



CEOS Intercalibration of Ground-Based Spectrometers and Lidars

First Progress Report

Overview of Scientific Results

Version 1.0
February 2011



CEOS Intercalibration of Ground-Based Spectrometers and Lidars

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1 Executive summary

This document reports on activities and achievements obtained during the first part of the ESA CEOS Intercalibration project. The period covered extends from March 2009 until December 2009.

Dobson activities

As part of the activities of the Regional Dobson Calibration Center for Europe (RDCC-E), three campaigns were organised: ElAreno2009 (Spain, September 2009), Irene2009 (South Africa, conducted in fall 2009, originally planned for spring 2009) and Izaña2010 (Tenerife, September/October 2010). While the ElAreno and Izana campaigns concentrated on the calibration of European instruments, the main reason for participation of the RDCC-E in the Irene2009 campaign was the capacity building of the new RDCC for Africa operated by the SAWS. The Dobson experts of the SAWS were trained and educated by the Dobson specialists from the WDCC and the RDCC Europe and Australia.

Brewer activities

As regards activities of the Regional Brewer Calibration Center for Europe (RBCC-E), four campaigns were organized in Arenosillo 2009, Izaña 2009, Arosa 2010 and Izaña 2010. The Arenosillo and Arosa campaigns were standard RBCC-E campaigns where the calibration of the reference triad was transferred to the participating instruments. The campaigns at Izaña were specific for this project. Izaña 2009, with the participation of brewer #037, tried to determine how the calibration transfer was affected by the atmospheric conditions, comparing the calibration at Izaña (Subtropical) to the calibration performed on site (Arctic). The calibration at Izaña 2010 was an absolute calibration focusing on the determination of the calibration based on Langley plots.

UV-Vis MAXDOAS activities

The Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments (CINDI) was organized in June-July 2009 in The Netherlands at the Cabauw Experimental Site for Atmospheric Research (CESAR). A large data set of continuous ground-based in-situ and remote sensing measurements of nitrogen dioxide, aerosols and other air pollution constituents has been collected under various meteorological conditions and under various air pollution loadings supported by the auxiliary measurement characterizing the state of the atmosphere. First detailed comparisons with the CINDI data have been performed and published or submitted for publication, in particular the semi-blind intercomparison of slant columns of NO₂ and O₄ (Roscoe et al., 2010), the comparison of aerosol extinction measurements (Zieger et al., 2010) and an exploratory study on multi-species retrievals during CINDI (Irie et al., 2010).

EARLINET calibration activities

Within EARLINET, the quality assurance program for instruments is reached through a two level strategy: internal quality checks and instrument intercomparison measurement campaigns using the reference lidar systems. The EARLINET reference lidar systems visit all the EARLINET sites and perform direct comparison with each lidar system in several atmospheric conditions and both in daytime and nighttime conditions. These intercomparisons, as planned, have been performed during the EARLINET-ASOS project. As stated in the ESA-CEOS project, funds from EARLINET-ASOS project cover only the campaigns for the new recent added stations (Alomar, Cabauw, Madrid and Sofia). The other stations are inter-compared using the ESA-CEOS project. In this context, five intercomparison measurement campaigns have been successfully carried out: EARLI09, ALI09, SOLI10, ROLI10 and SPALI10. These allowed checking the performances of the systems and when they were not fully satisfactory, the reasons of the failure were understood and the way to solve them were defined.



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2 Introduction

2.1 Scope of this document

This document is the first progress report of the CEOS Intercalibration of Ground-Based Spectrometers and Lidars project. It summarizes activities performed and results achieved within each team.

2.2 Acronyms and abbreviations

| | |
|---------------|--|
| ACSG | Atmospheric Composition Subgroup of the CEOS-WGCV |
| BAS | British Antarctic Survey |
| BIRA-IASB | Belgian Institute for Space Aeronomy |
| Cal/Val | Calibration and Validation |
| CEOS | Committee on Earth Observation Satellites |
| CNR-IMAA | Consiglio Nazionale delle Ricerche- Istituto di Metodologie per l'Analisi Ambientale |
| CNRS-SA | Service d'Aéronomie du CNRS |
| DOAS | Differential Optical Absorption Spectroscopy |
| DWD | Deutscher Wetterdienst (German National Meteorological Service) |
| EARLINET | European Aerosol Research Lidar Network |
| EARLINET-ASOS | European Aerosol Research Lidar Network - Advanced Sustainable Observation System |
| ENVISAT | Environmental Satellite |
| EO | Earth Observation |
| EOS | (NASA's) Earth Observing System |
| ERS-2 | European Remote Sensing Satellite-2 |
| ESA | European Space Agency |
| ESRIN | European Space Research Institute |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FFT | Fast Fourier Transform |
| FP7 | Seventh Framework Programme of the European Commission |
| FTIR | Fourier Transform Infrared Radiometer |
| GAW | Global Atmospheric Watch |
| GEO | Geostationary orbit |
| GEOSS | Global Earth Observation System of Systems |
| GMES | Global Monitoring of Environment and Security |
| GOME | Global Ozone Monitoring Experiment |
| IGACO | Integrated Global Atmospheric Chemistry Observations IGOS Theme |
| IGOS | The Integrated Global Observing Strategy |
| INTA | Instituto Nacional de Técnica Aeroespacial |
| IUP | Institute of Environmental Physics |
| KNMI | Royal Netherlands Meteorological Institute |
| MAXDOAS | Multi-Axis DOAS |
| METOP | Meteorological Operational satellite programme |
| MOHp | Meteorological Observatory Hohenpeissenberg |



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| | |
|-----------|--|
| MPI | Max-Planck-Institute |
| NASA | National Aeronautics and Space Administration |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| OMI | Ozone Monitoring Instrument |
| QA | Quality Assessment |
| RDCC-E | Regional Dobson Calibration Centre for Europe |
| RT | Radiative Transfer |
| SAWS | South African Weather Service |
| SCIAMACHY | SCanning Imaging Absorption spectrometer for Atmospheric Cartography |
| SOO-HK | Solar and Ozone Observatory Hradec Kralove |
| SOW | Statement of Work |
| SZA | Solar Zenith Angle |
| TOMS | Total Ozone Mapping Spectrometer |
| Vis | Visible |
| UniLEIC | University of Leicester, Department of Chemistry |
| US | United States (of America) |
| UV | Ultra Violet |
| WCWG | CEOS Working Group on Calibration and Validation |
| WDCC | World Dobson Calibration Centre |
| WMO | World Meteorological Office |
| WPDS | World Primary Dobson Spectrophotometer D083 |
| WOUDC | World Ozone and Ultraviolet Data Center |

2.3 Applicable documents

- [AD1] CEOS Intercalibration of Ground-Based Spectrometers and Lidars, Proposal in response to ESRIN/RFQ/3-12340/08/I-EC (ref. this proposal).
- [AD2] ESA/ESRIN Statement of Work, ref. SOW: CEOS Intercalibration of ground-based spectrometers and lidars, GMES-CLVL-EOPG-SW-08-0002.
- [AD3] Draft Contract, Appendix 2 to ESRIN/RFQ/3-12340/08/I-EC

2.4 Reference Documents

- [RD1] Vicarious Calibration and Geophysical Validation Functional Baseline, GMES-SPPA-EOPG-TN-06-0001.
- [RD2] ENVISAT Calibration and Validation Plan, PO-PL-ESA-GS-1092.
- [RD3] IGOS – Integrated Global Observing Strategy: Atmospheric Chemistry, <http://ioc.unesco.org/igodpartners/atmosphere.htm>
- [RD4] CEOS – Working Group on Calibration and Validation: Satellite missions/ Atmospheric Chemistry, [http://www.oma.be/NDSC_SatWG/Documents/SatelliteMissionsPlanning\(30Nov2007\)_A4.pdf](http://www.oma.be/NDSC_SatWG/Documents/SatelliteMissionsPlanning(30Nov2007)_A4.pdf)



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3 Work in progress

This chapter describes the activities having taken place during the first contractual part of the project. Main results obtained in each team are highlighted.

3.1 Dobson and Brewer calibration activities

3.1.1 Activities of the Regional Dobson Calibration Center for Europe (RDCC-E) at Meteorological Observatory Hohenpeissenberg (MOHp)

Three project campaigns with participation of various Dobson instruments have been organized, conducted and/or supported during the first part of the project:

- EIAreno2009 (Spain, September 2009) - Calibration service for 3 European Dobsons (D092 from Greenland, D108 as Regional standard for the Russian filter ozonometer network and D120 from Spain) and intercomparison of the European reference Dobson No. 64 (D064, Hohenpeissenberg) with the reference Brewer spectrophotometers (Canadian #017 and #185 from Izaña).
- Irene2009 (South Africa, conducted in fall 2009, originally planned for spring 2009) - Calibration service for the African Dobsons, conducted by the Regional Dobson Calibration Center for Africa with technical and scientific support by the RDCC-E as educational activity (capacity building for the Dobson experts of the South African Weather Service SAWS). In addition the regional standard Dobsons D064 (Europe) and D105 (Australia) were calibrated against the world primary standard Dobson No. 083 (NOOA, Boulder).
- Izaña2010 (Tenerife, September/October 2010) - Absolute calibration of the regional standard D064 after the Langley method; it was a repetition of Izaña2008, which was performed with three standard Dobsons D064 and D074 (two European regional standards) and D083 (world standard). This 2010-campaign was arranged simultaneously with the absolute calibration of the standard Brewers No. 017 (Canadian traveling standard) and No. 157 (Regional primary standard) and No. 185 (Regional traveling standard).

The Nordic campaign, planned to be held in spring 2010 had to be shifted and will now be conducted in March 2011.

Results of EIAreno 2009

The calibration service for three Dobsons was performed in the frame of the regular tasks of the RDCC-E Hohenpeissenberg. Each operational Dobson in the WMO GAW global ozone monitoring network should be calibrated at least every four to five years. A special focus was put on the calibration of the Russian D108 from St. Petersburg, as this instruments acts as standard instrument for the Russian network of filter ozonometer (M-124).

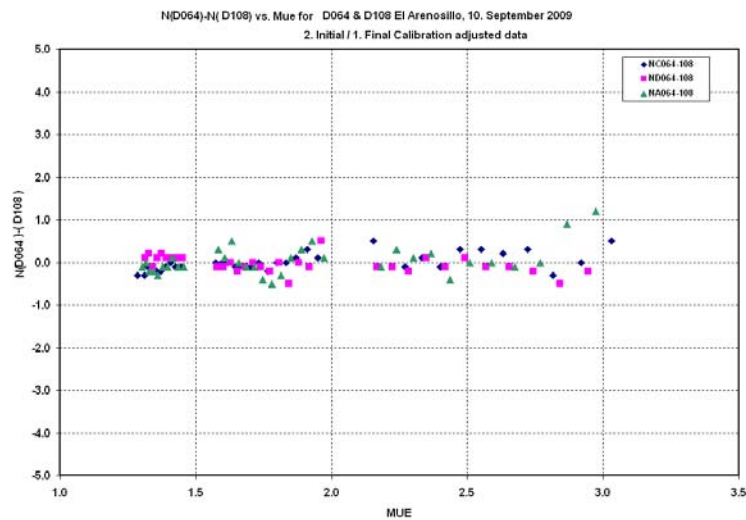


Figure 3-1: Differences of the raw N-values between Dobson 108 and the standards D064.

All three instruments were in good conditions and no intense work was necessary. Thus the data of the initial calibration on September 10 could also be used for final calibration. The Russian standard Dobson D108 had a difference of almost 0% to the European standard Dobson in the combined wavelength pairs AD and no dependence on SZA (Figure 3-1).

The comparison with the reference Brewers revealed two major patterns:

- Slightly higher Brewer values up to +1% (#17) and 1.5% (#185) with the higher values at noon (see results on September 9, 2009, figure 3.1.2, left panel)
- Better performance of the double monochromator Brewer No. 185 at low sun (see results on September 12, 2009, Figure 3-2, right panel)

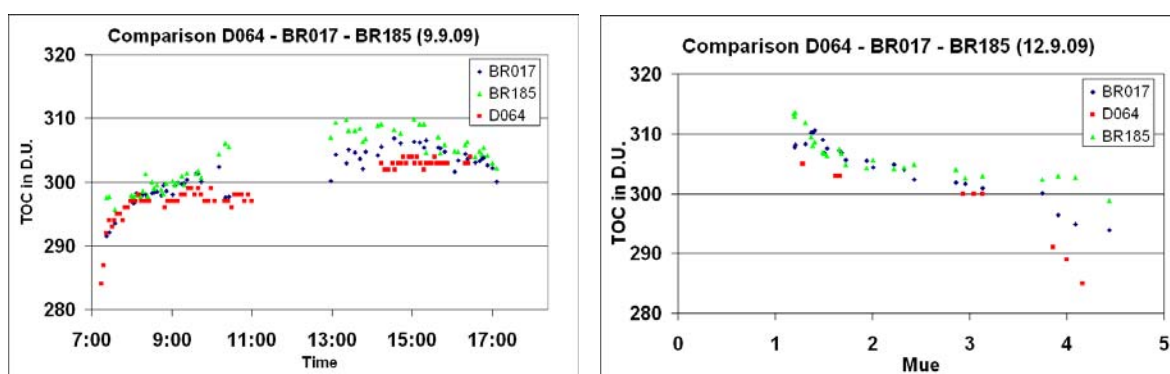


Figure 3-2: Daily course of ozone measured by D064 (red squares), BR017 (blue diamonds) and BR185 (green triangles) as function of time (left panel, September 9, 2009) and of the relative optical path Mue (right panel, September 12, 2009).

Both features could also be seen in other campaigns before (SAUNA I in Sodankylä in 2006, ELAreno2007) and after ELAreno2009 (Izaña2010). The first one comes from different calibration levels, the second one from different instrumental characteristics, here the different straylight elimination capabilities of single and double Brewers and the Dobson with its wider field of view (FOV).



