Izaña Atmospheric Research Center

Activity Report 2015-2016

Joint publication of State Meteorological Agency (AEMET) and World Meteorological Organization (WMO)

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Weather • Climate • Water

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Foreword

The World Meteorological Organization (WMO) coordinates international research through the Global Atmosphere Watch (GAW) Programme, the World Weather Research Programme (WWRP) and the co-sponsored World Climate Research Programme (WCRP). The GAW Programme was established more than twenty-five years ago in recognition of the need for improved scientific understanding of the increasing influence of human activities on atmospheric composition and subsequent environmental impacts. GAW provides international leadership in research and capacity development in atmospheric composition observations and analysis through maintaining and applying long-term systematic observations of the chemical composition and related physical characteristics of the atmosphere, emphasizing quality assurance and quality control, and delivering integrated products and services related to atmospheric composition of relevance to users.

The Izaña Atmospheric Research Center (IARC) is part of the State Meteorological Agency of Spain (AEMET). The Izaña Atmospheric Observatory, managed by the Izaña Atmospheric Research Center, celebrated its centenary on 1 January 2016. This observatory officially entered the list of WMO Centennial Stations that contribute significantly to the Global Climate Observing System (GCOS), and which are essential for understanding climate variability and change.

The Official Centenary Ceremony of the Izaña Atmospheric Observatory was held in April 2016. It brought together representatives of international meteorological and atmosphere science institutions such as the Director General of the European Centre for Medium-Range Weather Forecasts, the Director General of the European Organisation for the Exploitation of Meteorological Satellites, the Director of the Group of Earth Observations and the Directors of 16 national weather services in Europe, among many others.

The Izaña Atmospheric Research Centre has been contributing uninterruptedly with CO_2, CH_4 and surface O_3 observations since 1984. In 1989, and under the WMO GAW Programme, the observations were expanded significantly with other greenhouse gases, column ozone, solar radiation, in situ and column aerosols and selected reactive gases measurements. The IARC supports the GAW Programme through maintenance of a number of important facilities such as the Regional Brewer Calibration Centre for Europe, the AERONET-EUROPE calibration site, and the European Brewer Network (EUBREWNET) that provide important service to the scientific community.

The Izaña Atmospheric Research Centre plays an important role in support of international cooperation. Through its twinning programmes with the Global GAW stations of Tamanrasset (Algeria) and Ushuaia (Argentina) it supports the global research effort. The Izaña Atmospheric Research Centre also contributes to WWRP as an active member of the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Centre for Europe, Northern Africa and Middle East, focusing efforts on dust observations and atmospheric processes. Complementary to the GAW Aerosols programme, the IARC has recently developed many activities as a WMO Commission for Instruments and Methods of Observations (CIMO) Testbed for Aerosols and Water Vapour Remote Sensing Instruments.

The IARC has also participated in recent international initiatives such as the Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) project coordinated by the Stratosphere-troposphere Processes And their Role in Climate (SPARC) project of WCRP and to the first Tropospheric Ozone Assessment Report.

It is a pleasure for me to present this report summarizing the many activities at the Izaña Atmospheric Research Center to the broader community coinciding with its milestone centenary celebrations in 2016.

Dr Deon Terblanche

Director of the Atmospheric Research and Environment (ARE) Branch, Research Department

World Meteorological Organization

1 Organization

The Izaña Atmospheric Research Center (IARC) is part of the Department of Planning, Strategy and Business Development of the State Meteorological Agency of Spain (AEMET). AEMET is an Agency of the Spanish Ministry of Agriculture and Fisheries, Food and Environment also known as MAPAMA.

2 Mission and Background

The Izaña Atmospheric Research Center conducts observations and research related to atmospheric constituents that are capable of forcing change in the climate of the Earth (greenhouse gases and aerosols), and may cause depletion of the global ozone layer, and play key roles in air quality from local to global scales. The IARC is an Associated Unit of the Spanish National Research Council (CSIC), through the Institute of Environmental Assessment and Water Research (IDAEA). The main goal of the Associated Unit "Group for Atmospheric Pollution Studies" is to perform atmospheric air quality research in both rural and urban environments.

The IARC contributes to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) Programme, which was established in 1989 and has integrated a number of WMO research and monitoring activities in the field of atmospheric environment. The main objective of GAW is to provide data and other information on the chemical composition and related physical characteristics of the atmosphere and their trends, required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere.

The Izaña Atmospheric Research Center also contributes to the Network for the Detection of Atmospheric Composition Change (NDACC). NDACC is an international network for monitoring atmospheric composition using remote measurement techniques. Originally, NDACC was created to monitor the physical and chemical changes in the stratosphere, with special emphasis on the evolution of the ozone layer and the substances responsible for its destruction known as Ozone Depleting Substances. The current objectives of NDACC are to observe and to understand the physicochemical processes of the upper troposphere and stratosphere, and their interactions, and detect long-term trends of atmospheric composition. IARC also makes an important contribution to the WMO through the Global Climate Observing System and through the Commission for Instruments and Methods of Observation (CIMO), as a WMO-CIMO Testbed for Aerosols and Water Vapour Remote Sensing Instruments.

Izaña Atmospheric Observatory was inaugurated in its present location on 1 January 1916, initiating uninterrupted meteorological and climatological observations, which constituted a 100-year record in 2016. In 1984, the observatory became a station of the WMO Background Atmospheric Pollution Monitoring Network (BAPMoN). In 1989, BAPMoN and GO3OS (Global Ozone Observing System) merged in the current Global Atmosphere Watch Programme of which Izaña Atmospheric Observatory is one of the 31 GAW Global stations (Figure 2.1). GAW Global stations serve as centres of excellence, and perform extensive research on atmospheric composition change. Izaña Atmospheric Observatory is a key example of such a research facility.

Figure 2.1. WMO GAW Global stations.

3 Facilities and Summary of Measurements

The Izaña Atmospheric Research Center (IARC) manages four observatories in Tenerife (Fig. 3.1, Table 3.1): 1) Izaña Atmospheric Observatory (IZO); 2) Santa Cruz Observatory (SCO); 3) Botanic Observatory (BTO); and 4) Teide Peak Observatory (TPO).

