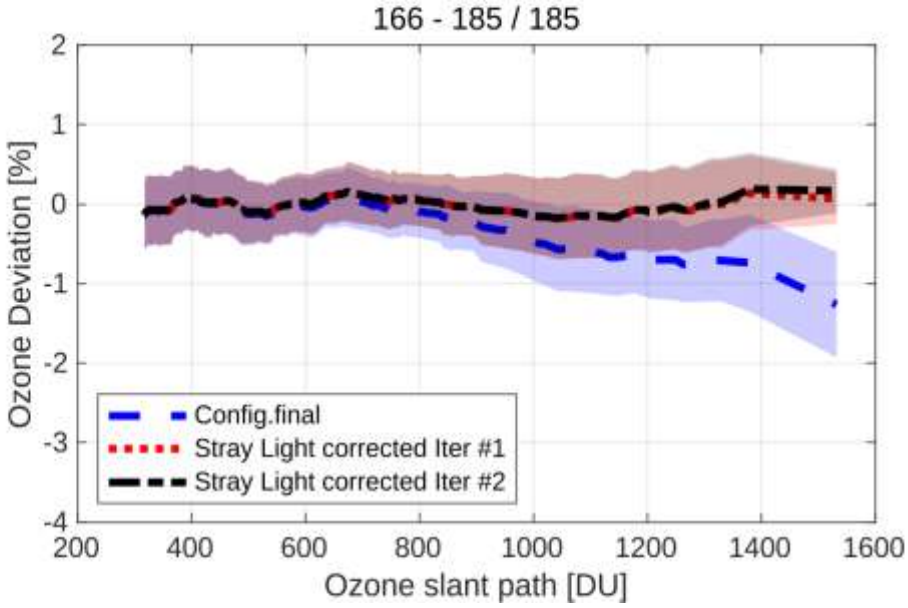


Figure 2. Mean DS ozone column percentage difference between Brewer ZAR#166 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the final (issued in this calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the stray light correction obtained after 1 iteration; the black line corresponds to results obtained after 2 iterations. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

Except during the winter months, the lamp test results from Brewer ZAR#166 have been very stable pver the last 2 years (see Figure 3). During the campaign, the standard lamp ratios were not stable as shown in Figures 23 and 24 where both R6 and R5 increased in the last days. This will require further checks at the instrument's station. With the current data, we can suggest reference values 1947 and 3720 for R6 and R5 respectively. Note the suggested R6 reference value is very close to the current one of 1955.

Noise during the winter months is also observed in the run/stop and dead time tests. All the other parameters analysed show reasonable results.

Once the winter months were removed from the analysis, we did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the temperature coefficients.

The neutral density filters did not show nonlinearity in the attenuation's spectral characteristics. We have not applied any correction to filters.

The cal step number (CSN) was updated during the campaign, changing from 283 to 286. Within a ± 1 step error, the new cal step is confirmed by the sun scan (SC) tests carried out during the campaign.

Dispersion tests suggest changing the ozone absorption coefficient, from 0.3432 to 0.3391.

Taking this into account, we suggest the following changes to the configuration of Brewer ZAR#166.

15.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer ZAR#166 have been very stable over the last 2 years. The old R6 reference value was 1955 and, although it is a rather small change, it could be updated to 1947. Note however that this value was not stable by the end of the campaign, so we recommend performing further checks at the station.
2. We suggest a new R5 reference value of 3720 but, as in the case of the R6 reference, note that this value was not completely stable by the end of campaign.
3. Data from the SL, DT and RS is very noisy during the winter months, but seems stable otherwise.
4. The neutral density filters do not show non-linearity effects and we do not suggest any ETC filter corrections.
5. For Brewer ZAR#166, stray light has an important effect on measurements taken at large ozone slant paths. We suggest applying a stray light correction with parameters $k = a = -10.7$, and $s = b = 4.75$.
6. The cal step number was updated to 286 during the campaign.
7. We suggest updating the ozone absorption coefficient to 0.3391.
8. The final calibration shows a very small change, if any, in the ETC value, so we recommend retaining the current value, 3175.

15.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/166/ICF17419.166

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1340512112

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/166/html/cal_report_166a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/166/html/cal_report_166a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/166/html/cal_report_166b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/166/html/cal_report_166c.html

15.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

15.2.1. Standard lamp test

As shown in Figures 3 and 4, the standard lamp test performance was quite stable in the intercampaign period, except for the winter months. Severe noise during winter was also observed in the lamp's intensity (Figure 5), and the RS and DT data (see next Section).

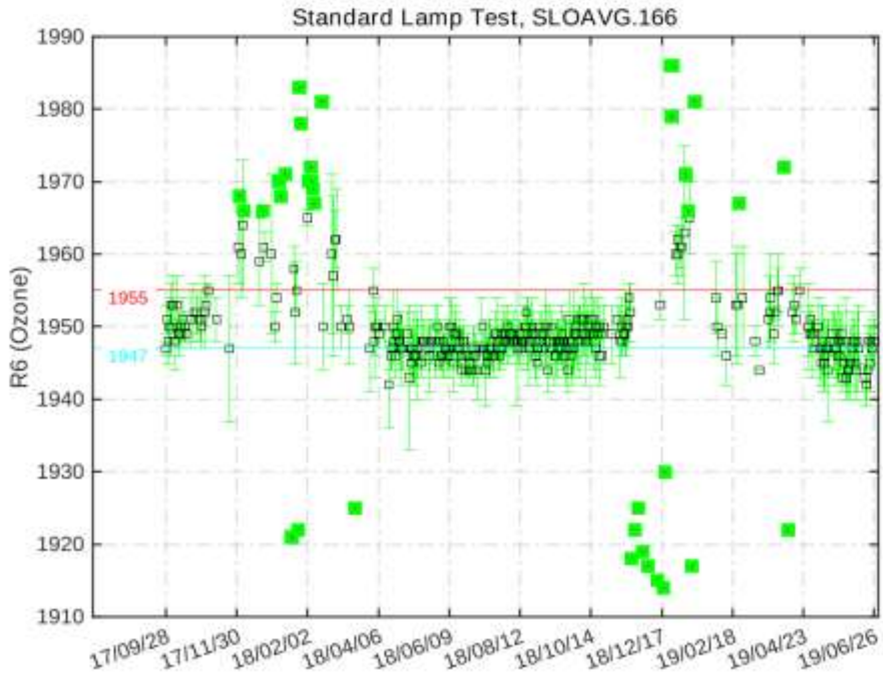


Figure 3. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

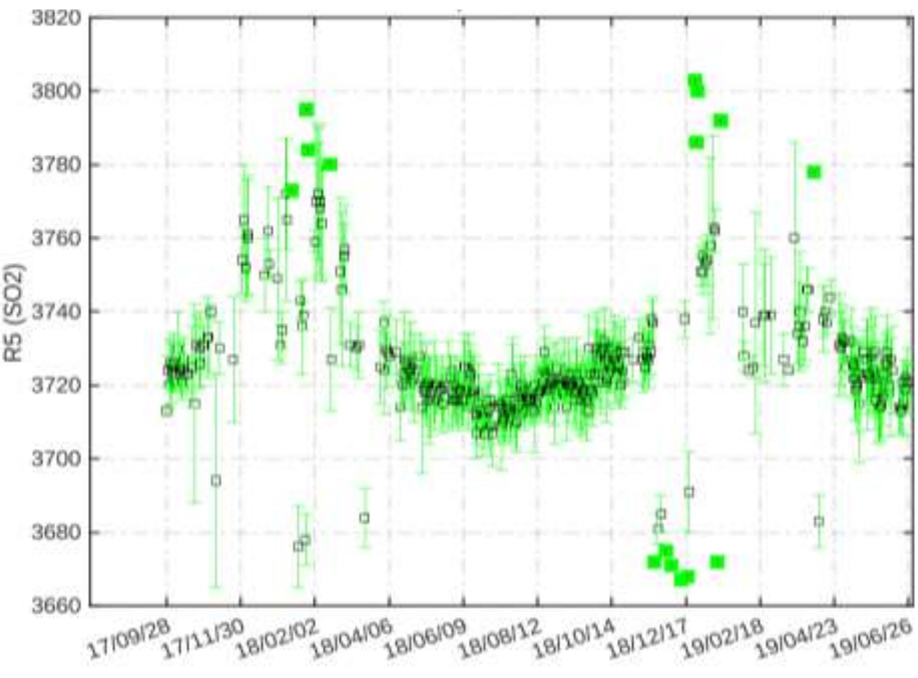


Figure 4. Standard lamp test R5 sulphur dioxide ratios

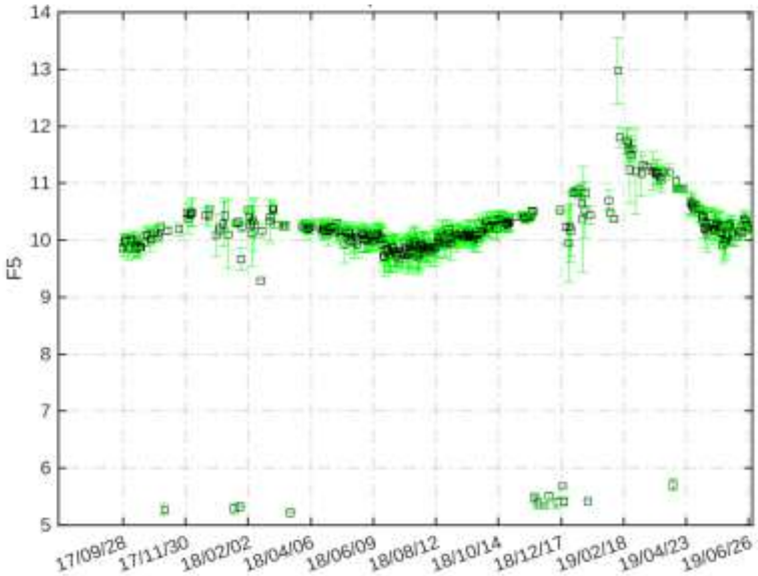


Figure 5. SL intensity for slit five

15.2.2. Run/Stop and dead time

Except during winter, run/stop test values were within the test tolerance limits (see Figure 6).

As shown in Figure 7, the current DT reference value of 3.3· 10^{-8} s is still in agreement with the results of the DT tests. Therefore, we suggest keeping this value in the ICF of the current campaign.

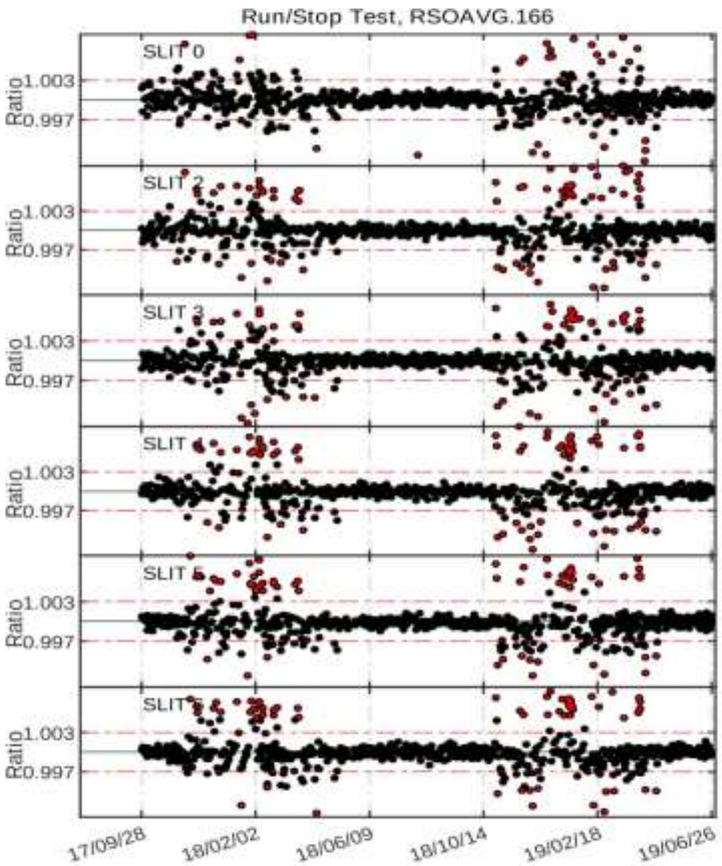


Figure 6. Run/stop test

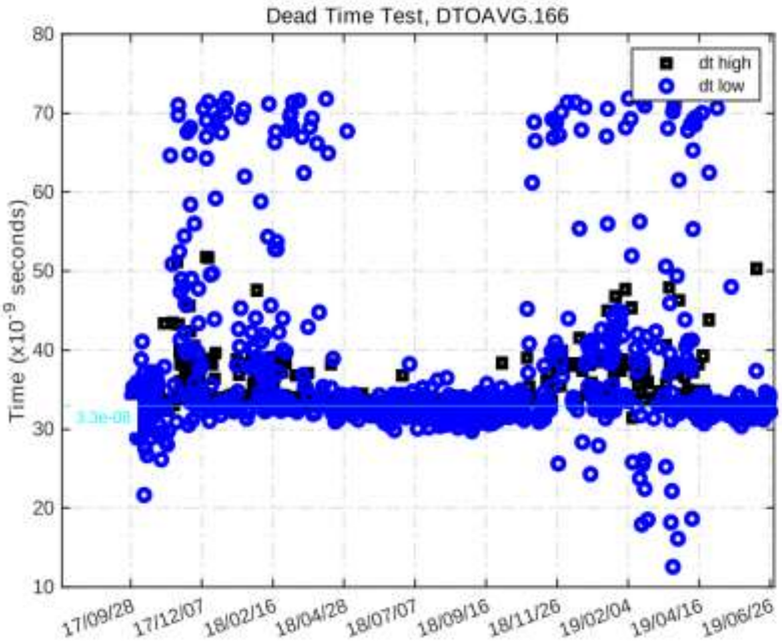


Figure 7. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

15.2.3. Analogue test

Figure 8 shows that the analogue test values are somewhat noisy and feature some seasonal trends, with maxima in the winter months.

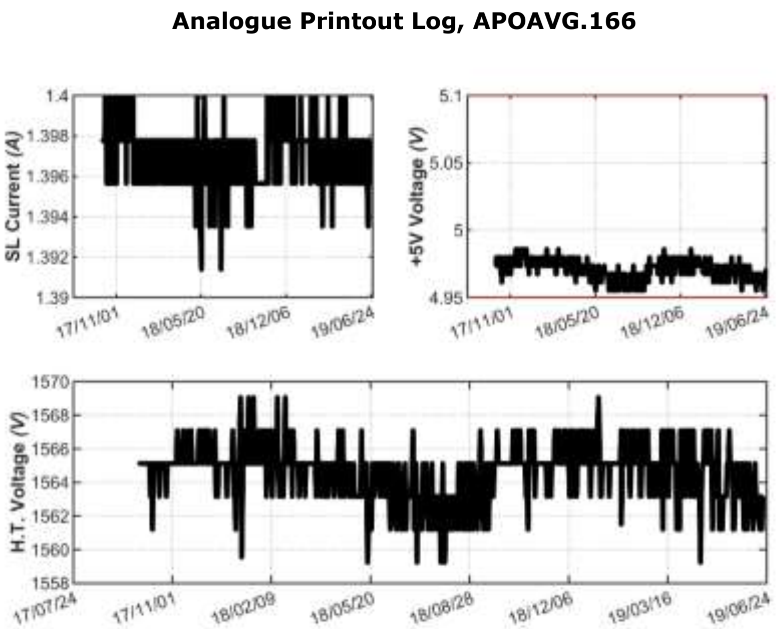


Figure 8. Analogue voltages and intensity

15.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign (see Figure 9). There is, however, quite a clear correlation between the lamp's intensity and the internal Brewer temperature.

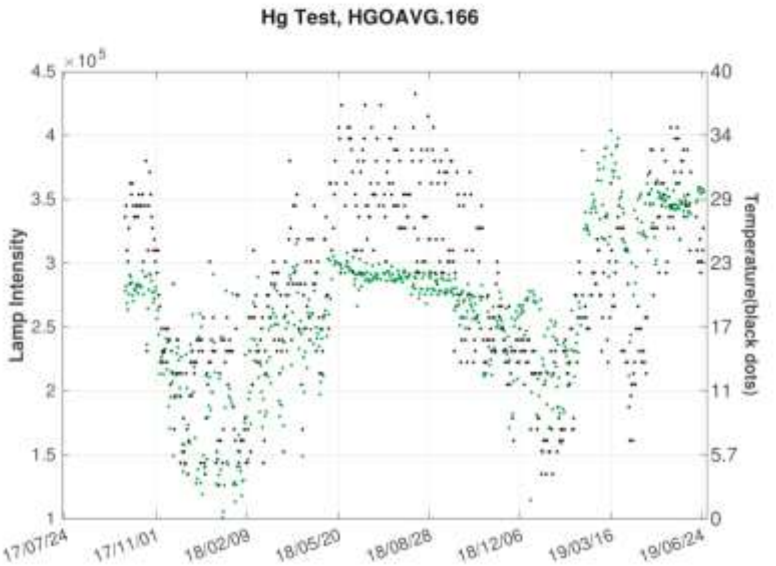
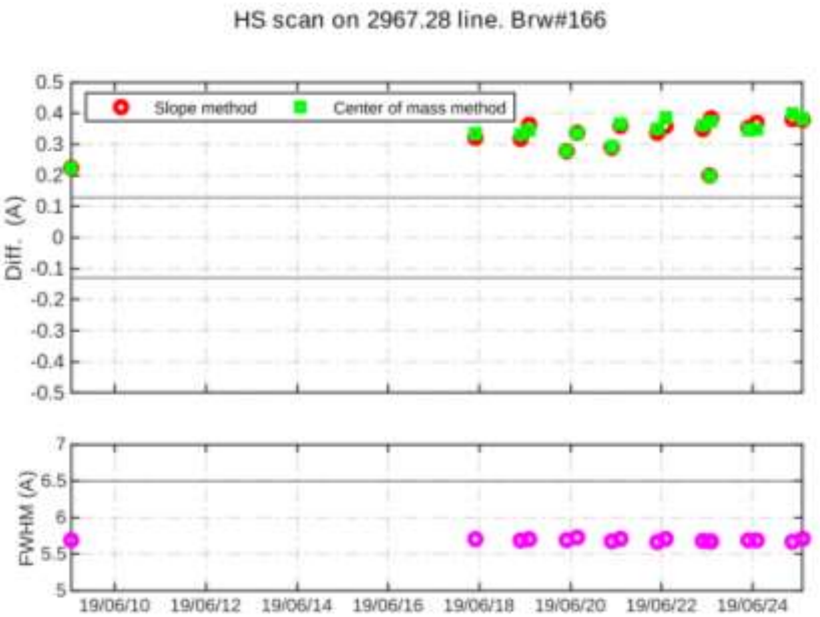


Figure 9. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

15.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 10). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer ZAR#166 during the campaign show reasonable results, except for the peak of the 2967.28 nm line, which is above the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.



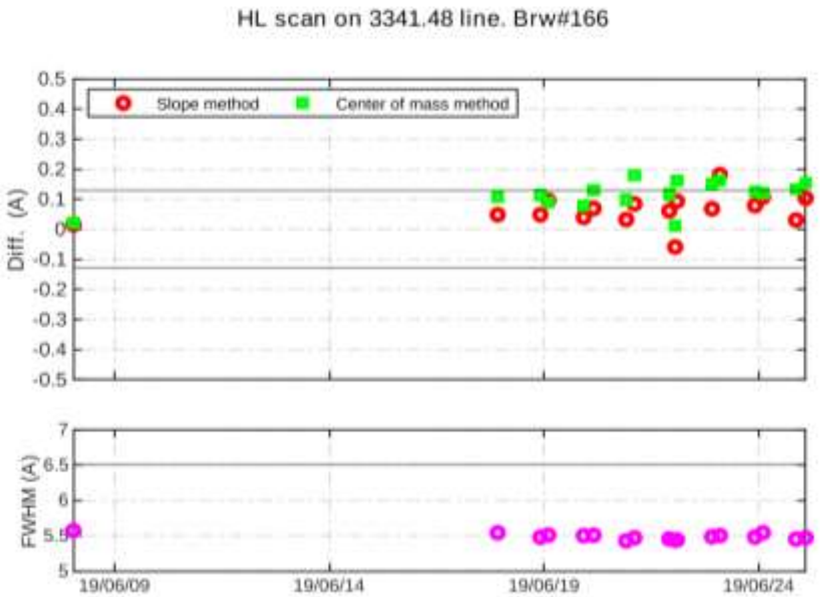


Figure 10. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

15.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 11, we show percentage ratios of the Brewer ZAR#166 CI scans performed during the campaign relative to the scan CI16819.166. As can be observed, lamp intensity varied with respect to the reference spectrum by around 5%. This behaviour is normal for an SL lamp.

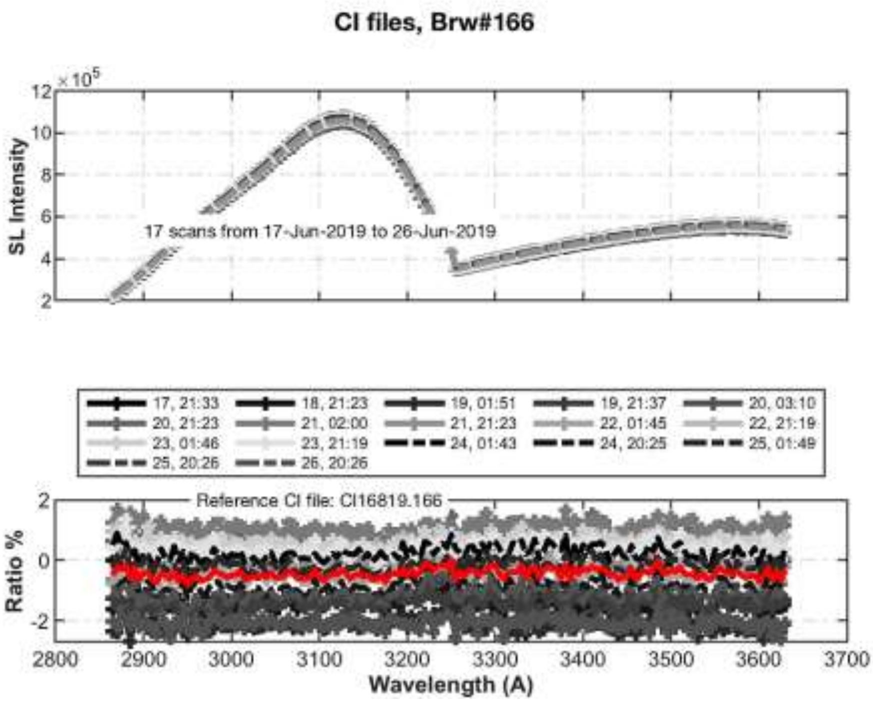


Figure 11. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

15.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 12 (temperature range from 18 ˚C to 32 ˚C), the current coefficients do an excellent job at reducing the temperature dependence, performing even better than the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign, removing the winter months. As shown in Figure 13, the performance of the current coefficients is quite good. For all these reasons, in the final ICF we have used the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	19.4005	19.1074	19.0426	18.4212	17.0415
Calculated	0.0000	0.7200	0.8000	0.4000	-0.9000
Final	19.4005	19.1074	19.0426	18.4212	17.0415

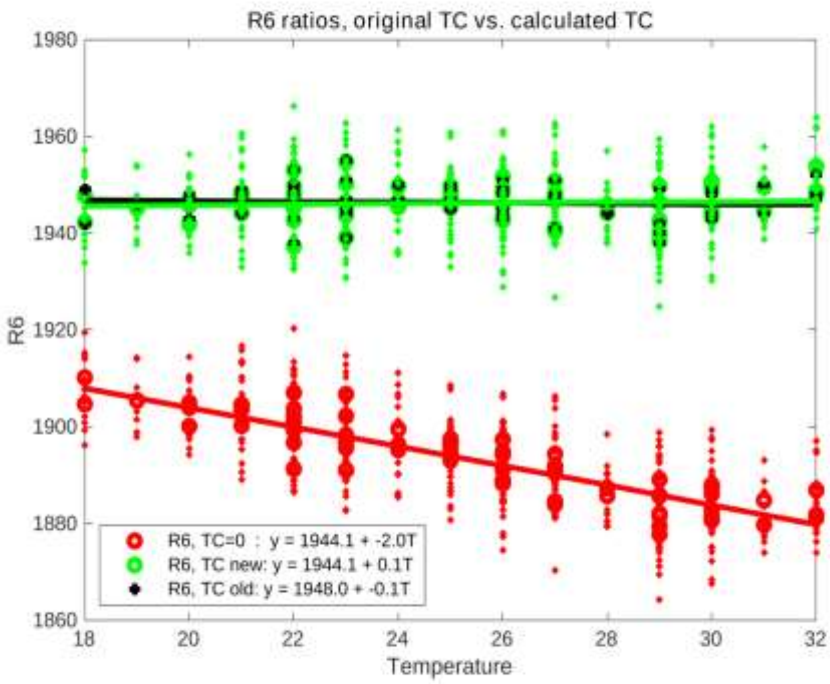


Figure 12. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

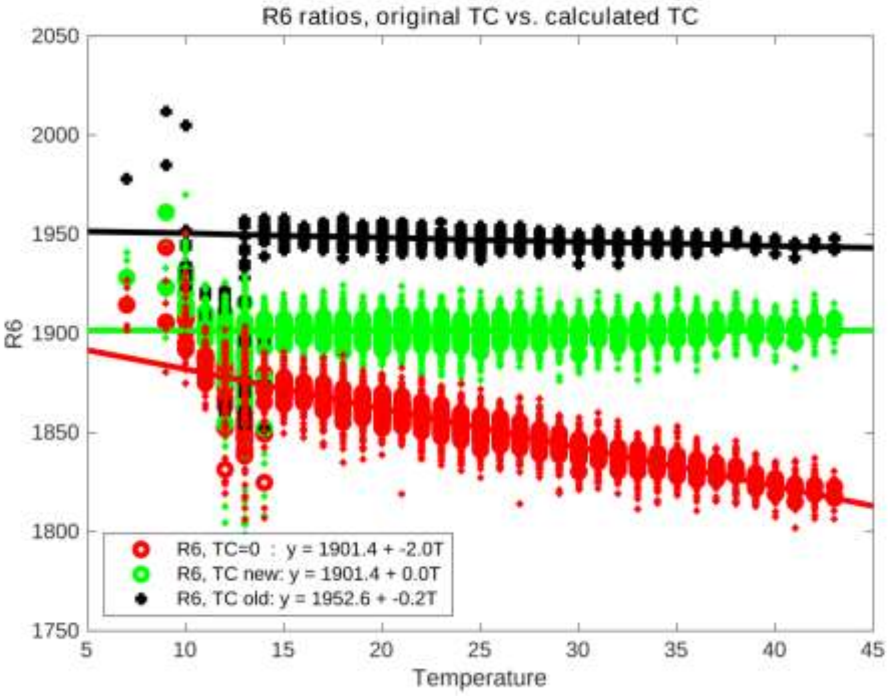


Figure 13. Same as Figure 12 but for the whole period between calibration campaigns

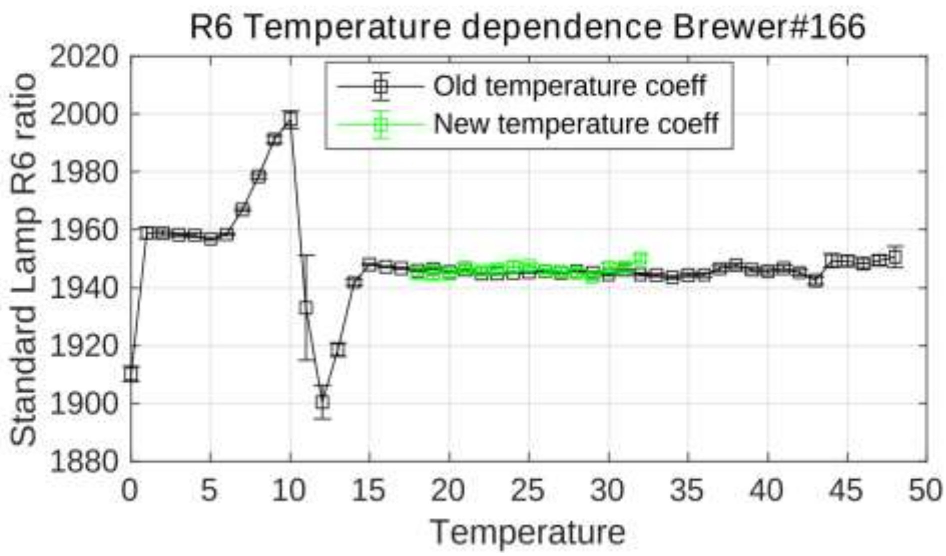


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

15.4. ATTENUATION FILTER CHARACTERIZATION

15.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 144 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Looking at these results, no correction seems necessary for any of the filters.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*Filter#5*
ETC Filt. Corr. (median)	-1	0	-2	-1	-3
ETC Filt. Corr. (mean)	1.4	-1.4	-1.5	1.4	2.3
ETC Filt. Corr. (mean 95% CI)	[-1.6 4.8]	[-5.2 3.1]	[-4.8 1.6]	[-5.7 8.6]	[-2.1 7.1]

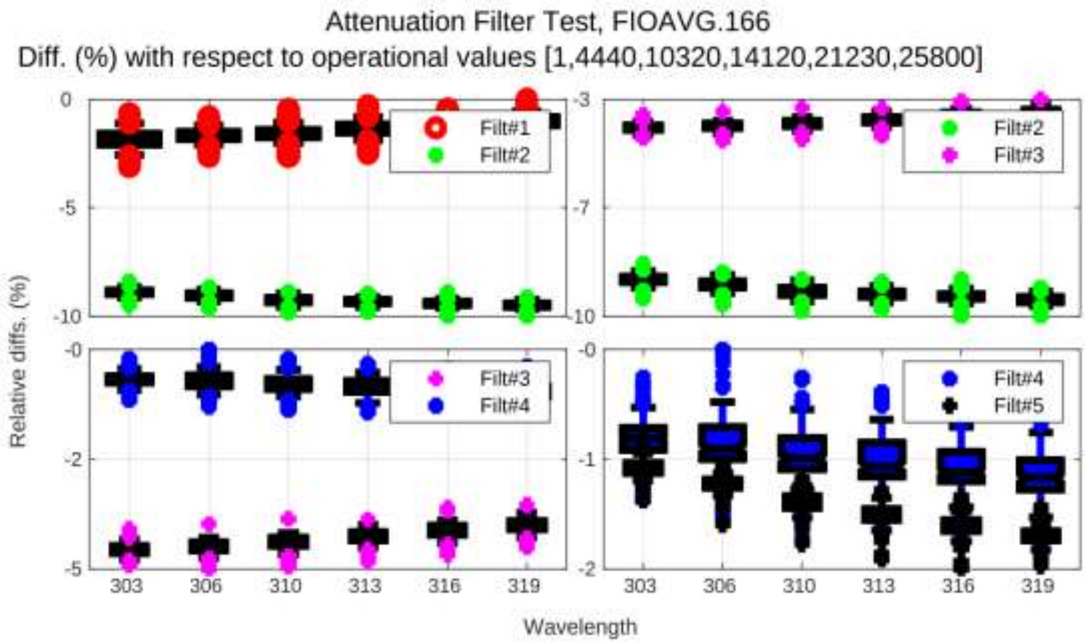


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

15.5. WAVELENGTH CALIBRATION

15.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

The cal step number (CSN) of the instrument was updated from 283 to 286 on day 172 of the campaign. Within a ± 1 step error, this value is confirmed by the analysis of the data from 4 sun scan (SC) tests carried out during the campaign, covering an ozone slant path range from approx. 400 to 1200 DU (see Figure 17).

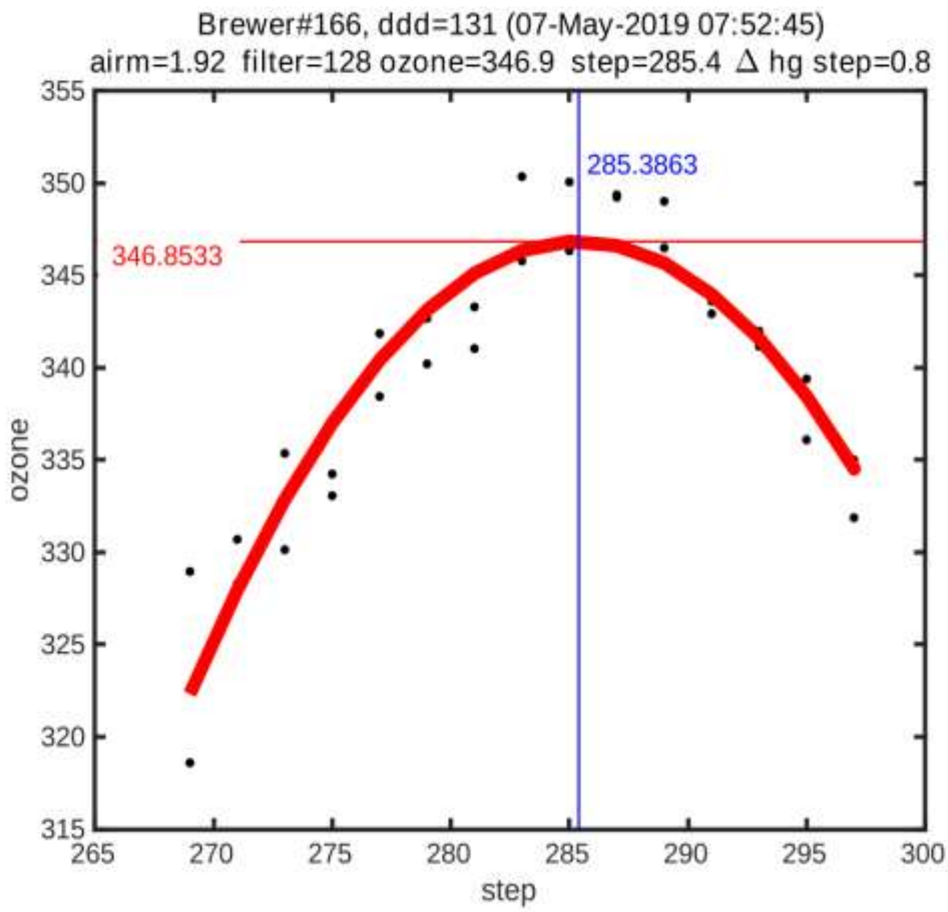


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

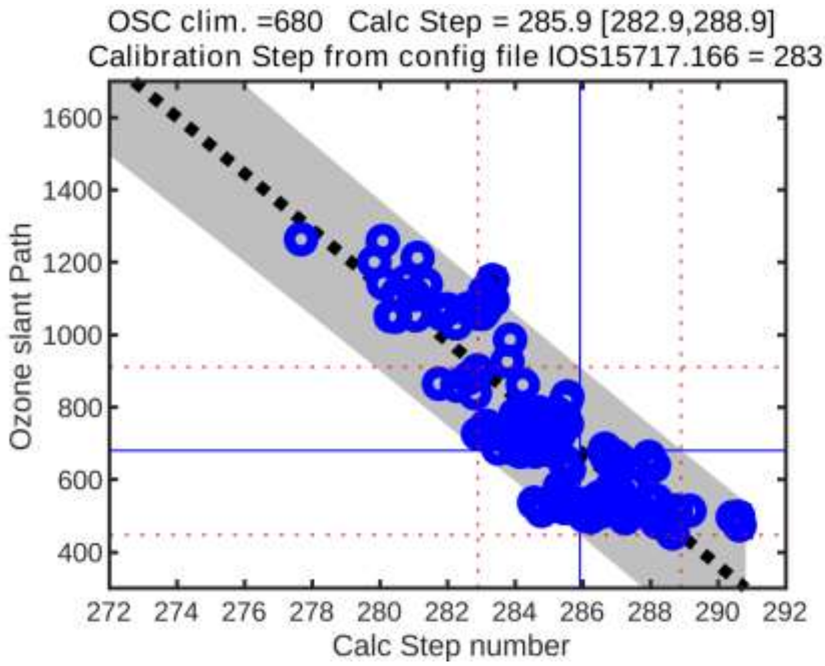


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

15.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.3391, 0.004 units (4 steps) lower than current value, is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	283	0.3432	2.3500	1.1481
15-Jun-2013	283	0.3436	3.1590	1.1505
01-Jun-2015	283	0.3427	3.1567	1.1493
01-Jun-2017	283	0.3442	3.1511	1.1542
23-Jun-2019	283	0.3423	3.1665	1.1464
23-Jun-2019	286	0.3391	3.1914	1.1360
Final	286	0.3391	2.3500	1.1481

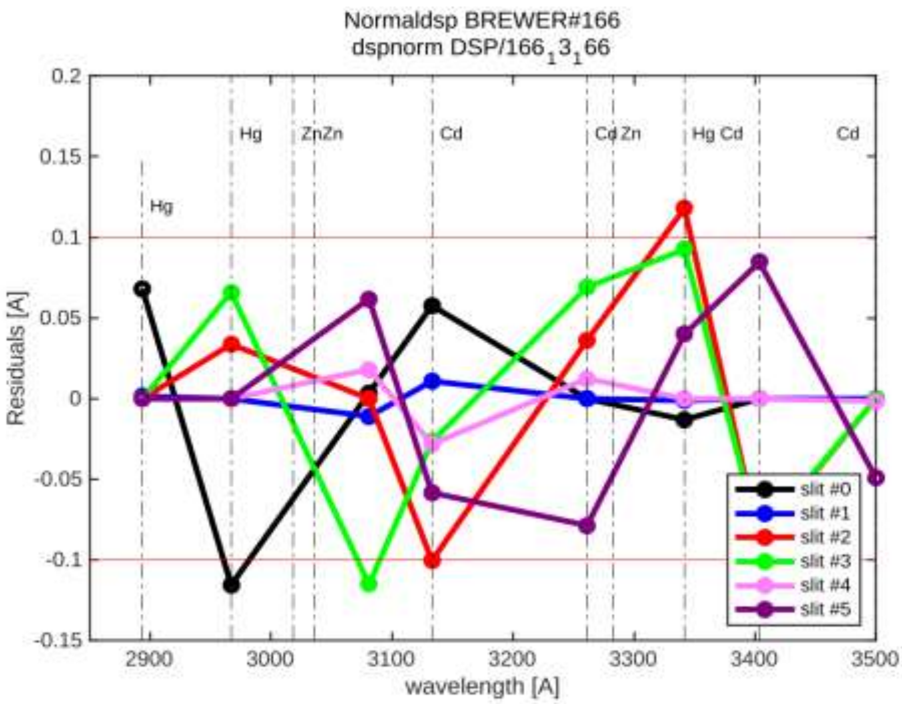


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 285	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032.04	3063.15	3100.53	3135.12	3168.16	3200.08
Res(A)	5.637	5.5965	5.4648	5.5706	5.4756	5.3732
O3abs(1/cm)	2.5946	1.7765	1.0048	0.67567	0.37515	0.2933
Ray abs(1/cm)	0.50497	0.48312	0.45846	0.43704	0.41776	0.40016
SO2abs(1/cm)	3.4121	5.6783	2.4117	1.8816	1.0577	0.6089
step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.11	3063.23	3100.6	3135.19	3168.24	3200.15
Res(A)	5.6369	5.5965	5.4647	5.5705	5.4755	5.3732
O3abs(1/cm)	2.5919	1.775	1.0045	0.67527	0.37523	0.2928
Ray abs(1/cm)	0.50492	0.48307	0.45841	0.43699	0.41772	0.40013
SO2abs(1/cm)	3.3981	5.6977	2.4199	1.8696	1.0589	0.60659
step= 287	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.19	3063.3	3100.67	3135.27	3168.31	3200.22
Res(A)	5.6368	5.5964	5.4646	5.5704	5.4754	5.3731
O3abs(1/cm)	2.5894	1.7734	1.0042	0.67484	0.37532	0.29223
Ray abs(1/cm)	0.50487	0.48302	0.45836	0.43695	0.41768	0.40009
SO2abs(1/cm)	3.3842	5.7157	2.4281	1.8579	1.0601	0.60421
Step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
285	0.34021	11.4149	3.1843	1.1395	0.35106	0.34233
286	0.33909	11.4121	3.1914	1.136	0.34997	0.34122
287	0.33782	11.4093	3.1969	1.1322	0.34885	0.34007

15.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1684. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 286	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.6369	5.5965	5.4647	5.5705	5.4755	5.3732
O3abs(1/cm)	2.5919	1.775	1.0045	0.67527	0.37523	0.2928
Ray abs(1/cm)	0.50492	0.48307	0.45841	0.43699	0.41772	0.40013
step= 1684	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3234	3265	3296
Res(A)	5.5218	5.4674	5.3578	5.4498	5.3599	5.2565
O3abs(1/cm)	0.6789	0.39311	0.29288	0.12054	0.060669	0.033381
Ray abs(1/cm)	0.43777	0.42015	0.40013	0.38271	0.36705	0.35267

15.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

For single monochromator Brewers, the ETC distribution (see Figure 1) shows a tail at the lower ETC values for high ozone slant column (OSC, the product of the total ozone content as a factor of air mass). For this type of Brewer, only the stray light-free region is used to determine the ETC, generally from 300 to 900 DU OSC, depending on the instrument.

The stray light effect can be corrected if the calibration is performed against a double monochromator instrument, assuming that it can be characterized following a power law of the ozone slant column

$$F = F_o + k(X\mu)^s$$

where F are the true counts and F_o the measured ones.

$$ETC_i = ETC_o + k(X\mu)^s$$

where ETC_o is the ETC for the stray light-free OSC region and k and s are retrieved from the reference comparison. These parameters, determined in several campaigns, have been found to be stable and independent of the ozone calibration.

As the counts (F) from the single Brewer are affected by stray light, the ozone is calculated using an iterative process:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

Only one iteration is needed to meet the conditions of the intercomparison, up to 1500 DU. For ozone slant path measurements in the 1500–2000 DU range, two iterations are enough to correct the ozone.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, are also obtained and serve as a quality indicator of the calibration. We consider a calibration optimal, when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 5 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

15.6.1. Initial calibration

For the evaluation of the initial status of Brewer ZAR#166, we used the period from days 169 to 173 which corresponds with 243 near-simultaneous direct sun ozone measurements. As shown in Figure 19, the initial calibration constants produce an ozone value slightly higher than the reference instrument (1.5%). When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results improve, but there is still a noticeable difference.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

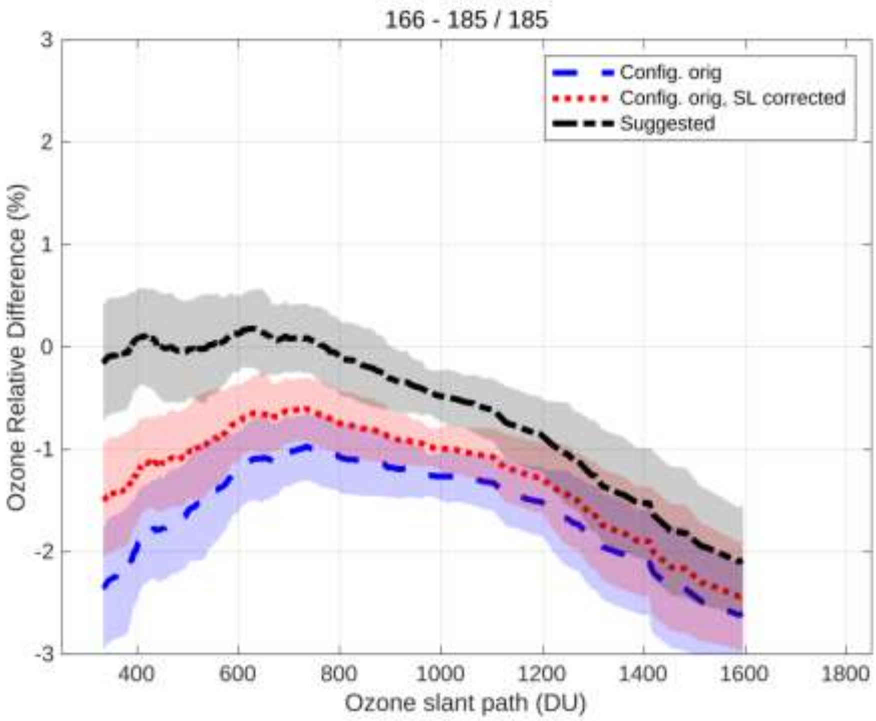


Figure 19. Mean direct sun ozone column percentage difference between Brewer ZAR#166 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=800	3148	3146	3432	3435
full OSC range	3148	3154	3432	3414

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#166*	*O3 std*	*%(166–185)/185*	*O3(*) #166*	*O3std*	*(*)%(166 – 185)/185*
18-Jun-2019	169	325	1.2	11	318.5	1.5	-2	325.2	1.1	0.1
19-Jun-2019	170	324.2	2.9	76	316.6	3.3	-2.3	323.1	3.2	-0.3
20-Jun-2019	171	333.7	3.8	35	328.5	3.8	-1.6	334.1	4.3	0.1
21-Jun-2019	172	336.9	3.4	93	331.4	2.9	-1.6	337.5	3.6	0.2
22-Jun-2019	173	327.8	2	28	320	1.8	-2.4	326.6	1.9	-0.4

15.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 20). For the final calibration, we used 288 simultaneous direct sun measurements from days 174 to 178. There was almost no change in the ETC with respect the current one (3175) so we suggest retaining it.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is within the maximum tolerance limit of 10 units, including for the full OSC range.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

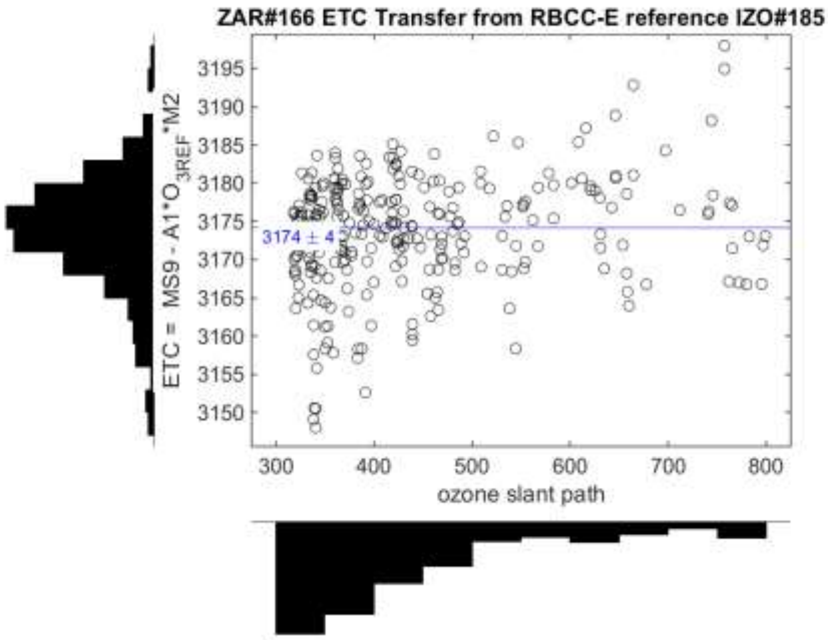


Figure 20. Mean direct sun ozone column percentage difference between Brewer ZAR#166 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days.

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=800	3174	3174	3391	3388
full OSC range	3172	3163	3391	3415

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#166*	*O3 std*	*%(166–185)/185*	*O3(*) #166*	*O3std*	*(*)%(166 – 185)/185*
22-Jun-2019	173	330.1	2.5	53	322.8	3.3	-2.2	326.7	3.3	-1
23-Jun-2019	174	323.1	4.5	74	319	4.6	-1.3	322.9	4.7	-0.1
24-Jun-2019	175	307.3	1.2	44	302.5	1.4	-1.6	306.1	1.4	-0.4
25-Jun-2019	176	308.6	1.9	85	304.6	2.1	-1.3	308.3	2.1	-0.1
26-Jun-2019	177	311.3	3.3	63	307.4	3.1	-1.3	311.2	3.2	0
27-Jun-2019	178	NaN	NaN	0	304.8	3.1	NaN	308.5	3.1	NaN

15.6.3. Stray light correction

The final calibration performs well with near zero error for low OSC and an underestimation of 1% at 800 OSC which is very good for a single Brewer. The empirical stray model fits quite well with coefficient values: $k = a = -10.7$, $s = b = 4.75$, and ETC=3175. These parameters produced a better agreement with the reference Brewer IZO#185 for the full range of OSC. In order to correct the ozone an iterative formula is used:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu}$$

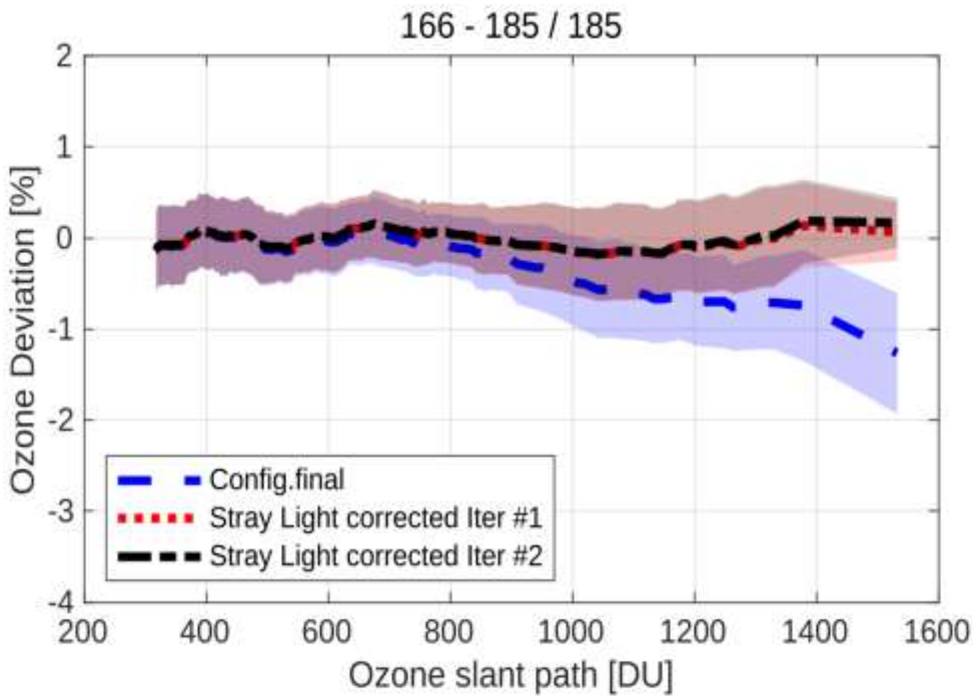


Figure 21. Ratio respect to the reference when final configuration is applied and stray light correction is introduced using empirical model

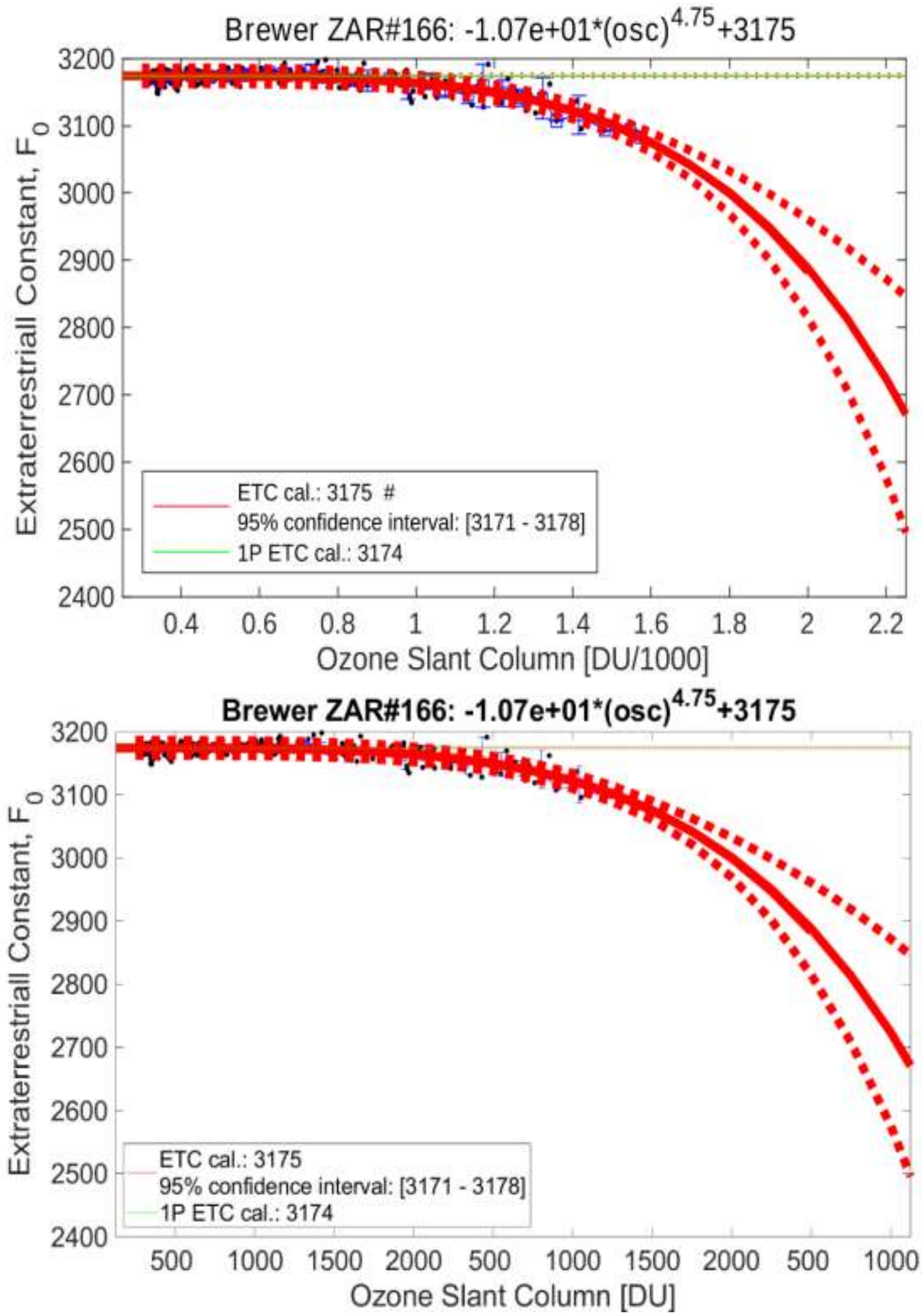


Figure 22. Stray light empirical model determination

15.6.4. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 1947 for R6 (Figure 23) and 3720 for R5 (Figure 24).

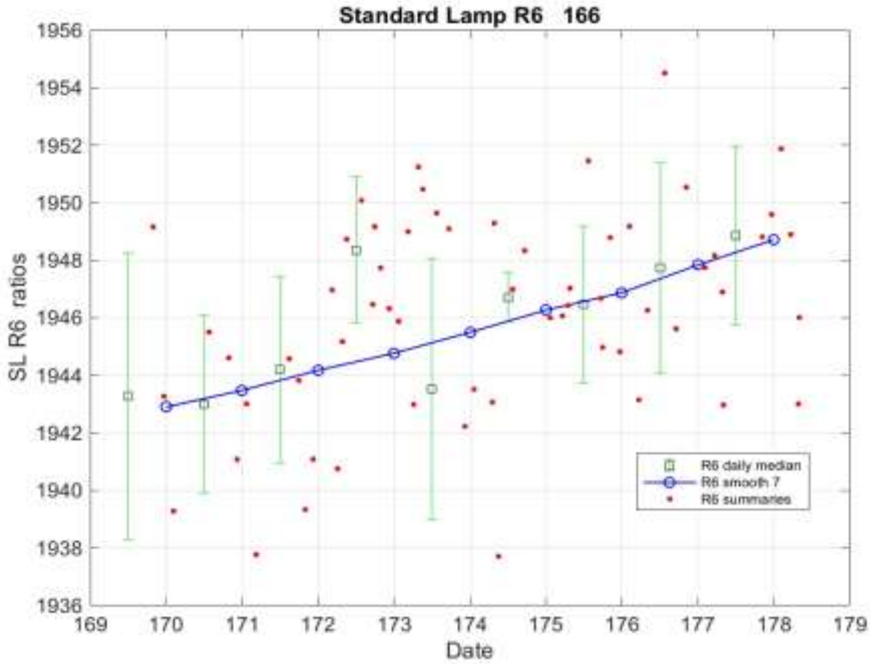


Figure 23. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

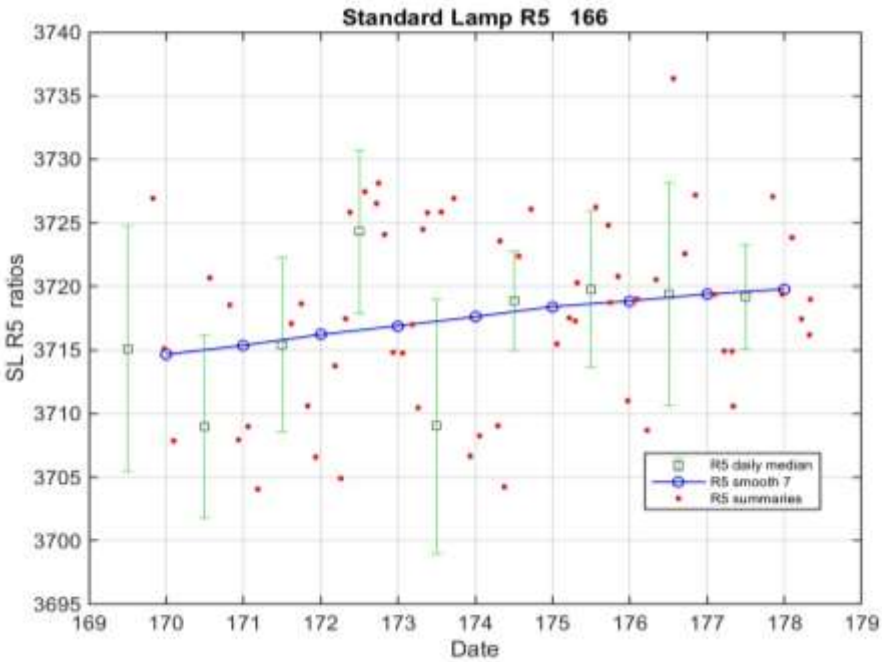


Figure 24. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

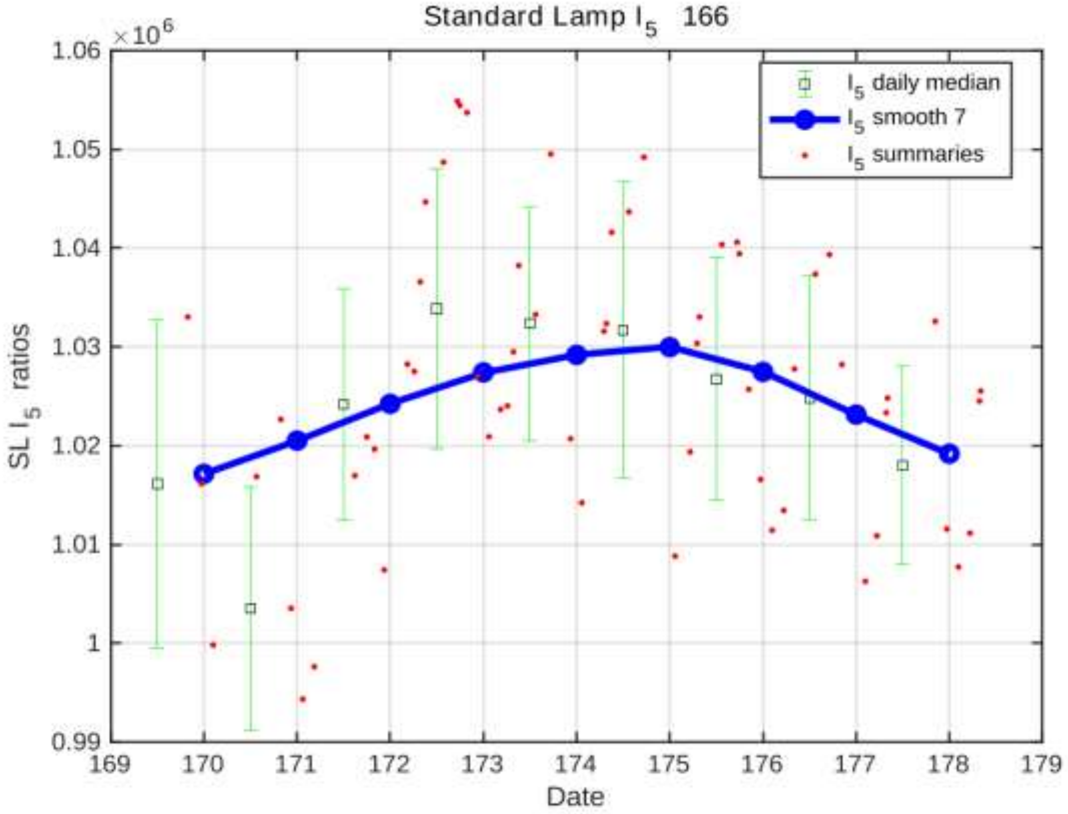


Figure 25. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

15.7. CONFIGURATION

15.7.1. Instrument constant file

	Initial (IOS15717.166)	*Final (ICF17419.166)*
o3 Temp coef 1	19.4005	19.4005
o3 Temp coef 2	19.1074	19.1074
o3 Temp coef 3	19.0426	19.0426
o3 Temp coef 4	18.4212	18.4212
o3 Temp coef 5	17.0415	17.0415
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3432	0.3391
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1481	1.1481
ETC on O3 Ratio	3175	3175
ETC on SO2 Ratio	3320	3320
Dead time (sec)	3.3e-08	3.3e-08
WL cal step number	283	286

	Initial (IOS15717.166)	*Final (ICF17419.166)*
Slitmask motor delay	14	14
Umkehr Offset	1701	1701
ND filter 0	0	0
ND filter 1	4440	4440
ND filter 2	10320	10320
ND filter 3	14120	14120
ND filter 4	21230	21230
ND filter 5	25800	25800
Zenith steps/rev	2972	2972
Brewer Type	0	0
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	7	0
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	759	759
NO2 zs etc	720	720
NO2 Mic #1 Offset	2511	0
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2510	2510
Grating Slope	0	0
Grating Intercept	0	0
Micrometre Zero	2665	2665
Iris Open Steps	250	250
Buffer Delay (s)	0.2	0.2

	Initial (IOS15717.166)	*Final (ICF17419.166)*
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	0	0
Zenith UVB Position	2226	2226

15.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	osc range	O3#185	O3std	N	O3#166	O3 std	%diff	(*)O3#166	O3 std	(*)%diff
169	700> osc> 400	324	0.2	4	323	0.3	-0.5	323	0.3	-0.5
169	osc< 400	325	1.4	7	321	1.2	-1.2	321	1.2	-1.2
170	1000> osc> 700	322	0.3	2	320	0.0	-0.7	320	0.0	-0.7
170	700> osc> 400	324	4.2	37	320	4.0	-1.1	320	4.0	-1.1
170	osc< 400	324	2.1	47	319	2.6	-1.6	319	2.6	-1.6
171	osc> 1500	334	0.2	3	324	1.5	-2.8	324	1.5	-2.8
171	1500> osc> 1000	328	6.8	10	322	7.5	-1.6	322	7.5	-1.6
171	1000> osc> 700	334	4.8	16	331	4.8	-0.9	331	4.8	-0.9
171	700> osc> 400	332	3.6	26	329	3.6	-0.8	329	3.6	-0.8
171	osc< 400	336	1.5	12	334	2.0	-0.8	334	2.0	-0.8
172	osc> 1500	325	0.6	2	315	2.7	-3.0	315	2.7	-3.0
172	1500> osc> 1000	333	3.7	17	327	4.5	-1.7	327	4.5	-1.7
172	1000> osc> 700	333	1.7	21	330	2.6	-0.7	330	2.6	-0.7
172	700> osc> 400	335	3.3	50	332	3.1	-0.9	332	3.1	-0.9
172	osc< 400	339	2.1	45	334	2.4	-1.4	334	2.4	-1.4
173	osc> 1500	322	0.0	1	314	0.0	-2.5	314	0.0	-2.5
173	1500> osc> 1000	325	1.1	16	320	2.7	-1.5	320	2.7	-1.5
173	1000> osc> 700	328	0.3	4	325	0.1	-1.1	325	0.1	-1.1
173	700> osc> 400	329	3.8	17	326	3.3	-0.8	326	3.3	-0.8
173	osc< 400	330	1.5	49	325	2.6	-1.5	325	2.6	-1.5
174	osc> 1500	314	0.0	1	305	0.0	-2.8	308	0.0	-1.7

Day	osc range	O3#185	O3std	N	O3#166	O3 std	%diff	(*)O3#166	O3 std	(*)%diff
174	1500> osc> 1000	318	4.7	12	314	4.2	-1.4	317	4.2	-0.4
174	1000> osc> 700	320	3.5	12	317	3.0	-0.8	320	3.0	0.1
174	700> osc> 400	324	2.4	22	322	2.2	-0.5	324	2.0	0.2
174	osc< 400	327	1.0	26	325	1.1	-0.6	326	1.1	-0.1
175	1500> osc> 1000	307	1.4	9	301	1.7	-1.8	304	1.6	-0.9
175	1000> osc> 700	308	1.5	9	304	1.1	-1.3	307	1.2	-0.4
175	700> osc> 400	307	1.0	24	304	1.3	-0.8	306	1.2	-0.1
175	osc< 400	307	0.3	2	305	1.9	-0.7	307	1.8	-0.1
176	1500> osc> 1000	308	2.0	6	302	1.8	-1.9	305	1.8	-0.9
176	1000> osc> 700	307	2.5	11	304	1.3	-1.0	307	1.3	-0.1
176	700> osc> 400	308	1.6	28	305	1.4	-0.8	308	1.3	0.0
176	osc< 400	310	1.1	38	308	1.6	-0.6	310	1.6	0.0
177	1000> osc> 700	315	4.5	5	312	3.8	-1.2	314	3.9	-0.2
177	700> osc> 400	312	4.2	24	310	3.6	-0.8	312	3.7	0.1
177	osc< 400	311	1.1	28	308	1.8	-0.8	310	1.8	-0.2
178	1500> osc> 1000	303	1.2	2	NaN	NaN	NaN	301	3.8	-0.6
178	1000> osc> 700	305	0.6	6	NaN	NaN	NaN	305	1.4	0.0
178	700> osc> 400	308	1.3	14	NaN	NaN	NaN	308	1.2	0.1
178	osc< 400	312	2.1	32	NaN	NaN	NaN	312	1.9	0.0

15.9. APPENDIX: SUMMARY PLOTS

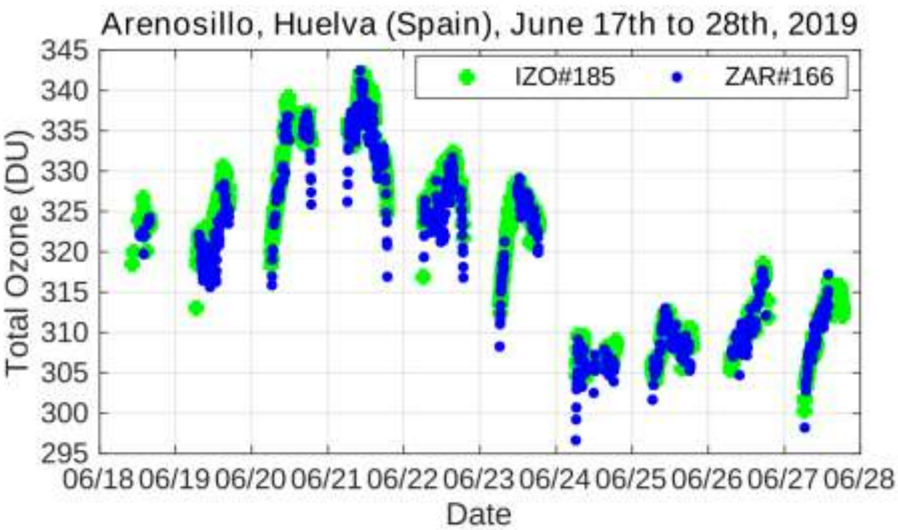
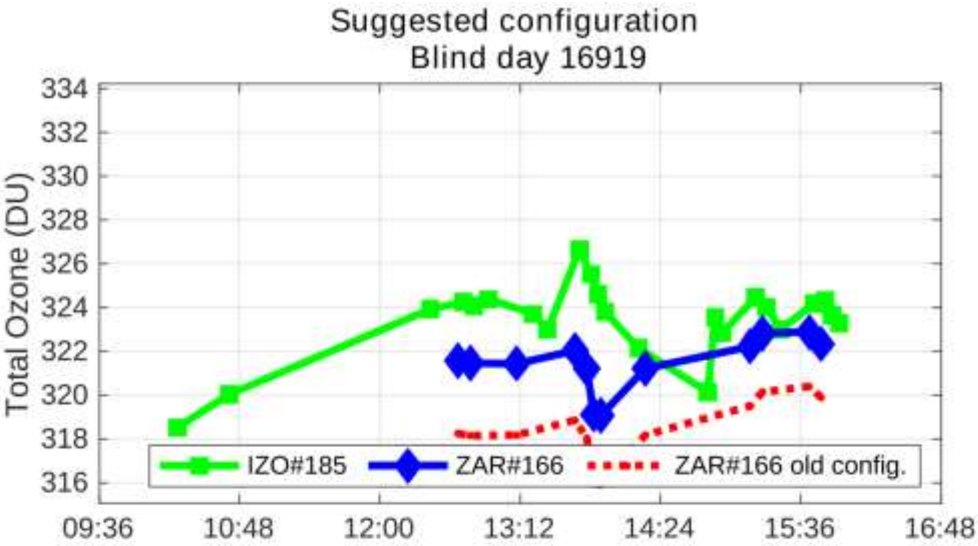
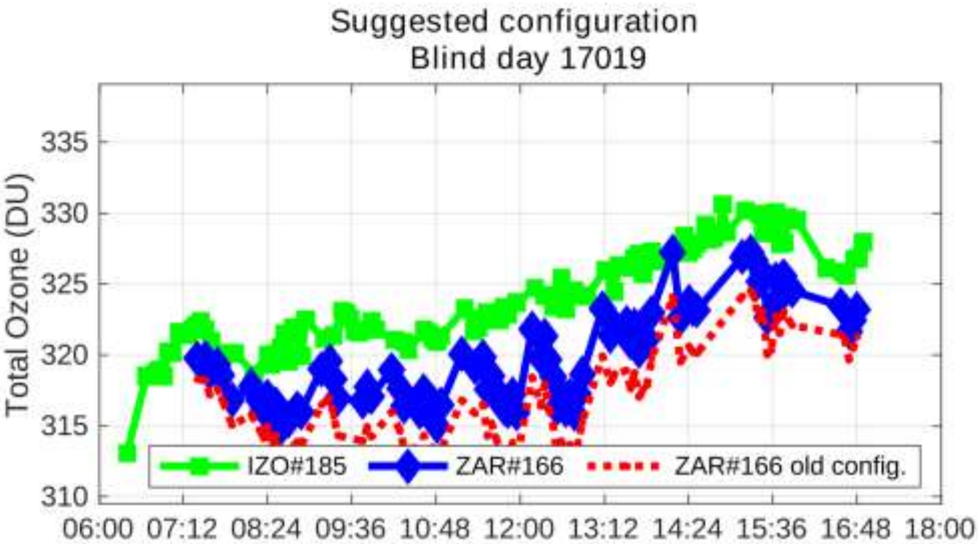
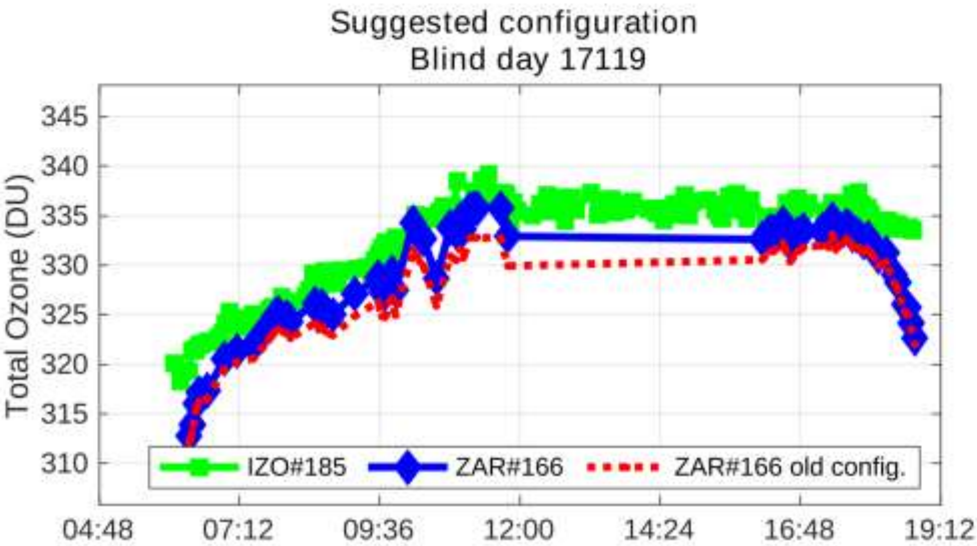
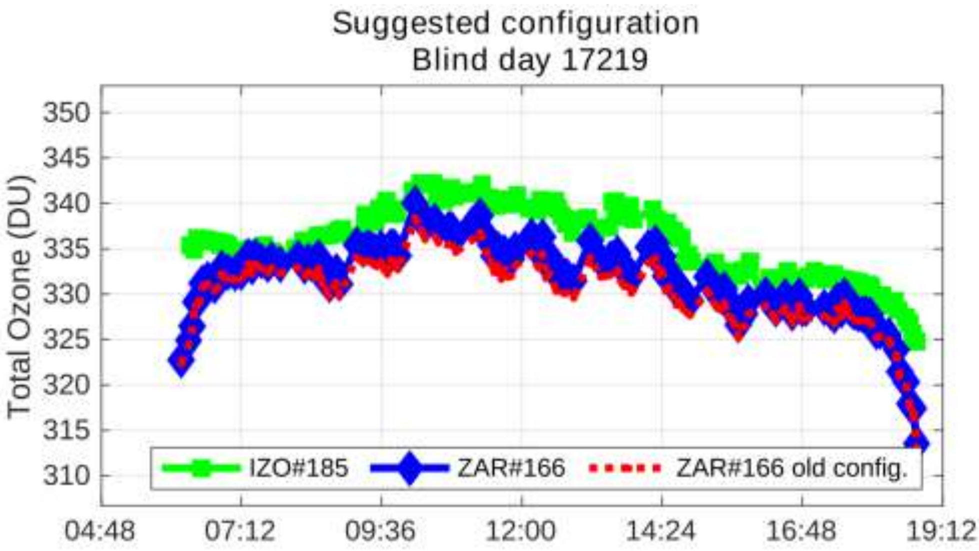


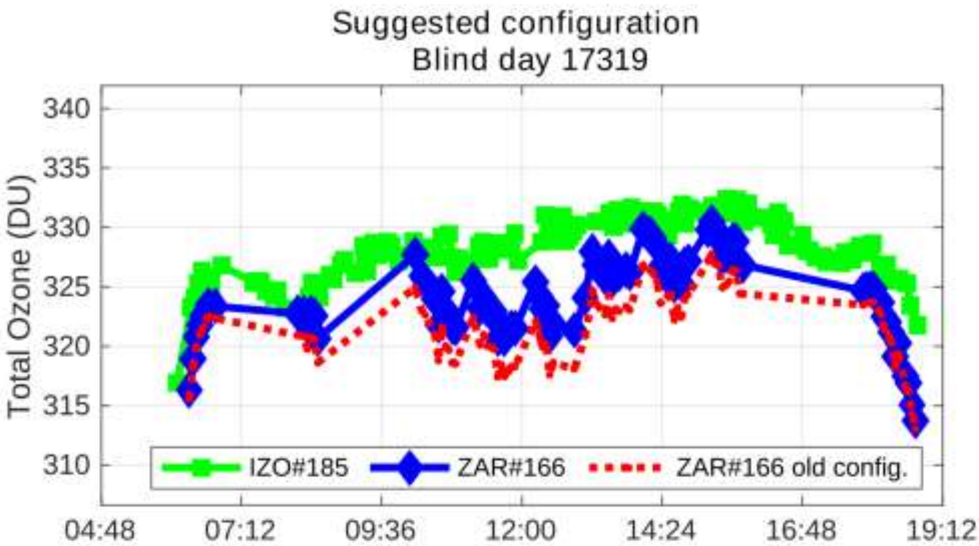
Figure 26. Overview of the intercomparison. Brewer ZAR#166 data were evaluated using final constants (blue circles)

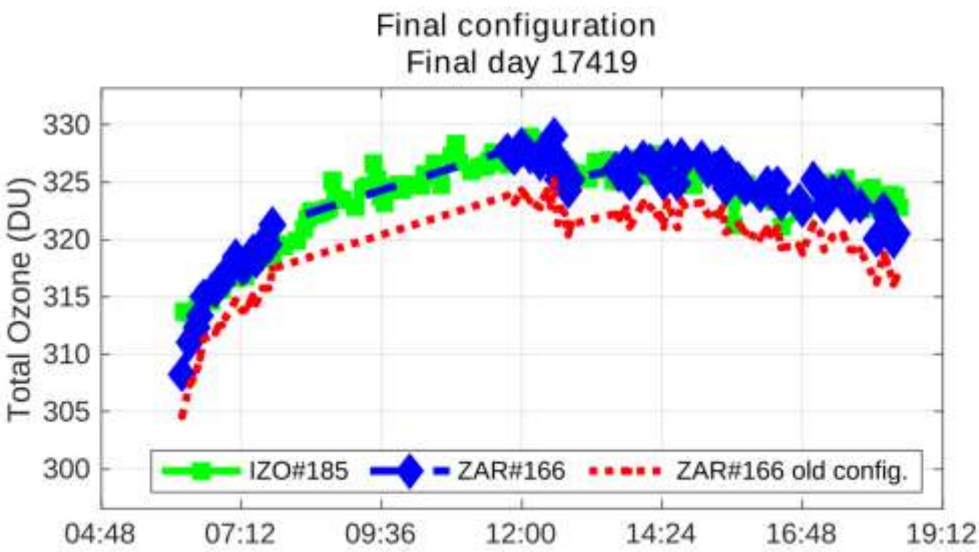

Suggested configuration
Blind day 16919
Total Ozone (DU)
334
332
330
328
326
324
322
320
318
316
09:36
10:48
12:00
13:12
14:24
15:36
16:48
IZO#185
ZAR#166
ZAR#166 old config.

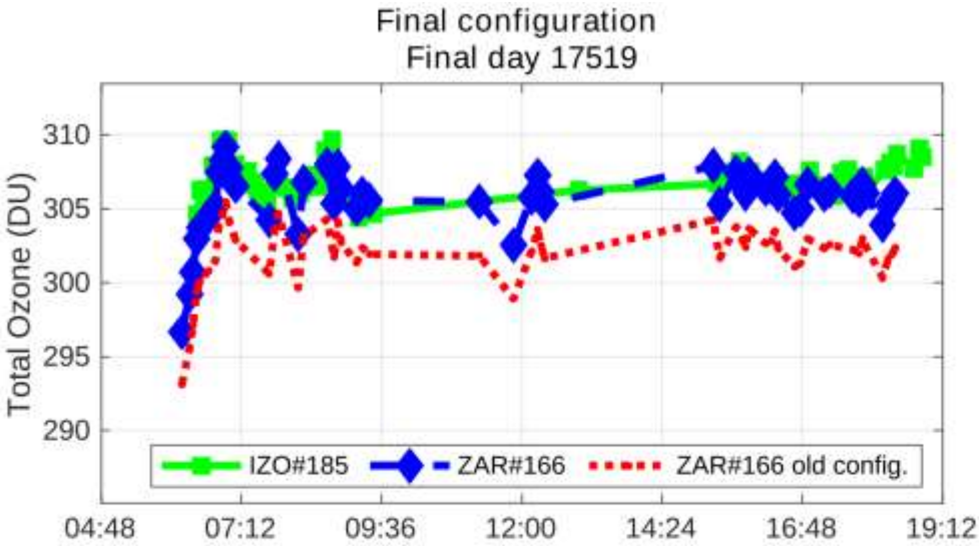

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
310
06:00
07:12
08:24
09:36
10:48
12:00
13:12
14:24
15:36
16:48
18:00
IZO#185
ZAR#166
ZAR#166 old config.

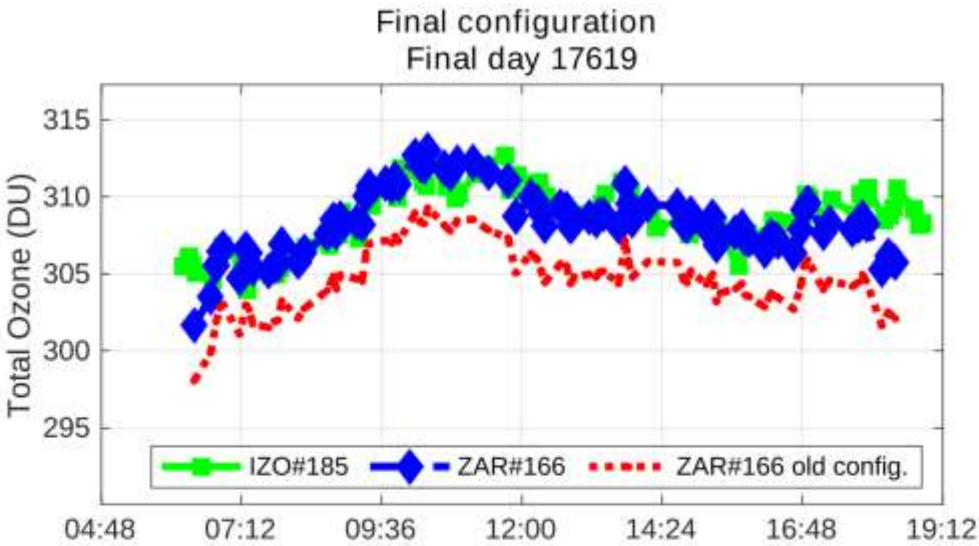

Suggested configuration
Blind day 17119
Total Ozone (DU)
345
340
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
ZAR#166
ZAR#166 old config.

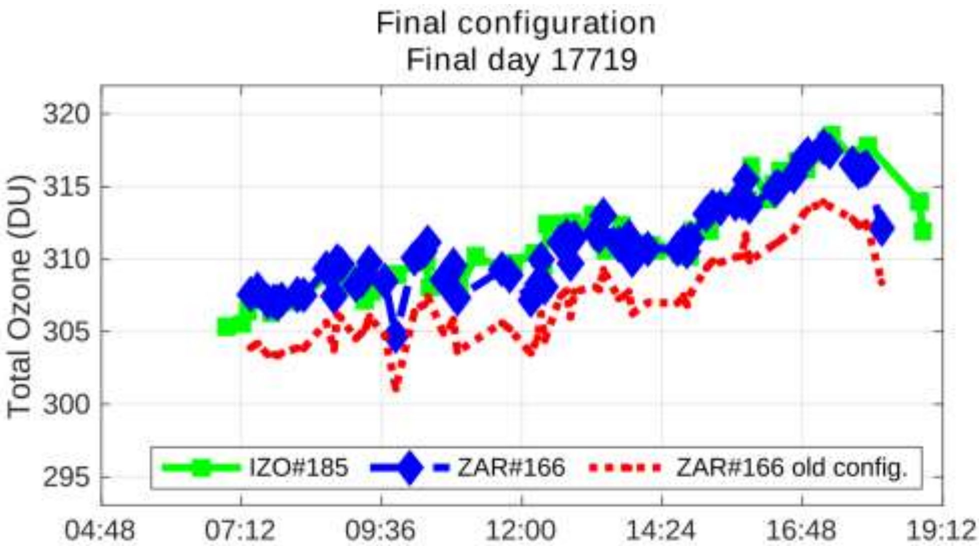

Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
320
315
310
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12

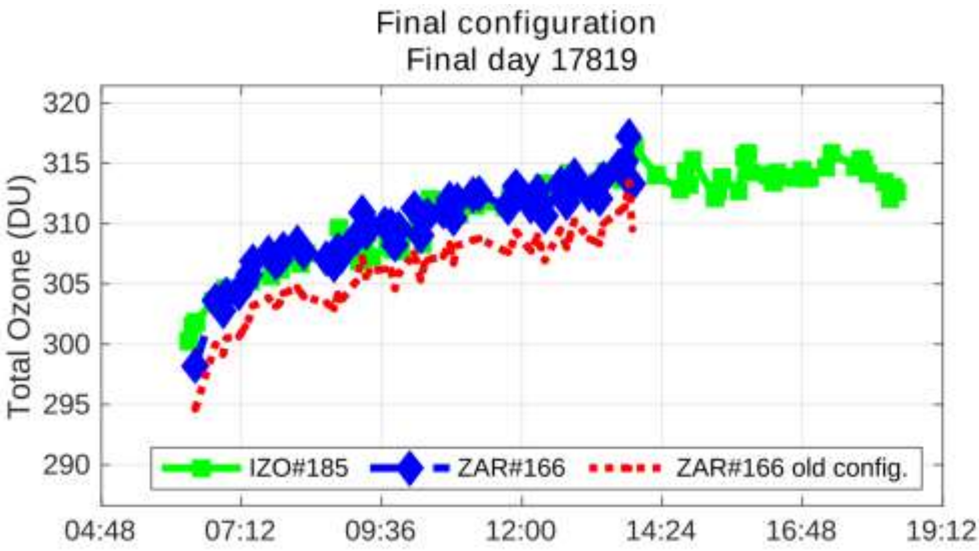

Suggested configuration
Blind day 17319
Total Ozone (DU)
340
335
330
325
320
315
310
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
305
300
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17519
Total Ozone (DU)
310
305
300
295
290
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17619
Total Ozone (DU)
315
310
305
300
295
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17719
Total Ozone (DU)
320
315
310
305
300
295
IZO#185
ZAR#166
ZAR#166 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17819
Total Ozone (DU)
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
ZAR#166
ZAR#166 old config.