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An improvement of the higher straylight sensitivity of the Dobson is one of the points of investigation currently done by the Dobson experts at the WDCC and the various RDCC's.

Results of Irene2009

Main reason for participation of the RDCC-E in this campaign was the capacity building of the new RDCC for Africa operated by the SAWS. Thus it was no major shortcoming that most of the African Dobsons, which were invited, could not come duly. The Dobson experts of the SAWS were trained and educated by the Dobson specialists from the WDCC and the RDCC Europe and Australia. The necessary equipment and tools for special tests and calibrations were left after their departure for use in the second part of the campaign after arrival of the African instruments. The experts of the RDCC Africa succeeded in the independent realization of this campaign applying the previously acquired skills and capabilities.

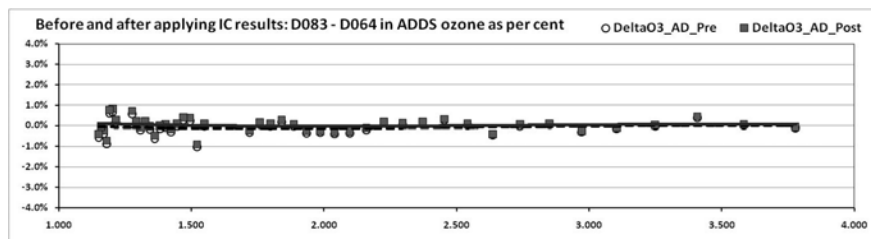


Figure 3-3: Relative difference of ozone values between world standard D083 and European standard D064 (graph from report by R. Evans)

The calibration of the regional standard Dobsons towards the world standard was the second main goal of Irene2009. Figure 3-3 confirms the very good agreement of D064 of the RDCC-E with the world standard D083 of the WDCC at NOAA in Boulder. The difference of the initial calibration was -0.1% .

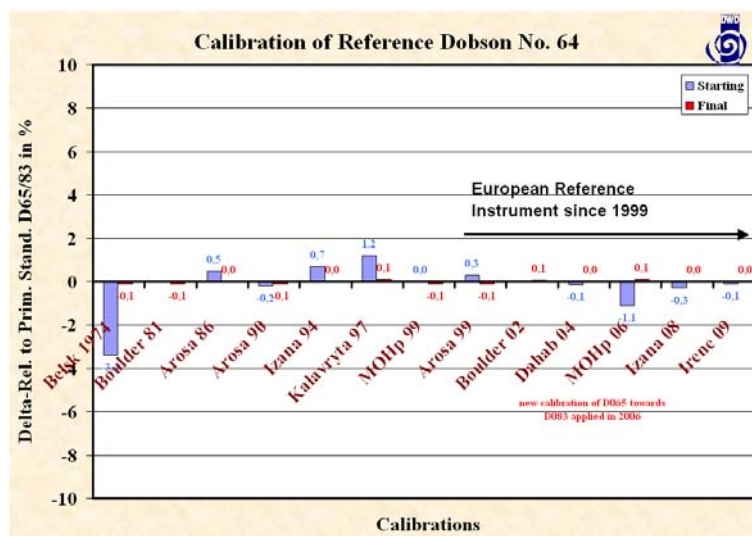


Figure 3-4: Calibration history of the European standard D064.

This excellent result is proved by the history of the D064-calibrations towards the world standards during the past 10 years (Figure 3-4) of its function as regional standard for Europe.



The highest difference since 1999 occurred in 2006 with -1.1% , when the calibration level of the world standard D065 was changed compared to the years before

Results of Izaña 2010

The Langley campaign at the Izaña observatory on Tenerife took place from September 20 to October 9, 2010. In these three weeks 8 days with perfect conditions (low turbidity, constant ozone) allowed a large number of direct observations. Although again only measurements in the morning were possible due to the RFI-effects by the near-by TV-antenna on the Dobson signal, a sufficient number of data sets could be obtained.

The Langley-plot evaluation provided almost identical results as in 2008. The necessary correction for the raw data (N-values) of the standard AD-wavelength pairs was 0.3 (0.2 in 2008), which results in a modification of the ozone value of less than 0.5% (Figure 3-5).

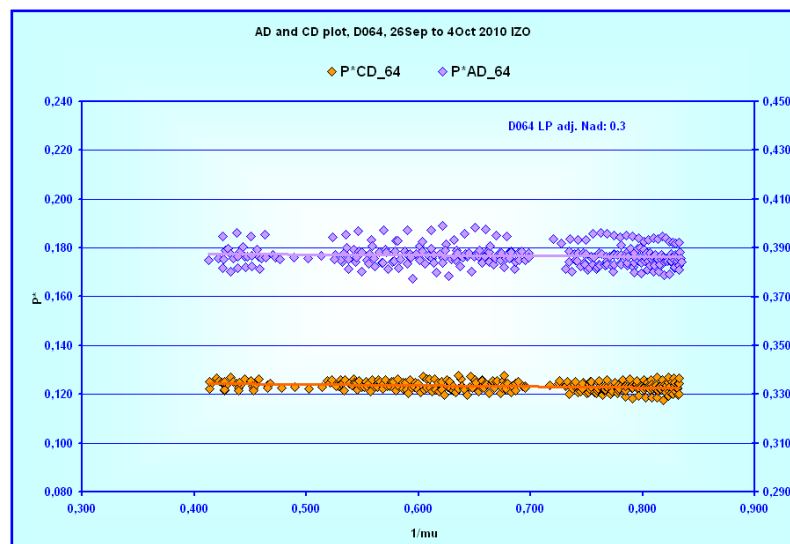


Figure 3-5: Plot of the D064 Langley observations.

The comparison of D064 with the simultaneous observations of the present standard Brewers BR017, BR157 and BR185 confirmed the results of all side-by-side campaigns since SAUNA I in 2006: higher Brewer values with a daily course and better straylight performance of the “double Brewers” (graph from evaluation by R. Evans).

These results are still preliminary and need more and detailed investigation, especially considering the proposed new ozone cross-sections after Daumont-Brion-Malicot (DBM), which are to replace the old Bass-Paur absorption coefficients in the near future.

Results of studies for improvement of Dobson data quality

The above mentioned introduction of new ozone cross-sections will be the most important activity in the next years, which will influence the data quality significantly. Still not finally determined temperature dependencies of the cross-sections might modify the picture of the currently seen differences between Dobson and Brewer with the well-known annual oscillation. At the present state it is too early to predict the effects of the new coefficients on the Dobson/Brewer relationship



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In the past months the colleagues from NOAA (Robert Evans as head of the WDCC in Boulder) and Jim Easson from the Australian Bureau of Meteorology (RDCC in Australia and South Pacific) started various investigations to measure slit widths and subsequently the slit-functions of several Dobsons and to determine straylight effects in close co-operation with the RDCC-E Hohenpeissenberg. The final goal is to determine effective absorption coefficients for each individual Dobson and to develop correction methods for straylight effects.

The special tests for measuring the optical characteristic of the Dobsons and the methods to align not correctly set optics were improved at the RDCC-E. This allows bringing the Dobsons as close as possible to the nominal values given by Prof. G.M.B. Dobson. The photography presented in Figure 3-6 shows the simple method to make the various spectral lines in the Dobson visible, to check and to align their optical path. The use of a fluorescent paper provides a clear picture of the horizontal and vertical position and orientation of the spectral lines coming from a normal mercury testlamp.

All these studies and tests are still ongoing and therefore no final results are possible until now.

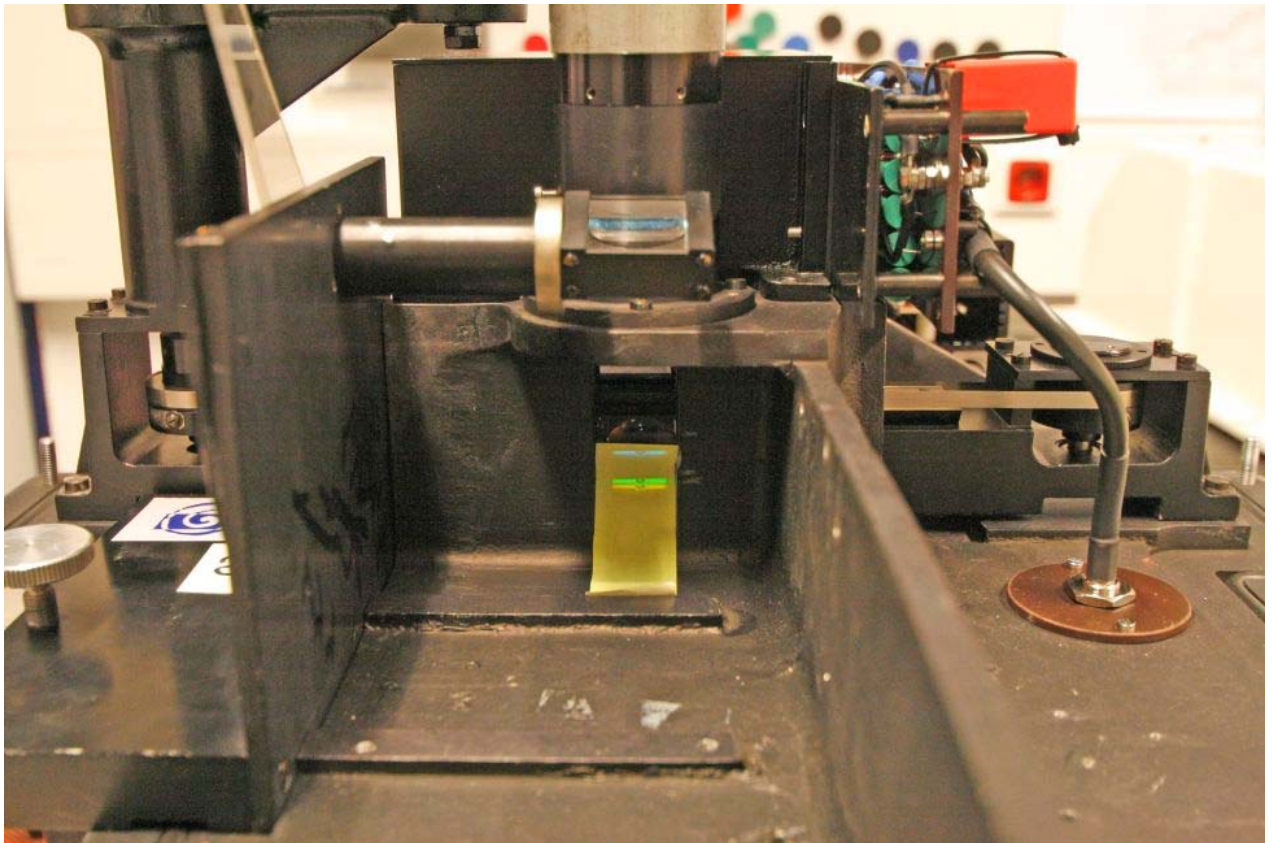


Figure 3-6: Photography of the optical path of the light inside a Dobson from the right hand. Different spectral lines are visible on the yellow fluorescent paper.



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3.1.2 Activities of the Regional Brewer Calibration Center for Europe (RBCC-E) at Izana and Nordic Brewer campaign activities (FMI)

3.1.2.1 European Brewer calibration

The Regional Brewer Calibration Center for Europe (RBCC-E) was established at the Izaña Atmospheric Research Centre in 2003. The RBCC-E transfers the calibration from the world reference triad located in Toronto (Canada) and managed by the EC-MS (Environmental Canada, Meteorological Service of Canada). The link of the triad is performed through the travelling brewer#017 managed by the private company IOS (International Ozone Services). The RBCC-E triad is calibrated once a year. In 2009 this happened before the Arenosillo campaign and in 2010 after the Arosa. In addition the calibration of the RBCC-E Triad can be determined independently using the Langley method. Three institutions provide calibrations in Europe:

1. **International Ozone Services (IOS):** a private company from Toronto, which historically performs on site calibration, in close relation with MS (maintainer of the World Triad)
2. **Kipp & Zonen:** Brewer manufacturer provides calibration of new/refurbished instruments some network instruments.
3. **RBCC-E:** Transfers calibrations by scheduled intercomparison campaigns, one in central Europe (Arosa Swiss) and one in South Europe (Huelva Spain)

There are key differences between the calibrations performed by IOS and the RBCC-E as summarized in Table 3.1. The main advantages of IOS resides in that they perform calibrations on site, without the risk that the instrument could be altered during the transport to the campaign. In addition IOS has the ability to perform repairs and maintenance work on the instrument. In contrast to the IOS travelling standard, the RBCC-E uses a double monochromator reference that does not suffer from any straylight issue. We can assure the calibration of the reference by comparisons before and after the campaigns.

| | IOS | RBCC-E |
|-------------------------------------|--|-----------------------------------|
| | Private | Public |
| Maintenance/ Repairs | Yes | No |
| Calibration of the referente | Before and after the travel to the continent (several travels without calibrations). | Before and after every campaign. |
| Instrument type | MK-II Single | MK-III Double |
| Calibration period | 5 days | 10 days |
| Place | On Site | Calibration Campaigns |
| Transport instrument | | Recommended by car |
| Transport of the referente | Plane | Plane (hand luggage) / Boat (car) |

Table 3-1: Summary of differences between International Calibration Service calibration transfer and RBCC-E

The main problem with IOS calibrations is that they do not provide a documented link between the travelling reference and the World Triad, including the calibrations of RBCC-E instruments where we found some inconsistencies. These inconsistencies can be related to the differences found between Brewer and Dobson (see previous section) is now analyzed using the Langley calibration and comparison with FTIR.