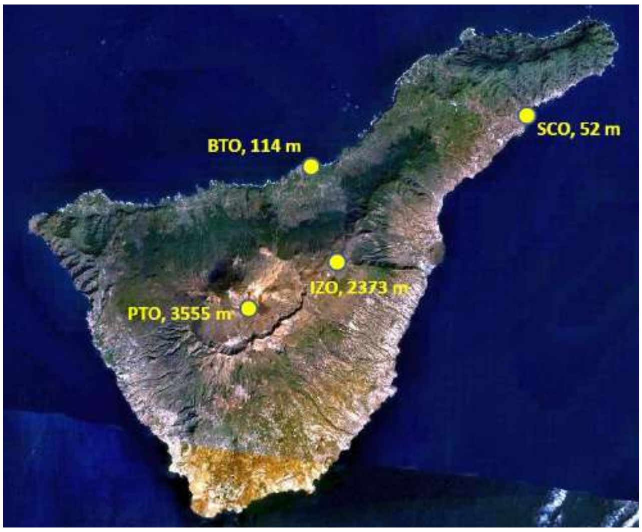

Figure 3.1. Location of IARC observatories on Tenerife.

Table 3.1. IARC observatories.

Observatory	Latitude	Longitude	Altitude (m a.s.l.)
IZO	28.309 ºN	16.499 ºW	2373
SCO	28.473 ºN	16.247 ºW	52
BTO	28.411 ºN	16.535 ºW	114
TPO	28.270 ºN	16.639 ºW	3555

3.1 Izaña Atmospheric Observatory

The Izaña Atmospheric Observatory (IZO) is located on the island of Tenerife, Spain, roughly 300 km west of the African coast. The observatory is situated on a mountain plateau, 15 km north-east of the volcano Teide (3718 m a.s.l.) (Figs 3.2 and 3.3). The local wind regime at the site is dominated by north-westerly winds. Clean air and clear sky conditions generally prevail throughout the year. IZO is normally above a temperature inversion layer, generally well established over the island, and below the descending branch of the Hadley cell.

Figure 3.2. Image of Izaña Atmospheric Observatory.

Consequently, it offers excellent conditions for trace gas and aerosol in situ measurements under "free troposphere" conditions, and for atmospheric observations by remote sensing techniques. The environmental conditions and pristine skies are optimal for calibration and validation activities of both ground based and space borne sensors. Due to its geographic location it is particularly valuable for the investigation of dust transport from Africa to the North Atlantic, long-range transport of pollution from the Americas, and large-scale transport from the tropics to higher latitudes.

The Izaña Atmospheric Observatory facilities consist of three separate buildings: the main building, inaugurated in 1916; the aerosols lab, a small nearby building of the same period which was renamed "Joseph M. Prospero Aerosols Laboratory" on 8 April 2016; and the technical tower, completely rebuilt in early 2000, which hosts most of the instruments. Details of the IZO measurement programme are given in Table 3.2.

The main building is a two-storey building with a total area of 1420 m^2, which hosts the following facilities: office space, dining room, kitchen, library, conference hall with audio-visual system, meeting room, engine rooms, a mechanical workshop, and an electronics workshop. In addition, there is residential accommodation available for visiting scientists (seven double en-suite rooms).

The technical tower is a seven-storey building with a total area of 900 m^2. It includes 20 laboratories distributed among the different floors. All the laboratories are temperature-controlled. Details of the IZO Technical Tower facilities are given in Table 3.3.

Figure 3.3 Izaña Atmospheric Observatory (2373 m) with the volcano Teide (3718 m) to the right of the image.

Table 3.2. Izaña Atmospheric Observatory (IZO) measurement programme.

Parameter	Start date	Present Instrument	Data Frequency
Greenhouse Gases and Carbon Cycle			
CO_2	Jun 1984	NDIR Licor 7000 (Primary instrument) NDIR Licor 6252 (Secondary instrument) CRDS Picarro G2401	30″ 30″ 30″
CH_4	Jul 1984	GC-FID Dani 3800 GC-FID Varian 3800 CRDS Picarro G2401	2 samples/hour 4 samples/hour 30″
N_2O	Jun 2007	GC-ECD Varian 3800	4 samples/hour
SF_6	Jun 2007	GC-ECD Varian 3800	4 samples/hour
CO	Jan 2008	GC-RGD Trace Analytical RGA-3 CRDS Picarro G2401	3 samples/hour 30″
In situ Reactive Gases			
O_3	Jan 1987	UV Photometry Teco 49-C (Primary instrument) Teco 49-C (Secondary instrument) Teco 49-I (New Primary instrument)	 1′ 1′ 1′
CO	Nov 2004	Non-dispersive IR abs. Thermo 48C-TL	1′
SO_2	Jun 2006	UV fluorescence Thermo 43C-TL	1′
$NO-NO_2-NO_x$	Jun 2006	Chemiluminescence Thermo 42C-TL	1′
Total Ozone Column and UV			
Column O_3	May 1991	Brewer Mark-III #157 (Primary Reference) Brewer Mark-III #183 (for developments) Brewer Mark-III #185 (Travelling Reference)	~100/day ~100/day ~100/day
Spectral UV: 290-365 nm	May 1991	Brewer Mark-III #157 (Primary Reference) Brewer Mark-III # 183 (for developments) Brewer Mark-III #185 (Travelling Reference)	~30′ ~30′ ~30′
Spectral UV: 290-450 nm	May 1998	Bentham DM 150	Campaigns
Column SO_2	May 1991	Brewer Mark-III #157 (Primary Reference) Brewer Mark-III # 183 (for developments) Brewer Mark-III #185 (Travelling Reference)	~100/day ~100/day ~100/day
Column SO_2	Oct 2011	Pandora#101	10′
Column HCNO	Oct 2011	Pandora#101	10′
Fourier Transform Infrared Spectroscopy (FTIR)			
Greenhouse gases, reactive gases, and O_3 depleting substances (O_3, HF, HCN, HCl, $ClONO_2$, C_2H_6, HNO_3, CH_4, CO, CO_2, N_2O, NO, NO_2, H_2O, HDO, OCS)	 Jan 1999 May 2007	Fourier Transform Infrared Spectroscopy Bruker IFS 120/5HR (co-managed with KIT) Middle infrared (MIR) solar absorption spectra Near infrared (NIR) solar absorption spectra	3 days/week (weather permitting)
Water vapour isotopologues (δD and $\delta^{18}O$)	Mar 2012	Picarro L2120-I δD and $\delta^{18}O$ Analyser	2″