16. BREWER UK #172

16.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer UK #172 participated in the campaign from 17 to 28 June, although few measurements were taken during the first two and last days. The campaign days of Brewer UK #172 correspond to Julian days 168 – 178.

For the evaluation of the initial status, we used 107 simultaneous direct sun (DS) ozone measurements from days 170 to 172. For final calibration purposes, we used 343 simultaneous DS ozone measurements taken from day 173 to 178.

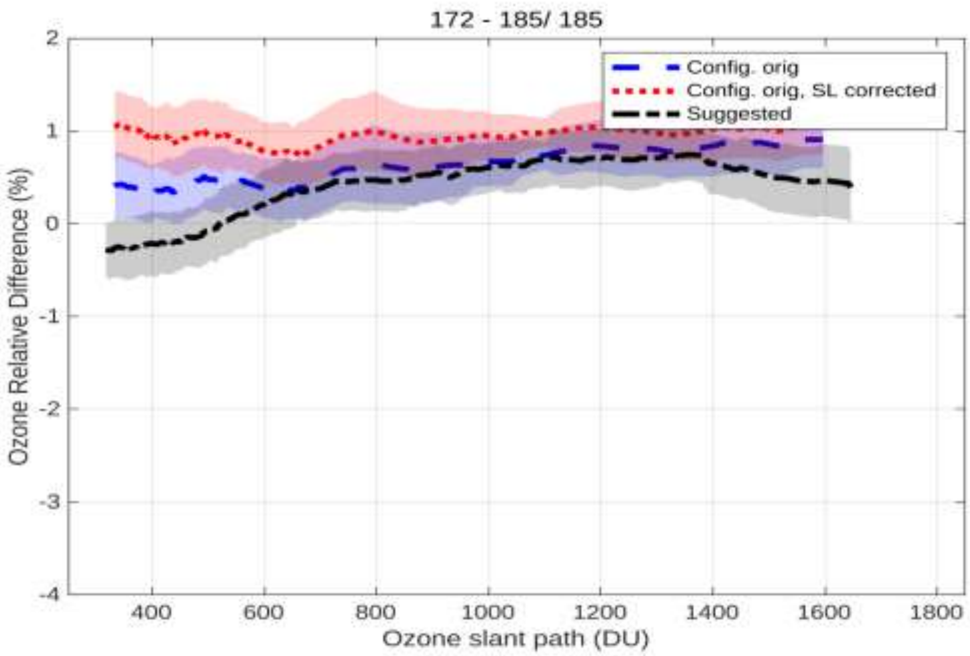


Figure 1. Mean DS ozone column percentage difference between Brewer UK #172 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15117.172, blue dashed line) produces ozone values with an average difference of around 0.5% with respect to the reference instrument. This is a rather small difference and highlights the stability of Brewer UK #172. This is confirmed by the stability of the R6 standard lamp measurements (see Figure 2). The SL correction (Figure 1, red dotted line) is therefore not necessary and does not improve the comparison with Brewer IZO#185.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) show results inside the tolerance limits, only dead time (DT) shows a small difference between the current and campaign values of around 1 ns, with its value changing from $3 \cdot 10^{-8}$ s to $2.9 \cdot 10^{-8}$ s.

We have not applied any correction to filters, but filter #4 shows no-linearity issues.

The sun scan tests (SC) at the instrument's station before the campaign and those performed during the first days of the intercomparison confirm the current cal step value (286, within a step error of ± 1).

We do not suggest changing the ozone absorption coefficient, retaining its current value of 0.341.

16.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer UK #172 have been very stable over the last 2 years. The old R6 reference value was 444 and, although the difference is almost within the acceptable error of ± 5 , it could be updated to 437.
2. We suggest a new R5 reference value of 700.
3. We suggest updating the DT to $2.9 \cdot 10^{-8}$ seconds, which is one unit less than the value proposed in the last intercomparison.
4. The neutral density filters show significative correction for filter #4 however we do not suggest the application of filter corrections at this time.
5. Due to the small change, we do not suggest changing the configuration, but if the DT value is updated, we suggest updating the ETC value from 1700 to 1706.
6. Despite the stability of the instrument and the good agreement with the reference, the instrument shows a slope on the comparison to the reference, underestimating at low airmasses and overestimating at high airmass. This suggests a change in the ozone absorption coefficient of two steps not confirmed during wavelength calibration.

16.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/172/ICF17819.172

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=401824256

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/172/html/cal_report_172a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/172/html/cal_report_172a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/172/html/cal_report_172b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/172/html/cal_report_172c.html

16.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

16.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp test performance has been quite stable since August 2017, with mean values around 437 and 700 for R6 and R5, respectively. The current R6 value is only 7 units less that the reference value given in the previous intercomparison campaign. A small change in R5 can be associated with a variation of the lamp's intensity as shown in Figure 4. Finally, small seasonal variations were identified.

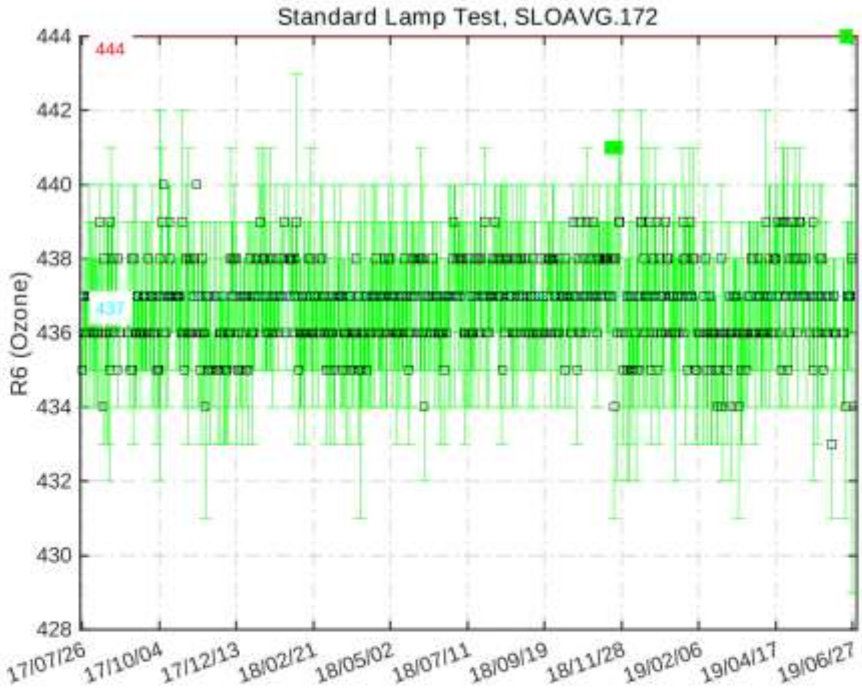


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

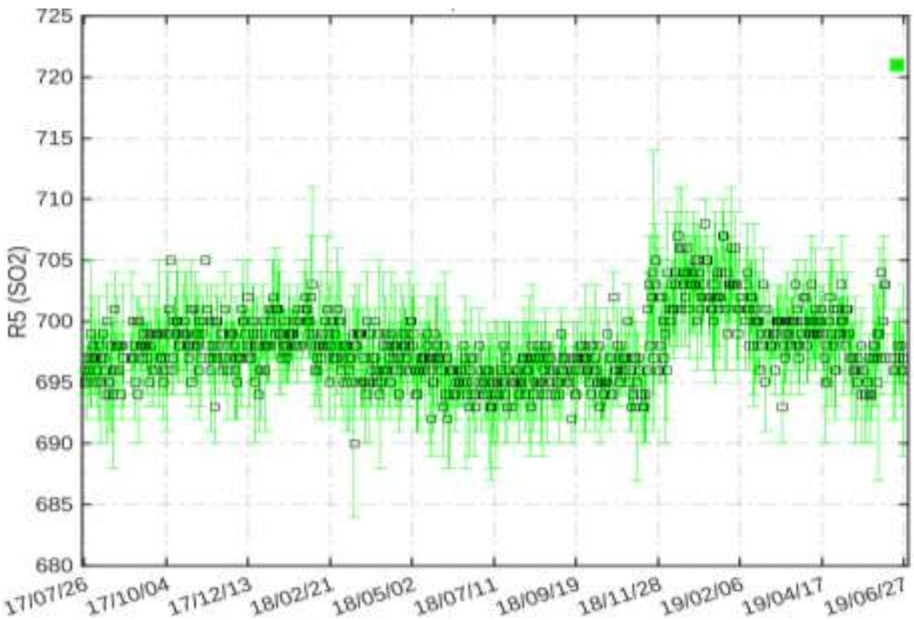


Figure 3. Standard lamp test R5 sulphur dioxide ratios

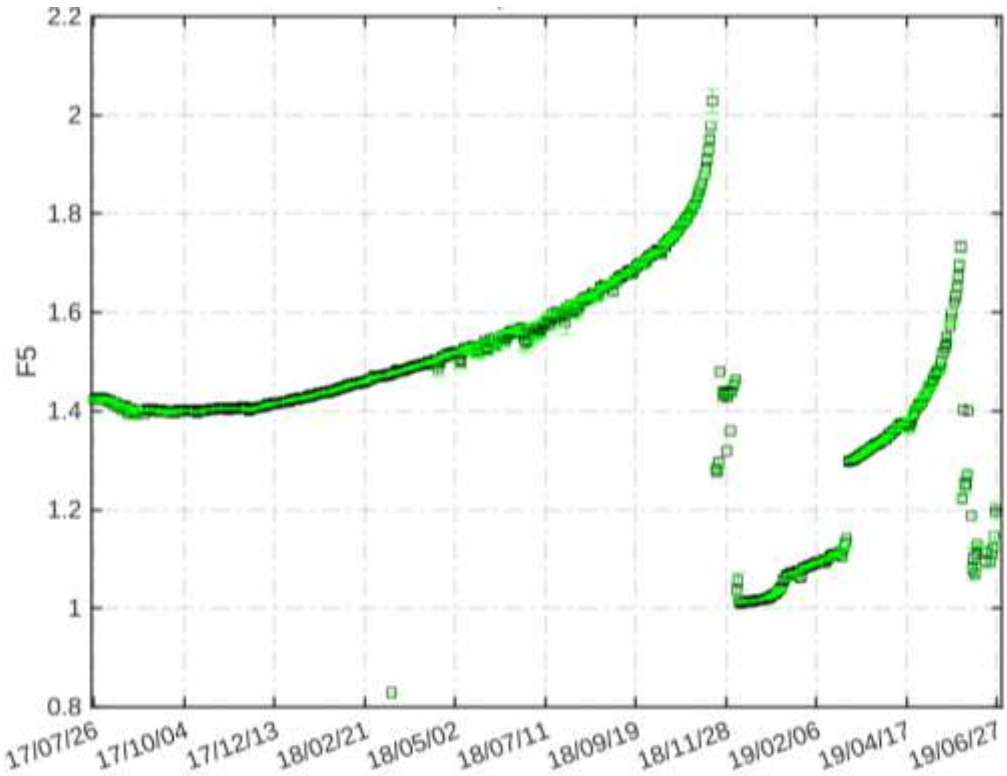


Figure 4. SL intensity for slit five

16.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, the current DT reference value of $3 \cdot 10^{-8}$ seconds is slightly larger than the value recorded during the calibration period, $2.9 \cdot 10^{-8}$ s. Therefore, this new value has been used in the new ICF.

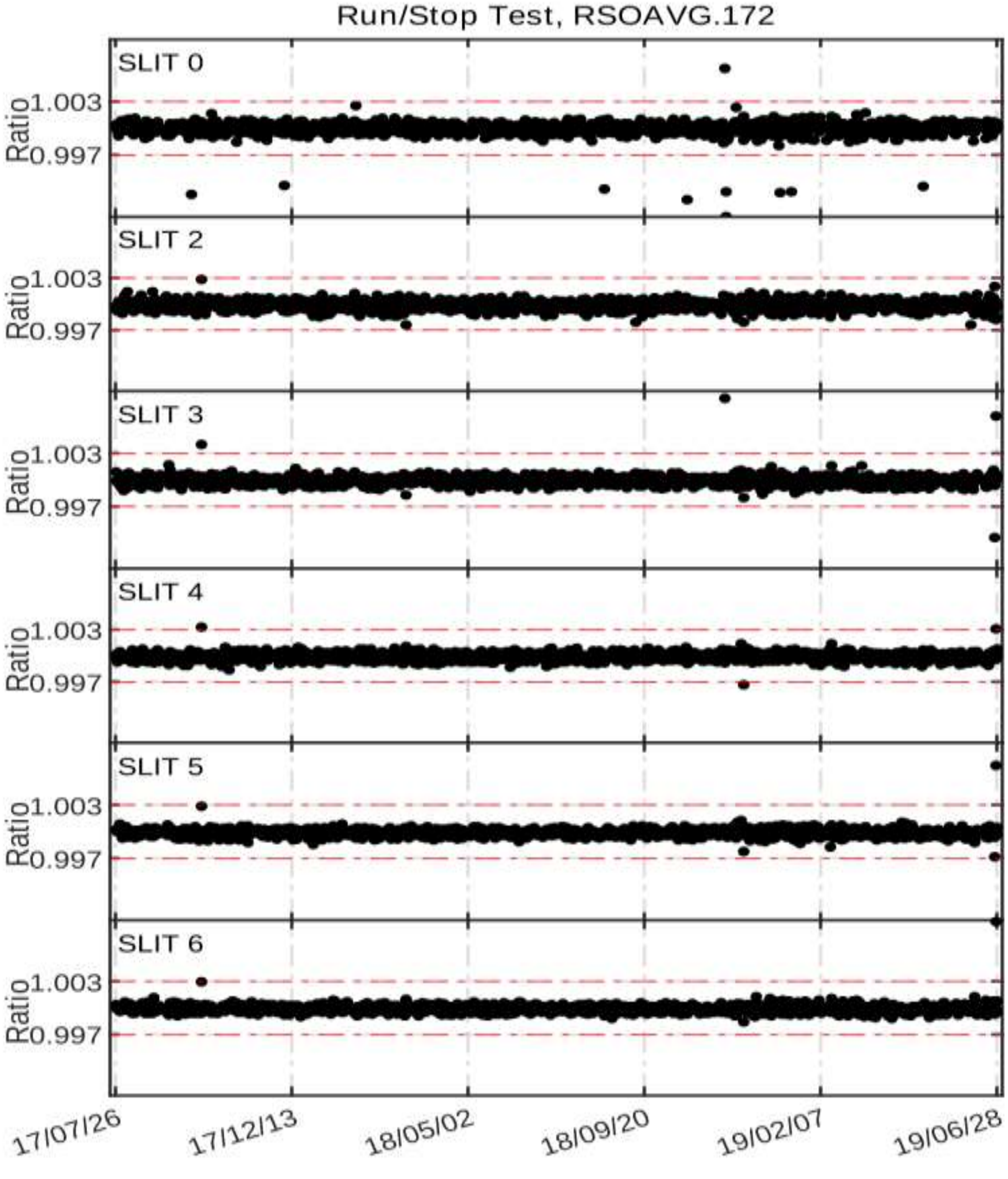


Figure 5. Run/stop test

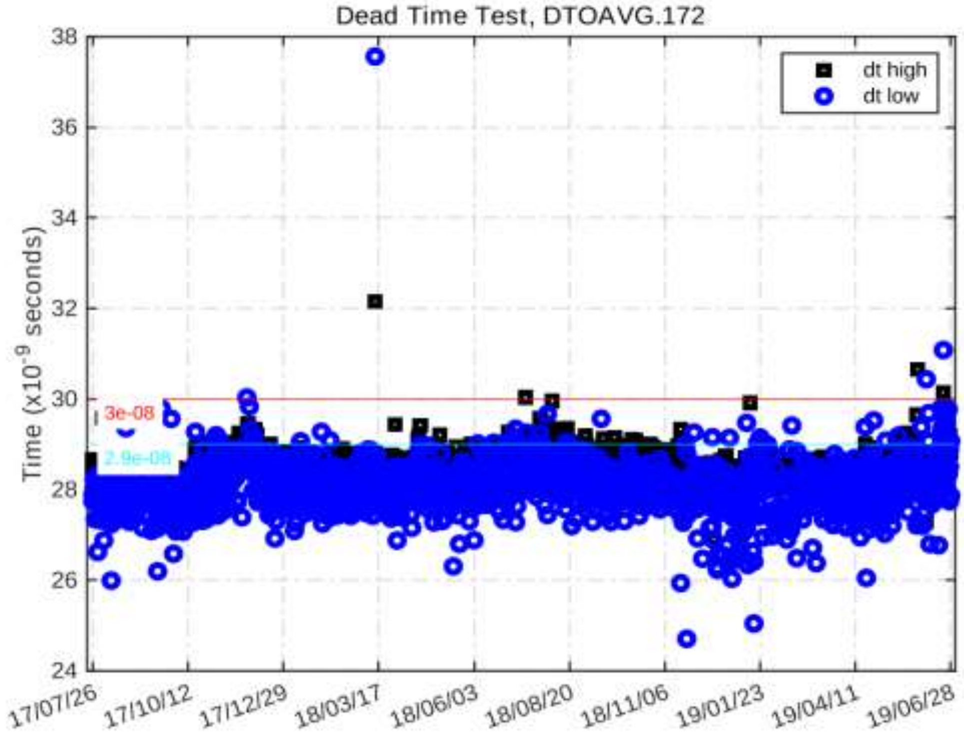


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

16.2.3. Analogue test

Figure 7 shows that high voltage has remained almost constant at around 1171 over the last two years. Furthermore, analogue test values were within the test tolerance range.

Analogue Printout Log, APOAVG.172

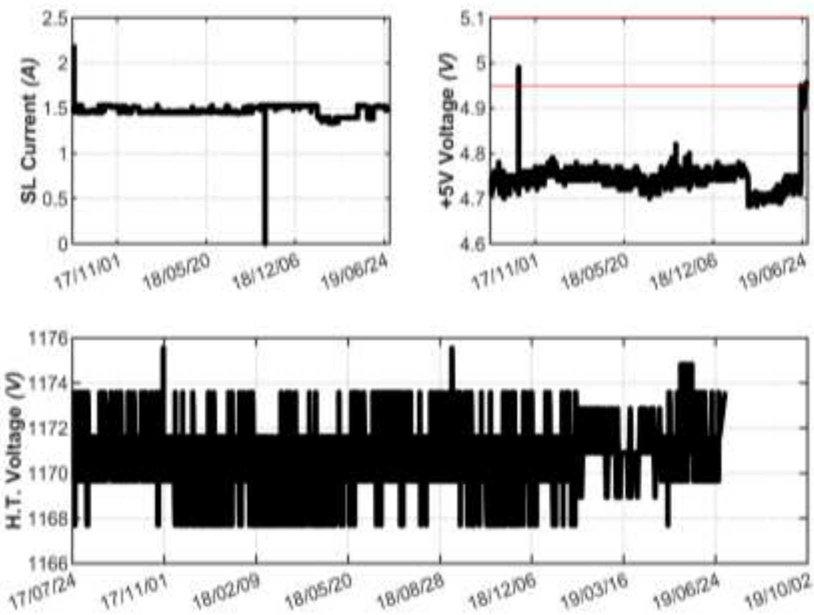


Figure 7. Analogue voltages and intensity

16.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign.

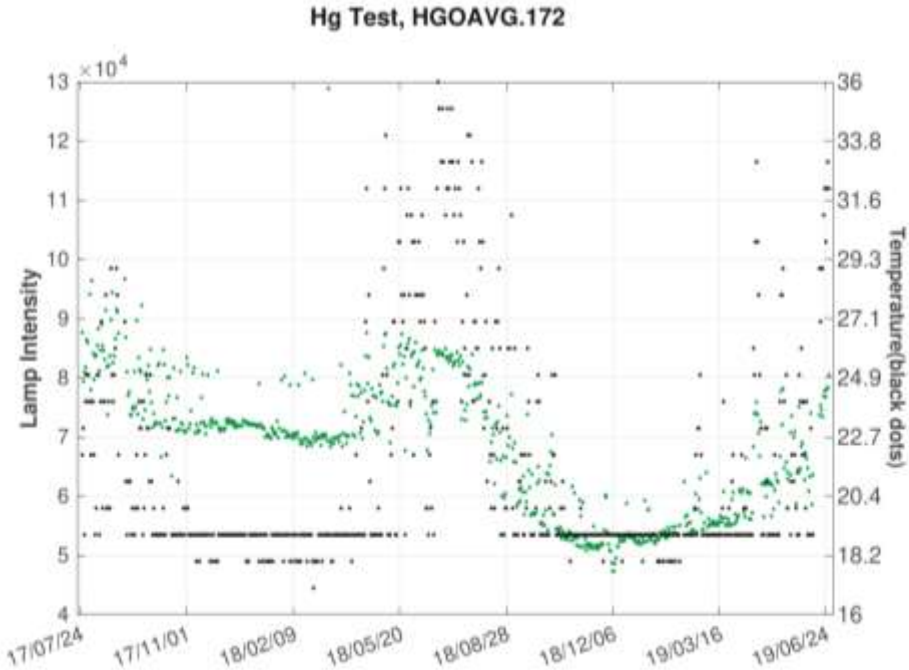


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

16.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer UK #172 during the campaign show reasonable results, with the peak of the calculated scans close, although slightly below, the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.

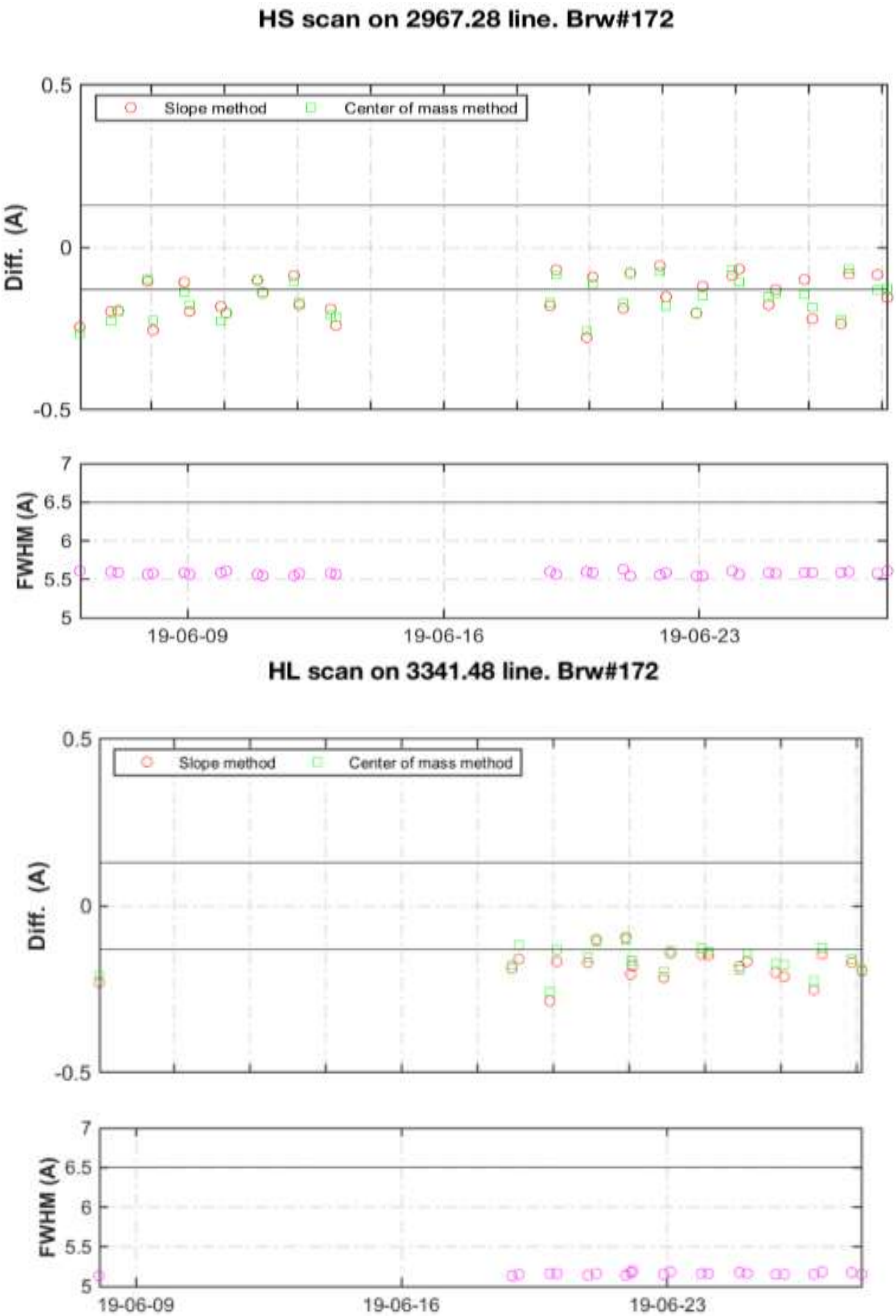


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

16.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer UK #172 CI scans performed during the campaign relative to the scan CI17217.172. As can be observed, lamp intensity varied with respect to the reference spectrum by around 5%.

Similar variations have been observed in the daily R6 and R5 values. This behaviour is normal for an SL lamp.

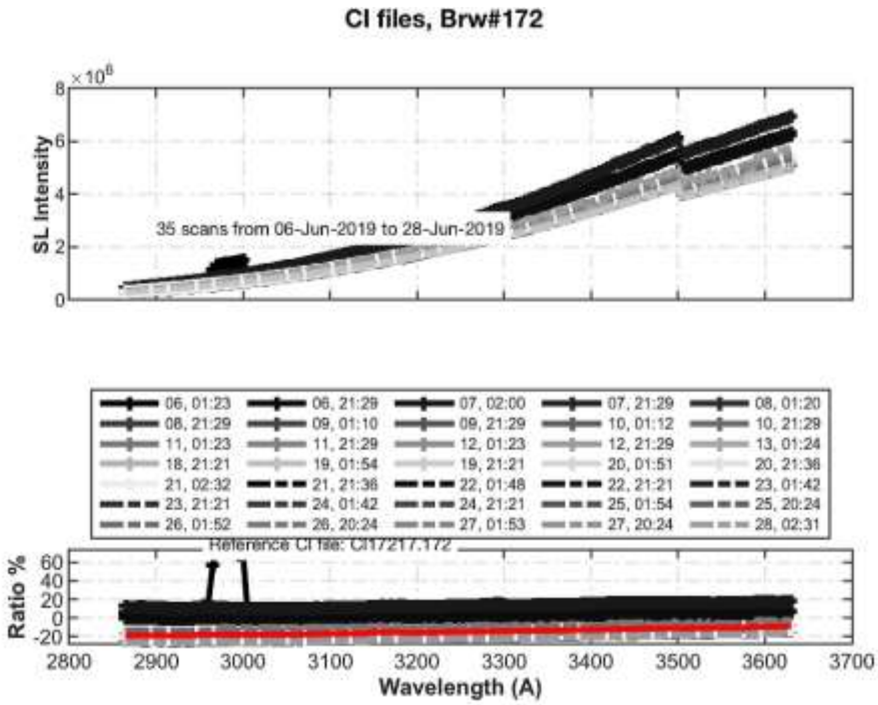


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

16.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this, we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 19 ˙C to 32 ˙C), the current coefficients do an excellent job at reducing the temperature dependence, performing even better than the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, the current and new coefficients perform similarly, with the current coefficients being slightly better. For this reason, in the final ICF we have used the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	6.2369	5.8351	5.7129	5.4500	5.0893
Calculated	0.0000	0.4000	0.3000	0.3000	-0.1000
Final	6.2369	5.8351	5.7129	5.4500	5.0893

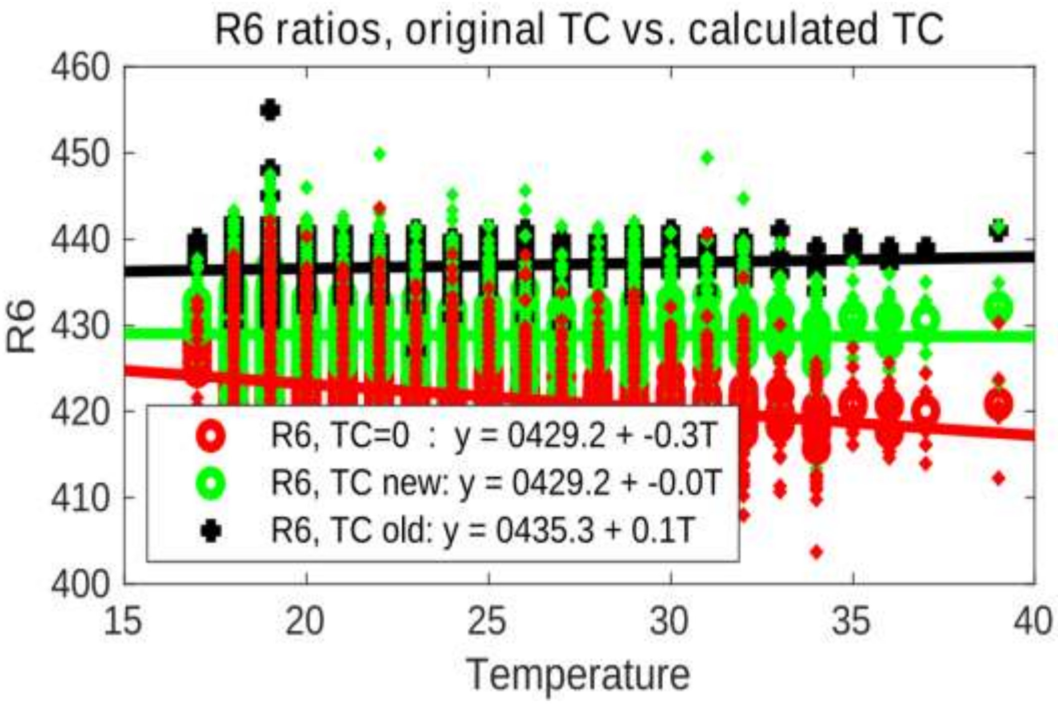


Figure 11. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

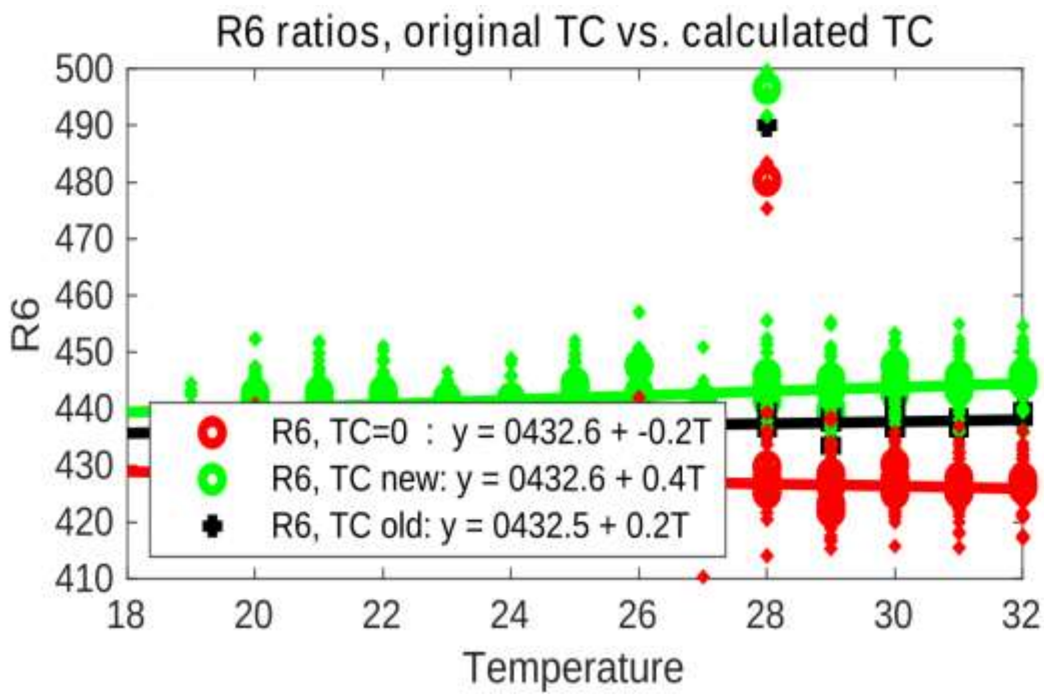


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

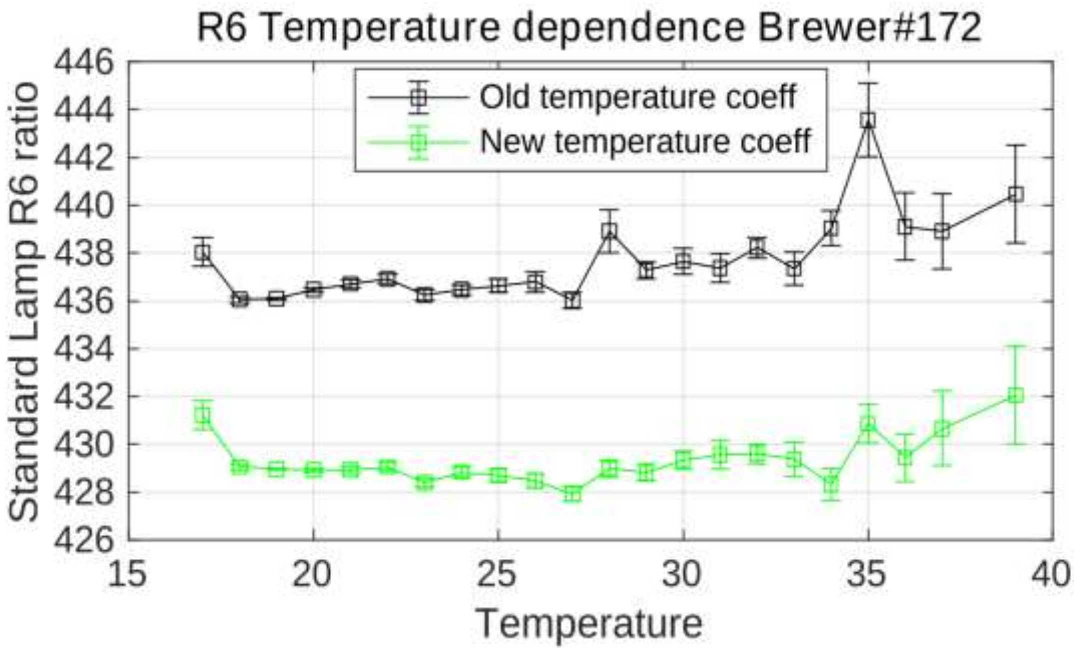


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

16.4. ATTENUATION FILTER CHARACTERIZATION

16.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 123 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Compared to the current ETC filter corrections, suggested in the previous calibration campaign, the corrections calculated at the present campaign are lower. This is especially the case for Filter #3, which has a correction of -15 in the current configuration – looking at the data of the present campaign (see Table 2) the correction is now within the ± 5 error, so it could be set to 0. Also as regards at the comparison with IZO#185, we do not recommend the application of any filter correction at this time, although we suggest checking the results of the FI tests regularly at the station.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-3	-6	-5	-17	1
ETC Filt. Corr. (mean)	-2.5	-7.5	-4.5	-12.3	1.5
ETC Filt. Corr. (mean 95% CI)	[-5.8 0.8]	[-11.3 -3.7]	[-7.9 -1.1]	[-18.6 -5.9]	[-8.3 11.6]

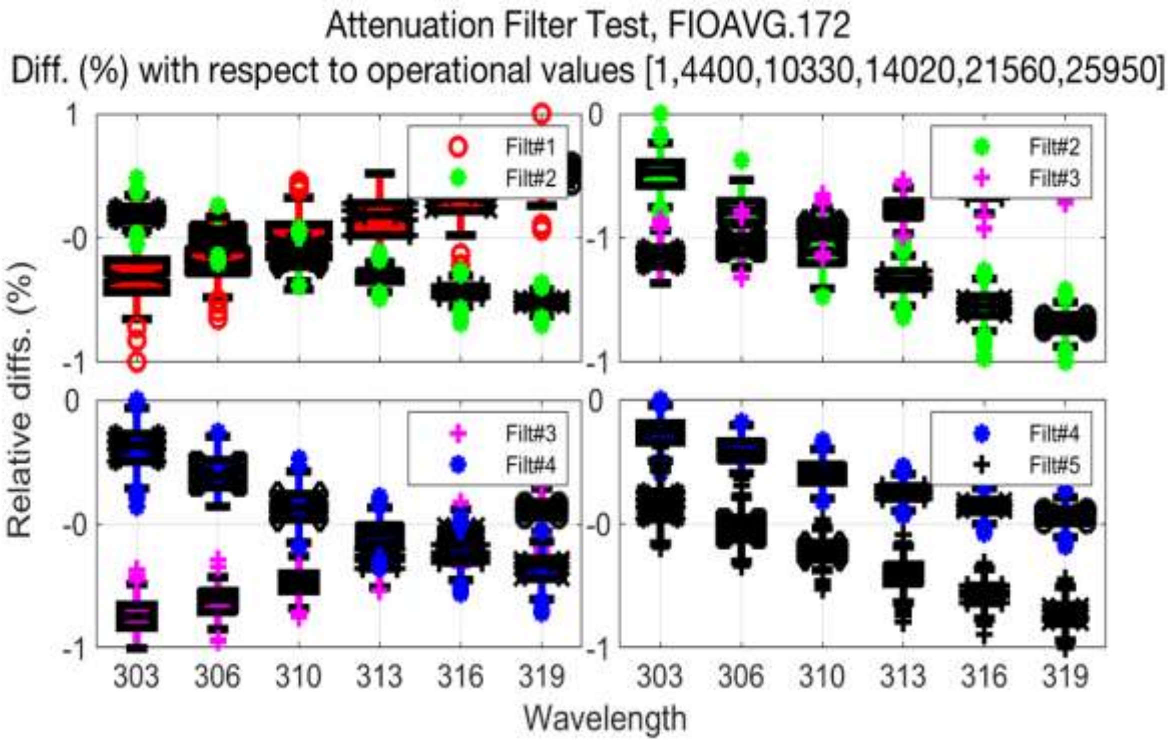


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

16.5. WAVELENGTH CALIBRATION

16.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 24 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out, (see Figure 16). The calculated cal step number (CSN) was 1 step lower than the value in the current configuration (285 vs. 286). SC tests performed at the station before the campaign provide a CSN of 287. These differences are within the ± 1 acceptable error limit, so we suggest keeping the current CSN (286).

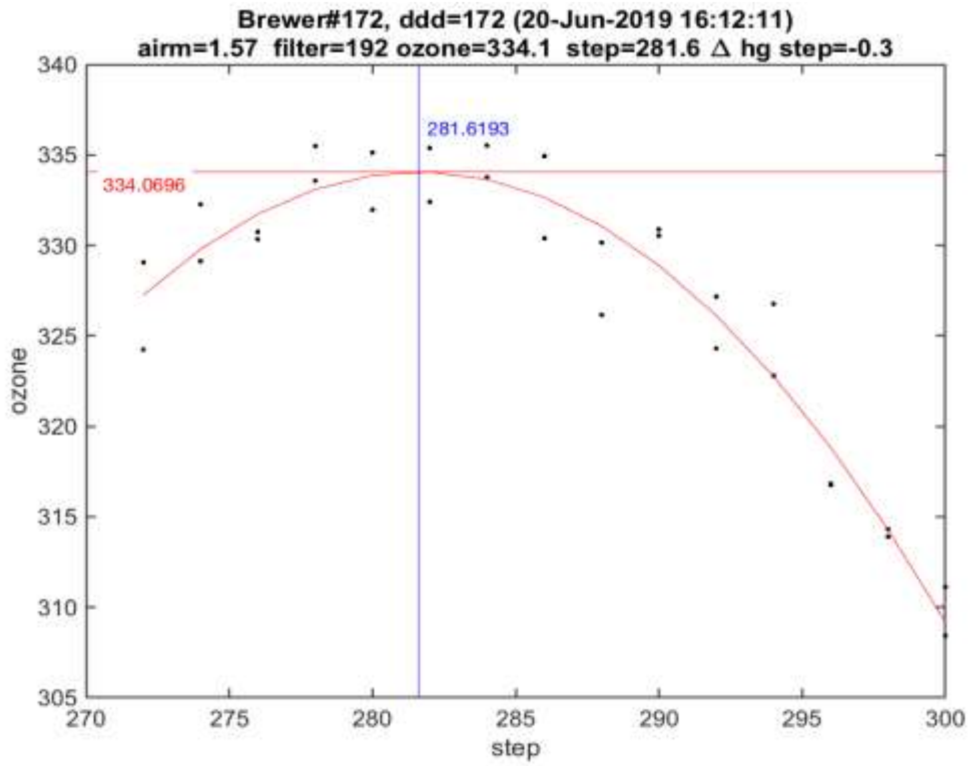


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

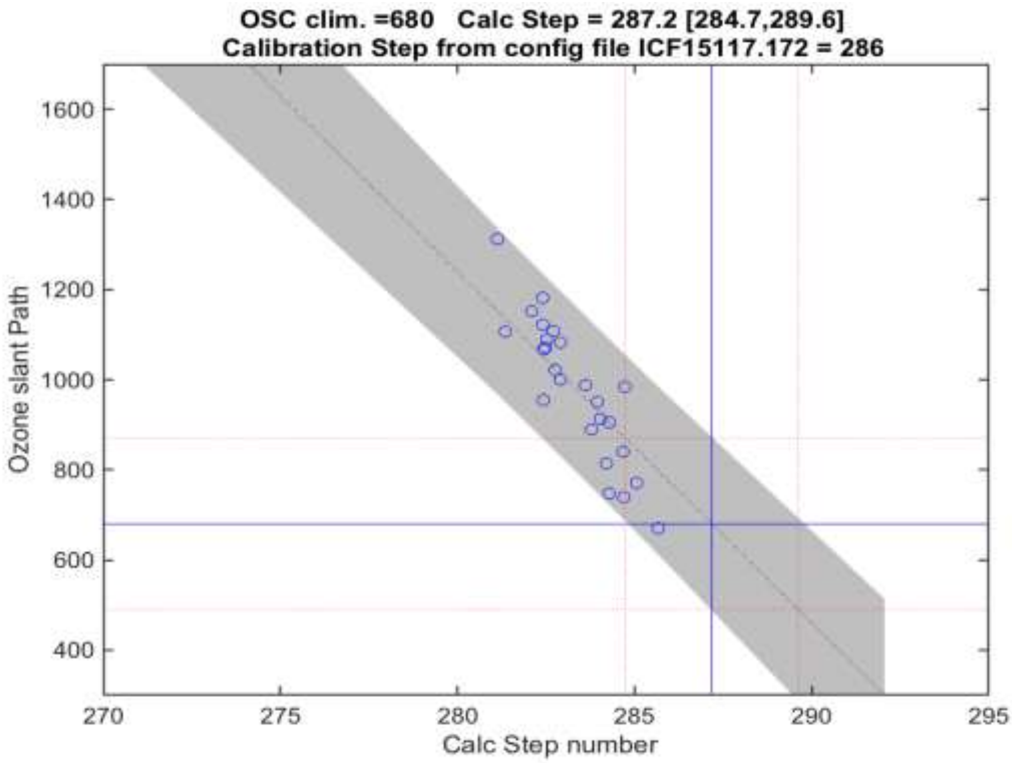


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

16.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

In the final configuration for the present campaign, we suggest retaining the current absorption coefficient (0.341).

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	286	0.3410	2.3500	1.1585
16-Jun-2013	286	0.3453	3.2066	1.1539
02-Jun-2015	286	0.3425	3.2190	1.1466
02-Jun-2017	286	0.3420	3.2256	1.1452
23-Jun-2019	286	0.3412	3.2053	1.1435
Final	286	0.3410	2.3500	1.1585

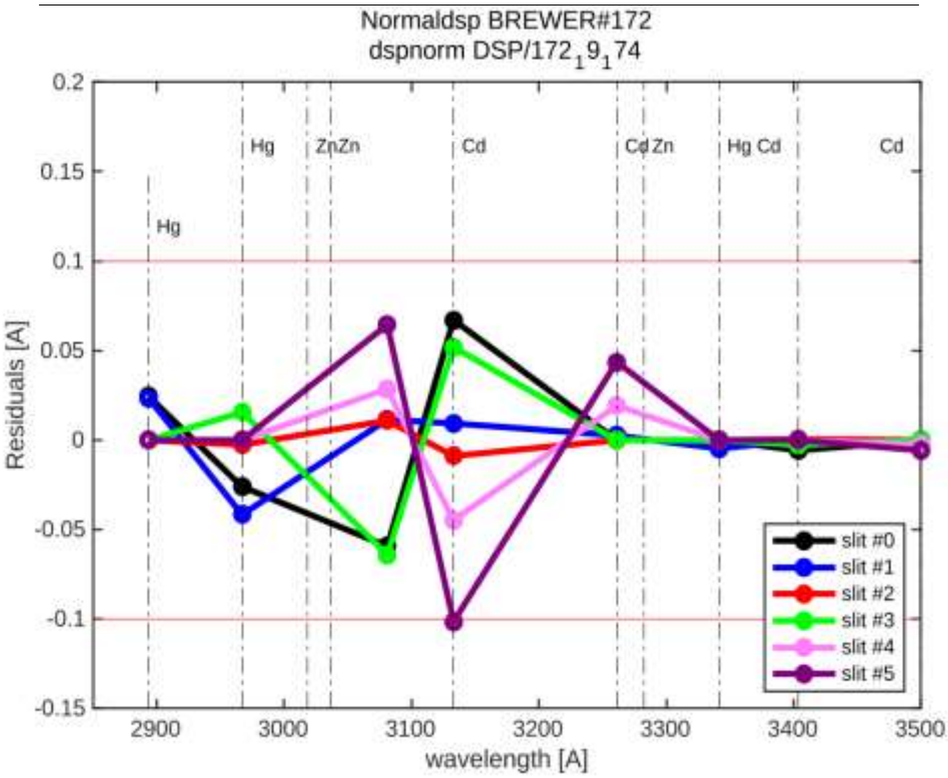


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 285	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.78	3063.03	3100.49	3135.06	3167.95	3199.95
Res(A)	5.5507	5.4847	5.4206	5.5129	5.4437	5.3591
O3abs(1/cm)	2.6034	1.78	1.005	0.67638	0.37488	0.29422
Ray abs(1/cm)	0.50516	0.48321	0.45848	0.43708	0.41788	0.40023
SO2abs(1/cm)	3.461	5.6609	2.4054	1.8918	1.0541	0.61315
step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.85	3063.1	3100.56	3135.13	3168.02	3200.02
Res(A)	5.5506	5.4846	5.4205	5.5128	5.4436	5.359
O3abs(1/cm)	2.6008	1.7783	1.0047	0.67598	0.37495	0.29375
Ray abs(1/cm)	0.50511	0.48316	0.45844	0.43703	0.41785	0.4002
SO2abs(1/cm)	3.4441	5.6825	2.4136	1.8801	1.0553	0.61093
step= 287	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.92	3063.18	3100.63	3135.2	3168.09	3200.09
Res(A)	5.5505	5.4845	5.4204	5.5127	5.4435	5.3589
O3abs(1/cm)	2.5983	1.7767	1.0044	0.67558	0.37502	0.29328
Ray abs(1/cm)	0.50505	0.48311	0.45839	0.43699	0.41781	0.40016
SO2abs(1/cm)	3.4271	5.7025	2.4219	1.8685	1.0565	0.60867
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
285	0.34221	9.9284	3.1959	1.147	0.35286	0.34423
286	0.34121	9.9254	3.2053	1.1435	0.3519	0.34323
287	0.34016	9.9224	3.2129	1.1401	0.35088	0.34219

16.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1694. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 286	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.5506	5.4846	5.4205	5.5128	5.4436	5.359
O3abs(1/cm)	2.6008	1.7783	1.0047	0.67598	0.37495	0.29375
Ray abs(1/cm)	0.50511	0.48316	0.45844	0.43703	0.41785	0.4002
step= 1694	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.4194	5.3569	5.2861	5.3867	5.3064	5.2301
O3abs(1/cm)	0.67894	0.39565	0.29407	0.1222	0.061082	0.033365

16.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

16.6.1. Initial calibration

For the evaluation of the initial status of Brewer UK #172, we used the period from days 170 to 172 which correspond with 107 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produce an ozone value slightly higher than the reference instrument (0.5%). When the ETC is corrected, taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

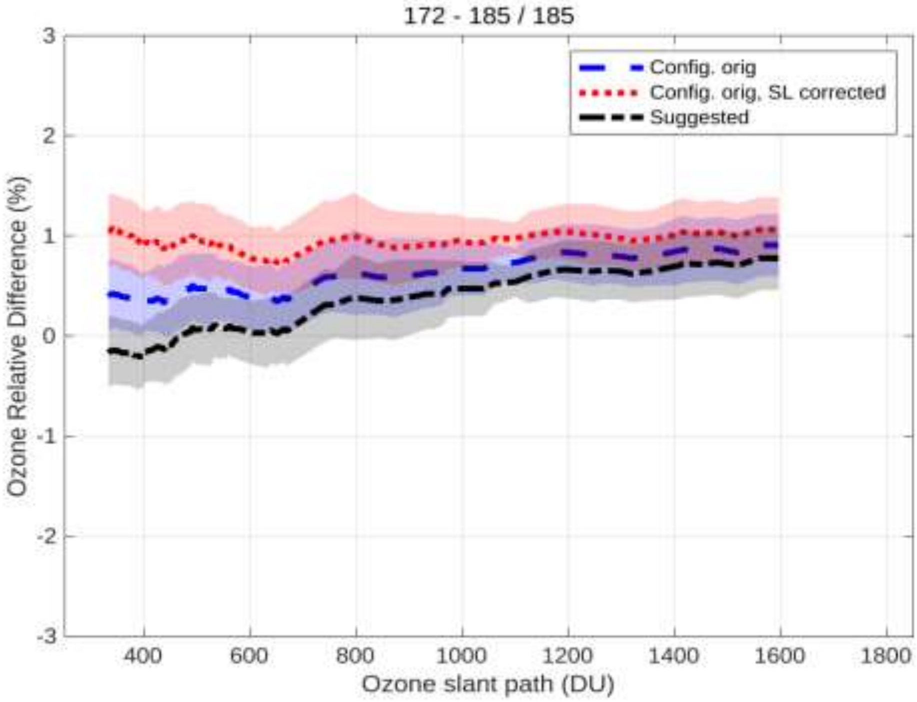


Figure 18. Mean direct sun ozone column percentage difference between Brewer UK #172 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=1000	1707	1712	3410	3396
full OSC range	1707	1703	3410	3417

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#172*	*O3 std*	*%(172–185)/185*	*O3(*) #172*	*O3std*	*(*)%(172 – 185)/185*
19-Jun-2019	170	324.3	3.2	54	325.8	3.3	0.5	324.2	3.3	0
20-Jun-2019	171	333.6	4.1	53	335	3.8	0.4	333.5	3.5	0

16.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 19). For the final calibration, we used 343 simultaneous direct sun measurements from days 173 to 178. The new value (1706) was only six units higher than the current ETC value (1700), due to the change in the Dead Time. The change is very small, so UK #172 could perhaps continue using the current configuration, although with the new proposed standard lamp reference ratios of 437 for R6. In all cases, we provide a new configuration with the new ETC, taking into account the new suggested dead time, $2.9 \cdot 10^{-8}$ s.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is within the maximum tolerance limit of 10 units.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

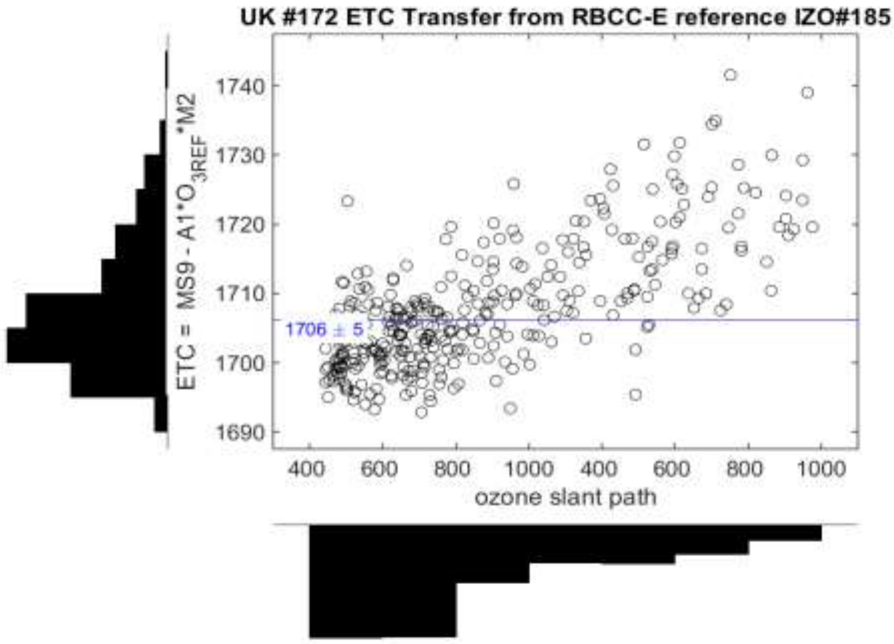


Figure 19. Mean direct sun ozone column percentage difference between Brewer UK #172 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1706	1697	3410	3423
full OSC range	1705	1681	3410	3459

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#172*	*O3 std*	*%(172–185)/185*	*O3(*) #172*	*O3std*	*(*)%(172–185)/185*
21-Jun-2019	172	334.3	3.3	37	335.7	3.2	0.4	334.1	2.9	-0.1
22-Jun-2019	173	328.3	2.8	60	329.3	2.4	0.3	328.1	2.3	-0.1
23-Jun-2019	174	324	3.1	93	325.5	2.7	0.5	324.1	2.4	0

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#172*	*O3 std*	*%(172–185)/185*	*O3(*) #172*	*O3std*	*(*)%(172–185)/185*
24-Jun-2019	175	307.1	1	44	308.4	1.5	0.4	307.3	1.7	0.1
25-Jun-2019	176	308.6	2.1	47	309.5	1.7	0.3	308.2	1.5	-0.1
26-Jun-2019	177	312	3.9	46	313.2	4.1	0.4	311.9	4.3	0
27-Jun-2019	178	NaN	NaN	0	308.3	2.6	NaN	307.2	2	NaN

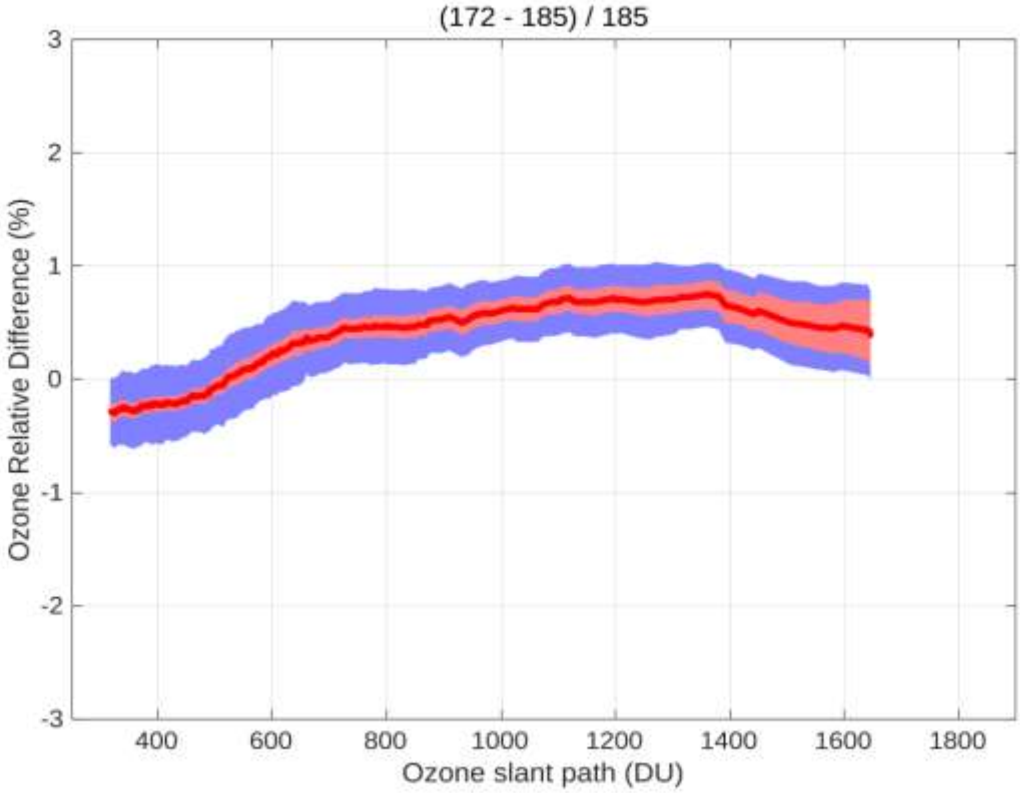


Figure 20. Mean direct sun ozone column percentage difference between Brewer UK #172 and Brewer IZO#185 as a function of ozone slant path

16.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 437 for R6 (Figure 21) and 697 for R5 (Figure 22).

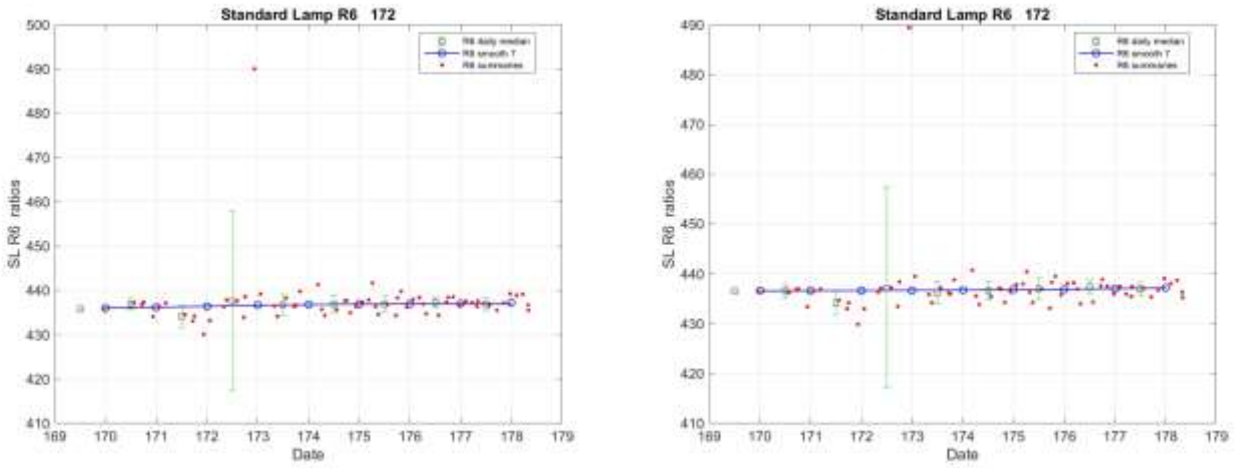


Figure 21. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

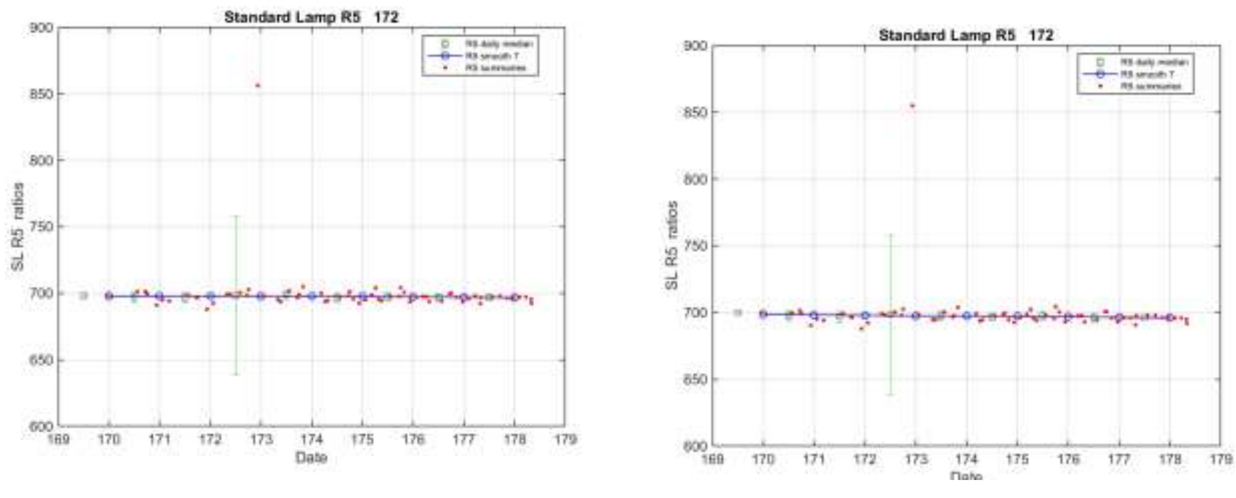


Figure 22. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

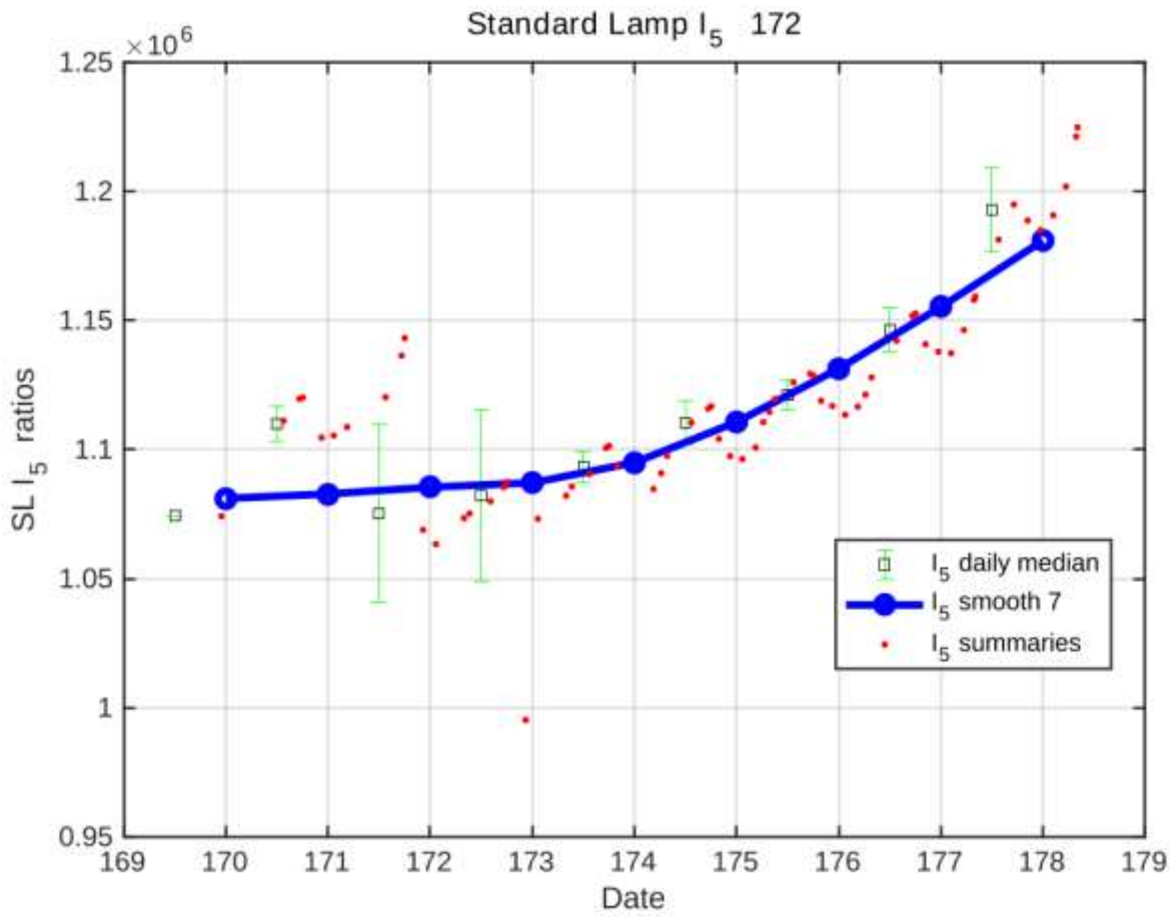


Figure 23. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

16.7. CONFIGURATION

16.7.1. Instrument constant file

	Initial (ICF15117.172)	Final (ICF17319.172)
o3 Temp coef 1	6.2369	6.2369
o3 Temp coef 2	5.8351	5.8351
o3 Temp coef 3	5.7129	5.7129
o3 Temp coef 4	5.45	5.45
o3 Temp coef 5	5.0893	5.0893
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.341	0.341
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1585	1.1585
ETC on O3 Ratio	1700	1706

	Initial (ICF15117.172)	Final (ICF17319.172)
ETC on SO2 Ratio	250	250
Dead time (sec)	3e-08	2.9e-08
WL cal step number	286	286
Slitmask motor delay	14	14
Umkehr Offset	1697	1697
ND filter 0	0	0
ND filter 1	4400	4400
ND filter 2	10330	10330
ND filter 3	14020	14020
ND filter 4	21560	21560
ND filter 5	25950	25950
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	0	0
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	655	655
NO2 zs etc	630	630
NO2 Mic #1 Offset	2508	2508
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2508	2508
Grating Slope	0.9986	0.9986
Grating Intercept	-3	-3

	Initial (ICF15117.172)	Final (ICF17319.172)
Micrometre Zero	2469	2469
Iris Open Steps	250	250
Buffer Delay (s)	0.2	0.2
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	64	64
Zenith Offset	0	0
Zenith UVB Position	2224	2224

16.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	osc range	O3#185	O3std	N	O3#172	O3 std	%diff	(*)O3#172	O3 std	(*)%diff
170	700> osc> 400	324	4.0	28	327	4.5	0.9	327	4.5	0.9
170	osc< 400	324	2.5	29	328	2.5	1.1	328	2.5	1.1
171	osc> 1500	329	8.9	3	333	7.7	1.3	333	7.7	1.3
171	1500> osc> 1000	325	5.9	8	328	6.4	1.0	328	6.4	1.0
171	1000> osc> 700	328	5.7	7	331	5.0	1.0	331	5.0	1.0
171	700> osc> 400	333	3.8	29	336	3.4	1.0	336	3.4	1.0
171	osc< 400	336	0.9	22	340	1.3	1.2	340	1.3	1.2
172	osc> 1500	325	0.6	2	329	0.6	1.2	329	0.6	1.2
172	1500> osc> 1000	334	3.2	8	337	2.8	0.9	337	2.8	0.9
172	1000> osc> 700	331	0.0	1	335	0.0	1.1	335	0.0	1.1
172	700> osc> 400	332	0.9	20	334	1.0	0.7	334	1.0	0.7
172	osc< 400	338	1.8	15	341	1.9	0.8	341	1.9	0.8
173	osc> 1500	322	0.0	1	324	0.0	0.7	323	0.0	0.5
173	1500> osc> 1000	325	1.2	13	328	1.7	0.9	327	1.6	0.6
173	1000> osc> 700	327	1.3	15	330	1.1	0.9	329	1.2	0.4
173	700> osc> 400	328	3.0	37	330	2.8	0.8	328	2.6	0.0
173	osc< 400	331	1.0	7	334	0.6	0.8	330	0.5	-0.3
174	osc> 1500	314	0.0	1	316	0.0	0.8	316	0.0	0.6

Day	osc range	O3#185	O3std	N	O3#172	O3 std	%diff	(*)O3#172	O3 std	(*)%diff
174	1500> osc> 1000	318	4.6	12	321	4.6	1.0	320	4.5	0.7
174	1000> osc> 700	320	3.7	18	324	3.4	0.9	322	3.3	0.5
174	700> osc> 400	323	2.0	38	326	1.9	0.9	324	1.7	0.1
174	osc< 400	326	1.2	37	330	1.3	1.0	326	1.1	-0.2
175	osc> 1500	309	0.3	3	309	1.6	0.2	309	1.6	-0.1
175	1500> osc> 1000	307	1.3	12	310	0.9	1.1	309	1.0	0.8
175	1000> osc> 700	307	1.1	14	311	1.3	1.0	309	1.4	0.6
175	700> osc> 400	307	1.0	26	309	1.0	0.8	307	1.1	0.0
175	osc< 400	307	0.6	2	310	0.7	1.0	306	0.1	-0.2
176	osc> 1500	308	1.4	4	309	0.7	0.5	308	0.7	0.3
176	1500> osc> 1000	308	2.2	8	310	2.2	0.8	309	2.2	0.5
176	1000> osc> 700	308	2.4	9	310	1.8	0.8	309	1.8	0.4
176	700> osc> 400	308	1.6	24	310	1.4	0.7	308	1.4	-0.1
176	osc< 400	310	1.4	13	312	0.9	0.6	309	0.9	-0.5
177	osc> 1500	314	0.0	1	316	0.0	0.5	315	0.0	0.3
177	1000> osc> 700	312	5.8	8	314	6.5	0.7	313	6.6	0.3
177	700> osc> 400	313	3.9	25	315	3.9	0.8	313	4.0	0.0
177	osc< 400	311	1.2	13	313	1.7	0.9	309	1.5	-0.4
178	1500> osc> 1000	307	6.0	8	NaN	NaN	NaN	309	5.8	0.5
178	1000> osc> 700	308	5.2	11	NaN	NaN	NaN	309	5.2	0.3
178	700> osc> 400	313	3.3	20	NaN	NaN	NaN	313	3.3	0.1
178	osc< 400	313	1.2	14	NaN	NaN	NaN	312	1.8	-0.3

16.9. APPENDIX: SUMMARY PLOTS

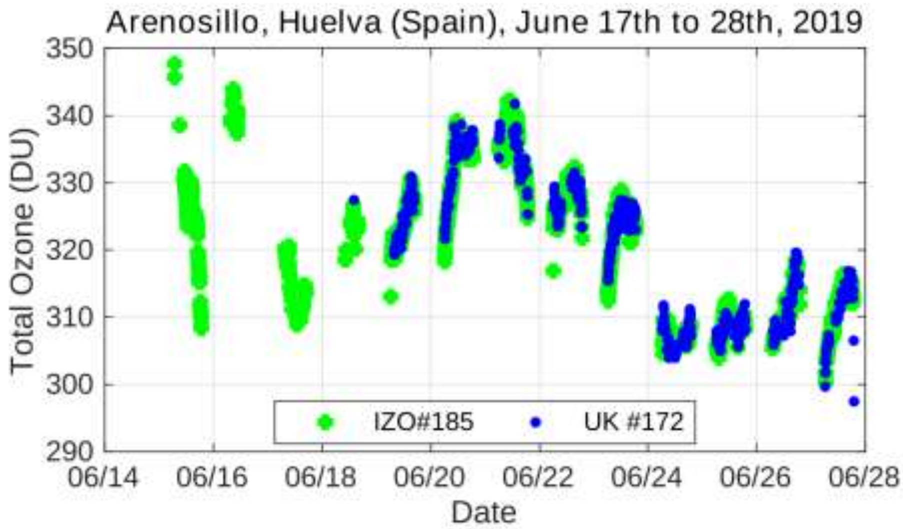
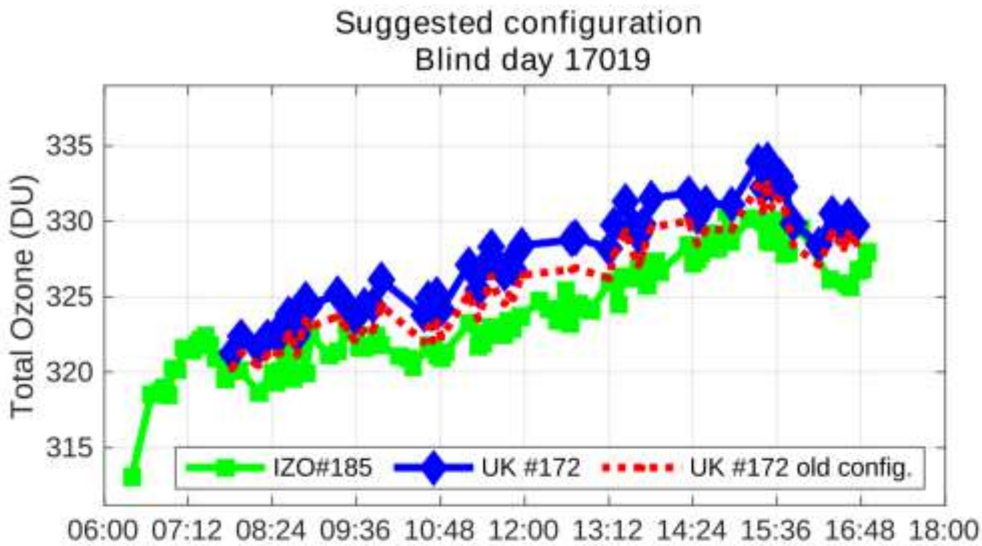
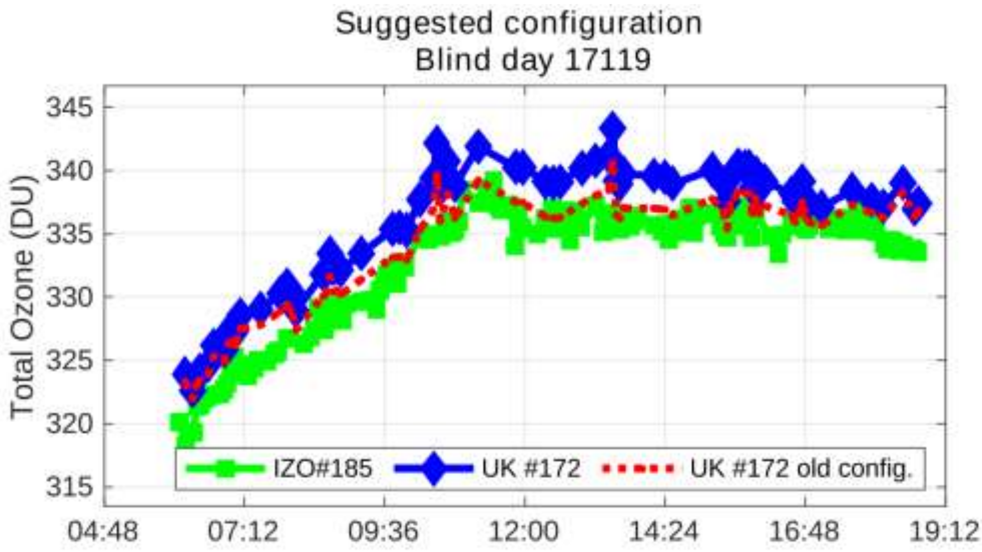
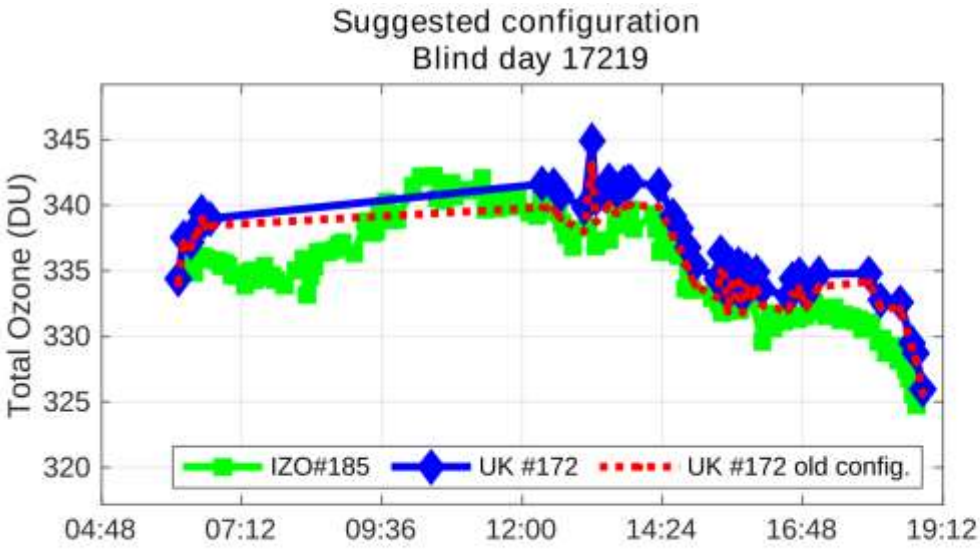
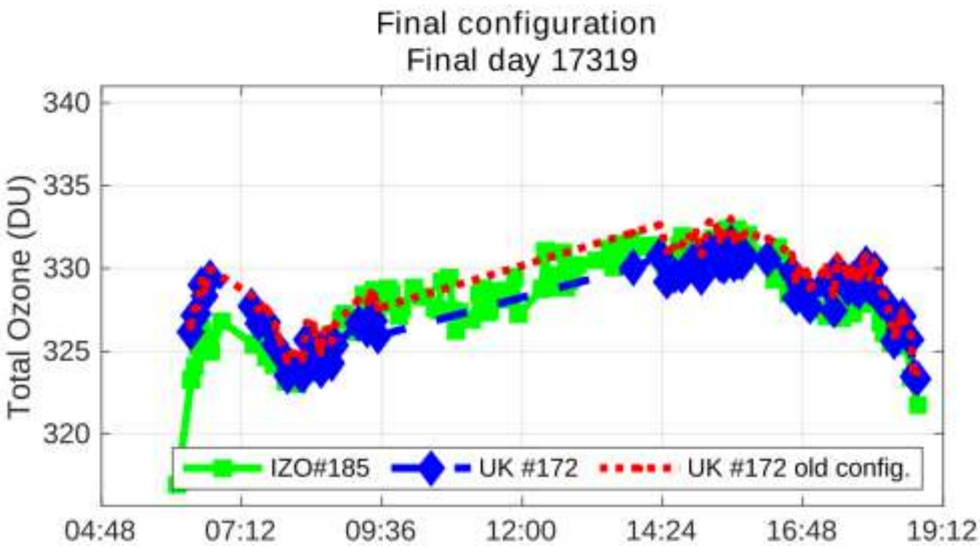


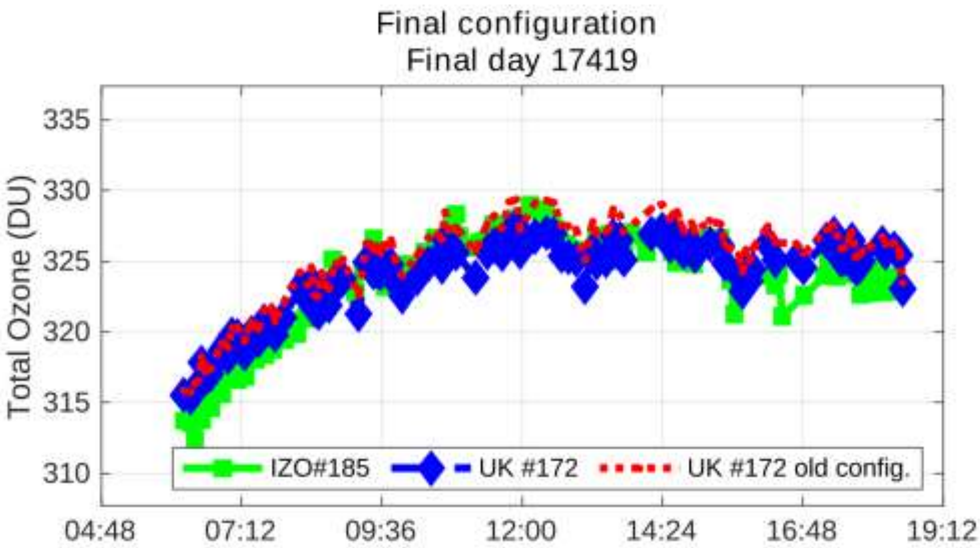
Figure 24. Overview of the intercomparison. Brewer UK #172 data were evaluated using final constants (blue circles)

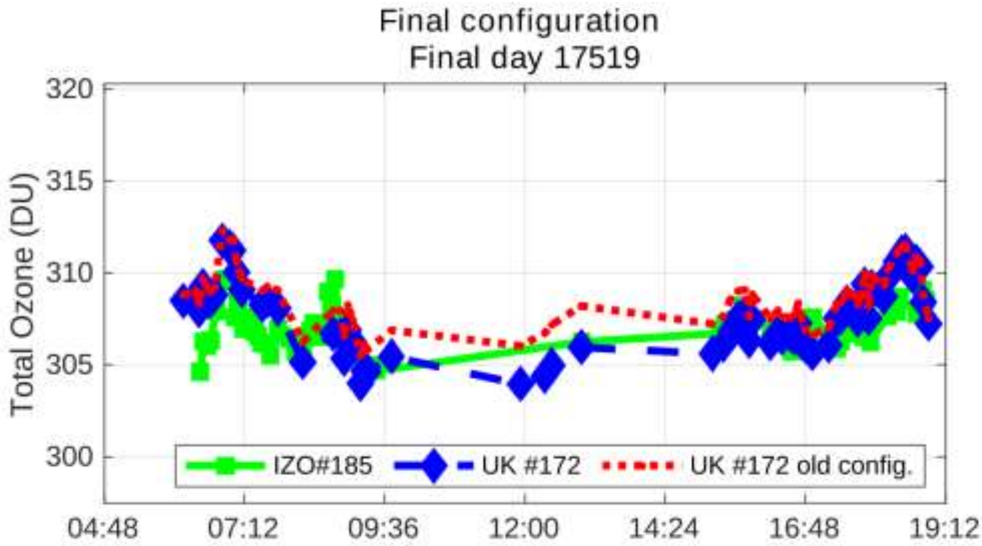


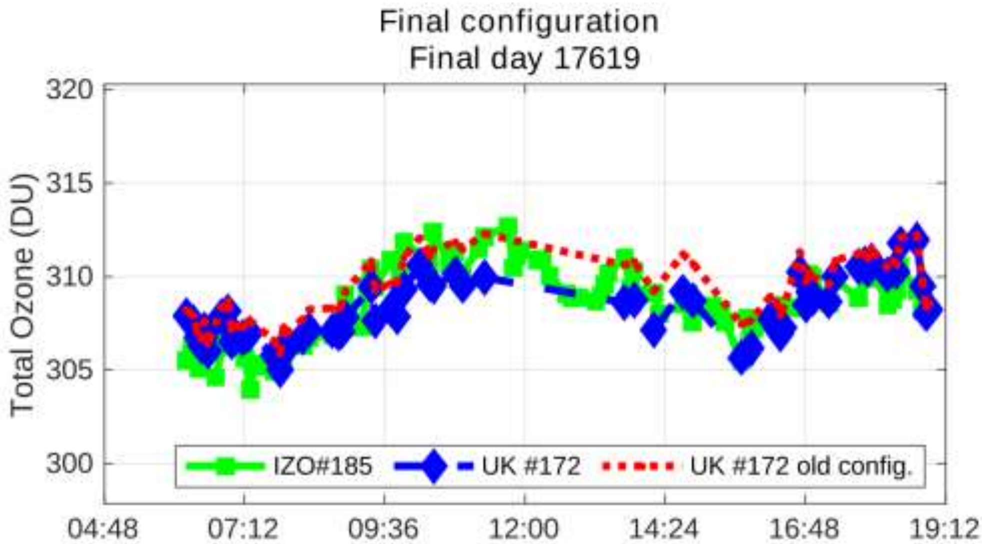


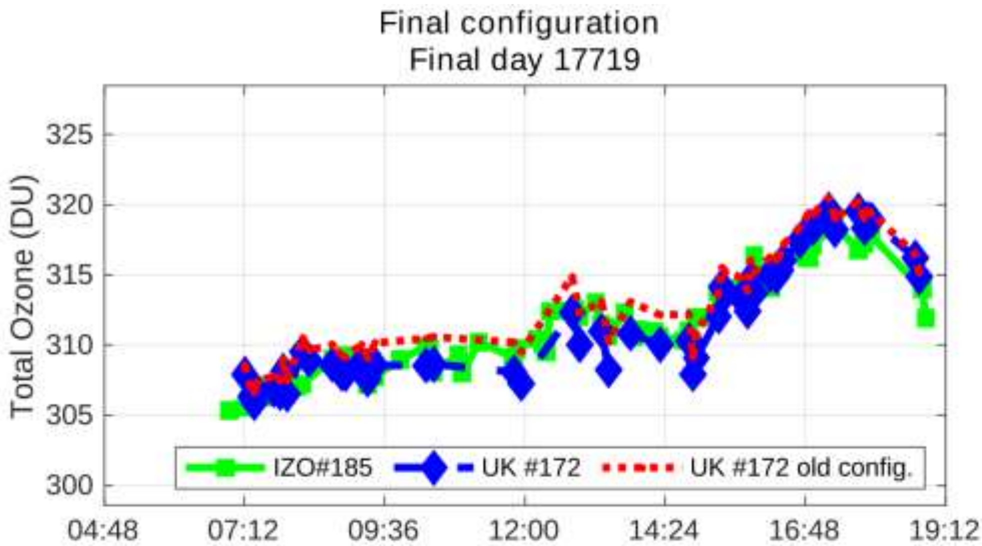

Suggested configuration
Blind day 17219
Total Ozone (DU)
345
340
335
330
325
320
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.