3.1.2.2 Campaigns

Four campaigns with the participation of the RBCC-E and one of FMI were organized with the support of this project: Arenosillo 2009, Izaña 2009, Arosa 2010 and Izaña 2010. During The Arenosillo and Arosa campaigns were standard RBCC-E campaigns where the calibration of the reference triad was transferred to the participating instruments. The campaigns at Izaña were specific for this project. Izaña 2009, with the participation of brewer #037, tried to determine how the calibration transfer was affected by the atmospheric conditions, comparing the calibration at Izaña (Subtropical) to the calibration performed on site (Arctic). The calibration at Izaña 2010 was an absolute calibration focusing on the determination of the calibration based on Langley plots.

Arenosillo 2009

The fourth Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison was held at El Arenosillo Atmospheric Sounding Station of the "Instituto Nacional de Técnica Aeroespacial" (INTA) during the period September 7-17, 2009. This fourth campaign was a joint exercise of the Regional Dobson Calibration Center for Europe (RDCC-E) and the Regional Brewer Calibration Center for Europe (RBCC-E) in collaboration with the Area of Instrumentation and Atmospheric Research of INTA, with the support of the Global Atmospheric Watch (GAW) program of the World Meteorological Organization (WMO) and the present ESA CEOS project. At the Arenosillo campaign seventeen Brewer instruments participated from seven countries. In addition seven Dobson and DOAS instruments joined in the ozone comparison in the second part of the campaign (see details in Table 3-2). At the same time a UV campaign was conducted with the participation of brewer instruments and the Spanish broad band sensors managed by the University of Extremadura.

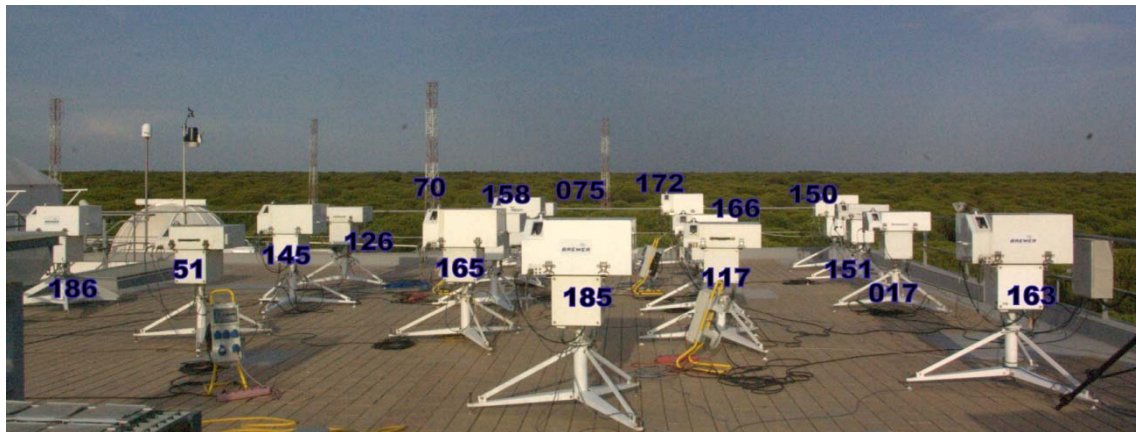


Figure 3-7: Brewer instruments participating to the IV RBCC-E campaign in Arenosillo, September 2009.

The initial comparison of the brewer, using the home calibration at the campaign, can give us an idea of the behaviour of the brewer network. The instruments show this general view (Figure 3.7).

- All the instruments are between -1%, and 2% with the exception of two instruments with serious and known problems
- Twelve of the instruments are inside +/- 1%, and five instruments show a perfect agreement within +/- 0.5%.

The provisional final calibration is shown on Figure 3.8 and Figure 3.9, with two different calibration methods (one parameter vs. two parameters). The recommended method by Ozone SAG of WMO is one parameter calibration while the two parameters calibration were suggested after the SAUNA campaign in order to improve the homogeneity of the network. This will be discussed later on in the next section (Figure 3.13, Figure 3.14).



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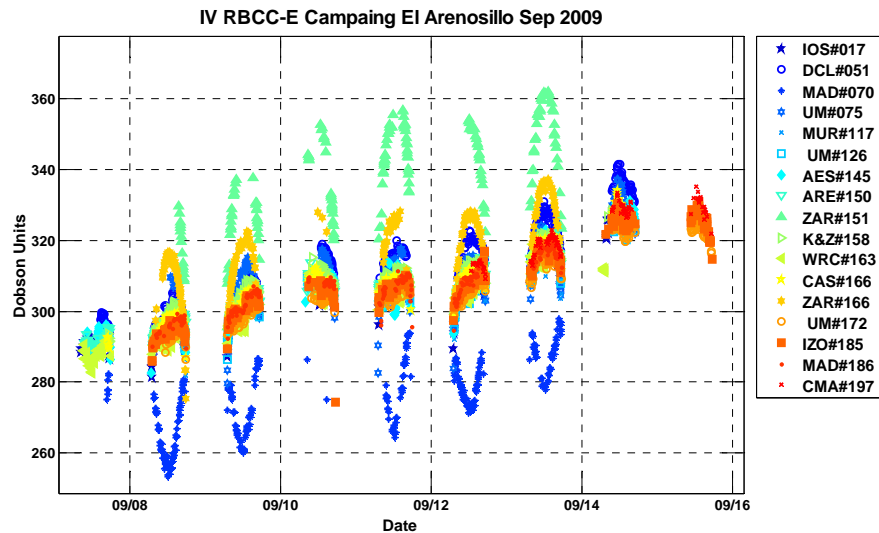


Figure 3-8: Ozone direct sun measurements of the seventeen participating instruments

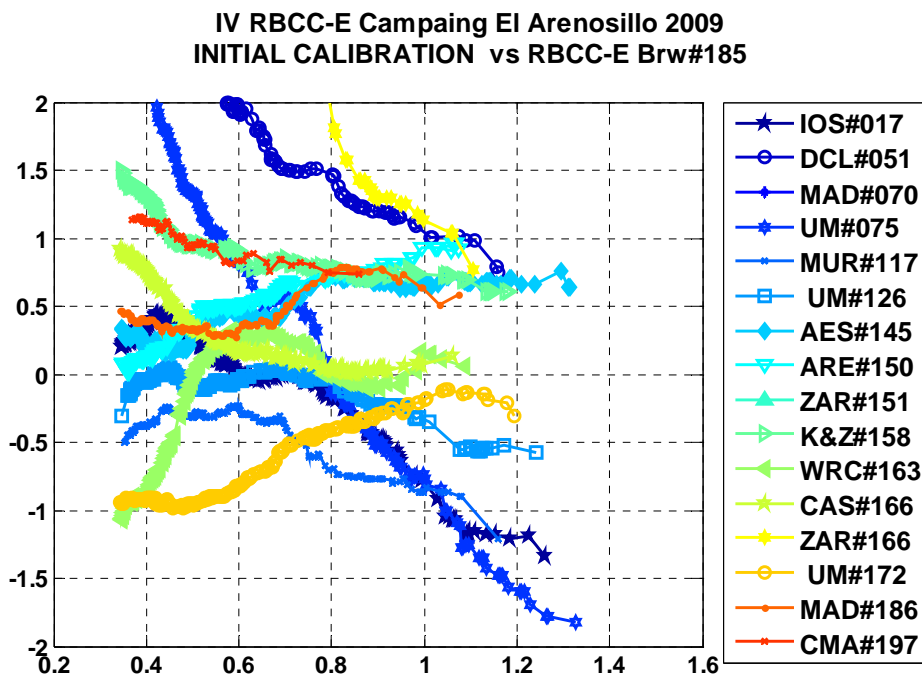


Figure 3-9: Ratio to the reference vs Ozone Slant Column of the initial calibration of the instruments participating to the Arenosillo 2009 campaign.

Izaña 2009

The calibration of the Brewer #037 provides an opportunity to check the impact of calibrations performed in two complete different atmospheric conditions: the arctic Sodankyla, and the subtropical Tenerife. This objective will be accomplished after the next Arctic campaign. The



instrument was calibrated by IOS in June 2009. In general the calibration was found to be good and the instrument is qualified as stable. A detailed analysis shows that the ozone is overestimated a lower OSP (ozone slant path) and underestimated at higher (Figure 3.10). Most of the measurements are on 400-1200 range so the mean value is unaffected. The final calibration reveals the stray light that affects single brewers, in this case the ozone is underestimated for OSP greater than 800 (DU) gradually reaching the 1% at 1400 (DU).

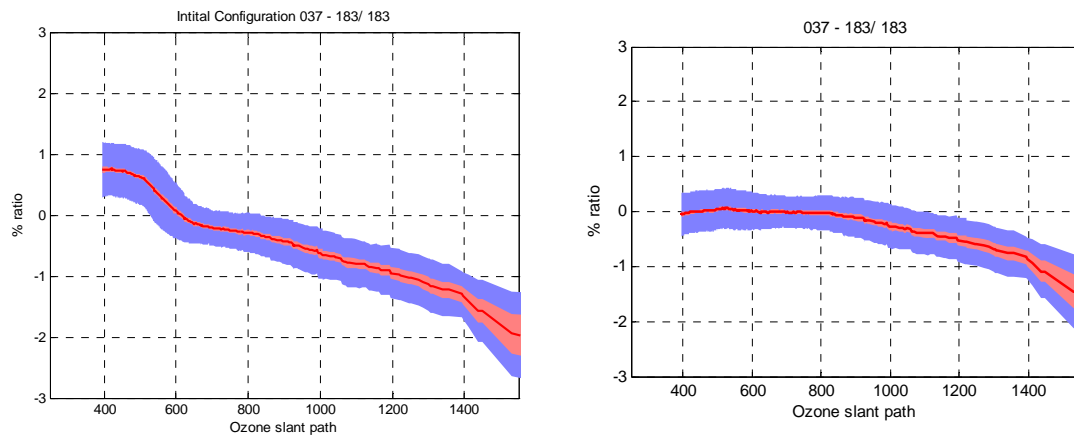


Figure 3-10: Initial (left) and final (right) comparison of the Brewer #037 with the Brewer #183 at Izaña 2009.

It is possible that the increase of the initial ozone values of B037 in low slant path as compared to the primary standard is related to an anomaly in the neutral density filter no. 4, which is needed in Tenerife. However, it should be noted that this does not affect the home measurement at Sodankylä since NDF as high as no.4 is never needed there.

Arosa 2010

The fifth RBCC-E intercomparison was held at Arosa Lichtklimatisches Observatorium (LKO) of Meteo Swiss during the period July 19 to 30, 2010. Seven brewer instruments managed by 11 experts of five countries participated to the campaign. The instruments were compared with the RBCC-E travelling reference Brewer#185 for ozone and with the QASUME unit for UV, European UV reference from the [World Radiation Center](#) (WRC). The maintenance of the instruments was performed by IOS ([International Ozone Services](#)).

It is remarkable to note the absence of the travelling reference of Kipp & Zonen (brewer manufacturer) due the last minute calibration request. The intended comparison of the three world travelling reference instruments, #017 (IOS), #158 (Kipp & Zonen) and #185 from RBCC-E finally did not take place.

The weather was not perfect but we get enough direct sun measurements to have a successful calibration (Figure 3-11). Rainy days were used to characterize brewer instruments, in particular slit functions of single brewer where determined, this data will be used to characterize the stray light effect on the ozone measurements. In addition a new portable setup for cosine response determination recently developed at WRC was tested.



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| Institution | Name | Brewer | Country |
|-------------|--|--------------------------------------|-------------|
| IOS | Volodya Savastiouk Martin Stanek | #017-MKII | Canada |
| LKO | René Stübi Herbert Schill Ruedi Burren | #040-MKII #072-MKII #156-MKIII | Switzerland |
| IGFPAS | Janusz Jaroslawski Bonawentura Rajewska- Wiech | #064-MKII | Poland |
| WRC | Julian Gröbner Gregor Hulsen Jan Grünenfelder | #163-MKIII | Switzerland |
| AEMET-IARC | Alberto Redondas Juan J. Rodriguez Isabel García | #185-MKIII | Spain |

Table 3-2: Instruments participating to the Arosa 2009 campaign.

The individual calibration reports for Arosa are already published and available on the web. The main conclusion from the Arosa 2010 campaign is related to the triad of instruments of LKO Arosa observatory and confirms the findings obtained in 2008. The wavelength calibration for all of these brewers is 1% higher than the set value. This produces a lower ETC and an artificial underestimation of the ozone at high ozone slat column (OSC) as well as an overestimation at low (OSC). This is more clearly seen during the 2008 campaign with better weather conditions. We look forward to the next campaign at Arosa 2012 to see how this change affects the Brewer-Dobson comparison.

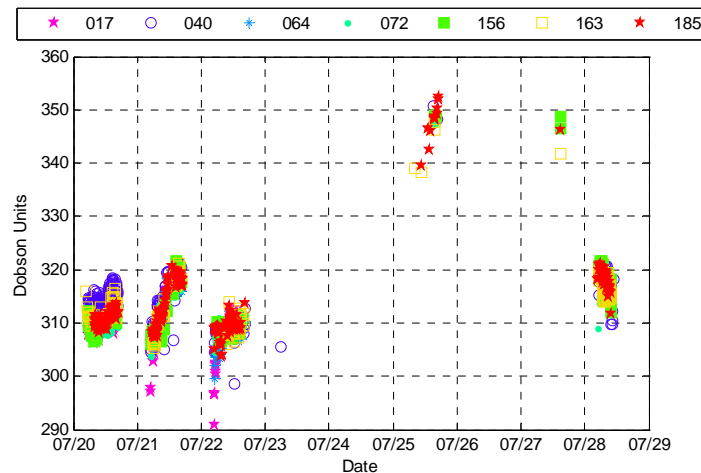


Figure 3-11: Ozone Direct Sun Measurements during the Arosa 2010 campaign

During the campaign a meeting of calibrations service took place with the purpose to unify and standardize the brewer calibration and reporting. A draft of a standard form was adopted for RCBC-E and IOS which allows users and data managers to obtain a quick asset of the quality of the calibration.