Parameter	Start date	Present Instrument	Data Frequency
In situ aerosols			
Chemical composition of total particulate matter (PM_T)	Jul 1987	High-volume sampler custom built/MVC™/MCZ™ Concentrations of soluble species by ion chromatography (Cl-, NO3- and SO4=) and FIA colorimetry (NH4+), major elements (Al, Ca, K, Na, Mg and Fe) and trace elements by ICP-AES and ICP-MS were determined at CSIC	8h sampling at night
$PM_{2.5}$ Chemical composition	Apr 2002	High-volume sampler custom built/MVC™/MCZ™	8h sampling at night
PM_{10} Chemical composition	Jan 2005	High-volume sampler custom built/MVC™/MCZ™	8h sampling at night
Number of particles > 3 nm	Nov 2006	TSI™, UCPC 3025A	1′
Number of particles > 2.5 nm	Dec 2012	TSI™, UCPC 3776	1′
Number of particles > 10 nm	Dec 2012	TSI™, UCPC 3772	1′
Size distribution of 10-400 nm	Nov 2006	TSI™, class 3080 + CPC 3010	5′
Size distribution of 0.7-20 µm	Nov 2006	TSI™, APS 3321	10′
Absorption coeff. 1λ	Nov 2006	Thermo™, MAAP 5012	1′
Attenuation 7λ	Jul 2012	Magee™, Aethalometer AE31-HS	1′
Scattering coeff. 3λ	Jun 2008	TSI™, Integration Nephelometer 3563	1′
PM_{10} concentration	Dec 2015	Thermo, 5014i	5′
$PM_{2.5}$ and $PM_{2.5-10}$ concentrations	Dec 2015	Thermo, 5014i	6′
Column aerosols			
AOD and Angstrom at 415, 499, 614, 670, 868, and 936 nm	Feb 1996	YES Multi Filter-7 Rotating Shadow-Band Radiometer (MFRSR)	1′
AOD and Angstrom at 340, 380, 440, 500, 675, 870, 936, 1020 nm	Mar 2003	CIMEL CE318 sun photometer	~ 15′
Fine/Coarse AOD Fine mode fraction	Mar 2003	CIMEL CE318 sun photometer	~ 15′
Optical properties	Mar 2003	CIMEL CE318 sun photometer	~ 1h
AOD and Angstrom during night period	July 2012	CIMEL CE318-T sun-sky-lunar photometer	~ 15′ during moon phases
AOD and Angstrom at 368, 412, 500 and 862 nm	July 2001	WRC Precision Filter Radiometer (PFR)	1′
AOD at 769.9 nm	July 1976	MARK-I (at the IAC)	AOD at 769.9 nm
Radiation			
Global Rad. 285-2600nm	Jan 1977	2 CM-21 & CM-11 Kipp & Zonen Pyranom. (in parallel) and EKO MS-801	1′
Global Rad. 300-1100 nm	Feb 1996	YES MFRSR	1′
Estim. Direct Rad.	Feb 1996	YES MFRSR	1′
Direct Rad. 200-4000nm	Aug 2005	2 CH-1 Kipp & Zonen and EKO MS-56 Pyrheliometers	1′

Parameter	Start date	Present Instrument	Data Frequency
Radiation			
Direct Rad. 200-4000nm	Jun 2014	Absolute Cavity Pyrheliometer PMO6	Calibration campaigns (1′)
Spectral direct Radiation	Dec 2016	Spectrorradiometer EKO MS-711	5’
Diffuse Rad.	Feb 1996	YES MFRSR	1′
Diffuse Rad. 285-2600nm	Aug 2005	2 CM-21 Kipp & Zonen Pyranometer (in parallel) and and EKO MS-801	1′
Downward Longwave Rad. 4.5-42µm	Mar 2009	2 CG-4 Kipp & Zonen Pyrgeometer (in parallel)	1′
UVB Radiation 315-400nm	Aug 2005	2 Yankee YES UVB-1 Pyranometer (in parallel)	1′
UVA Radiation 280-400nm	Mar 2009	Radiometers UVS-A-T	1′
PAR 400-700nm	Aug 2005	Pyranometer K&Z PQS1	1′
Net Radiation	Nov 2016	Net Radiometer EKO MR-60	1′
DOAS (managed by the Spanish National Institute for Aerospace Technology, INTA)			
Column NO_2	May 1993	UV-VIS DOAS EVA and MAXDOAS RASAS II (INTA’s homemade; www.inta.es)	Every ~3′ during twilight
Column O_3	Jan 2000	UV-VIS MAXDOAS RASAS II (INTA’s homemade)	Every ~3′ during twilight
Column BrO	Jan 2002	UV-VIS MAXDOAS ARTIST-II (INTA’s homemade)	Every ~3′ during twilight
Tropospheric O_3	May 2010	UV-VIS MAXDOAS RASAS II (INTA’s homemade)	Every ~3′ during twilight
Tropospheric NO_2	May 2010	UV-VIS MAXDOAS RASAS II (INTA’s homemade)	Every ~3′ during twilight
Tropospheric IO	May 2010	UV-VIS MAXDOAS RASAS II (INTA’s homemade)	Every ~3′ during twilight
Column HCHO	Jan 2015	UV-VIS MAXDOAS ARTIST II (INTA’s homemade)	Every ~3′ during twilight
Column Water Vapour			
Precipitable Water Vapour (PWV)	Feb 1996	YES MFRSR-7 Radiometer (941 nm)	1′
PWV	Jul 2008	GPS-GLONASS LEICA receiver	15′ (ultra-rapid orbits) and 1h (precise orbits)
Vertical relative humidity	Dec 1963	Vaisala RS-92	Daily at 00 and 12 UTC
PWV	Mar 2003	CIMEL CE318 sun photometer	~ 15′
PWV	Jan 1999	Fourier Transform Infrared Spectroscopy	3 days/week when cloud-free conditions