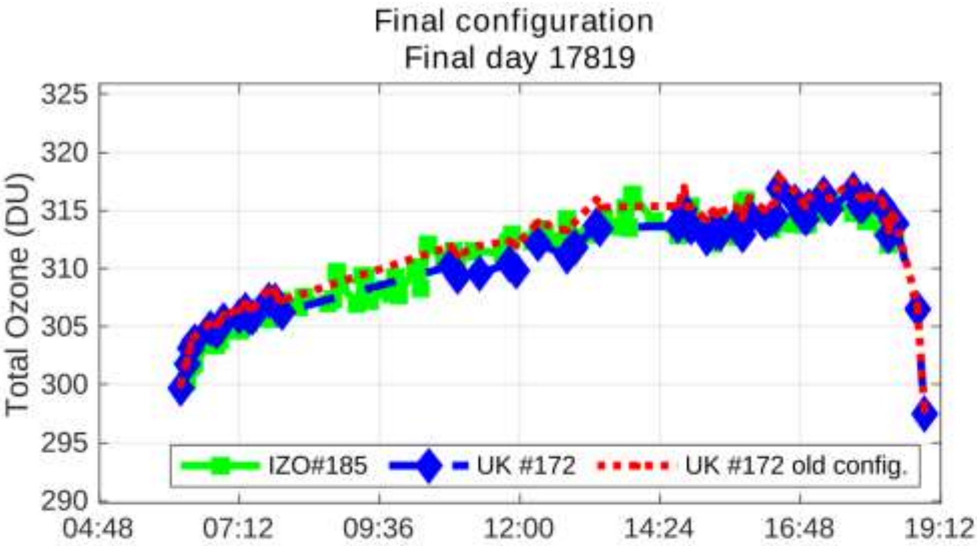

Final configuration
Final day 17319
Total Ozone (DU)
340
335
330
325
320
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.


Final configuration
Final day 17419
Total Ozone (DU)
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.

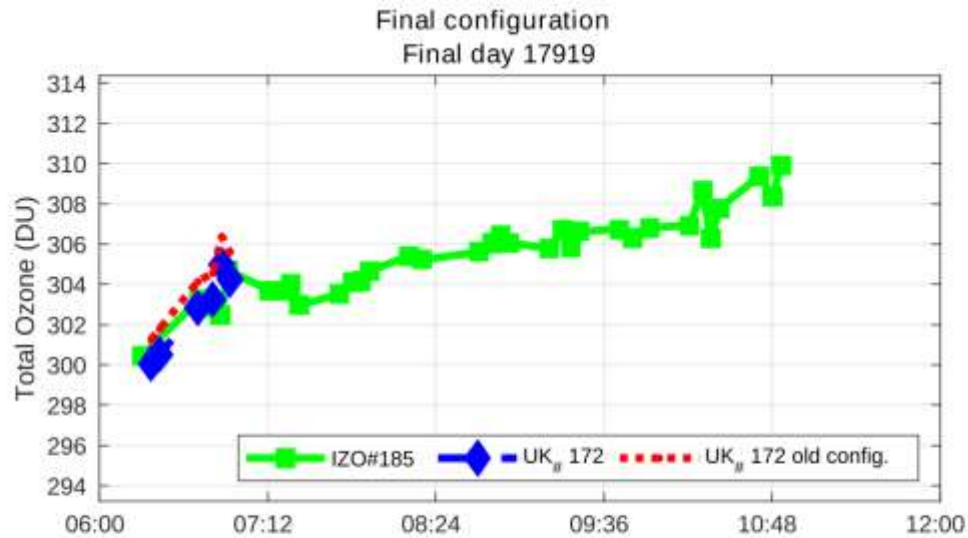

Final configuration
Final day 17519
Total Ozone (DU)
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.


Final configuration
Final day 17619
Total Ozone (DU)
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.



Final configuration
Final day 17819
Total Ozone (DU)
325
320
315
310
305
300
295
290
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
UK #172
UK #172 old config.



Final configuration
Final day 17919
Total Ozone (DU)
314
312
310
308
306
304
302
300
298
296
294
06:00
07:12
08:24
09:36
10:48
12:00
IZO#185
UK# 172
UK# 172 old config.

17. BREWER JAP#174

17.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer JAP#174 participated in the campaign from 17 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer JAP#174 correspond to Julian days 169 – 178.

The instrument did not require maintenance, so we used the same data set both to evaluate the initial status of the instrument and for final calibration purposes: 572 simultaneous DS ozone measurements taken from day 169 to 178.

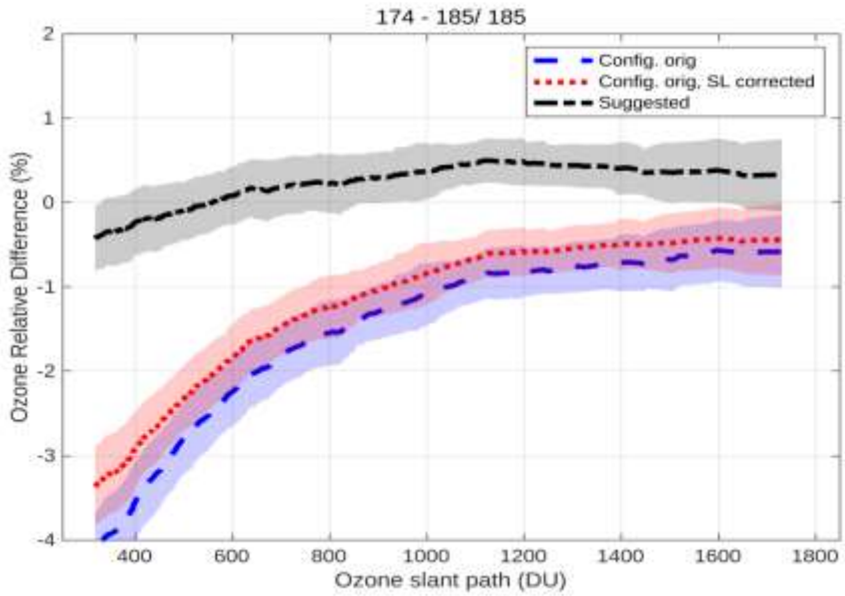


Figure 1. Mean DS ozone column percentage difference between Brewer JAP#174 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the whole campaign.

As shown in Figure 1, the current ICF (ICF20718.174, blue dashed line) produces ozone values with an average difference of approx. 1.5% with respect to the reference instrument. The application of the SL correction (red dotted line in Figure 1) does not produce a noticeable improvement.

The lamp test results from Brewer JAP#174 have been quite stable over the last 2 years, with some seasonal dependence. There was however a noticeable change in April 2019. During the campaign, the standard lamp ratios stabilized around values 596 and 1068 for R6 and R5, respectively (Figure 20 and 21).

Dead time (DT) shows a noticeable difference between the current and campaign values of approx. 3 ns, with its value changing from $2.8 \cdot 10^{-8}$ s to $2.5 \cdot 10^{-8}$ s in the final configuration suggested in the present campaign.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) show reasonable results, although analysis of CZ scans performed during the campaign show a small discrepancy between the nominal and calculated peak of the 296.728 nm line.

We did not detect any appreciable temperature dependence in the ozone or the standard lamp observations, which indicates the correct choice of the current temperature coefficients.

The neutral density filters did not show nonlinearity in the attenuation's spectral characteristics. We do not suggest the application of filter corrections.

The sun scan tests (SC) at the instrument's station before the campaign and those performed during the first days of the intercomparison, gave 287 for the cal step, a value 2 units lower than the current one of 289. The cal step was not updated during the campaign, and we suggest confirming the optimal cal step over the following months. We have kept the value of 289 in the final configuration file (ICF16919.174).

Without changes in the cal step, the dispersion tests confirm the current value of the ozone absorption coefficient (0.3388). This value should be checked again if the cal step is changed. In the final ICF, we have kept the current value of 0.3388.

Taking this into account, we suggest the following changes to the configuration of Brewer JAP#174.

17.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer JAP#174 have been quite stable over the last 2 years, but there was a noticeable change last April. The old R6 reference value was 605 and we suggest updating it to 596.
2. We suggest a new R5 reference value of 1068.
3. We suggest updating the DT to $2.5 \cdot 10^{-8}$ seconds, which is 3 units less than the value in the current configuration.
4. The cal step number was not updated during the campaign, but the sun scan tests performed both at the station and the campaign suggest a value 2 units lower than the one currently in use (289). We suggest confirming the optimal cal step number in the following months. We have kept the value of 289 in the final ICF.
5. Without changes to the cal step, the current ozone absorption coefficient is confirmed. We have kept the value of 0.3388 in the final ICF.
6. Finally, we suggest updating the ETC value from 1873 to 1826.

17.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/174/ICF16919.174

Calibration report
https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1905222212

Calibration reports detailed
Historic and instrumental
http://rbcce.aemet.es/svn/campaigns/are2019/latex/174/html/cal_report_174a1.html

Temperature & filter
http://rbcce.aemet.es/svn/campaigns/are2019/latex/174/html/cal_report_174a2.html

Wavelength
http://rbcce.aemet.es/svn/campaigns/are2019/latex/174/html/cal_report_174b.html

ETC transfer
http://rbcce.aemet.es/svn/campaigns/are2019/latex/174/html/cal_report_174c.html

17.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

17.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp has been quite stable over the last two years, although it seems to have seasonal dependence. There is however a noticeable discontinuity, most visible in the R6 values shown in Figure 2, which took place in the middle of April 2019. All these changes can also be observed in the standard lamp's intensity shown in Figure 4.

During the campaign, mean values of approx. 596 and 1068 were found for R6 and R5, respectively. Note this R6 reference value is only 9 units less that the reference value in the current configuration.

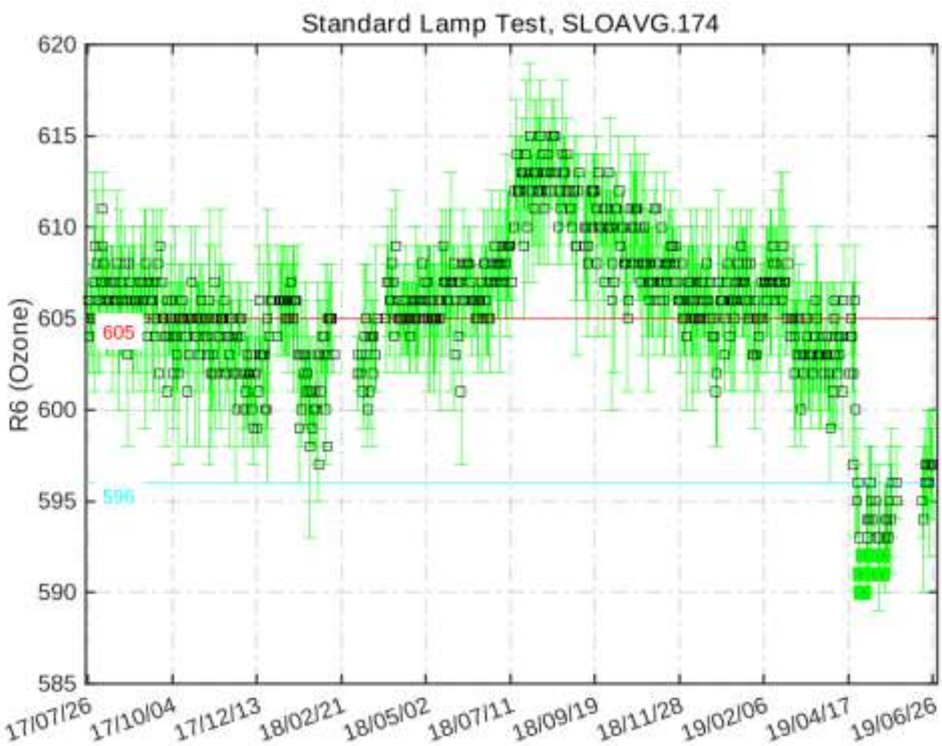


Figure 2. Standard lamp test – R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

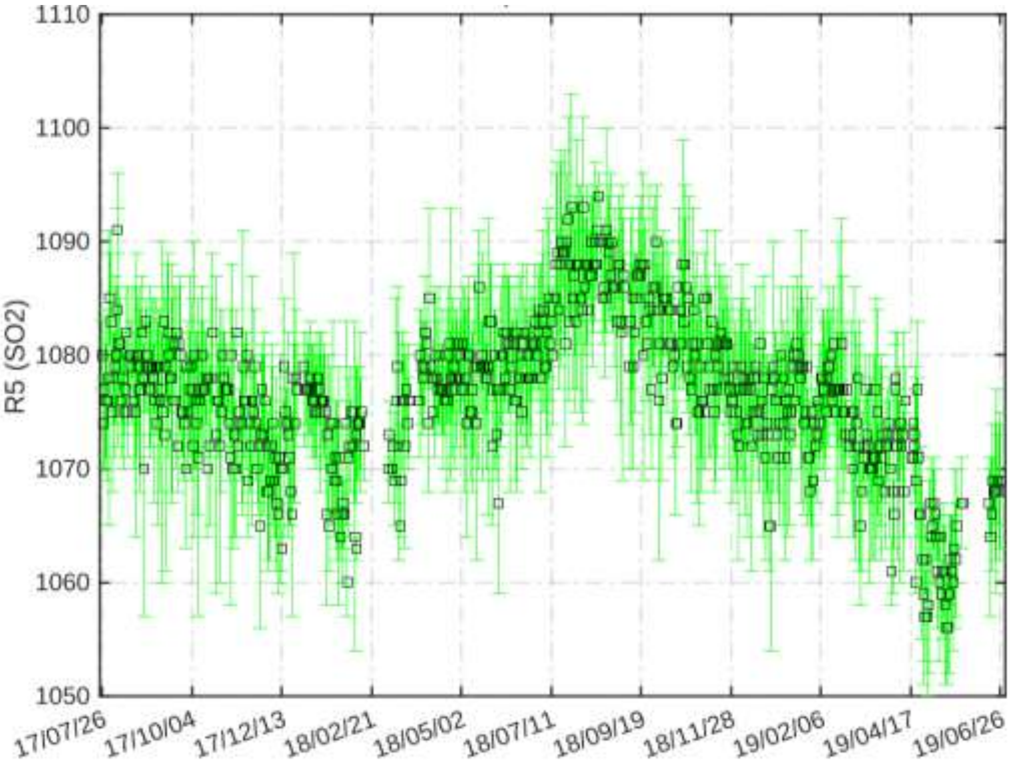


Figure 3. Standard lamp test – R5 sulphur dioxide ratios

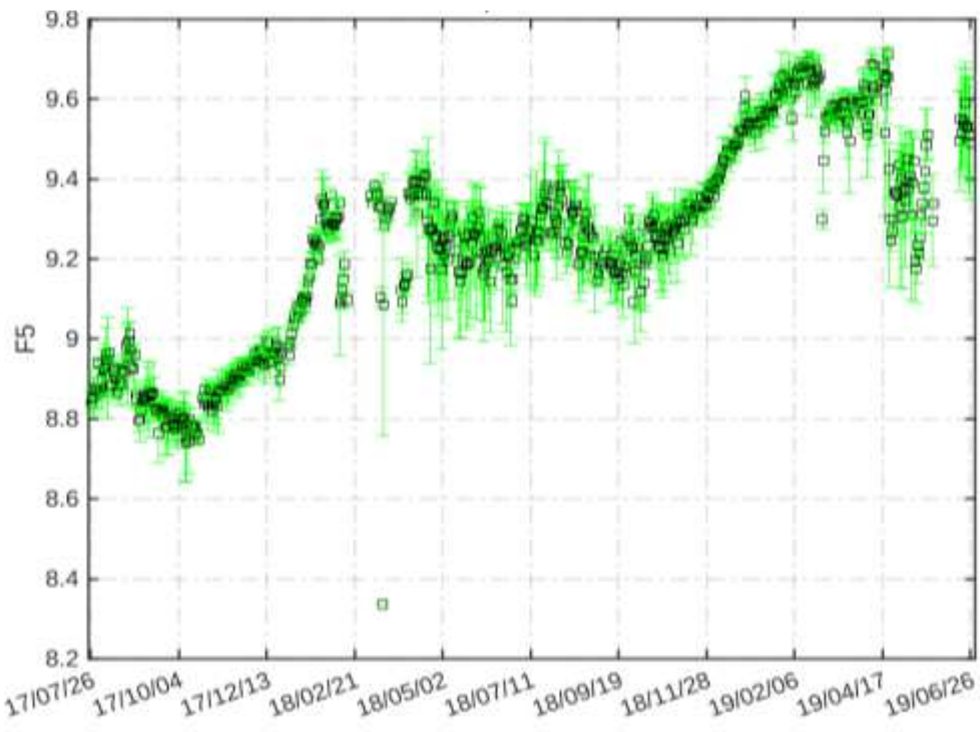


Figure 4. SL intensity for slit five

17.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, Dead time decreased steadily from the middle of 2017 until early 2019. This probably explains why the current DT reference value of $2.8 \cdot 10^{-8}$ seconds is noticeably larger than the value recorded during the calibration period ($2.5 \cdot 10^{-8}$ s). We have used this latter value in the new ICF.

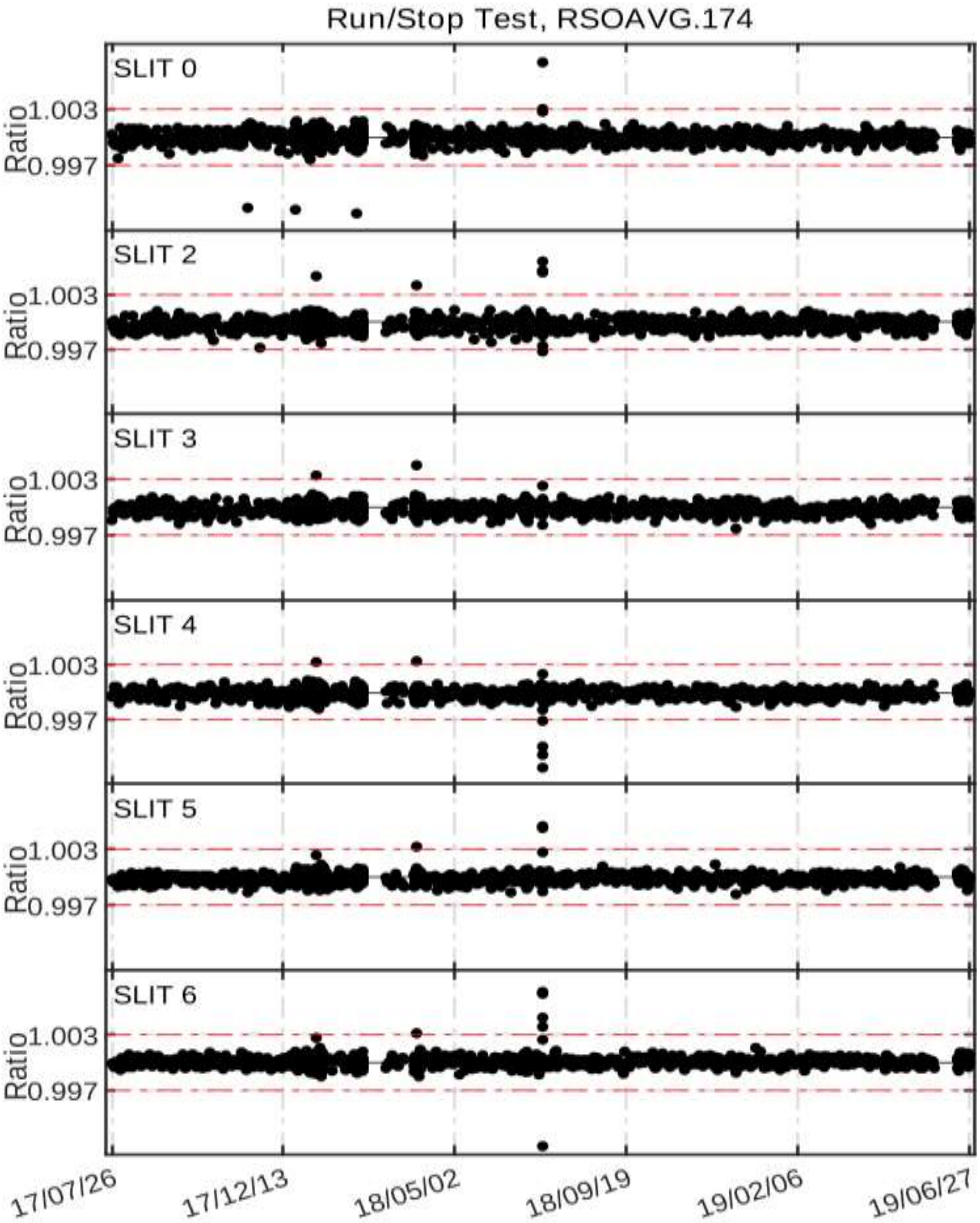


Figure 5. Run/stop test

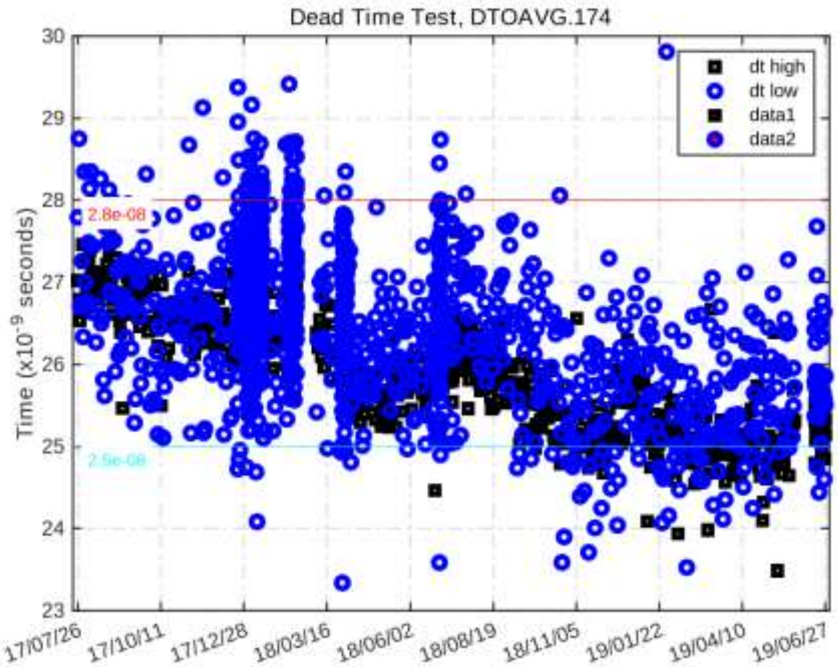


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

17.2.3. Analogue test

Figure 7 shows that, despite some noise, high voltage has remained almost constant at approx. 1128 over the last two years. Furthermore, analogue test values were within the test tolerance range.

However, some seasonal cycles in the +5 voltage power supply can be observed. This could show that the seasonal cycle observed in the SL ratios (see Sec. 1.2.1) is not related to the instrument's response.

Analogue Printout Log, APOAVG.174

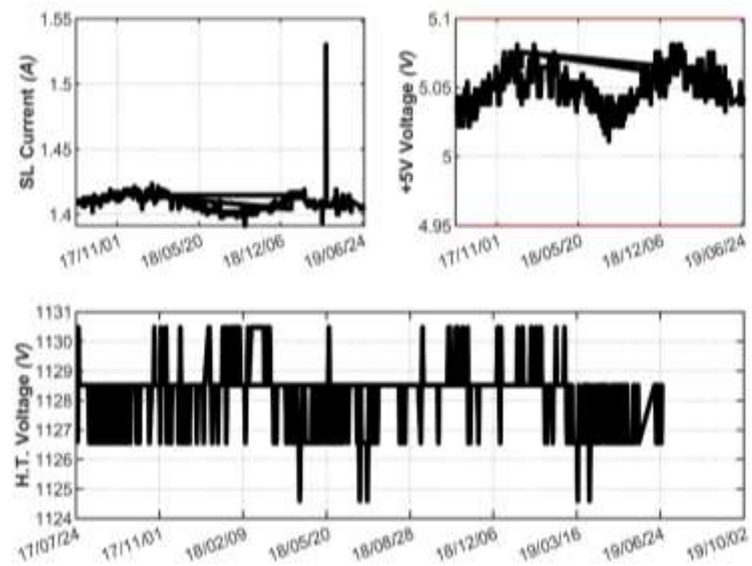


Figure 7. Analogue voltages and intensity

17.2.4. Mercury lamp test

Figure 8 shows the intensity of the Hg lamp, plotted together with the instrument's temperature. Some correlation between both variables seems clear and, furthermore, it follows the same seasonal trend already observed in the standard lamp (Sec. 1.2.1).

During the campaign, however, no noticeable internal mercury lamp intensity events was observed.

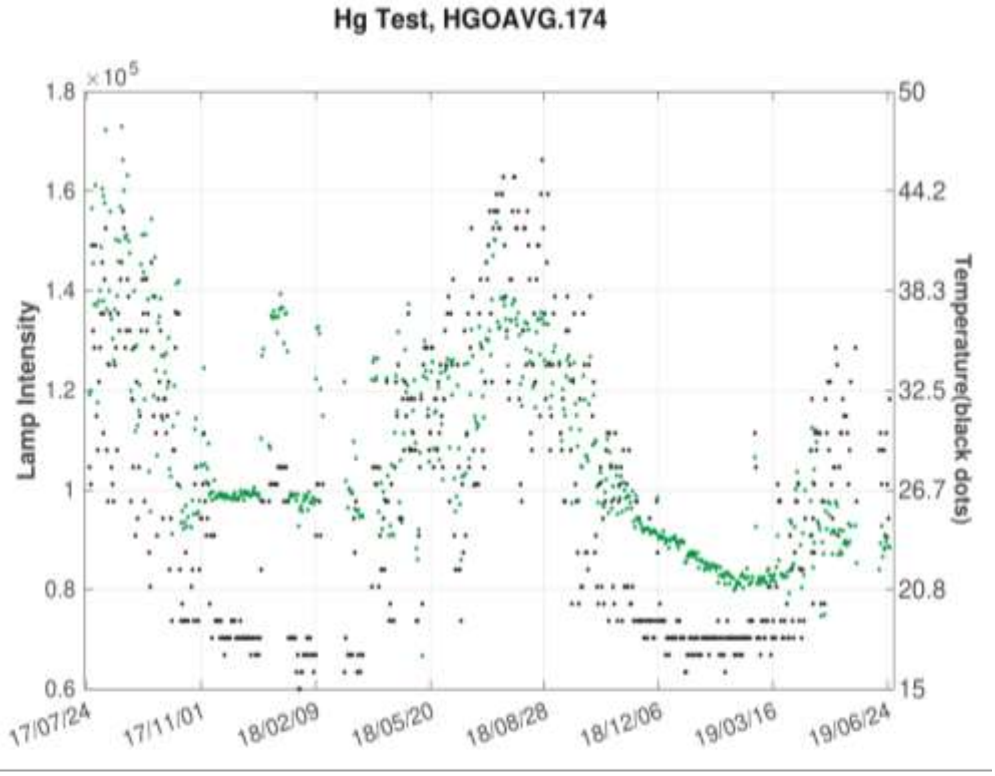


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

17.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm.

Analysis of CZ scans performed on Brewer JAP#174 during the campaign showed a discrepancy between the nominal and calculated line peak, which is just slightly outside the tolerance limits, especially for the 296.728 nm line (see Figure 9a). With regard to the slit function's width, results were good, with a FWHM lower than 0.65 nm.

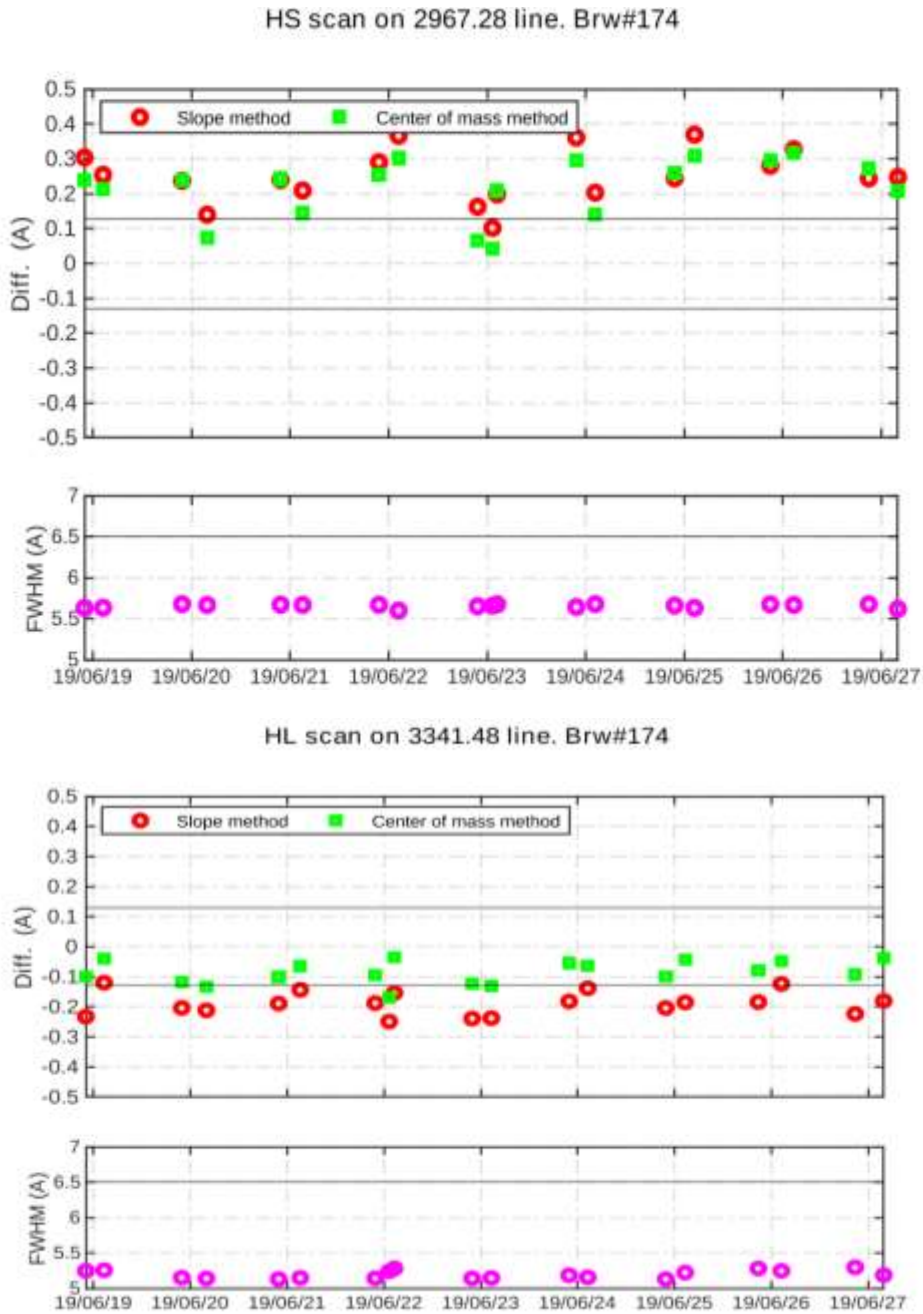


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

17.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of Brewer JAP#174 CI scans performed during the campaign relative to scan CI17819.174. As can be observed, lamp intensity varied with respect to the reference spectrum by less than a 2%. The exception is one measurement at the beginning of the campaign, but this is most likely the result of some error. Overall, this is a normal behaviour for the standard lamp.

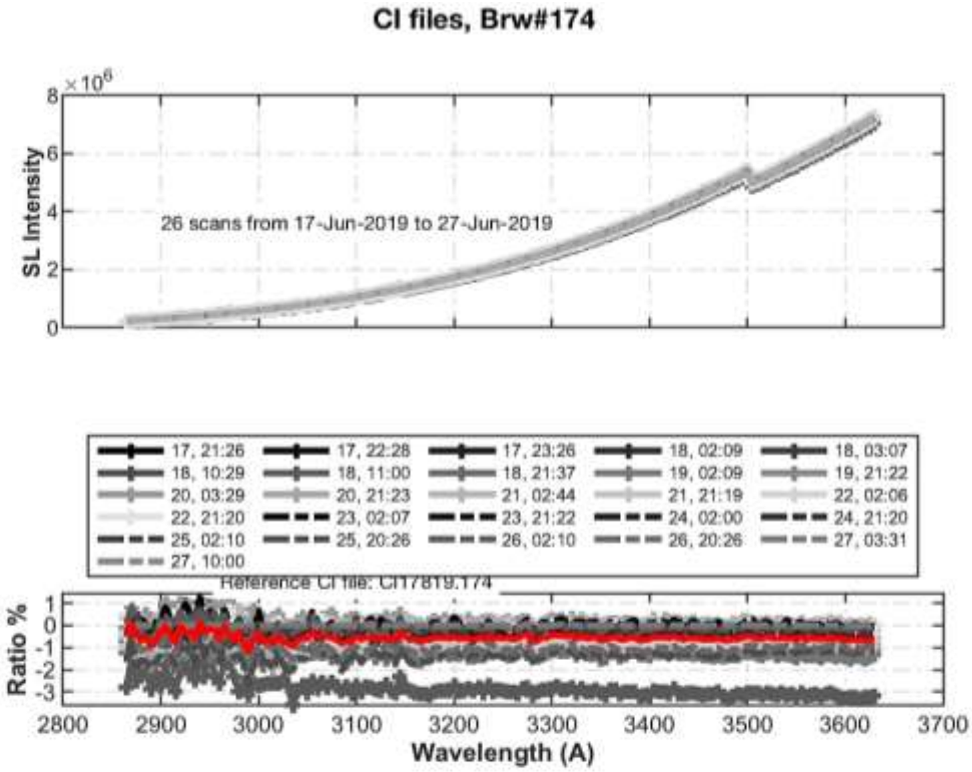


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

17.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 with data from the present campaign (temperature range from 19 °C to 32 °C), the current temperature coefficients did not improve the behaviour of the instrument. However, the temperature dependence of Brewer JAP#174 is within reasonable limits (less than 5 SL units per 10 °C). The values of the coefficients, both current and new, are summarized in Table 1.

We have also extended our analysis using the data recorded in the last two years. As shown in Figures 12 and 13, the current and new coefficients perform similarly. The new coefficients could improve the temperature behaviour of the instrument, but the current ones perform within acceptable limits, so we have decided to keep the current coefficients in the final ICF.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	10.4312	10.3785	10.3761	10.1856	10.0785
Calculated	0.0000	0.2000	0.1900	-0.3900	-0.4300
Final	10.4312	10.3785	10.3761	10.1856	10.0785

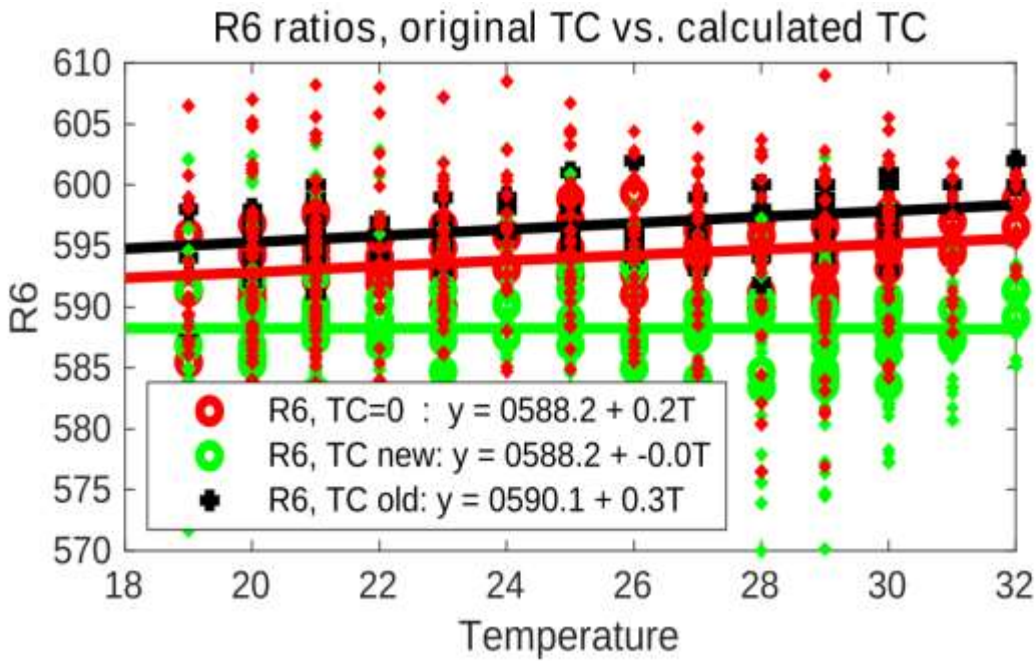


Figure 11. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond with the measurements obtained during the campaign.

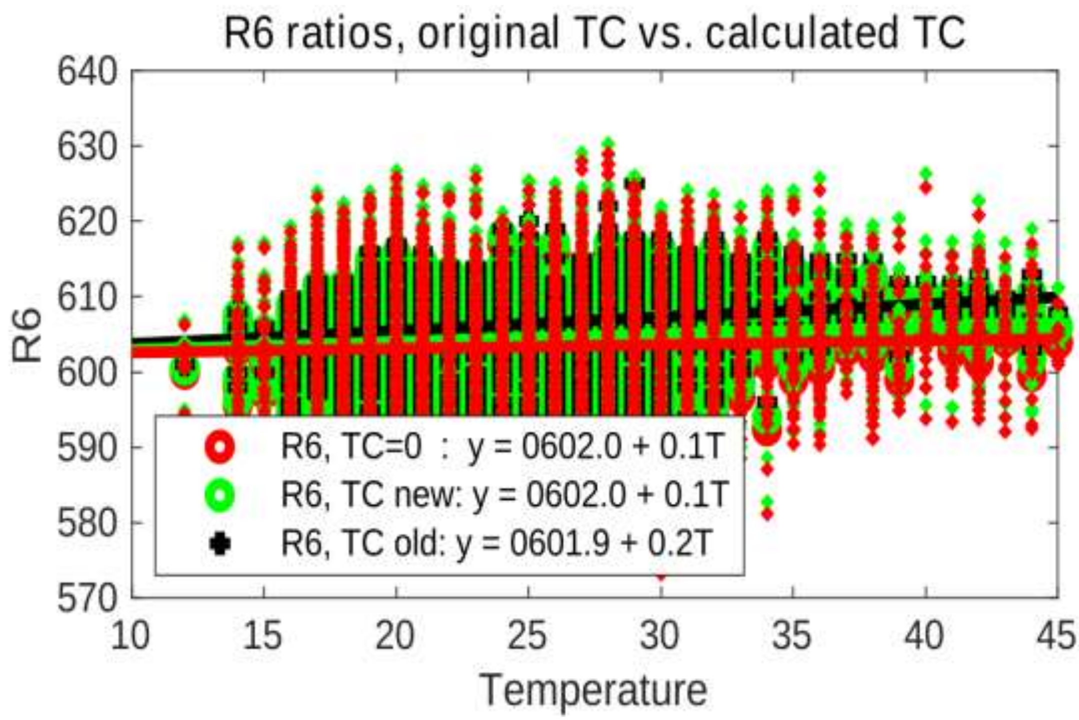


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

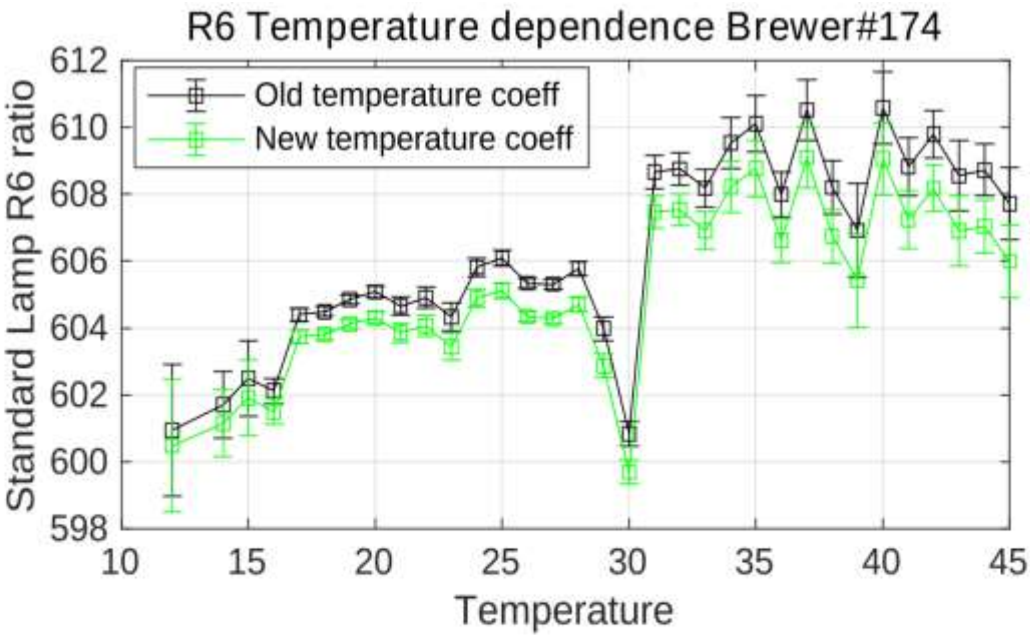


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted the R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

17.4. ATTENUATION FILTER CHARACTERIZATION

17.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 57 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Table 2 shows that only ND#2 and ND#4 present a correction factor higher than 5 units, but the median value of the correction is still just 6. Note also that the median and mean values for ND#4 are quite different, which indicates that the data is quite noisy. Furthermore, Figure 14 shows that in the change from ND#3 to ND#4 alone, there is difference larger than 10%. However, this result must be taken with caution because of noise in the data from ND#4. Overall, no correction factor that takes into account the non-linearity of ND filters is therefore suggested.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals were calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-3	-6	-2	-6	-3
ETC Filt. Corr. (mean)	-5.1	-7.2	-7.4	-1.6	-5
ETC Filt. Corr. (mean 95% CI)	[-8 -2.1]	[-11.2 -3.1]	[-10.3 -4.5]	[-5.4 2.7]	[-8.5 -1.5]

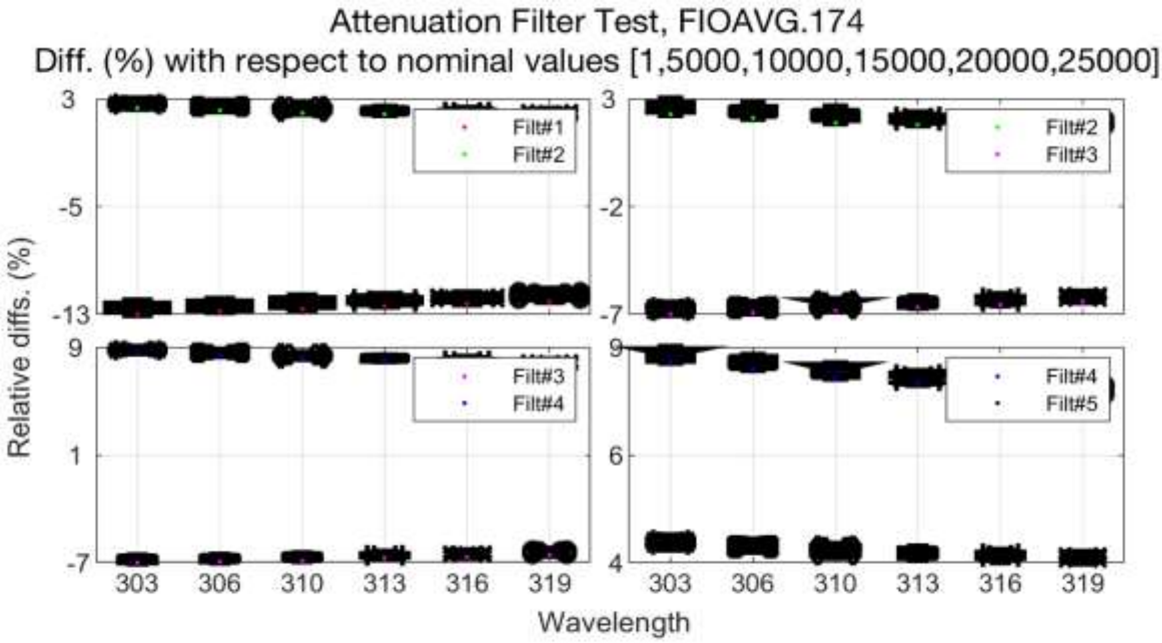


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

17.5. WAVELENGTH CALIBRATION

17.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 6 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1000 DU were carried out, (see Figure 16). The calculated cal step number (CSN) was 2 steps lower than the value in the current configuration: 287 vs. 289. SC tests performed at the station before the campaign also provided a CSN of 287. These results seem to indicate that the CSN should be updated, but this was not done during the campaign. We suggest confirming the optimal CSN in the following months. We have kept the value of 289 in the final ICF.

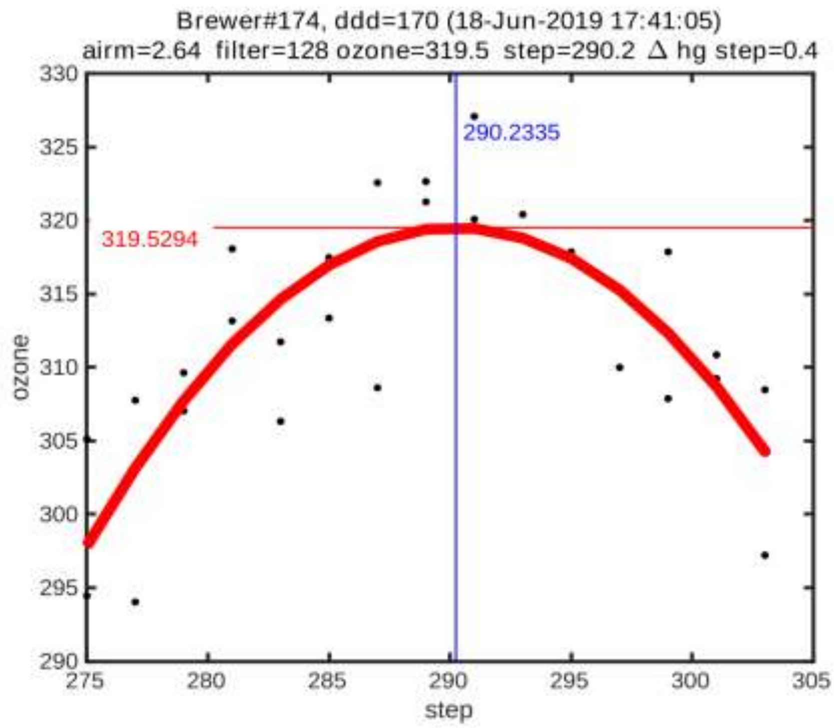


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

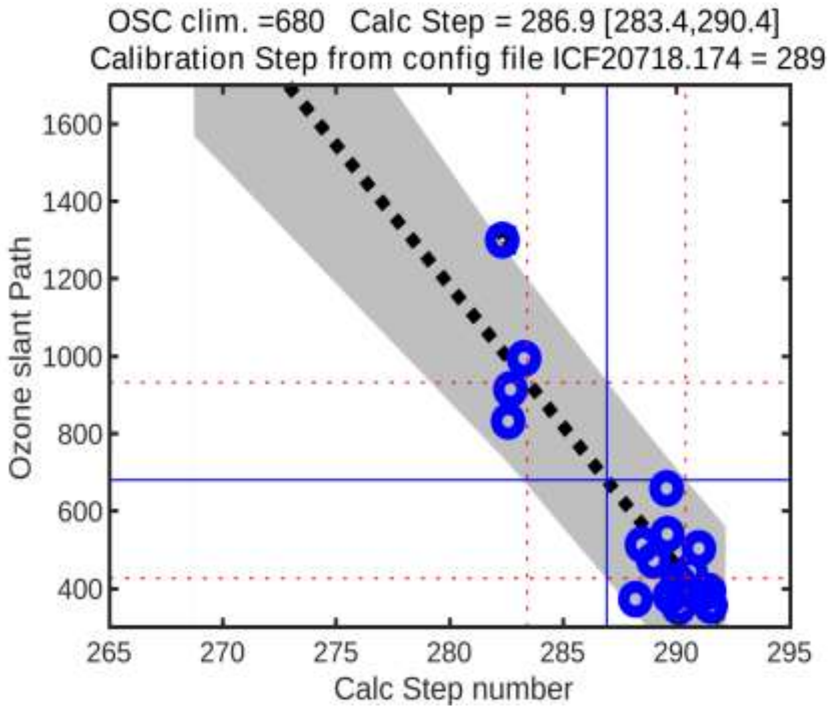


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

17.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

With no changes to the cal step, the current ozone absorption coefficient of 0.3388 is confirmed by the dispersion tests carried out during the campaign. We have kept this value (0.3388) in the final ICF of the campaign.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	289	0.3388	2.3500	1.1405
15-May-2019	289	0.3400	3.1469	1.1449
23-Jun-2019	289	0.3383	3.1428	1.1399
Final	289	0.3388	2.3500	1.1405

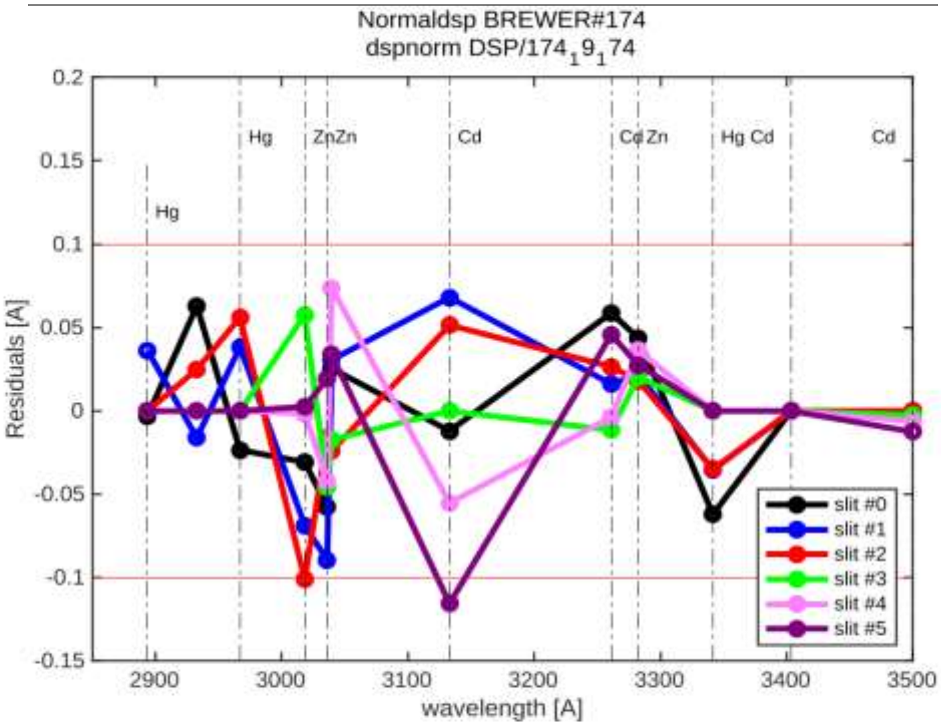


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 288	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.76	3062.93	3100.49	3134.92	3167.98	3200.09
Res(A)	5.6051	5.5766	5.4308	5.5909	5.5215	5.4443
O3abs(1/cm)	2.6042	1.7816	1.0049	0.67662	0.37505	0.29285

step= 288	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
Ray abs(1/cm)	0.50517	0.48327	0.45848	0.43716	0.41787	0.40015
SO2abs(1/cm)	3.4701	5.6172	2.4066	1.9152	1.0543	0.60775
step= 289	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.83	3063.01	3100.57	3134.99	3168.05	3200.16
Res(A)	5.605	5.5765	5.4307	5.5908	5.5214	5.4442
O3abs(1/cm)	2.6017	1.7799	1.0047	0.67625	0.37509	0.29231
Ray abs(1/cm)	0.50512	0.48322	0.45843	0.43712	0.41783	0.40012
SO2abs(1/cm)	3.4533	5.6389	2.4149	1.9036	1.0555	0.6054
step= 290	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.91	3063.08	3100.64	3135.06	3168.12	3200.23
Res(A)	5.605	5.5764	5.4306	5.5907	5.5213	5.4441
O3abs(1/cm)	2.5991	1.7782	1.0044	0.67589	0.37516	0.29174
Ray abs(1/cm)	0.50507	0.48317	0.45839	0.43708	0.41779	0.40008
SO2abs(1/cm)	3.4366	5.6605	2.4232	1.8921	1.0568	0.60307
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
288	0.33935	8.4722	3.1338	1.1436	0.35032	0.34161
289	0.33826	8.4696	3.1428	1.1399	0.34927	0.34053
290	0.33702	8.4671	3.1519	1.1361	0.34817	0.3394

17.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1688. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 289	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.605	5.5765	5.4307	5.5908	5.5214	5.4442
O3abs(1/cm)	2.6017	1.7799	1.0047	0.67625	0.37509	0.29231
Ray abs(1/cm)	0.50512	0.48322	0.45843	0.43712	0.41783	0.40012
step= 1688	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.5017	5.44	5.3182	5.4822	5.3846	5.286
O3abs(1/cm)	0.67884	0.3943	0.29291	0.12169	0.060577	0.033472
Ray abs(1/cm)	0.4379	0.42021	0.40012	0.38276	0.36702	0.35254

17.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 10 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

17.6.1. Initial calibration

For the evaluation of initial status of Brewer JAP#174, we used the period from days 169 to 178 which correspond with 572 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produce an ozone value with an average difference of approx. 1.5% with respect to the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve noticeably.

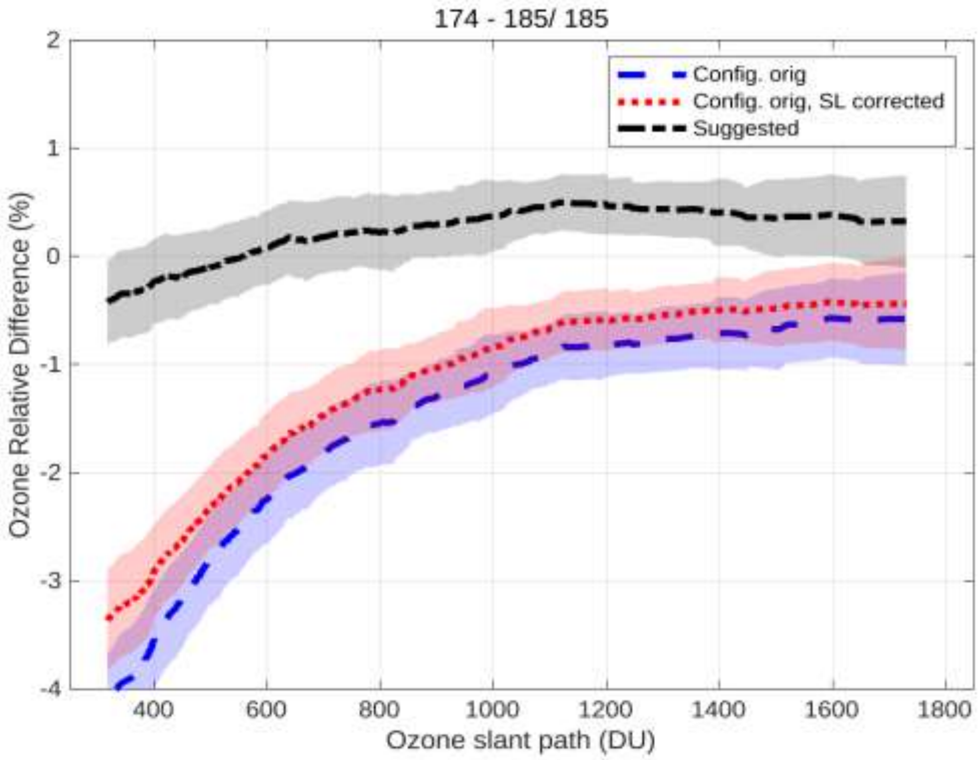


Figure 18. Mean direct sun ozone column percentage difference between Brewer JAP#174 and Brewer IZO#185 as a function of ozone slant path

17.6.2. Final calibration

A new ETC value was calculated (see Figure 19) using the 572 simultaneous direct sun measurements from days 169 to 178. The new value of 1826 is approximately 50 units lower than the current ETC (1873). Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (596 for R6). We have updated the calibration constants in ICF16919.174 provided. Of course, the new ETC has been calculated taking into account the new suggested dead time of $2.5\cdot 10^{-8}$ s. The value of the ozone absorption coefficient (0.3388) remains unchanged from the previous configuration.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 6, the agreement between the 1P and 2P methods is only slightly outside the maximum tolerance limit of 10 ETCs.

Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

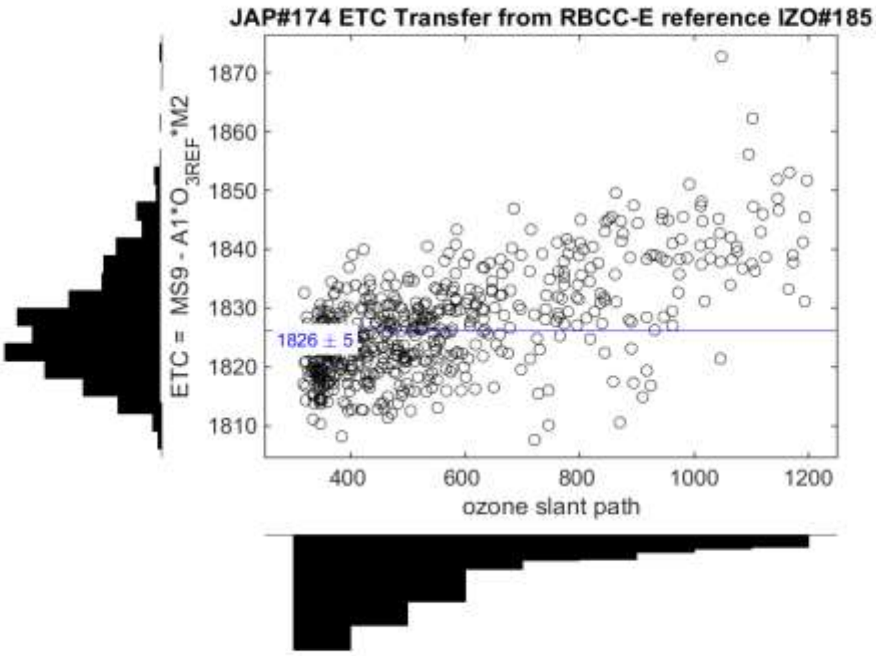


Figure 19. Mean direct sun ozone column percentage difference between Brewer JAP#174 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1200	1826	1814	3388	3410
full OSC range	1825	1811	3388	3417

Table 7. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#174*	*O3 std*	*%(174–185)/185*	*O3(*) #174*	*O3std*	*(*)%(174–185)/185*
19-Jun-2019	170	324.2	3	64	312.6	3.3	-3.6	323	3.1	-0.4
20-Jun-2019	171	332.7	4.8	100	323.5	4.2	-2.8	332.2	4.3	-0.2
21-Jun-2019	172	335.1	3.4	93	326.6	2.9	-2.5	335.2	3.1	0
22-Jun-2019	173	329.3	1.9	36	322.2	1	-2.2	329.5	1.6	0.1
23-Jun-2019	174	323.4	3.3	87	314.6	2.4	-2.7	323.5	2.7	0
24-Jun-2019	175	307.2	1.1	65	300	3	-2.3	307.4	1.3	0.1
25-Jun-2019	176	308.6	2	63	299.9	2.8	-2.8	308.5	1.6	0
26-Jun-2019	177	311.9	3.8	49	302.1	5.7	-3.1	311.1	4.4	-0.3
27-Jun-2019	178	NaN	NaN	0	299.9	1	NaN	306.7	1.7	NaN

17.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 596 for R6 (Figure 20) and 1068 for R5 (Figure 21).

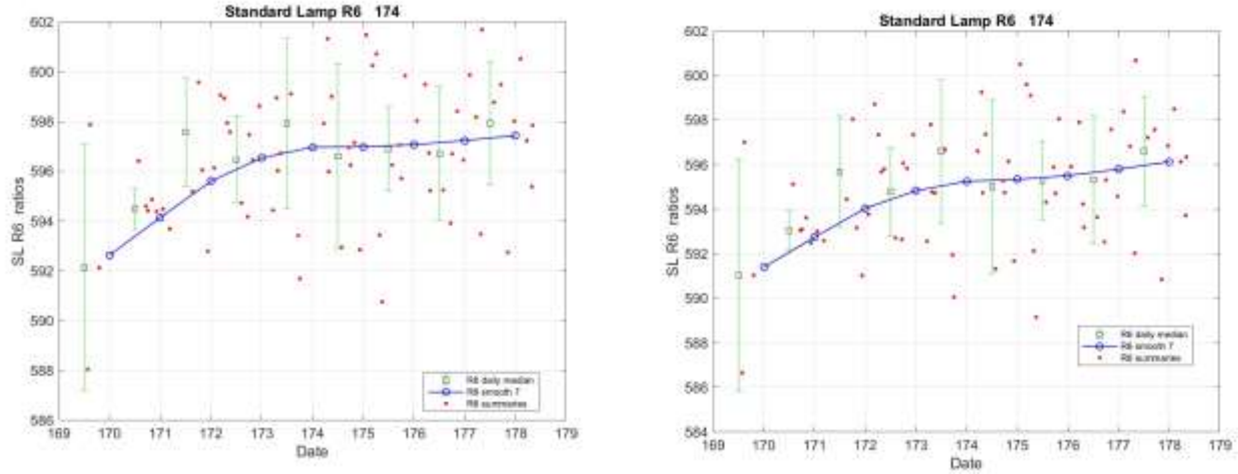


Figure 20. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

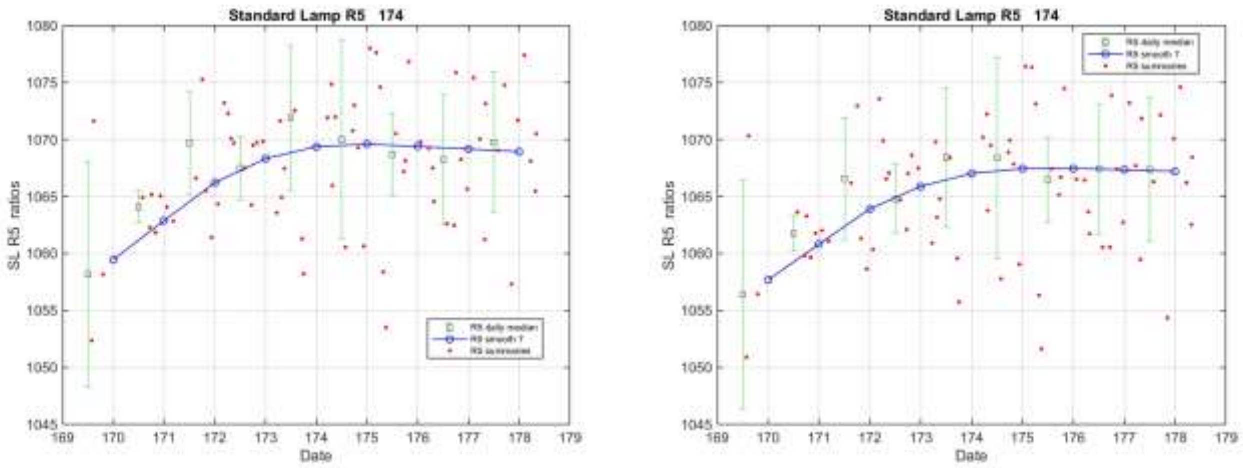


Figure 21. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

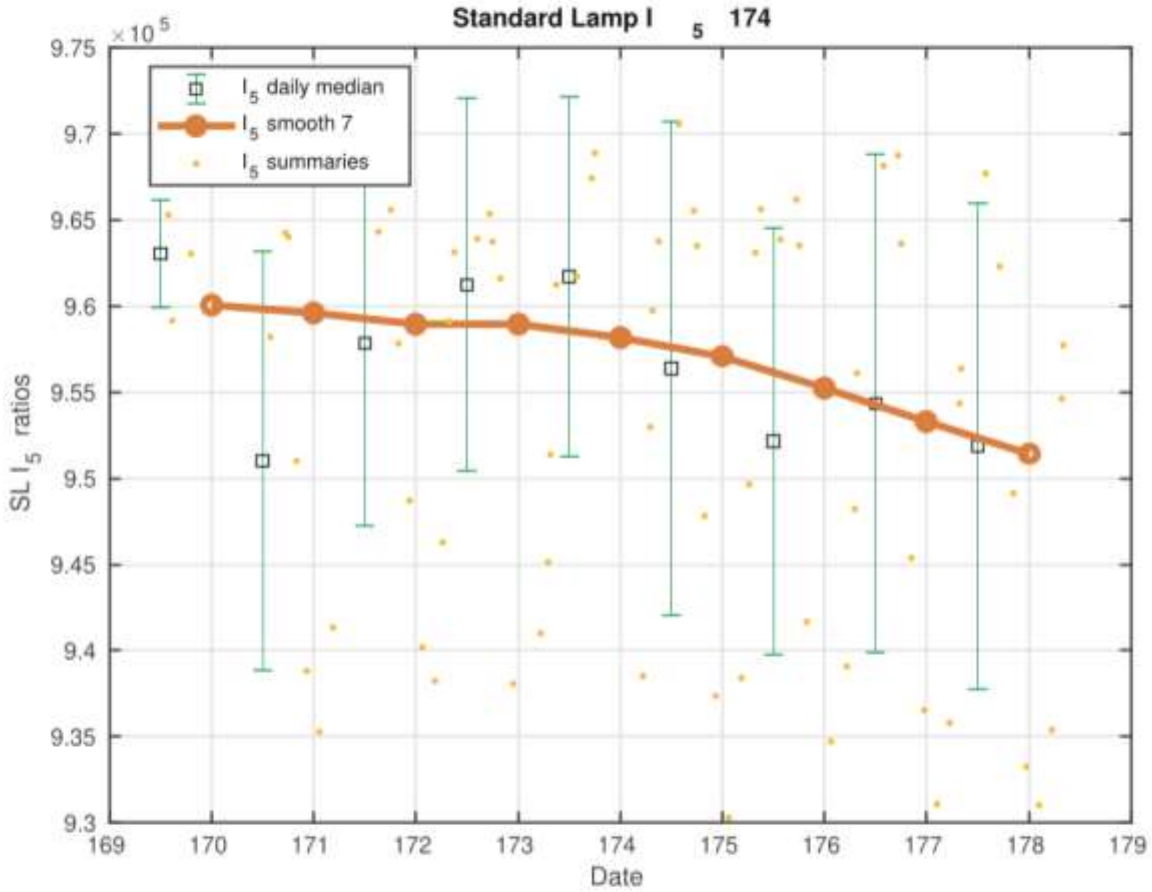


Figure 22. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

17.7. CONFIGURATION

17.7.1. Instrument constant file

	Initial (ICF20718.174)	*Final (ICF16919.174)*
o3 Temp coef 1	10.4312	10.4312
o3 Temp coef 2	10.3785	10.3785
o3 Temp coef 3	10.3761	10.3761
o3 Temp coef 4	10.1856	10.1856
o3 Temp coef 5	10.0785	10.0785
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3388	0.3388
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1405	1.1405
ETC on O3 Ratio	1873	1826

	Initial (ICF20718.174)	*Final (ICF16919.174)*
ETC on SO2 Ratio	821	821
Dead time (sec)	2.8e-08	2.5e-08
WL cal step number	289	289
Slitmask motor delay	14	14
Umkehr Offset	1682	1682
ND filter 0	0	0
ND filter 1	4375	4375
ND filter 2	10260	10260
ND filter 3	14100	14100
ND filter 4	21600	21600
ND filter 5	25900	25900
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	-183	-183
Mic #2 Offset	46	46
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2518	2518
Grating Slope	1.001	1.001
Grating Intercept	-4	-4

	Initial (ICF20718.174)	*Final (ICF16919.174)*
Micrometre Zero	2469	2469
Iris Open Steps	260	260
Buffer Delay (s)	0.2	0.2
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2228	2228

17.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#174*	*O3 std*	*%diff*	*(*)O3#174*	*O3 std*	*(*)%diff*
170	1000> osc> 700	321	0.8	3	316	0.5	-1.7	320	0.7	-0.3
170	700> osc> 400	324	3.8	22	316	4.2	-2.4	323	4.1	-0.3
170	osc< 400	324	2.5	34	314	2.3	-3.1	324	2.3	-0.3
171	osc> 1500	324	9.0	3	323	7.9	-0.1	326	8.1	0.7
171	1500> osc> 1000	328	6.3	12	326	6.6	-0.7	329	6.6	0.3
171	1000> osc> 700	330	6.0	22	326	6.0	-1.1	331	6.0	0.3
171	700> osc> 400	332	3.8	46	324	3.6	-2.4	332	3.6	-0.1
171	osc< 400	336	1.3	26	325	1.4	-3.4	335	1.4	-0.4
172	1500> osc> 1000	333	3.4	15	331	3.3	-0.6	334	3.3	0.4
172	1000> osc> 700	333	1.8	17	330	2.7	-1.0	334	2.7	0.3
172	700> osc> 400	334	2.6	41	327	2.5	-2.1	334	2.5	0.0
172	osc< 400	339	2.0	26	329	2.3	-3.1	338	2.4	-0.3
173	osc> 1500	319	3.4	2	318	3.5	-0.3	321	3.6	0.5
173	1500> osc> 1000	325	1.2	9	323	0.6	-0.6	327	1.0	0.4
173	1000> osc> 700	328	0.6	9	324	0.8	-1.2	329	0.7	0.2
173	700> osc> 400	330	1.6	21	323	0.6	-2.1	330	1.2	0.0
173	osc< 400	332	0.0	1	324	0.0	-2.4	333	0.0	0.3
174	osc> 1500	314	0.0	1	312	0.0	-0.6	314	0.0	0.1

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#174*	*O3 std*	*%diff*	*(*)O3#174*	*O3 std*	*(*)%diff*
174	1500> osc> 1000	319	4.6	10	317	4.9	-0.5	320	5.0	0.6
174	1000> osc> 700	320	3.6	18	317	3.2	-1.0	322	3.3	0.4
174	700> osc> 400	323	2.0	40	316	1.5	-2.2	324	1.9	0.1
174	osc< 400	326	1.2	26	316	1.4	-3.3	325	1.4	-0.4
175	osc> 1500	308	0.0	1	305	0.0	-1.0	308	0.0	-0.3
175	1500> osc> 1000	307	1.1	13	306	1.6	-0.4	309	1.4	0.7
175	1000> osc> 700	307	1.3	10	304	1.5	-1.1	308	1.2	0.3
175	700> osc> 400	307	1.1	40	300	1.4	-2.1	307	1.0	0.1
175	osc< 400	307	0.4	3	297	2.2	-3.2	305	1.5	-0.4
176	osc> 1500	308	1.4	4	306	1.1	-0.7	308	1.0	0.1
176	1500> osc> 1000	308	2.2	7	306	2.1	-0.6	309	2.1	0.4
176	1000> osc> 700	308	2.2	10	304	2.0	-1.3	308	1.9	0.1
176	700> osc> 400	308	1.6	26	301	1.5	-2.2	308	1.0	0.0
176	osc< 400	310	1.4	22	300	1.4	-3.2	309	1.4	-0.2
177	osc> 1500	314	0.0	2	313	0.1	-0.3	316	0.0	0.5
177	1000> osc> 700	312	5.8	8	307	6.5	-1.5	312	6.3	0.0
177	700> osc> 400	313	4.1	22	306	4.8	-2.3	313	4.4	-0.1
177	osc< 400	310	1.4	16	299	2.0	-3.6	309	1.6	-0.5
178	1500> osc> 1000	302	1.1	3	NaN	NaN	NaN	302	1.3	-0.2
178	1000> osc> 700	304	0.9	4	NaN	NaN	NaN	305	0.6	0.3
178	700> osc> 400	307	1.2	10	NaN	NaN	NaN	308	1.1	0.1

17.9. APPENDIX: SUMMARY PLOTS

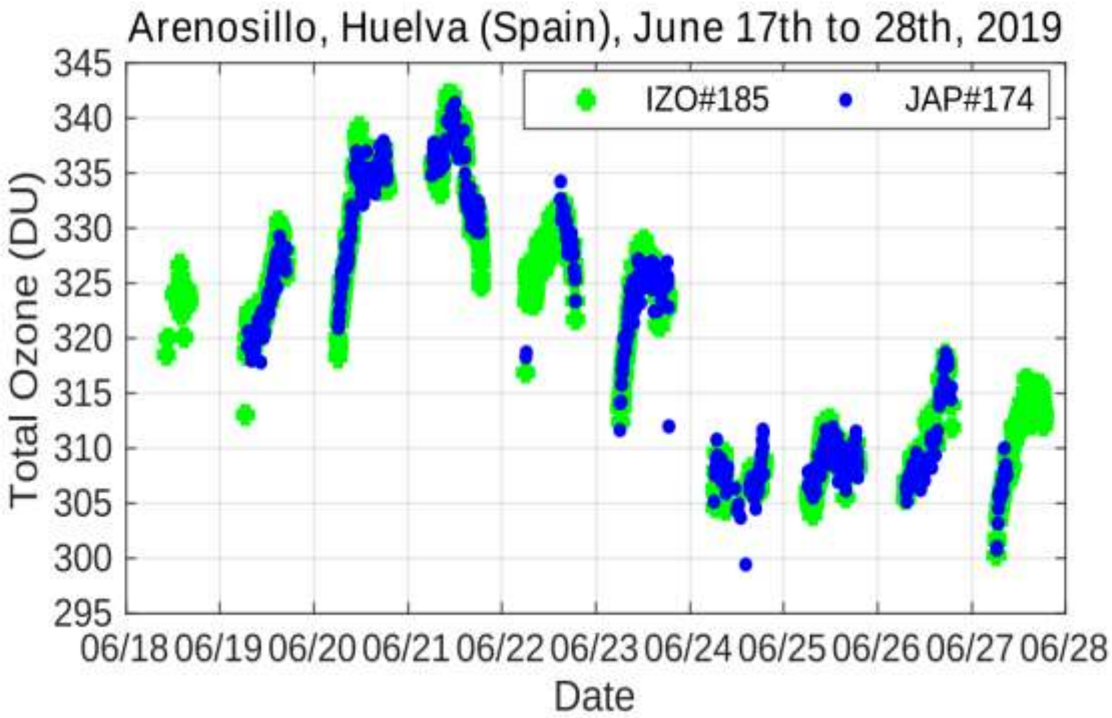
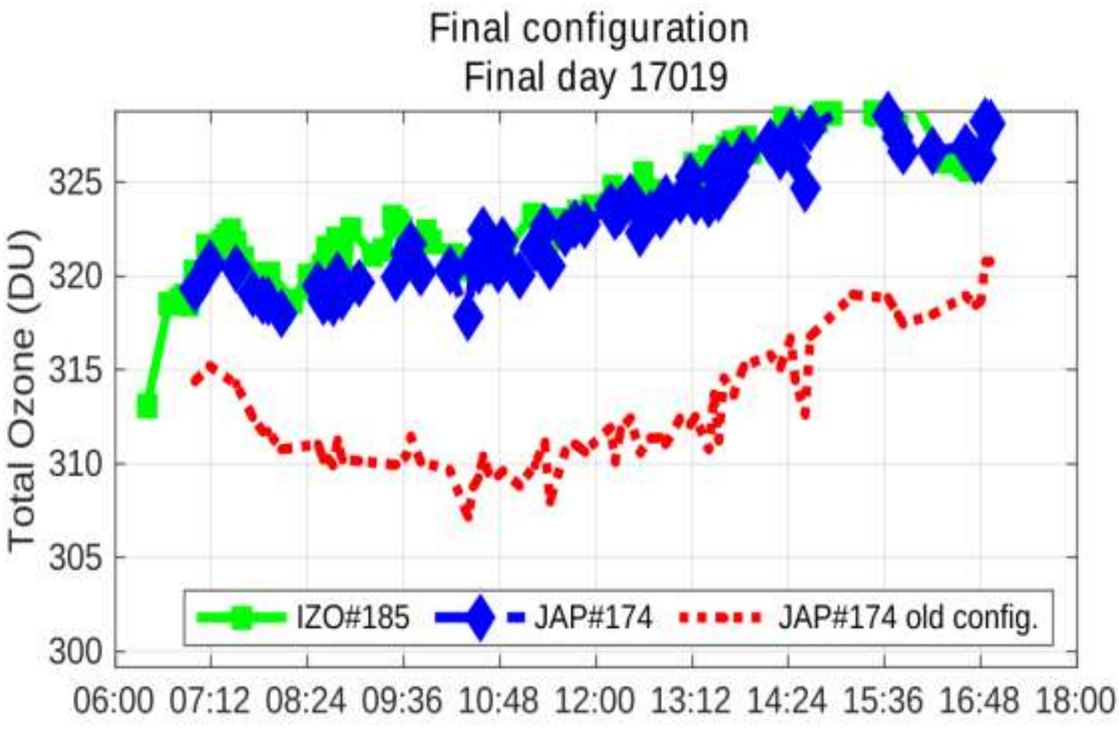
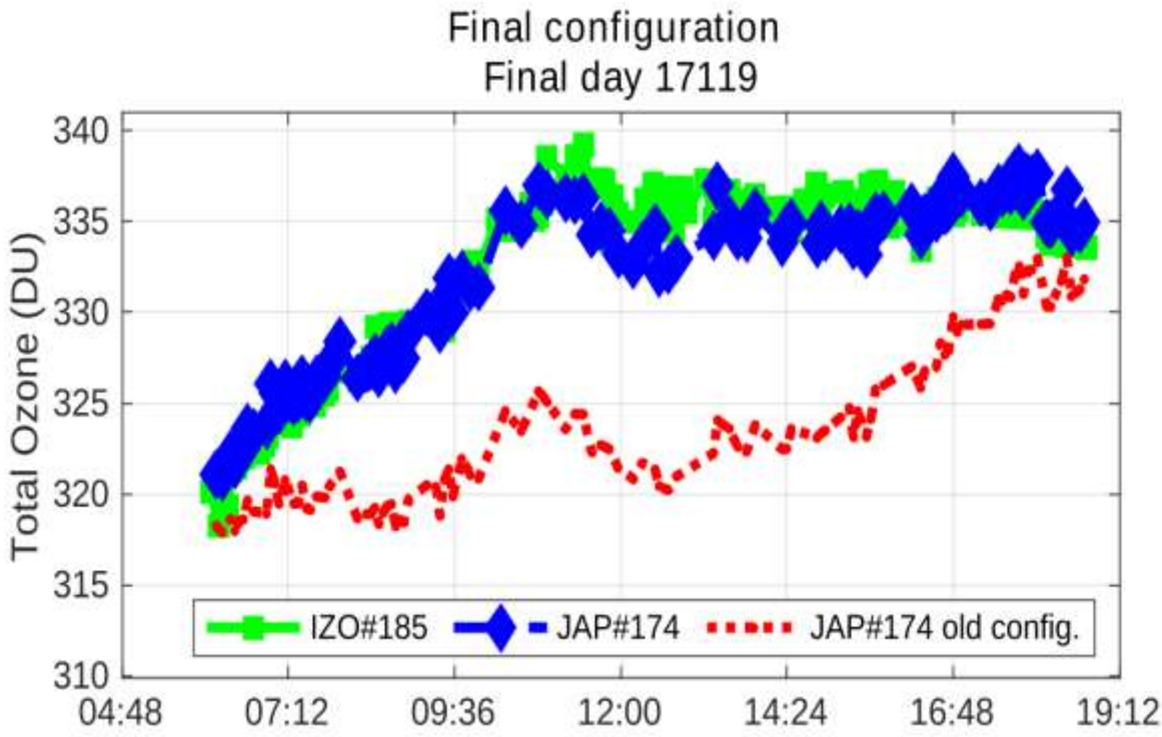
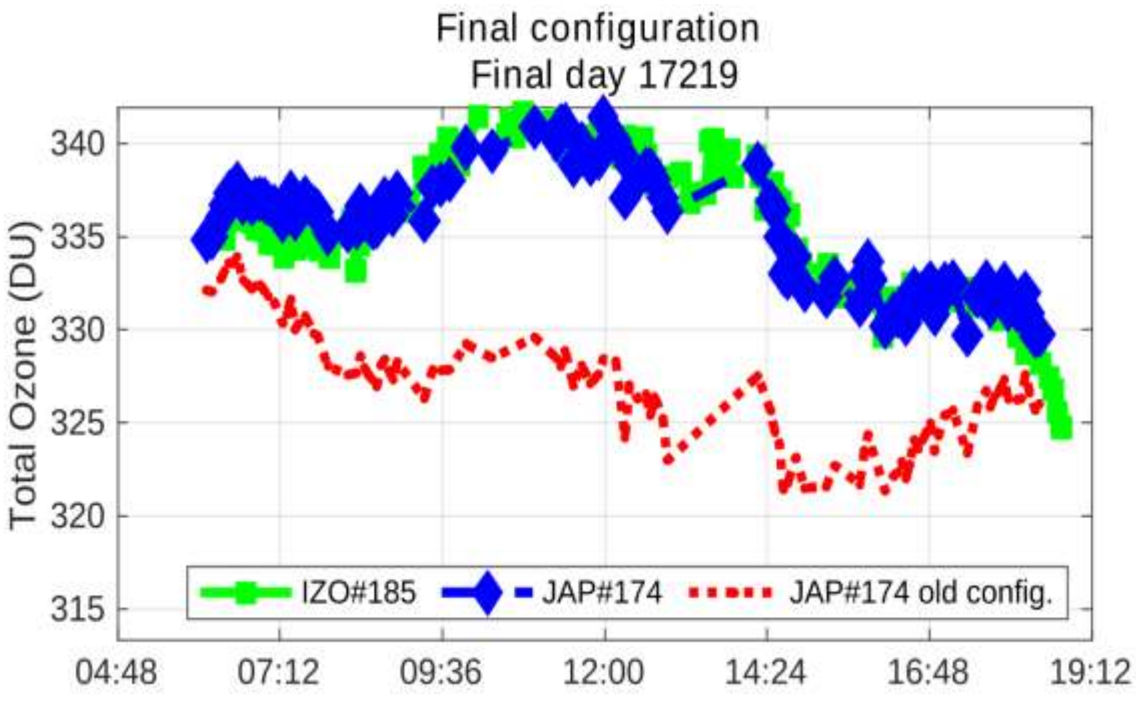
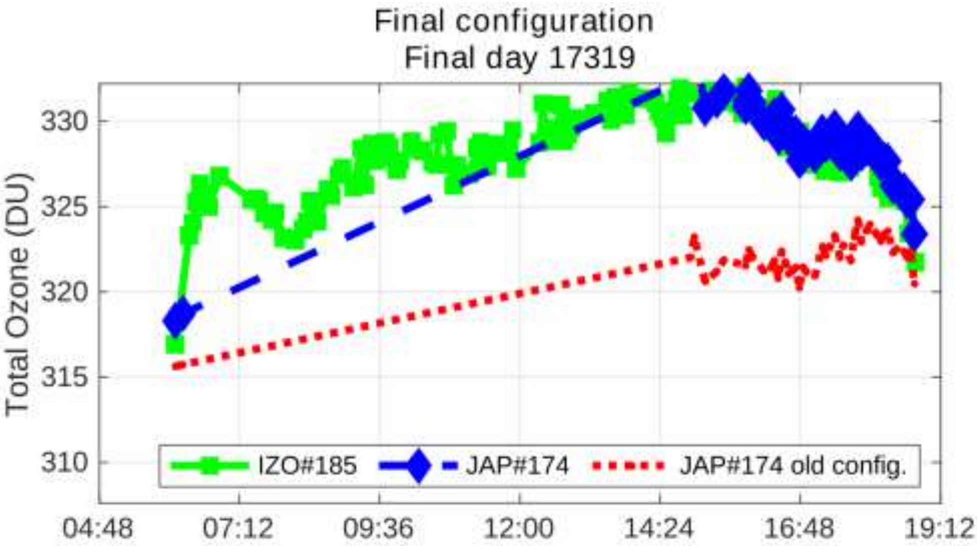


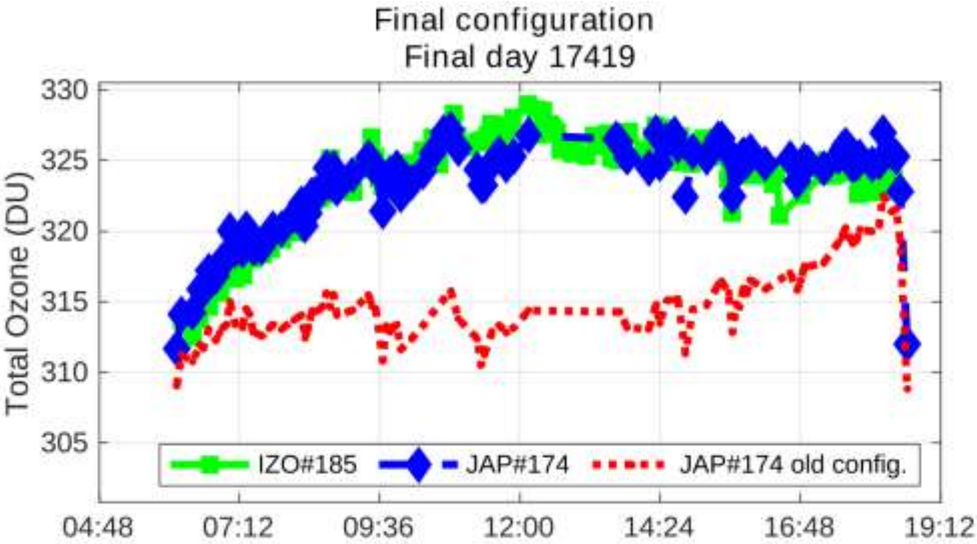
Figure 23. Overview of the intercomparison. Brewer JAP#174 data were evaluated using final constants (blue circles)

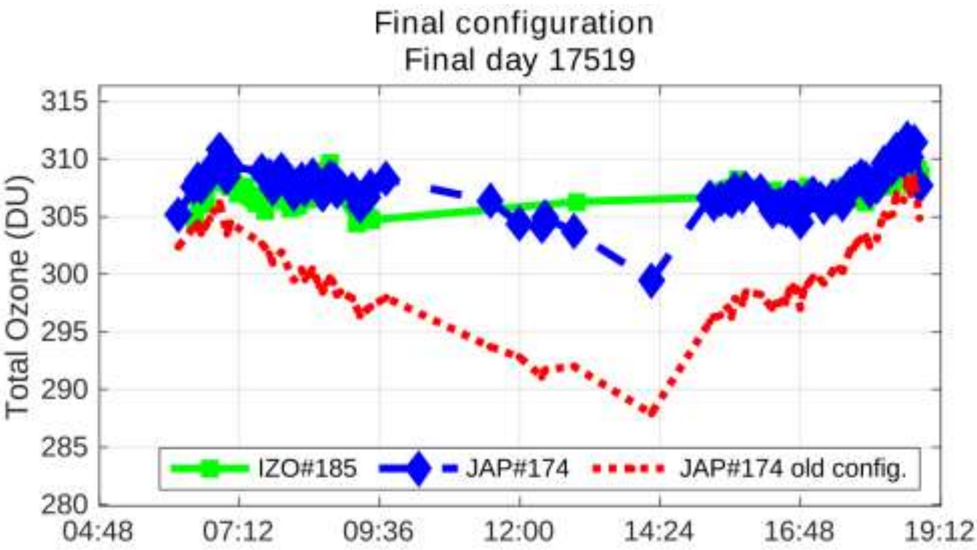


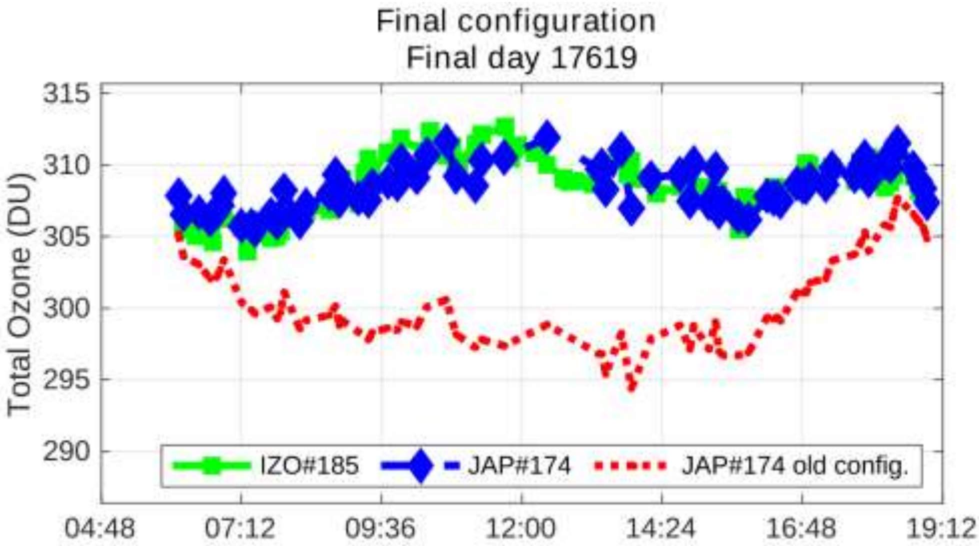

Final configuration
Final day 17119
Total Ozone (DU)
340
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
JAP#174
JAP#174 old config.