3.1.2.3 Results of studies for improvement of Brewer data quality

Two major instrumental problems, the straylight effect and the method of calibration are analyzed based on the results of the intercomparison campaigns.

Straylight

One of the findings of the SAUNA campaign is that Dobsons and single monochromator brewers show an underestimation of the ozone at high OSC measurements (high ozone and high air mass). (Figure 3.12). During SAUNA, an empirical correction was established and some preliminary model calculations were performed. At the meeting with IOS at Arosa we agreed to increase the measurements of the slit functions of the instruments to properly characterize the straylight and until the model calculations are not final only give a quantitative description of the straylight without providing the empirical correction used at SAUNA.

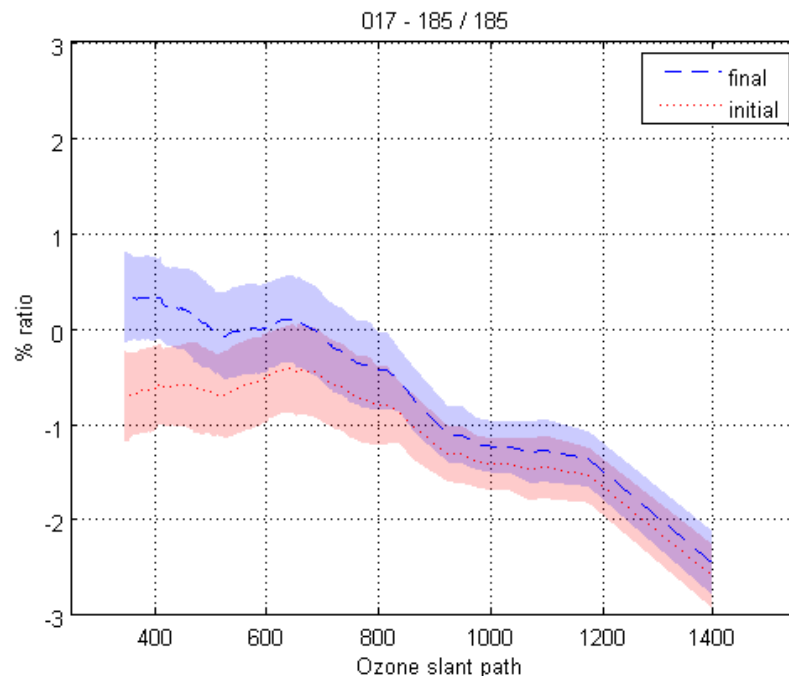


Figure 3-12: Initial (red) and final (blue) comparison of the Brewer #017 (Single monochromator) against Brewer#185 (double) at Huelva 2010. The single instrument underestimate the ozone starting in 700 (DU) of Ozone Slant Path reaching 1% at 900 DU.

One parameter versus two parameters calibration transfer

Briefly, the total ozone measured by the brewer spectrophotometer can be derived from the following simple formula:

$$O_3 = \frac{F - ETC}{\alpha m}$$

Where **F** is the ratio of irradiances measured by the instrument, **m** is the air mass, **α** is the ozone absorption coefficient and **ETC** is the Extraterrestrial Constant. **F** is measured and **m** can be easily calculated. There are two calibration methods: one parameter calibration determines **α** by wavelength characterization of the instrument and ETC is transferred by a reference instrument,



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(Fioletov et al 2005) whereas in two parameters calculation both ozone absorption coefficient and ETC are transferred from the reference instrument (Stahelin et al, 2003).

The calibration of a Brewer can be divided in three steps, instrumental, wavelength and ETC constant transfer. Instrumental and wavelength calibration can be performed by characterizing the instrument and ETC is transferred by comparison to a reference instrument or determined by Langley method.

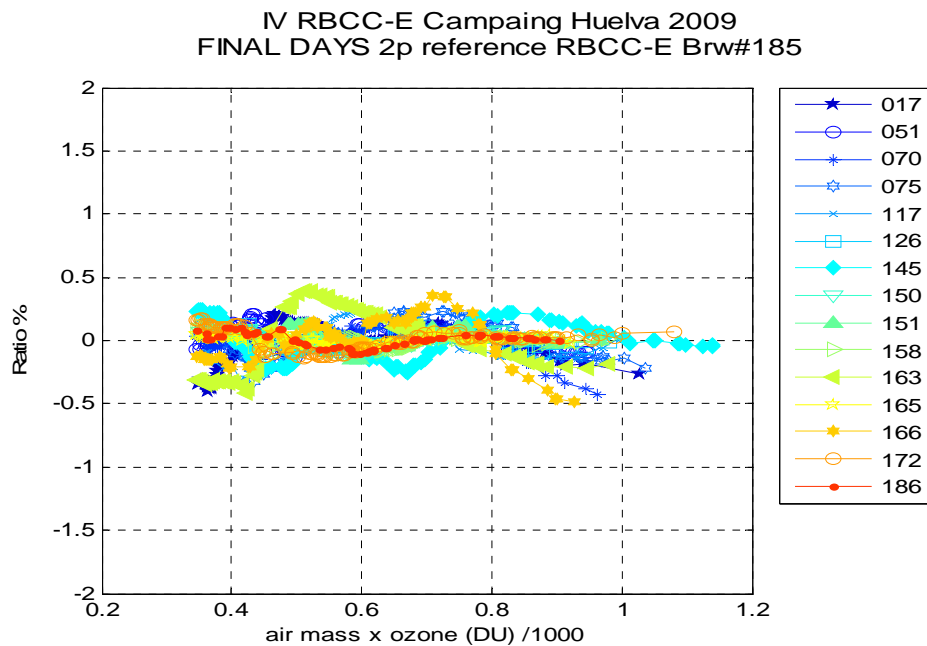


Figure 3-13: Ratio to the reference, two parameters calibration (provisional data)

There is a controversy of either one parameter or two parameters methods have to be used; one parameter is more robust (Fioletov et al 2008) but results of SAUNA reveals that modelization of straylight in single Brewer and measurements during the campaign agree if two parameters calibration is used (Bojkov B et al 2008). Historically the two parameter method was used until around year 2000 after that one parameter method has been adopted on the Brewer network. Although both methods give the same results in the 500-800 DU range, the two parameters calibration gives uniform results, smoothing the instrumental differences and reduces the straylight effect on single Brewer. On the other hand, the one parameter calibration is more robust, it does not depend on reference wavelength calibration, and it highlights instrumental differences.



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IV RBCC-E Campaign Huelva 2009
FINAL DAYS 1p reference RBCC-E Brw#185

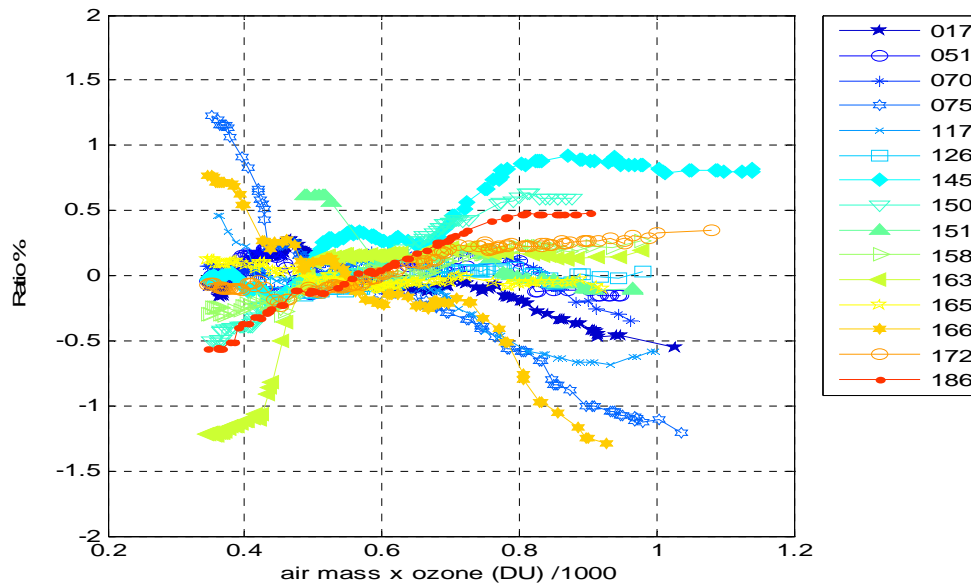


Figure 3-14: Ratio to the reference, one parameter calibration

The calibration of Brewer #037 at Izaña 2009 and the Arosa 2009 give us the confidence that both calibrations should give the same results within the precision of the instrument. If the two calibrations methods do not agree, this reveals a problem in the instrumental calibration or in the wavelength calibration of the instrument. We can estimate the precision of the instrument based on the wavelength resolution of the instrument. One micrometer step corresponds to about 0.3% in ozone and one can also use results of Langley plots. The precision in ETC determination is not better than 5 units ($\sim 0.5\%$ in ozone). Within these limits both calibration methods give the same result.

Conclusions

1. We have found inconsistencies in the calibration transfer of IOS to the RBCC-E reference triad at Izaña and Arosa campaign. These small inconsistencies of 0.5% in measurements at high solar zenith angles agree with the differences found in the Brewer-Dobson comparisons (see RDCC-E section).
2. The current status of the brewer network can be inferred based on the results from the calibration campaigns. In Arenosillo, with 17 instruments, 15 show a difference with the reference below $\pm 1\%$ and five show a perfect agreement (below 0.5%).
3. We have found that there are no significant differences between one parameter and two parameter calibrations, within the precision of the Brewer instrument.
4. Three Calibration campaigns were successfully realized; the reports for the campaigns are publicly available at the RBCC-E web page (www.rbcc-e.org) and will be published by WMO/AEMET.



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Recommendations

1. Most of the Intercomparison campaigns results are based on the comparison of the reference. The reference instrument has to be carefully characterized and comparison of the travelling standard has to be performed before and after the calibration campaign.
2. The comparison of the one parameter and two parameter calibrations has to be reported as a skill measure of the quality of the calibration of the instrument.
3. The inconsistencies in the calibration from the IOS travelling reference suggest to have a direct link to the World Standard Triad in Toronto, by comparison with the travelling RBCC-E instruments at Toronto or by simultaneous absolute calibration with the Toronto triad when is performed at Mauna Loa.

Outgoing work

- An analysis of the RBCC-E reference triad Langley and comparison with external measurements is in progress in order to quantify the inconsistencies found in the calibration transfer from IOS. After this analysis a comparison with Dobson will be performed using the transferred calibration from IOS and the independently obtained by Langley.
- A summary of the calibration reports of a Brewer instrument, useful for users and data managers are in develop to be adopted for the calibration institutions.

Update of campaigns schedule until October 2012

| | |
|----------------------|---|
| Izana (2009) | FMI Brewer # 037 |
| Arosa 2010 (July) | RBCC-E |
| Izana 2010 (October) | Brewer Dobson Langley |
| Nordic campaign 2011 | FMI-RBCC-E (Nordic) |
| Huelva 2011 (june) | RBCC-E /RDCC-E |
| Izana 2011 (October) | FMI Brewer #037 |
| Arosa 2012 (July) | RDCC-E /RDCC-E |
| Izana 2012 (Sep) | Brewer Dobson Langley & FMI Brewer #037 |

Table 3-3: Updated schedule of Brewer campaigns

3.1.3 Nordic Brewer campaign activities

In the springs of 2006 and 2007 FMI arranged two campaigns at Sodankylä on the request of NASA with the aim of assessing the performances and comparability of different ozone monitoring instruments both ground based and satellite based and both total ozone and profiling instruments. One of the main findings of these campaigns was that in the conditions of high slant path (high total ozone and low solar angle) typically existing in high Northern latitudes spring significant stray light error is found both in Dobson and in single monochromator Brewer spectrophotometers. The varying impact of these errors to monthly means can be seen in Figure 3-15 where Sodankylä Brewer standard data and straylight corrected data are plotted. In the conditions of "Nordic ozone hole springs" following the cold Arctic winters the difference is very small (e.g. in 1996 only 3 DU) whereas in the conditions of high ozone in March a significant stray light error develops (e.g. 11 DU in 1999). Therefore decadal ozone records are modulated by



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this error and in today's requirement of un-biased sub 1 % precision in total ozone measurements it is necessary to get rid of it. FMI and its single monochromator Brewer no. 37 is participating in this context to the project and will arrange CEOS Intercal Nordic campaign at Sodankylä.

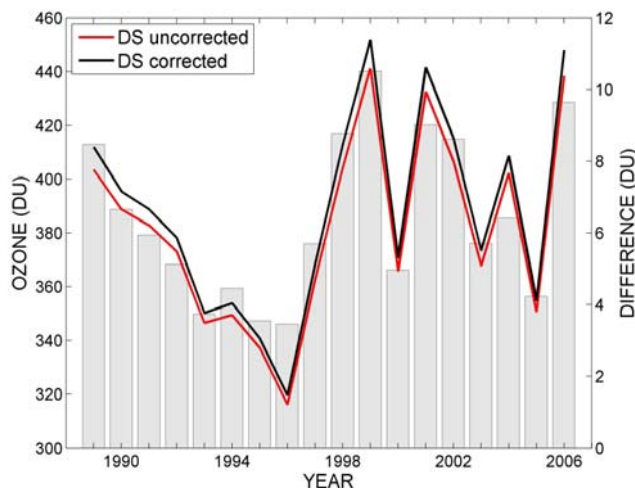


Figure 3-15: Effect of straylight error on monthly mean data level, March months of 1989-2006 at Sodankylä. Red and black traces show the total ozone values on uncorrected and corrected total ozone values, respectively and columns show the difference.