Parameter	Start date	Present Instrument	Data Frequency
Meteorology			
Temperature	Jan 1916	THIES CLIMA 1.1005.54.700 3 VAISALA HMP45C (in parallel) VAISALA PTU300 THIES CLIMA 1.0620.00.000 (thermo-hygrograph) CAMPBELL SCIENTIFIC CS215 (Tower top)	1′ 1′ 1′ Continuous 1′
Relative humidity	Jan 1916	THIES CLIMA 1.1005.54.700 3 VAISALA HMP45C (in parallel) VAISALA PTU300 THIES CLIMA 1.0620.00.000 (thermo-hygrograph) CAMPBELL SCIENTIFIC CS215 (Tower top)	1′ 1′ 1′ Continuous 1′
Wind direction and speed	Jan 1916	DELTA OHM Sonic 3D HD2003 Young Wind Monitor HD Alpine 05108-45 Young Wind Monitor HD Alpine 05108-45 Young Wind Monitor HD Alpine 05108-45 (tower Top)	1′ 1′ 1′ 1′
Pressure	Jan 1916	SETRA 470 VAISALA PTU 300 BELFORT 5/800AM/1 (Barograph) SETRA 470 (tower top)	1′ 1′ Continuous 1′
Rainfall	Jan 1916	THIES CLIMA Tipping Bucket THIES CLIMA Tipping Bucket Hellman rain gauge Hellman pluviograph	1′ 1′ Daily Continuous
Sunshine duration	Aug 1916	KIPP & ZONEN CSD3 Campbell Stokes Sunshine recorder	10′ Continuous
Present weather and visibility	Jul 1941	THIES CLIMA drisdrometer BIRAL 10HVJS	10′ 10′
Vertical profiles of T, RH, P, wind direction and speed, from sea level to ~30 km altitude	Dec 1963	RS92+GPS radiosondes launched at Güimar automatic radiosonde station (WMO GUAN station #60018) (managed by the Meteorological Centre of Santa Cruz de Tenerife)	Daily at 00 and 12 UTC
Soil surface temperature	Jan 1953	2 THIES CLIMA Pt100 (in parallel)	10′
Soil temperature (20 cm)	Jan 2003	2 THIES CLIMA Pt100 (in parallel)	10′
Soil temperature (40 cm)	Jan 2003	2 THIES CLIMA Pt100 (in parallel)	10′
Atmospheric electric field	Apr 2004	Electric Field Mill PREVISTORM-INGESCO	10″
Lightning discharges	Apr 2004	Boltek LD-350 Lightning Detector	1′
Cloud cover	Sep 2008	Sieltec Canarias S.L. SONA total sky camera	5′
Fog-rainfall	Nov 2009	THIES CLIMA Tipping Bucket with 20 cm^2 mesh Hellman rain gauge with 20 cm^2 mesh	1′ Daily

Parameter	Start date	Present Instrument	Data Frequency
Sea-cloud cover	Nov 2010	AXIS Camera: West View (Orotava Valley) AXIS Camera: South View (Meteo Garden) AXIS Camera: North View AXIS Camera: East View (Güimar Valley)	5′ 5′ 5′ 5′
Drop size distribution and velocity of falling hydrometeors	May 2011	OTT Messtechnik OTT Parsivel	1′
Aerobiology			
Pollens and spores	Jun 2006	Hirst, 7-day recorder VPPS 2000 spore trap (Lanzoni S.r.l.). Analysis performed with a Light microscope, 600 X at the Laboratori d'Anàlisis Palinològiques, Universitat Autònoma de Barcelona	Continuous (1 h resolution) from April to October
Phenology			
Emergence of the inflorescence, the appearance of flower buds, flowering, and fruit development according to the BBCH code of 7 taxa	Jan 2014	Visual inspection/counting	Weekly during growing season, and monthly the rest of the year

Figure 3.4. Images of IZO Instrument terrace.

Table 3.3. Izaña Atmospheric Observatory Technical Tower facilities.

Floor	Facilities	Description
Ground Floor	Mechanical Workshop	33 m^2 room with the necessary tools to carry out first-step mechanical repairs.
	Electronics Workshop	25 m^2 room equipped with oscilloscopes, power supplies, multimeters, soldering systems, etc. to carry out first-step electronic repairs.
	Heating system	Central heating and hot water 90 kW system.
	Air Conditioning System	Central air conditioning system for labs.
	Engine Room: Backup Generators	General electrical panel and two automatic start-up backup generators (400 kVA and 100 kVA, respectively).
	UPS room	Observatory's main UPS (40 kVA redundant) used for assuring the power of the equipment inside the building and an additional UPS (10 kVA) for the outside equipment.
	Compressor room	Room with clean oil-free air compressors used for calibration cylinders filling. It also contains the general pumps for the East and West sample inlets.
	Warehouse / Central Gas Supply System	30 m^2 warehouse authorized for pressure cylinders. Central system for high purity gas (H_2, N_2, Ar/CH_4) and synthetic air supply.
	Lift	6-floors. No lift access to roof terrace.
First Floor	Archive room	Archive of bands and historical records.
	Technical equipment warehouse	Spare parts for the Observatory's technical equipment.
	Meeting room	8 person meeting room
Second Floor	Optical Calibration Facility	30 m^2 dark room hosting vertical and horizontal absolute irradiance, absolute radiance, angular response, and spectral response calibration set ups.
	T2.1 Laboratory	10 m^2 lab with access to West sample inlet.
	T2.2 Laboratory	9 m^2 lab with access to East sample inlet.
	T2.3 Laboratory	13 m^2 lab hosting Picarro L2120-I δD and δ18O analyser with access to East sample inlet
Third Floor	Greenhouse Gases Laboratories	70 m^2 shared in two labs hosting CO_2, CH_4, N_2O, SF_6 and CO analysers with access to the East and West sample inlets.
Fourth Floor	All purpose laboratories	Three labs with access to the East and West sample inlets.
Fifth Floor	Reactive Gases Laboratory	10 m^2 lab hosting NO-NO_2, CO, and SO_2 analysers with access to West sample inlet.
	Communications room	Server room and WIFI connection with Santa Cruz de Tenerife headquarters.
	Brewer Laboratory	20 m^2 lab for Brewer campaigns.
Sixth Floor	Surface Ozone Laboratory	10 m^2 laboratory hosting surface O_3 analysers with access to West sample inlet.
	Solar Photometry Laboratory	10 m^2 maintenance workshop for solar photometers.
	Spectroradiometer Laboratory	25 m^2 laboratory hosting two MAXDOAS and two spectroradiometers connected with optical fibre.
Roof	Instrument Terrace	160 m^2 flat horizon-free terrace hosting outdoor instruments, East and West sample-inlets, wind, pressure, temperature and humidity gauges.