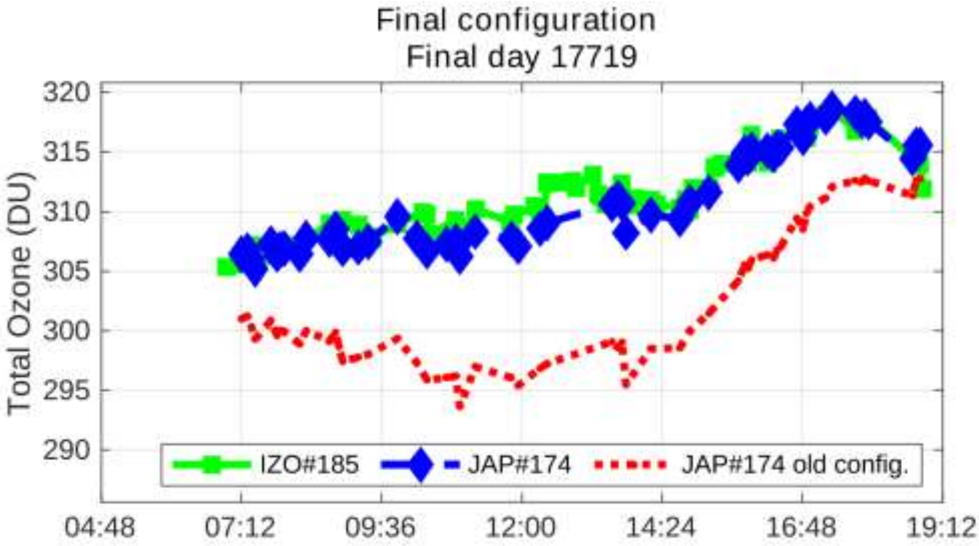

Final configuration
Final day 17219
Total Ozone (DU)
340
335
330
325
320
315
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
JAP#174
JAP#174 old config.

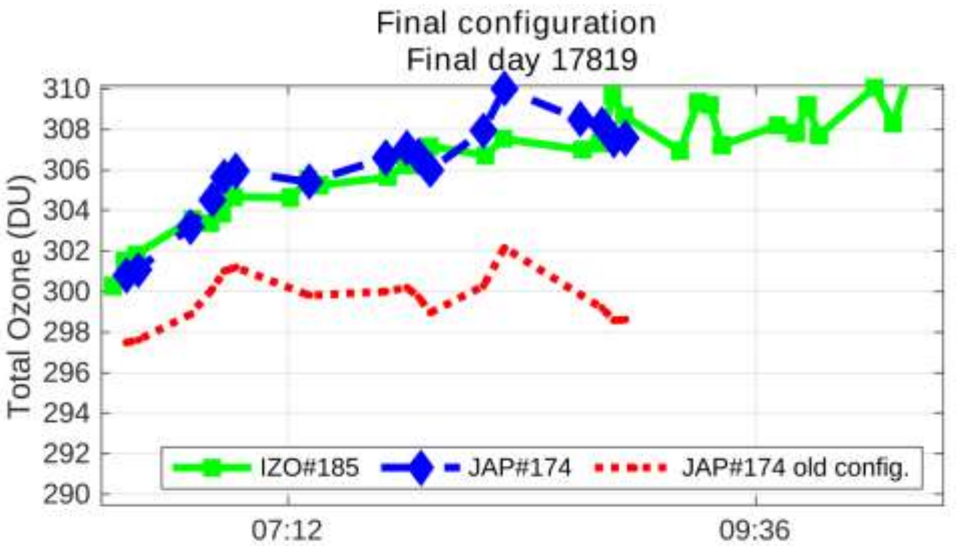

Final configuration
Final day 17319
Total Ozone (DU)
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
JAP#174
JAP#174 old config.


Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
305
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
JAP#174
JAP#174 old config.


Final configuration
Final day 17519
Total Ozone (DU)
315
310
305
300
295
290
285
280
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
JAP#174
JAP#174 old config.


Final configuration
Final day 17619
Total Ozone (DU)
IZO#185
JAP#174
JAP#174 old config.


Final configuration
Final day 17719
Total Ozone (DU)
IZO#185
JAP#174
JAP#174 old config.


Final configuration
Final day 17819
Total Ozone (DU)
IZO#185
JAP#174
JAP#174 old config.

18. BREWER MAD#186

18.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer MAD#186 participated in the campaign from 17 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer MAD#186 correspond to Julian days 168 – 178.

For the evaluation of the initial status, we used 165 simultaneous direct sun (DS) ozone measurements from days 168 to 172. For final calibration purposes, we used 248 simultaneous DS ozone measurements taken from day 173 to 178.

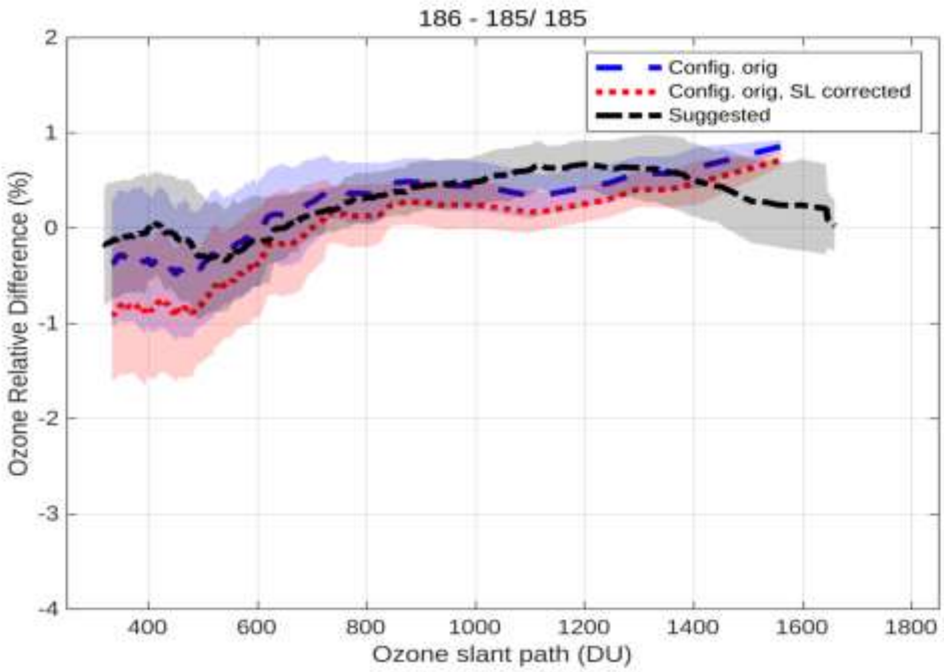


Figure 1. Mean DS ozone column percentage difference between Brewer MAD#186 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15317.186, blue dashed line) produces ozone values with an average difference of approx. 0.5% with respect to the reference Brewer IZO#185. The SL correction (Figure 1, red dotted line) is therefore not necessary and indeed its application makes the comparison slightly worse.

The lamp test results from Brewer MAD#186 show a very noticeable seasonal trend, with maxima in the winter months (see Figure 2). During the campaign days, the standard lamp ratios stabilized around values 326 and 537 for R6 and R5, respectively (Figures 20 and 21). Note that the final reference value for R6 is very close to the current one (315).

Dead time (DT) tests are somewhat noisy, especially as regards the low values and, in the CZ scans, the peak of the 334.148 nm line is outside the tolerance limits. All the other parameters analysed (run/stop tests, Hg lamp intensity, and so forth) showed reasonable results.

We have updated the temperature coefficients due to the seasonality observed in the SL record.

Concerning the filters' performance, filter #4 features some wavelength dependency, but the results of the FI tests do not suggest that the application of filter corrections are necessary. We observed some abnormal behaviour of filters #3 and/or #4 by the end of the campaign, but this seems to have been solved at the instrument's station.

The sun scan tests (SC) at the instrument's station before the campaign suggest 287 for the cal step number, while those performed during the first days of the intercomparison resulted in 285. However, the CSN was not changed during the campaign and Brewer MAD#186 continues operating with a CSN of 283. We recommend performing more SC tests at the instrument's station and the CSN.

Without changes to the CSN, we do not suggest changing the ozone absorption coefficient, retaining its current value of 0.3425.

Taking this into account, we suggest the following changes to the configuration of Brewer MAD#186.

18.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer MAD#186 show a marked seasonal trend. Despite that, the old R6 reference value was 315 and, although the difference is within the ± 5 acceptable error, it could be updated to 326.
2. We suggest a new R5 reference value of 537.
3. We have updated the temperature coefficients due to the seasonality observed in the SL record.
4. According to the FI tests, no filter correction is strictly necessary.
5. Although the difference is within the tolerance limit of ± 5 units, we suggest updating the ETC value from 1567 to 1577.
6. Finally, we recommend performing more sun scan tests, because the current CSN does not agree with the results of the tests performed during the campaign. Note we have not changed the CSN.

18.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/186/ICF17319.186

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1744927760

Calibration reports detailed

Historic and instrumental
http://rbcce.aemet.es/svn/campaigns/are2019/latex/186/html/cal_report_186a1.html

Temperature & filter
http://rbcce.aemet.es/svn/campaigns/are2019/latex/186/html/cal_report_186a2.html

Wavelength
http://rbcce.aemet.es/svn/campaigns/are2019/latex/186/html/cal_report_186b.html

ETC transfer
http://rbcce.aemet.es/svn/campaigns/aro2019/latex/186/html/cal_report_186c.html

18.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

18.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp tests show seasonal dependence with maxima in the winter months. By the end of the campaign, the R6 and R5 values stabilized at approx. 326 and 547, respectively. This new R6 value is only 5 units higher than the reference value given in the previous intercomparison campaign.

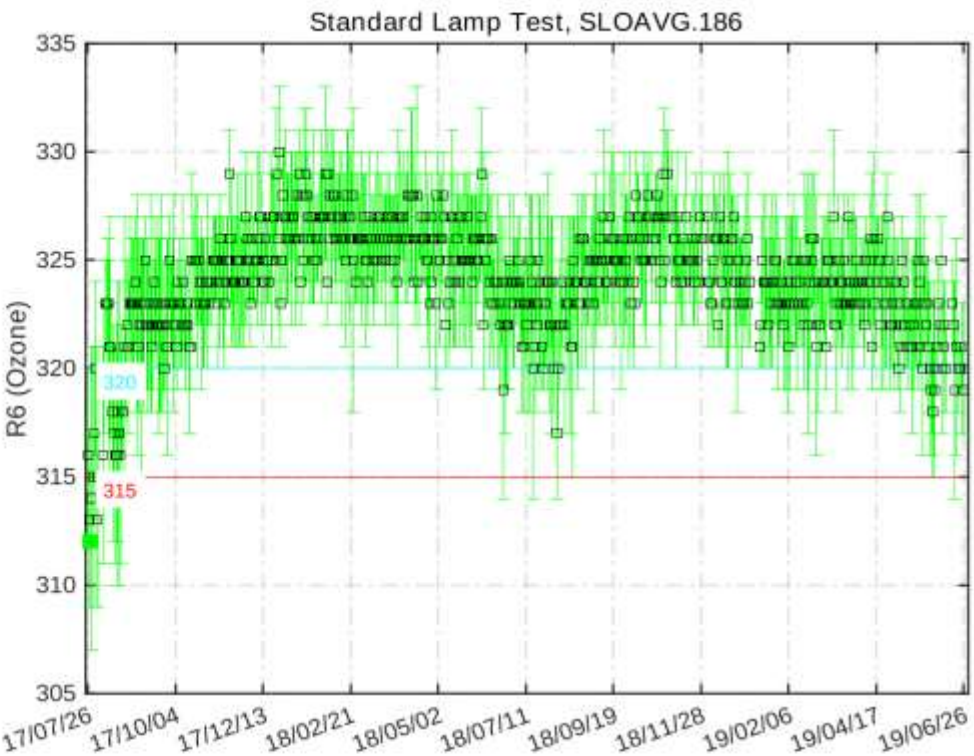


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

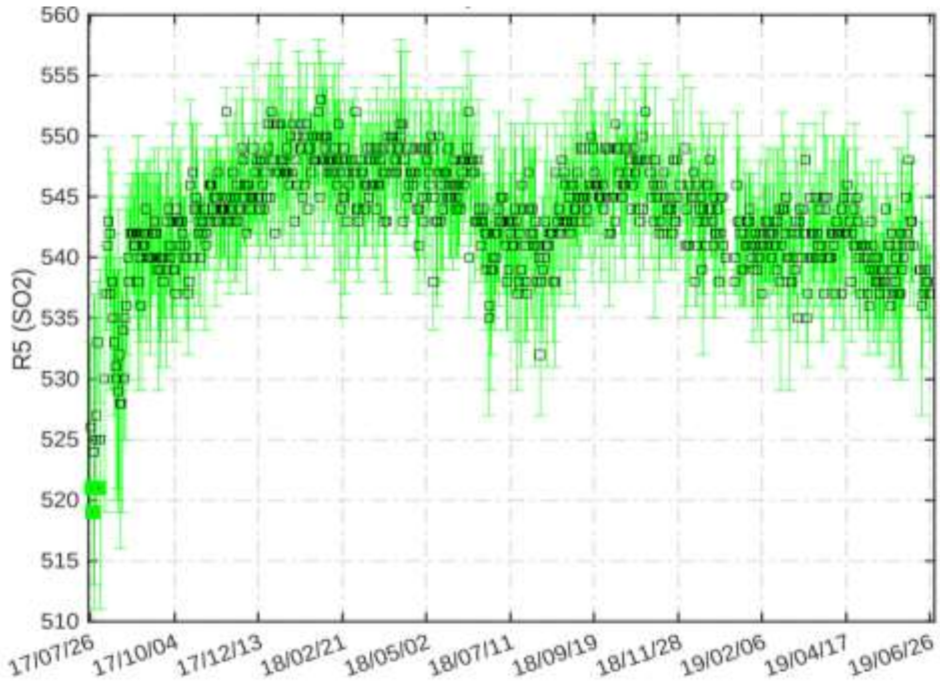


Figure 3. Standard lamp test R5 sulphur dioxide ratios

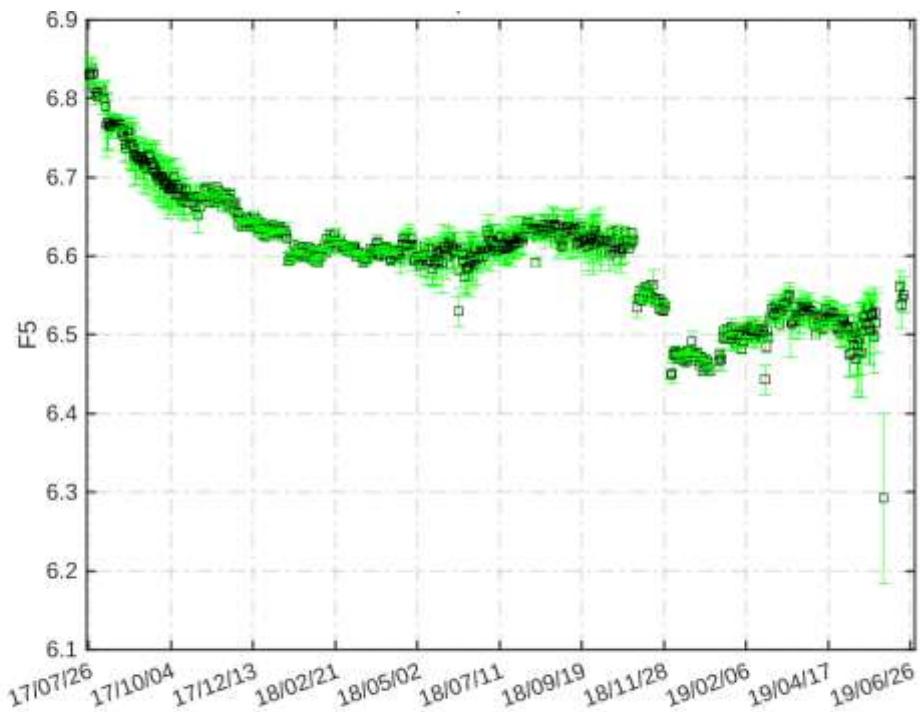


Figure 4. SL intensity for slit five

18.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, the DT low values are very noisy. Nevertheless, the current DT reference value of $3.1\cdot 10^{-8}$ seconds seem reasonable and we recommend retaining it in the final ICF of the present campaign.

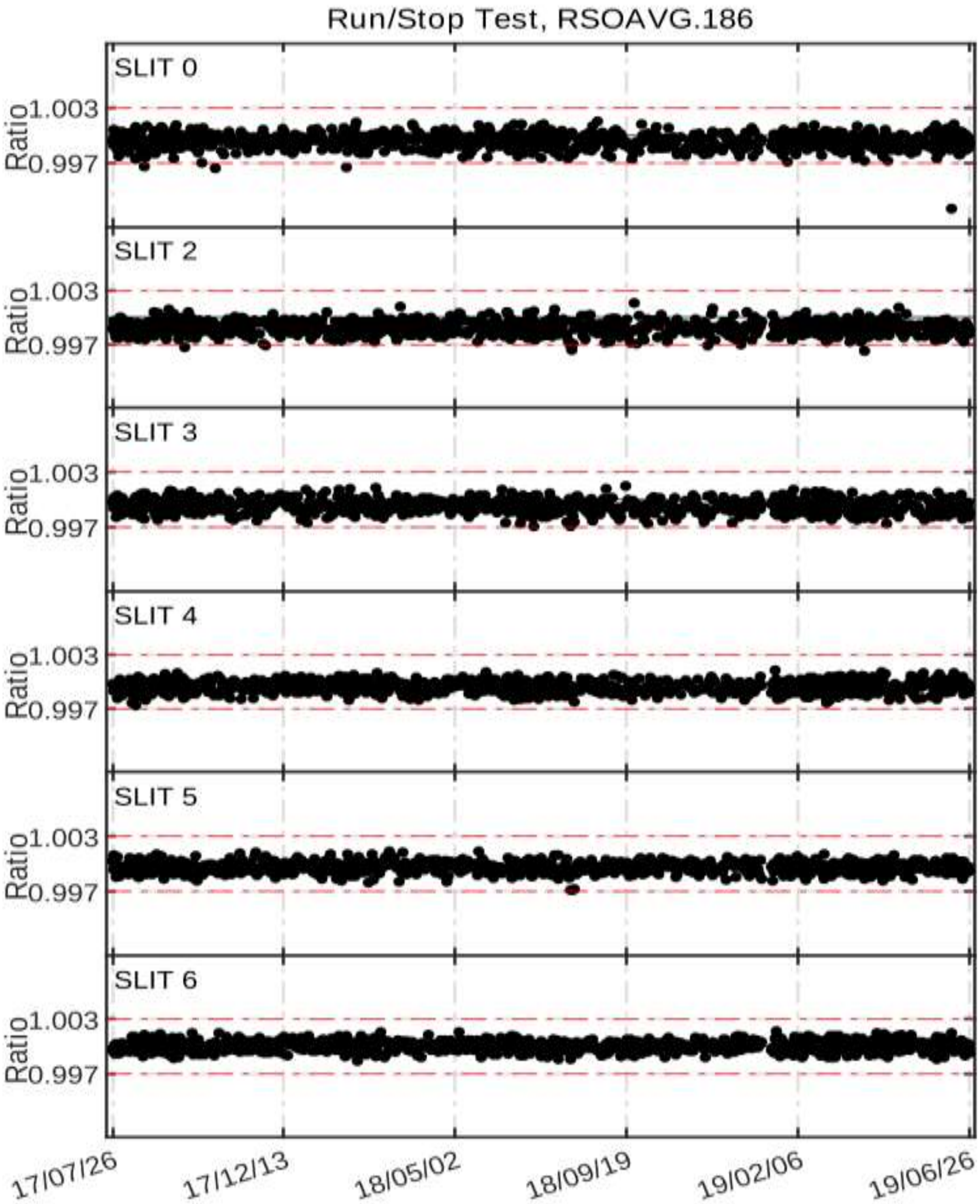


Figure 5. Run/stop test

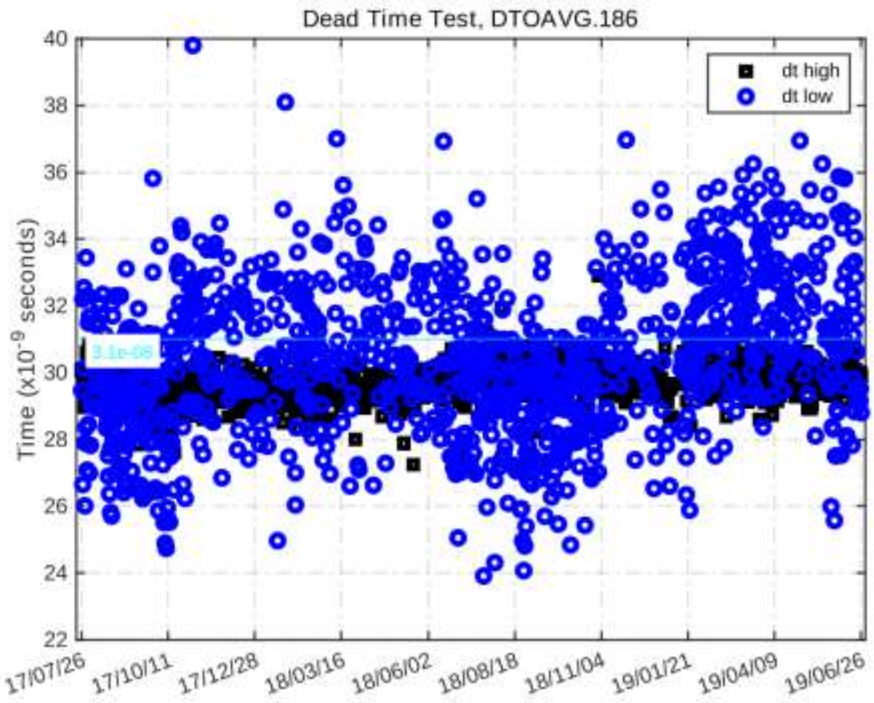


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

18.2.3. Analogue test

Figure 7 shows that results of the AP tests have been quite stable over the last 2 years, the +5 Voltage being close to the minimum tolerance limit. Maintenance work during the campaign produced the large increases observed in all three magnitudes plotted.

Analogue Printout Log, APOAVG.186

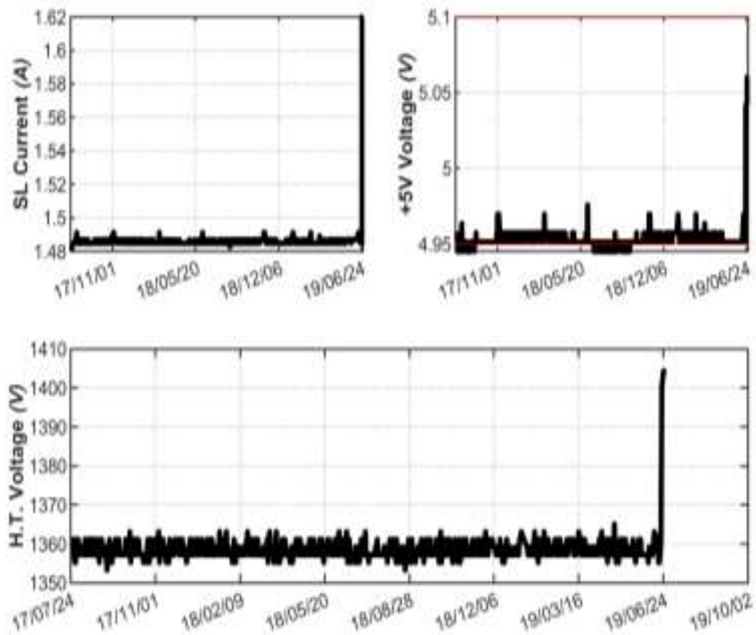


Figure 7. Analogue voltages and intensity

18.2.4. Mercury lamp test

Overall, internal mercury lamp intensity shows a downward trend. Despite that, there appears to be some correlation with the internal Brewer temperature (see Figure 8).

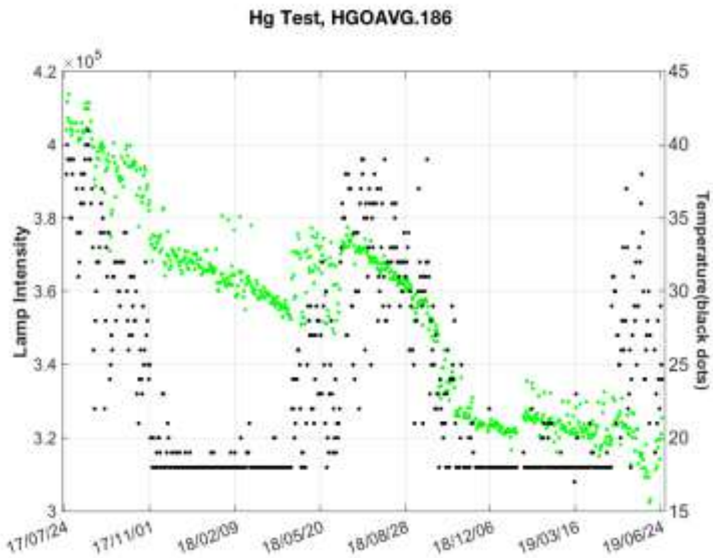
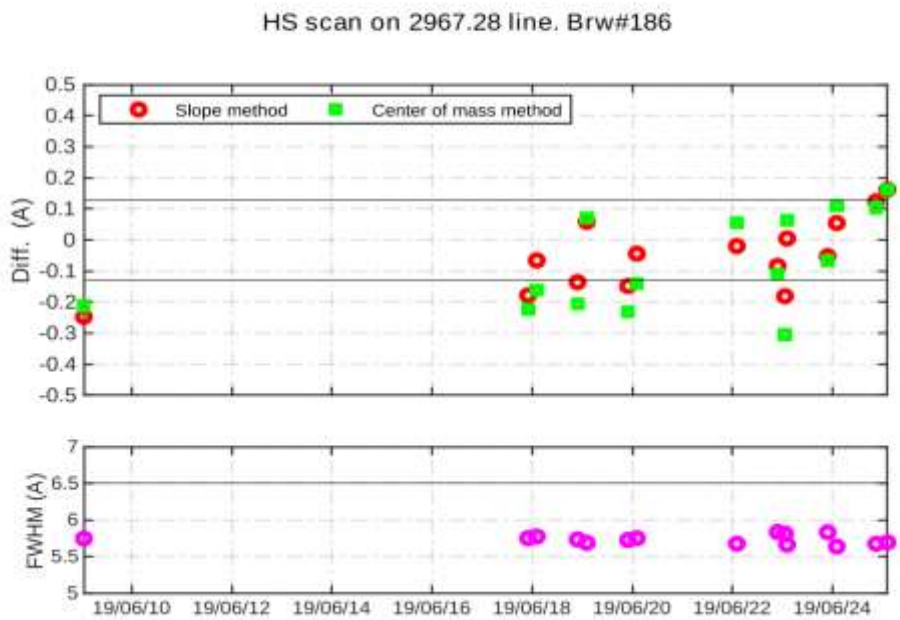


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

18.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm and 334.148 nm mercury lines, see Figure 9. As a reference, the calculated scan peak in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer MAD#186 during the campaign show reasonable results except for the position of the 334.148 nm line, whose centre is not within the tolerance limits.



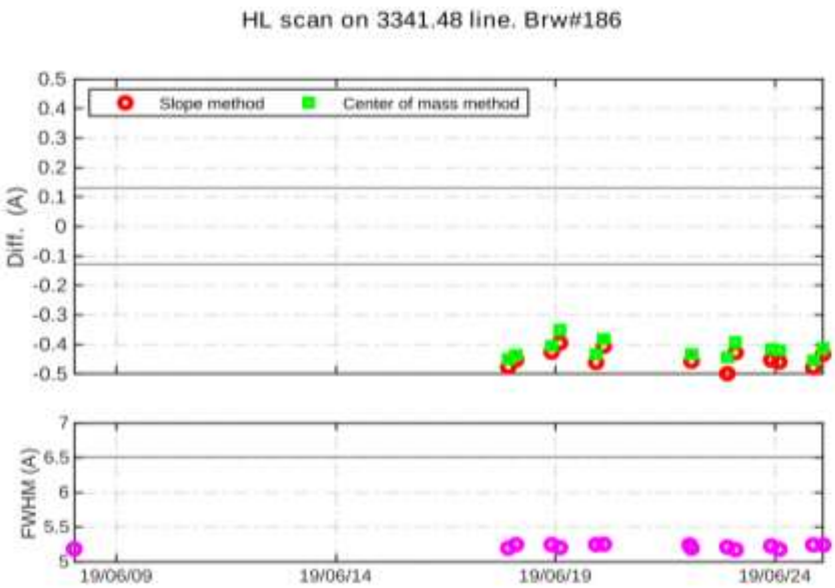


Figure 9. CZ scan on the 296.728 and 334.148 nm Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

18.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer MAD#186 CI scans performed during the campaign relative to scan CI17319.186. As can be observed, lamp intensity varied with respect to the reference spectrum by a rather small percentage, although some increase at very long wavelengths was present.

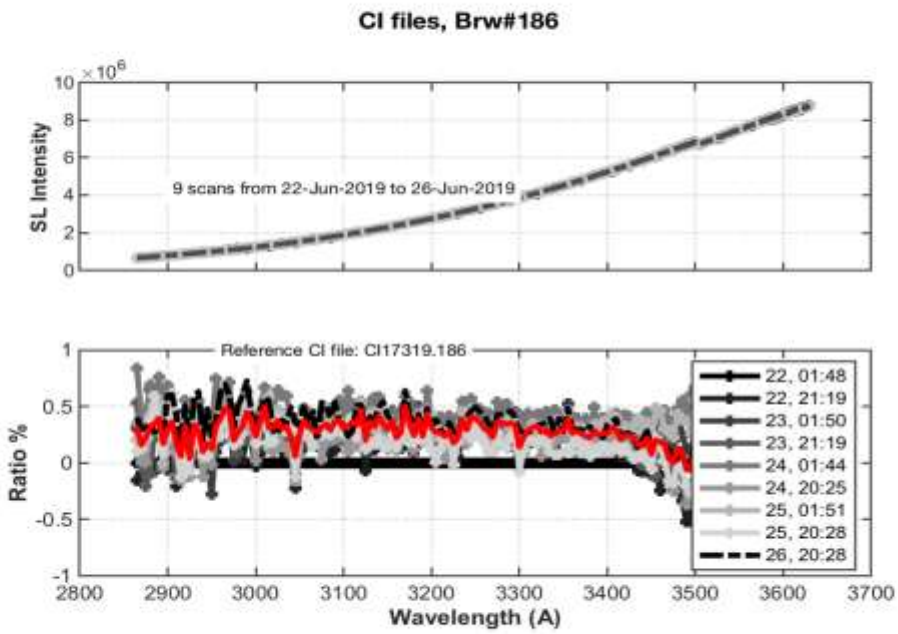


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

18.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 18 ˚C to 31 ˚C) the current coefficients perform reasonably well, although temperature coefficients determined during the campaign performed even better. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, new coefficients can be calculated to almost remove the temperature dependence. For this reason, in the final ICF we have used these new temperature coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.0028	-0.0817	-0.1711	-0.2317
Calculated	0.0000	0.0900	0.1900	0.2700	0.2300
Final	0.0000	0.1000	0.2300	0.2800	0.2300

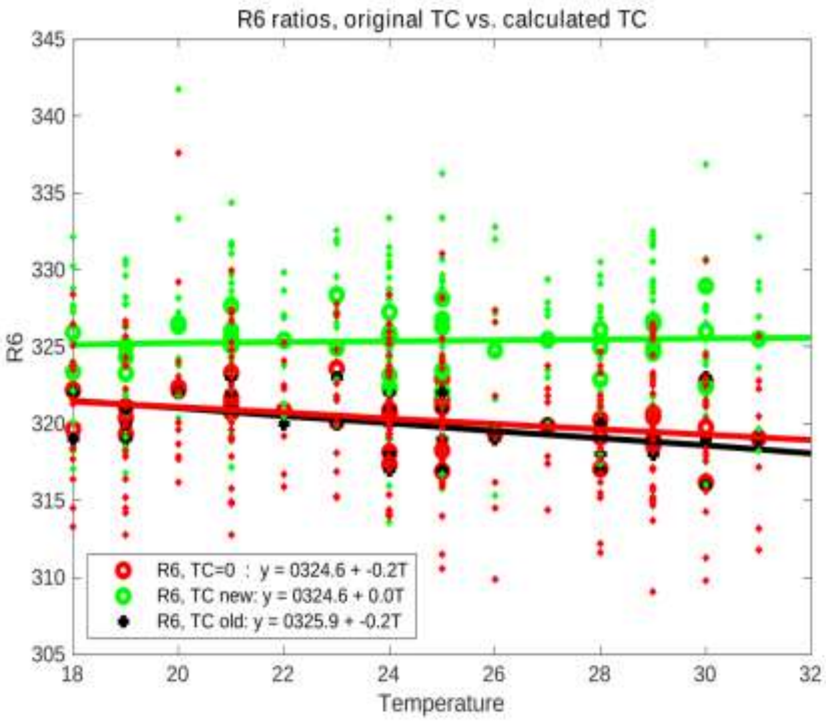


Figure 11. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

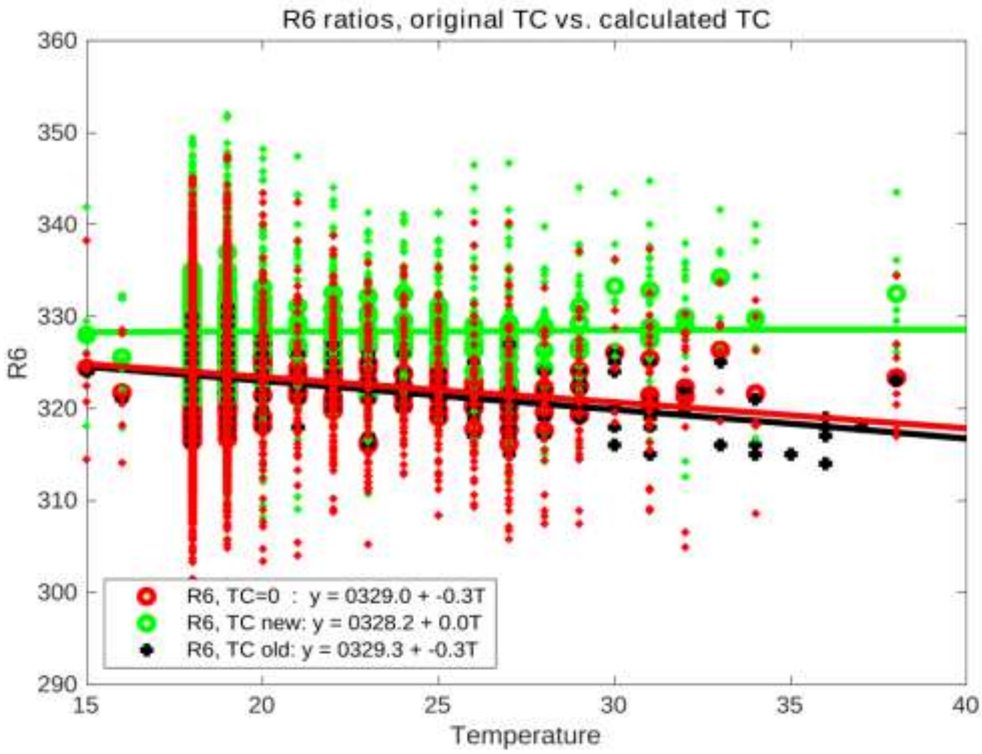


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

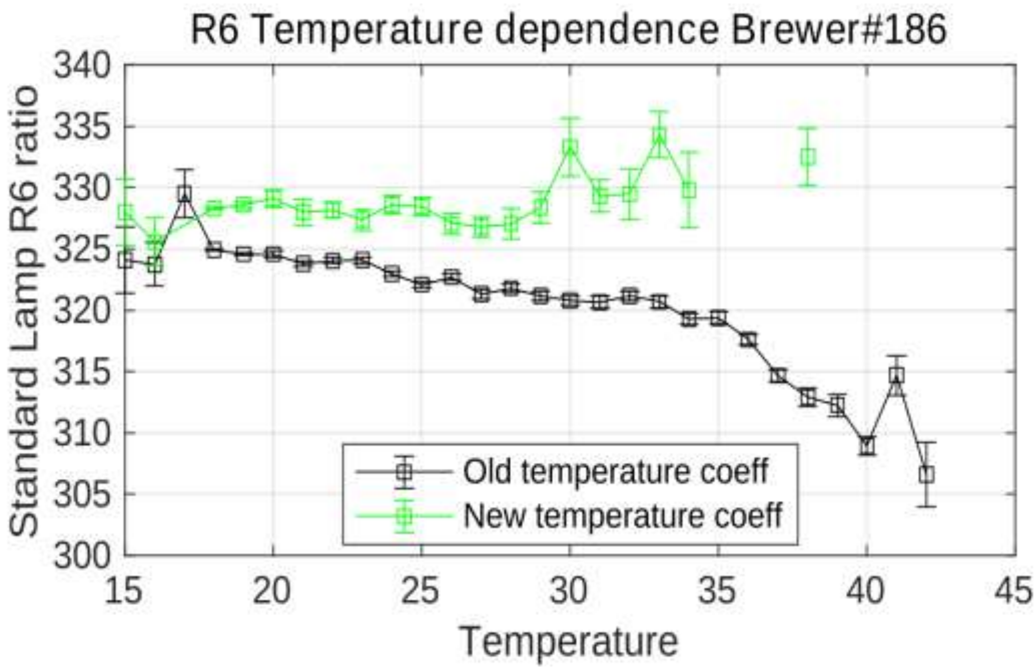


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted the R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

18.4. ATTENUATION FILTER CHARACTERIZATION

18.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 112 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter. From these results, it does not seem like any filter correction is strictly necessary. We have noticed however that Filter #4 has some dependence with the wavelength. Furthermore, some abnormal behaviour of Filters #3 and/or #4 was observed by the end of the campaign, but this problem seems to have been solved at the instrument's station.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals were calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-2	-3	-8	-2	-5
ETC Filt. Corr. (mean)	-0.7	-5.7	-6.7	-3.7	-8.6
ETC Filt. Corr. (mean 95% CI)	[-3.8 2.4]	[-9.2 -2]	[-9.7 -3.4]	[-8 0.8]	[-19.4 2.1]

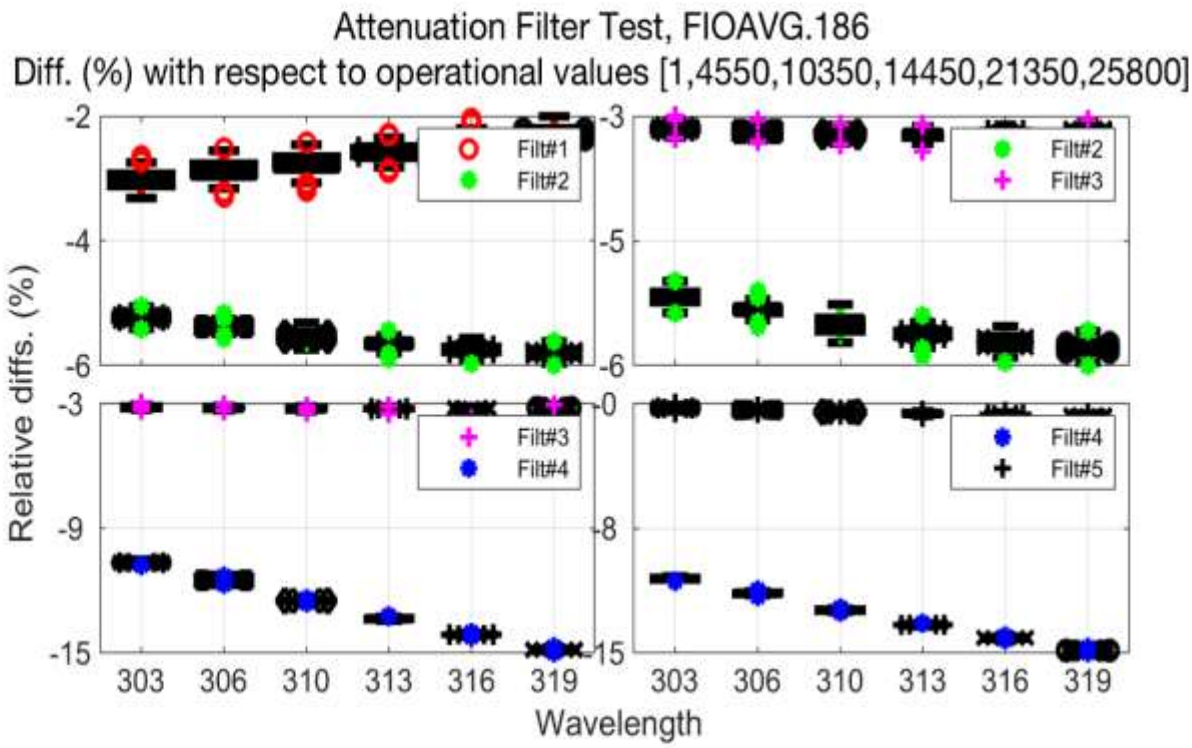


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

18.5. WAVELENGTH CALIBRATION

18.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 9 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1200 DU were carried out (see Figure 16). The calculated cal step number (CSN) was 285, 2 steps higher than the value in the current configuration (283). SC tests performed at the station before the campaign provide an even higher CSN (287). Nevertheless, the CSN was not updated during the campaign, so in the final ICF we retain the current value of 283.

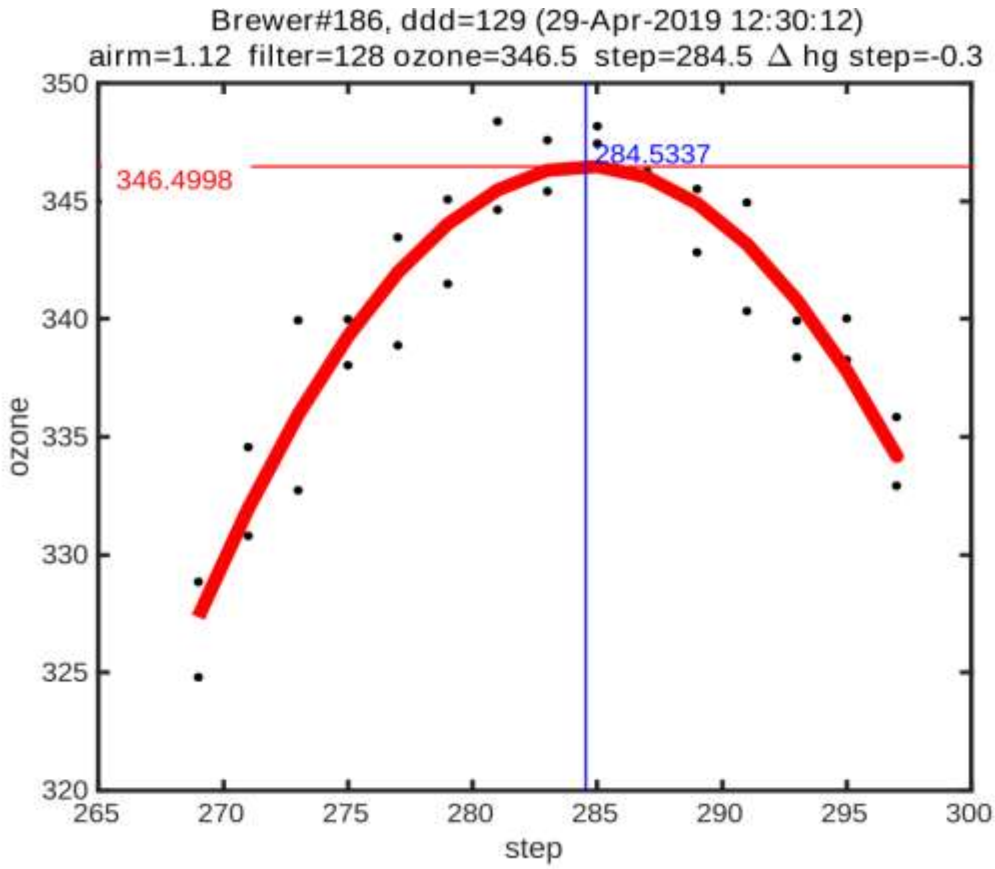


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

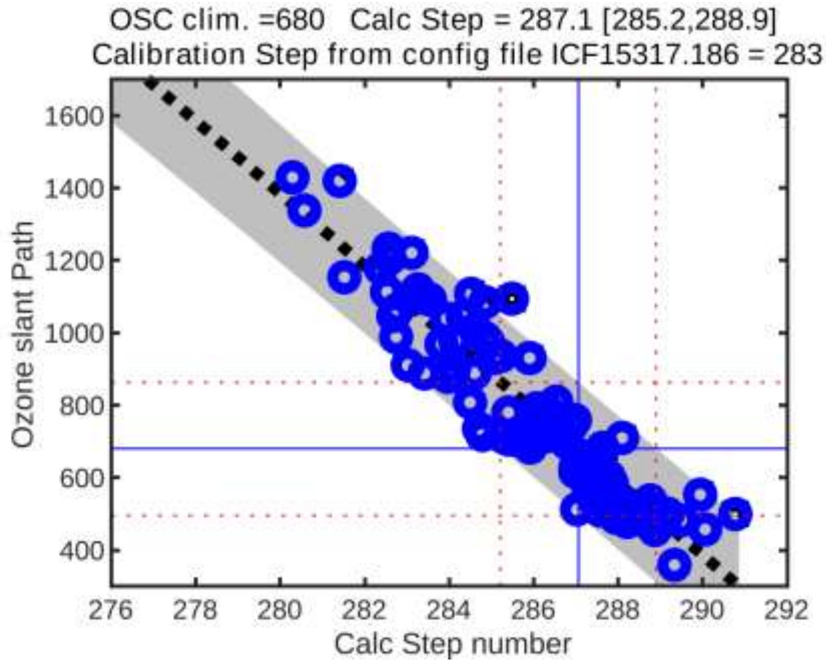


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

18.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

Because the CSN has not been changed, we suggest retaining the current absorption coefficient of 0.3425.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	283	0.3425	2.3500	1.1512
09-Jul-2011	283	0.3420	3.1980	1.1479
16-Jun-2013	283	0.3422	3.1900	1.1440
04-Jun-2015	283	0.3423	3.2155	1.1436
01-Jun-2017	283	0.3414	3.1950	1.1438
23-Jun-2019	283	0.3433	3.1394	1.1518
Final	283	0.3425	2.3500	1.1512

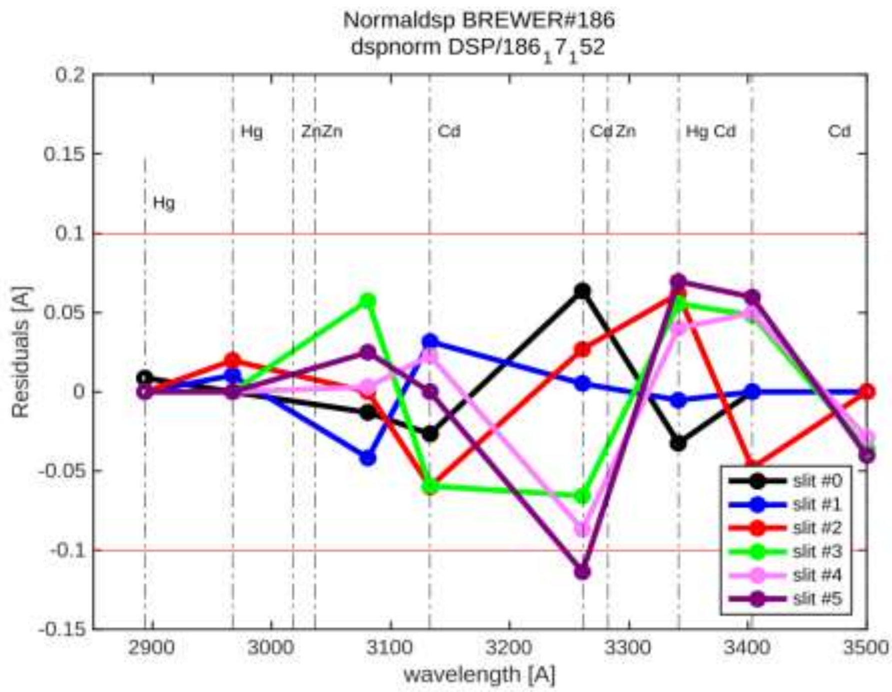


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 282	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.88	3063	3100.41	3135.02	3167.96	3199.9
Res(A)	5.664	5.5215	5.4973	5.573	5.5445	5.3995
O3abs(1/cm)	2.6005	1.7804	1.0052	0.67619	0.37509	0.29438
Ray abs(1/cm)	0.50509	0.48323	0.45853	0.4371	0.41788	0.40026
SO2abs(1/cm)	3.4501	5.6458	2.3994	1.8979	1.054	0.61442
step= 283	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.95	3063.07	3100.48	3135.09	3168.03	3199.97
Res(A)	5.6639	5.5214	5.4972	5.5729	5.5444	5.3995
O3abs(1/cm)	2.5979	1.7787	1.0049	0.67581	0.37511	0.29391
Ray abs(1/cm)	0.50504	0.48318	0.45849	0.43705	0.41784	0.40022
SO2abs(1/cm)	3.434	5.6679	2.4075	1.8863	1.0552	0.61221
step= 284	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.02	3063.15	3100.55	3135.17	3168.1	3200.04
Res(A)	5.6638	5.5213	5.4971	5.5728	5.5443	5.3994
O3abs(1/cm)	2.5952	1.7771	1.0046	0.67542	0.37518	0.29344
Ray abs(1/cm)	0.50498	0.48313	0.45844	0.43701	0.4178	0.40018
SO2abs(1/cm)	3.4182	5.6891	2.4156	1.8743	1.0564	0.60995
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
282	0.34235	10.9615	3.1851	1.147	0.35288	0.34428
283	0.34139	10.9572	3.195	1.1438	0.35192	0.3433
284	0.34035	10.9529	3.204	1.1404	0.35093	0.34228

18.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1677. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 283	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.6639	5.5214	5.4972	5.5729	5.5444	5.3995
O3abs(1/cm)	2.5979	1.7787	1.0049	0.67581	0.37511	0.29391
Ray abs(1/cm)	0.50504	0.48318	0.45849	0.43705	0.41784	0.40022
step= 1679	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.5257	5.4164	5.3664	5.4581	5.3954	5.2824
O3abs(1/cm)	0.67872	0.39566	0.29405	0.12442	0.061219	0.03338
Ray abs(1/cm)	0.43791	0.42029	0.40022	0.38288	0.36716	0.35273

18.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements over 6 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

18.6.1. Initial calibration

For the evaluation of the initial status of Brewer MAD#186, we used the period from days 168 to 172 which correspond to 165 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced ozone values which only differ by approx. 0.5% with respect to the reference Brewer. This is a very small difference, and when the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve. In fact, they became slightly worse.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

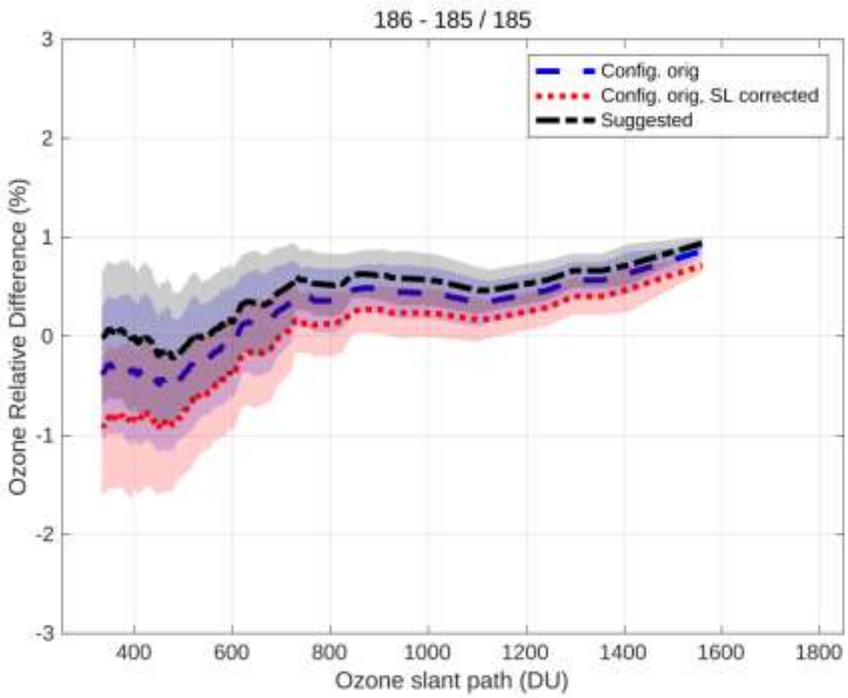


Figure 18. Mean direct sun ozone column percentage difference between Brewer MAD#186 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=1000	1563	1562	3425	3426
full OSC range	1563	1562	3425	3426

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#186*	*O3 std*	*%(186–185)/185*	*O3(*) #186*	*O3std*	*(*)%(186–185)/185*
18-Jun-2019	169	323.5	1.9	20	324.6	2	0.3	325.7	2	0.7
19-Jun-2019	170	324.5	3.6	58	323.8	4.3	-0.2	324.8	4.4	0.1
20-Jun-2019	171	335	3.4	61	333	3.2	-0.6	334	3.2	-0.3
21-Jun-2019	172	339.5	2.5	26	338.6	3.7	-0.3	339.6	3.7	0

18.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 19). For the final calibration we used 248 simultaneous direct sun measurements from days 173 to 178. The new value of 1577, 10 units higher than the current one (1567) resulted in a similar ozone value to the initial calibration. Nevertheless, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (326 for R6). We updated the new calibration constants in the ICF provided which includes the updated Temperature Coefficients.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is within the maximum tolerance limit of 10 units using data up to OSC=1000 DU. When data from the whole OSC range up to 1650 DU is used, the comparison becomes noticeably worse, but it should be noted that the 1P result does not change. Regardless, the comparison with Brewer IZO#185 was quite good, as shown in Table 9.

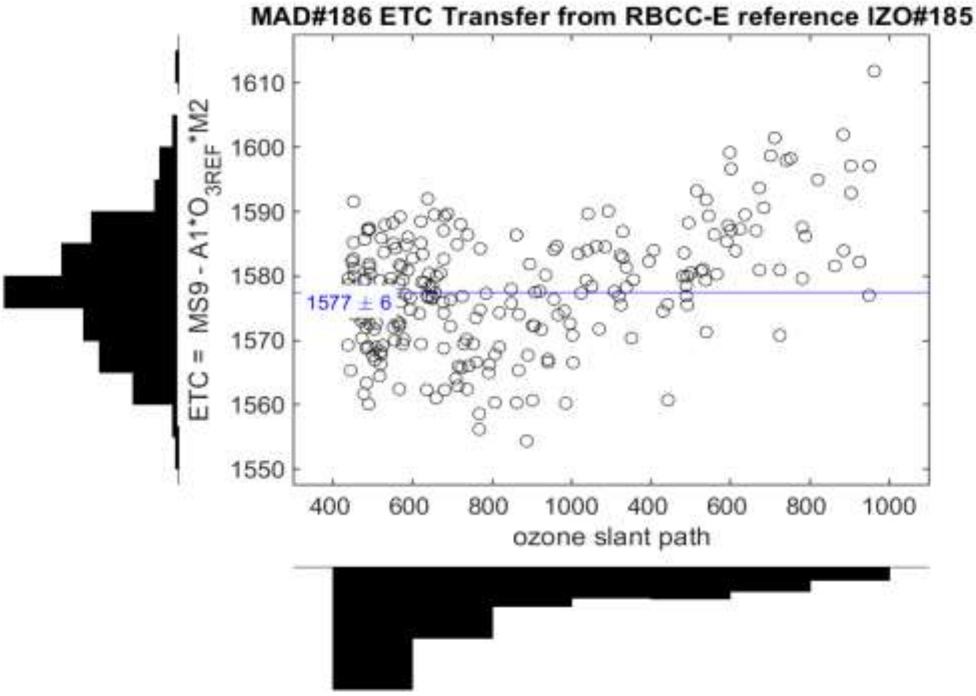


Figure 19. Mean direct sun ozone column percentage difference between Brewer MAD#186 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1577	1568	3425	3445
full OSC range	1577	1551	3425	3484

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#186*	*O3 std*	*%(186–185)/185*	*O3(*) #186*	*O3std*	*(*)%(186 – 185)/185*
21-Jun-2019	172	331.7	0.6	2	330.8	0.6	-0.3	330.4	0.6	-0.4
22-Jun-2019	173	328.9	2.9	66	328.2	3.1	-0.2	327.6	3.1	-0.4
23-Jun-2019	174	323.4	4.5	38	324.5	4.4	0.3	324	4.3	0.2
24-Jun-2019	175	307.5	1.1	22	308.9	1.5	0.5	308.5	1.6	0.3
25-Jun-2019	176	308.4	2	51	309.2	2.3	0.3	308.7	2.3	0.1
26-Jun-2019	177	312	3.7	43	312.2	4.5	0.1	311.7	4.6	-0.1
27-Jun-2019	178	NaN	NaN	0	309.2	2.9	NaN	308.6	2.9	NaN

18.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 326 for R6 (Figure 20) and 547 for R5 (Figure 21).

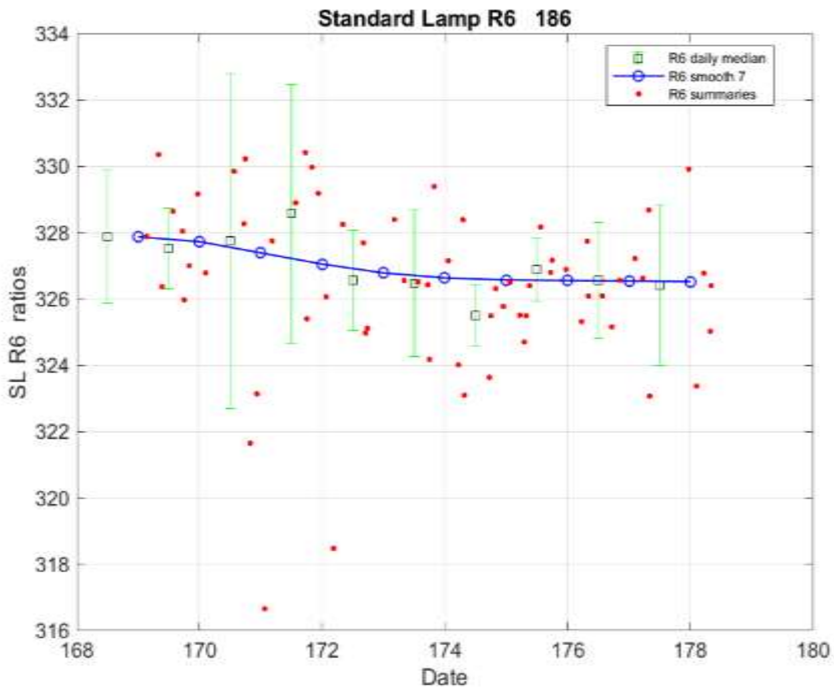


Figure 20. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots), processed with the new temperature coefficients

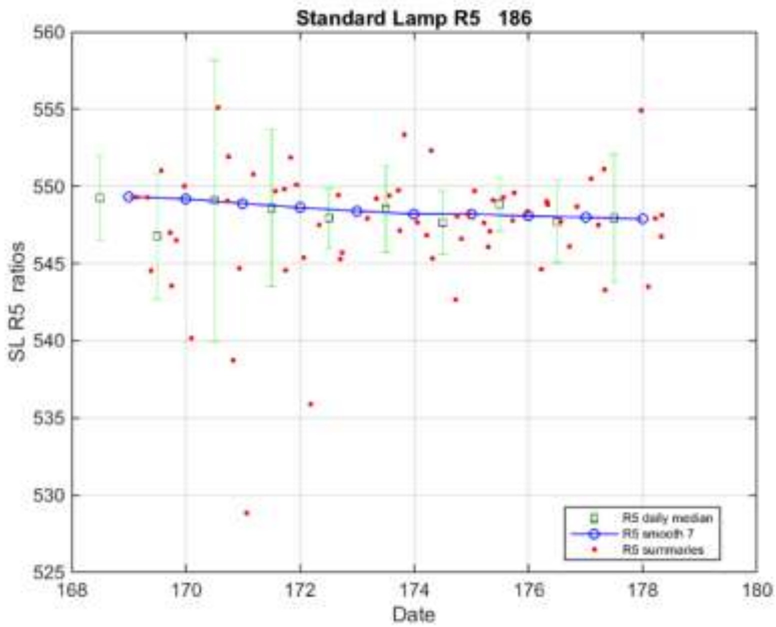


Figure 21. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots), processed with the new temperature coefficients

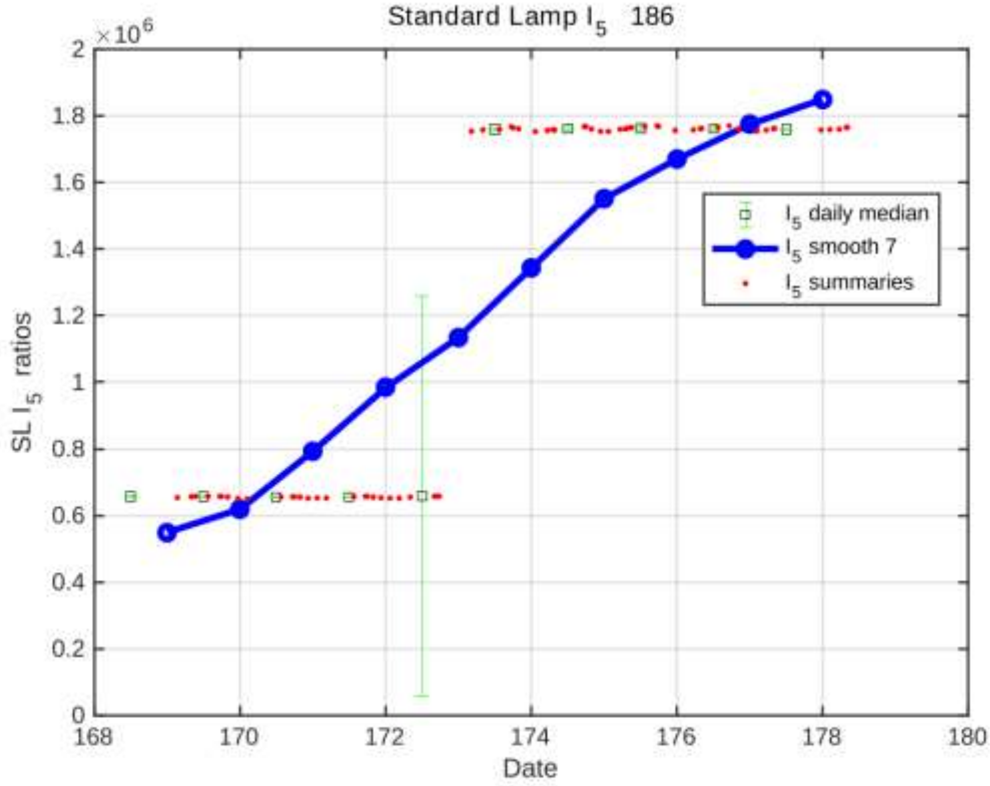


Figure 22. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

18.7. CONFIGURATION

18.7.1. Instrument constant file

	Initial (ICF15317.186)	*Final (ICF17319.186)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.0028	0.1
o3 Temp coef 3	-0.0817	0.23
o3 Temp coef 4	-0.1711	0.28
o3 Temp coef 5	-0.2317	0.23
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3425	0.3425
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1512	1.1512
ETC on O3 Ratio	1567	1577
ETC on SO2 Ratio	135	135
Dead time (sec)	3.1e-08	3.1e-08

	Initial (ICF15317.186)	*Final (ICF17319.186)*
WL cal step number	283	283
Slitmask motor delay	14	14
Umkehr Offset	1694	1694
ND filter 0	0	0
ND filter 1	4550	4550
ND filter 2	10350	10350
ND filter 3	14450	14450
ND filter 4	21350	21350
ND filter 5	25800	25800
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	0	0
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2526	2526
Grating Slope	1.01	1.01
Grating Intercept	-20	-20
Micrometre Zero	2469	2469
Iris Open Steps	250	250

	Initial (ICF15317.186)	*Final (ICF17319.186)*
Buffer Delay (s)	0	0
NO2 FW#1 Pos	64	64
O3 FW#1 Pos	256	256
FW#2 Pos	64	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2213	2213

18.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#186*	*O3 std*	*%diff*	*(*)O3# 186*	*O3 std*	*(*)%diff*
169	700> osc> 400	324	0.6	6	325	1.4	0.4	328	1.4	1.2
169	osc< 400	323	2.2	14	322	1.5	-0.3	325	1.6	0.7
170	1500> osc> 1000	319	0.1	3	319	0.2	0.0	320	0.3	0.3
170	1000> osc> 700	321	1.4	9	321	1.4	0.1	322	1.5	0.5
170	700> osc> 400	324	4.2	28	321	4.4	-0.8	323	4.5	-0.2
170	osc< 400	325	2.9	28	324	3.9	-0.5	326	3.9	0.3
171	osc> 1500	318	0.0	1	321	0.0	0.8	321	0.0	1.0
171	1500> osc> 1000	321	1.4	5	322	0.9	0.6	323	1.0	0.8
171	1000> osc> 700	330	6.6	5	330	5.9	0.0	331	5.9	0.5
171	700> osc> 400	334	3.8	34	331	3.5	-0.8	333	3.5	-0.1
171	osc< 400	336	1.3	26	332	2.1	-1.3	335	2.1	-0.4
172	1000> osc> 700	334	1.5	3	334	3.6	0.0	335	3.4	0.3
172	700> osc> 400	338	2.9	19	336	3.7	-0.5	338	3.9	0.1
172	osc< 400	341	0.9	11	338	3.2	-0.9	341	3.1	-0.1
173	osc> 1500	322	0.0	1	322	0.0	0.2	322	0.0	0.2
173	1500> osc> 1000	325	1.1	15	327	1.2	0.5	327	1.2	0.5

Day	osc range	O3#185	O3std	N	O3#186	O3 std	%diff	(*)O3# 186	O3 std	(*)%diff
173	1000> osc> 700	327	1.4	13	327	1.4	0.1	328	1.4	0.1
173	700> osc> 400	328	3.2	37	326	3.3	-0.5	327	3.4	-0.4
173	osc< 400	331	1.0	16	329	2.2	-0.5	330	2.2	-0.3
174	osc> 1500	314	0.0	1	315	0.0	0.3	315	0.0	0.3
174	1500> osc> 1000	314	1.2	7	316	1.0	0.7	316	1.0	0.7
174	1000> osc> 700	317	0.9	10	319	0.3	0.5	319	0.3	0.5
174	700> osc> 400	319	0.4	4	320	0.4	0.2	320	0.5	0.3
174	osc< 400	327	0.9	24	326	2.4	-0.1	327	2.4	0.1
175	osc> 1500	309	0.4	2	309	1.1	0.1	309	1.1	0.2
175	1500> osc> 1000	307	1.5	10	310	1.5	0.8	310	1.5	0.9
175	1000> osc> 700	308	1.5	8	309	1.9	0.5	310	1.8	0.6
175	700> osc> 400	307	0.7	11	307	1.0	0.0	308	1.1	0.3
175	osc< 400	307	0.2	3	307	0.6	0.2	308	0.6	0.5
176	osc> 1500	308	1.4	4	306	1.5	-0.3	307	1.6	-0.3
176	1500> osc> 1000	308	2.0	8	309	1.9	0.4	309	1.9	0.4
176	1000> osc> 700	307	2.4	10	308	2.8	0.3	308	2.9	0.3
176	700> osc> 400	308	1.7	20	308	2.1	0.1	308	2.1	0.2
176	osc< 400	310	1.4	21	309	2.0	-0.2	310	1.9	-0.1
177	osc> 1500	313	1.5	2	312	2.2	-0.2	312	2.2	-0.2
177	1000> osc> 700	314	5.3	6	315	5.9	0.3	315	6.0	0.3
177	700> osc> 400	313	4.0	21	312	4.9	-0.3	312	4.9	-0.2
177	osc< 400	310	1.4	14	309	2.4	-0.2	310	2.4	-0.1
178	1500> osc> 1000	302	0.0	1	NaN	NaN	NaN	301	0.0	-0.1
178	1000> osc> 700	305	0.4	4	NaN	NaN	NaN	306	0.3	0.2
178	700> osc> 400	307	1.2	11	NaN	NaN	NaN	307	1.3	0.0
178	osc< 400	312	2.0	18	NaN	NaN	NaN	312	2.5	0.0

18.9. APPENDIX: SUMMARY PLOTS

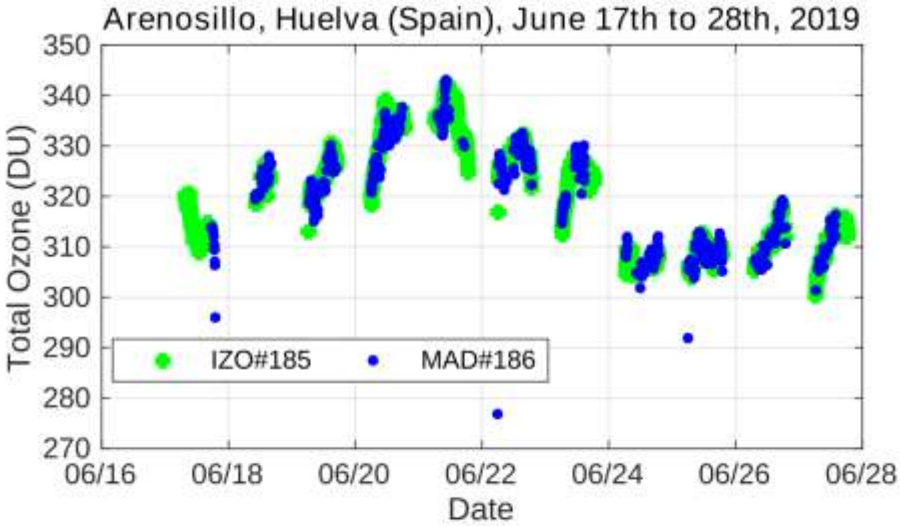
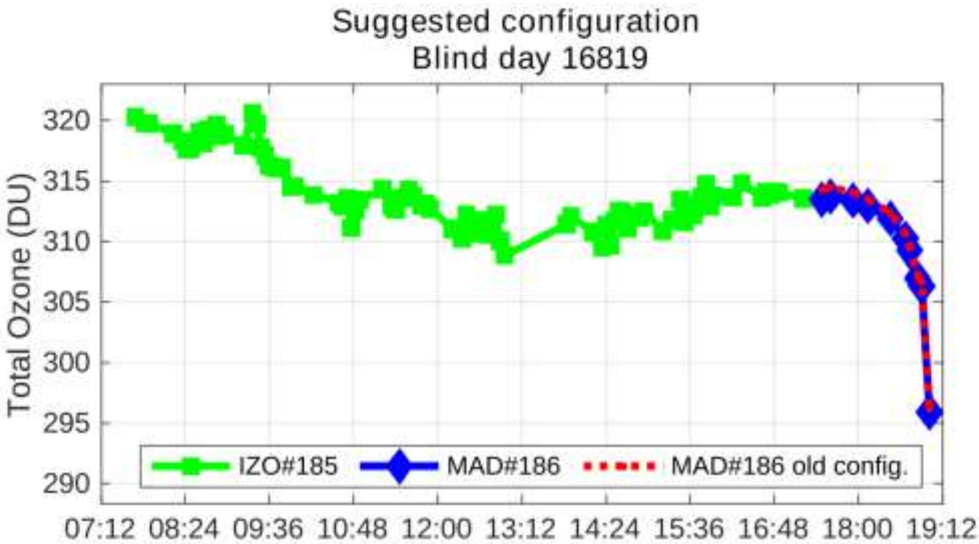
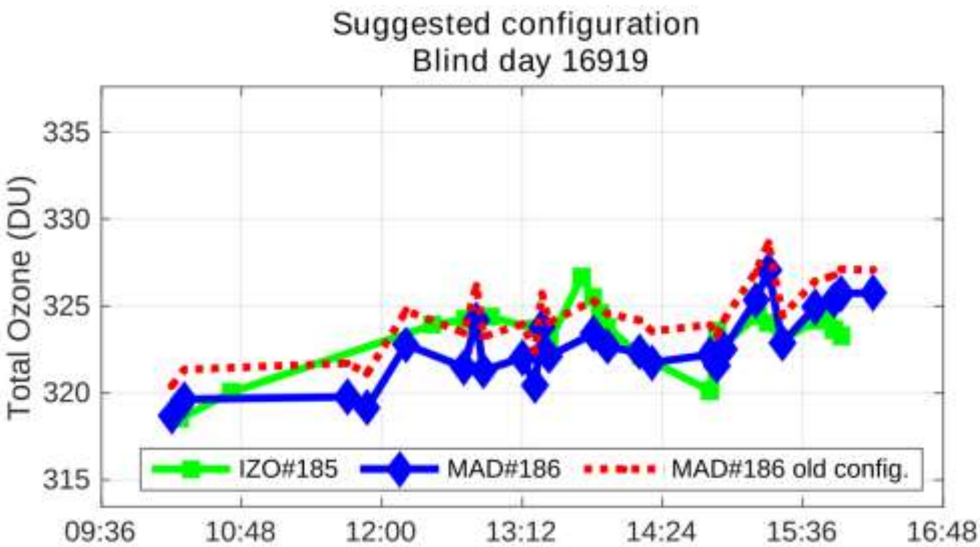
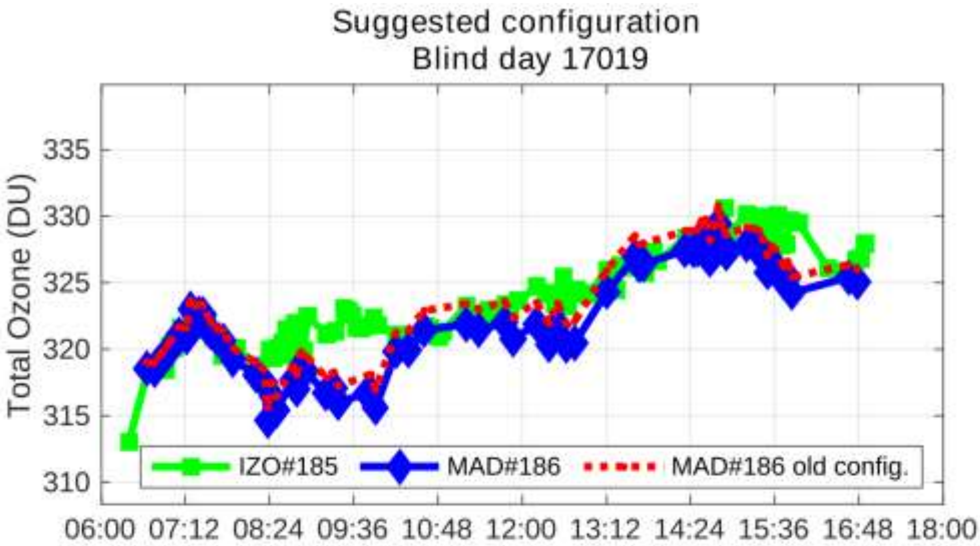
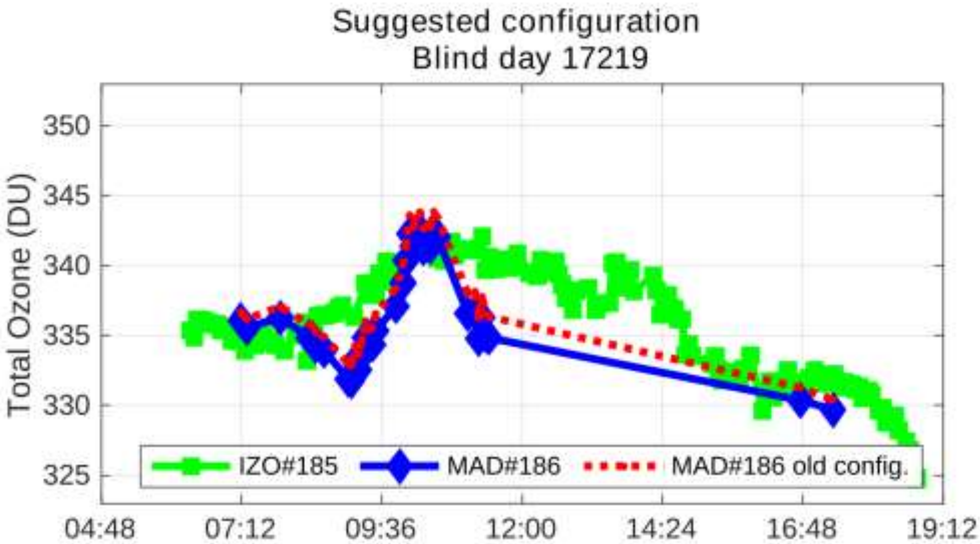


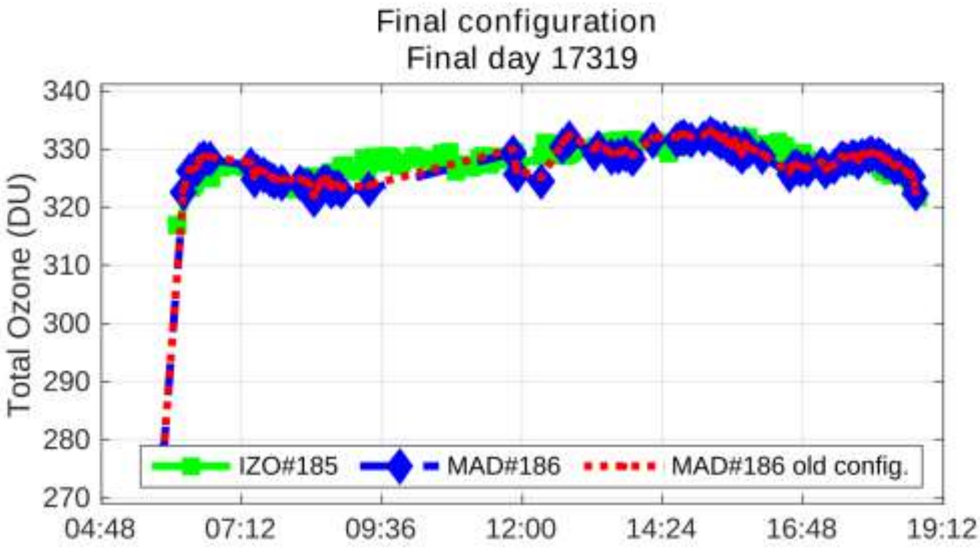
Figure 23. Overview of the intercomparison. Brewer MAD#186 data were evaluated using final constants (blue circles)

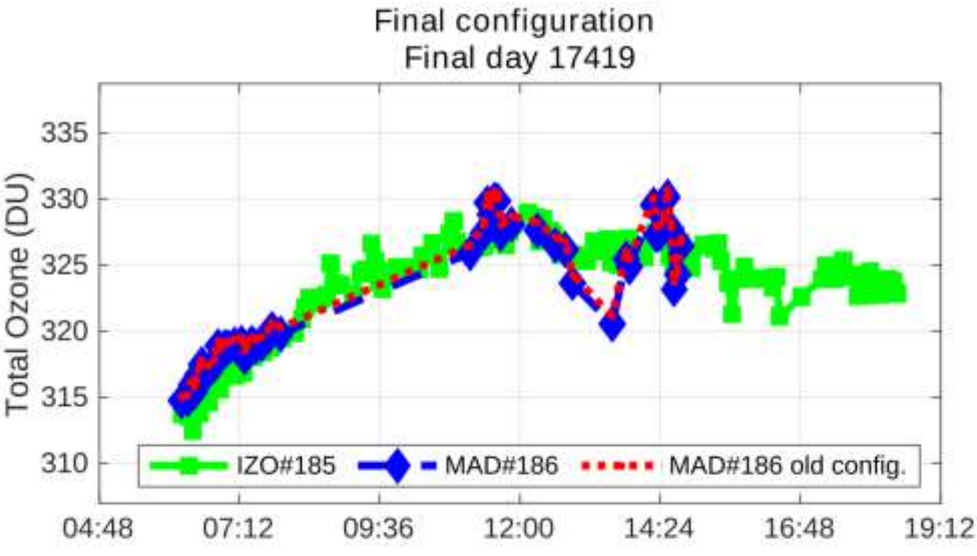


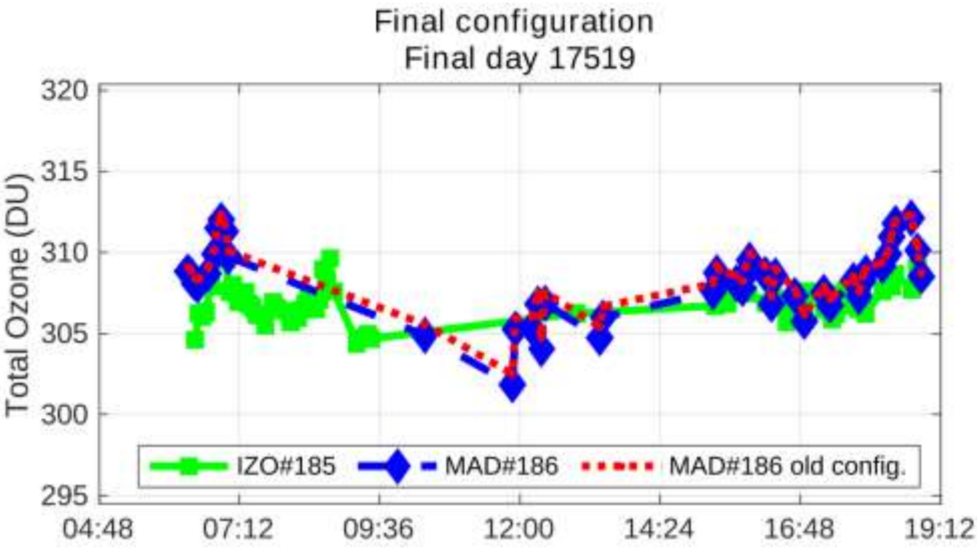


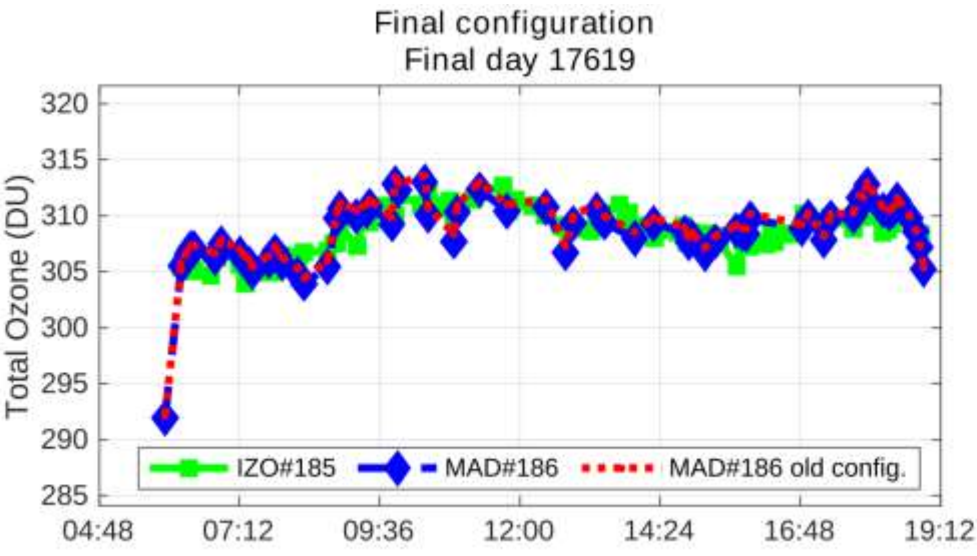

Suggested configuration
Blind day 17019
Total Ozone (DU)
335
330
325
320
315
310
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00
IZO#185
MAD#186
MAD#186 old config.