Jokioinen campaign 2010

Later in May-June 2010 Brewer 037 participated in the Nordic QASUME UV campaign at Jokioinen, Finland. QASUME was an important further opportunity to characterize B037 UV spectrum performance against the standard of the World Radiation Center (WRC) and at the same time to compare ozone measurements against the double Brewer no. 107, which has an excellent straylight behavior. Both Izana and Jokioinen intercomparisons showed stable behaviour of Brewer 037.

Sodankylä campaign 2011

The Arctic aspect of CEOS intercalibration of Brewers and Dobsons will be realized in the Nordic campaign, which will take place in March 2011 at Sodankylä. Arrangement of this campaign is the main contribution of FMI. The preparations have been going on some time already. The mission will take place from March 4 - 25, 2011. Arrival and configuration of the ground-based instruments is scheduled for March 7-8. The formal intercomparison begins on March 9 and continues through March 23. Instruments will be prepared for shipping and participants will depart on March 24-25. During the effective intercomparison period the sky measurements are taken always when good conditions for sun or moon observations exists. On the less-good-sky days we need to reserve sufficient time for the calibration-lamp and HeCd-laser measurements. Team Meetings will be held regularly. Once the intercomparison period is underway, scientific results from the most recent measurements will be the focus of the meetings. Data will be exchanged for further collaborative analysis in the field. Participation will consist of 2 Dobson teams and 5 Brewer teams (http://fmiarc.fmi.fi/Ceos_Nordic.htm).



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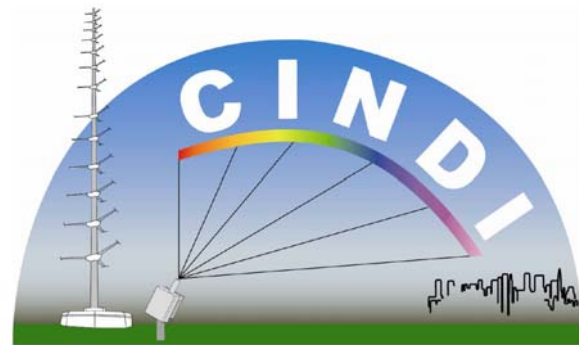
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3.2 The CINDI campaign

In June-July 2009, over thirty different in-situ and remote sensing instruments from all over the world, all capable of measuring atmospheric nitrogen dioxide (NO_2), were jointly operated during the Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments (CINDI). The campaign took place in The Netherlands at the Cabauw Experimental Site for Atmospheric Research (CESAR), which is managed by the Royal Netherlands Meteorological Institute (KNMI). The main objectives were to determine the accuracy of state-of-science ground-based NO_2 measuring techniques and to investigate their use in satellite validation. The campaign will result in recommendations regarding the operation and calibration of such instruments, retrieval settings, and observation strategies for the use in ground-based networks for satellite validation.

Twenty-four optical spectrometers participated in the campaign, of which twenty-one had the capability to scan different elevation angles consecutively, the so-called Multi-axis DOAS systems, thereby collecting vertical profile information for NO_2 and aerosol, as well as other trace gases such as HCHO , O_3 , SO_2 , H_2O and BrO . The CINDI campaign was performed under the auspices of the European Space Agency (ESA), the International Network for Detection of Atmospheric Composition Change (NDACC) and the EU Framework 6 ACCENT-AT2 Network of Excellence and GEOMON Integrated Project. The instruments operation and travel costs of 8 European participants (see Table 3-4) were funded by the ESA CEOS Intercalibration project.

The CINDI campaign was organized around two main objectives. The first one was to determine the accuracy of state-of-science ground-based NO_2 measuring techniques, to test these techniques under different atmospheric conditions, and improve them, in order to provide a reference for the validation of satellite retrievals. This responds to the need for developing and maintaining accurate ground-based measurement capability, including the detection of vertical profiles of NO_2 , expressed in the conclusions of the ACCENT-AT2 supported workshop on “Tropospheric NO_2 measured by satellites”, held at KNMI, De Bilt, The Netherlands from 10 to 12 September 2007 (Piters et al., 2007). The second objective was to investigate the potential of the different instruments for satellite validation, focusing on the potential for mapping the three-dimensional NO_2 distribution. The aim of CINDI is to provide an estimate of the accuracy of tropospheric NO_2 columns and profiles for the participating instruments under different atmospheric conditions (clouds/aerosols) and viewing geometries and to provide a set of recommendations for the validation of satellite-derived tropospheric NO_2 concerning instrumentation, calibration, and measurement and retrieval strategy.

These main objectives resulted in a two-phase approach. The first phase, running from 15 June to 5 July, consisted of an extensive intercomparison campaign for ~ 22 MAX-DOAS and zenith-sky spectrometers that were lined up together at Cabauw (Table 3-4). The result of this study has already been published in Roscoe et al. (2010). In the second phase of CINDI, running from 5 July to 26 July, the observation modes and locations of the instruments were optimized for investigating the influence of different viewing geometries and for investigating spatial variability on the scale of a typical satellite ground pixel footprint over the measurement site.



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Table 3-4. Characteristics of the various spectrometers taking part in the CINDI intercomparison campaign (Roscoe et al., 2010). The European contribution to the campaign was supported by the ESA CEOS Intercalibration project.

| Instrument | observed wavelengths (nm) | width of spectral response (nm FWHM) | detector type | cooled or not | fibre or not |
|-------------------|----------------------------------|---|----------------------|----------------------|---------------------|
| BIRA-Vis | 400 to 700 | 0.95 | 2D CCD | yes | yes |
| Bremen-Vis | 400 to 573 | 0.8 | 2D CCD | yes | yes |
| CNRS-SAOZ * + | 270 to 630 | 1.17 | 1D NMOS | no | no |
| CNRS-mobile * | 270 to 630 | 1.5 | 1D NMOS | no | no |
| CNRS-mini * # | 270 to 800 | 0.7 | 2D CCD | no | yes |
| Heidelberg1 + | 290 to 789 | 0.88 | 1D CCD | yes | yes |
| INTA-NEVA2 | 387 to 514 | 0.6 | 2D CCD | yes | yes |
| INTA-RASAS2 | 393 to 510 | 0.45 | 2D CCD | yes | yes |
| JAMSTEC | 223 to 558 | 0.7 | 1D CCD | no | yes |
| KNMI-2 | 400 to 600 | 0.9 | 1D CCD | yes | yes |
| Leicester | 425 to 490 | 0.54 | 2D CCD | yes | yes |
| MPI-Mainz # | 310 to 461 | 0.55 to 0.87 | 1D CCD | yes | yes |
| NASA | 269 to 532 | 0.6 | 2D CCD | no | yes |
| NIWA | 389 to 510 | 0.48 | 2D CCD | yes | yes |
| Toronto * | 340 to 550** | 0.5 to 2.5** | 2D CCD | yes | yes |
| Washington | 282 to 498 | 0.83 | 2D CCD | yes | no |
| BIRA-UV | 300 to 388 | 0.37 | 2D CCD | yes | yes |
| BIRA-Mini # | 290 to 434 | 0.7 | 1D CCD | no | yes |
| Bremen-UV | 315 to 384 | 0.37 | 2D CCD | yes | yes |
| Heidelberg2 + | 320 to 463 | 0.45 | 2D CCD | yes | yes |
| GIST-Korea | 290 to 430 | 0.7 | 1D CCD | yes | yes |
| KNMI-1 # | 290 to 433 | 0.7 | 1D CCD | yes | yes |

* zenith only

+ at the wind profiler site

mounted on the tower

** changed on 30 June to 315 to 380 and 0.2 to 0.8 nm, for MAX-DOAS measurements in the UV

Complementing the DOAS systems, the RIVM nitrogen dioxide lidar operating from a mobile truck provided vertical profiles of nitrogen dioxide at moderate resolution that can be used to evaluate MAX-DOAS profiles of nitrogen dioxide (Volten et al., 2009). The RIVM aerosol lidar CAELI also measured vertical profiles of aerosols microphysical properties at a high resolution (Apituley, 2009). Additional in-situ nitrogen dioxide instruments equipped with photolytic converters (Boersma, 2009) were operated on the ground and on the various tower platforms. Also a novel balloon-borne nitrogen dioxide sonde developed by KNMI (Sluis et al., 2010) was flown for the first time providing in-situ measurements of NO₂ at a high vertical resolution. Ozone was measured with an ozone lidar located in Bilthoven and by ozone sondes launched from the CESAR site.

An illustrative collection of images is shown in Figure 3-16 where the tremendous variety of optical detection system designs is highlighted.



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Figure 3-16. Snapshots of the various optical instruments installed at the remote sensing site indicating the large variety of optical detection system designs actively involved in the campaign effort. Clockwise from the upper left corner are the systems operated by BIRA (2x), JAMSTEC, INTA, BIRA, NASA, NIWA, NASA, IUP-Bremen, IUP-Heidelberg, Universities of Leicester and Leeds, KNMI. Center images are WSU (left) and IUP-Heidelberg (right). Some images display complete stand-alone systems (e.g. WSU), others are only displaying the optical receiver (e.g. NASA Pandora). Adapted from Piters et al (2011).

The extensive data set obtained during CINDI enables us to perform in-depth intercomparisons to assess the accuracy of the NO₂ measuring instruments. These studies will point to the possible origins of differences in the derived geophysical parameters, and whether they are related to instrumental, algorithm, or interpretation differences.

Semi-blind intercomparison of slant column measurements of NO₂ and O₄ by MAX-DOAS and zenith-sky UV and visible spectrometers

The first two weeks of the campaign a semi-blind intercomparison was performed between the 22 MAX-DOAS and Zenith Sky instruments (Roscoe et al., 2010). These instruments pointed in the same direction and scanned almost the same air mass every 20-30 minutes. The wavelength ranges and inversion algorithm to obtain slant columns of NO₂ and O₄ were prescribed to minimise differences caused by these algorithms. The 30-minute averages of the slant column densities of NO₂ and O₄ matched within 5% for most participating instruments and all elevation angles (see Figure 3-17, and Figure 3-18). The level of agreement for zenith-sky measurements of NO₂ – all instruments within 5% of the mean – equals that of previous intercomparisons despite the site not being ideal for zenith twilight measurements. Previous intercomparisons were only for zenith instruments, hence they focussed on stratospheric NO₂. The fact that almost as good agreement



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was found in MAX-DOAS measurements of NO_2 , which have a much shorter heritage than zenith measurements, and that almost as good agreement was found for MAX-DOAS measurements of O_4 , which are important to diagnose the state of cloud and aerosol in the troposphere, bodes well for the future of measurements of tropospheric NO_2 by this important technique. It was concluded that most instruments meet the zenith-sky criteria for endorsement by NDACC. From this study it became clear that a proper calibration of the elevation angles is crucial for the interpretation of the measurements. Also, the variability of the NO_2 in time is observed to be quite large, and a significant part of the scatter in the comparisons is caused by time differences in the measurements.

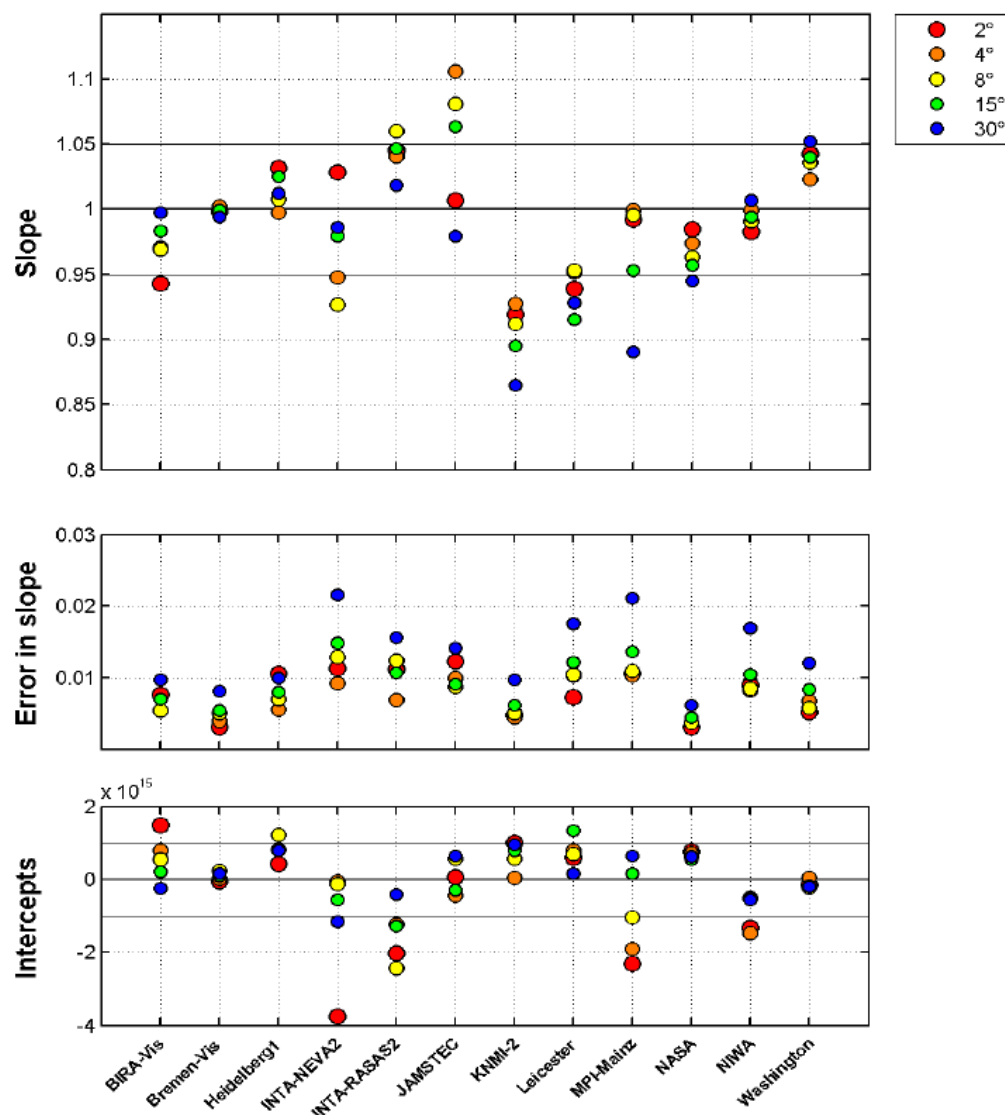


Figure 3-17. Straight-line slopes and their standard errors of NO_2 slant columns against those of the reference data set, for each instrument at instrument at visible wavelengths and for the whole campaign. Colours refer to elevation angles shown top right. (Roscoe et al., 2010)

Despite the agreement between the measurements from all the instruments is good, some points have been identified that are of particular relevance for MAX-DOAS observations:



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1. Exact alignment of the elevation angle is of uttermost importance, and probably should be checked on a regular basis. During the campaign, problems with pointing were detected for several instruments, which would have gone unnoticed in normal operations.
2. Temporal variability in the tropospheric signals is large, and good sampling is needed to come to representative results. For future intercomparison campaigns, synchronisation of measurements is to be considered as a significant part of the scatter observed is probably due to differences in time of measurement.
3. The consistency of NO_2 observations in the visible and UV as well as the O_4 observations is good but not perfect. The spread of values gives an indication of the uncertainties to be assigned to these quantities when used in profile inversion techniques.