On the ground floor of the technical tower, there are two storage spaces, one of them for pressured cylinders (tested and certified at the Canary Islands Regional Council for Industry) and the other one for cylinder filling using oil-free air compressors. This floor also includes the central system for supplying high purity gases (H_2, N_2, Ar/CH_4) and synthetic air to the different laboratories. On the second floor, there is a dark-room with the necessary calibration set-ups for the IZO radiation instruments. On the top of the technical tower there is a 160 m^2 flat horizon-free terrace for the installation of outdoor scientific instruments that need sun or moon radiation (Fig. 3.4). It also has the East and West sample-inlets which supply the ambient air needed by in situ trace gas analysers set up in different laboratories.

The "Joseph M. Prospero Aerosol Research Laboratory" is a 40 m^2 building used as an on-site aerosol measurement laboratory. It has four sample-inlets connected to aerosol analysers. For more details, see Section 8. Outside Izaña Atmospheric Observatory there are the following facilities: 1) a 160 m^2 flat horizon-free platform with communications and UPS used for measurement field campaigns; 2) the meteorological garden, containing two fully-automatic meteorological stations (one of them the SYNOP station and the second one for meteorological research), manual meteorological gauges, a total sky camera, a GPS/GLONAS receiver, a lightning detector, and an electric field mill sensor; and 3) the Sky watch cabin hosting four cameras for cloud observations with corresponding servers.

The following sections give further details of some of the facilities located at IZO.

3.1.1 Optical Calibration Facility

The optical calibration facility at IZO has been developed within the framework of the Specific Agreement of Collaboration between the University of Valladolid and the IARC-AEMET: "To establish methodologies and quality assurance systems for programs of photometry, radiometry, atmospheric ozone and aerosols within the atmospheric monitoring programme of the World Meteorological Organization". The main objective of the optical calibration facility is to perform Quality Assurance & Quality Control (QA/QC) assessment of the solar radiation instruments involved in the ozone, aerosols, radiation, and water vapour programs of the IARC. The seven set-ups available are the following:

1) Set-up for the absolute irradiance calibration by calibrated standard lamps in a horizontally oriented position suitable for small radiometers (Fig. 3.5A). The basis of the absolute irradiance scale consists of a set of FEL-type 1000 W lamps traceable to the primary irradiance standard of the Physikalisch-Technische Bundesanstalt (PTB).

2) Set-up for the absolute irradiance calibration by calibrated standard lamps in a vertical oriented position suitable for relatively large spectrophotometers (Fig. 3.5B). The basis of the absolute irradiance scale consists of a set of DXW-type 1000 W lamps traceable to the primary irradiance standard of the PTB.

3) Set-up for the absolute radiance calibration by calibrated integrating sphere (Fig. 3.4C). The system is traceable to the AERONET standard at Goddard Space Flight Center (Washington, USA). This set-up is mainly used by Cimel sun-photometers, but other instruments are also calibrated.

4) Set-up for the angular response calibration (Fig. 3.5D). It is used to quantify the deviations of the radiometer's angular response from an ideal cosine response. The relative angular response function is measured rotating the mechanical arm where the seasoned DXW-type 1000 W lamp is located. The rotation over ±90º is controlled by a stepper motor with a precision of 0.01º while the instrument is illuminated by the uniform and parallel light beam of the lamp.

5) Set-up for the spectral response calibration. It is used to quantify the spectral response of the radiometer. The light is scattered by an Optronic double monochromator OL 750 within the range 200 to 1100 nm with a precision of 0.1 nm. An OL 740-20 light source positioned in front of the entrance slit acts as radiation source and two lamps, UV (200-400nm) and Tungsten (250-2500nm) are available.

Figure 3.5. Images of the IZO Optical calibration facility. A) Horizontal absolute irradiance calibration set up, B) Three stages of a Brewer irradiance calibration with the vertical set up, C) Absolute radiance calibration of a Cimel CE318, D) Angular response function determination of a Brewer (Photo: Alberto Redondas), E) Set up for Slit function determination and F) Alignment of a Brewer spectrophotometer optics (Photo: Alberto Redondas).

6) Set-up for the slit function determination (Fig. 3.5E). The characterization of the slit function is performed illuminating the entrance slit of the spectrophotometer with the monochromatic light of a VM-TIM He-Cd laser. The nominal wavelength of the laser is 325 nm, its power is 6mW, and its beam diameter is 1.8 mm.

7) Set-up for the alignment of the Brewer spectrophotometer optics (Fig. 3.5F). It is suitable to perform adjustments of the optics without sending the instrument to the manufacturer.