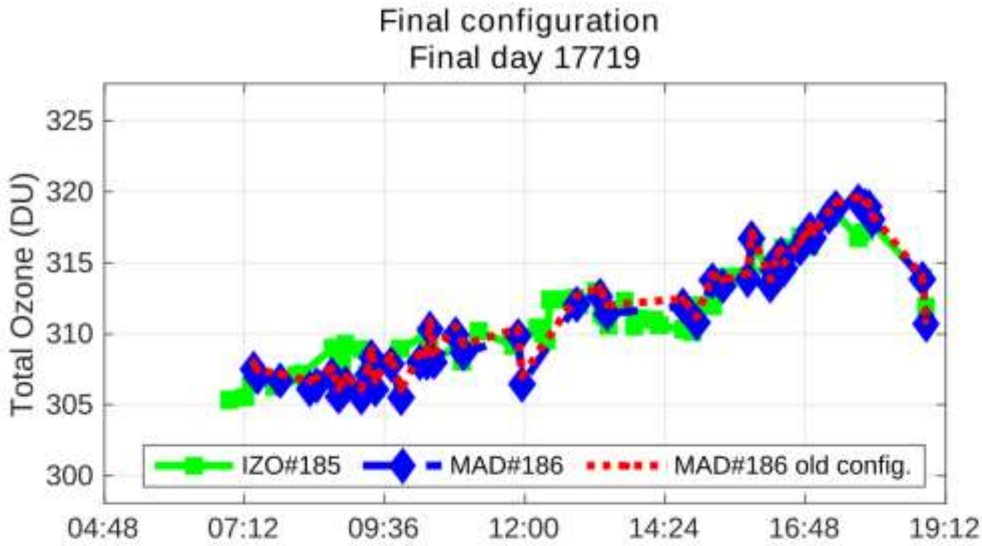

Suggested configuration
Blind day 17219
Total Ozone (DU)
350
345
340
335
330
325
04:48 07:12 09:36 12:00 14:24 16:48 19:12
IZO#185
MAD#186
MAD#186 old config.

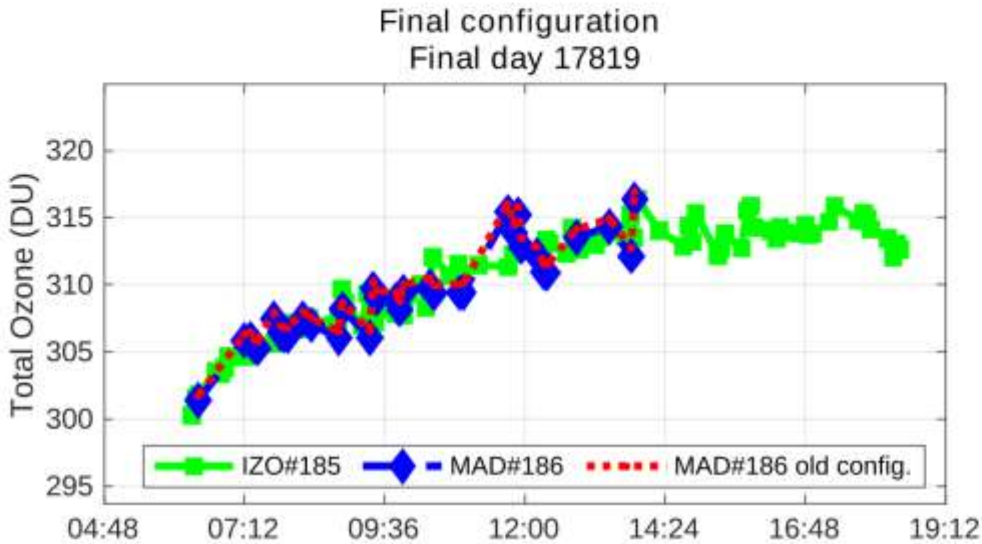

Final configuration
Final day 17319
Total Ozone (DU)
340
330
320
310
300
290
280
270
04:48 07:12 09:36 12:00 14:24 16:48 19:12
IZO#185
MAD#186
MAD#186 old config.


Final configuration
Final day 17419
Total Ozone (DU)
335
330
325
320
315
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#186
MAD#186 old config.


Final configuration
Final day 17519
Total Ozone (DU)
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#186
MAD#186 old config.


Final configuration
Final day 17619
Total Ozone (DU)
320
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#186
MAD#186 old config.


Final configuration
Final day 17719
Total Ozone (DU)
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#186
MAD#186 old config.


Final configuration
Final day 17819
Total Ozone (DU)
320
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
MAD#186
MAD#186 old config.

19. BREWER CAN#190

19.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer CAN#190 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer CAN#190 correspond to Julian days 166 – 178.

The instrument did not require maintenance, so we used the same data set both to evaluate the initial status of the instrument and for final calibration purposes: 471 simultaneous DS ozone measurements taken from day 170 to 177.

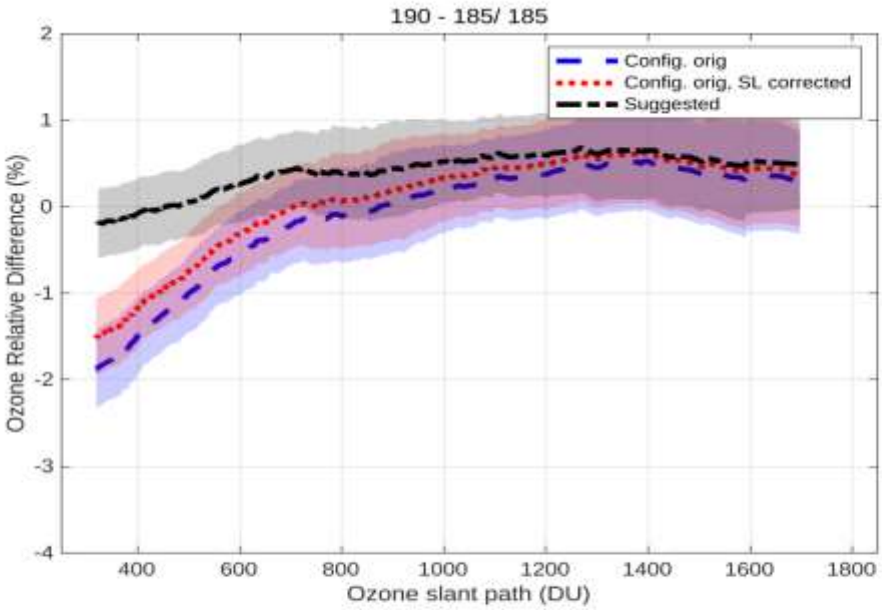


Figure 1. Mean DS ozone column percentage difference between Brewer CAN#190 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean

As shown in Figure 1, the current ICF (ICF11419.190, blue dashed line) produces ozone values with an average difference of approx. 1% with respect to the reference instrument in the lower OSC range. The SL correction (Figure 1, red dotted line) does not improve the comparison with Brewer IZO#185.

The lamp test results from Brewer CAN#190 show multiple changes over the last two years (see Figures 2 and 3). During the campaign, the standard lamp ratio values stabilized at around 416 and 670 for R6 and R5, respectively (see Figures 20 and 21). These values were calculated taking into account the new temperature coefficients calculated in this campaign.

Results from the analogue (AP) tests also showed multiple changes. Dead time (DT) results were somewhat noisy, but the current DT reference value of $2.1 \cdot 10^{-8}$ seconds still seems to be slightly larger than the value recorded during the calibration period, $2 \cdot 10^{-8}$ s. Therefore, this new value has been used in the new ICF.

All the other instrumental parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, and so forth) showed reasonable results.

We have detected a noticeable temperature dependence in the standard lamp measurements. New temperature coefficients are suggested in the final ICF (ICF17519.190) for the present campaign.

The neutral density filters did not show any clear nonlinearity in the attenuation's spectral characteristics. We have not applied any correction to filters.

The sun scan tests (SC) at the instrument's station before the campaign, and those performed during the first days of the intercomparison confirm the current cal step value (1017) within a step error of ± 1 .

The ozone absorption coefficient in use (0.3398) is slightly different to the value derived from dispersion tests performed in the present campaign. A new value of 0.341 is suggested in the final configuration.

Taking this into account, we suggest the following changes to the configuration of Brewer CAN#190:

19.1.1. Recommendations and remarks

1. We suggest a new R6 reference value of 416. This value has been calculated using new temperature coefficients.
2. We also suggest a new R5 reference value of 670.
3. We suggest updating the DT to $2 \cdot 10^{-8}$ seconds, which is 1 ns less than the current value.
4. From the results of the dispersion tests carried out at this campaign, we suggest updating the Ozone absorption coefficient from 0.3398 to 0.341.
5. We have detected a noticeable temperature dependence in the standard lamp measurements, so we have included new temperature coefficients in the final ICF of the present campaign.
6. Finally, we suggest updating the ETC value from 1690 to 1678.

19.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/190/ICF17519.190

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=606501928

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/190/html/cal_report_190a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/190/html/cal_report_190a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/190/html/cal_report_190b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/190/html/cal_report_190c.html

19.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

19.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp tests show multiple changes over the last 2 years. The average values for this period are 406 and 646 for R6 and R5, respectively. The same changes are also observed in the lamp's intensity (see Figure 4).

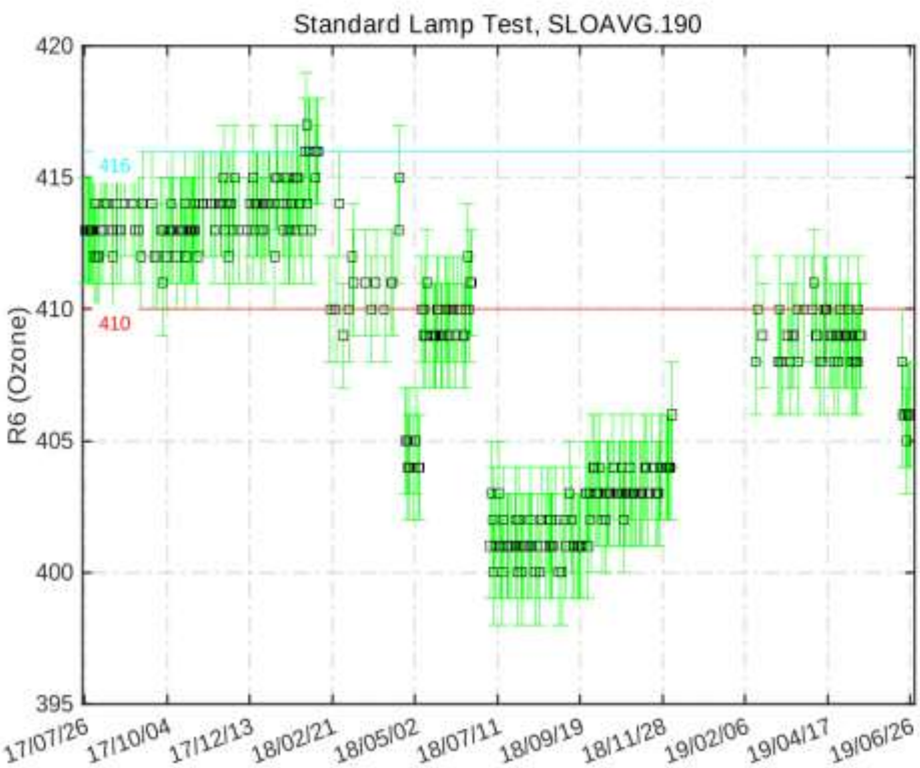


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original reference and 2-year average values (red and blue lines, respectively)

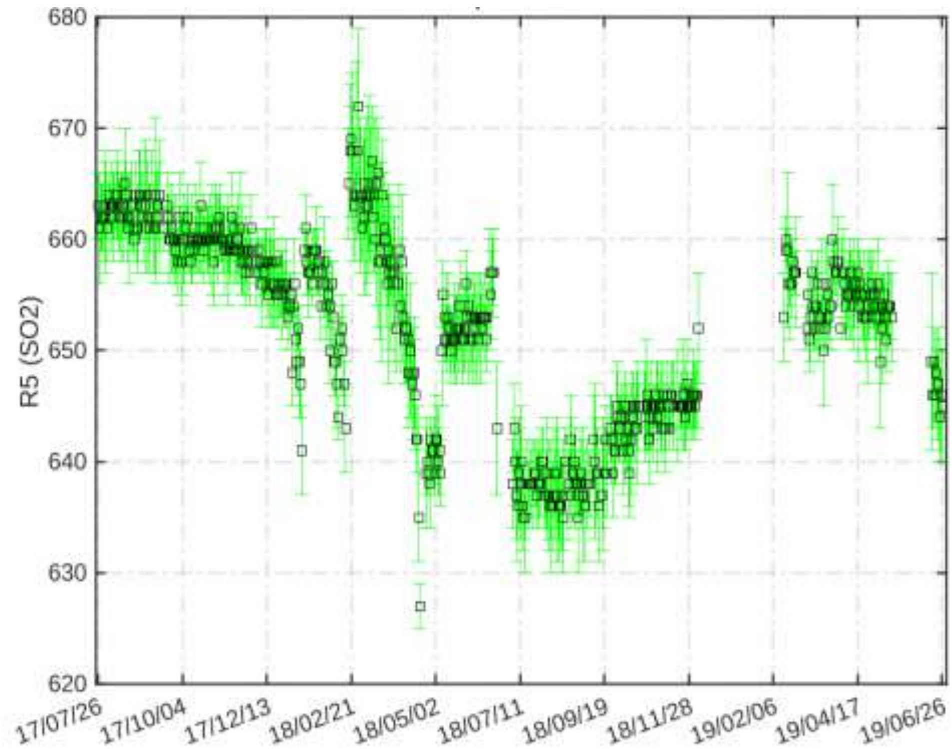


Figure 3. Standard lamp test R5 sulphur dioxide ratios

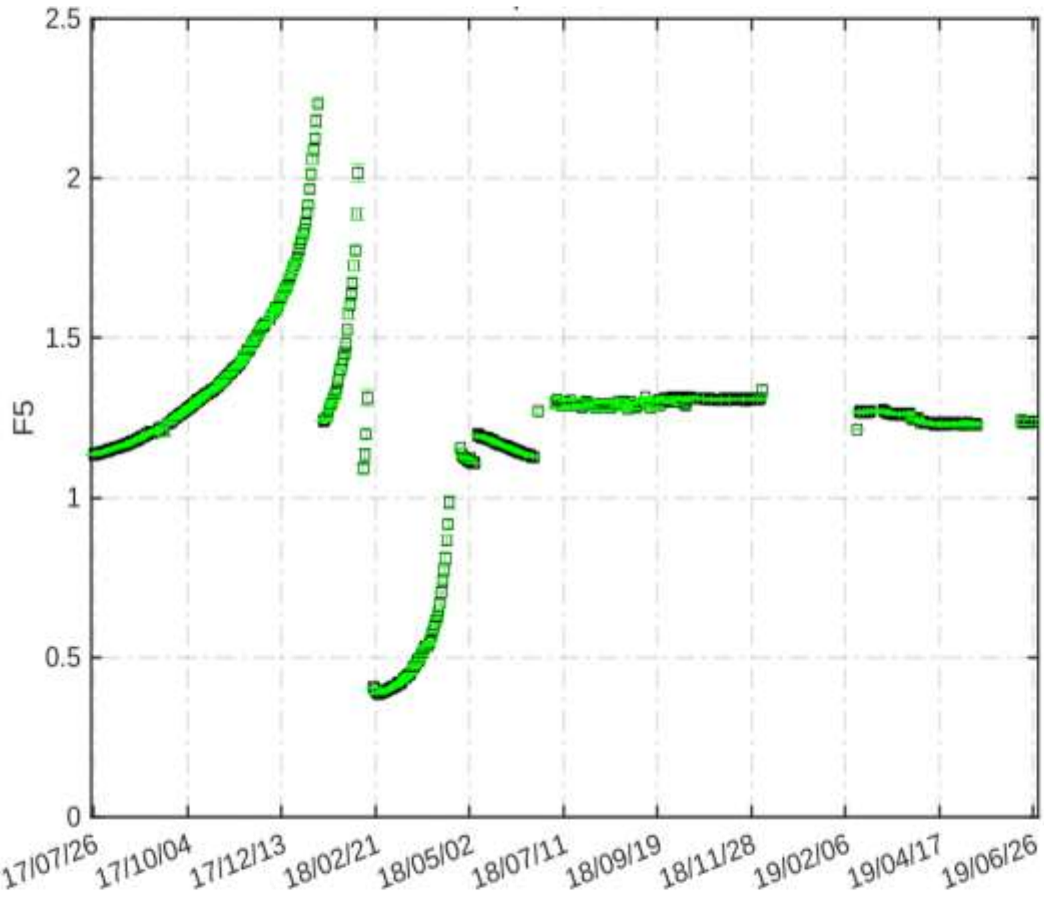


Figure 4. SL intensity for slit five

19.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, DT results over the last two years have been somewhat noisy. Despite that, the current DT reference value of $2.1 \cdot 10^{-8}$ seconds seems slightly larger than the value recorded during the calibration period, $2 \cdot 10^{-8}$ s. Therefore, this new value has been used in the new ICF.

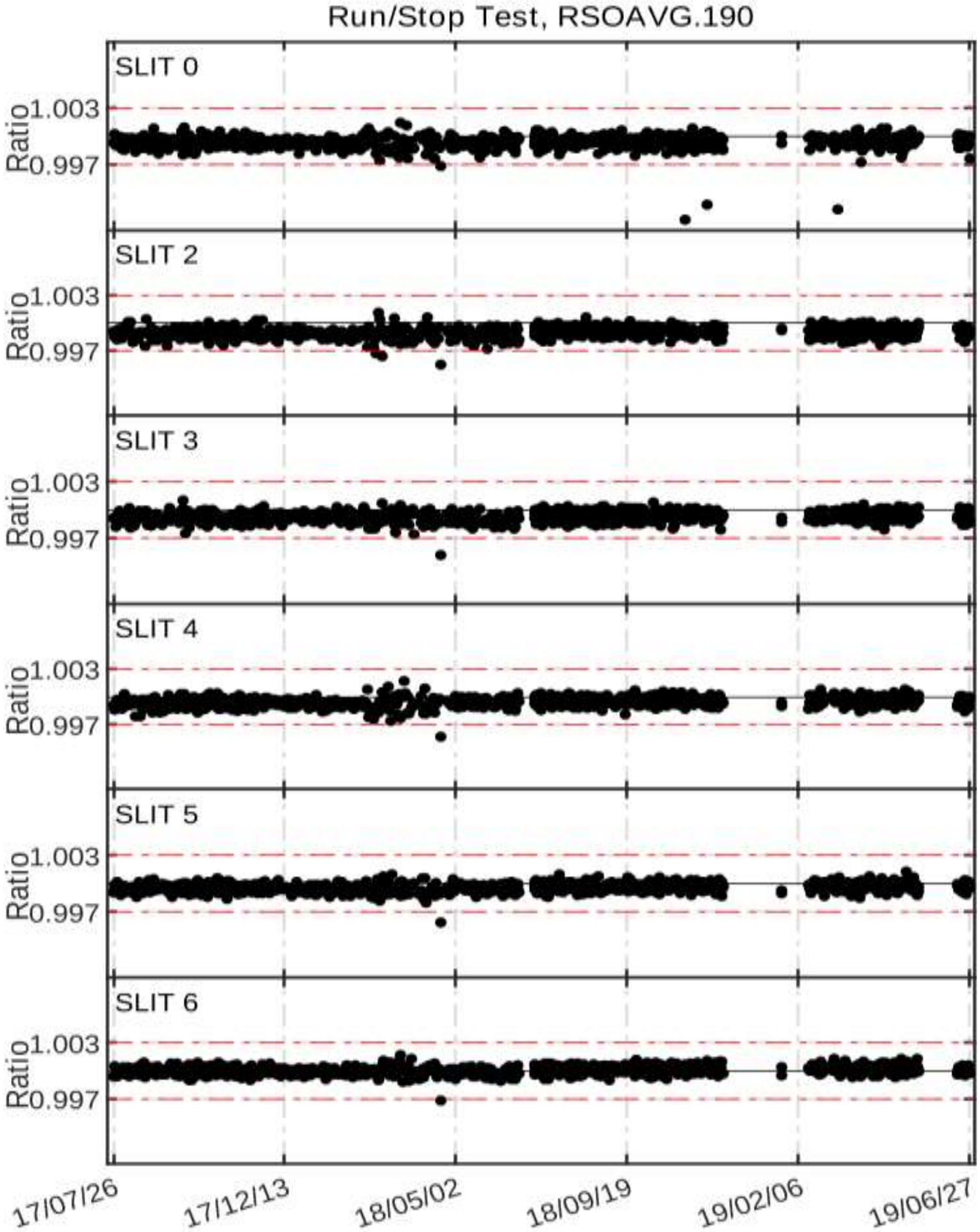


Figure 5. Run/stop test

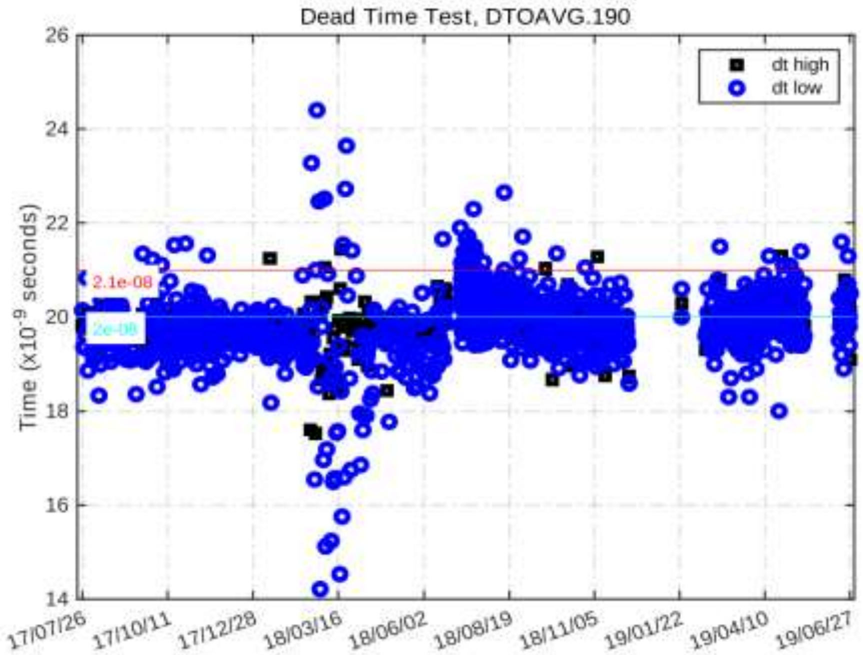


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

19.2.3. Analogue test

Figure 7 shows multiple changes in the high and +5 voltages, and also in the SL current. Note that the +5 voltage is always slightly above the upper tolerance limit.

Analogue Printout Log, APOAVG.190

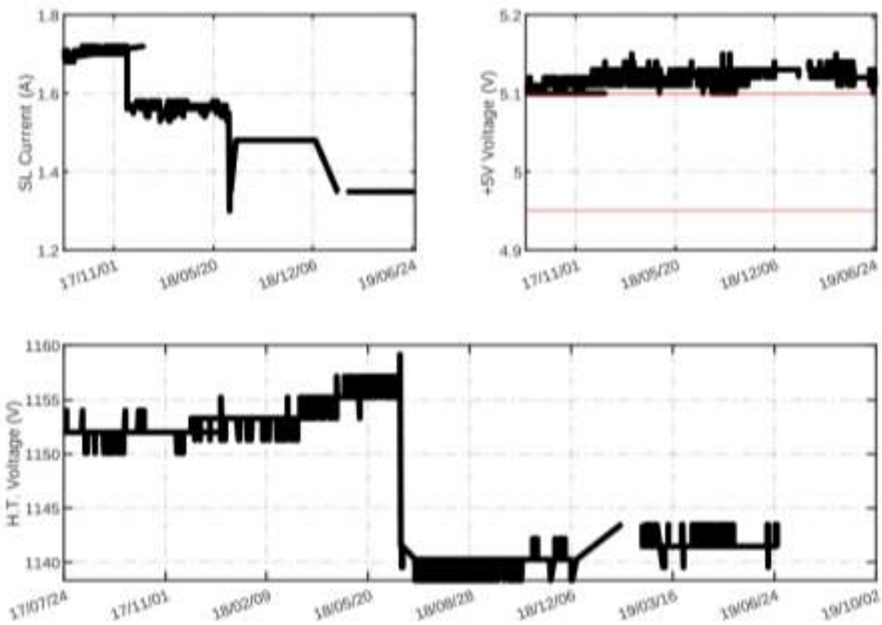


Figure 7. Analogue voltages and intensity

19.2.4. Mercury lamp test

Multiple changes were also observed in the internal mercury lamp intensity (see Figure 8). Some temperature dependence can be identified.

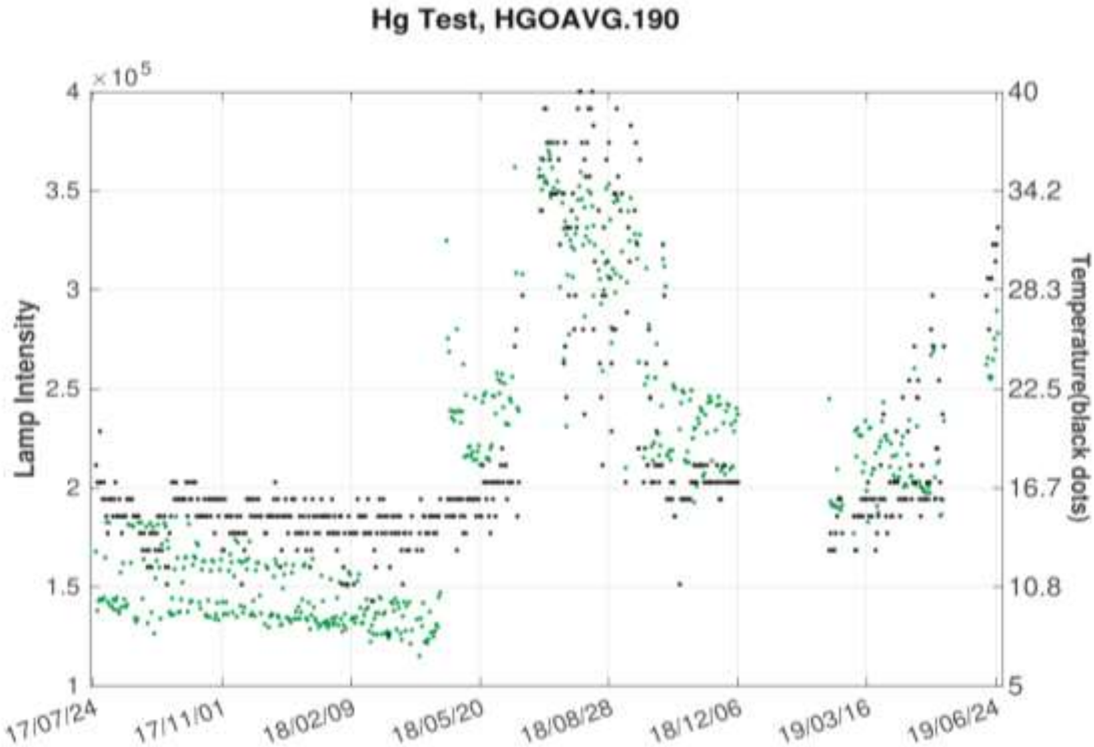


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

19.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer CAN#190 during the campaign showed reasonable results, with the peak of the calculated scans within the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.

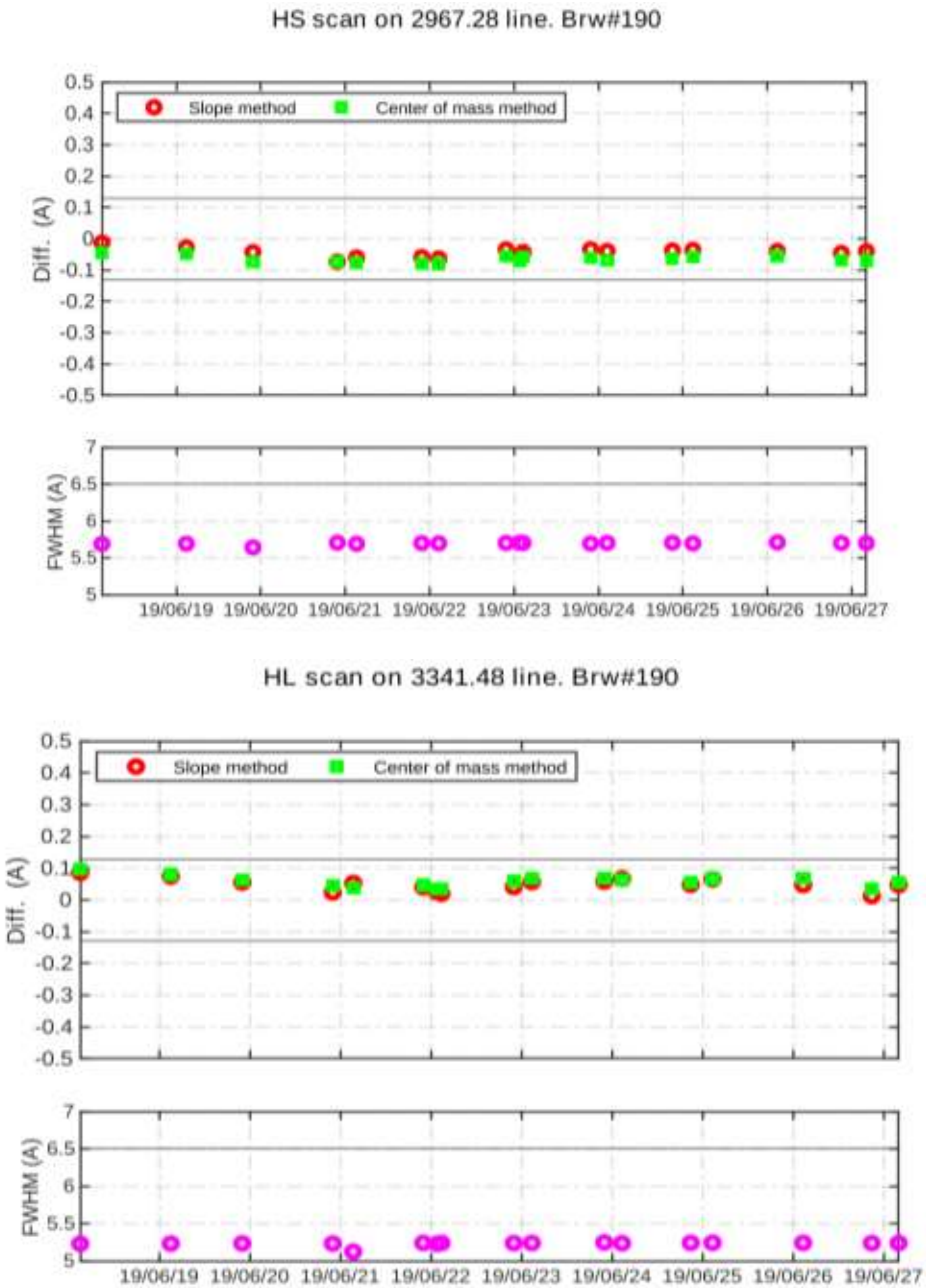


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

19.2.6. CI scan on internal *SL*

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer CAN#190 CI scans performed during the campaign relative to the scan CI17019.190. As can be observed, lamp intensity varied with respect to the referece spectrum by approx. 0.5%. This behaviour is normal for a SL lamp.

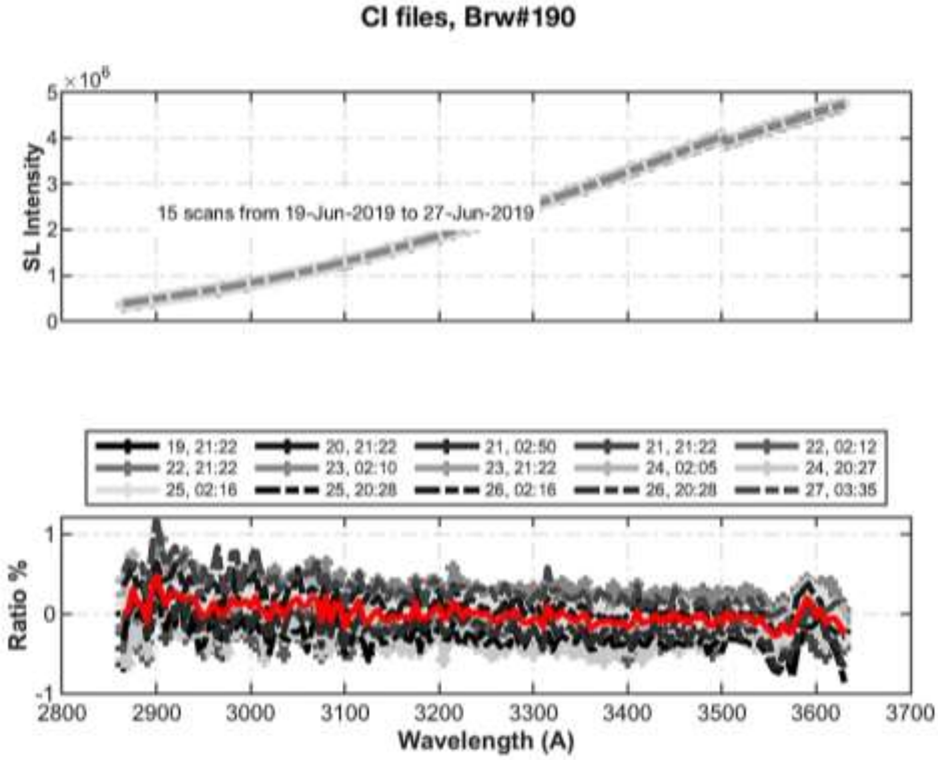


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

19.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 18 ˚C to 31 ˚C, using data from the present campaign), the current coefficients can be improved.

We have extended our analysis using the data recorded over the previous 2 years. As shown in Figures 12 and 13, the current coefficients also perform worse than those calculated using the data from the entire period. For this reason, in the final ICF we have used these new coefficients. The values of the coefficients are summarized in Table 1.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2. The coefficients in the "Calculated" row correspond to those obtained using data from the campaign. Those in the "Final" row have been determined using data measured during the last 2 years.

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	6.4772	6.2821	6.0600	5.8088	5.7584
Calculated	0.0000	-0.1800	-0.5300	-0.6300	-0.9400
Final	0.0000	-0.0960	-0.4410	-0.5390	-0.8600

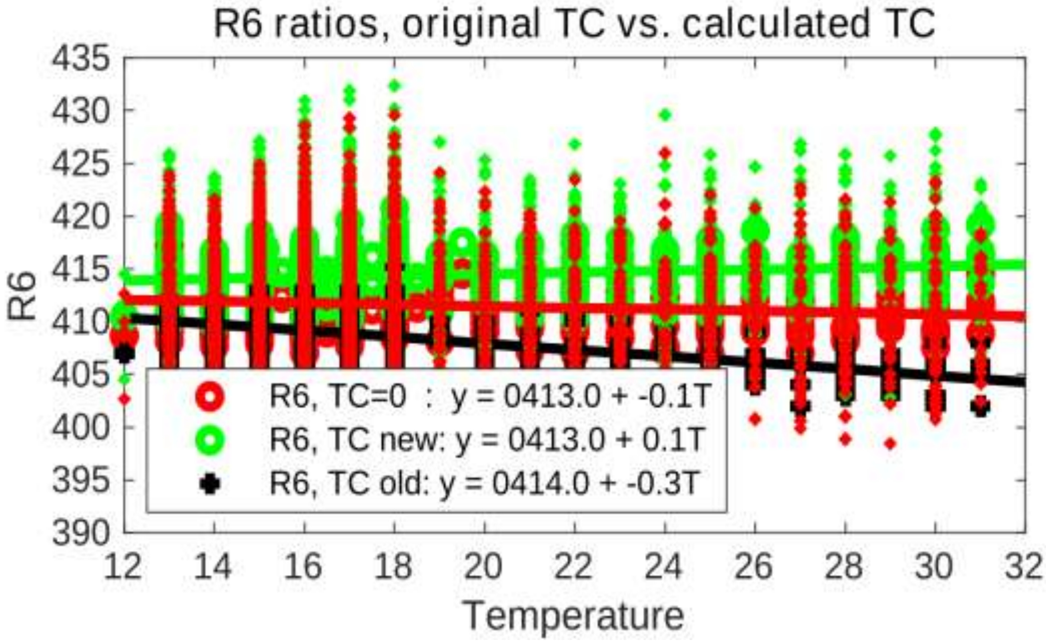


Figure 11. Temperature coefficients performance. Red circles represent standard lamp R6 ratio calculated from raw counts without temperature correction (temperature coefficients null). Black crosses and green circles represent standard lamp R6 ratio corrected with original temperature coefficients and corrected with calculated temperature coefficients respectively. The values plotted correspond to the measurements obtained during the campaign.

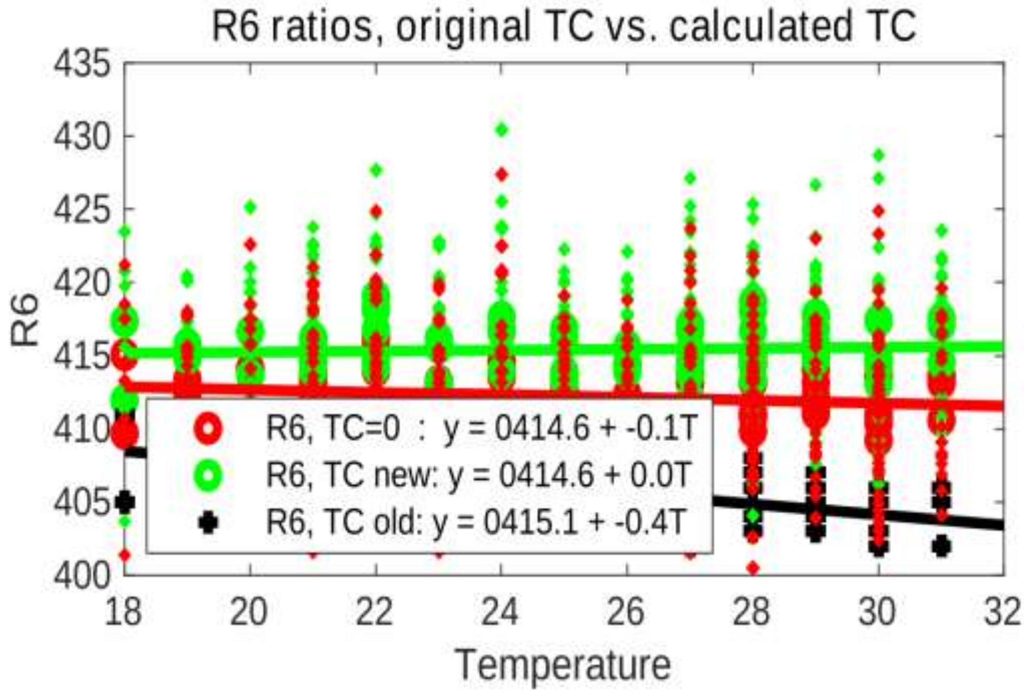


Figure 12. Same as Figure 11 but for the last 2 years

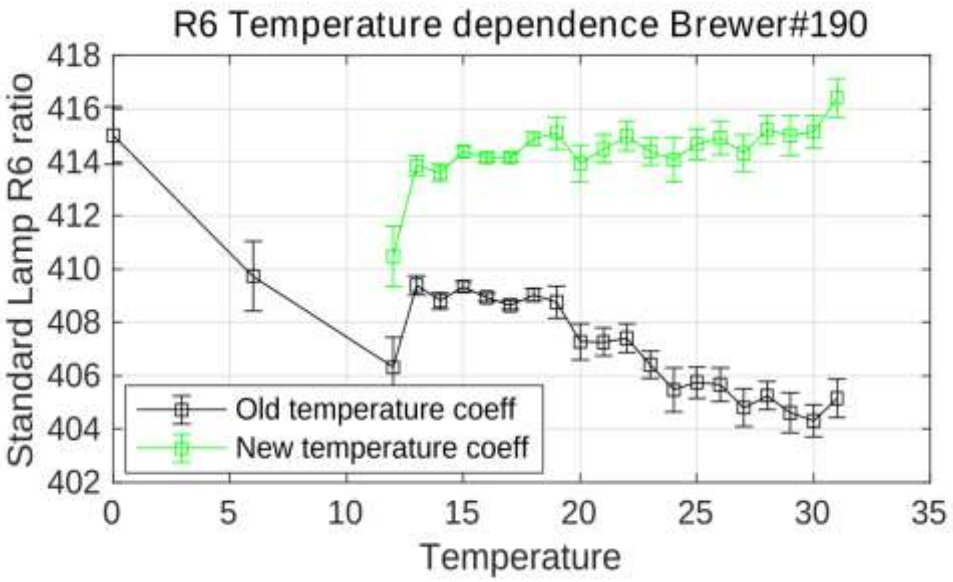


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

19.4. ATTENUATION FILTER CHARACTERIZATION

19.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 213 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

No correction factor is suggested to account for the non-linearity of ND filters. Taking into account an error of ± 5 units, Table 2 shows that Filters ND#2, #3 and #4 have a non-zero correction. However, once the median, mean and confidence intervals are all taken into consideration, only ND#4 is clearly outside the tolerance limits, but with very near values of Filter #3. Note also that the relative differences during filter changes shown in Figure 14 are all within tolerance limits. Also, taking into account the relative ozone difference with respect to the reference Brewer IZO#185, we do not suggest the application of correction factors for the filters.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	5	-8	-9	-11	-5
ETC Filt. Corr. (mean)	-0.8	-4.7	-6.2	-7.5	-5.6
ETC Filt. Corr. (mean 95% CI)	[-2.4 0.7]	[-6.2 -3.1]	[-7.7 -4.6]	[-9.1 -5.9]	[-7.5 -3.8]

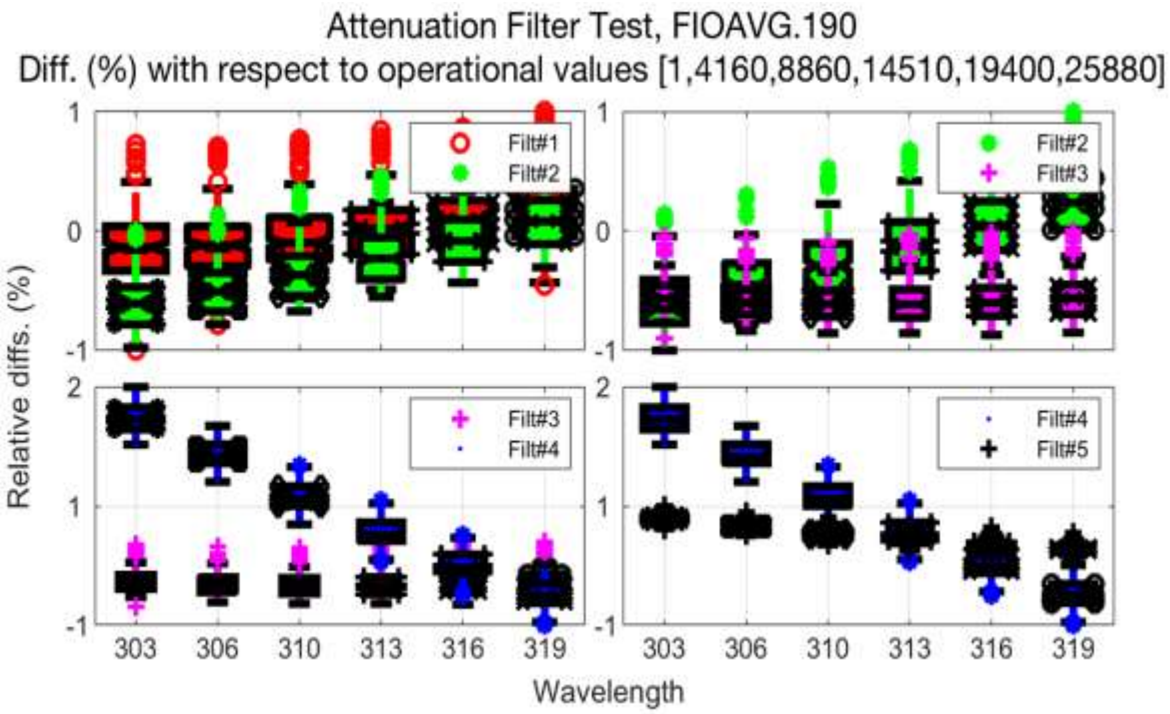


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

19.5. WAVELENGTH CALIBRATION

19.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan, see Figure 15.

During the campaign, 17 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1200 DU were carried out (see Figure 16). The calculated cal step number (CSN) was the same as that in the current configuration (1017). SC tests performed at the station before the campaign also provide the same CSN. Taking all this into account, we suggest keeping the current CSN (1017).

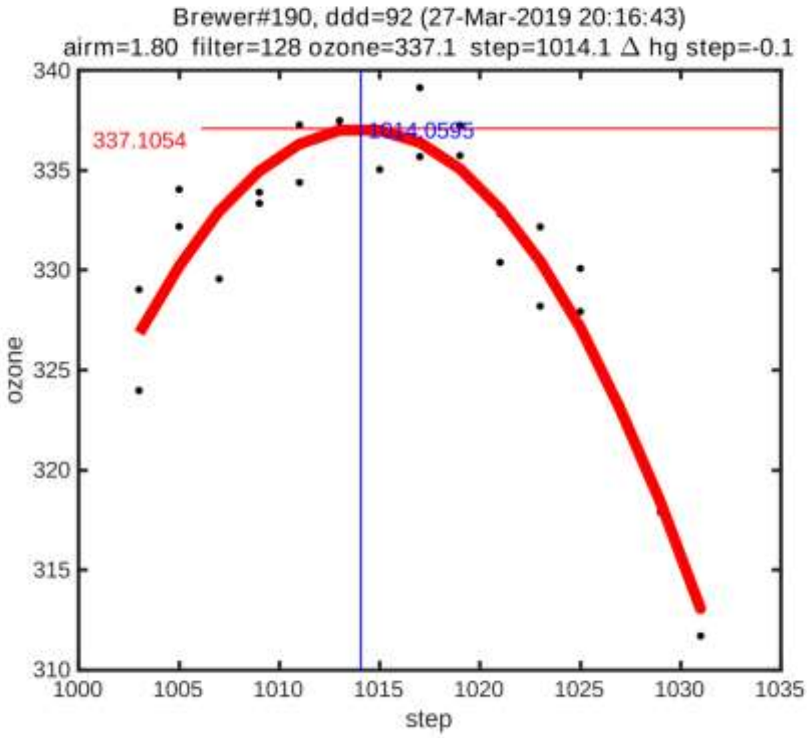


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

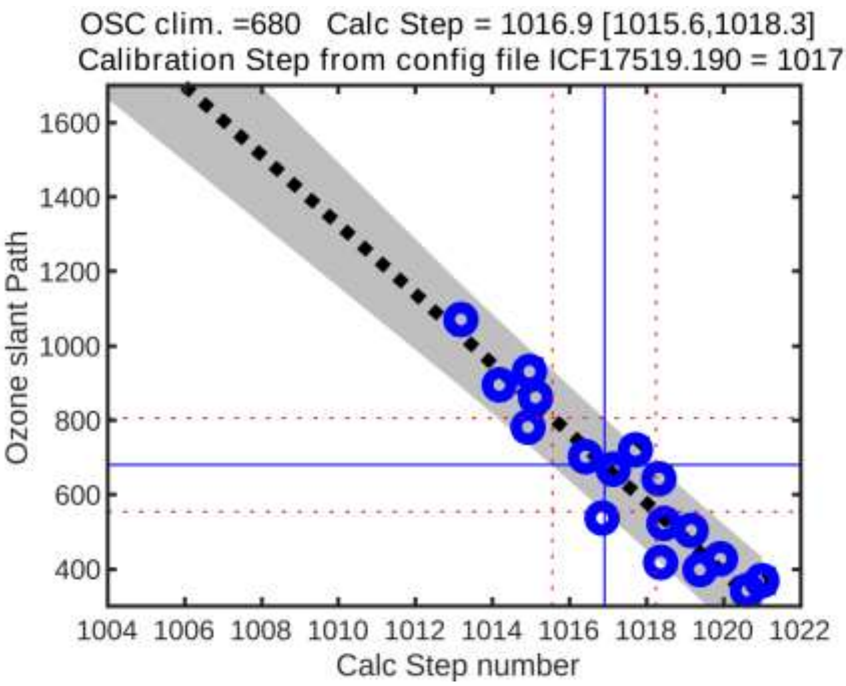


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

19.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was reasonably good for all the dispersion tests, with residuals being lower than 0.01 nm in most slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An updated absorption coefficient equal to 0.341 is suggested in the final configuration. Note that within the ± 1 cal step error, this is almost the same as the current value (0.3398).

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	1017	0.3398	2.3500	1.1424
27-Feb-2019	1017	0.3409	3.1304	1.1457
23-Jun-2019	1017	0.3408	3.1191	1.1465
Final	1017	0.3410	2.3500	1.1424

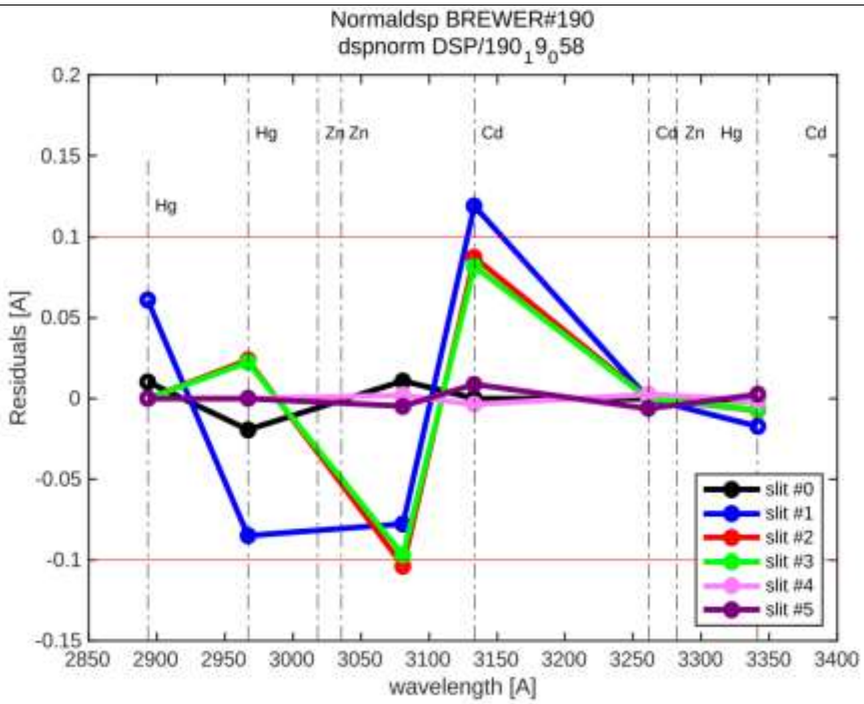


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 1016	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.68	3062.81	3100.35	3134.92	3167.91	3199.99
Res(A)	5.6754	5.6042	5.4678	5.5867	5.4721	5.382
O3abs(1/cm)	2.6071	1.784	1.0055	0.67661	0.37492	0.29383
Ray abs(1/cm)	0.50523	0.48336	0.45857	0.43716	0.4179	0.40021

SO2abs(1/cm)	3.4958	5.5747	2.3923	1.9141	1.0534	0.61158
step= 1017	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.76	3062.89	3100.42	3134.99	3167.98	3200.06
Res(A)	5.6753	5.6042	5.4677	5.5867	5.472	5.3819
O3abs(1/cm)	2.6046	1.7826	1.0052	0.67625	0.37496	0.29336
Ray abs(1/cm)	0.50517	0.48331	0.45853	0.43711	0.41786	0.40017
SO2abs(1/cm)	3.4777	5.5986	2.3997	1.9026	1.0546	0.60932
step= 1018	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.83	3062.96	3100.49	3135.07	3168.05	3200.13
Res(A)	5.6752	5.6041	5.4676	5.5866	5.472	5.3818
O3abs(1/cm)	2.6022	1.7809	1.0049	0.67588	0.37503	0.29288
Ray abs(1/cm)	0.50512	0.48326	0.45848	0.43707	0.41783	0.40013
SO2abs(1/cm)	3.461	5.6204	2.4078	1.8911	1.0558	0.60703
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
1016	0.34184	9.5651	3.1077	1.1496	0.35283	0.34415
1017	0.34084	9.5626	3.1191	1.1465	0.35183	0.34312
1018	0.33977	9.5602	3.1285	1.143	0.35079	0.34205

19.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2426. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 1017	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.6753	5.6042	5.4677	5.5867	5.472	5.3819
O3abs(1/cm)	2.6046	1.7826	1.0052	0.67625	0.37496	0.29336
Ray abs(1/cm)	0.50517	0.48331	0.45853	0.43711	0.41786	0.40017
step= 2426	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.5447	5.4724	5.3508	5.4589	5.3704	5.2388
O3abs(1/cm)	0.67862	0.39458	0.29349	0.12193	0.060914	0.033375
Ray abs(1/cm)	0.43791	0.42023	0.40017	0.38277	0.3671	0.35267

19.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 8 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

The network Brewers were calibrated using the one parameter ETC transfer method (1P) and only the ozone ETC constant was transferred from the reference instrument. The so-called 'two-parameters calibration method' (2P) where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and used as a quality indicator of the calibration. We consider a good calibration when both ETC agrees in 10 ETC units and the ozone absorption coefficient calculated from dispersion and obtained by 2P agrees in +/- 2 micrometre steps or approximately +/- 0.002 $atm.cm^{-1}$. This range represents a total ozone difference of about 0.5% at air mass equal to 2 and total ozone of 300 DU.

19.6.1. Initial calibration

For the evaluation of initial status of Brewer CAN#190, we used the period from days 170 to 177 which correspond to 471 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced ozone values on average 1% lower than the reference instrument in the lower OSC range. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

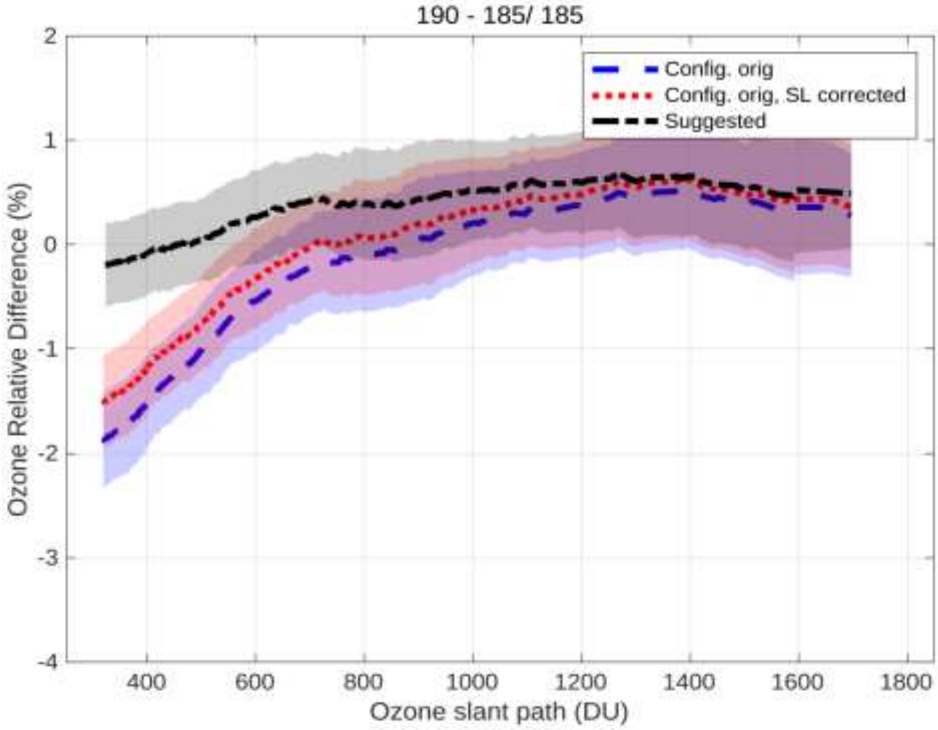


Figure 18. Mean direct sun ozone column percentage difference between Brewer CAN#190 and Brewer IZO#185 as a function of ozone slant path

19.6.2. Final calibration

A new ETC value was calculated (see Figure 19) using the same 471 simultaneous direct sun measurements from days 170 to 177. The new value, 1678, is almost 20 units lower than the current ETC value of 1690. Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (416 for R6). We updated the new calibration constants in ICF17519.190 provided. Of course, the new ETC has been calculated taking into account the new suggested value for the dead time of $2 \cdot 10^{-8}$ s.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 6, there is a difference of approx. 15 units between the ETC of the 1P and 2P methods.

Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

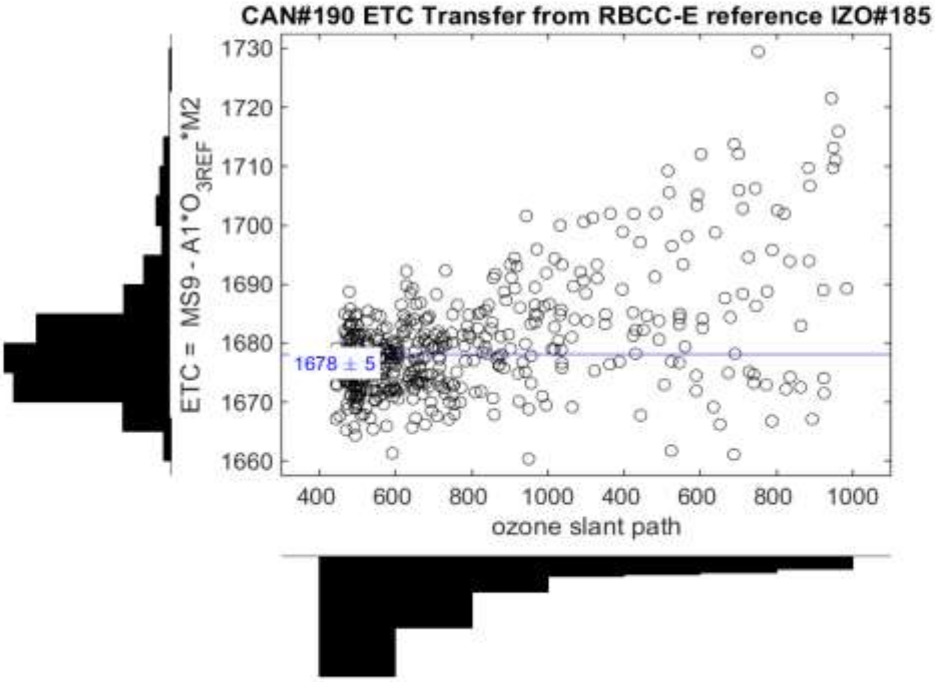


Figure 19. Mean direct sun ozone column percentage difference between Brewer CAN#190 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1678	1663	3398	3447
full OSC range	1678	1662	3398	3447

Table 7. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#190*	*O3 std*	*%(190–185)/185*	*O3(*) #190*	*O3std*	*(*)%(190–185)/185*
18-Jun-2019	169	324.6	1.2	8	319.9	1.8	-1.4	325.1	1.7	0.2
19-Jun-2019	170	324.3	3.3	63	319.7	3.3	-1.4	323.9	3.2	-0.1
20-Jun-2019	171	333.9	4.3	84	330.2	2.8	-1.1	333.7	3.3	-0.1
21-Jun-2019	172	335.9	3.5	80	332.2	3	-1.1	335.9	3.4	0
22-Jun-2019	173	330.1	1.7	55	325	1.7	-1.5	329.2	1.4	-0.3
23-Jun-2019	174	323.9	2.9	78	320.8	1.4	-1	324.4	2.1	0.2
24-Jun-2019	175	307.4	1.2	32	305.2	3.2	-0.7	308	2.3	0.2
25-Jun-2019	176	308.7	2.2	47	305.3	1.8	-1.1	308.9	1.6	0.1
26-Jun-2019	177	308.5	1.2	24	304.4	1.6	-1.3	308.6	0.9	0

19.6.3. Standard lamp reference values

Using the updated temperature coefficients, the reference values of the standard lamp ratios during the calibration period were 416 for R6 (Figure 20) and 670 for R5 (Figure 21).

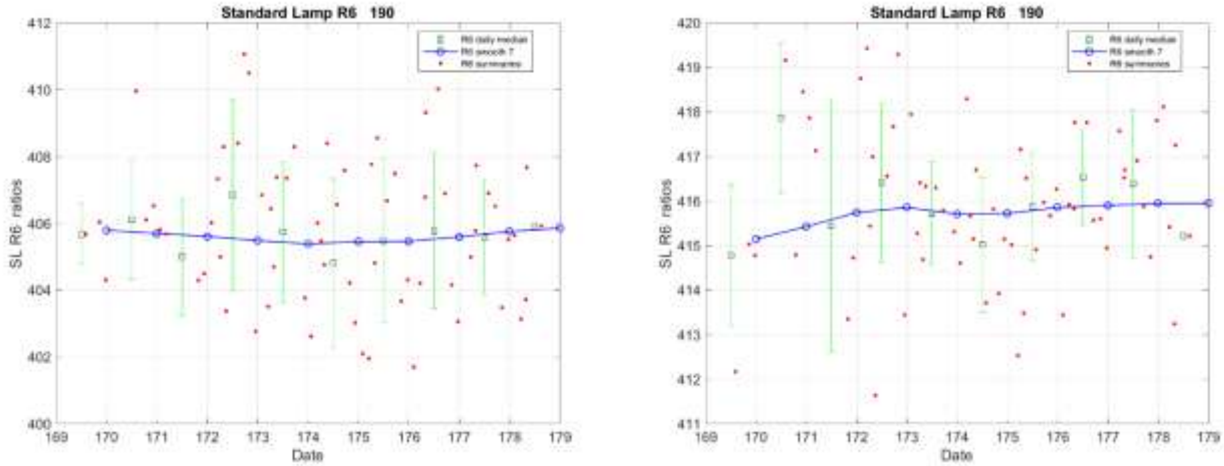


Figure 20. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

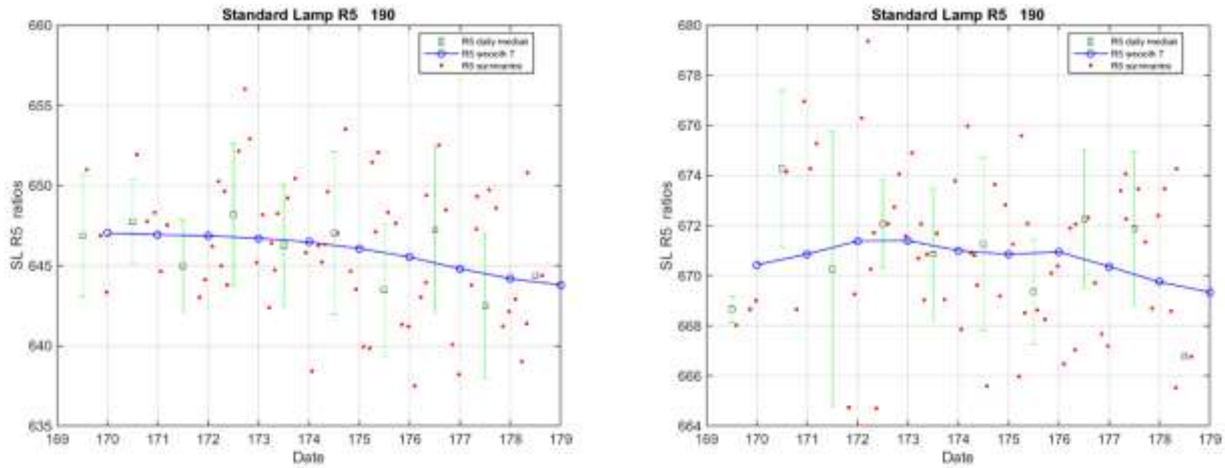


Figure 21. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using the old and new instrumental constants

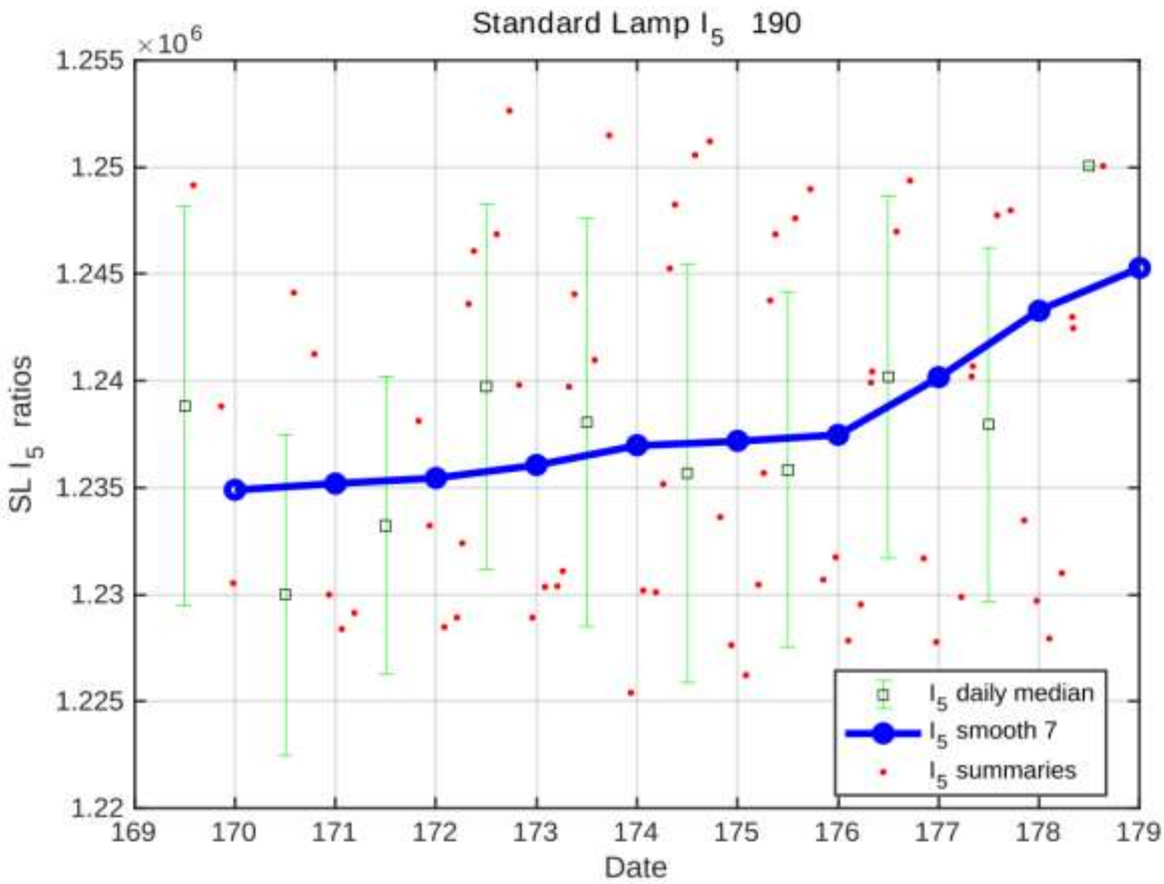


Figure 22. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

19.7. CONFIGURATION

19.7.1. Instrument constant file

	Initial (ICF11419.190)	*Final (ICF17519.190)*
o3 Temp coef 1	6.4772	0
o3 Temp coef 2	6.2821	-0.096
o3 Temp coef 3	6.06	-0.441
o3 Temp coef 4	5.8088	-0.539
o3 Temp coef 5	5.7584	-0.86
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.3398	0.341
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1424	1.1424
ETC on O3 Ratio	1690	1678

	Initial (ICF11419.190)	*Final (ICF17519.190)*
ETC on SO2 Ratio	365	365
Dead time (sec)	2.1e-08	2e-08
WL cal step number	1017	1017
Slitmask motor delay	14	14
Umkehr Offset	1714	1714
ND filter 0	0	0
ND filter 1	4160	4160
ND filter 2	8860	8860
ND filter 3	14510	14510
ND filter 4	19400	19400
ND filter 5	25880	25880
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	6984	6984
Mic #2 Offset	6381	6381
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2515	2515
Grating Slope	0.9969	0.9969
Grating Intercept	-2.5	-2.5

	Initial (ICF11419.190)	*Final (ICF17519.190)*
Micrometre Zero	1738	1738
Iris Open Steps	250	250
Buffer Delay (s)	0	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2212	2212

19.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	osc range	O3#185	O3std	N	O3#190	O3 std	%diff	(*)O3#190	O3 std	(*)%diff
169	osc< 400	323	2.2	8	320	2.1	-0.9	320	2.1	-0.9
170	1500> osc> 1000	319	0.1	4	320	0.1	0.4	320	0.3	0.5
170	700> osc> 400	324	3.8	62	321	3.6	-0.9	322	3.9	-0.5
170	osc< 400	324	2.7	60	320	2.5	-1.3	322	3.2	-0.7
171	osc> 1500	329	8.0	6	330	6.1	0.3	329	6.2	0.3
171	1500> osc> 1000	328	6.2	20	330	5.1	0.5	330	5.1	0.5
171	1000> osc> 700	331	5.9	38	331	4.3	0.1	332	4.4	0.2
171	700> osc> 400	333	4.0	62	331	3.0	-0.6	332	3.4	-0.3
171	osc< 400	336	1.0	68	332	1.2	-1.3	334	2.2	-0.7
172	osc> 1500	325	0.5	4	326	0.2	0.3	326	0.2	0.4
172	1500> osc> 1000	333	3.6	24	335	4.6	0.5	335	4.6	0.6
172	1000> osc> 700	332	1.5	26	332	3.1	-0.1	332	3.1	0.1
172	700> osc> 400	335	3.1	74	333	3.4	-0.7	334	3.7	-0.3
172	osc< 400	339	1.9	60	334	2.3	-1.5	336	3.1	-0.9
173	osc> 1500	319	2.8	4	321	0.1	0.6	321	0.2	0.6
173	1500> osc> 1000	325	1.2	30	327	2.5	0.5	327	2.5	0.5
173	1000> osc> 700	328	0.5	12	326	0.4	-0.4	327	0.7	-0.3

Day	osc range	O3#185	O3std	N	O3#190	O3 std	%diff	(*)O3#190	O3 std	(*)%diff
173	700> osc> 400	330	1.6	42	327	0.9	-0.9	328	1.7	-0.5
173	osc< 400	330	1.5	54	325	1.3	-1.5	327	2.5	-0.8
174	osc> 1500	314	0.0	4	315	1.6	0.5	315	1.6	0.5
174	1500> osc> 1000	319	4.5	18	321	2.8	0.5	321	2.8	0.5
174	1000> osc> 700	321	3.4	40	321	2.0	0.1	322	2.1	0.2
174	700> osc> 400	323	2.1	62	322	1.3	-0.4	323	2.0	0.0
174	osc< 400	326	1.1	52	322	1.2	-1.3	324	2.4	-0.7
175	1500> osc> 1000	307	1.3	18	309	0.8	0.6	309	0.8	0.6
175	1000> osc> 700	308	1.4	16	310	2.4	0.6	310	2.3	0.8
175	700> osc> 400	307	1.1	40	305	1.7	-0.6	306	2.0	-0.3
175	osc< 400	307	0.2	6	303	0.5	-1.3	305	2.0	-0.7
176	osc> 1500	306	0.0	2	308	0.0	0.8	308	0.0	0.8
176	1500> osc> 1000	308	2.2	16	308	1.2	0.2	308	1.2	0.3
176	1000> osc> 700	307	2.2	20	308	1.1	0.2	308	1.2	0.4
176	700> osc> 400	308	1.6	40	306	1.6	-0.6	307	2.0	-0.2
176	osc< 400	310	1.4	34	306	1.6	-1.5	308	2.6	-0.9
177	osc> 1500	313	1.2	4	312	1.0	-0.3	312	1.0	-0.3
177	1000> osc> 700	313	5.6	14	313	5.2	0.0	313	5.3	0.2
177	700> osc> 400	313	4.2	44	310	4.2	-0.8	312	4.2	-0.4
177	osc< 400	311	1.4	54	306	1.7	-1.7	308	2.7	-1.0
178	1500> osc> 1000	302	1.1	3	304	0.7	0.5	304	0.7	0.5
178	1000> osc> 700	305	0.0	2	306	0.4	0.5	306	0.4	0.5
178	osc< 400	315	0.9	2	310	0.3	-1.5	310	0.3	-1.5

19.9. APPENDIX: SUMMARY PLOTS

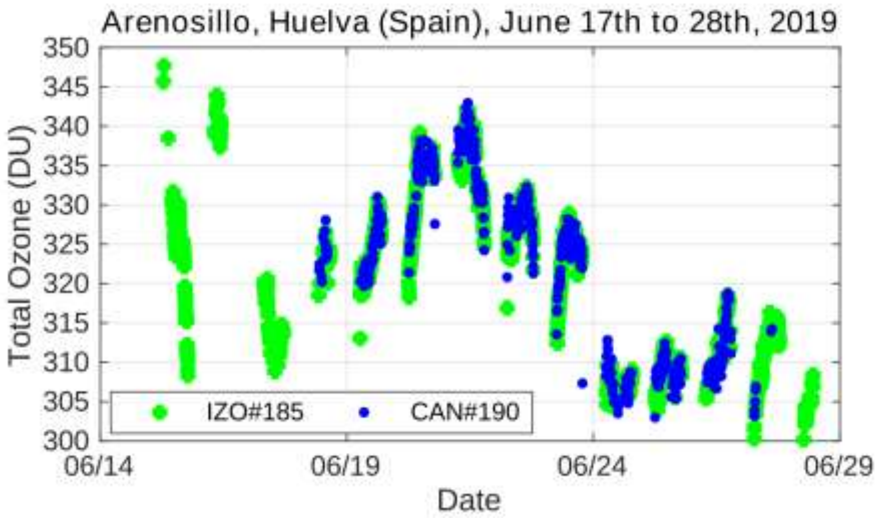
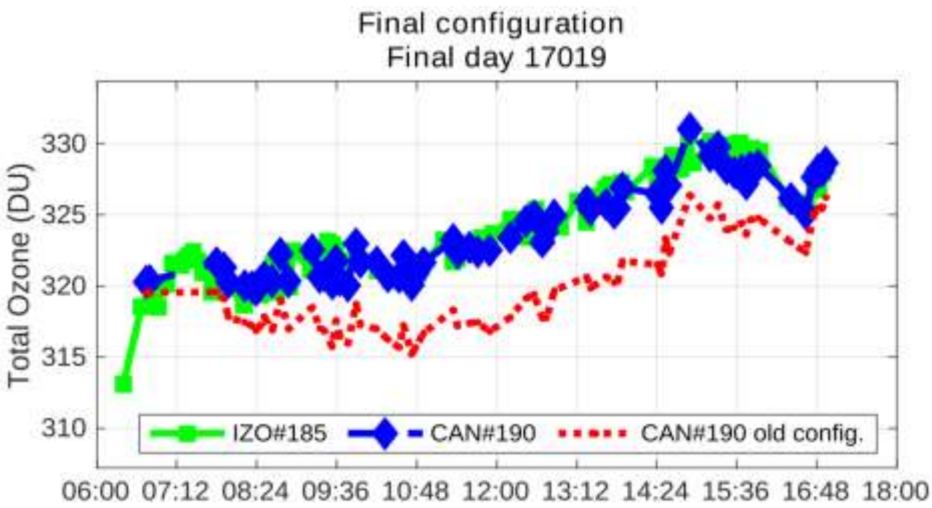
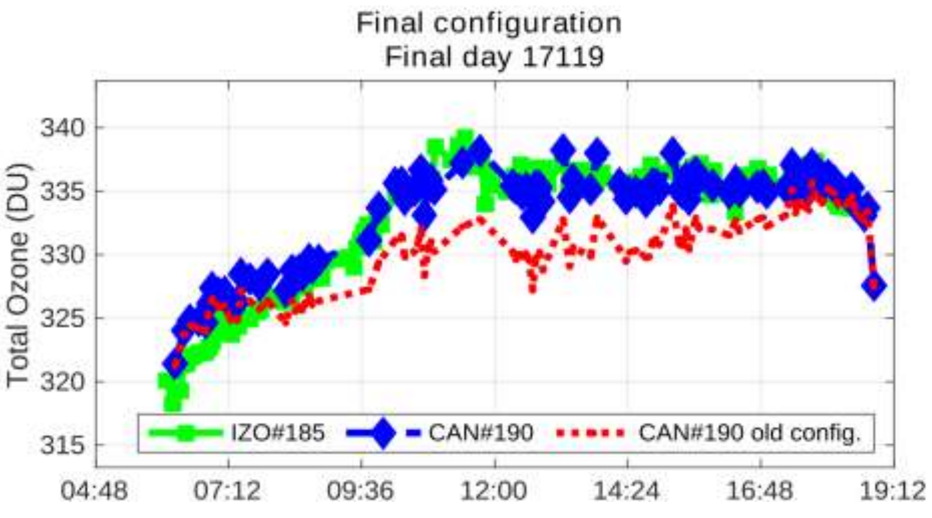
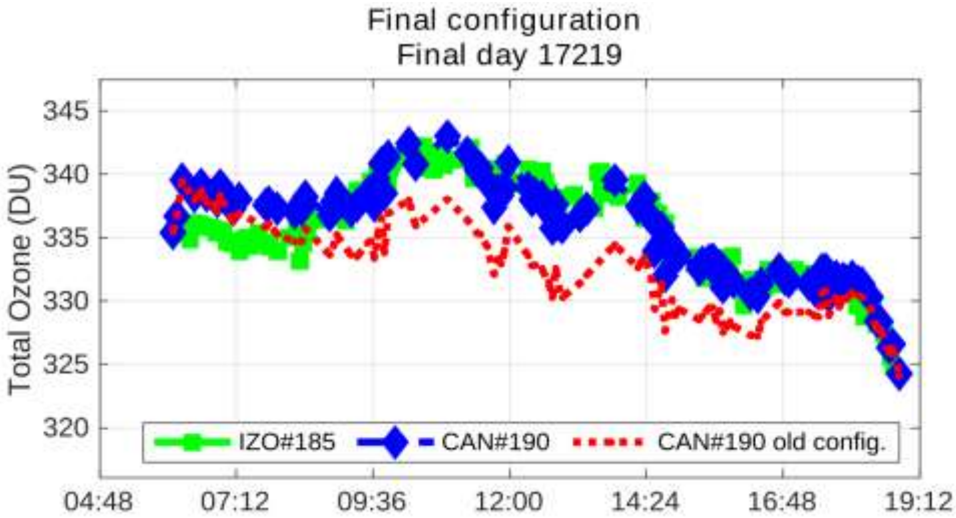
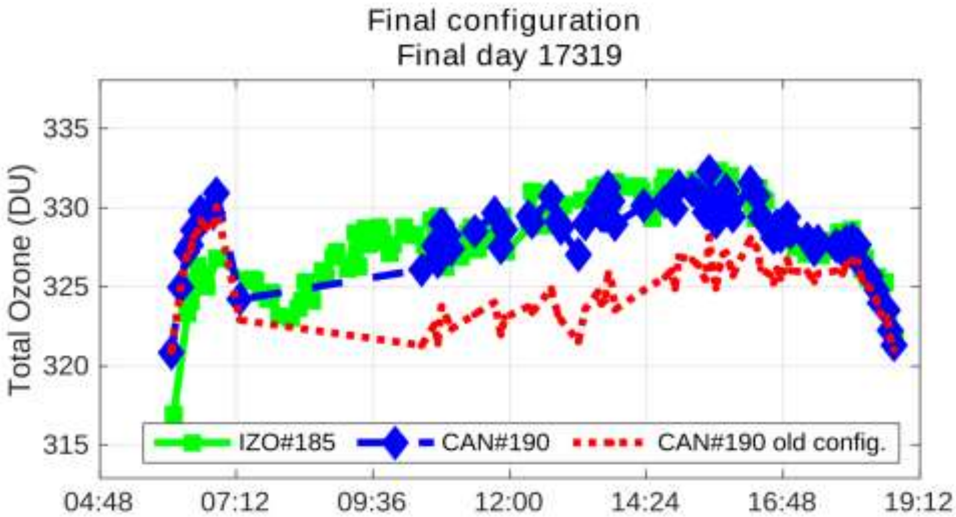


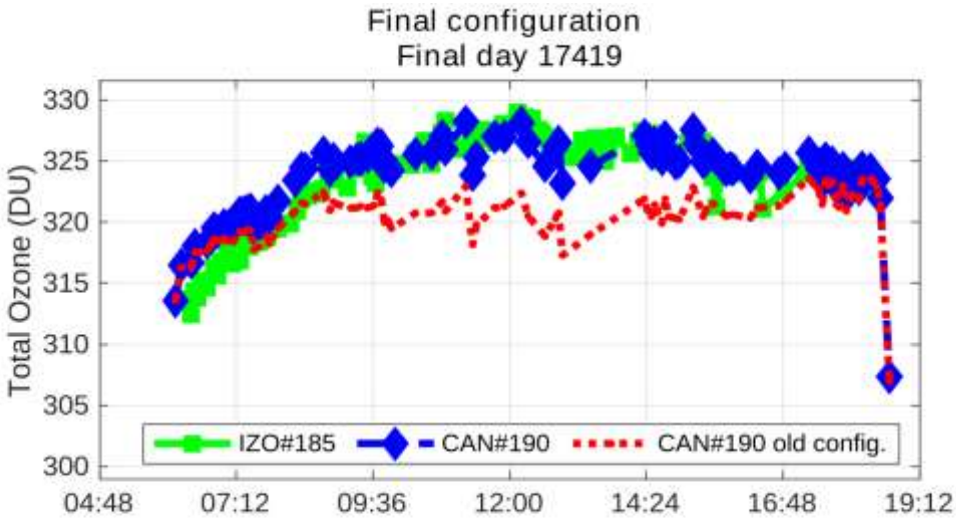
Figure 23. Overview of the intercomparison. Brewer CAN#190 data were evaluated using final constants (blue circles)

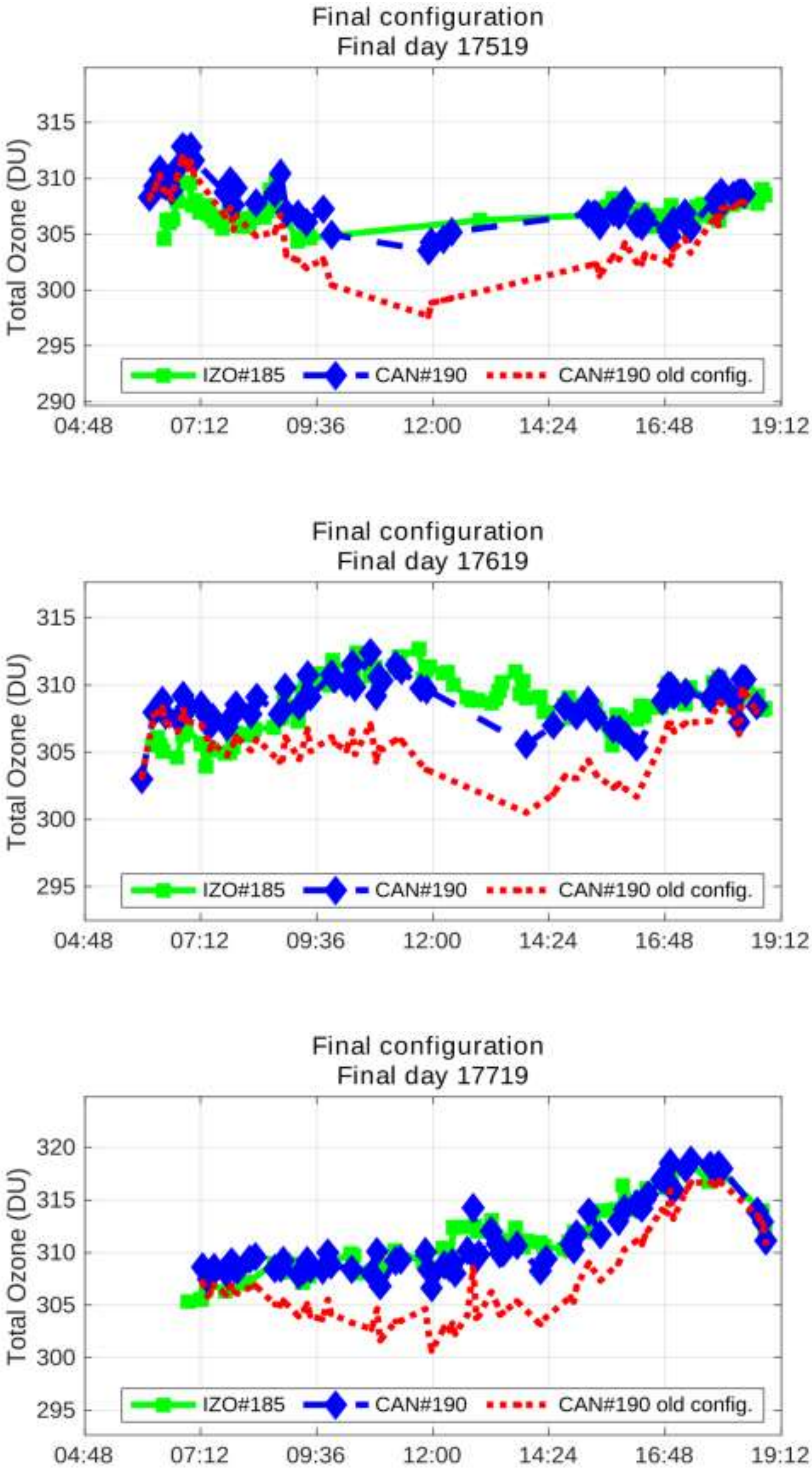





Final configuration
Final day 17219
Total Ozone (DU)
345
340
335
330
325
320
IZO#185
CAN#190
CAN#190 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17319
Total Ozone (DU)
335
330
325
320
315
IZO#185
CAN#190
CAN#190 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17419
Total Ozone (DU)
330
325
320
315
310
305
300
IZO#185
CAN#190
CAN#190 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17519
Total Ozone (DU)
IZO#185
CAN#190
CAN#190 old config.
Final configuration
Final day 17619
Total Ozone (DU)
IZO#185
CAN#190
CAN#190 old config.
Final configuration
Final day 17719
Total Ozone (DU)
IZO#185
CAN#190
CAN#190 old config.