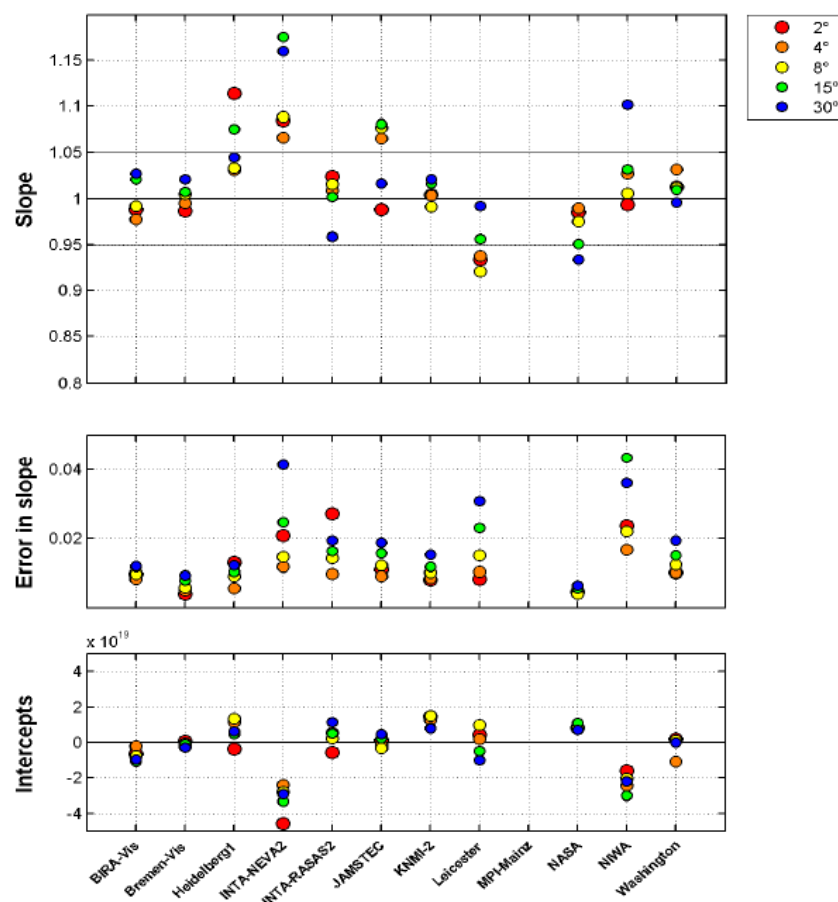


Figure 3-18. Straight-line slopes and their errors of O_4 slant columns against those of the reference data set, for each instrument at visible wavelengths and instrument at visible wavelengths and for the whole campaign. Colours refer to elevation angles shown top right. MPI-Mainz used a non-standard wavelength range for analysis, which did not produce an O_4 amount.

Other ongoing CINDI data exploitation activities

Several instruments participating in CINDI have the capability to derive information about the vertical distribution of NO_2 . A study has been performed comparing the different retrieval methods, and to determine the advantages and limitations of the different approaches. These results are currently collected and will be soon submitted for publication in AMT (Wittrock et al., 2010). Likewise vertical profiles and optical depth of aerosol have been retrieved by several MAXDOAS groups. Frieß et al (2010) performed an intercomparison between these retrievals, see



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Figure 3-19. A reasonable agreement of the boundary layer vertical structure is found between the different algorithms. Note also that the aerosol optical depth is in good agreement with the AERONET measurements, although it tends to be too low in the afternoon. This might be related to difficulties in retrieving aerosol properties for measurements taken in a direction close to the sun.

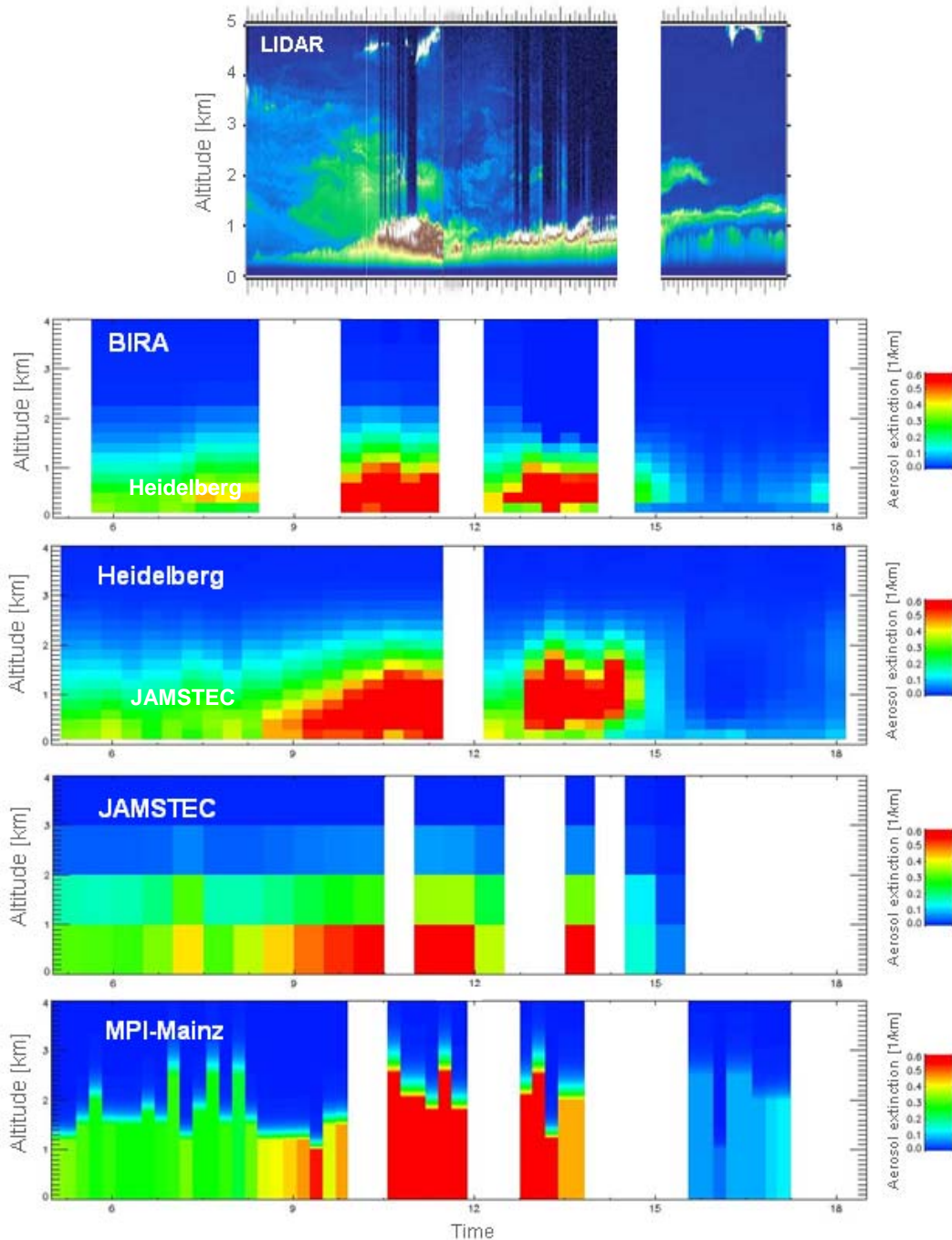


Figure 3-19. Intercomparison between aerosol extinction profiles determined from the MAXDOAS systems of BIRA, Heidelberg, JAMSTEC and MPI-Mainz and backscatter ratios measured by the CAELI lidar of RIVM (Friess et al., in preparation)



Zieger et al. (2010) also compared MAX-DOAS retrieved surface aerosol extinction with in-situ measurements. The values agree better than expected, where the agreement is better for low AOD (from sun photometer) and low PBL cases. The retrieval for some of the instruments improves when ambient in-situ measurements are used as input. Possible reasons for this could be for instance the stability of the boundary layer, the influence of upper layers, the influence of homogeneous gradient of aerosol concentration or maybe the influence of nitrate partitioning.

Good correlation was found between in-situ and MAX-DOAS measurements as can be seen from Figure 3-20. For certain cases (low AOD and low PBL height) good agreement was found, but for most of the time MAX-DOAS retrieved a 1.5 – 3.4 higher extinction coefficient. Differences could have been caused by e.g. particle losses in the inlet system (all remote-sensing instruments were measuring generally higher extinction) or by the fact that the limited vertical resolution of the MAX-DOAS retrieval overestimated the extinction in the lowest layer when lofted layers were present. In addition, the MAX-DOAS retrieval could have been influenced by the horizontal aerosol gradient, which could have exhibited large variations. The smaller slope of the regression line for the MPI measurements could indicate that the coarser resolution with more simplified assumptions is a more robust MAX-DOAS aerosol retrieval.

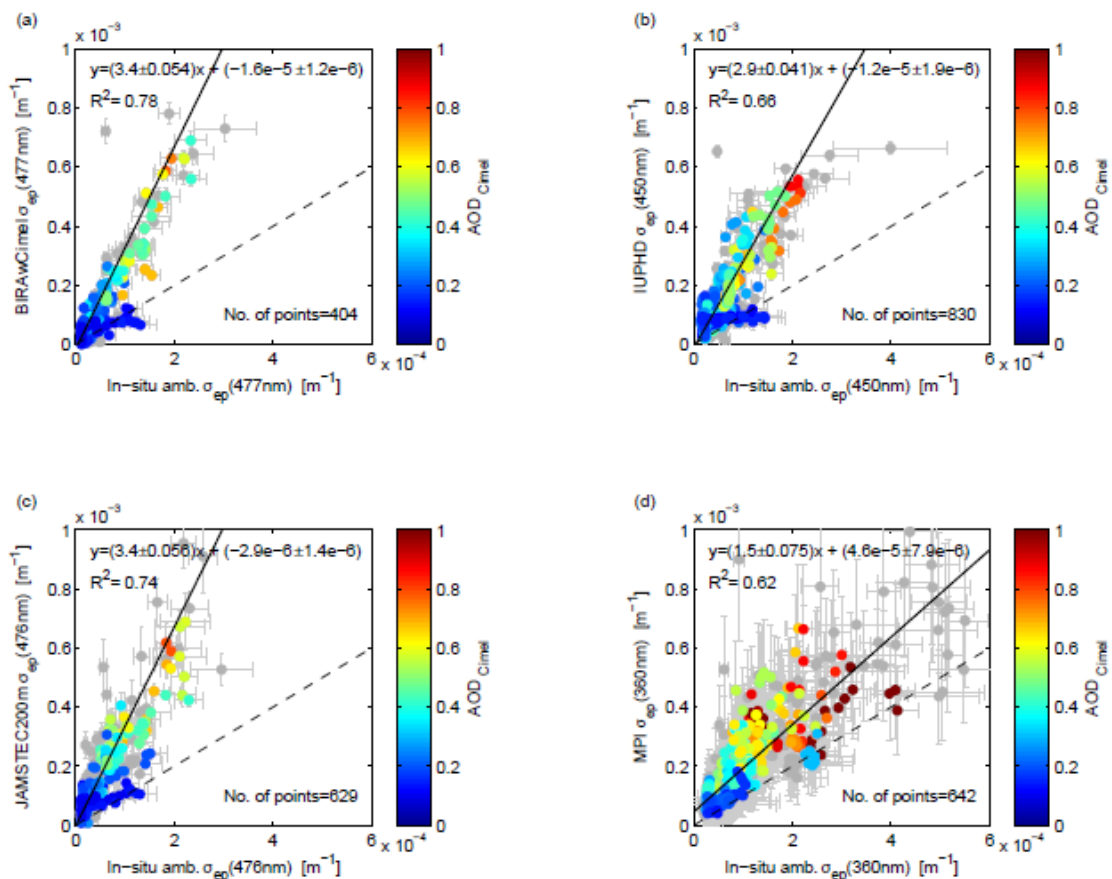


Figure 3-20. Ambient extinction coefficient retrieved by MAX-DOAS vs. in-situ measurement brought to ambient conditions. The color code denotes the AOD measured by the Cimel sun photometer (grey points are times with no sun photometer measurements). The solid black line represents a bivariate linear regression including weights (with calculated uncertainty of slope and intercept). The dashed line is the 1:1-line (Zieger et al., 2010)



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Conclusion

The CINDI campaign has been very successful in achieving its scientific objectives. A large data set of continuous ground-based in-situ and remote sensing measurements of nitrogen dioxide, aerosols and other air pollution constituents has been collected under various meteorological conditions and under various air pollution loadings supported by the auxiliary measurement characterizing the state of the atmosphere. The campaign included many cloud-free periods: ten days were labeled as 'category A' days with at least ten sunny hours, and 13 days as 'category B' days with at least four sunny hours. The air surrounding Cabauw was observed in multiple azimuthal and elevation directions by the MAXDOAS and Direct Sun instruments from morning twilight to evening twilight. First detailed comparisons with the CINDI data have been performed and published or submitted for publication, notably the semi-blind intercomparison of slant columns of NO₂ and O₄ (Roscoe et al., 2010, see Section 4.1), the intercomparison of NO₂ profiles and methods (Wittrock et al., 2010), the comparison of aerosol extinction measurements (Zieger et al., 2010) and an exploratory study on multi-species retrievals during CINDI (Irie et al., 2010)

Other studies that are currently being performed include the comparisons of tropospheric NO₂ columns, aerosol profiles, ozone profiles, and HCHO columns, the spatial variability of NO₂, and the application to satellite validation. The discussion of CINDI results already made the subject of three scientific workshops, respectively at KNMI, Utrecht, The Netherlands (6-8 July 2009), at BIRA-IASB, Brussels, Belgium (10-11 March 2010) and at MPI, Mainz, Germany (1-2 December 2010). For more details, see the CINDI web-site (<http://www.knmi.nl/samenw/cindi/>). Altogether, one expects over 10 publications to be issued on CINDI results.