3.1.2 In situ system used to produce working standards containing natural air

GAW requires very high accuracy in the atmospheric greenhouse gas mole fraction measurements, and a direct link to the WMO primary standards maintained by the GAW GHG CCLs (Central Calibration Laboratories), most of which are located at NOAA-ESRL-GMD. To accomplish these requirements, IARC uses Laboratory Standards prepared (using natural air) and calibrated by NOAA-ESRL-GMD. Indeed, the Laboratory Standards used at IARC are WMO tertiary standards.

However, due to the fact that the consumption of standard and reference gases by the IARC GHG measurement systems is relatively high, an additional level of standard gases (working standards) prepared with natural air is used. These working standards are prepared at IZO using an in situ system (Fig. 3.6) and then calibrated against the Laboratory Standards using the IARC GHG measurement systems. The system used to fill the high pressure cylinders (up to 120-130 bars) with dried natural air, takes clean ambient air from an inlet located on top of the IZO tower (30 m above ground), and pumps (using an oil-free compressor) it inside the cylinders after drying it (using magnesium perchlorate), achieving a H_2O mole fraction lower than 3 ppm.

Additionally, it is possible to modify slightly the CO_2 mole fraction of the natural air pumped inside the cylinders. To this end, air from a cylinder containing natural air with zero CO_2 mole fraction (prepared using the same system but adding a CO_2 absorber trap) or a tiny amount of gas from a spiking CO_2 cylinder (5% of CO_2 in $N_2/O_2/Ar$) is added to the cylinder being filled, not affecting the CRDS technique. This system is similar to that used by NOAA-ESRL-GMD to prepare WMO secondary and tertiary standards, and it is managed and operated at IZO through a subcontractor (Air Liquide Canarias). The prepared working standards are mainly used in the GHG measurement programme, but some of them are used for other purposes, natural air for a H_2O isotopologue Cavity Ring-Down Spectroscopy (CRDS) analyser located at Teide peak and for a CO NDIR analyser located at SCO.

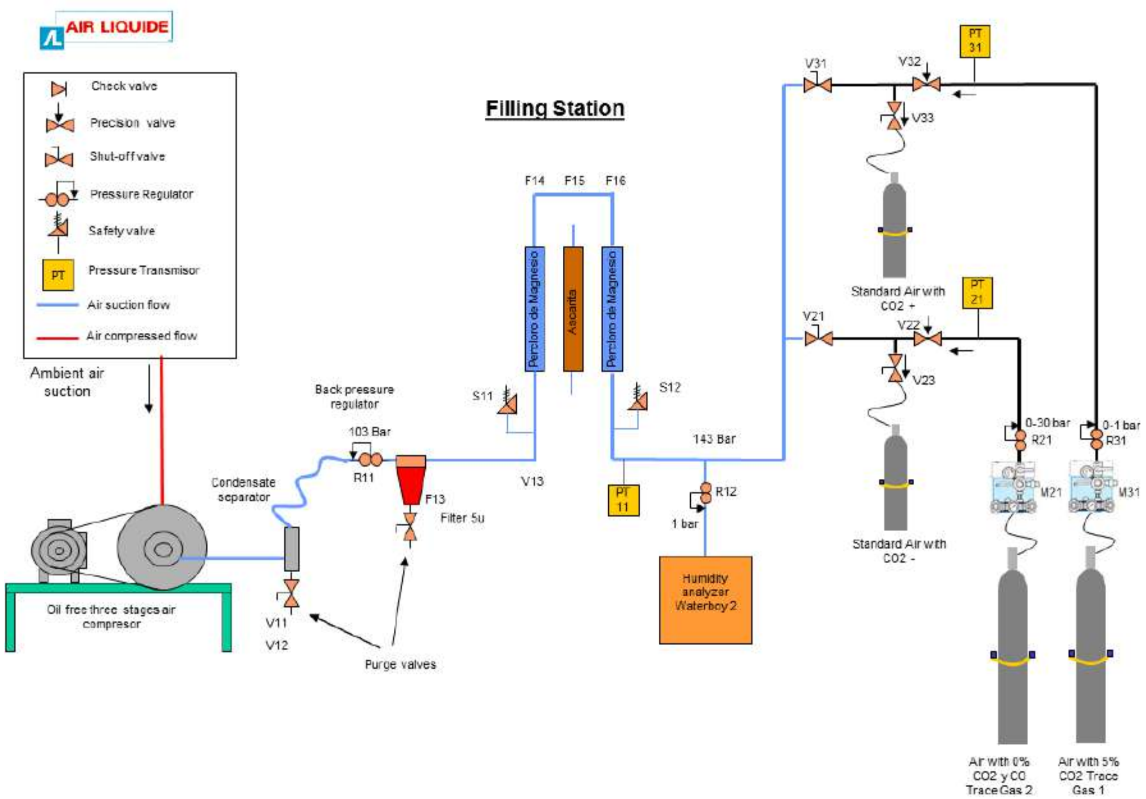

Figure 3.6. In situ system used to produce working standards containing natural air at Izaña Atmospheric Observatory.

3.1.3 Central Gas Supply System

There is a gas central facility located on the IZO tower ground floor for supplying chromatographic gases to the different instruments. This central facility supplies high purity: N_2 (used as carrier gas for the GC-FIDs, and for the IZO H_2O isotopologue CRDS analyser), synthetic air (used as oxidizer in the FIDs, as carrier gas in the GC-RGD, as carrier gas in the IZO H_2O isotopologue CRDS analyser, and as diluting air used in the calibrations of the reactive gas instruments), 95% Ar / 5% CH_4 (used as carrier gas for the GD-ECD), and H_2 (used as combustible in the FIDs). This facility and the chromatographic gases are managed and provided, respectively, by a subcontractor (Air Liquide Canarias). The H_2O isotopologue CRDS analyser located at Teide peak has its own dedicated high purity N_2 supply. The reactive gas analysers located at SCO have their own dedicated high purity synthetic air supply (used as diluting air in the calibrations).