20. BREWER TAM#201

20.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer TAM#201 participated in the campaign from 19 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer TAM#201 correspond to Julian days 170 – 178.

For the evaluation of the initial status, we used 39 simultaneous direct sun (DS) ozone measurements from days 171 to 173. For final calibration purposes, we used 92 simultaneous DS ozone measurements taken from day 177 to 178.

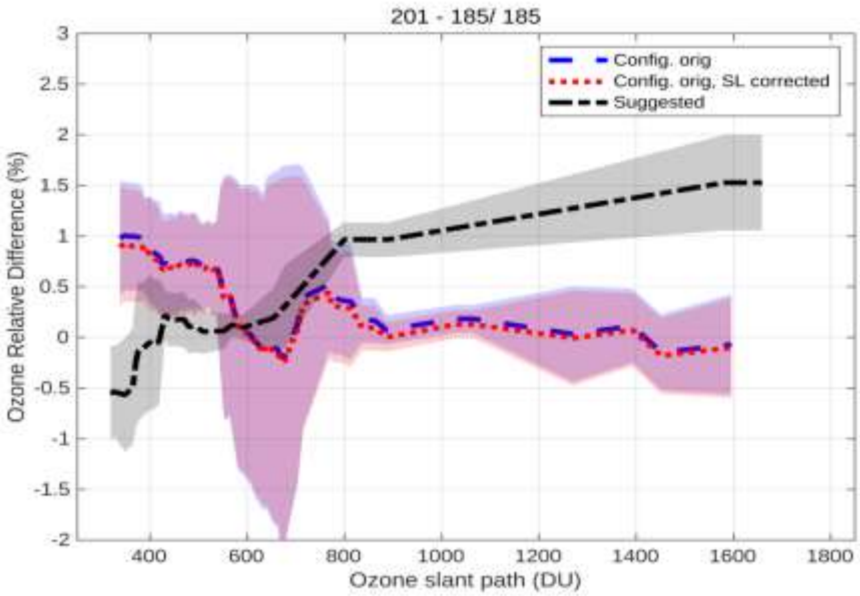


Figure 1. Mean DS ozone column percentage difference between Brewer TAM#201 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICB14315.201, blue dashed line) produces ozone values with an average difference of around 0.5% with respect to the reference instrument. This is quite a small difference and highlights the good performance of Brewer TAM#201 despite the multiple problems the instrument has had since the last calibration in 2015. This is confirmed by the R6 standard lamp measurements (see Figure 2). The SL correction (Figure 1, red dotted line) was therefore not necessary and did not improve the comparison with Brewer IZO#185.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) showed reasonable results.

The neutral density filters did not show nonlinearity in the attenuation's spectral characteristics. We have not applied any correction to filters.

It was not possible to carry out the sun scan tests (SC) at the instrument's station before the campaign, but the tests performed during the intercomparison confirm the current cal step value (285, within a step error of ± 1).

The suggested new ETC and R6 values reflect the changes made to the instrument during maintenance, which include temperature sensor reparation, correction of the prism position, removal of the hard stop, adjustment of second mirror central spring, maintenance of micrometre and software update to v. 4.21.

20.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer TAM#201 have been stable over the last 4 years, despite some periods in which the intensity of the lamp has been very low. The old R6 reference value of 348 has remained within the acceptable error margin of ± 5 . But after maintenance we suggest updating its value to 270.
2. We also suggest a new R5 reference value of 361.
3. We have adopted the current temperature coefficients because there is very little data available to carry out a new characterization of the thermal sensitivity. We recommend paying special attention to this point in the next calibration.
4. We recommend performing sun scans at the station to confirm the settings of the campaign.
5. We suggest updating the ETC value from 1552 to 1517.
6. Finally, to evaluate the total ozone between intercomparisons, it is recommended to compare with the collocated Dobson data at the station.

20.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/201/ICF17719.201

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=1237449112

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/201/html/cal_report_201a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/201/html/cal_report_201a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/201/html/cal_report_201b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/are2019/latex/201/html/cal_report_201c.html

20.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

20.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp test has remained quite stable since July 2015, except for two periods, between 20 October and 10 November 2015, and between 4 April 2016 and 28 June 2017, in which the intensity of the SL was significantly reduced as shown in Figure 4. The low intensity of the lamp may cause the observed instability in the determination of R5 and R6.

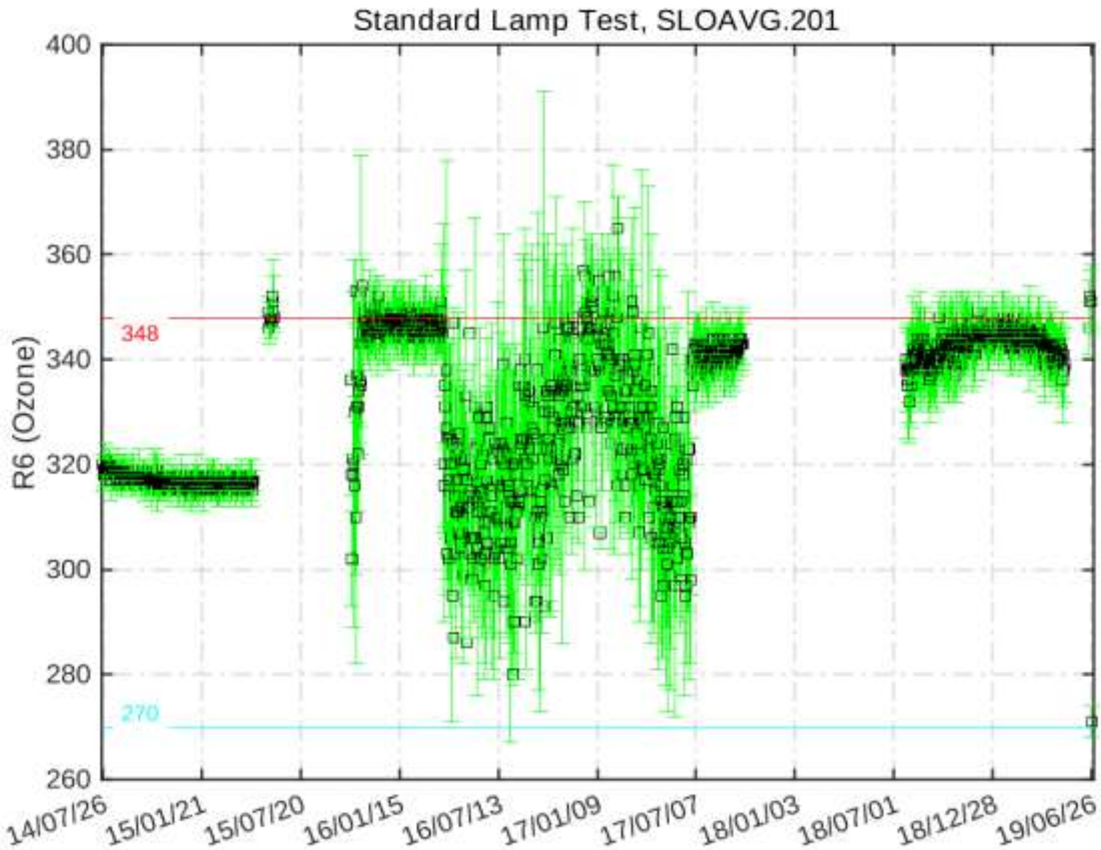


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

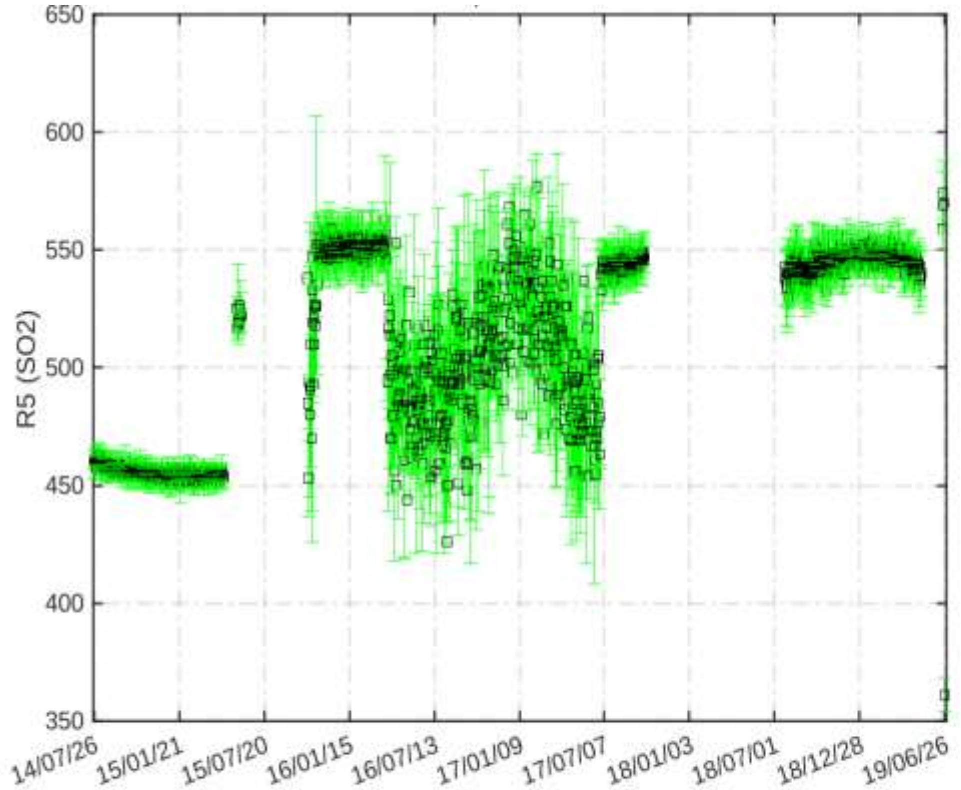


Figure 3. Standard lamp test R5 sulphur dioxide ratios

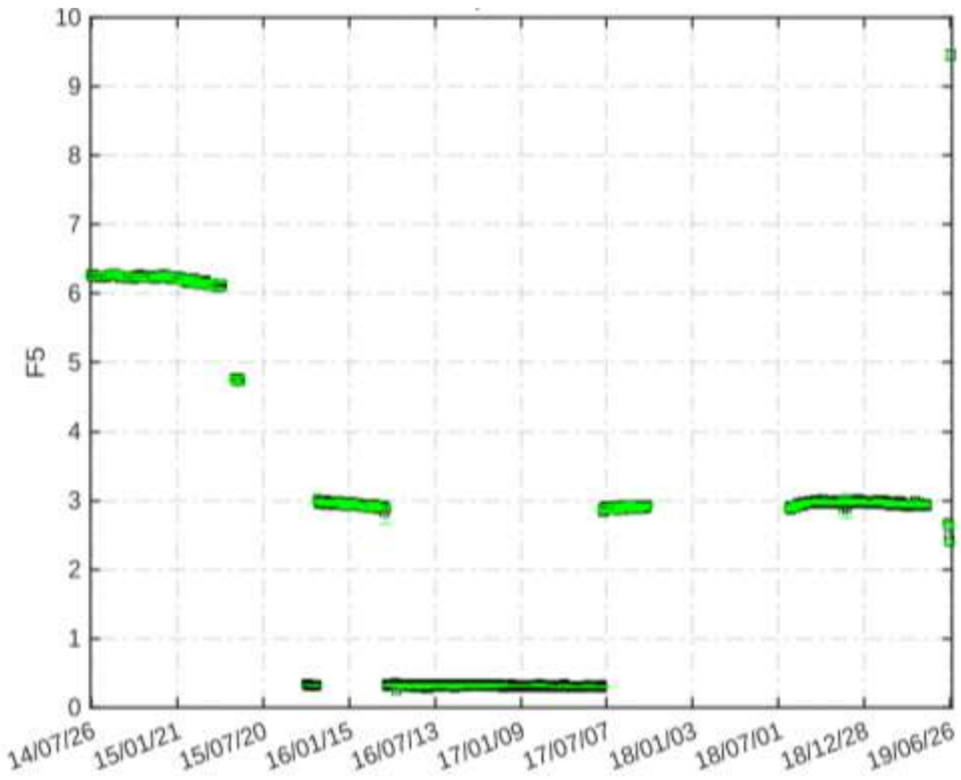


Figure 4. SL intensity for slit five

20.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits except in the period of instability between 2016 and 2017 (Figure 5).

As shown in Figure 6, the current DT reference value of $2.8 \cdot 10^{-8}$ seconds equals that recorded during the calibration period. Therefore, the current value is maintained in the new ICF.

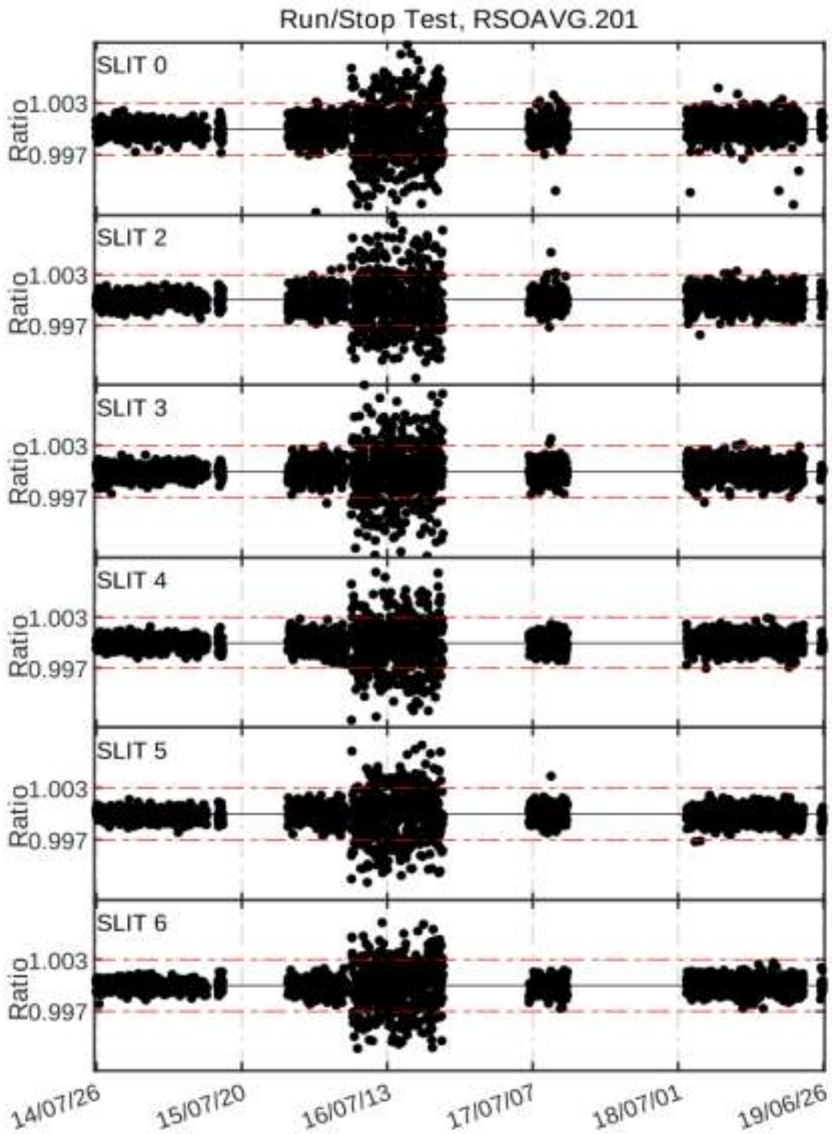


Figure 5. Run/stop test

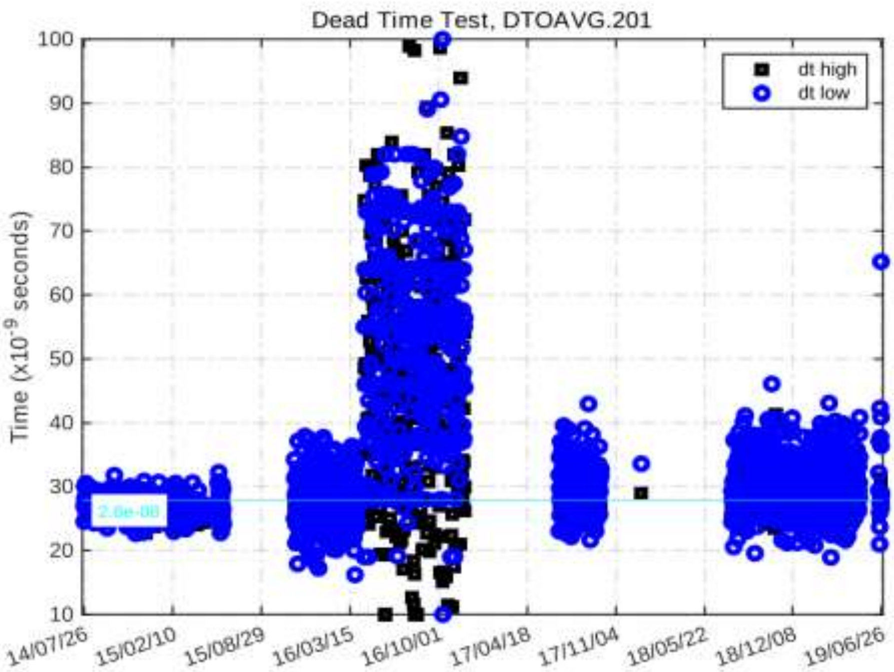


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

20.2.3. Analogue test

Figure 7 shows an important change in the high and +5 voltages in 2018 after a period of inactivity. This was due to problems with the power supply and its replacement in July 2018. Note that the +5 voltage is always slightly above the upper tolerance limit.

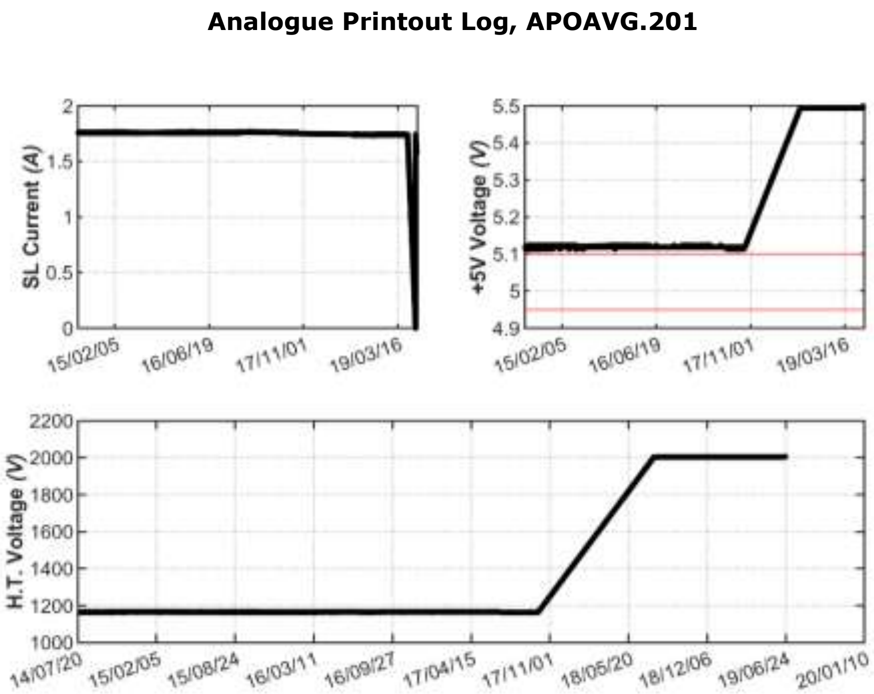


Figure 7. Analogue voltages and intensity

20.2.4. Mercury lamp test

Aside from some temperature dependence, several changes in the intensity of the mercury lamp can be identified in Figure 8, matching the observed changes in the SL lamp. It is also possible to identify the problem with the temperature detector in Figure 8, which has returned a constant value since 2018.

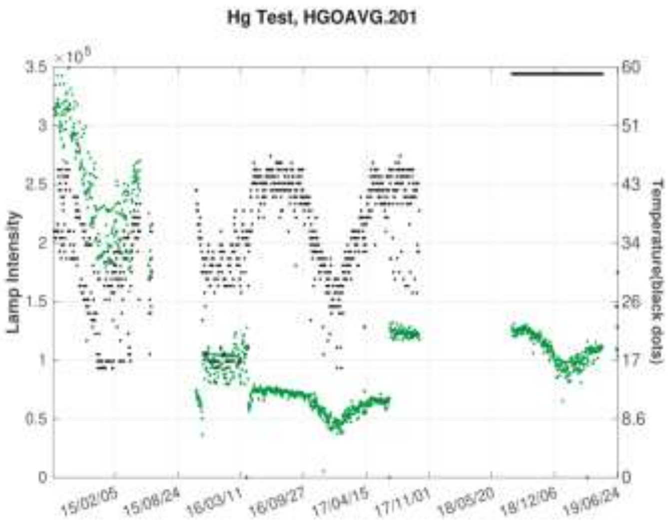
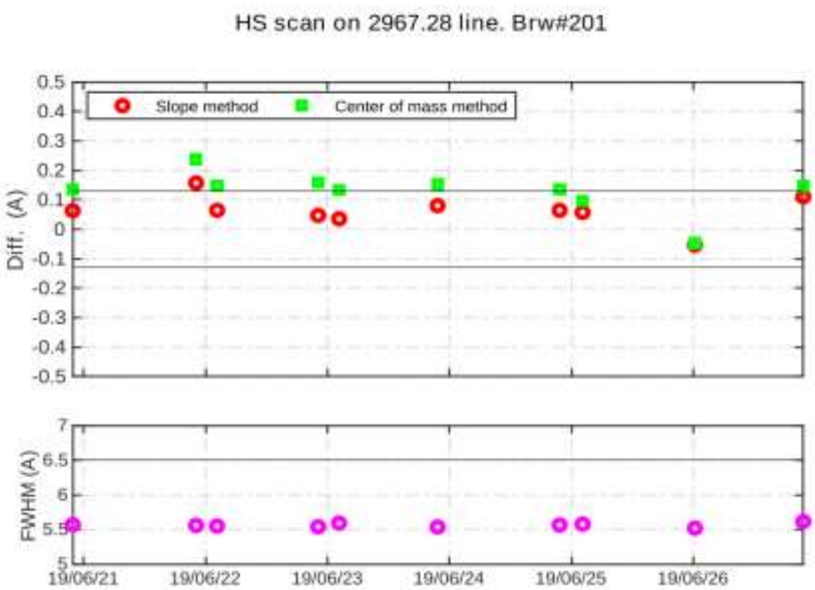


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

20.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm.

Analysis of the CZ scans performed on Brewer TAM#201 during the campaign show reasonable results for the 296.728 nm line, but a discrepancy between the calculated 334.148 nm line peak and the nominal value slightly below the lower tolerance limit (see Figure 9), was observed. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.



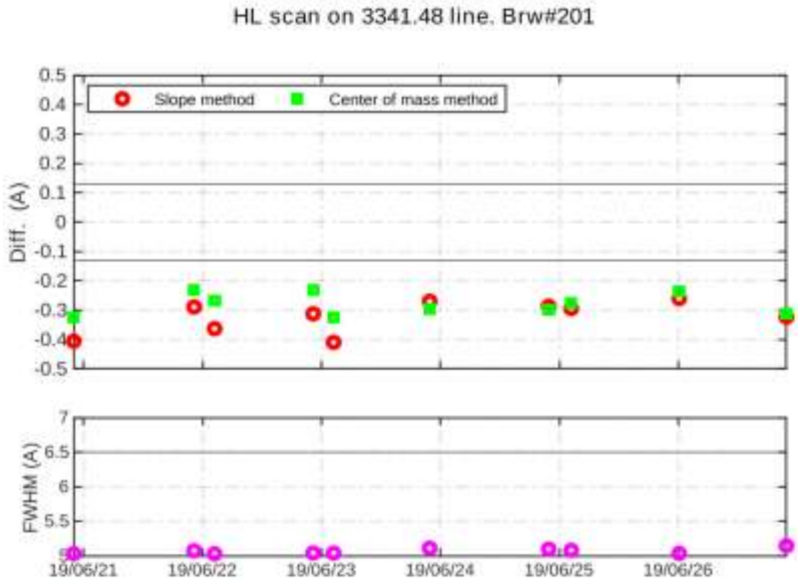


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and center of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

20.2.6 CI scan on internal *SL*

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer TAM#201 CI scans performed during the campaign relative to the scan CI17217.201. As can be observed, lamp intensity varied with respect to the reference spectrum by around 10%. Unfortunately, the possible changes in the lamp intensity were due to maintenance operations. Therefore, the results of this test are inconclusive.

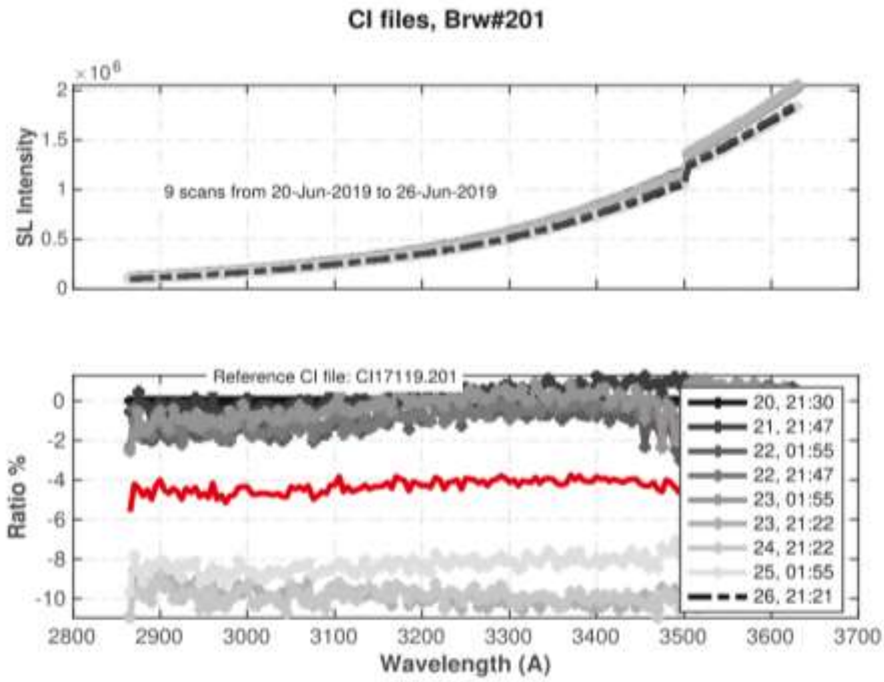


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

20.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this, we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

In the case of Brewer TAM#201, the temperature detector has been damaged since 2018, and was repaired on 25 June during the maintenance carried out in this campaign. Therefore, only two-day temperature data is available in the campaign (Figure 11) with a temperature range from 23 ˚C to 32 ˚C. Because of the paucity of data, this analysis is considered inconclusive.

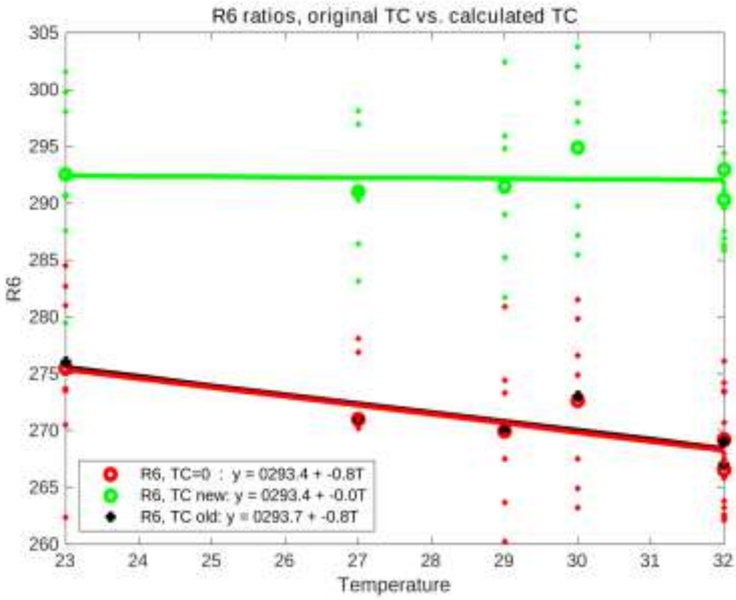


Figure 11. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

New temperature coefficients were calculated using Brewer data since the previous campaign, but the most suitable period for this analysis was reduced to a few months in 2017, after the period of instability observed in the SL and before the failure of the temperature sensor (Figure 12). Therefore, we chose a stable period after the campaign, between February and May 2020 (Figure 13). The differences between these two analyses may be related to instrument problems before the campaign, and therefore we consider the post-campaign analysis as the most suitable. The coefficients calculated in this last period are summarized in Table 1. As shown in Figure 14, the current and these last coefficients perform similarly, so we have decided to keep the current coefficients in the final ICF.

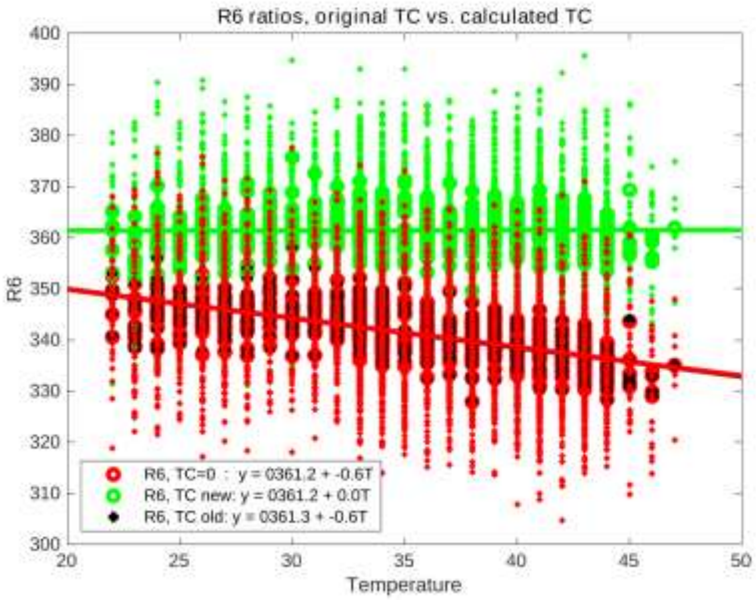


Figure 12. Same as Figure 11 but for measurements between July and September 2017

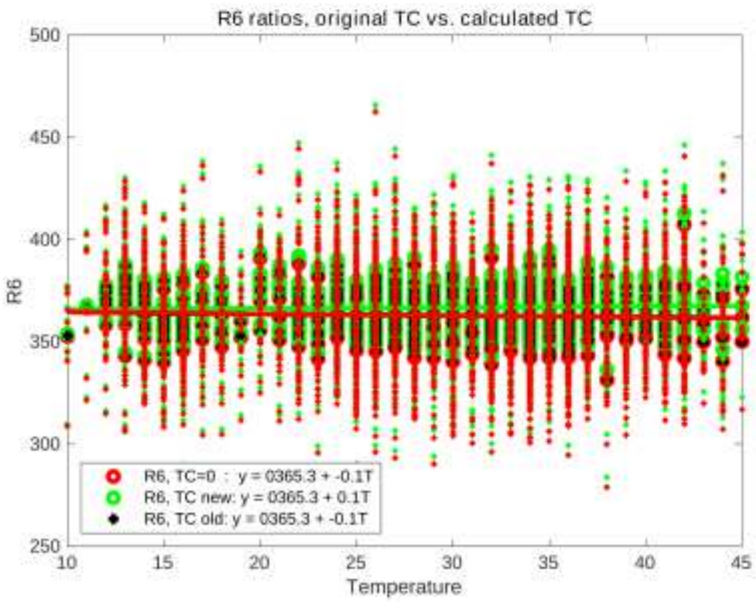


Figure 13. Same as Figure 11 but for measurements between February and May 2020

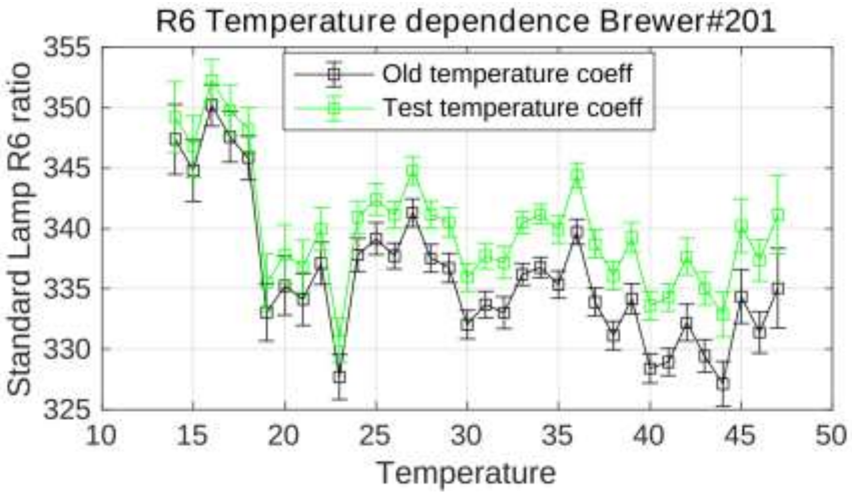


Figure 14. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted the R6 ratio recalculated with the original (black) and the test (green) temperature coefficients from the analysis performed between February and May 2020

Table 1. Temperature Coefficients normalized to slit#2. Calculated coefficients correspond to the analysis performed between February and May 2020

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	0.0000	0.0000	0.0000	0.0000
Calculated	0.0000	0.0000	0.1000	0.5000	0.6000
Final	0.0000	0.0000	0.0000	0.0000	0.0000

20.4. ATTENUATION FILTER CHARACTERIZATION

20.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 125 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

The filter corrections are very similar for all the filters so no correction is suggested.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*Filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-6	-7	-4	-7	2
ETC Filt. Corr. (mean)	-2.6	-13.1	-8.9	-7.8	8.2
ETC Filt. Corr. (mean 95% CI)	[-7.8 2.9]	[-20.3 -7.3]	[-14.6 -3.3]	[-14.4 -1.5]	[-0.8 17.8]

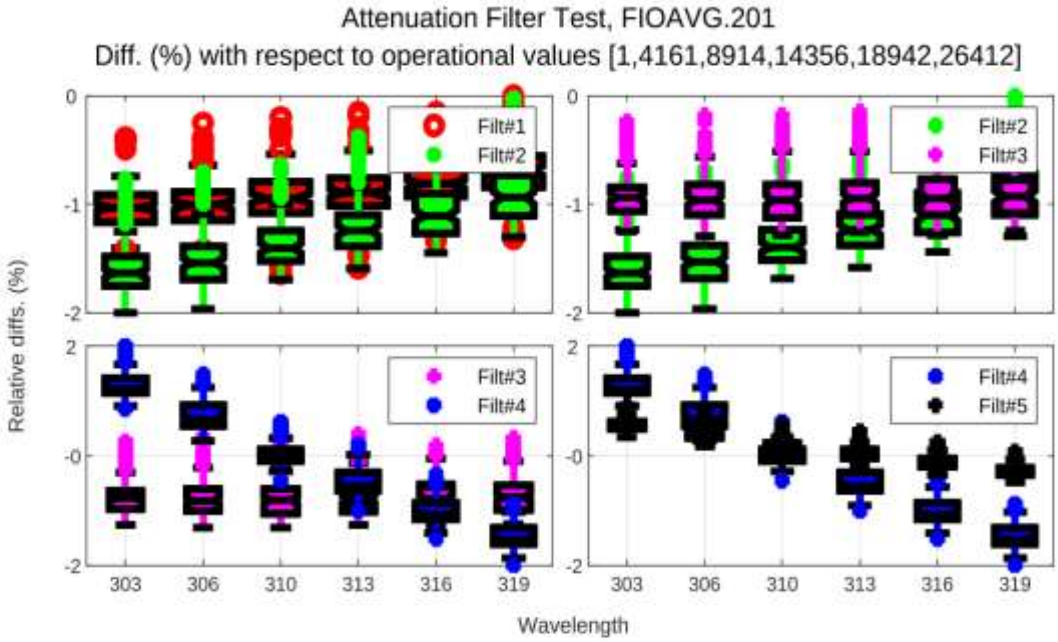


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

20.5. WAVELENGTH CALIBRATION

20.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

During the campaign, 8 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out (see Figure 17). The calculated cal step number (CSN) was less than 1 step higher than the value in the current configuration (285.6 vs. 285). Hence, we suggest keeping the current CSN of 285.

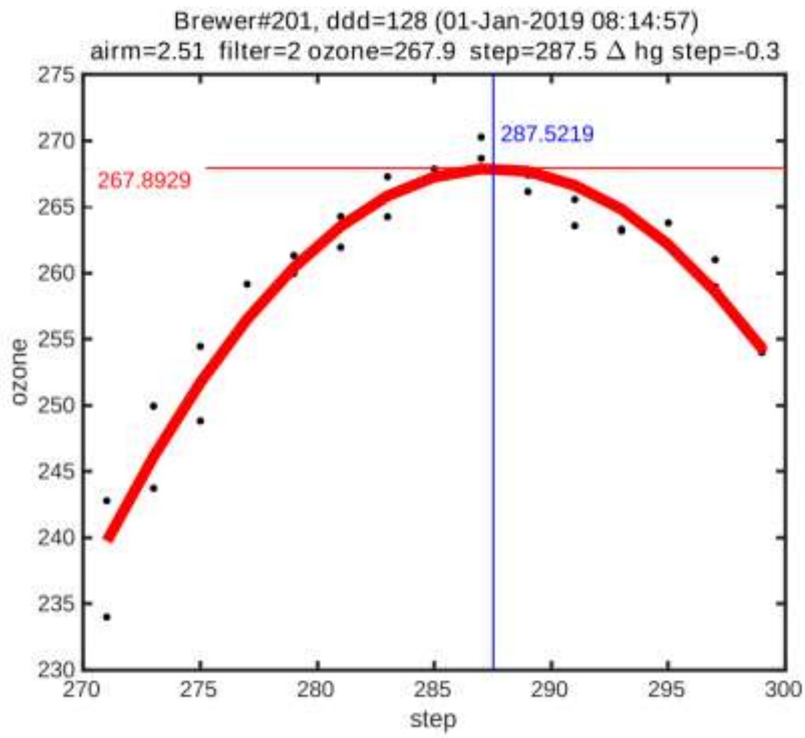


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

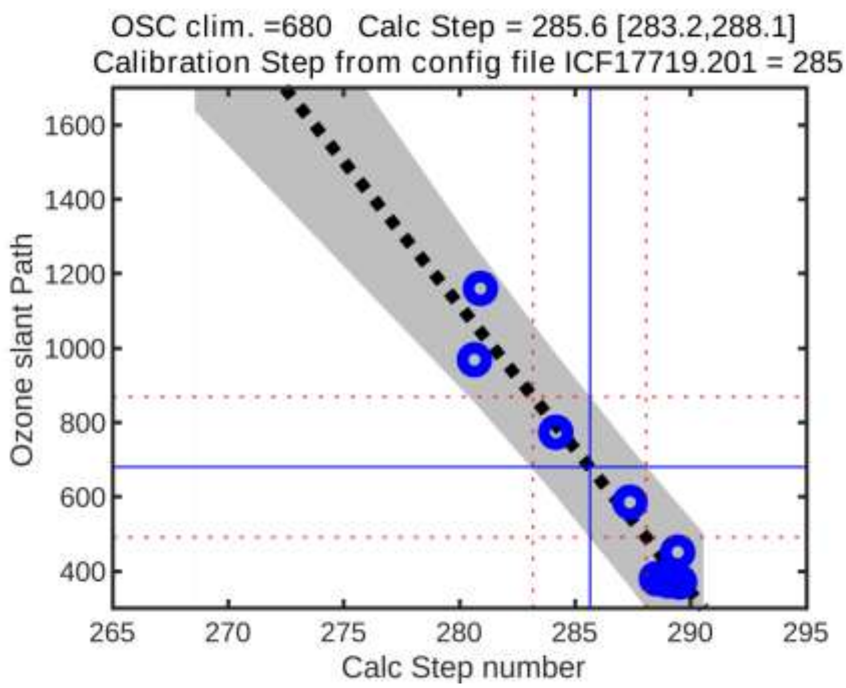


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

20.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.341 is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	285	0.3465	2.3500	1.1366
15-Jun-2013	285	0.3442	3.2359	1.1496
26-May-2015	285	0.3456	3.2031	1.1539
24-Jun-2019	285	0.3451	3.1884	1.1554
28-Jun-2019	285	0.3414	3.2259	1.1426
Final	285	0.3410	2.3500	1.1366

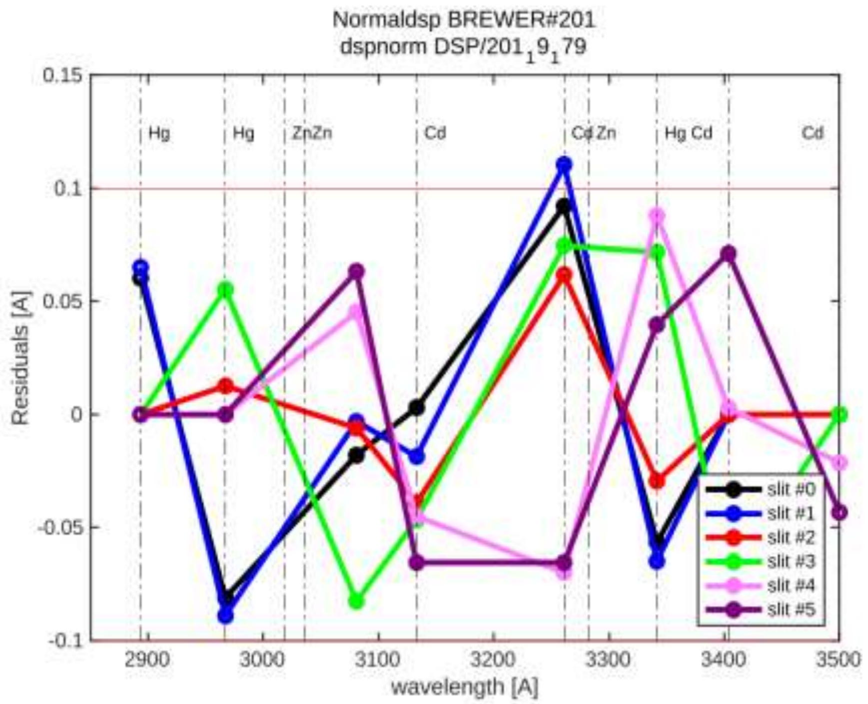


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 284	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.72	3062.82	3100.37	3134.87	3167.7	3199.71
Res(A)	5.5866	5.4549	5.2816	5.5166	5.3556	5.3319
O3abs(1/cm)	2.6055	1.7845	1.0056	0.67724	0.37457	0.29601
Ray abs(1/cm)	0.5052	0.48335	0.45856	0.43719	0.41803	0.40036
SO2abs(1/cm)	3.4773	5.599	2.3876	1.9234	1.0498	0.6209
step= 285	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.79	3062.89	3100.44	3134.94	3167.77	3199.78
Res(A)	5.5866	5.4548	5.2816	5.5166	5.3556	5.3319
O3abs(1/cm)	2.6029	1.783	1.0053	0.67697	0.3746	0.29553
Ray abs(1/cm)	0.50515	0.4833	0.45851	0.43715	0.41799	0.40032
SO2abs(1/cm)	3.4604	5.6228	2.3954	1.9117	1.051	0.61876
step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.87	3062.97	3100.51	3135.01	3167.84	3199.85
Res(A)	5.5865	5.4548	5.2816	5.5165	5.3555	5.3318
O3abs(1/cm)	2.6004	1.7814	1.0051	0.67664	0.37462	0.29505
Ray abs(1/cm)	0.50509	0.48325	0.45847	0.4371	0.41795	0.40029
SO2abs(1/cm)	3.4436	5.6458	2.4033	1.8998	1.0523	0.61664
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
284	0.34612	9.2248	3.1769	1.1585	0.35614	0.34763
285	0.34513	9.2216	3.1884	1.1554	0.35535	0.3468
286	0.34414	9.2185	3.1992	1.1521	0.3545	0.34592

20.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1683. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 285	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3101	3135	3168	3200
Res(A)	5.602	5.5342	5.358	5.5489	5.4456	5.4063
O3abs(1/cm)	2.595	1.7764	1.0044	0.67595	0.37492	0.29401
Ray abs(1/cm)	0.50498	0.48311	0.45837	0.43705	0.41786	0.40023
step= 1683	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.4859	5.4344	5.2756	5.4622	5.3572	5.3085
O3abs(1/cm)	0.67873	0.39579	0.29459	0.12421	0.061672	0.033379
Ray abs(1/cm)	0.43799	0.42029	0.40023	0.38287	0.36726	0.35282

20.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method and only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 2 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

20.6.1. Initial calibration

For the evaluation of initial status of Brewer TAM#201, we used the period from days 171 to 173 which correspond with 39 near-simultaneous direct sun ozone measurements. As shown in Figure 19, the initial calibration constants produced an ozone value slightly higher than the reference instrument (0.5%). When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results did not improve.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

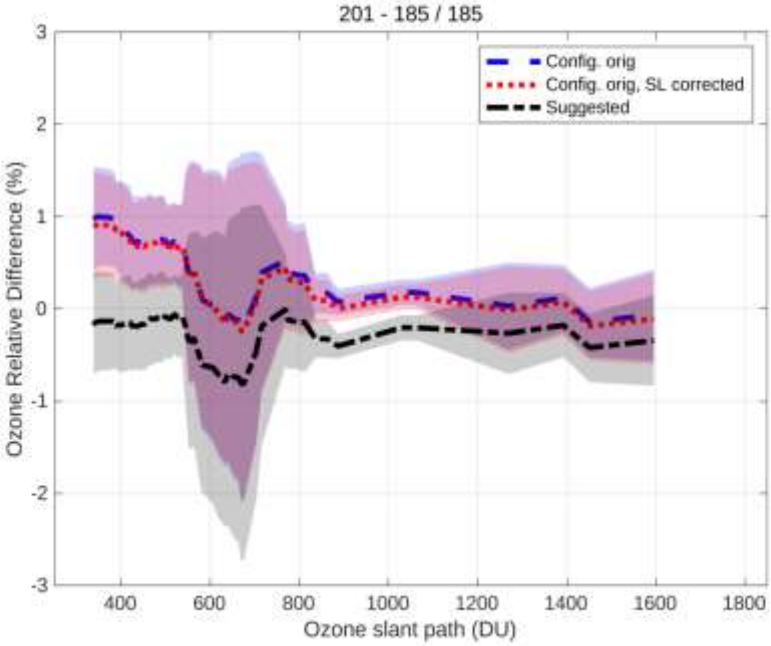


Figure 19. Mean direct sun ozone column percentage difference between Brewer TAM#201 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=1000	1566	1572	3465	3446
full OSC range	1566	1572	3465	3446

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#201*	*O3 std*	*%(201–185)/185*	*O3(*) #201*	*O3std*	*(*)%(201–185)/185*
20-Jun-2019	171	335.9	0.6	2	336.1	0.1	0.1	334.4	0.2	-0.4
21-Jun-2019	172	335.5	4.2	19	338.2	6.6	0.8	335	6	-0.1
22-Jun-2019	173	327.4	1.8	18	330.1	2.1	0.8	327	1.7	-0.1

20.6.2. Final calibration

After the maintenance on day 176, a new ETC value was calculated (see Figure 20). For the final calibration, we used 92 simultaneous direct sun measurements from days 177 to 178. The new value was approximately 35 units lower than the current ETC value (1552). Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (270 for R6). The new ETC and R6 values reflect the changes made to the instrument during maintenance. We have updated the new calibration constants in the ICF provided.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is below the maximum tolerance limit of 10 units.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

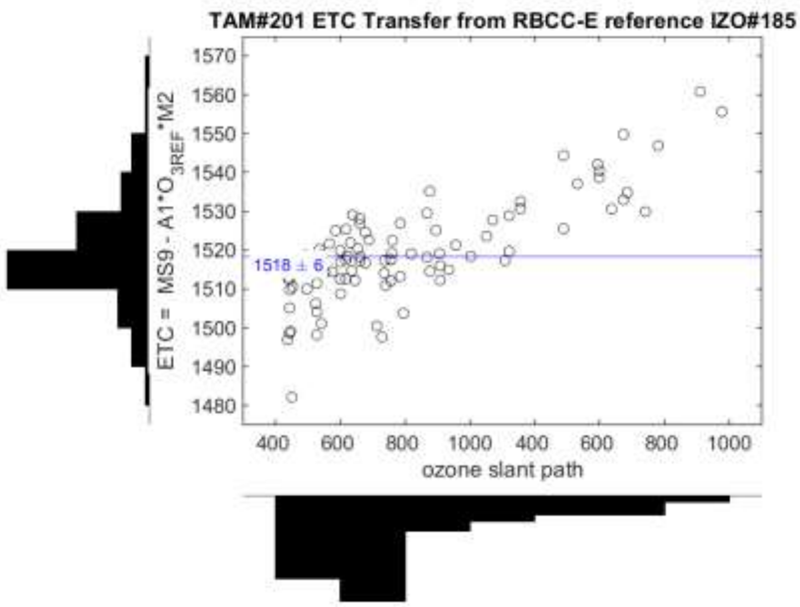


Figure 20. Mean direct sun ozone column percentage difference between Brewer TAM#201 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1000	1518	1506	3410	3434
full OSC range	1517	1511	3410	3421

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#201*	*O3 std*	*%(201–185)/185*	*O3(*) #201*	*O3std*	*(*)%(201–185)/185*
25-Jun-2019	176	308.6	1.1	26	296.9	3.8	-3.8	308.6	2.3	0
26-Jun-2019	177	313.2	3.1	44	300.9	6.2	-3.9	313.2	4.6	0
27-Jun-2019	178	NaN	NaN	0	296.5	2.5	NaN	307.2	1.4	NaN

20.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 270 for R6 (Figure 21) and 361 for R5 (Figure 22).

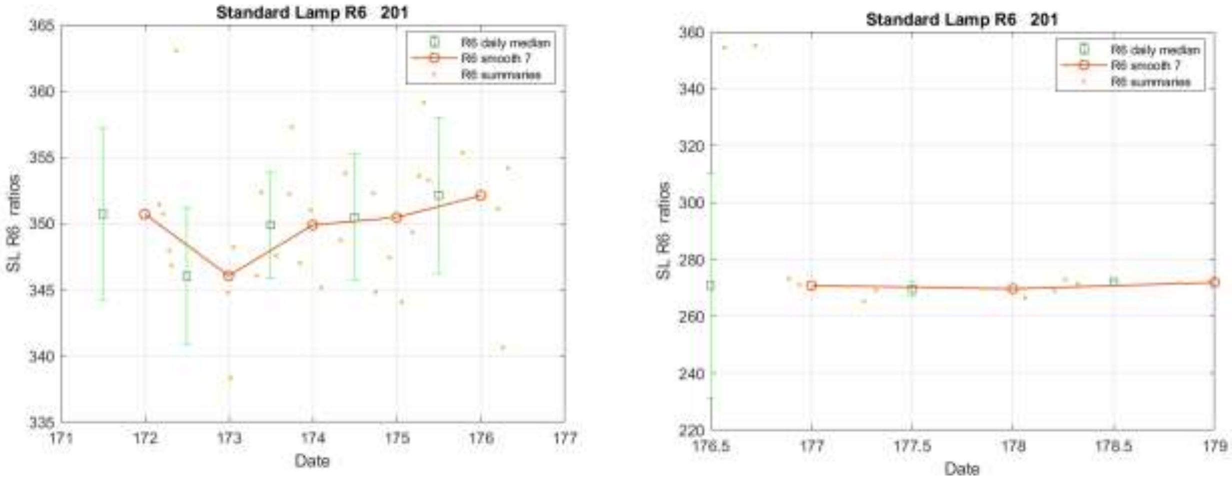


Figure 21. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Data for the blind and calibration days are shown separately.

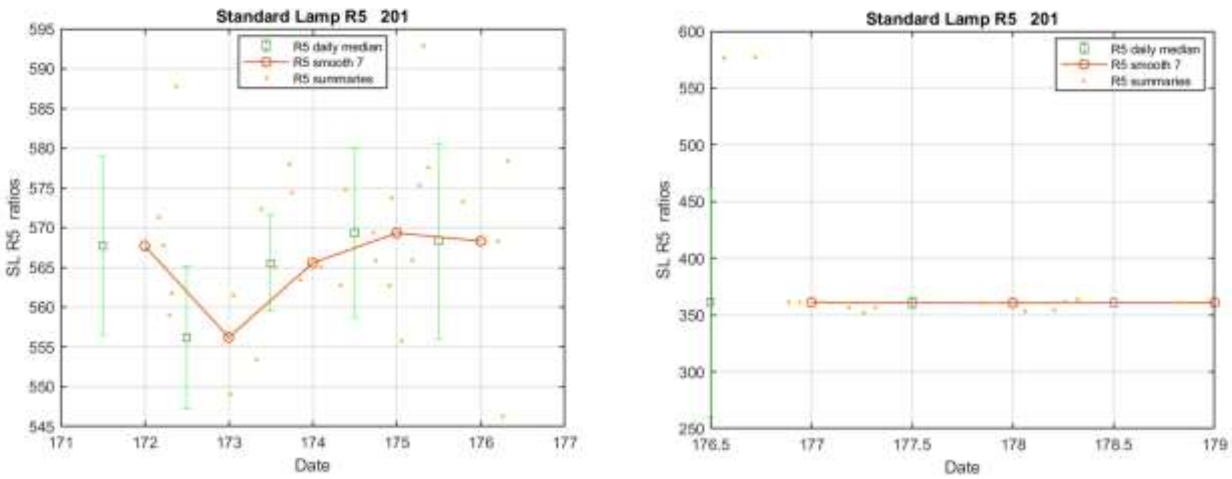


Figure 22. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Data for the blind and calibration days are shown separately.

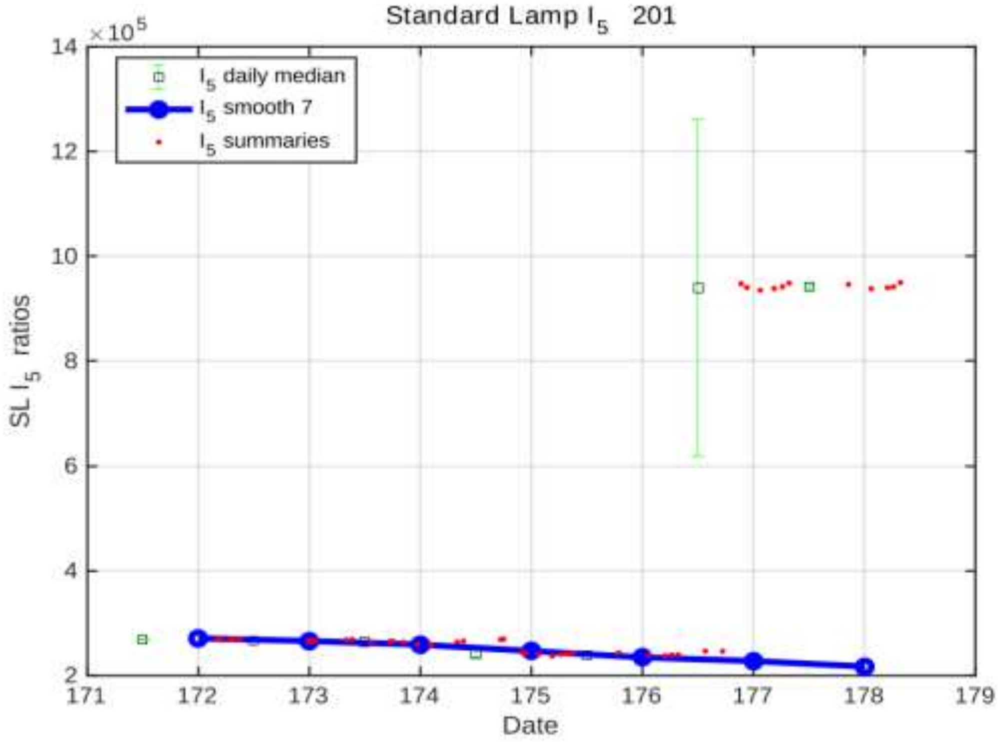


Figure 23. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

20.7. CONFIGURATION

20.7.1. Instrument constant file

	Initial (ICB14315.201)	*Final (ICF17719.201)*
o3 Temp coef 1	0	0
o3 Temp coef 2	0	0
o3 Temp coef 3	0	0
o3 Temp coef 4	0	0
o3 Temp coef 5	0	0
Micrometre steps/deg	0.056	0.056
O3 on O3 Ratio	0.3465	0.341
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1366	1.1366
ETC on O3 Ratio	1552	1517
ETC on SO2 Ratio	421	421
Dead time (sec)	2.8e-08	2.8e-08
WL cal step number	285	285
Slitmask motor delay	14	14
Umkehr Offset	1707	1707

	Initial (ICB14315.201)	*Final (ICF17719.201)*
ND filter 0	0	0
ND filter 1	4161	4161
ND filter 2	8914	8914
ND filter 3	14356	14356
ND filter 4	18942	18942
ND filter 5	26412	26412
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	0	0
Mic #2 Offset	0	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2515	2515
Grating Slope	1.0033	1.0033
Grating Intercept	-16.15	-16.15
Micrometre Zero	2469	2469
Iris Open Steps	250	250
Buffer Delay (s)	0.1	0
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2214	2224

20.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#201*	*O3 std*	*%diff*	*(*)O3#201*	*O3 std*	*(*)%diff*
171	1000> osc> 700	336	0.6	2	336	0.1	0.0	336	0.1	0.0
172	700> osc> 400	332	1.2	15	333	4.5	0.4	333	4.5	0.4
172	osc< 400	340	0.8	9	345	2.0	1.4	345	2.0	1.4
173	1500> osc> 1000	325	1.7	4	324	3.1	-0.1	324	3.1	-0.1
173	1000> osc> 700	327	1.3	3	328	0.5	0.2	328	0.5	0.2
173	700> osc> 400	328	2.9	25	330	3.1	0.7	330	3.1	0.7
173	osc< 400	330	1.6	19	332	2.0	0.9	332	2.0	0.9
177	osc> 1500	314	0.0	1	315	0.0	0.4	318	0.0	1.2
177	1000> osc> 700	317	0.4	5	320	0.7	0.8	320	0.9	0.9
177	700> osc> 400	314	2.9	21	318	2.6	1.3	315	3.2	0.2
177	osc< 400	311	1.3	11	316	1.8	1.5	309	1.8	-0.6
178	1500> osc> 1000	303	1.0	3	NaN	NaN	NaN	306	0.8	0.9
178	1000> osc> 700	305	0.7	8	NaN	NaN	NaN	308	0.7	0.9
178	700> osc> 400	308	1.1	14	NaN	NaN	NaN	308	1.1	-0.1
178	osc< 400	313	0.0	1	NaN	NaN	NaN	303	0.0	-3.1

20.9. APPENDIX: SUMMARY PLOTS

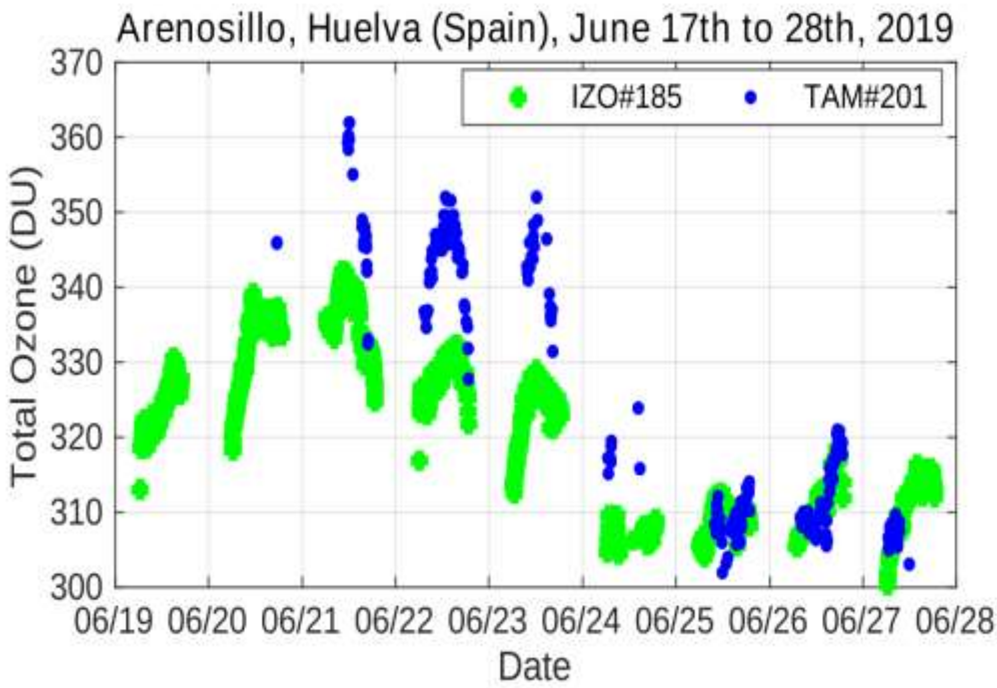
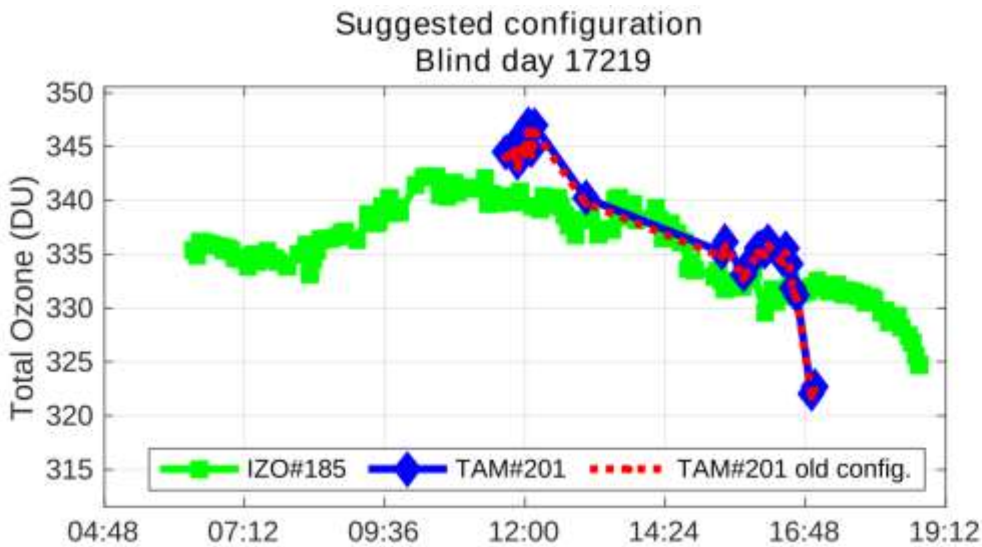
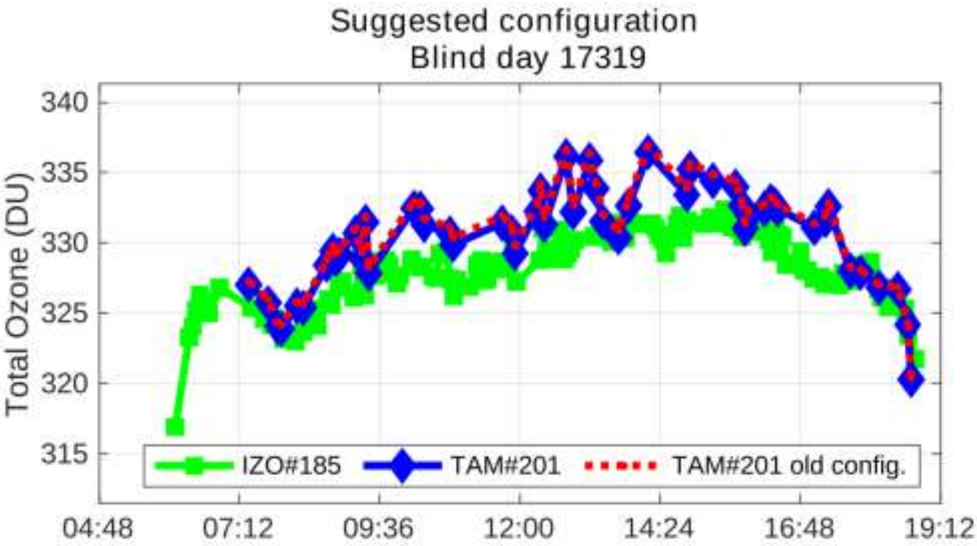
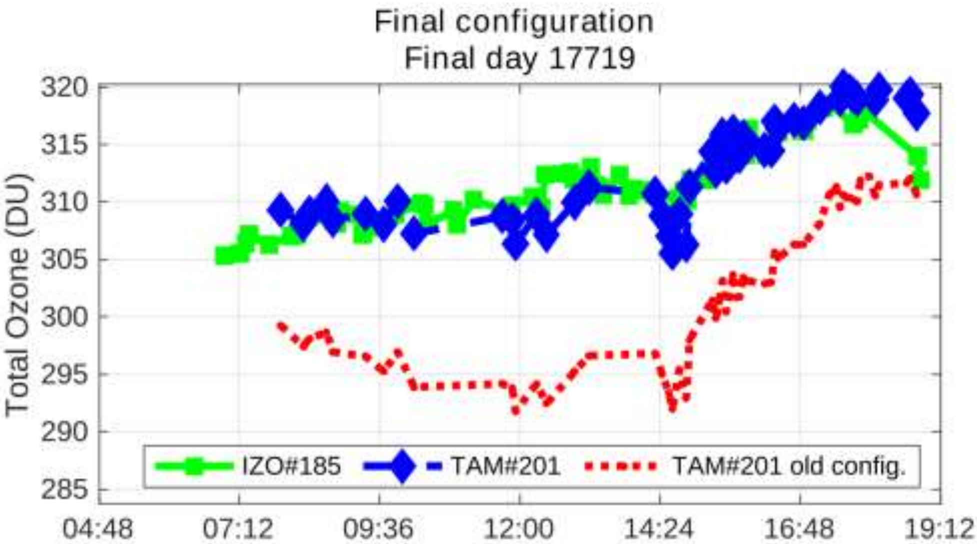


Figure 24. Overview of the intercomparison. Brewer TAM#201 data were evaluated using final constants (blue circles)

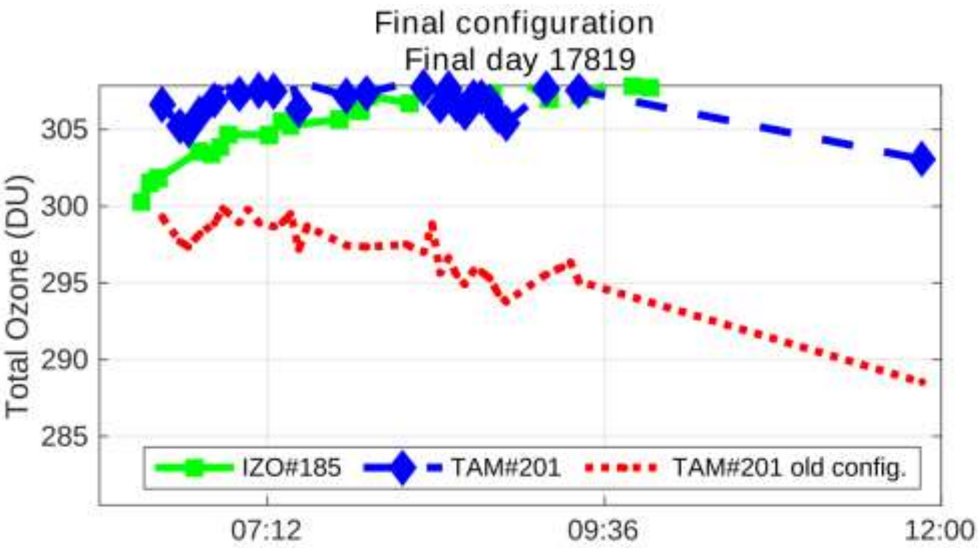




Suggested configuration
Blind day 17319
Total Ozone (DU)
340
335
330
325
320
315
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TAM#201
TAM#201 old config.



Final configuration
Final day 17719
Total Ozone (DU)
320
315
310
305
300
295
290
285
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
TAM#201
TAM#201 old config.



Final configuration
Final day 17819
Total Ozone (DU)
305
300
295
290
285
07:12
09:36
12:00
IZO#185
TAM#201
TAM#201 old config.

21. BREWER DNK#202

21.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the El Arenosillo Atmospheric Sounding Station of the Instituto Nacional de Técnica Aeroespacial (INTA), Spain.

Brewer DNK#202 participated in the campaign from 17 to 27 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer DNK#202 correspond to Julian days 166 – 178.

No maintenance work was performed on Brewer DNK#202, so we used the same data set to evaluate its initial status and to calibrate the instrument. This data set comprises 466 simultaneous DS ozone measurements taken from day 166 to 178.

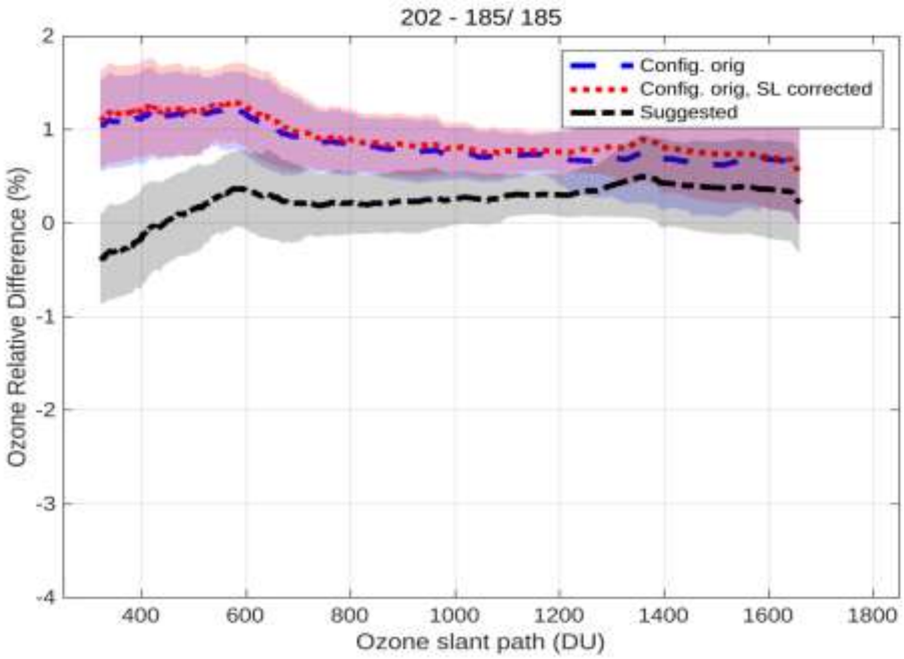


Figure 1. Mean DS ozone column percentage difference between Brewer DNK#202 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean

As shown in Figure 1, the current ICF (ICF15017.202, blue dashed line) produces ozone values with an average difference of approx. 1% with respect to the reference instrument. This is a rather small difference and highlights the stability of Brewer DNK#202. This is confirmed by the stability of the R6 standard lamp measurements, see Figure 2. The SL correction (Figure 1, red dotted line) was therefore not necessary and did not improve the comparison with Brewer IZO#185.

All the other parameters analysed (run/stop tests, Hg lamp intensity, CZ & CI files, dead time, and so forth) showed reasonable results.

Dead time (DT) shows a change of two nanoseconds during the campaign, with the original value of $2.5 \cdot 10^{-8}$ s increasing to 27. However, data from Brewer DNK#202 after the campaign finished and the instrument was back at its station again showed the original value of $2.5 \cdot 10^{-8}$ ns. In the final configuration of the present campaign, ICF17519.202, we therefore retained the original value, but we recommend checking the DT value frequently.

Note we also observed the same behaviour in the AP tests, with changes during the campaign which revert back to the original values once the instrument is back at its station. In this case, the changes might be related to different versions of the AP.RTN at the station and during the campaign. Nevertheless, we suggest checking the results of the AP test frequently.

The cal step number (CSN) from sun scan tests (SC) performed at the instrument's station before the campaign was 5 units higher than that in the current ICF (291 vs. 286). However, data from these tests seem to be very noisy and the SC tests performed during the campaign confirm the value in ICF15017.202 within the ± 1 step error. In the final configuration (ICF17519.202 file) of the present campaign, we retained the 286 value for the CSN.

We do not suggest changing the ozone absorption coefficient, retaining its current value, 0.3444.

Taking this into account, we suggest very few changes to the configuration of Brewer DNK#202.

21.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer DNK#202 have been very stable during the last 2 years. The old R6 reference value was 270 and we suggest keeping this value.
2. For R5, we suggest a value of 417.
3. Although during the campaign we observed some changes in the DT, it seems to have reverted to its original value after the campaign, so we do not suggest changing the DT value, retaining $2.5 \cdot 10^{-8}$ seconds. However, we do suggest checking this value frequently at the instrument's station. Similarly, we also suggest checking the results of the AP tests and sun scan tests.
4. Finally, we suggest updating the ETC value from 1480 to 1497.

21.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/202/ICF17519.202

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=821146812

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/202/html/cal_report_202a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/202/html/cal_report_202a2.html

Wavelength

http://rbcce.aemet.es/svn/campaigns/are2019/latex/202/html/cal_report_202b.html

ETC transfer

http://rbcce.aemet.es/svn/campaigns/aro2019/latex/202/html/cal_report_202c.html

21.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

21.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp test performance has been quite stable since July 2017, with mean values of approx. 270 and 417 for R6 and R5, respectively. A change during the campaign can be also observed in the lamp's intensity (Figure 4). This latter figure also shows a seasonal trend, with yearly maxima in February and minima in October.

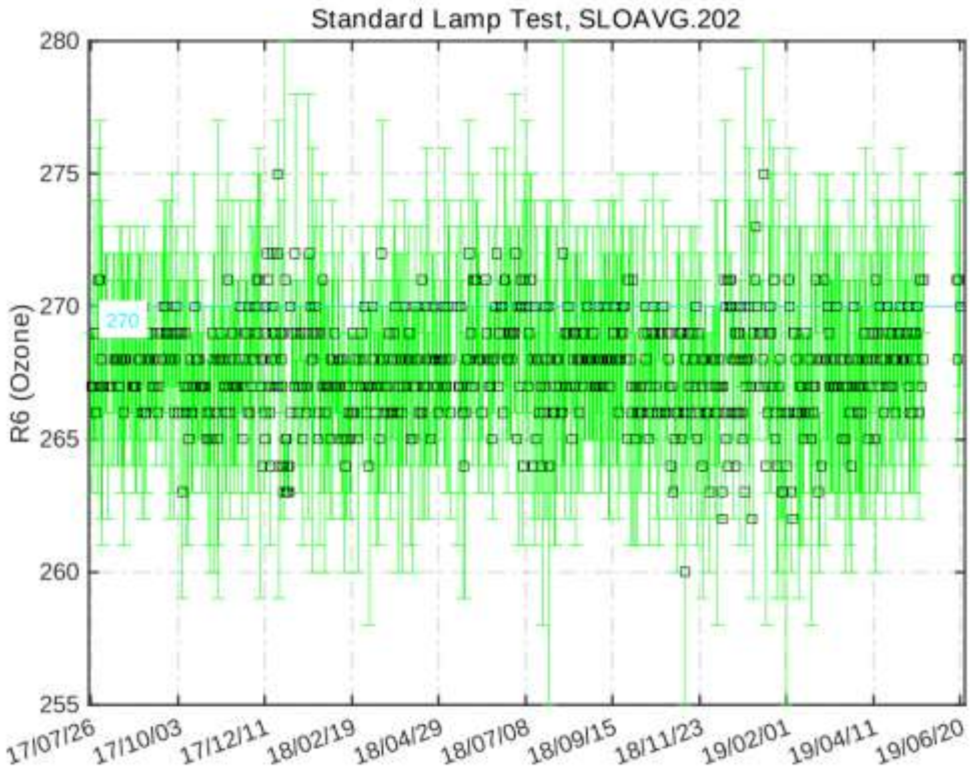


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

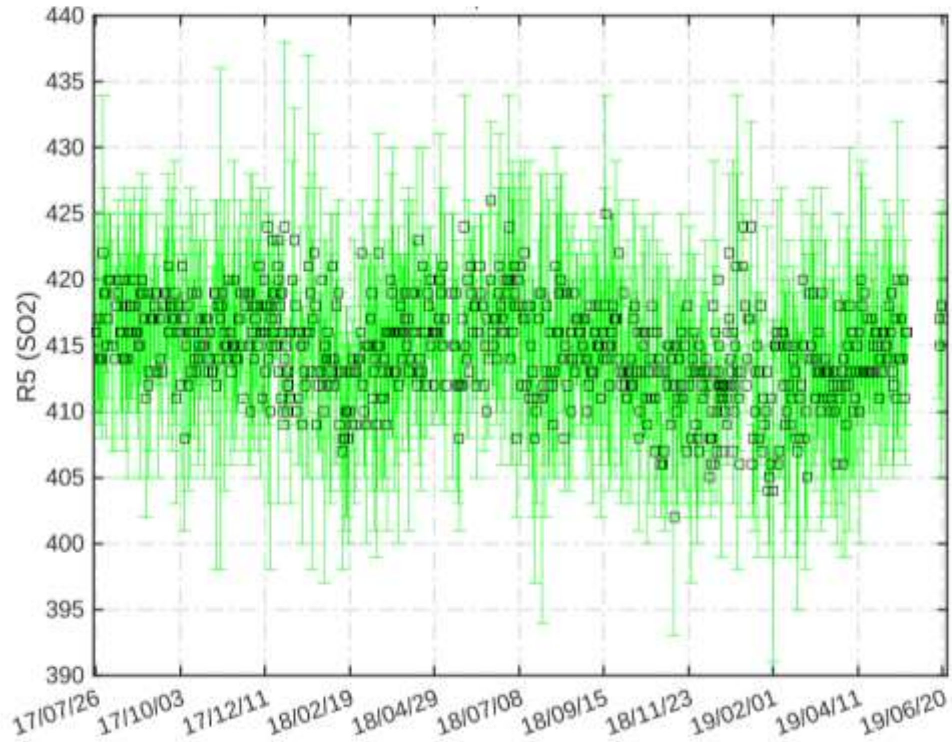


Figure 3. Standard lamp test R5 sulphur dioxide ratios

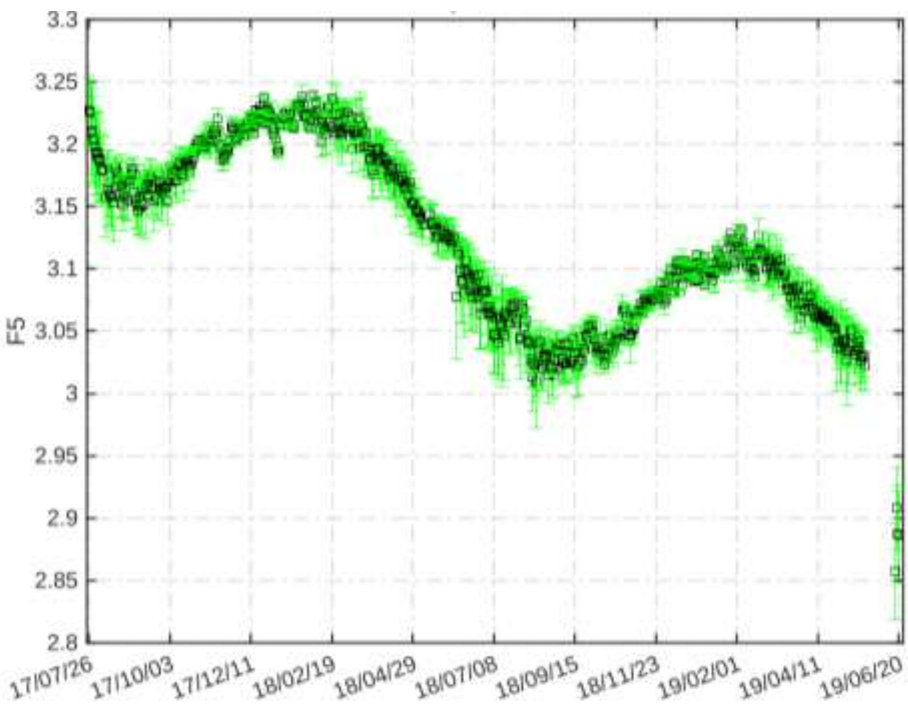


Figure 4. SL intensity for slit five

21.2.2. Run/Stop and dead time

Run/stop test values were within the test tolerance limits (see Figure 5).

As shown in Figure 6, DT was very stable during the intercomparison period, with a value of 2.5 $\cdot$ 10^{-8} seconds. This increased during the campaign up to 2 ns. However, as already discussed, DT reverted to its pre-campaign value once the instrument started to operate again at its station. We have thus kept the 2.5$\cdot$ 10^{-8} s in the ICF17519.202.