It is also expected that the studies performed during the CINDI campaign will result in increased knowledge about the performance of ground-based remote sensing instruments regarding the accuracy with which NO₂ and aerosol information in terms of vertical profiles and tropospheric/total columns can be derived. The intercomparisons will result in harmonization of retrieval settings and observation methods, and in recommendations for building the networks of ground-based systems urgently needed for satellite data validation.



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3.3 EARLINET measurement campaigns

EARLINET, the European Aerosol Research Lidar NETWORK, established in 2000, is the first coordinated lidar network for tropospheric aerosol study on the continental scale. The network activity is based on scheduled measurements, a rigorous quality assurance program addressing both instruments and evaluation algorithms, and a standardised data exchange format. At present, the network includes 27 lidar stations distributed over Europe.

The quality assurance program for instruments is reached through a two level strategy: the internal quality check (through the use of specific check tools developed in the frame of the EARLINET-ASOS project) and instrument intercomparison measurement campaigns using the EARLINET reference lidar systems. The EARLINET reference lidar systems visit all the EARLINET sites and perform direct comparison with each lidar system in several atmospheric conditions and both in daytime and nighttime conditions.

These intercomparisons, as planned, have been performed during the EARLINET-ASOS project. As stated in the the ESA-CEOS project, funds from EARLINET-ASOS project cover only the campaigns for the new recent added stations (Alomar, Cabauw, Madrid and Sofia). The other stations are inter-compared using the ESA-CEOS project.

During the EARLINET-ASOS project, five intercomparison measurement campaigns have been carried out: EARLI09, ALI09, SOLI10, ROLI10 and SPALI10.

EARLI09

The first measurement campaign (EARLI09, EARlinet Reference Lidar Intercomparison campaign) was performed in Leipzig (Germany) from 5 May to 5 June 2009. It was addressed mainly to the intercomparison among the five reference lidar systems from Hamburg, Munich, Potenza and Minsk, but further six EARLINET stations joined the measurement campaign. In the following table, all the stations involved in EARLI09 are listed:

| System name | Station | Comment |
|-------------|--|------------------------|
| MSTL-2 | BISIP.SMO, Minsk (Belarus) | Reference lidar system |
| ARL2 mobile | MPIMET, Hamburg (Germany) | Reference lidar system |
| MUSA | CNR-IMAA, Potenza (Italy) | Reference lidar system |
| MULIS | LMU, München (Germany) | Reference lidar system |
| POLIS | LMU, München (Germany) | Reference lidar system |
| CAELI | RIVM, Bilthoven/Cabauw (The Netherlands) | EARLINET lidar system |
| HSRL | FZK, Garmisch-Partenkirchen (Germany) | EARLINET lidar system |
| - | JRC, Ispra (Italy) | EARLINET lidar system |
| MARTHA | IFT, Leipzig (Germany) | EARLINET lidar system |
| PollyXT | IFT, Leipzig (Germany) | EARLINET lidar system |
| RALI | INOE, Magurele-Bucharest (Romania) | EARLINET lidar system |

In Figure 3-21, it is reported the picture of the laser beams at 532nm emitted by the several lidar systems involved in the measurement campaign.

While the participation of the reference lidar systems was supported through the EARLINET-ASOS project the other systems were partially supported by the ESA-CEOS project.

The ESA-CEOS project supported also the use of other ancillary measurements: radiosonde launches performed systematically during the whole field campaign period, for each measurement session. These ancillary observations were important to obtain the molecular backscatter used in the comparison.



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The reference lidar systems measured at the three "standard" backscatter and two Raman wavelengths. These reference systems will be used for direct intercomparison with the remaining EARLINET systems.

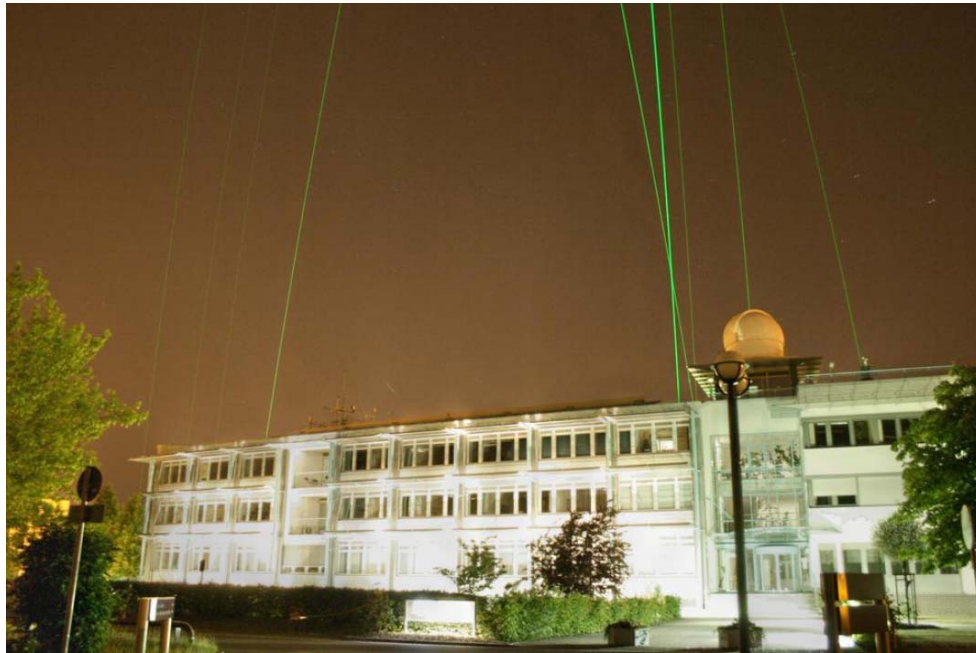
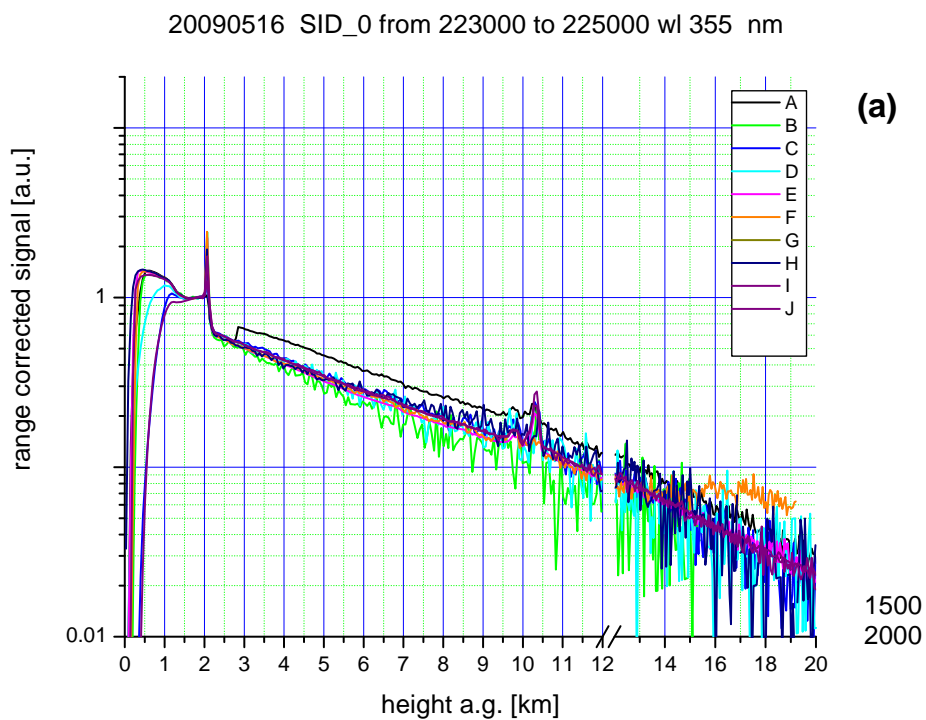


Figure 3-21. An evocative picture of the laser beams at 532nm emitted by the lidar systems during the EARLI09 intercomparison measurement campaign in Leipzig at IfT.



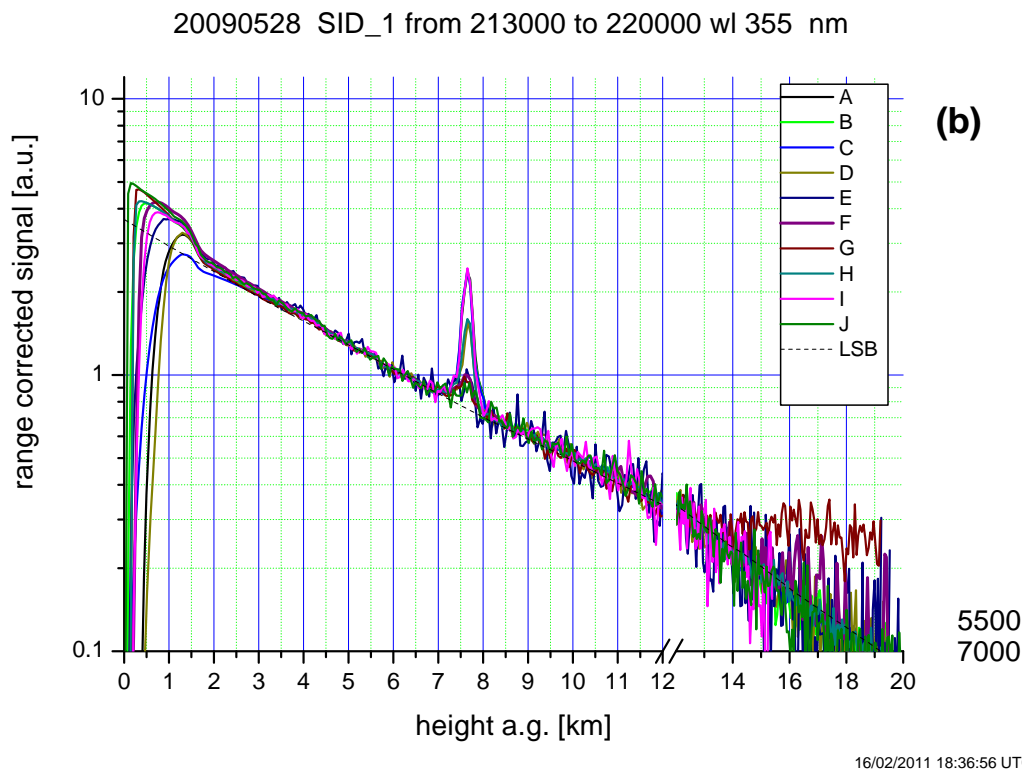


Figure 3-22. An example of comparison of range corrected lidar signals at 355nm during the EARLI09 intercomparison measurement campaign.

The first week of the campaign was addressed to the instrument setup and to the verification that the data were correctly submitted to be automatically pre-processed by means of the Single Calculus Chain, the calculus tool developed in the frame of the EARLINET-ASOS project with the goal to process EARLINET lidar data in automatic and standardized way.

During the following three weeks, measurement sessions were regularly scheduled during nighttime and daytime sessions on the base of the weather forecasts performed by the meteorologists at IFT supported by the ESA-CEOS project. Measurement sessions lasted at least three hours, in order to select the best time intervals were to compare the measurements taking into account the particular vertical atmospheric structures (e.g. clouds, aerosol layers). During a daily meeting, the measurements were discussed and decisions about the corrections on the systems were individuated.

The comparison was performed among the range corrected signals of the lidar signals measured by the participating groups after they were pre-processed in the same way by the Single Calculus Chain, on the base of the information relative to the measurement configuration provided by the single group or contained in the relational database of the Single Calculus Chain.

In Figure 3-22, an example of comparison among lidar range corrected signals at 355 nm is showed. In particular, Figure 3-22(a) reports an example of comparison among lidar range corrected signals where it is evident some disagreement for some of the systems. The reasons for this not satisfactory comparison were understood and the problems in these lidar systems were solved as showed in Figure 3-22(b).