Additionally, other gases (provided by the same subcontractor) are used at IZO: high purity CO_2 for the calibration of an aerosol nephelometer, high purity N_2O for FTIR instrumental line shape monitoring, liquid N_2 to cryocool the FTIR detectors, and calibrated concentrated gas standards in N_2 (19.4 ppm NO and 19.4 ppm NO_x, 1.01 ppm CO, 1.04 ppm CO, 99.9 ppm CO, 102 ppm SO_2, and 1 ppm SO_2) for the calibration of the instruments of the reactive gases programme.

3.1.4 Transportation

Two electric golf carts abandoned in the scrap were refurbished and tuned by maintenance personnel in order to provide local internal service for transportation of personnel and equipment between the different facilities of IZO.

Figure 3.7. "Babieca" (left) and "Pegaso" (right) golf carts used for internal transport of tools and equipment within the IZO facilities.

Following the initiative in IZO to gradually introduce means of transport that do not damage the environment, in 2015 the combustion engine vehicle (IVECO 4x4) was replaced by a 100% electric Nisan NV-200 EVALIA. This vehicle serves for transportation between the different IARC facilities (IZO, SCO and BTO).

Figure 3.8. New 100% electric car in front of the IZO main entrance.

On some occasions during the winter period the snowfall is so copious that it is not possible to access the Observatory even with a four-wheel drive vehicle. In these occasions we have counted on the generous collaboration of our neighbors of the detachment of Army engineers (Ministry of Defense) who have shared the use of their Transport Mountain Caterpillar. Thanks to this vehicle, we have been able to provide supplies of equipment and food, and also make changes of service personnel.

Figure 3.9. The Transport Mountain Caterpillar belonging to Army Engineers detachment, helping us to make a change in service personnel.

3.1.5 Modifications and improvements to the IZO facilities carried out in 2015-2016

The local network of lightning rods was reinforced with the renovation of three new active sensors. The Joseph M. Prospero Aerosol Research Laboratory was completely refurbished in 2016, both façades and the external perimeter area in which ventilation holes with air extractors were made to prevent moisture on the walls. A new and robust stair access to the lab terrace was installed, with enough width to be able to carry equipment between two people. The old power transformation center was cleaned and renovated. This small building houses from time to time a gravimeter from the Spanish National Geographic Institute (IGN) and in the near future will be the place where the Cimel Lidar is installed.

3.2 Santa Cruz Observatory

The Santa Cruz de Tenerife Observatory (SCO) is located on the roof of the IARC headquarters at 52 m a.s.l. in the capital of the island (Santa Cruz de Tenerife), close by the city harbour (Figs. 3.10 and 3.11). Details of the SCO measurement programme are given in Table 3.4.

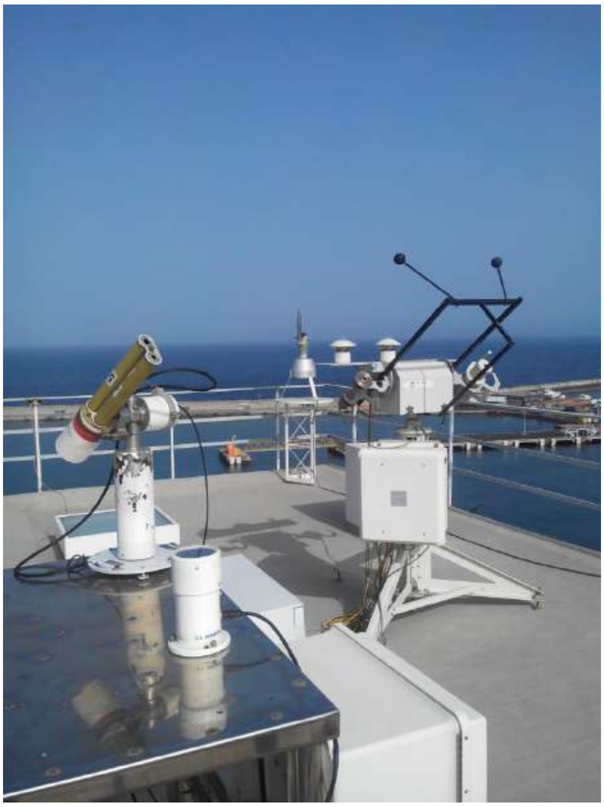

Figure 3.10. Image of Santa Cruz Observatory instument terrace: ZEN-41-R radiometer (in the foreground), Cimel AERONET photometer, radiation instruments mounted on the sun-tracker and the HIRST pollen sampler (in the background).

This observatory has two main objectives: 1) to provide information of background urban pollution for atmospheric research and interactions with long-range pollution transport driven by trade winds or Saharan dust outbreaks and 2) to perform complementary measurement programmes to those performed at IZO. The IARC headquarters include the following facilities:

- A laboratory for reactive gases (surface O_3, NO-NO_2, CO and SO_2).
- A laboratory for micro pulse Lidar (MPL) and ceilometer VL-51.
- A laboratory to dry and weigh filters of high and low volume aerosol samplers.
- A laboratory for the preparation of ozonesondes
- A 25 m^2 flat horizon-free terrace for radiation instruments and air intakes.

Figure 3.11. Air quality analyzers in the SCO Lab (left), and Ramón Ramos and Pedro Miguel Romero (right) with the Vaisala CL51 ceilometer on the SCO terrace.

3.2.1 Aerosol Filters Laboratory

The Aerosol Filters Laboratory is equipped with an auto-calibration microbalance (Mettler Toledo XS105DU) with a resolution of 0.01 mg, a set of standard weights, and an oven that reaches 300 ºC. Filters are weighed after temperature and humidity conditioning following the requirements of the EN-14907 standards. This filter weighing procedure is used for determining the concentrations of TSP, PM_{10}, $PM_{2.5}$ and PM_1 by means of standardized methods. Filters are conditioned to 20 ºC and a fixed relative humidity (50% RH for air quality studies and 30% RH for research studies) within a methacrylate chamber, which also contains the balance used for weighing the filters (Fig. 3.12).

Figure 3.12. Aerosol Filters laboratory: temperature and relative humidity controlled chamber.