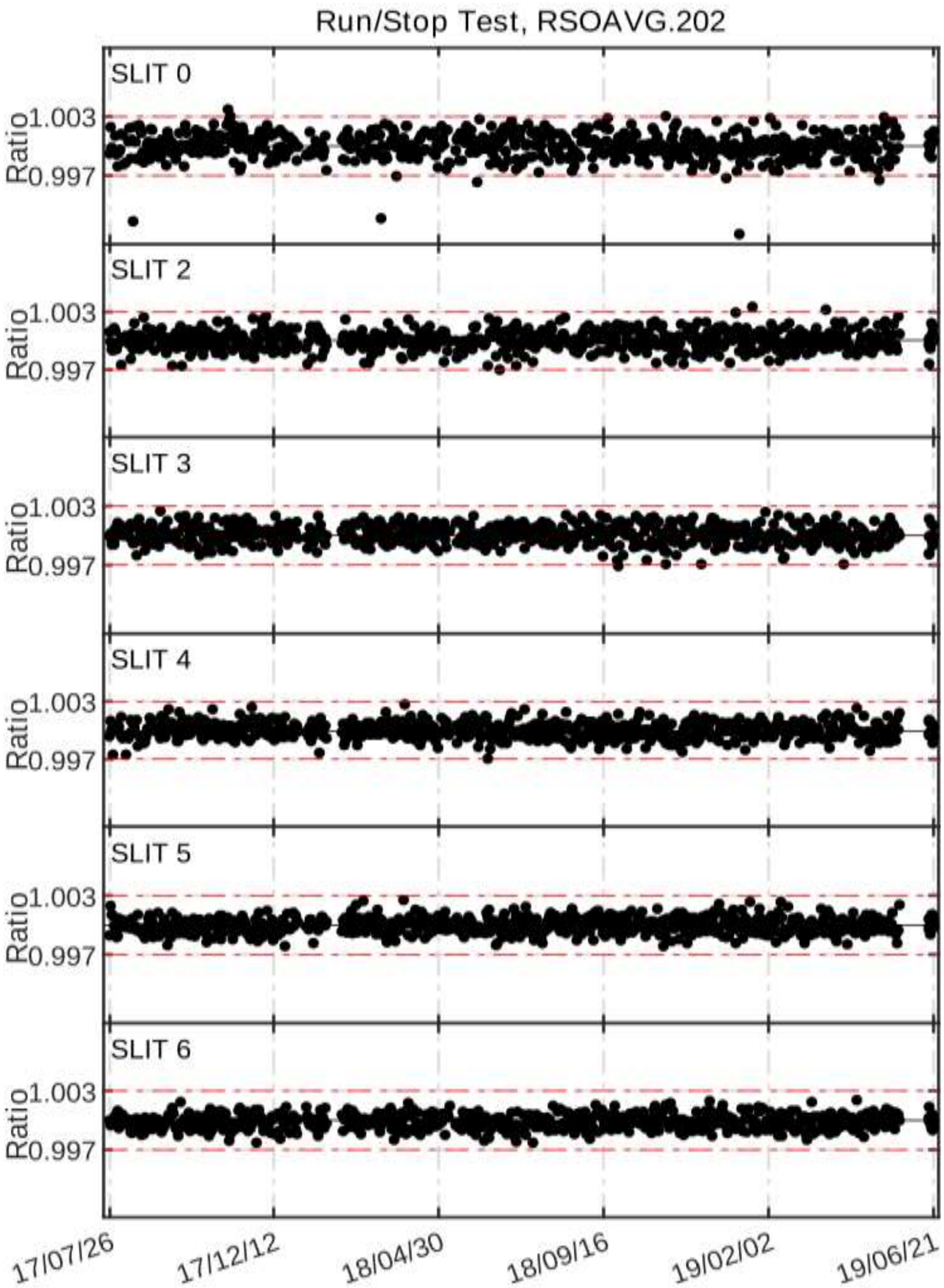


Figure 5. Run/stop test

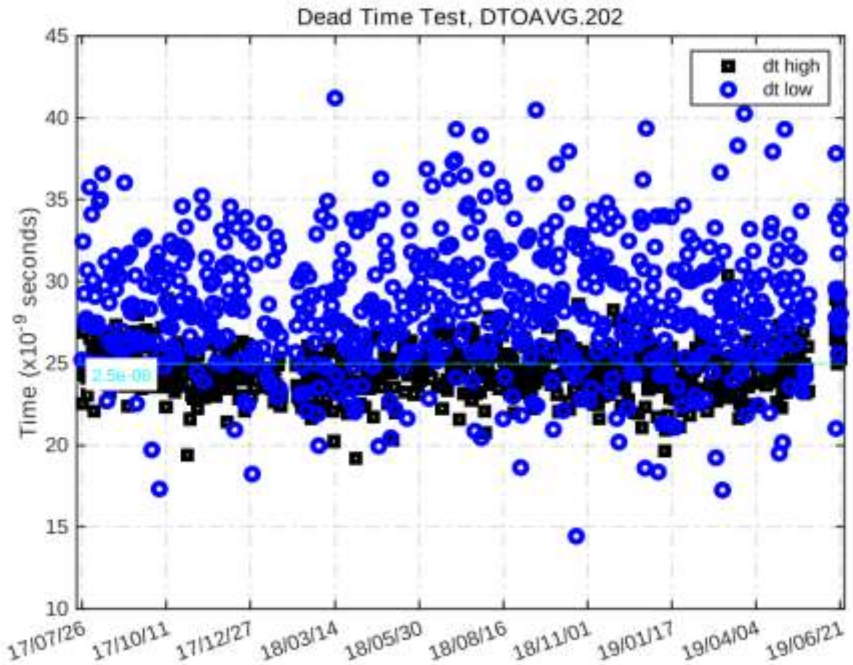


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

21.2.3. Analogue test

Figure 7 shows that the results of the AP tests were quite stable in the intercomparison period. There were, however, very noticeable changes especially in the SL current and +5 Voltage during the campaign. Again, these variables seem to have reverted to their pre-campaign values once the instrument started to operate at its station.

Analogue Printout Log, APOAVG.202

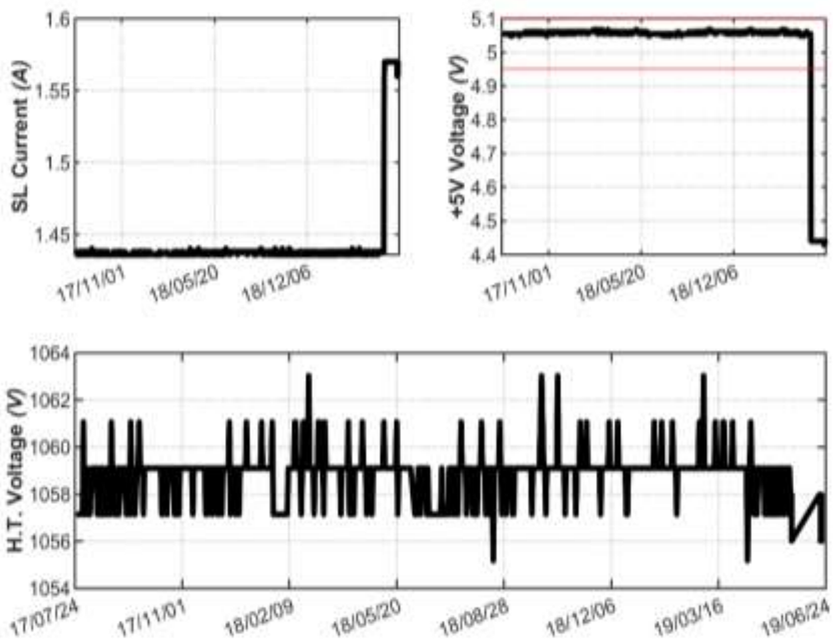


Figure 7. Analogue voltages and intensity

21.2.4 Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign (see Figure 8). There is also no clear correlation between the lamp's intensity and the instrument's temperature.

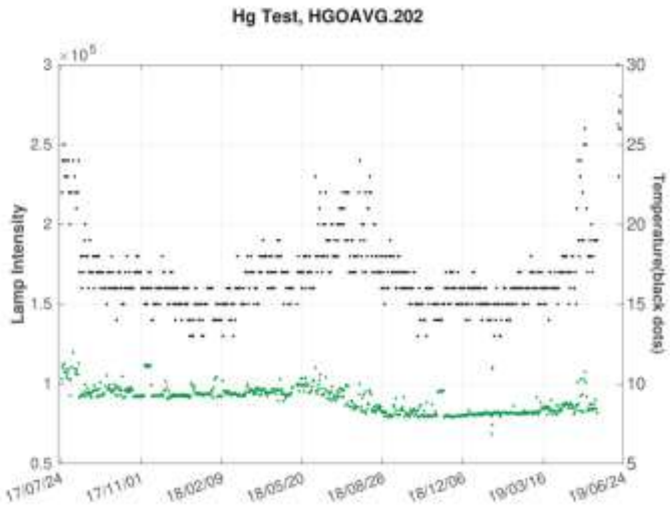
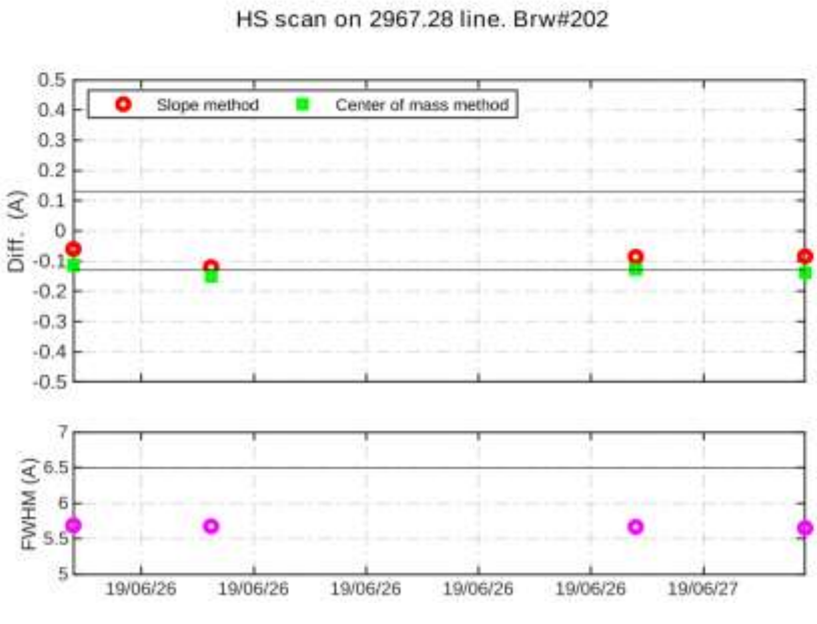


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

21.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm.

Although there is little data, analysis of the CZ scans performed on Brewer DNK#202 during the campaign show reasonable results, with the peak of the calculated scans close to, although slightly below, the accepted tolerance range. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.



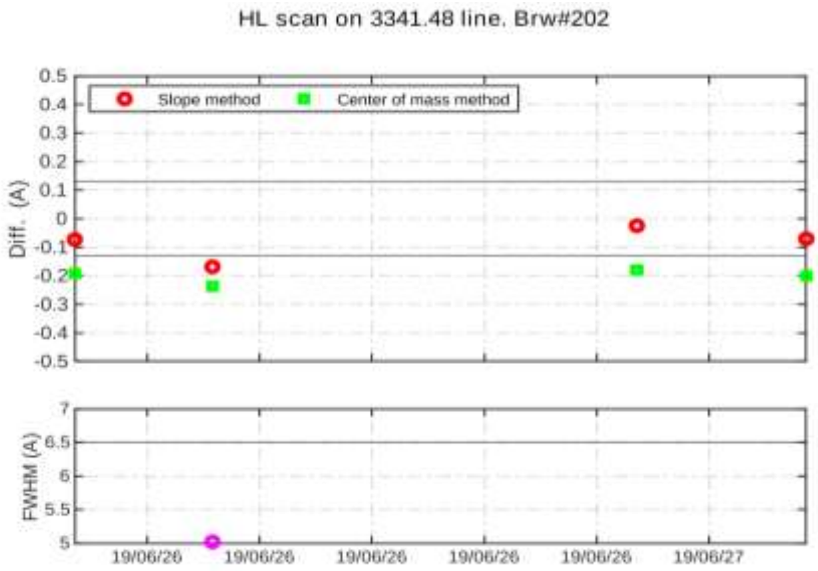


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

21.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10 we show percentage ratios of the Brewer DNK#202 CI scans performed during the campaign relative to the scan CI17619.202. As can be observed, lamp intensity varied with respect to the reference spectrum by approx. 0.5%.

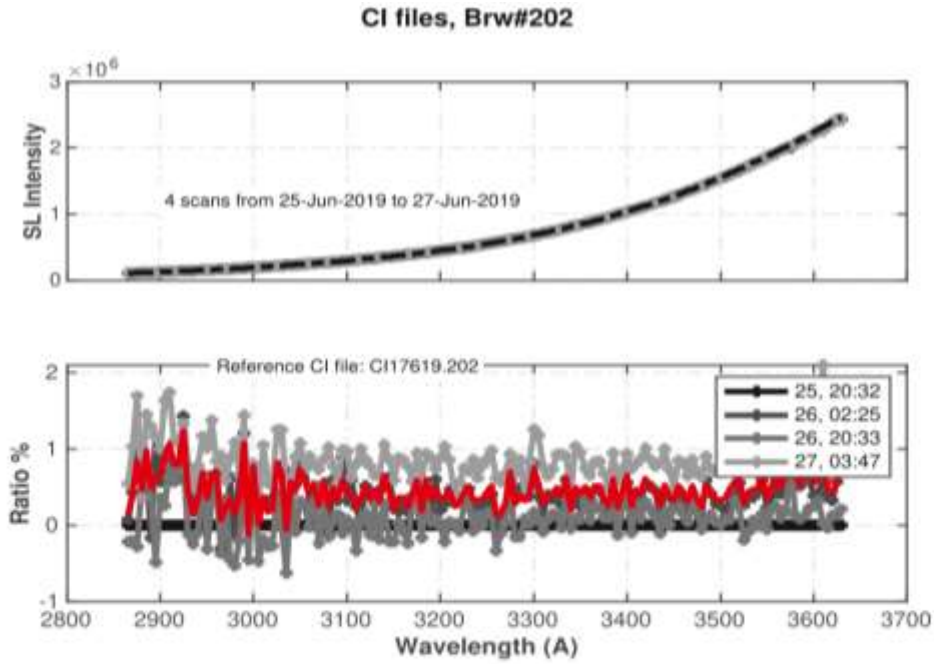


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

21.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 19 °C to 32 °C), the current coefficients do an excellent job at reducing the temperature dependence, performing almost on par with the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, the current and new coefficients perform similarly. For this reason, in the final ICF we have retained the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.5461	-0.8458	-0.9926	-1.0442
Calculated	0.0000	-0.7200	-1.4300	-1.9200	-2.4100
Final	0.0000	-0.5461	-0.8458	-0.9926	-1.0442

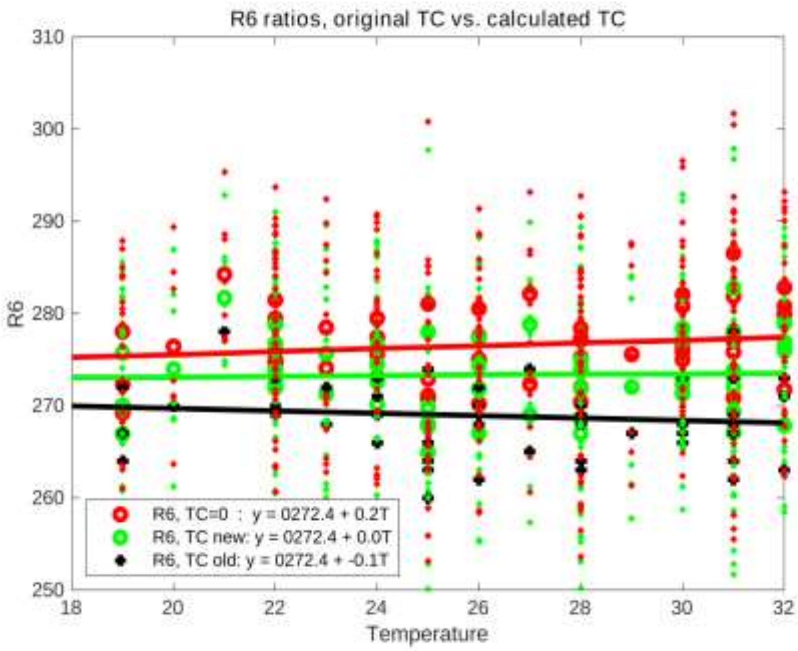


Figure 11. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

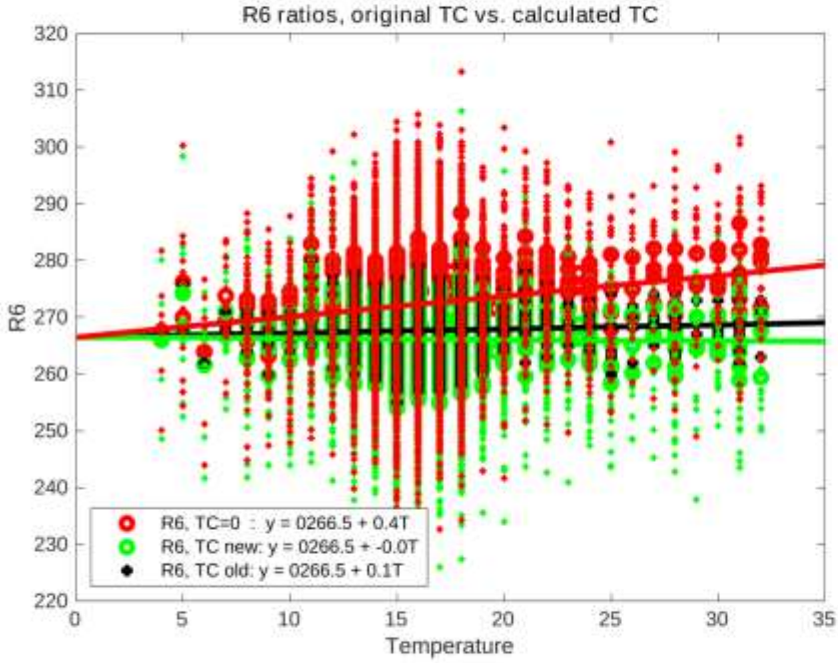


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

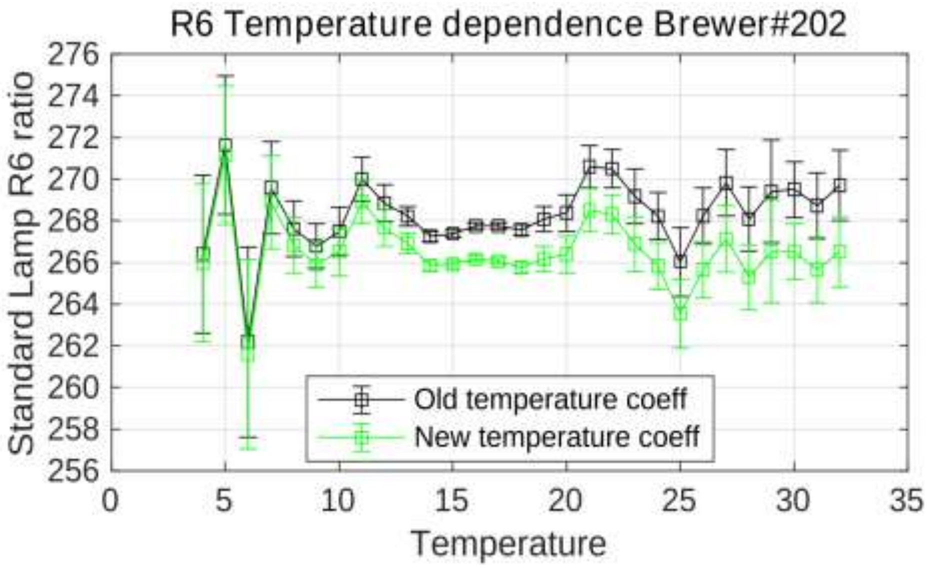


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted the R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

21.4. ATTENUATION FILTER CHARACTERIZATION

21.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 29 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 14 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

The results in Table 2 show large differences between mean and median values, and the confidence intervals are large. All this points to the FI tests having a lot of noise. Also, looking at the comparison with reference Brewer IZO#185, we do not suggest the application of filter corrections.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals were calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	8	18	-8	12	-8
ETC Filt. Corr. (mean)	8.5	9.2	5.8	4.3	11.1
ETC Filt. Corr. (mean 95% CI)	[-1 17]	[2.4 14.7]	[-0.7 11.8]	[-2.5 10.3]	[0.2 20.5]

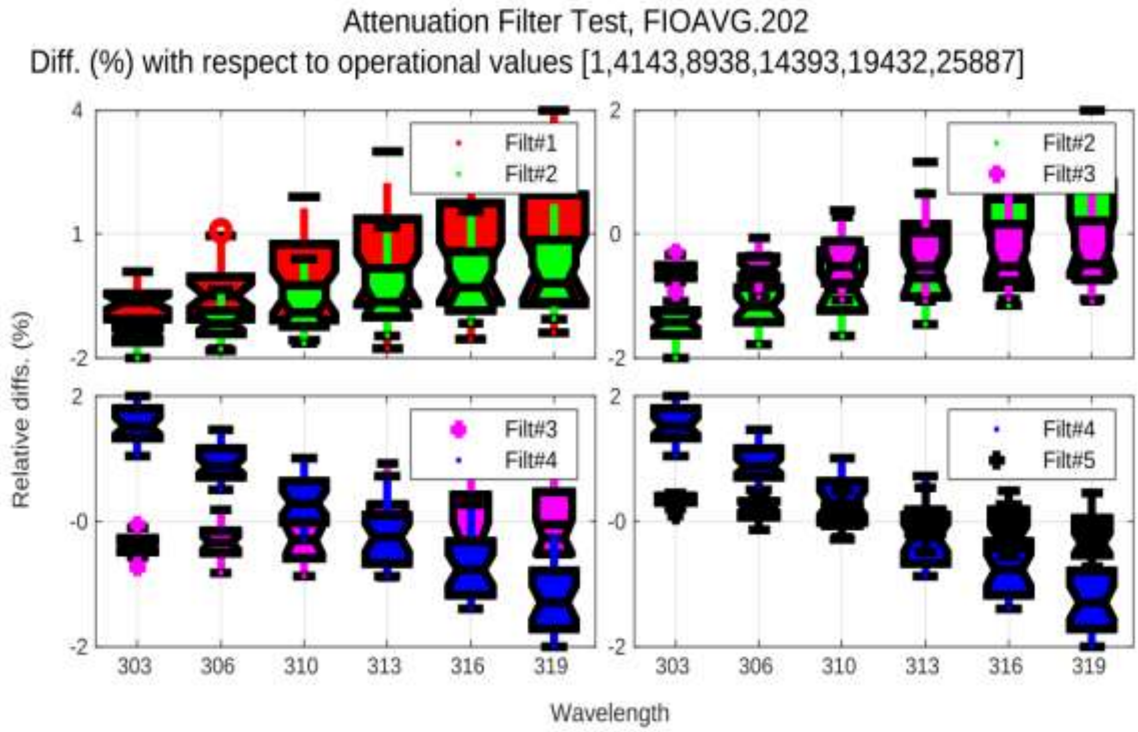


Figure 14. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

21.5. WAVELENGTH CALIBRATION

21.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is

required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 15).

During the campaign, 8 sun scan (SC) tests covering an ozone slant path range from approx. 400 to 1200 DU were carried out (see Figure 16). The calculated cal step number (CSN) was 1 step higher than the value in the current configuration (287 vs. 286). SC tests performed at the station before the campaign provide a CSN of 292, but those results seem to have a lot of noise. Taking all this into account, we suggest keeping the current CSN of 286.

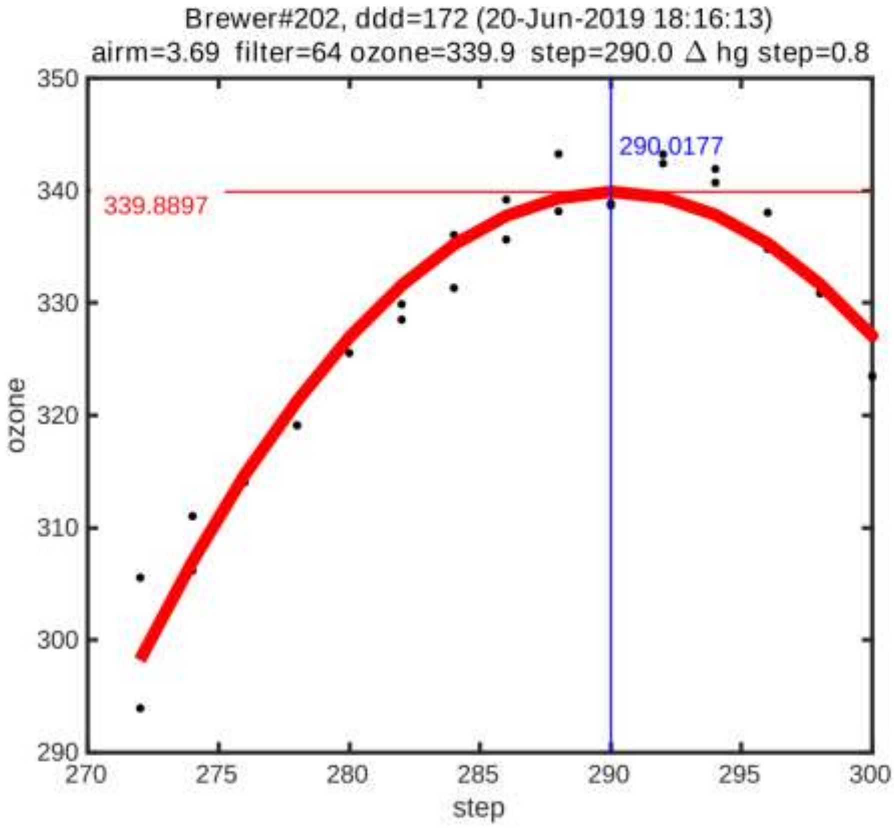


Figure 15. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

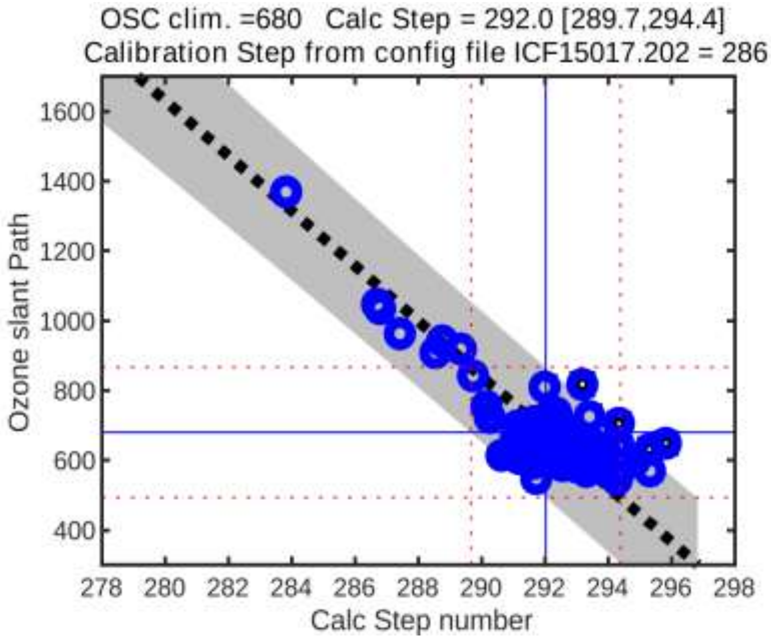


Figure 16. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated *cal step number* for a climatological OSC equal to 680 DU (horizontal solid line). The blue area represents a 95% confidence interval.

21.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 17 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. Note however that we had to stop the analysis at 330 nm, because results for higher wavelengths had a lot of noise.

For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

The dispersion tests performed at the campaign provide a value 2 steps (approx. 0.002 units) lower than the current value. This is a rather small difference and since the cal step has not changed, we suggest retaining the current value of the ozone absorption coefficient of 0.3444.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	286	0.3444	2.3500	1.1417
02-Jun-2017	286	0.3490	2.9932	1.1717
06-Jun-2017	286	0.3431	3.0695	1.1552
22-Jun-2019	286	0.3418	3.1243	1.1491
24-Jun-2019	286	0.3424	3.1108	1.1505
Final	286	0.3444	2.3500	1.1417

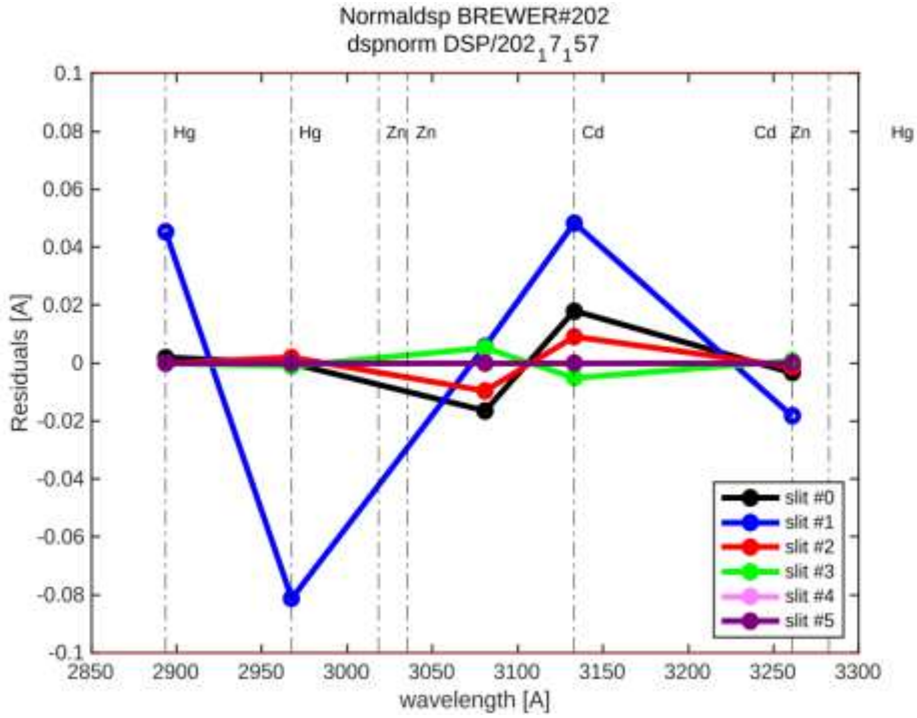


Figure 17. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 285	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3031.54	3062.72	3100.18	3134.79	3167.81	3199.87
Res(A)	5.6164	5.5912	5.4301	5.5899	5.5018	5.419
O3abs(1/cm)	2.6121	1.7859	1.0062	0.67714	0.37494	0.2945
Ray abs(1/cm)	0.50533	0.48342	0.45868	0.43724	0.41796	0.40027
SO2abs(1/cm)	3.5252	5.5461	2.3735	1.9368	1.0515	0.61518
step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.62	3062.8	3100.25	3134.86	3167.88	3199.94
Res(A)	5.6163	5.5911	5.43	5.5898	5.5017	5.4189
O3abs(1/cm)	2.6093	1.7844	1.0059	0.67687	0.37497	0.29403
Ray abs(1/cm)	0.50528	0.48337	0.45863	0.4372	0.41792	0.40024
SO2abs(1/cm)	3.5064	5.5705	2.3809	1.9251	1.0527	0.61303
step= 287	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3031.69	3062.87	3100.32	3134.93	3167.95	3200.01
Res(A)	5.6162	5.591	5.4299	5.5897	5.5016	5.4189
O3abs(1/cm)	2.6067	1.783	1.0056	0.67657	0.37499	0.29357
Ray abs(1/cm)	0.50522	0.48332	0.45859	0.43716	0.41788	0.4002
SO2abs(1/cm)	3.4878	5.5945	2.3882	1.9135	1.0539	0.61083
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
285	0.34343	10.0781	3.0984	1.1535	0.35423	0.34561
286	0.34239	10.0759	3.1108	1.1505	0.3533	0.34465
287	0.3414	10.0736	3.1226	1.1474	0.35234	0.34366

21.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 1705. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 286	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.6163	5.5911	5.43	5.5898	5.5017	5.4189
O3abs(1/cm)	2.6093	1.7844	1.0059	0.67687	0.37497	0.29403
Ray abs(1/cm)	0.50528	0.48337	0.45863	0.4372	0.41792	0.40024
step= 1705	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3296
Res(A)	5.457	5.4495	5.2986	5.4259	5.3505	5.3291
O3abs(1/cm)	0.67881	0.39622	0.29456	0.12293	0.06091	0.033395
Ray abs(1/cm)	0.438	0.42032	0.40024	0.38282	0.36711	0.35271

21.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 13 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

21.6.1. Initial calibration

For the evaluation of the initial status of Brewer DNK#202, we used the period from days 166 to 178 which correspond to 466 near-simultaneous direct sun ozone measurements. As shown in Figure 18, the initial calibration constants produced an ozone value slightly higher than the reference instrument, by approx. 1%. When the ETC is corrected, taking into account the difference between the SL and R6 reference value (the so-called SL correction), the results did not improve.

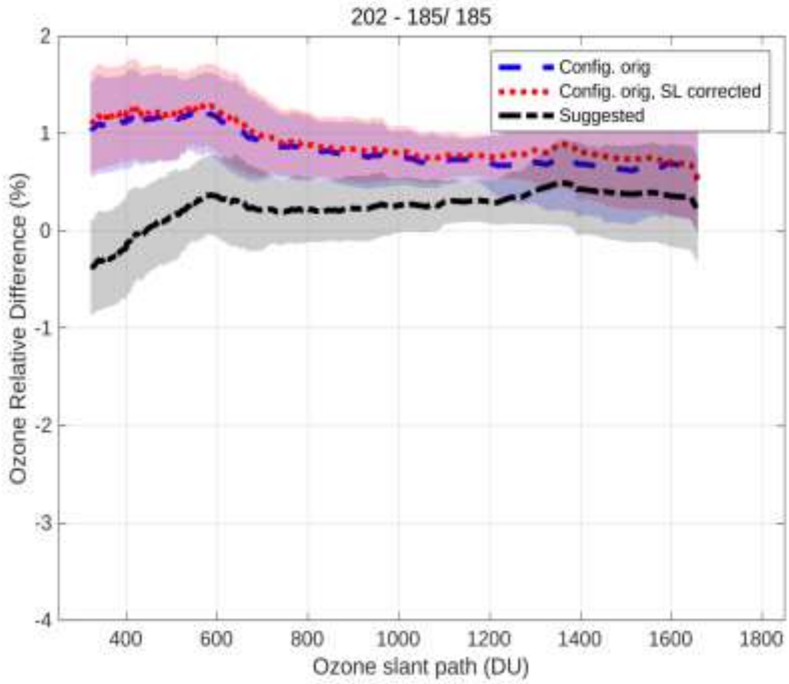


Figure 18. Mean direct sun ozone column percentage difference between Brewer DNK#202 and Brewer IZO#185 as a function of ozone slant path

Table 6. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#202*	*O3 std*	*%(202–185)/185*	*O3(*) #202*	*O3std*	*(*)%(202–185)/185*
17-Jun-2019	168	312.5	0.9	11	312.3	1.9	-0.1	309.4	2	-1
18-Jun-2019	169	325.7	0.7	6	325.9	0.9	0.1	323	0.9	-0.8
19-Jun-2019	170	326.7	2.7	41	328.8	3.7	0.6	326	3.8	-0.2
20-Jun-2019	171	336.1	3	59	338	2.7	0.6	335.5	2.5	-0.2
21-Jun-2019	172	337.6	3.6	49	339.8	3.5	0.7	337.3	3.1	-0.1
22-Jun-2019	173	329.8	2.6	46	331.7	2.8	0.6	329.2	2.5	-0.2
23-Jun-2019	174	325.1	3.2	51	327.7	3.5	0.8	325.5	3.1	0.1
24-Jun-2019	175	307.7	0.8	26	310.2	1.2	0.8	308.5	1.1	0.3
25-Jun-2019	176	309.9	2	54	312.9	2.8	1	310.6	2.4	0.2
26-Jun-2019	177	312.7	2.8	39	315.2	3.4	0.8	312.8	3.5	0
27-Jun-2019	178	306.6	1.2	5	308.3	1.2	0.6	306.8	1	0.1

21.6.2. Final calibration

The same data set of measurements from day 166 to 178 was used to obtain the final calibration of Brewer DNK#202. As shown in Figure 19, we obtain a new 1P ETC value of 1497. This is almost 20 units higher than the value in the current ICF, so we recommend using this new ETC. We have updated the new calibration constants in the ICF17519.202 provided.

As shown in Table 7, the agreement between the 1P and 2P ETCs is within the tolerance limit of 10 units. Similarly, the ozone absorption coefficient determined from the dispersion tests and that from the 2P calibration are also within the tolerance limit of 0.002 units

Mean daily total ozone values for the original and the final configurations are shown in Table 8, as well as relative differences with respect to IZO#185.

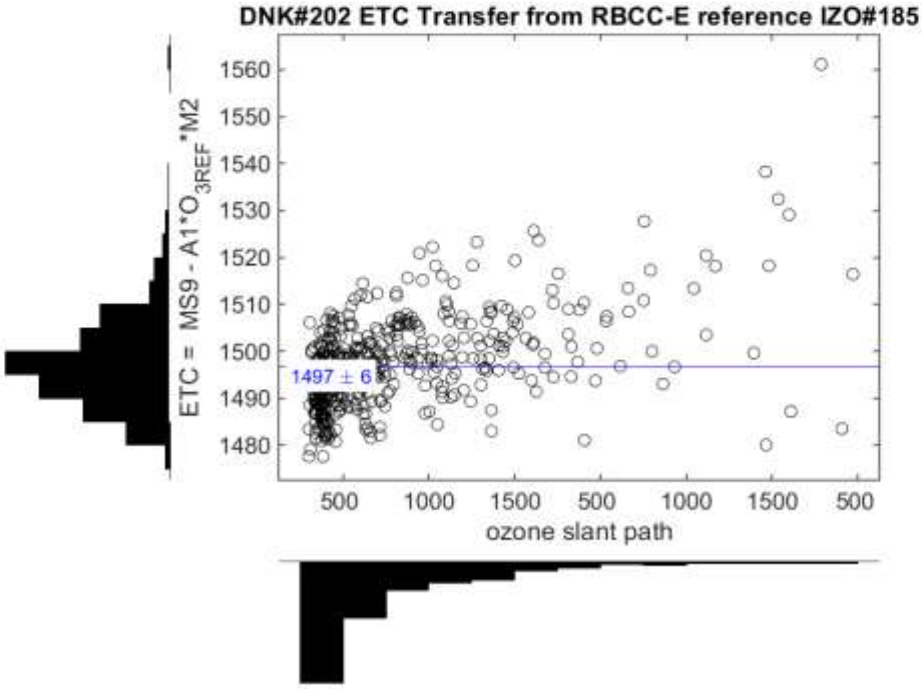


Figure 19. Mean direct sun ozone column percentage difference between Brewer DNK#202 and Brewer IZO#185 as a function of ozone slant path

Table 7. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=1600	1497	1489	3444	3460
full OSC range	1496	1489	3444	3460

Table 8. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#202*	*O3 std*	*%(202–185)/185*	*O3(*) #202*	*O3std*	*(*)%(202–185)/185*
17-Jun-2019	168	311.1	1.1	12	312.7	1.5	0.5	308.2	1.6	-0.9
18-Jun-2019	169	323.2	1.8	8	325.3	1.7	0.6	320.9	1.7	-0.7
19-Jun-2019	170	325.1	2.9	37	328.4	3.2	1	323.9	3.4	-0.4
20-Jun-2019	171	334.9	2.8	66	338	2.7	0.9	334.1	2.5	-0.2
21-Jun-2019	172	335.1	3.9	69	338.5	4.1	1	335.1	3.2	0
22-Jun-2019	173	328.2	2.5	52	331.1	2.9	0.9	327.4	2.3	-0.2
23-Jun-2019	174	323.7	3.2	55	327	3.7	1	323.7	3	0

Date	Day	O3#185	O3std	N	O3#202	O3 std	%(202–185)/185	O3(*) #202	O3std	(*)%(202–185)/185
24-Jun-2019	175	307.1	0.9	44	310.2	1.1	1	307.6	1.2	0.2
25-Jun-2019	176	308.7	2	56	311.9	2.1	1	308.8	1.7	0
26-Jun-2019	177	311.8	3.5	53	315.2	3.8	1.1	311.6	4.1	-0.1
27-Jun-2019	178	NaN	NaN	0	307.1	2.8	NaN	305.1	2.3	NaN

21.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 270 for R6 (Figure 20) and 417 for R5 (Figure 21).

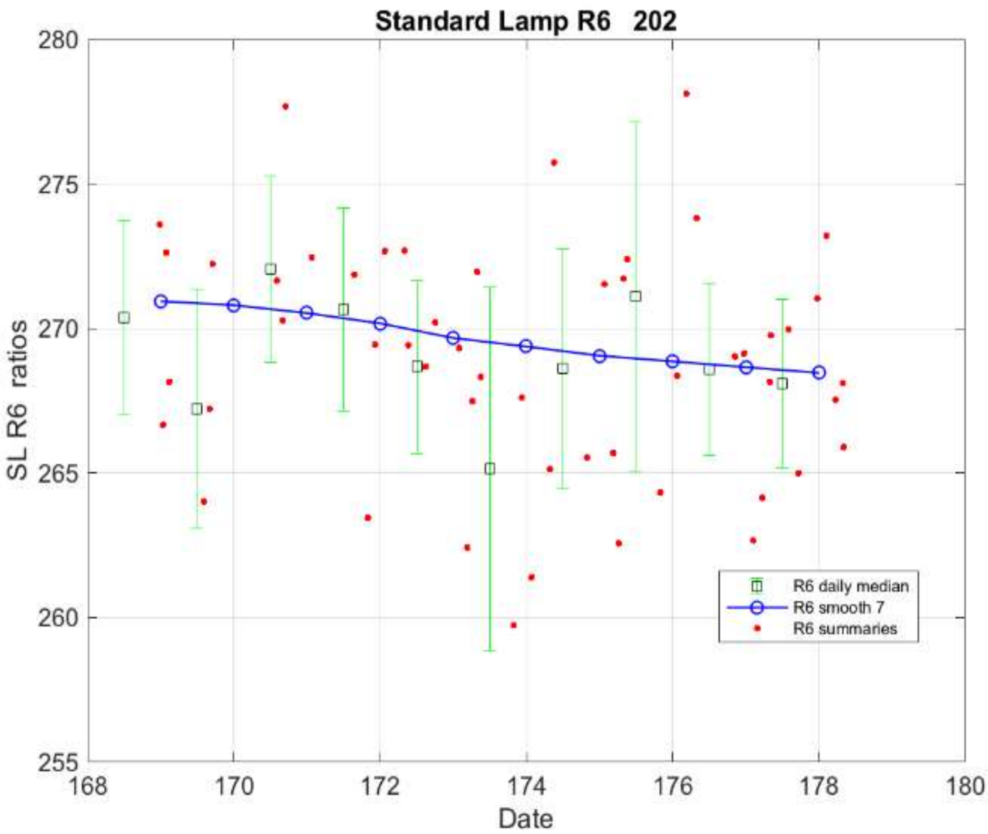


Figure 20. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

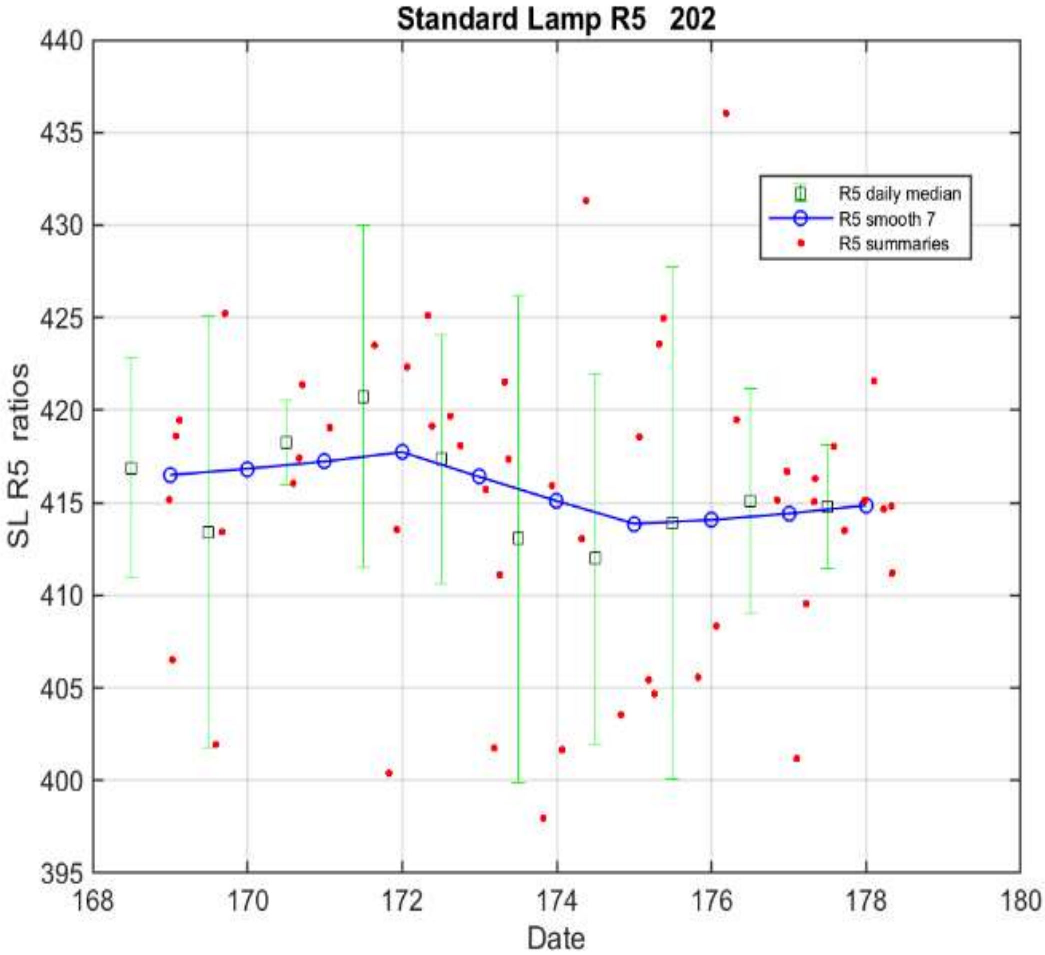


Figure 21. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

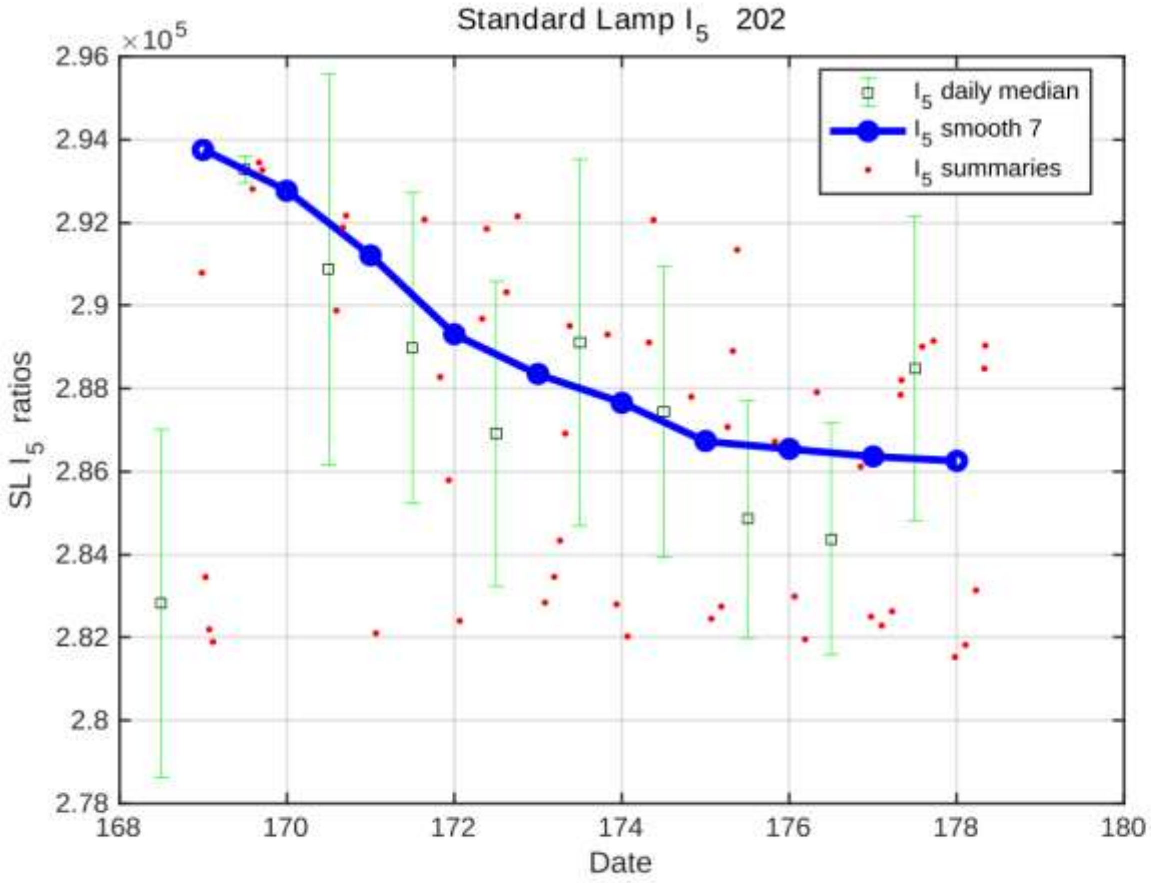


Figure 22. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

21.7. CONFIGURATION

21.7.1. Instrument constant file

	Initial (ICF15017.202)	*Final (ICF17519.202)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.5461	-0.5461
o3 Temp coef 3	-0.8458	-0.8458
o3 Temp coef 4	-0.9926	-0.9926
o3 Temp coef 5	-1.0442	-1.0442
Micrometre steps/deg	0.056	0.056
O3 on O3 Ratio	0.3444	0.3444
SO2 on SO2 Ratio	2.35	2.35
O3 on SO2 Ratio	1.1417	1.1417
ETC on O3 Ratio	1480	1497

	Initial (ICF15017.202)	*Final (ICF17519.202)*
ETC on SO2 Ratio	206	206
Dead time (sec)	2.5e-08	2.5e-08
WL cal step number	286	286
Slitmask motor delay	14	14
Umkehr Offset	1699	1699
ND filter 0	0	0
ND filter 1	4143	4143
ND filter 2	8938	8938
ND filter 3	14393	14393
ND filter 4	19432	19432
ND filter 5	25887	25887
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	1	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	3	3
Mic #2 Offset	2	2
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2515	2515
Grating Slope	1	1
Grating Intercept	-18	-18

	Initial (ICF15017.202)	*Final (ICF17519.202)*
Micrometre Zero	2469	2469
Iris Open Steps	250	250
Buffer Delay (s)	0.4	0.4
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2210	2210

21.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#202*	*O3 std*	*%diff*	*(*)O3#202*	*O3 std*	*(*)%diff*
168	osc< 400	310	0.8	8	313	1.6	0.8	309	1.7	-0.6
169	700> osc> 400	324	0.0	1	327	0.0	0.8	322	0.0	-0.6
169	osc< 400	324	0.7	4	327	0.8	1.0	322	0.7	-0.7
170	700> osc> 400	328	3.2	7	331	3.8	0.7	327	3.8	-0.3
170	osc< 400	324	2.0	27	327	2.5	0.9	323	2.6	-0.3
171	osc> 1500	334	0.0	1	335	0.0	0.4	334	0.0	0.2
171	1500> osc> 1000	334	0.1	2	337	0.2	0.9	335	0.4	0.5
171	1000> osc> 700	336	1.1	3	338	1.3	0.7	336	1.2	0.1
171	700> osc> 400	333	3.6	28	336	2.7	0.9	333	2.7	-0.1
171	osc< 400	336	1.1	31	339	1.9	1.0	335	1.8	-0.3
172	osc> 1500	325	0.5	3	328	2.2	1.0	327	2.2	0.7
172	1500> osc> 1000	332	3.7	11	335	3.1	0.8	334	3.2	0.3
172	1000> osc> 700	332	1.9	8	336	2.8	1.0	334	2.7	0.3
172	700> osc> 400	334	2.6	22	338	2.9	1.2	334	2.5	0.1
172	osc< 400	338	2.1	29	342	2.6	1.1	337	2.5	-0.4
173	1500> osc> 1000	326	0.3	5	328	0.9	0.8	326	0.9	0.3

Day	*osc range*	*O3#185*	*O3std*	*N*	*O3#202*	*O3 std*	*%diff*	*(*)O3#202*	*O3 std*	*(*)%diff*
173	1000> osc> 700	326	1.6	7	329	1.5	0.7	326	1.7	-0.1
173	700> osc> 400	326	1.7	12	330	2.6	1.4	326	2.1	0.1
173	osc< 400	329	1.6	30	334	2.4	1.4	328	2.4	-0.3
174	1000> osc> 700	320	3.2	10	323	3.7	1.0	321	3.7	0.3
174	700> osc> 400	323	2.2	26	327	3.1	1.3	324	2.7	0.2
174	osc< 400	327	1.0	17	330	1.5	1.1	325	1.5	-0.4
175	osc> 1500	309	0.0	1	309	0.0	0.0	308	0.0	-0.3
175	1500> osc> 1000	308	0.4	5	310	0.5	0.8	309	0.6	0.5
175	1000> osc> 700	307	0.5	11	310	0.7	0.9	308	0.7	0.3
175	700> osc> 400	307	1.0	26	310	1.2	1.1	307	1.3	0.2
175	osc< 400	307	0.0	1	312	0.0	1.6	308	0.0	0.5
176	osc> 1500	308	0.0	2	308	1.8	-0.2	307	1.7	-0.5
176	1500> osc> 1000	310	0.9	5	312	1.5	0.6	310	1.5	0.2
176	1000> osc> 700	308	2.4	9	310	2.2	0.8	308	2.3	0.1
176	700> osc> 400	308	1.5	26	312	1.6	1.3	308	1.6	0.2
176	osc< 400	310	1.5	18	314	1.8	1.2	309	1.5	-0.2
177	osc> 1500	312	0.0	1	316	0.0	1.3	315	0.0	1.0
177	1000> osc> 700	312	6.0	6	314	6.6	0.7	312	6.7	0.0
177	700> osc> 400	314	4.0	21	317	4.0	1.1	314	4.2	0.0
177	osc< 400	311	1.3	23	315	2.4	1.5	310	2.4	-0.1
178	1500> osc> 1000	302	1.7	3	NaN	NaN	NaN	302	2.5	0.0
178	1000> osc> 700	305	0.7	6	NaN	NaN	NaN	305	1.4	0.2
178	700> osc> 400	307	0.7	5	NaN	NaN	NaN	307	1.4	0.0

21.9. APPENDIX: SUMMARY PLOTS

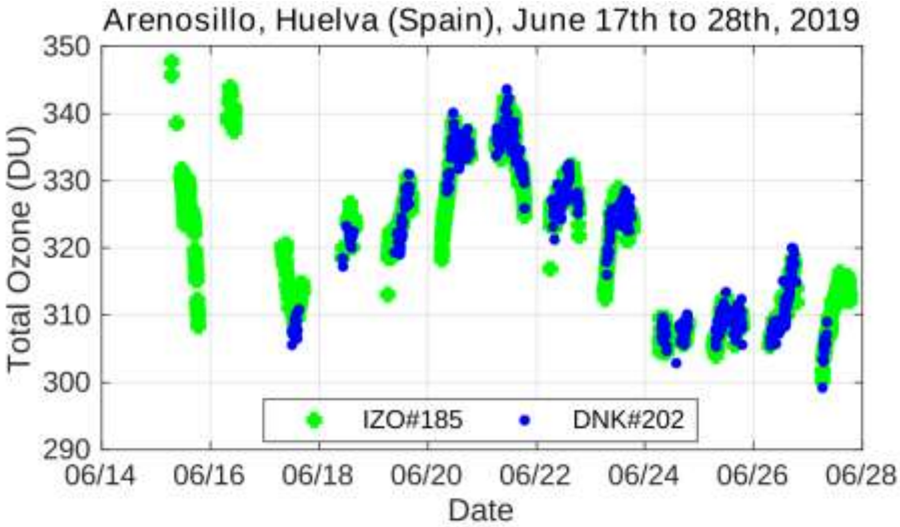
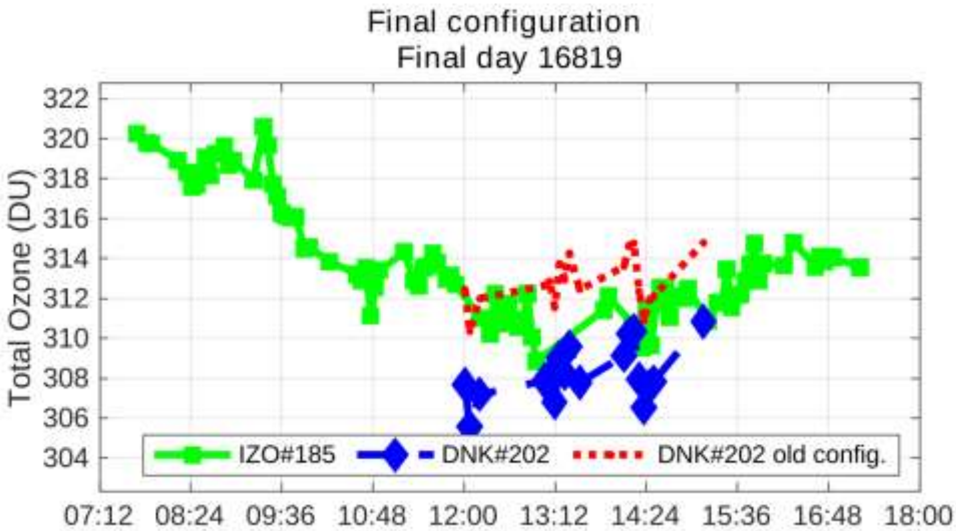
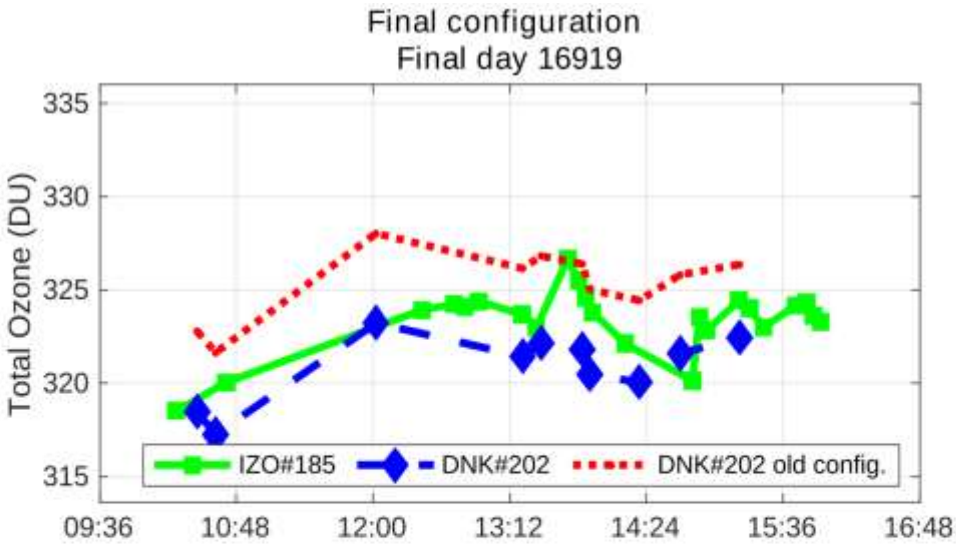
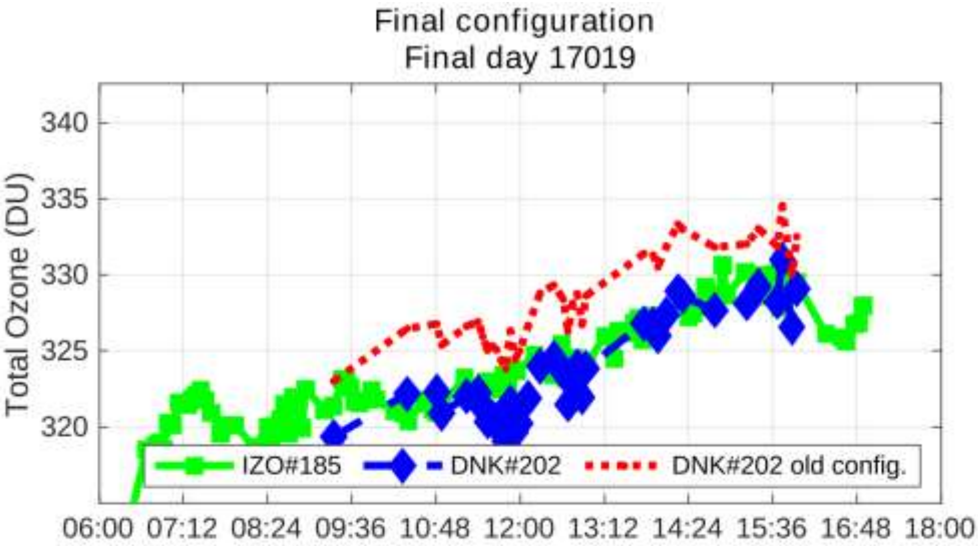
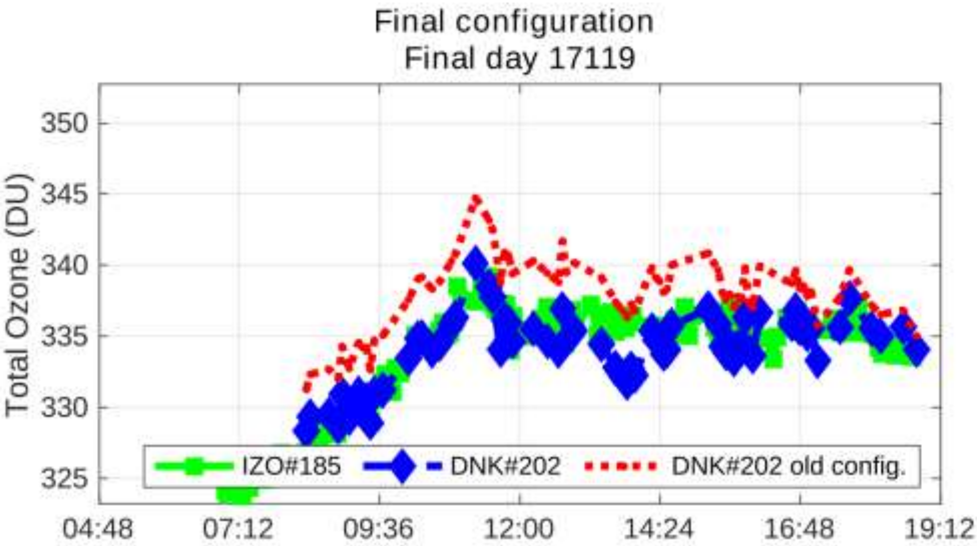


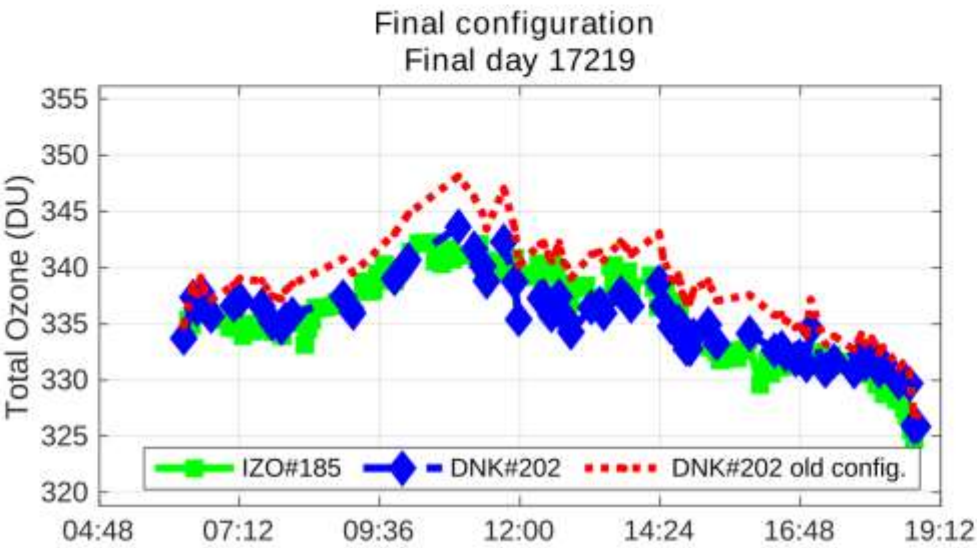
Figure 23. Overview of the intercomparison. Brewer DNK#202 data were evaluated using final constants (blue circles)

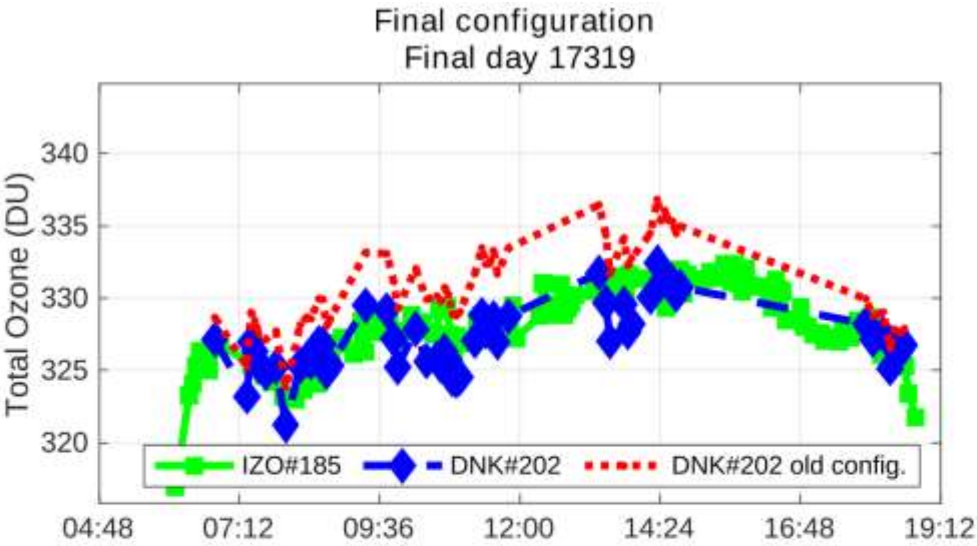


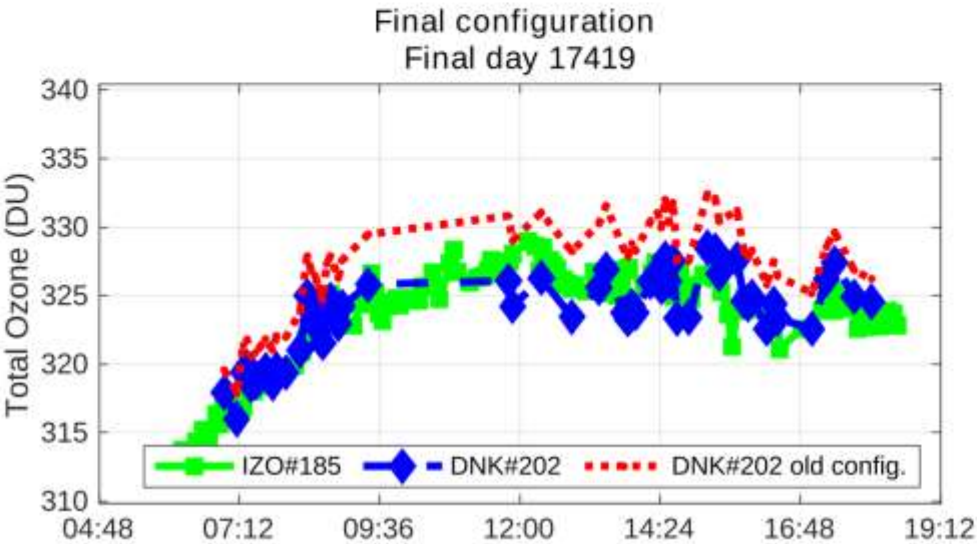


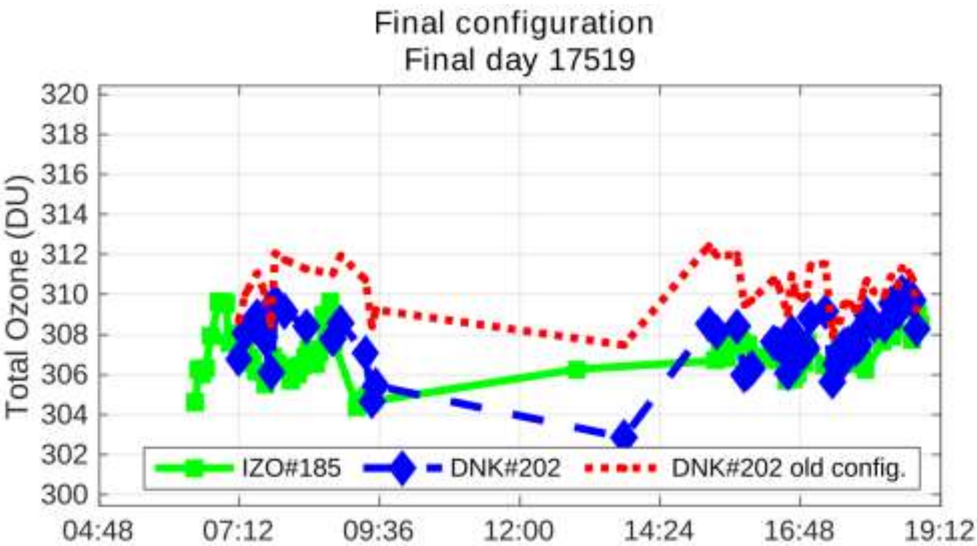

Final configuration
Final day 17019
Total Ozone (DU)
340
335
330
325
320
06:00 07:12 08:24 09:36 10:48 12:00 13:12 14:24 15:36 16:48 18:00
IZO#185
DNK#202
DNK#202 old config.

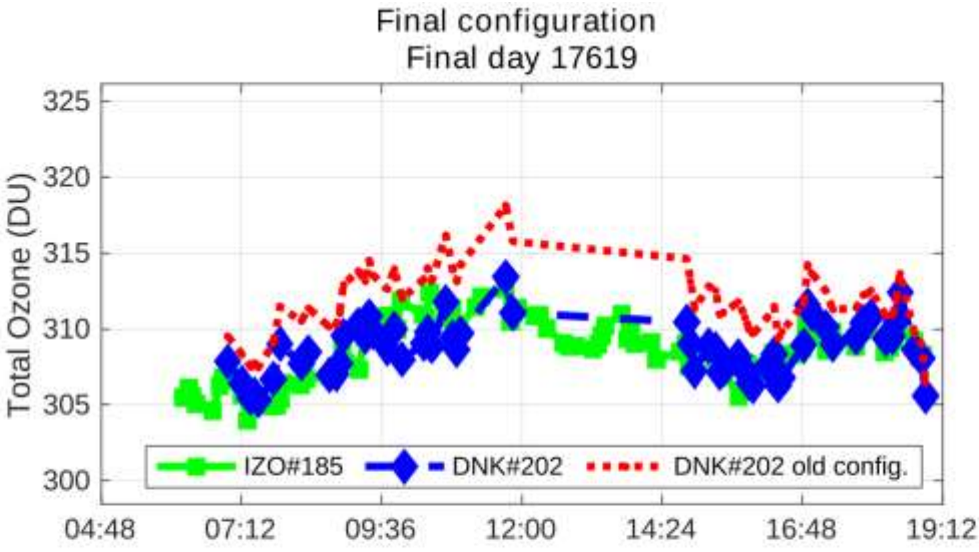

Final configuration
Final day 17119
Total Ozone (DU)
350
345
340
335
330
325
04:48 07:12 09:36 12:00 14:24 16:48 19:12
IZO#185
DNK#202
DNK#202 old config.

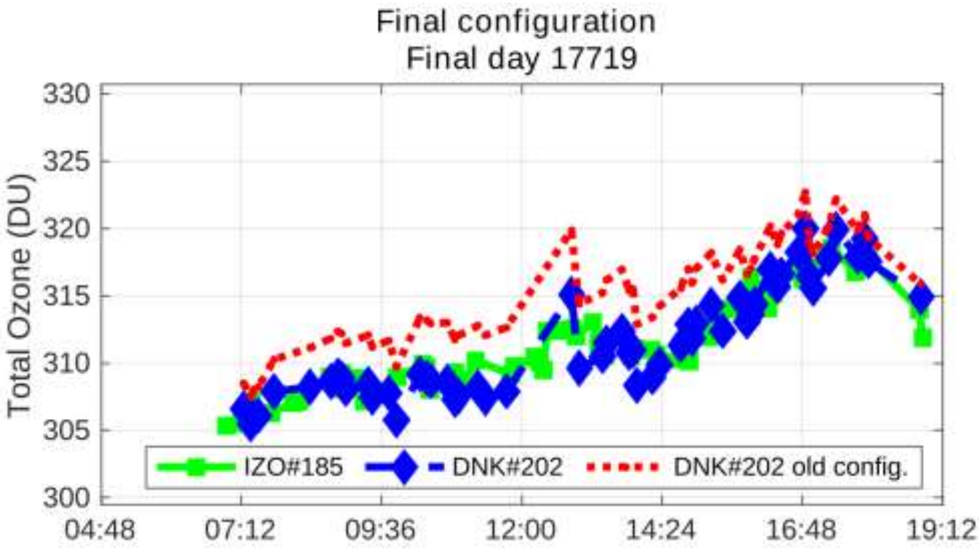

Final configuration
Final day 17219
Total Ozone (DU)
355
350
345
340
335
330
325
320
04:48 07:12 09:36 12:00 14:24 16:48 19:12
IZO#185
DNK#202
DNK#202 old config.

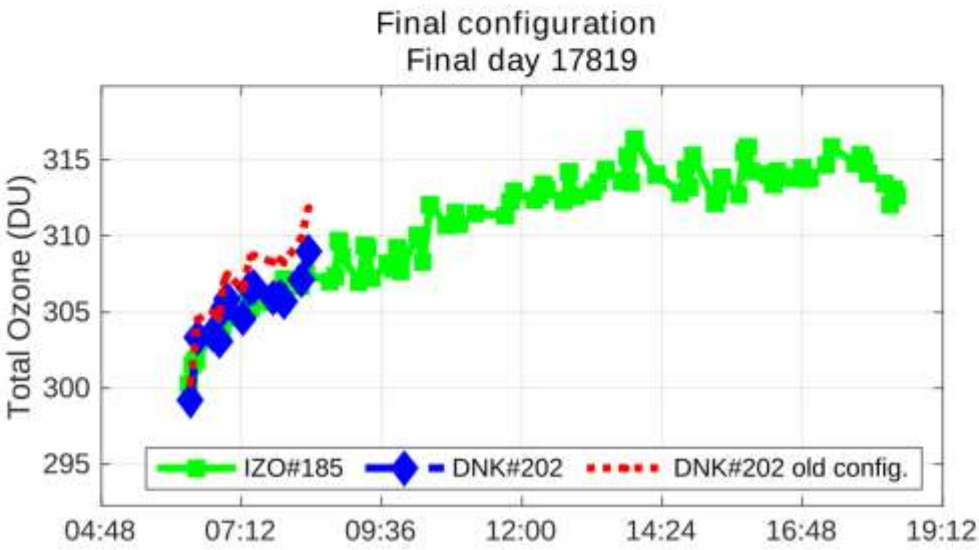

Final configuration
Final day 17319
Total Ozone (DU)
340
335
330
325
320
IZO#185
DNK#202
DNK#202 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17419
Total Ozone (DU)
340
335
330
325
320
315
310
IZO#185
DNK#202
DNK#202 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17519
Total Ozone (DU)
320
318
316
314
312
310
308
306
304
302
300
IZO#185
DNK#202
DNK#202 old config.
04:48
07:12
09:36
12:00
14:24
16:48
19:12


Final configuration
Final day 17619
Total Ozone (DU)
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#202
DNK#202 old config.


Final configuration
Final day 17719
Total Ozone (DU)
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#202
DNK#202 old config.


Final configuration
Final day 17819
Total Ozone (DU)
315
310
305
300
295
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#202
DNK#202 old config.

22. BREWER DNK#228

22.1. CALIBRATION SUMMARY

The Fourteenth Intercomparison Campaign of the Regional Brewer Calibration Center Europe (RBCC-E) was held from 17 to 28 June 2019, at the *El Arenosillo* Atmospheric Sounding Station of the *Instituto Nacional de Técnica Aeroespacial* (INTA), Spain.

Brewer DNK#228 participated in the campaign from 17 to 28 June, although few measurements were taken on the last day before the instrument was packed. The campaign days of Brewer DNK#228 correspond to Julian days 166 – 179.

The evaluation of the initial status was not possible. The instrument required important repairs before measurements could be made. After this reparation, we were able to use 31 simultaneous direct sun (DS) ozone measurements from days 166 to 171 before the change in cal step that could have an indication of the initial status of the instrument. For final calibration purposes, we used 233 simultaneous DS ozone measurements taken from day 173 to 179.

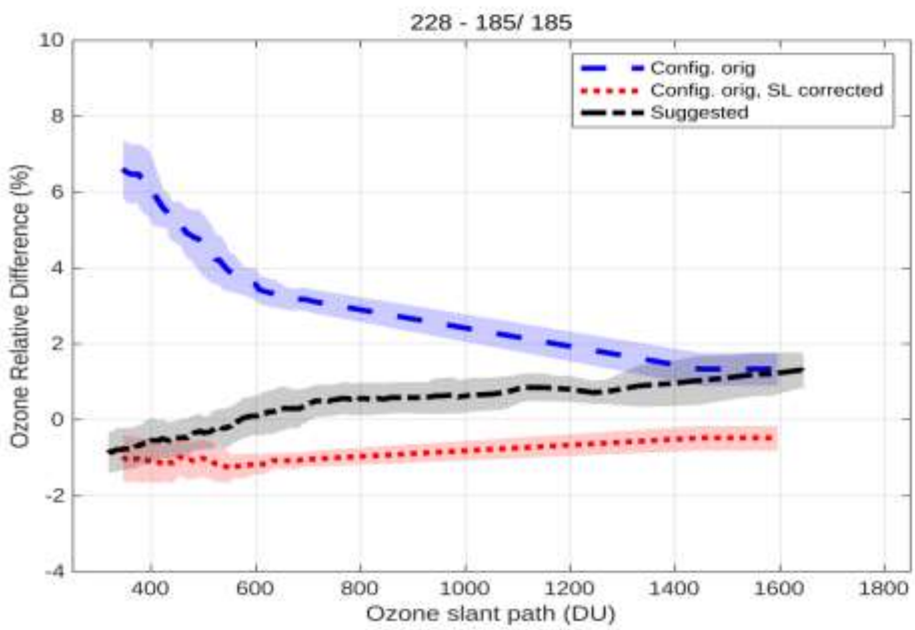


Figure 1. Mean DS ozone column percentage difference between Brewer DNK#228 and Brewer IZO#185, plotted as a function of the ozone slant path. Results for the current (issued in the previous calibration campaign) configuration are shown in blue; the red dotted line corresponds to the same configuration, but with the standard lamp correction applied; the black line corresponds to results obtained with the updated configuration proposed in the current campaign. The shadow areas represent the standard deviation from the mean. The plot corresponds to the final days of the campaign.

As shown in Figure 1, the current ICF (ICF15017.228, blue dashed line) produces ozone values with an average difference of around 5% with respect to the reference instrument. The SL correction 1, red dotted line) brings the agreement to inside 1%, suggesting that we can use the SL correction for the evaluation of the instrument. The final calibration showed a good agreement which slightly underestimates the ozone at midday.

The lamp test results from Brewer DNK#228 have been stable over the last 2 years. After maintenance, the standard lamp ratios stabilized around values 303 for R6 (Figures 21 and 22). These values have been calculated taking into account the new temperature coefficients obtained after this campaign.

Due to the maintenance of the spectrometer, a new dispersion relation is advised. Dead time (DT) shows a small difference between the current and campaign values of around 1 ns, with its value changing from $3.8\cdot 10^{-8}$ s to $2.7\cdot 10^{-8}$ s. This is a significant change for single Brewers.

The neutral density filters did not show significant nonlinearity in the attenuation's spectral characteristics. We have not applied any correction to filters.

The sun scan (SC) tests performed during the campaign suggested that there was a change in cal step number. It was updated to a new value 1023.

We changed the ozone absorption coefficient to the new value 0.3465 (see Section 1.5 for more details).

Taking this into account, we suggest the following changes to the configuration of Brewer DNK#228.

22.1.1. Recommendations and remarks

1. The R6 standard lamp test results from Brewer due to the new temperature coefficients suggest it could be updated to 303.
2. We suggest a new R5 reference value of 534.
3. We have adopted new temperature coefficients.
4. We suggest updating the DT to $2.7\cdot 10^{-8}$ seconds, which is 11 ns less than the value proposed in the last intercomparison.
5. The neutral density filters show the same behaviour as in the previous campaign, and we suggest retaining the same correction factors.
6. We suggest updating the ETC value from 1499 to 1525.
7. Finally, a new dispersion relation is needed after the maintenance. This will not affect the ozone calibration, but will largely affect the UV spectral measurements.

22.1.2. External links

Configuration file

http://rbcce.aemet.es/svn/campaigns/are2019/bfiles/228/ICF17419.228

Calibration report

https://docs.google.com/spreadsheets/d/1WBzxK6bPrkD6mKIzkG8BbhlQgx0zLpsvvSmhllwDCiw/edit#gid=2070746743

Calibration reports detailed

Historic and instrumental

http://rbcce.aemet.es/svn/campaigns/are2019/latex/228/html/cal_report_228a1.html

Temperature & filter

http://rbcce.aemet.es/svn/campaigns/are2019/latex/228/html/cal_report_228a2.html

Wavelength
http://rbcce.aemet.es/svn/campaigns/are2019/latex/228/html/cal_report_228b.html
ETC transfer
http://rbcce.aemet.es/svn/campaigns/aro2019/latex/228/html/cal_report_228c.html

22.2. INSTRUMENT HISTORY: ANALYSIS OF AVERAGE FILES

22.2.1. Standard lamp test

As shown in Figures 2 and 3, the standard lamp test performance has been quite stable since August 2017, with mean values around 303 and 440 for R6 and R5, respectively. The figure does not reflect the updated temperature coefficients calculated with the observations after the campaign.

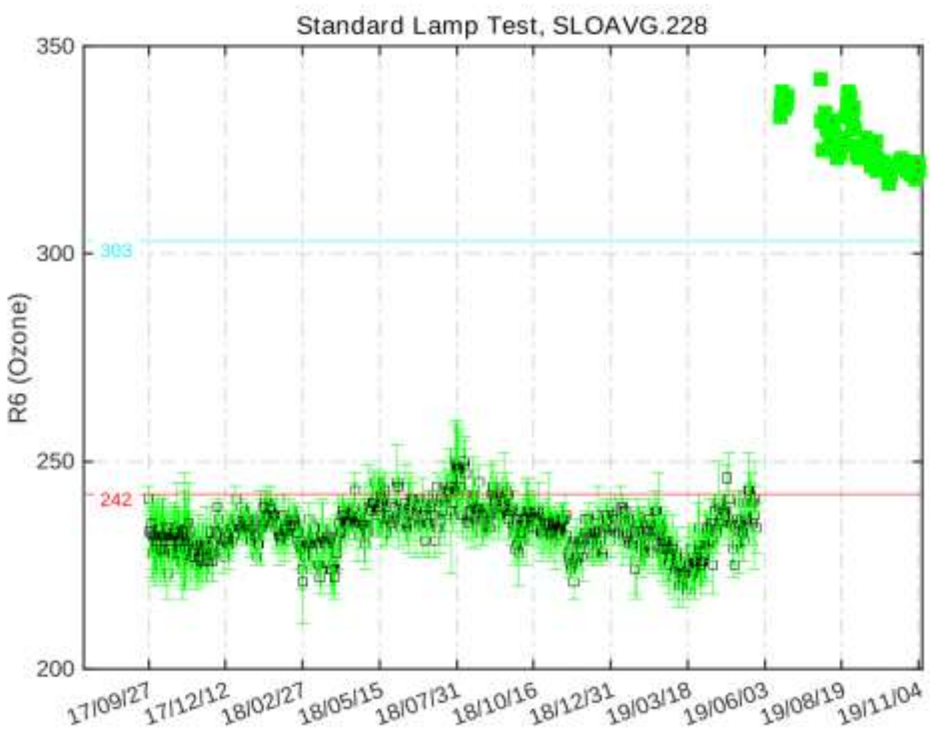


Figure 2. Standard lamp test R6 ozone ratios. Horizontal lines are labelled with the original and final reference values (red and blue lines, respectively).