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ALI09

The intercomparison measurement campaign ALI09 (Alomar Lidar Intercomparison campaign) was carried out at Alomar, Norway, from 21 October to 5 November 2009 in order to check the performances of the Alomar lidar system with the mobile reference lidar system from Hamburg. This intercomparison campaign was completely supported by the EARLINET-ASOS project.

SOLI10

The intercomparison measurement campaign SOLI10 (Sofia Lidar Intercomparison) was carried out from 9 to 14 October 2010 at the EARLINET station in Sofia (Bulgaria), Institute of Electronics, BAS. The intercomparison has been performed using the reference lidar system POLIS from the Meteorologisches Institut der LMU, München, Germany. Figure 3-23 shows an example of the comparison between the range corrected lidar signals measured with POLIS and the Sofia systems at 532 nm. This campaign was completely supported by the EARLINET-ASOS project.

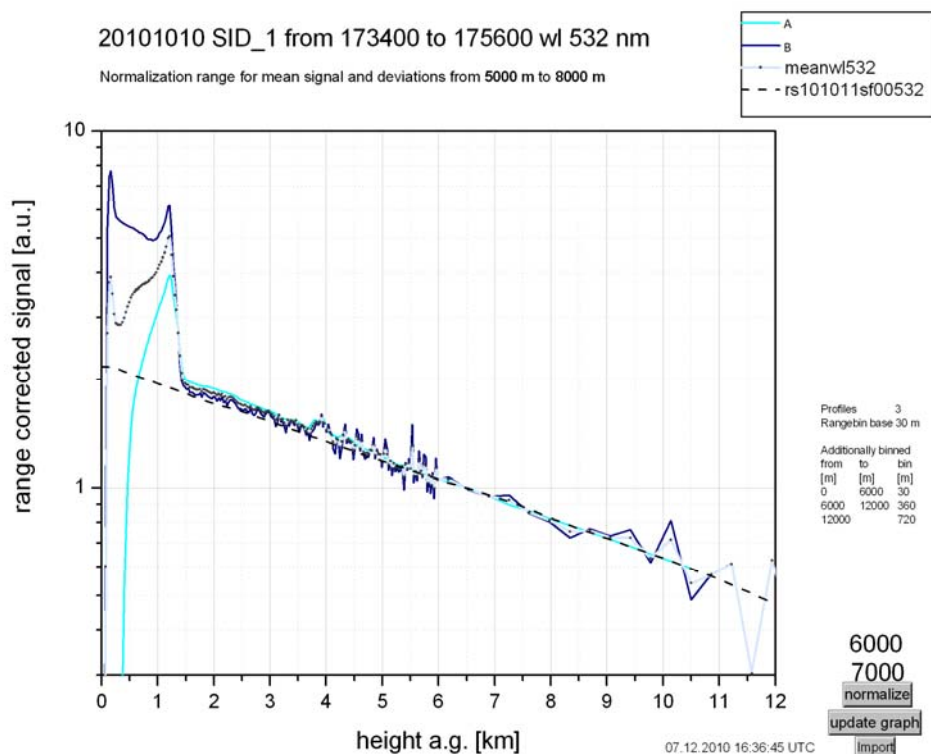


Figure 3-23. An example of comparison of range corrected lidar signals at 532nm during the SOLI10 intercomparison measurement campaign.

ROLI10

The fourth intercomparison measurement campaign (ROLI10, Romanian Lidar Intercomparison) was carried out from 17 to 23 October 2010 for the Multiwavelength Raman Lidar RALI operative at the EARLINET station of the National Institute of Research and Development of Optoelectronics, INOE 2000, Bucharest, Romania. The intercomparison measurement campaign was carried out at Babes Bolyai University, Cluj Napoca, Romania, using the reference lidar system POLIS from the Meteorologisches Institut der LMU, München, Germany. Further three lidar systems, not EARLINET stations operating in Romania took the opportunity of the intercomparison measurement campaign to join in the measurements in order to check the



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performances of their systems in view of future possible cooperation in the frame of a Romanian network or also in the frame of EARLINET. Moreover, also the new UV Raman-Depolarisation Lidar RM108 from the EARLINET station of Ethnikon Metsovion Polytechnion Athinon, Athens, Greece joined the campaign in order to check the performances. In the following table, all the stations participating in the ROLI09 measurement campaign are listed:

| System name | Station | Comment |
|---|--|--------------------------|
| POLIS | LMU, München (Germany) | Reference lidar system |
| RALI (Multiwavelength Raman Lidar) | INOE 2000, Bucharest (Romania) | EARLINET lidar system |
| RM108 | NTUA, Athens (Greece) | EARLINET lidar system |
| MILI (UV π -polarized backscatter lidar) | INOE 2000, Bucharest (Romania) | No EARLINET lidar system |
| TOLI (Multiwavelength Raman Lidar) | Politehnica University of Timisoara (Romania) | No EARLINET lidar system |
| COLI (Elastic backscatter lidar) | Babes Bolyai University of Cluj-Napoca (Romania) | No EARLINET lidar system |

As for the EARLI09 measurement campaign the comparison was performed among the range corrected signals of the lidar signals measured by the participating groups after they were pre-processed in the same way by the Single Calculus Chain. Figure 3-24 shows an example of the comparison between the range corrected lidar signals measured with POLIS and RALI systems at 355 nm.

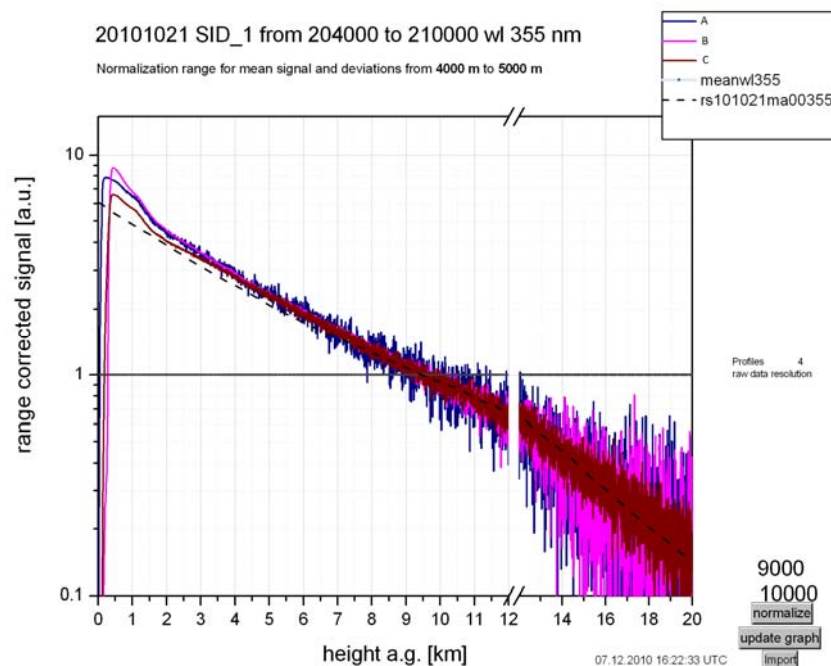


Figure 3-24. An example of comparison of range corrected lidar signals at 355nm during the ROLI10 intercomparison measurement campaign.



SPALI10

SPALI10 (SPANish Lidar Intercomparison) is the measurement campaign, addressed to the instrumental quality check of the lidar system of the EARLINET station of Madrid. The measurement campaign was carried out from 18 October to 5 November 2010 at CIEMAT, Madrid, Spain. The reference lidar system was MUSA from CNR-IMAA, Potenza, Italy. Further three lidar EARLINET stations (Evora, Granada and Barcelona) joined the measurement campaign with their systems, supported by the ESA-CEOS project. In the following table, all the stations participating in the SPALI10 measurement campaign are listed:

| System name | Station | Comment |
|-----------------------|---------------------------------------|------------------------|
| MUSA | CNR-IMAA, Potenza (Italy) | Reference lidar system |
| Lidar-Ciemat | CIEMAT, Madrid, Spain | EARLINET lidar system |
| UPCLidar | UPC, Barcelona, Spain | EARLINET lidar system |
| Raymetrics LR321-D400 | University of Granada, Granada, Spain | EARLINET lidar system |
| PAOLI | Centro de Geofisica, Evora | EARLINET lidar system |

As for the EARLI09 and ROLI10 measurement campaigns, the comparison was performed among the range corrected signals of the lidar signals measured by the participating groups after they were pre-processed in the same way by the Single Calculus Chain. Figure 3-25 shows an example of the comparison between the range corrected lidar signals at 532nm measured with the reference lidar system MUSA and the other systems involved in SPALI10.

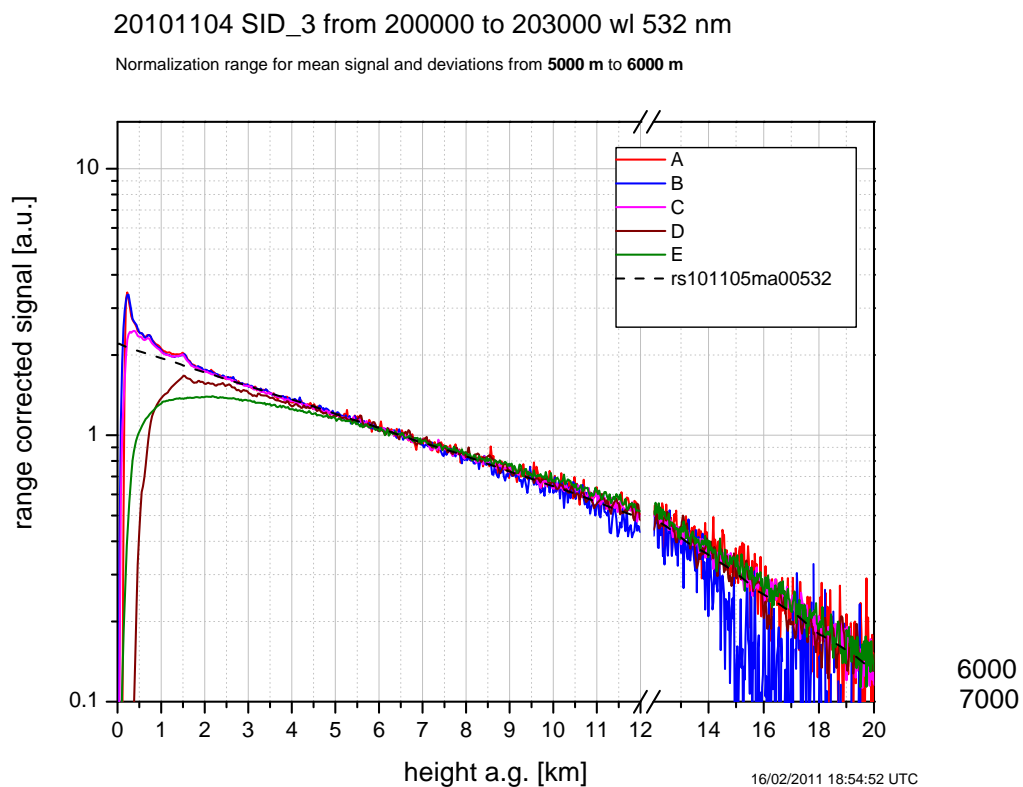


Figure 3-25. An example of comparison of range corrected lidar signals at 532nm during the SPALI10 intercomparison measurement campaign.



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All the measurement campaigns can be considered successfully realized.

In particular, EARLI09 was sufficiently long to allow a good comparison among the reference lidar systems. This campaign was important also because it allowed fixing the standard procedure to carry out the instruments intercomparison.

The following intercomparison measurement campaigns allowed checking the performances of the systems and when they were not fully satisfactory, the reasons of the failure were understood and the way to solve them were defined.



4 Planned activities

This chapter contains a description of the relevant expertise of the institutes in the project team and a more general description of each institute and their (overall) experience.

4.1 Dobson/Brewer team

Following four campaigns are planned to be held in the coming 18 months:

- Nordic campaign in Sodankylä (Finland) with Dobson and Brewers in March 2011
- Intercomparison at INTA (El Arenosillo, Spain) in July 2011
- Intercomparison at LKO (Arosa, Switzerland) in July 2012
- Langley campaign at Izaña in August/September 2012

These campaigns should confirm and deepen the obtained results of the already organized activities.

The investigations of the optical properties (slit functions, straylight effects) will be continued. The most important activity, however, will be the introduction of the new DBM cross-sections, the reprocessing of the data and especially the determination of the effect of the different temperature dependencies on the differences between Dobson and Brewer in the annual course.

4.2 UV-Vis remote-sensing team

In the coming 18 months, activities will concentrate on the further exploitation and publication of CINDI results. E.g. the following studies are currently ongoing:

- The Cabauw Intercomparison campaign for Nitrogen Dioxide Measuring Instruments (CINDI): Design, Execution, and First Results (Piters et al., 2011)
- Intercomparison of MAXDOAS NO₂ profile retrieval algorithms (Wittrock et al.)
- Intercomparison of MAXDOAS aerosol profile retrieval algorithms (Friess et al.)
- Intercomparison of MAXDOAS formaldehyde slant column measurements (Pinaridi et al.)
- Lidar NO₂ profiles during CINDI and comparison with in-situ sensors (Berkhout et al.)
- Comparison of direct-sun and MAXDOAS retrievals of NO₂ tropospheric columns (Spiney et al.)
- Study of the horizontal distribution of tropospheric NO₂ during CINDI (Piters et al.)
- In-situ tropospheric NO₂ profile measurements using a new lightweight sensor (Sluis et al.)

4.3 EARLINET team

Planned activities in the next 18 months:

- Continuous internal quality check
- Intercomparison campaigns: Napoli, Lecce and L'Aquila EARLINET stations
- Data analysis
- Preparation of the final report covering all the intercomparison campaigns



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