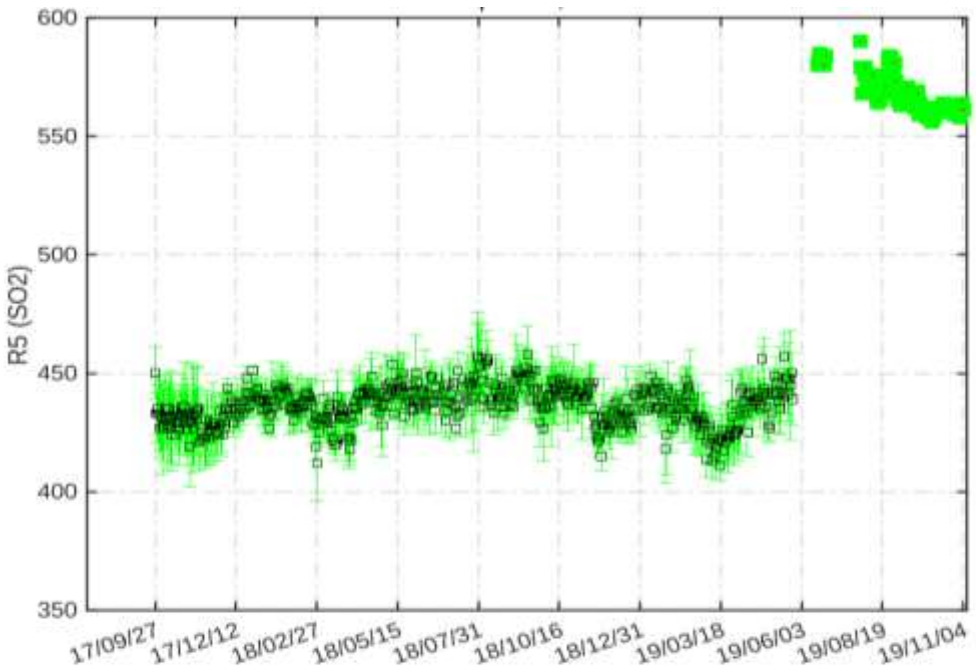


Figure 3. Standard lamp test R5 sulphur dioxide ratios

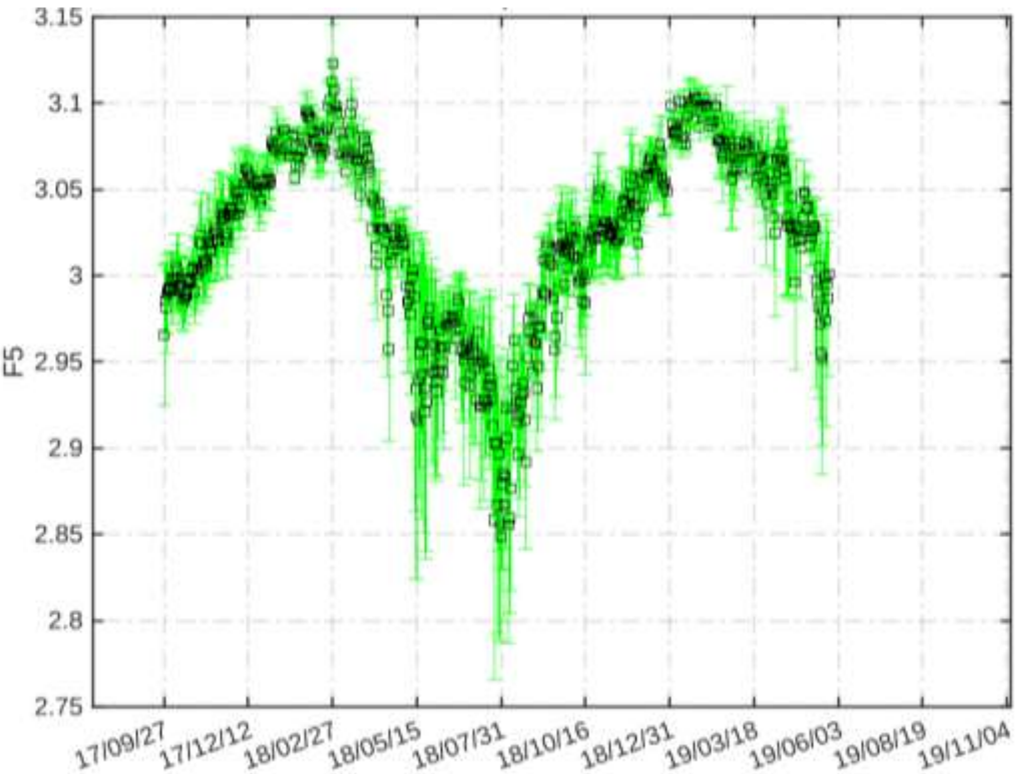


Figure 4. SL intensity for slit five

22.2.2. Run/Stop and dead time

Run/stop test values were outside the test tolerance limits (see Figure 5) and were corrected during the campaign.

As shown in Figure 6, the current DT reference value of $3.8 \cdot 10^{-8}$ seconds is larger than the value recorded during the calibration period, after major repairs on the instrument. Therefore, this new value $2.7 \cdot 10^{-8}$ s has been used in the new ICF.

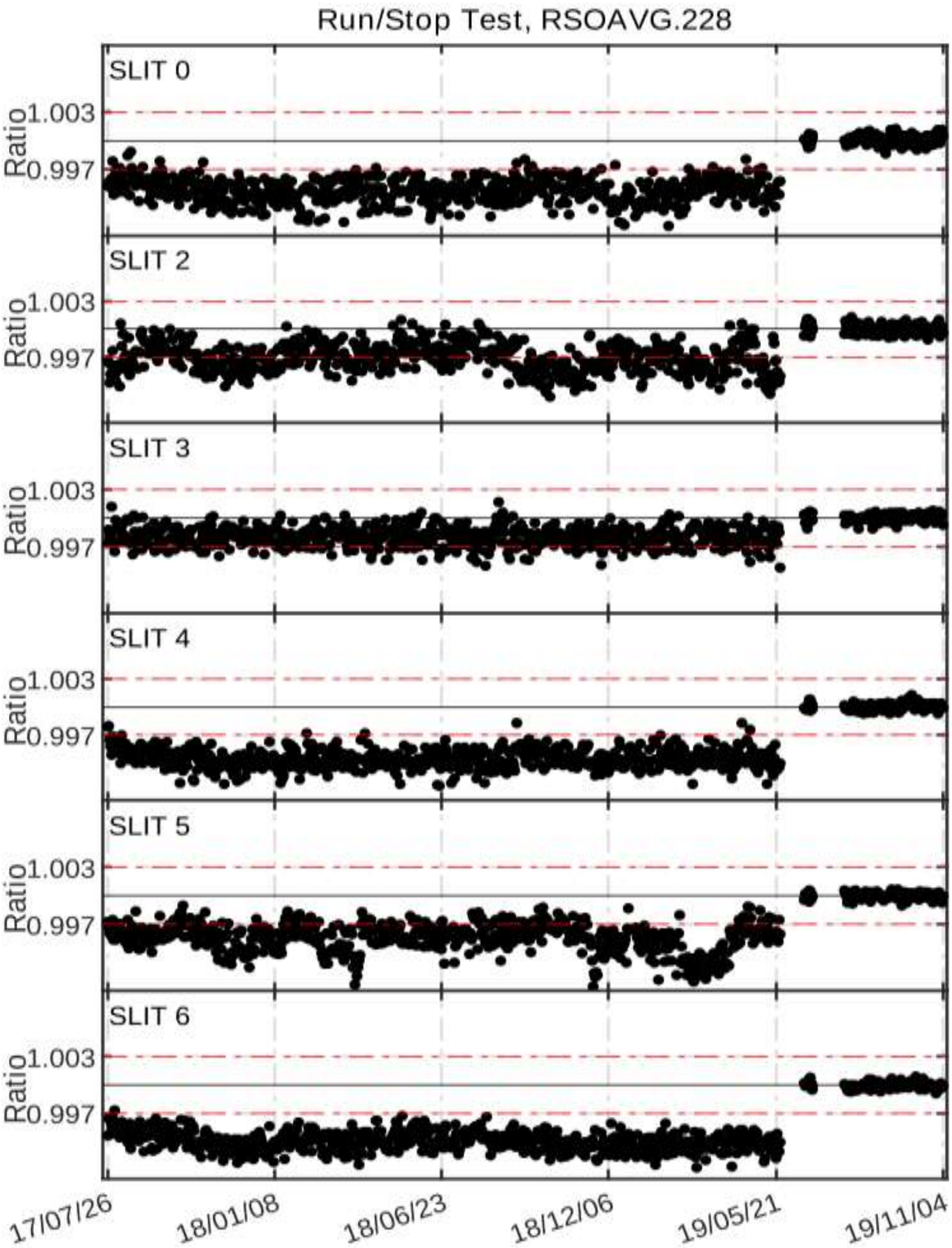


Figure 5. Run/stop test

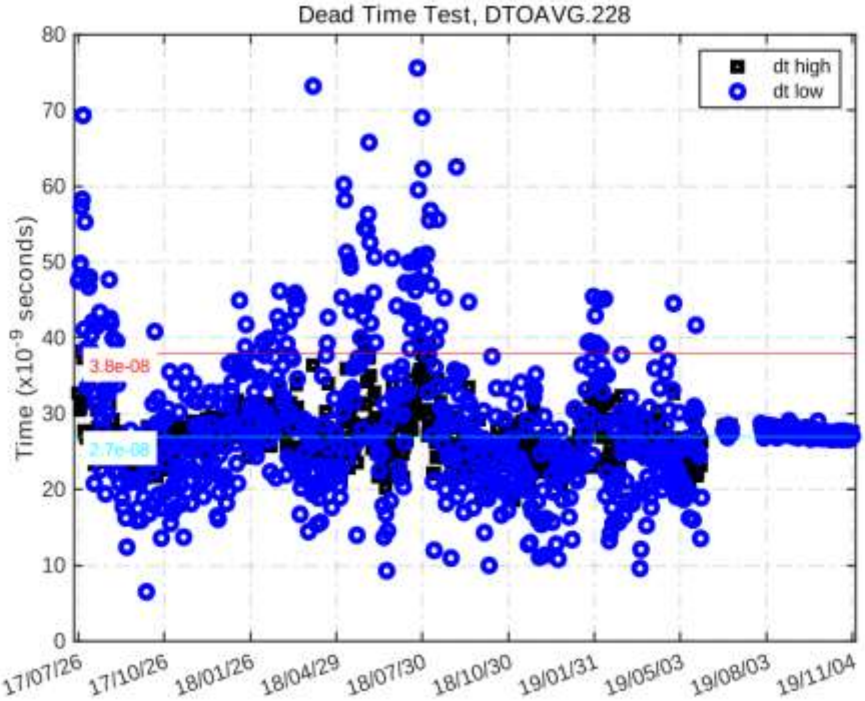


Figure 6. Dead time test. Horizontal lines are labelled with the current (red) and final (blue) values.

22.2.3. Analogue test

Figure 7 shows that the high voltage has remained almost constant at around 1171 over the last two years. Furthermore, analogue test values were within the test tolerance range.

Analogue Printout Log, APOAVG.228

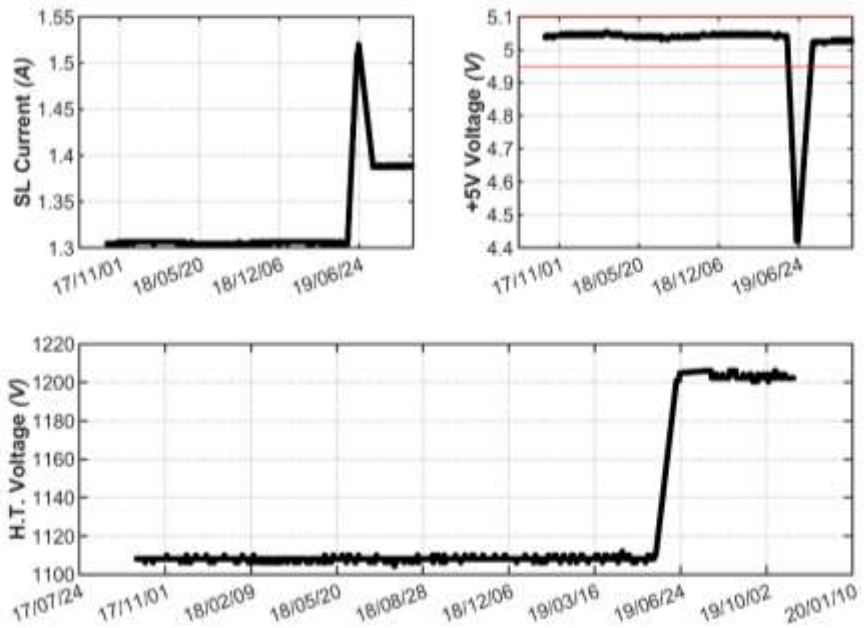


Figure 7. Analogue voltages and intensity

22.2.4. Mercury lamp test

No noticeable internal mercury lamp intensity events were observed during the campaign, see Figure 8.

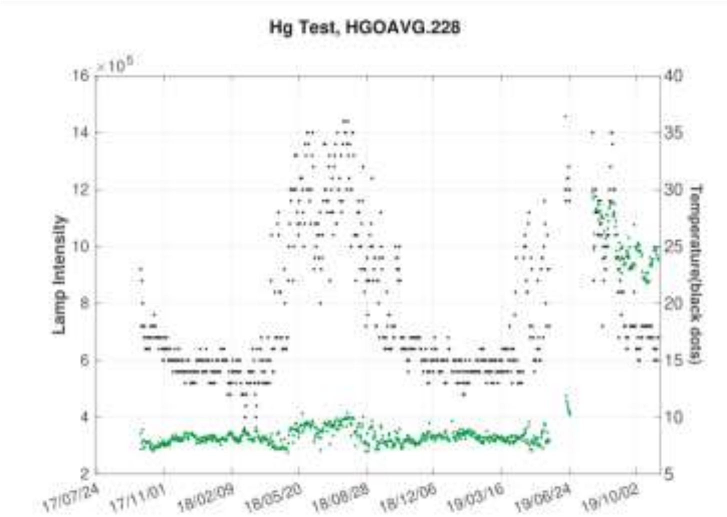
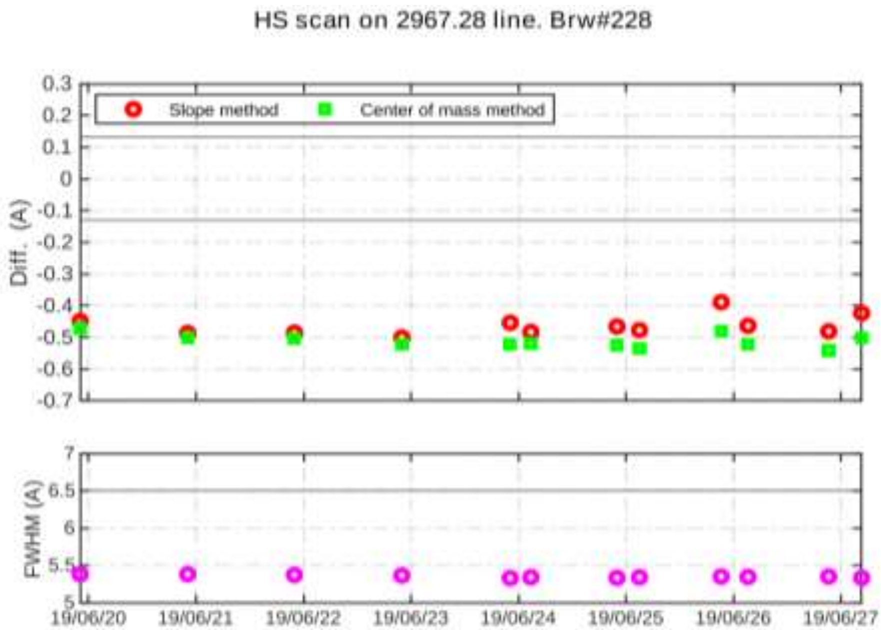


Figure 8. Mercury lamp intensity (green squares) and Brewer temperature registered (black dots). Both parameters refer to maximum values for each day.

22.2.5. CZ scan on mercury lamp

In order to check both the wavelength settings and the slit function width, we analysed the scans performed on the 296.728 nm, and 334.148 nm mercury lines (see Figure 9). As a reference, the calculated scan peak, in wavelength units, should be within 0.013 nm from the nominal value, whereas the calculated slit function width should be no more than 0.65 nm. Analysis of the CZ scans performed on Brewer DNK#228 during the campaign showed a huge shift during reparation and the dispersion file had to be adjusted, this did not affect the ozone calibration but greatly affected the UV measurements. Regarding the slit function width, results were good, with a FWHM lower than 0.65 nm.



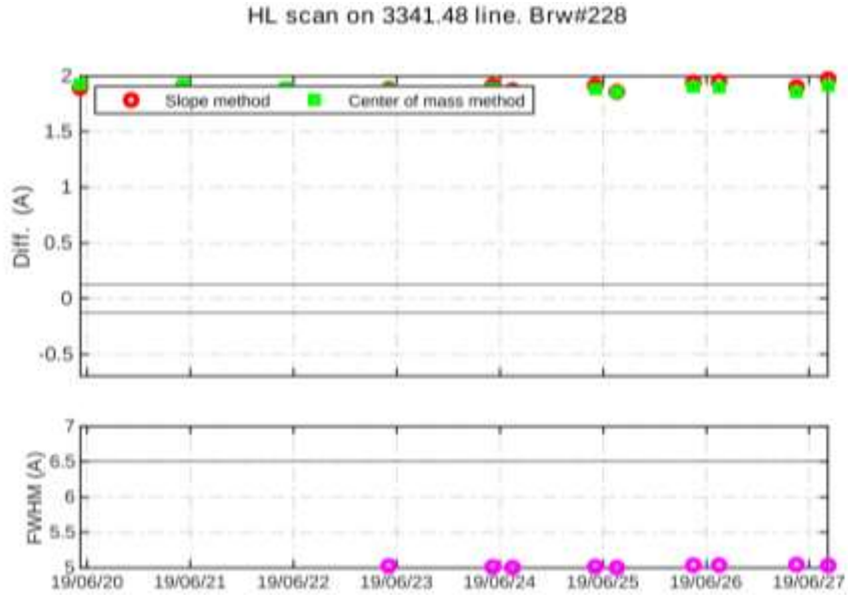


Figure 9. CZ scan on Hg lines. The upper panels show differences with respect to the reference line (solid lines represent the limit ± 0.013 nm) as computed by the slopes (red circles) and centre of mass (green squares) methods. Lower panels show the Full Width at Half Maximum value for each scan performed (solid lines represent the 0.65 nm limit)

22.2.6. CI scan on internal SL

CI scans of the standard lamp recorded at different times can be compared to investigate whether the instrument has changed its spectral sensitivity. In Figure 10, we show percentage ratios of the Brewer DNK#228 CI scans performed during the campaign relative to scan CI17217.228. As can be observed, lamp intensity varied with respect to the reference spectrum by around 0.5% due to very good stability.

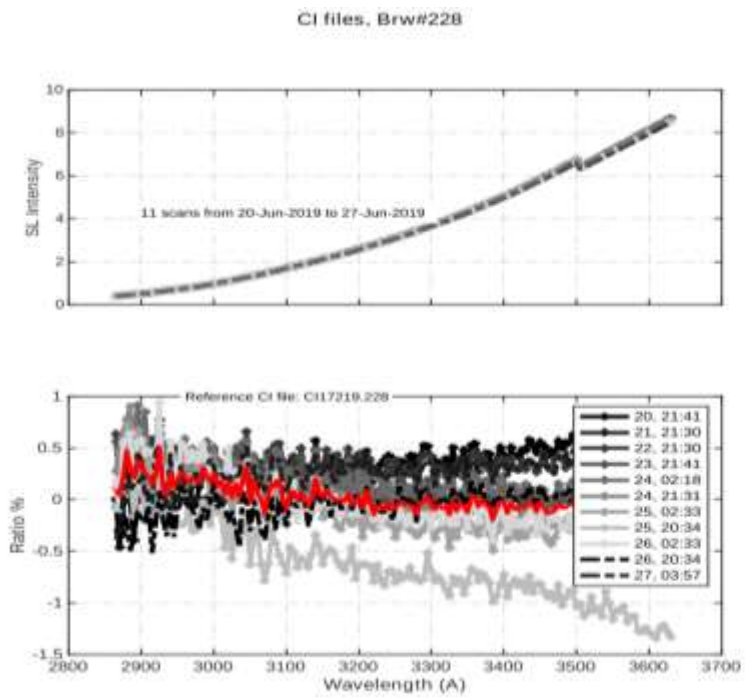


Figure 10. CI scan of standard lamp performed during the campaign days. Scans processed (upper panel) and relative differences with respect to a selected reference scan (lower panel). The red line represents the mean of all relative differences.

22.3. ABSOLUTE TEMPERATURE COEFFICIENTS

Temperature coefficients are determined using the standard lamp test. For every slit, the raw counts corrected for zero temperature coefficients are used in a linear regression against temperature with the slopes representing the instrument's temperature coefficients. From this we obtain the corrected R6 and R5 ratios to analyse the new temperature coefficients' performance.

As shown in Figure 11 (temperature range from 21 °C to 32 °C), the current coefficients do an excellent job at reducing the temperature dependence, performing even better than the coefficients calculated using the data from the present campaign. The values of the coefficients are summarized in Table 1.

We have also extended our analysis using the data recorded since the previous campaign. As shown in Figures 12 and 13, the current and new coefficients perform similarly, the current coefficients being slightly better. For this reason, in the final ICF we have used the current coefficients.

Table 1. Temperature Coefficients. Calculated coefficients are normalized to slit#2

	slit#2	*slit#3*	*slit#4*	*slit#5*	*slit#6*
Current	0.0000	-0.9038	-0.8881	-1.0180	-1.7807
Calculated	0.0000	-0.2900	-0.2800	-0.3000	-0.2600
Final	0.0000	-0.0300	-0.0600	0.0200	0.1600

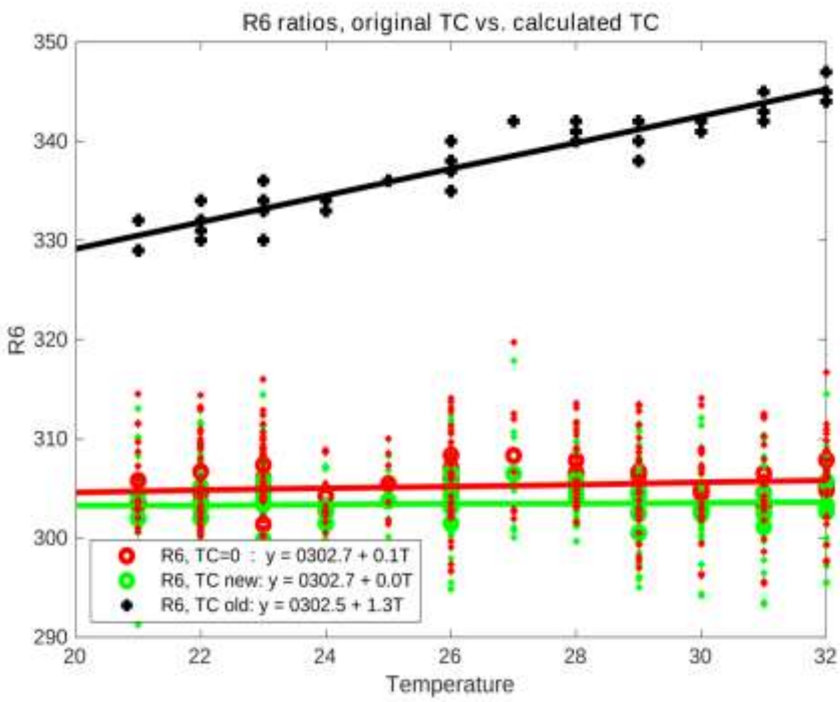


Figure 11. Temperature coefficients' performance. Red circles represent standard lamp R6 ratios calculated from raw counts without temperature correction (temperature coefficients set to 0). Black crosses and green circles represent standard lamp R6 ratios corrected with original and calculated temperature coefficients, respectively. Data shown correspond to the present campaign.

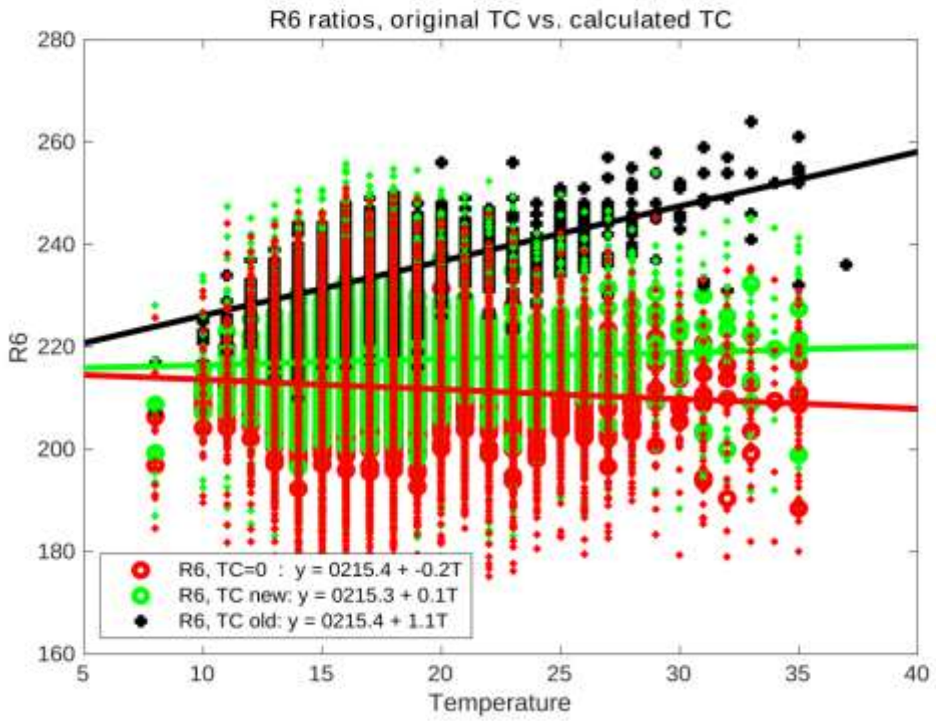


Figure 12. Same as Figure 11 but for the whole period between calibration campaigns

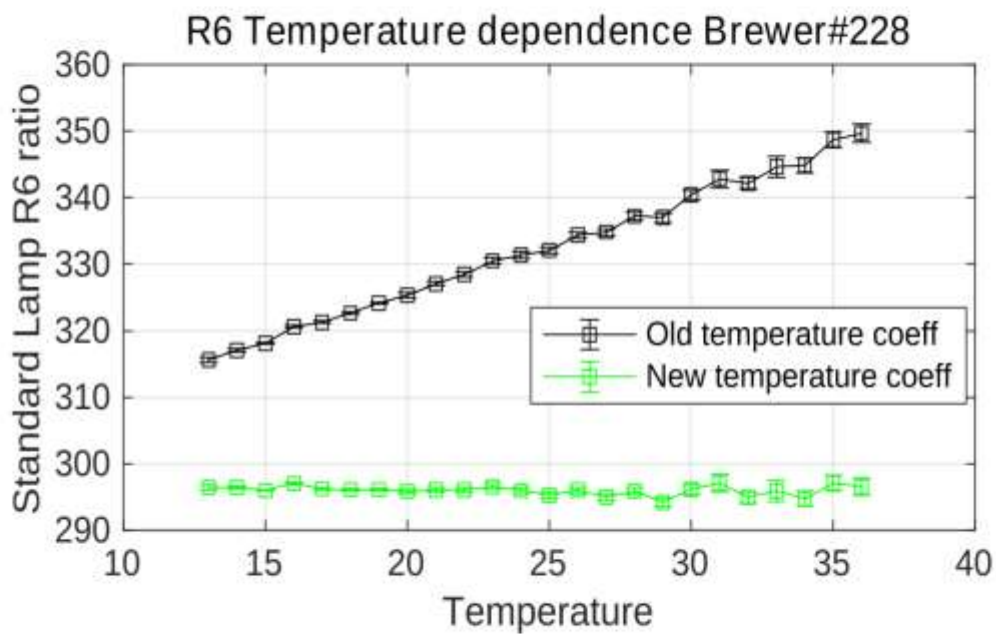


Figure 13. Standard lamp R6 (MS9) ratio as a function of temperature. We plotted the R6 ratio recalculated with the original (black) and the new (green) temperature coefficients.

22.4. ATTENUATION FILTER CHARACTERIZATION

22.4.1. Attenuation filter correction

The filter's spectral dependence affects the ozone calculation because the Brewer software assumes that their attenuation is wavelength neutral. We can estimate the correction factor needed for this non-linearity by multiplying the attenuation of every filter and every wavelength by the ozone weighting coefficients.

During the calibration period, a total of 25 FI tests were analysed to calculate the attenuation for every filter and slit. Figure 15 shows the results of these tests and Table 2 shows the calculated ETC corrections for each filter.

Due to the low number of measurements, any filter correction calculated is significant. Attenuation correction factors are not suggested. Note that the slope of the wavelength dependence (Figure 14) is quite pronounced for Filters ND#3, ND#4 and ND#5 which increases the potential effect of the non-linearity. Regular monitoring of the wavelength dependence is advised.

Table 2. ETC correction due to filter non-linearity. Median value, mean values and 95% confidence intervals are calculated using the bootstrap technique.

	filter#1	*filter#2*	*filter#3*	*filter#4*	*filter#5*
ETC Filt. Corr. (median)	-16	1	-8	-12	-19
ETC Filt. Corr. (mean)	-1	0.4	-11.4	-16	-13.3
ETC Filt. Corr. (mean 95% CI)	[-14.5 10]	[-14 17.6]	[-33.2 8.2]	[-30 -1.6]	[-34.5 0.9]

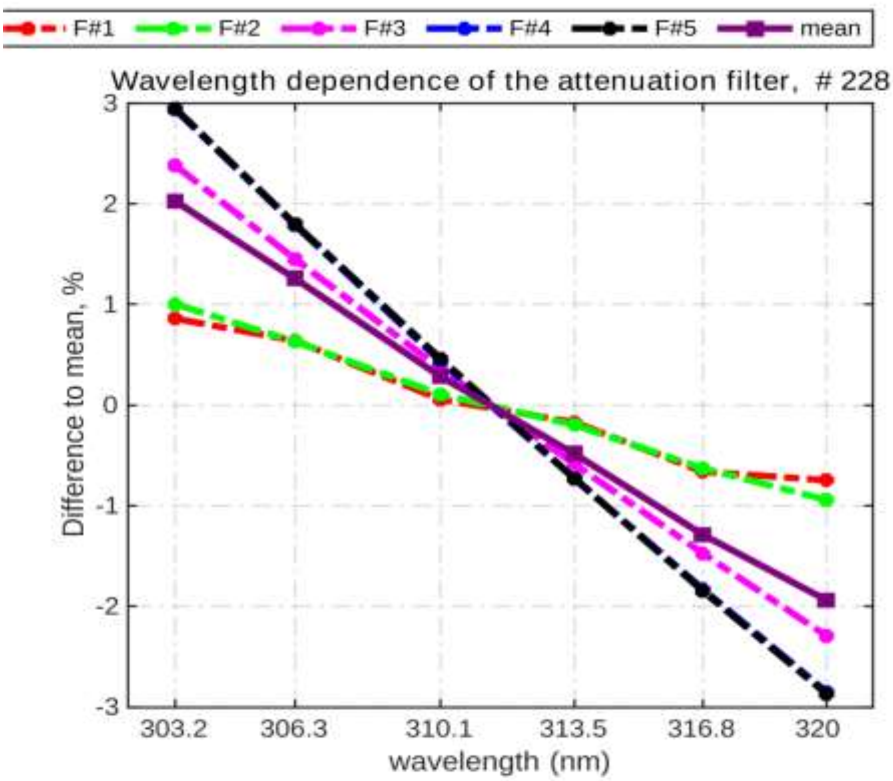


Figure 14. Wavelength dependence of the attenuation filters calculated from FI AVG test percent ratio over the mean

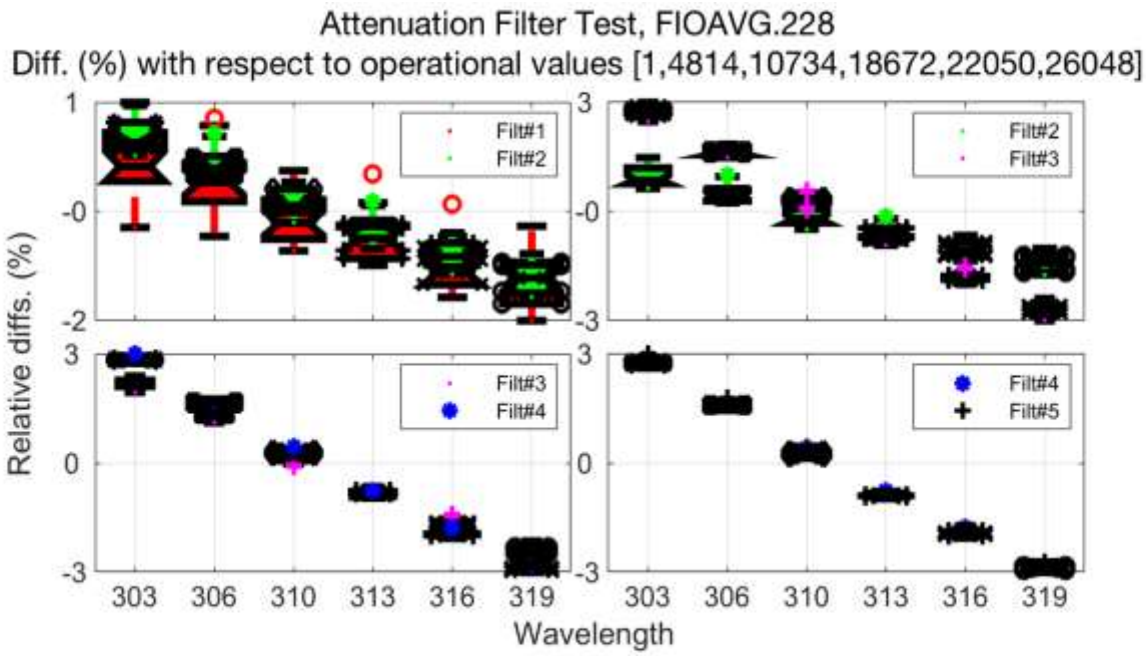


Figure 15. Notched boxplot for the calculated attenuation relative differences of neutral density filters with respect to operational values. We show for each subplot relative differences corresponding to correlative filters (colour boxplots). Solid lines and boxes mark the median, upper and lower quartiles. The point whose distance from the upper or lower quartile is 1 times larger than the interquartile range is defined as an outlier.

22.5. WAVELENGTH CALIBRATION

22.5.1. Cal step determination

The sun scan routine takes DS ozone measurements by moving the micrometre about 15 steps below and above the ozone reference position (wavelength calibration step number). A Hg test is required before and after the measurement to assure the correct wavelength setting during the sun scan test. Ozone versus step number ideally shows a parabolic shape with a maximum at the ozone reference position. With this choice, small wavelength shifts ($\approx \pm$ 2 steps) do not affect the ozone value. This optimal micrometre position is a near-linear function of the ozone slant path at the time of the scan (see Figure 16).

During the campaign, 15 sun scan (SC) tests covering an ozone slant path range from 400 to 1200 DU were carried out (see Figure 17). The calculated cal step number (CSN) was 17 steps lower than the value in the current configuration: 1023 vs. 1030. SC tests performed at the station before the campaign provide a CSN of 1026. Taking all this into account, we suggest updating the CSN to 1023.

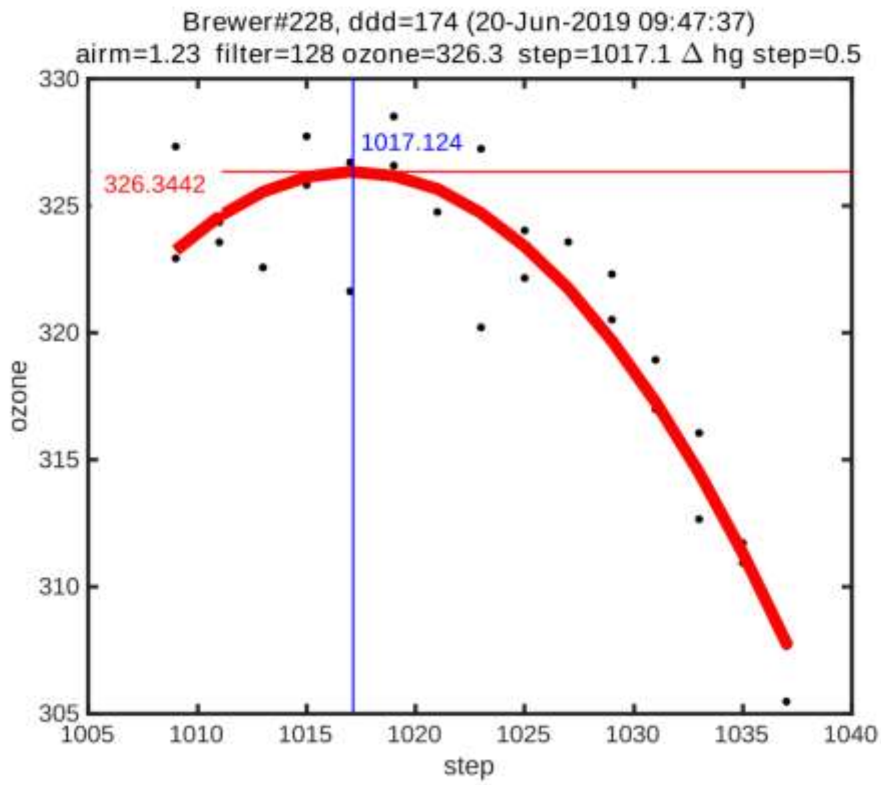


Figure 16. Ozone measurements moving the micrometre 15 steps around the operational CSN defined in the initial configuration

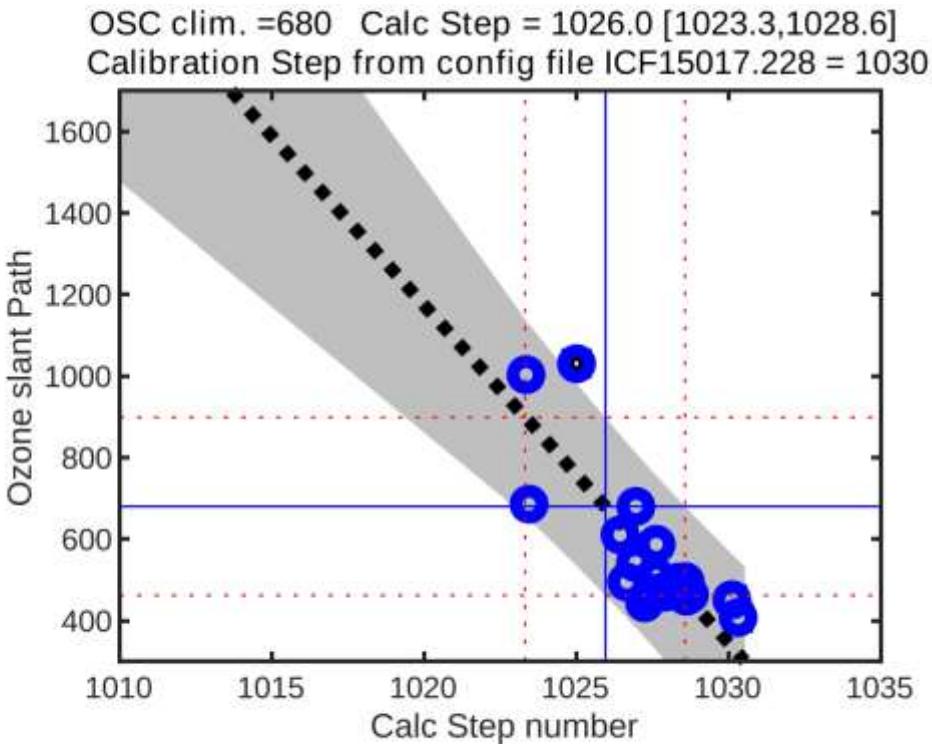


Figure 17. Ozone slant path vs. Calc-Step number. Vertical solid line marks the calculated cal step number for a climatological OSC equal to 680 DU (horizontal solid line). The grey area represents a 95% confidence interval.

22.5.2. Dispersion test

We analysed the dispersion tests carried out in the previous and present calibration campaigns. For all of them, we processed data from mercury and cadmium spectral lamps, using quadratic functions to adjust the micrometre step number to wavelength positions. The results of this historical analysis are summarized in Table 3.

For the current campaign in particular, Figure 18 shows that the quadratic fitting was good for all the dispersion tests, with residuals being lower than 0.01 nm in all slits. For the dispersion tests performed using the UV dome and the internal Hg lamp, Table 4 provides individual wavelength resolution, ozone absorption coefficient, sulphur dioxide absorption coefficient and Rayleigh absorption for the operational CSN and those at ± 1 step.

An absorption coefficient equal to 0.3465 is suggested in the final configuration.

Table 3. Dispersion derived constants

	Calc-step	*O3abs coeff.*	*SO2abs coeff.*	*O3/SO2*
Current	1030	0.3410	4.4707	1.1530
06-Aug-2014	1030	0.3548	3.1106	1.1844
30-May-2015	1030	0.3453	3.3029	1.1518
02-Jun-2017	1030	0.3410	3.3115	1.1382
08-Jun-2017	1030	0.3413	3.3168	1.1390
23-Jun-2019	1030	NaN	NaN	NaN
23-Jun-2019	1023	0.3464	3.2703	1.1558
Final	1023	0.3465	4.4707	1.1530

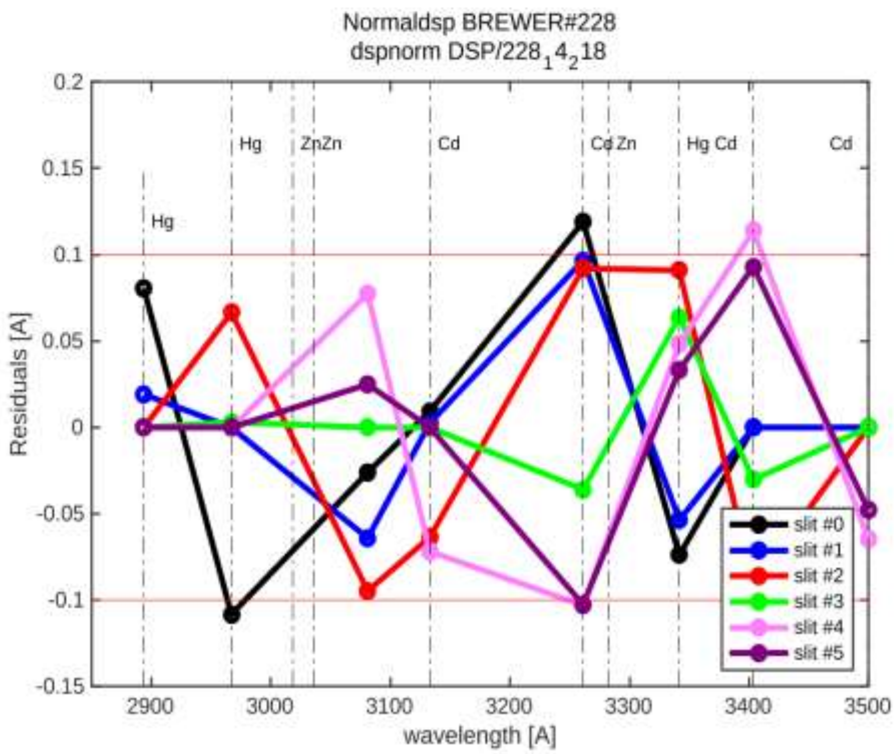


Figure 18. 2019 Residuals of quadratic fit

Table 4. 2019 Dispersion derived constants

step= 1022	*slit#0*	*slit#1*	*slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032.09	3062.95	3100.4	3134.86	3167.78	3199.78
Res(A)	5.2805	5.3159	5.2429	5.3368	5.2637	5.1568
O3abs(1/cm)	2.591	1.7824	1.0055	0.67838	0.37439	0.29631
Ray abs(1/cm)	0.50493	0.48326	0.45854	0.43719	0.41798	0.40032
SO2abs(1/cm)	3.3645	5.663	2.3899	1.9249	1.0514	0.61995
step= 1023	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.17	3063.02	3100.47	3134.93	3167.85	3199.85
Res(A)	5.2804	5.3158	5.2428	5.3367	5.2636	5.1567
O3abs(1/cm)	2.5885	1.7809	1.0052	0.67805	0.37447	0.29591
Ray abs(1/cm)	0.50488	0.48322	0.45849	0.43715	0.41794	0.40029
SO2abs(1/cm)	3.3502	5.6849	2.3978	1.9129	1.0527	0.61781
step= 1024	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3032.24	3063.09	3100.54	3135	3167.92	3199.92
Res(A)	5.2803	5.3157	5.2427	5.3366	5.2635	5.1566
O3abs(1/cm)	2.586	1.7794	1.005	0.67772	0.37455	0.2954
Ray abs(1/cm)	0.50483	0.48317	0.45844	0.43711	0.4179	0.40025
SO2abs(1/cm)	3.336	5.7067	2.4057	1.9013	1.054	0.61557
step	O3abs	Rayabs	SO2abs	O3SO2Abs	Daumont	Bremen
1022	0.34639	9.2973	3.2309	1.1582	0.3568	0.3482
1023	0.34543	9.2959	3.2404	1.1551	0.35596	0.34731
1024	0.3443	9.2944	3.2496	1.1516	0.35506	0.34637

22.5.3. Umkehr

For the Umkehr calibration, only the lines shorter than 340 nm were used. The Umkehr offset is calculated by forcing the wavelength of slit #4 at the ozone position to be the same as on slit #1 at the Umkehr setting. The Umkehr offset calculated was 2431. Table 5 summarizes the dispersion test for Umkehr: wavelength, resolution and ozone absorption coefficient.

Table 5. 2019 Umkehr dispersion constants

step= 1023	*slit#0*	*slit#1*	*Slit#2*	*slit#3*	*slit#4*	*slit#5*
WL(A)	3032	3063	3100	3135	3168	3200
Res(A)	5.2801	5.3162	5.2445	5.3378	5.2591	5.157
O3abs(1/cm)	2.5906	1.7797	1.0052	0.67809	0.37443	0.29646
Ray abs(1/cm)	0.50492	0.48317	0.45848	0.43716	0.41796	0.40034
step= 2431	slit#0	slit#1	slit#2	slit#3	slit#4	slit#5
WL(A)	3134	3164	3200	3233	3265	3295
Res(A)	5.1701	5.2067	5.1348	5.2272	5.1067	5.0266
O3abs(1/cm)	0.67987	0.39732	0.29661	0.12666	0.061783	0.033327
Ray abs(1/cm)	0.43799	0.42039	0.40034	0.38299	0.36732	0.35291

22.6. ETC TRANSFER

Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$X = \frac{F - ETC}{\alpha\mu}$$

where F are the measured double ratios corrected for Rayleigh effects, α is the ozone absorption coefficient, μ is the ozone air mass factor, and ETC is the extraterrestrial constant. The F , α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients $w = [0,1,-0.5,-2.2,1.7]$ for slits 1 to 5, with nominal wavelengths equal to $[306.3,310.1,313.5,316.8,320.1]$ nm.

The transfer of the calibration scale (namely ETC) is performed side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant with the condition that the measured ozone will be the same for simultaneous measurements. In terms of the previous equation for ozone, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu$$

For a well-characterized instrument, the ETC determined values show a Gaussian distribution and the mean value is used as the instrument constant. One exception to this rule is the single monochromator Brewer models (MK-II and MK-IV) which are affected by stray light.

Brewers are calibrated with the one-parameter (1P) ETC transfer method: only the ozone ETC constant is transferred from the reference instrument. The so-called "two-parameters calibration method" (2P), where both the ozone absorption coefficient and the ETC are calculated from the reference, is also obtained and serves as a quality indicator of the calibration. We consider a calibration optimal when both ETC values agree within 10 units, and the ozone absorption coefficient calculated from the dispersion tests and obtained with the 2P method agree within ± 2 micrometre steps, or approx. ± 0.002 atm.cm^{-1}. This range represents a total ozone difference of about 0.5% at air mass equal to 2, and total ozone of 300 DU.

The ETC is obtained by comparison with the reference Brewer IZO#185 using near-simultaneous measurements during 7 days (two measurements are considered near-simultaneous if they are taken less than 3.5 minutes apart). Measurements with air mass differences greater than 3% were removed from the analysis.

22.6.1. Initial calibration

The instrument did not have any measurements for the initial evaluation due to major repairs before any measurements were possible. Consequently the evaluation of the initial status was not possible after this reparation. However we were able to use 31 simultaneous direct sun (DS) ozone measurements from days 166 to 171 before the change in cal step that could provide an indication of the initial status of the instrument. As shown in Figure 19, the initial calibration constants produced an ozone value 5% higher than the reference instrument. When the ETC is corrected by taking into account the difference between the SL and R6 reference (SL correction), the results improved.

Table 6 shows the results of the 1P and 2P calibration methods. Mean daily total ozone values for the original and the final configurations are shown in Table 7, as well as relative differences with respect to IZO#185.

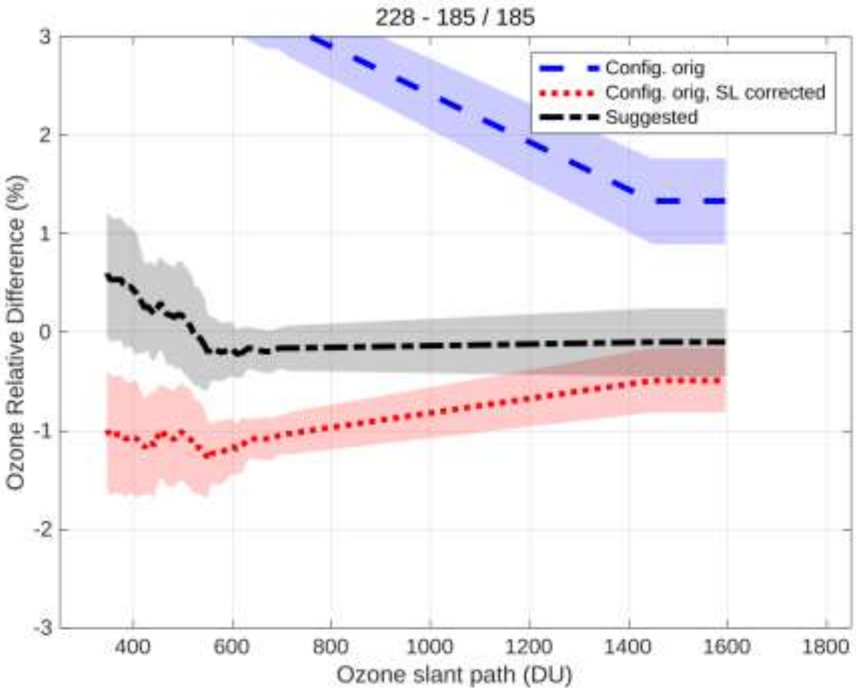


Figure 19. Mean direct sun ozone column percentage difference between Brewer DNK#228 and Brewer IZO#185 as a function of ozone slant path

Table 6. Comparison between the results of the 1P and 2P ETC transfer methods for the blind days

	ETC 1P	*ETC 2P*	*O3Abs blind*	*O3Abs 2P*
up to OSC=2000	1573	1629	3410	3276
full OSC range	1578	1629	3410	3276

Table 7. Daily mean ozone with initial calibration, without and with (the latter, in the columns marked with a star) the standard lamp correction and the reference. Initial calibration

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#228*	*O3 std*	*%(228–185)/185*	*O3(*) #228*	*O3std*	*(*)%(228 – 185)/185*
20-Jun-2019	*171*	*334.1*	*5.1*	*31*	*351.6*	*9.7*	*5.2*	*334.4*	*6.1*	*0.1*

22.6.2. Final calibration

After the maintenance on day 172, a new ETC value was calculated (see Figure 20). For the final calibration, we used 233 simultaneous direct sun measurements from days 173 to 179. The new value (1525) is quite far from the current ETC value (1499). Therefore, we recommend using this new ETC, together with the new proposed standard lamp reference ratios (303 for R6). We updated the new calibration constants in the ICF provided. Of course, the new ETC has been calculated taking into account the new suggested dead time of $2.7 \cdot 10^{-8}$ s.

The ETC value in the final ICF corresponds to the 1P transfer. As shown in Table 8, the agreement between the 1P and 2P ETCs is above the maximum tolerance limit of 10 units. The suggested ozone absorption coefficient from the 2P calibration is very removed from the measured value from the dispersion. The final calibration slightly overestimates the ozone at midday. The final calibration slightly overestimates the ozone at midday.

A filter correction and using the 2P calibration solved this issue but in both cases the correction of the filter and the A1 coefficients were not consistent with the values obtained during the characterization.

Mean daily total ozone values for the original and the final configurations are shown in Table 9, as well as relative differences with respect to IZO#185.

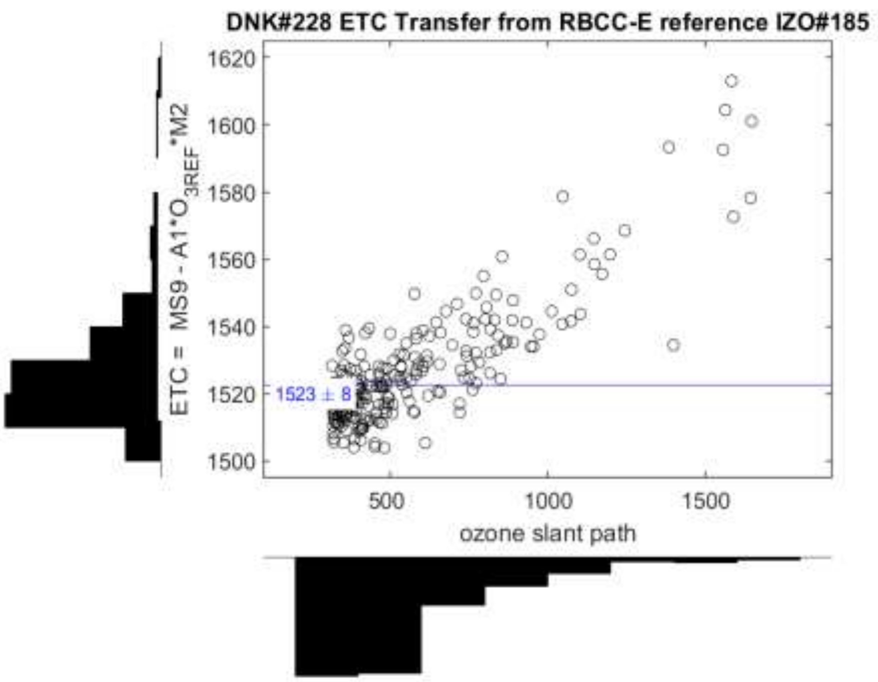


Figure 20. Mean direct sun ozone column percentage difference between Brewer DNK#228 and Brewer IZO#185 as a function of ozone slant path

Table 8. Comparison between the results of the 1P and 2P ETC transfer methods for the final days

	ETC 1P	*ETC 2P*	*O3Abs final*	*O3Abs 2P*
up to OSC=2000	1523	1502	3465	3506
full OSC range	1519	1502	3465	3506

Table 9. Daily mean ozone and relative differences with respect to the reference, with the original and final (the latter, in the columns marked with a star) calibrations. Data from the final days

Date	*Day*	*O3#185*	*O3std*	*N*	*O3#228*	*O3 std*	*%(228–185)/185*	*O3(*) #228*	*O3std*	*(*)%(228 – 185)/185*
21-Jun-2019	172	333	4	31	350.7	8.5	5.3	333.4	3.2	0.1
22-Jun-2019	173	331.1	1.4	7	357.2	2.9	7.9	332	2.5	0.3
23-Jun-2019	174	324	2.9	46	343.5	6.8	6	323.1	2.4	-0.3
24-Jun-2019	175	307.1	1.1	46	323.3	3.5	5.3	307.5	2.2	0.1
25-Jun-2019	176	309	1.9	53	327.5	6	6	308.1	2.1	-0.3
26-Jun-2019	177	312	3.4	43	331.8	4	6.3	310.5	4.8	-0.5
27-Jun-2019	178	305.6	1.1	7	319	2.8	4.4	306.4	1.8	0.3

22.6.3. Standard lamp reference values

The reference values of standard lamp ratios during the calibration period were 303 for R6 (Figure 21) and 534 for R5 (Figure 22).

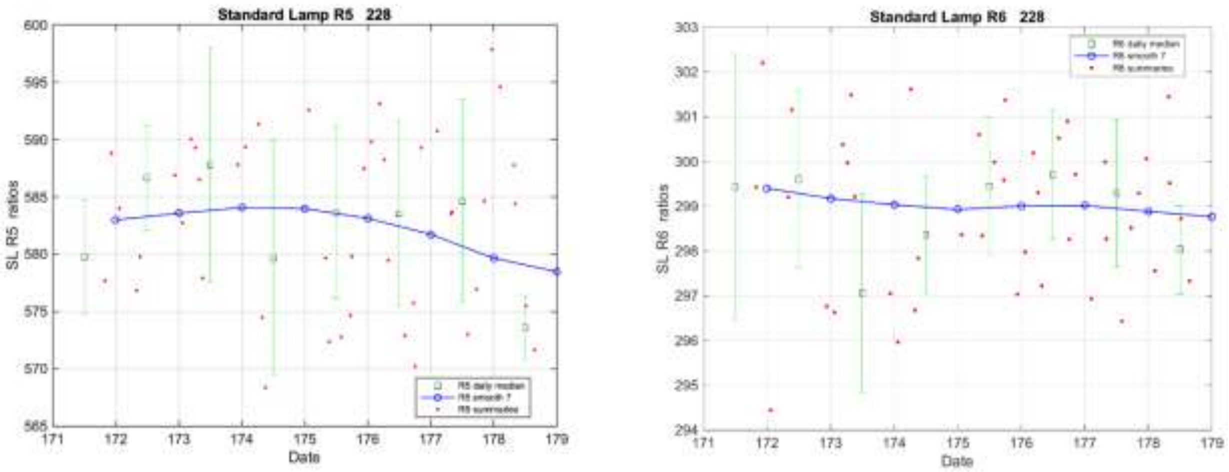


Figure 21. Standard lamp ozone R6 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

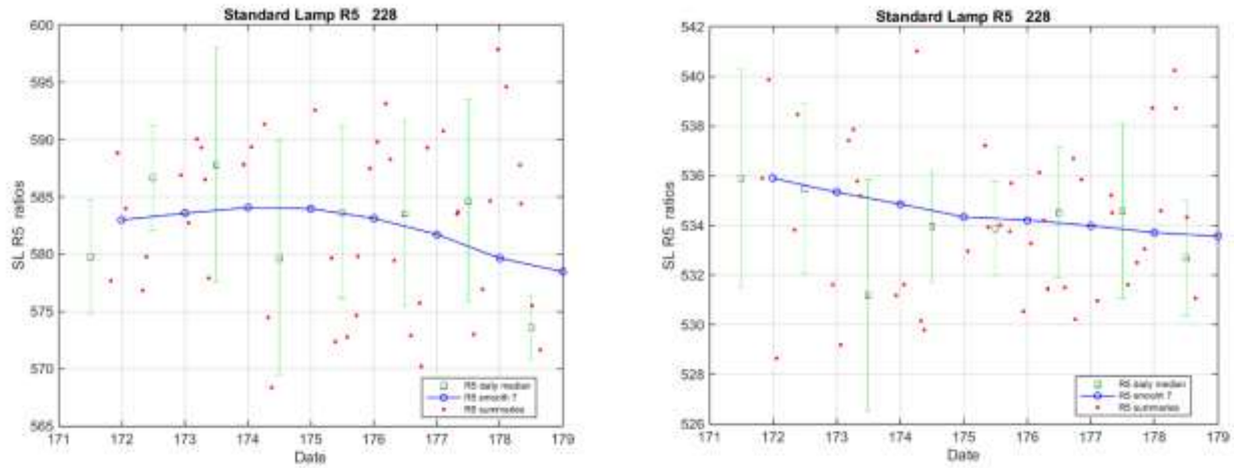


Figure 22. Standard lamp sulphur dioxide R5 ratios: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots). Reprocessed using old and new instrumental constants

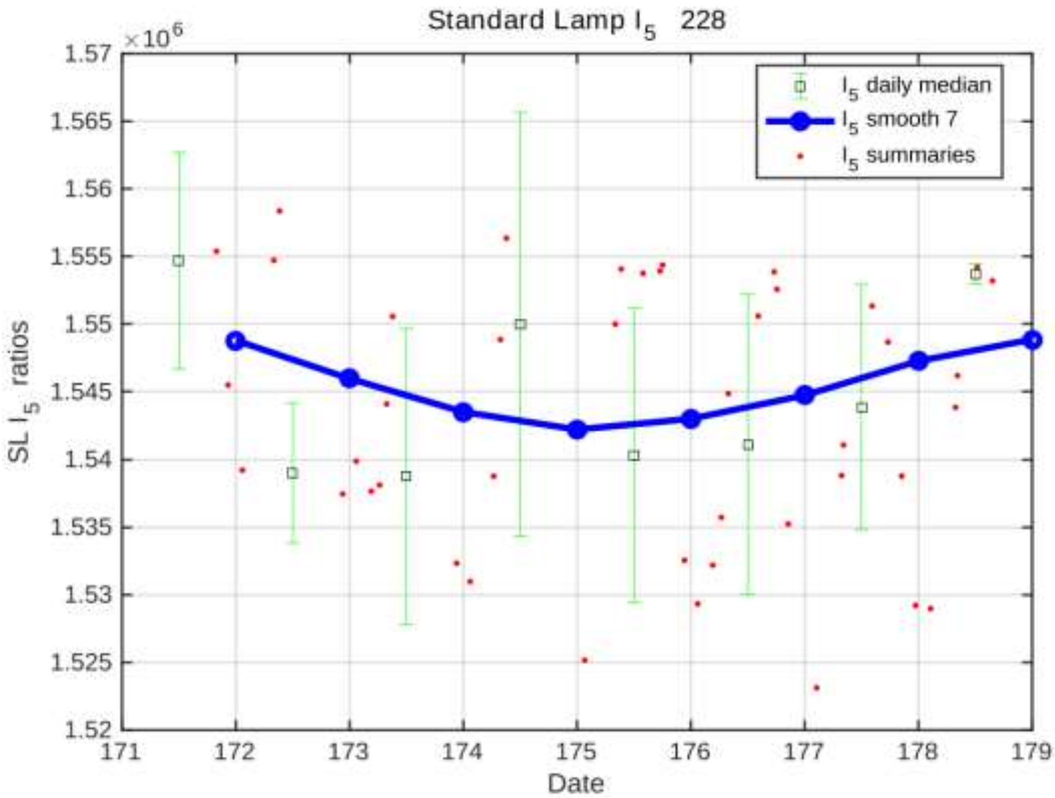


Figure 23. Standard lamp intensity: daily mean and standard deviation (squares), seven day running mean (circle) and individual tests (black dots)

22.7. CONFIGURATION

22.7.1. Instrument constant file

	Initial (ICF15017.228)	*Final (ICF17419.228)*
o3 Temp coef 1	0	0
o3 Temp coef 2	-0.90381	-0.03
o3 Temp coef 3	-0.88811	-0.06
o3 Temp coef 4	-1.018	0.02
o3 Temp coef 5	-1.7807	0.16
Micrometre steps/deg	0	0
O3 on O3 Ratio	0.341	0.3465
SO2 on SO2 Ratio	4.4707	4.4707
O3 on SO2 Ratio	1.153	1.153
ETC on O3 Ratio	1499	1525
ETC on SO2 Ratio	-328	-328

	Initial (ICF15017.228)	*Final (ICF17419.228)*
Dead time (sec)	3.8e-08	2.7e-08
WL cal step number	1030	1023
Slitmask motor delay	14	14
Umkehr Offset	2463	2463
ND filter 0	0	0
ND filter 1	4814	4814
ND filter 2	10734	10734
ND filter 3	18672	18672
ND filter 4	22050	22050
ND filter 5	26048	26048
Zenith steps/rev	2972	2972
Brewer Type	3	3
COM Port #	2	1
o3 Temp coef hg	0	0
n2 Temp coef hg	0	0
n2 Temp coef 1	0	0
n2 Temp coef 2	0	0
n2 Temp coef 3	0	0
n2 Temp coef 4	0	0
n2 Temp coef 5	0	0
O3 Mic #1 Offset	-66	0
Mic #2 Offset	1	0
O3 FW #3 Offset	242	242
NO2 absn Coeff	-3	-3
NO2 ds etc	770	770
NO2 zs etc	740	740
NO2 Mic #1 Offset	8028	8028
NO2 FW #3 Offset	178	178
NO2/O3 Mode Change	2515	2515
Grating Slope	0.99476	0.99476
Grating Intercept	12.88	12.88
Micrometre Zero	1725	1725

	Initial (ICF15017.228)	*Final (ICF17419.228)*
Iris Open Steps	250	250
Buffer Delay (s)	0.4	0.4
NO2 FW#1 Pos	0	0
O3 FW#1 Pos	256	256
FW#2 Pos	0	0
uv FW#2 Pos	0	0
Zenith Offset	0	0
Zenith UVB Position	2216	2216

22.8. DAILY SUMMARY REPORT

Ozone Summary Report. Mean daily ozone, grouped by ozone slant path ranges, with original and final configuration (with an asterisk)

Day	osc range	O3#185	O3std	N	O3#228	O3 std	%diff	(*)O3#228	O3 std	(*)%diff
171	osc> 1500	334	0.0	2	331	0.2	-0.7	331	0.2	-0.7
171	1500> osc> 1000	334	0.0	1	333	0.0	-0.1	333	0.0	-0.1
171	700> osc> 400	332	4.3	26	329	5.0	-0.9	329	5.0	-0.9
171	osc< 400	336	1.2	36	334	2.3	-0.6	334	2.3	-0.6
173	osc< 400	331	1.5	6	330	3.0	-0.2	332	2.7	0.5
174	1500> osc> 1000	323	0.0	1	330	0.0	2.1	328	0.0	1.5
174	1000> osc> 700	320	3.1	7	321	4.3	0.4	320	3.7	0.2
174	700> osc> 400	323	2.1	19	324	2.0	0.1	323	1.8	-0.1
174	osc< 400	326	1.0	18	324	1.3	-0.5	324	1.6	-0.7
175	osc> 1500	309	0.4	2	316	0.5	2.3	313	0.7	1.4
175	1500> osc> 1000	307	1.3	7	310	1.0	1.1	309	0.7	0.7
175	1000> osc> 700	307	0.4	8	310	1.1	1.0	309	0.9	0.7
175	700> osc> 400	307	1.2	24	306	1.8	-0.2	306	1.9	-0.1
175	osc< 400	307	0.4	3	306	0.6	-0.3	307	0.3	0.0
176	osc> 1500	308	0.1	2	314	0.3	2.0	312	0.6	1.1
176	1500> osc> 1000	308	2.1	7	313	3.6	1.4	311	3.1	0.8
176	1000> osc> 700	308	2.7	7	309	4.0	0.5	308	3.4	0.2
176	700> osc> 400	308	1.5	17	307	1.9	-0.3	307	1.6	-0.4
176	osc< 400	310	1.3	21	308	1.5	-0.9	308	1.5	-0.6
177	osc> 1500	314	0.0	1	322	0.0	2.6	319	0.0	1.6

Day	osc range	O3#185	O3std	N	O3#228	O3 std	%diff	(*)O3#228	O3 std	(*)%diff
177	1000> osc> 700	315	5.6	4	318	6.7	1.0	317	5.9	0.6
177	700> osc> 400	313	4.2	16	312	5.5	-0.4	312	4.9	-0.3
177	osc< 400	311	1.3	18	307	1.6	-1.2	308	1.5	-1.0
178	1000> osc> 700	305	0.6	5	308	1.4	0.9	306	1.3	0.5
178	700> osc> 400	306	0.5	3	307	2.7	0.3	306	2.5	-0.1

22.9. APPENDIX: SUMMARY PLOTS

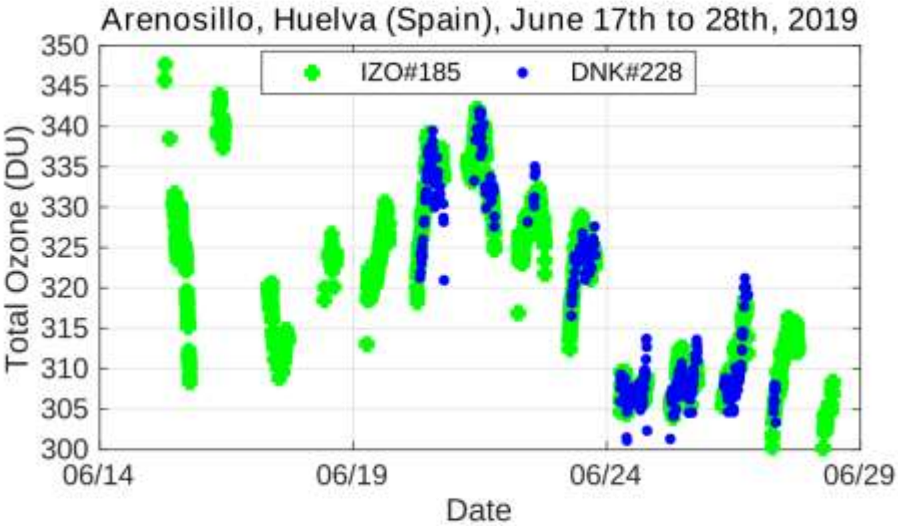
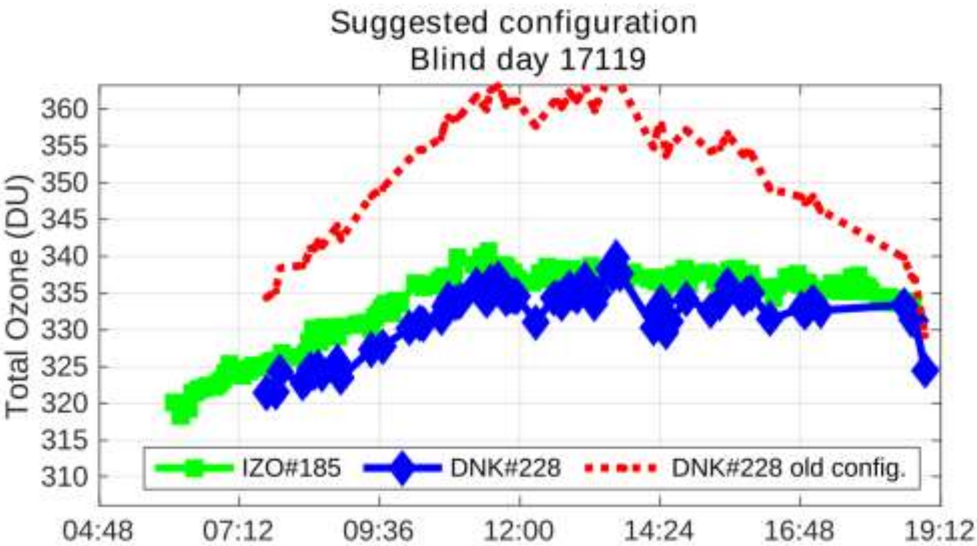
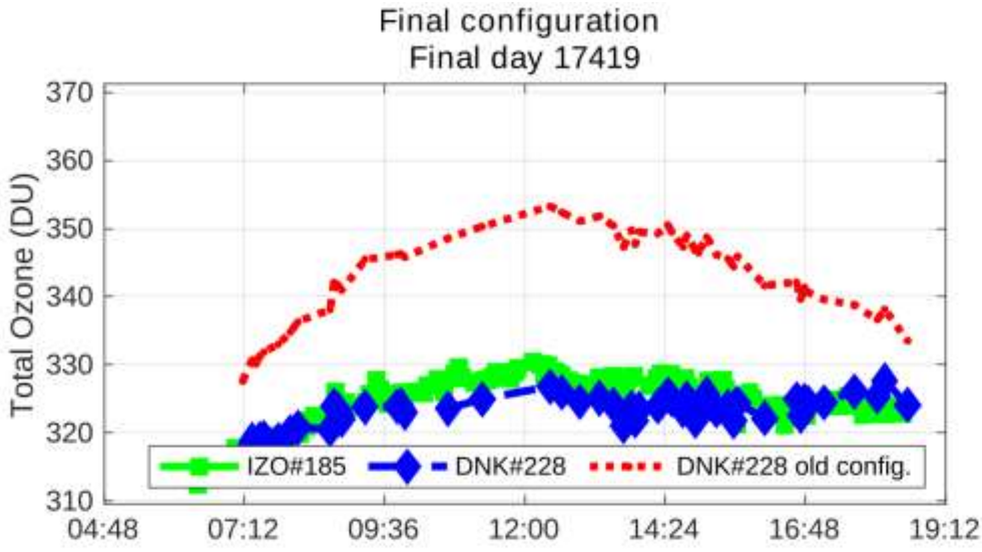
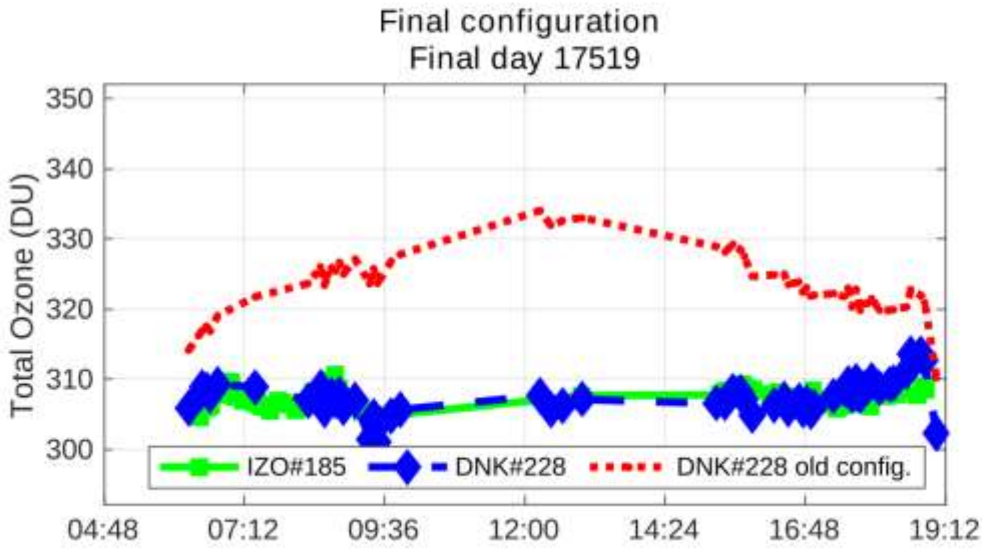
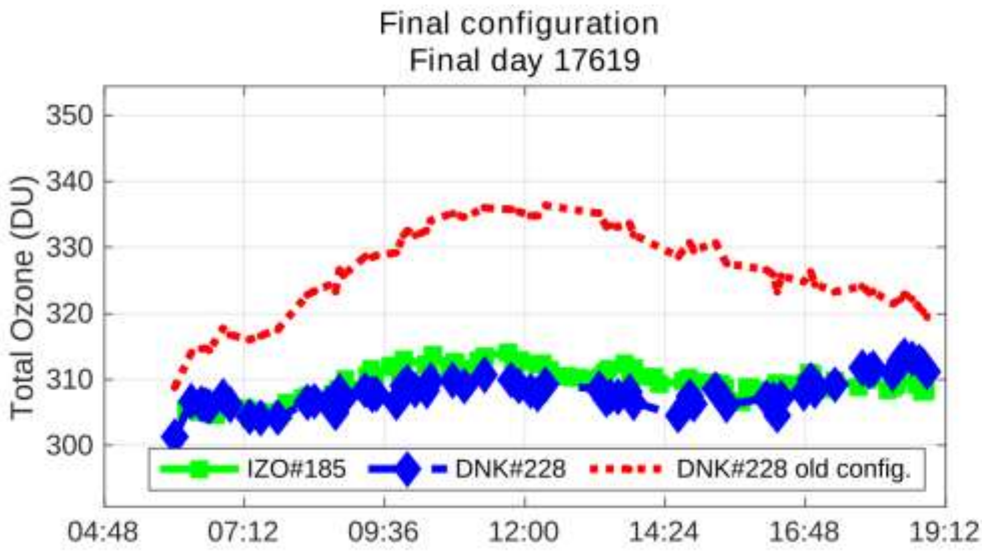


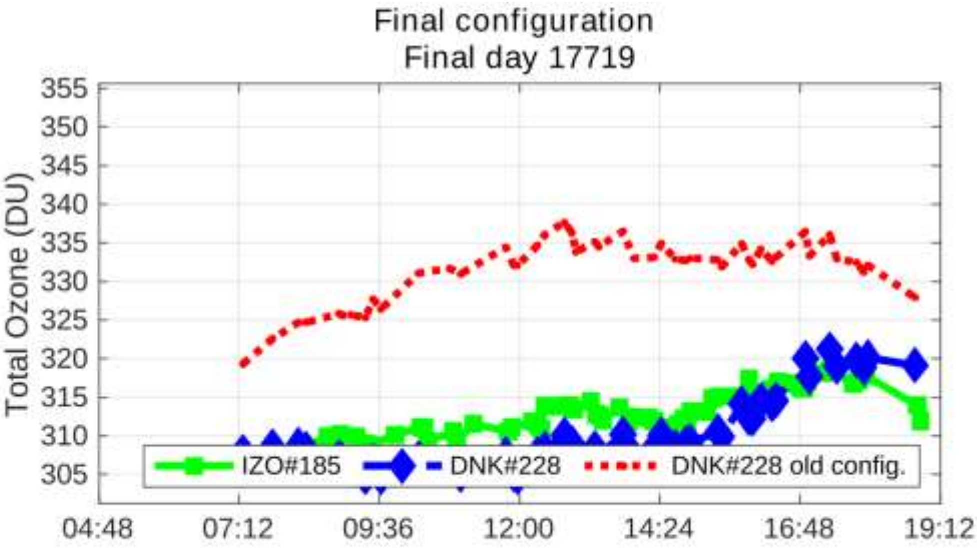
Figure 24. Overview of the intercomparison. Brewer DNK#228 data were evaluated using final constants (blue circles)



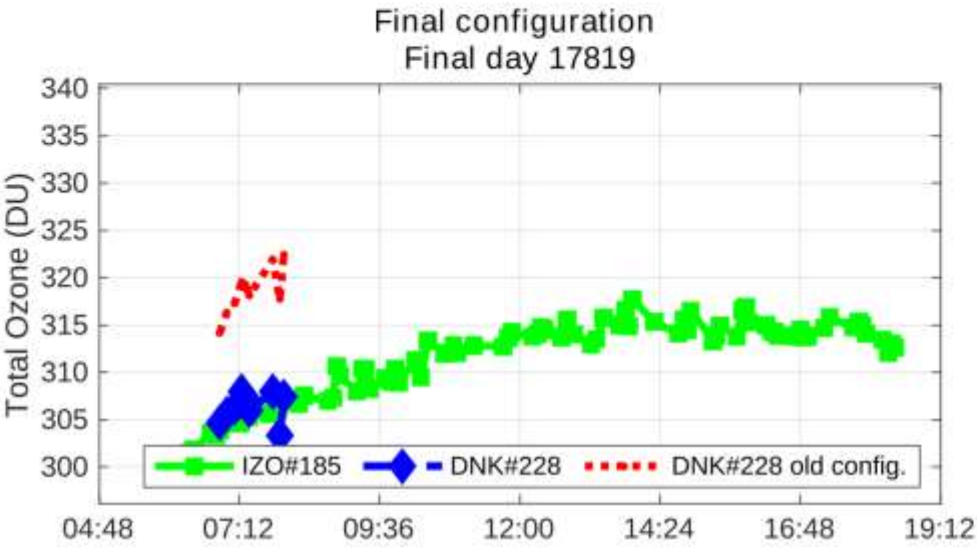

Final configuration
Final day 17419
Total Ozone (DU)
370
360
350
340
330
320
310
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#228
DNK#228 old config.


Final configuration
Final day 17519
Total Ozone (DU)
350
340
330
320
310
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#228
DNK#228 old config.


Final configuration
Final day 17619
Total Ozone (DU)
350
340
330
320
310
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#228
DNK#228 old config.



Final configuration
Final day 17719
Total Ozone (DU)
355
350
345
340
335
330
325
320
315
310
305
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#228
DNK#228 old config.



Final configuration
Final day 17819
Total Ozone (DU)
340
335
330
325
320
315
310
305
300
04:48
07:12
09:36
12:00
14:24
16:48
19:12
IZO#185
DNK#228
DNK#228 old config.

23. REFERENCES

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APPENDIX 1

Maintenance Table

The below table shows the most significant maintenance work carried out on each participant instrument on each campaign day.

149			16/6/2019	17/6/2019	18/6/2019	19/6/2019	20/6/2019	21/6/2019	22/6/2019
JD			167	168	169	170	171	172	173
		Previous Events	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Brewer#									
5	Gre			Mounting	Stopped in the morning/ Card Replaced		Standar Lamp housing replaced		dispersion
17	IOS			Mounting		Foreoptics of 017 in 150 from 15:20	**Foreoptics of 017 in 150. From 9:45. Foreoptics back in its place**		
33	Esp			Mounting				**6:50. Down for maintenance. Improved earthing of PMT BNC and 24v voltage. Changed SL. Back to roof 8:25. Changed ICF... Steps from zenit to hard stop from 45 to 29**	
70	Esp			Mounting				Maintenance from 8:15 to 8:50. Minor changes	
75	Uk			Mounting		11:05 desmontado para mantenimiento. (Filter changed) 14:15 back to the roof			**Will be mantained today**
102	Por			Mounting					
117	Esp			Mounting				Maintenance from 9:30 approx to 10:30	
126	Uk			Mounting		15:00 Changed from SC to O3			
150	Are			Local one	**Stopped for Maintenance 15:01-16:30 GMT. Only cleaning for the moment**	**Foreoptics of 017 in 150 from 15:20 Increased main PS +5V to +5.2V. This improved +24V line**	**Foreoptics of 017 in 150. From 9:45. Foreoptics back in its place**		
151	Esp			Mounting					Maintenance from sunrise to 9:55
158	Hol			Mounting				Schedule crashed "out of memory"	**Tests during the morning, change HV from 1300 to 1350. DT changed from 27 to 30**
163	Sui			Mounting		Schedule adelantado			
166	Esp			Mounting		Stopped at 3:00 AM, in schedule at 7:30	Maintenance from 14:00 approx. Slit mask adjustment		
172	Uk			Mounting	**Located in Manchester, changed 15:25**			Maintenance from 9:45	
174	Jap			Mounting		15:00 Changed from SC to O3		Changed schedule from 03 to OZO	
185	IZO	Mounted		11:53 se ajusta hora y se activa D4	Con schedule adelantado desde mediodia				
186	Esp			Mounting				**Maintenance in the evening, finish at 15:45. Changed ICF, FW#2 position from 64 to 0**	
190	Can			Mounting					
201	Arg					Mounted today (?)	**Checking temperature sensors during the morning... and evening. Changed EXT (11) sensor to PMT (1) sensor. Mounting**	Computer switched off during the night. Then SC. At 16:20 se vuelve a enfocar, desajustado. Sun scan introducidos a mano	
202	Den			Mounting		Wrong schedule o30529b			
228	Den			Mounting		Not working... maintenance. Micrometers issue, dispersive mirror moved. 15:00 begins data adquisition (SC). HV changed to 1200V	Tracker stoped during the night and not measuring DS in the morning	**Infinite cicle searching for micrometer. 15:30 Cal step changed from 1030 to 1023. New ICF17219**	Infinite cicle searching for micrometer.
ERMIS									
METEO				**Very foggy in the morning**	**Overcast in the morning, and in the evening**	**Foggy in the early morning, clear sky the rest of the day**	**Clear sky**	**Clear sky**	**Some clouds in the early morning, them some cirrus and clear from noon**

149		23/6/2019	24/6/2019	25/6/2019	26/6/2019	27/6/2019	28/6/2019	29/6/2019
JD		174	175	176	177	178	179	180
		Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Brewer#								
5	Gre				packed today			
17	IOS							
33	Esp					packed today		
70	Esp					packed today		
75	Uk							
102	Por							
117	Esp					Standard lamp maintenance (Sergio says Mike was doing something with the lamp, but that it won't affect the calibration; JLS says San Atanasio says it was just a change in the new version of the software, because it was not writting some values) packed today		
126	Uk	CALSTEP changed from 286 to 291						
150	Are	Software updated to 4.21						
151	Esp					packed today		
158	Hol						packed today	
163	Sui					packed today		
166	Esp	CALSTEP changed from 283 to 286				packed today		
172	Uk							
174	Jap					packed today		
185	IZO			Schedule +1 day, corrected				
186	Esp					packed today		
190	Can							
201	Arg	Micrometers basic maintenance (IOS) Software updated to 4.21 Dispersion	1000w lamps	Maitenance. UV counts come to 1/3 from 2015. Prism position corrected and hard stop removed. 2nd mirror central spring loose. Adjusted and tightened. UV recalibration needed, Temperature Fixed	slight adjustment of the tracker drive tightness. Still need UV calibration,	Power button with bad electric contact. Lost communication regularly. packed today		
202	Den	Stopped at arriving. Soft crash	Stopped at arriving. Soft crash	Finally Volodya found the crash reason.. directory AVG-202 was created as AVG_202		packed today		
228	Den	Stopped at arriving. In schedule but not looking to sun				packed today		
ERMIS								
METEO		Mainly clear, some cirrus in the morning towards SW, covering all the sky from mid morning	Very cloudy from the early morning. Cloudiness increasing during the day.... Foggy	Clear Sky	Overcast in the very early morning, then clear sky with some scattered Cu	Clear Sky		

Glossary

CI	Scan on the internal Standard lamp
CSN	Cal step number
CZ	Custom scan, generally on the internal lamps
DSP	Dispersion file
DT	Dead time
Hg	Internal mercury line
HL	Scan on the internal mercury line of 295.nm
HS	Scan on the internal mercury line of 345.nm
ICF	Instrument constant file
OSC	Ozone slant column or ozone slant path
R6	Ratio 6, standard lamp ozone ratio
R5	Ratio 5, standard lamp SO_2 ratio
SL	Standard lamp
RS	Run/Stop test
TC	Temperature coefficients

APPENDIX 3

List of Participants

Country	*Brewer*	*Institutions*	*Participants*
Greece	005	Thessaloniki University	Alkis Bais
Canada	017	International Ozone Services	Vladimir Savastiouk
Spain	033	State Meteorological Agency of Spain	Juan R. Moreta
Spain	070	State Meteorological Agency of Spain	Ana Díaz
UK	075	Manchester University	John Rimmer
Spain	117	State Meteorological Agency of Spain	Juan R. Moreta
UK	126	Manchester University	John Rimmer
Spain	150	Instituto Nacional de Técnica Aeroespacial	J. M. Vilaplana
Spain	151	State Meteorological Agency of Spain	Ana Díaz
The Netherlands	158	Kipp & Zonen	Pavel Babal
Switzerland	163	World Radiation Center	Luca Egli
Spain	166	State Meteorological Agency of Spain	Ana Díaz
UK	172	Manchester University	John Rimmer
Japan	174	Japan Meteorological Agency	Hiroaki Fujiwara
Spain	185	RBCC-E/State Meteorological Agency of Spain	Alberto Redondas
Spain	186	State Meteorological Agency of Spain	Ana Díaz
Canada	190	Environmental Canada	Michael Brohart
Algeria	201	Office Nationale de la Météorologie	Sidi Baika
Denmark	202	Danish Meteorological Institute	Nis Jepsen
Denmark	228	Danish Meteorological Institute	Nis Jepsen

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