Table 3.4. Santa Cruz Observatory (SCO) measurement programme.

Parameter	Start date	Present Instrument	Data Frequency
		In situ Reactive Gases	
O_3	Nov 2004	UV Photometry Teco 49-C	1′
CO	Mar 2006	Non-dispersive IR abs. Thermo 48C-TL	1′
SO_2	Mar 2006	UV fluorescence Thermo 43C-TL	1′
NO-NO_2-NO_x	Mar 2006	Chemiluminescence Thermo 42C-TL	1′
Ozone and UV (managed by the AEMET's Special Networks Service at the nearby Met Center)			
Column O_3	Oct 2000	Brewer Mark-II#033	> ~20/day
Spectral UV	Oct 2000	Brewer Mark-II#033	~30′
SO_2	Oct 2000	Brewer Mark-II#033	~30′
		Column aerosols	
AOD and Angstrom at 340, 380, 440, 500, 675, 870, 936, 1020 nm	Jul 2004	CIMEL CE318 sun photometer	~ 15′
Fine/Coarse AOD	Jul 2004	CIMEL CE318 sun photometer	~ 15′
Vertical Backscatter-extinction @523 nm, clouds alt. and thickness	Nov 2005	Micropulse Lidar MPL-3, SES Inc., USA (co-managed with INTA (www.inta.es))	1′
Vertical backscatter-extinction @910 nm, cloud alt. and thickness	Jan 2011	Vaisala CL-51 Ceilometer	1′
Vertical Backscatter-extinction @500 and 800 nm, clouds alt. and thickness (with depolarizarion channels)	Dec 2015	CIMEL CE376 lidar	1’
		Radiation	
Global Radiation	Feb 2006	Pyranometer CM-11 Kipp & Zonen	1′
Direct Radiation	Feb 2006	Pyrheliometer EPPLEY	1′
Diffuse Radiation	Feb 2006	Pyranometer CM-11 Kipp & Zonen	1′
UV-B Radiation	Aug 2011	Yankee YES UVB-1 Pyranom. (managed by the AEMET's Special Networks Service at the nearby Met Centre)	1′
		Column Water Vapour	
Vertical relative humidity	Dec 1963	Vaisala RS-92	Daily at 00 and 12 UTC
Precipitable Water Vapour (PWV)	Mar 2003	CIMEL CE318 sun photometer	~ 15′
PWV	Jan 2009	GPS/GLONASS GRX1200PRO receiver	15′ (ultra-rapid orbits) and 1 h (precise orbits)
PWV (total column) over SCO when cloudless skies Cloud base heights when cloudy skies over SCO	Jun 2014	1 SIELTEC Sky Temperature Sensor (infrared thermometer prototype)	Every 30″ during the complete day

Meteorology*			
Vertical profiles of T, RH, P, wind direction and speed, from sea level to ~30 km altitude	Dec 1963	RS92+GPS radiosondes launched at Güimar automatic radiosonde station (WMO GUAN station #60018) (managed by the Meteorological Centre of Santa Cruz de Tenerife)	Daily at 00 and 12 UTC
Temperature	Jan 2002	VAISALA HMP45C	1′
Relative humidity	Jan 2002	VAISALA HMP45C	1′
Wind Direction and speed	Jan 2002	RM YOUNG wind sentry 03002	1′
Pressure	Jan 2002	VAISALA PTB100A	1′
Rainfall	Jan 2002	THIES CLIMA Tipping Bucket	1′
Aerobiology			
Pollens and spores	Oct 2004	Hirst, 7-day recorder VPPS 2000 spore trap (Lanzoni S.r.l.).	Continuous (1 h resolution)

* Meteorological data from Santa Cruz de Tenerife Meteorological Center headquarters, 1 km distant, are also available since 1922.

3.2.2 The Ozonesonde Laboratory

Advanced preparation of the Science Pump Corporation (SPC) ECC ozone sensor (Model ECC-6A), together with digital Vaisala RS92 radiosonde and digital interface, is performed at the Ozonesonde Lab at SCO. Expendables such as radiosondes, interfaces, ozonesondes, ozone solution chemicals, syringes, needles, protection gloves, and triple distilled water are stored in this lab.

A Science Pump Corporation Model TSC-1 Ozonizer/Test Unit is used for ozonesonde preparation. This unit has been designed for conditioning ECC ozonesondes with ozone, and for checking the performance of the sondes prior to balloon release. The Ozonizer/Test Unit is installed inside a hood in which ambient air is passed through an active charcoal filter to destroy ozone and other pollutants (ozone-free air). The volumetric flow of the gas sampling pump of each ECC sonde is individually measured at the Ozonesonde Lab before flight. The pump flow rate of the sonde is measured with a bubble flow meter at the gas outlet of the sensing cell.

On the day before release, two ECC-6A ozonesondes are checked for proper operation and filled with sensing solution. The day of the ozonesonde launching the sensors are transported to BTO ozonesonde launching station (30 km distance) where pre-launch tests are performed at ground including a final double check of the RS-92, and a comparison of surface ozone from ECC-6A with a TECO-49C ozone analyser.

3.3 Botanic Observatory

The Botanic Observatory (BTO) is located 13 km north-east of IZO at 114 m a.s.l. in the Botanical Garden of Puerto de la Cruz (Fig. 3.13). BTO is hosted by the Canary Institute of Agricultural Research (ICIA). The Botanic Observatory includes the following facilities:

- Ozone Sounding Monitoring Laboratory: equipped with a Digicora MW31 receiver with Vaisala METGRAPH data acquisition and processing software and a surface ozone analyser
- Launch container: equipped with a Helium supply system used for ozonesonde balloons filling.

In addition to the ozonesonde measurements, there is a fully equipped automatic weather station (temperature, relative humidity, pressure, precipitation, wind speed and direction), a global irradiance pyranometer and a surface ozone analyser (also used for additional ECC electrochemical sondes ground checking). For details of the BTO measurement programme, see Table 3.5.

Figure 3.13. Image of Botanic Observatory (BTO).

Table 3.5. Botanic Observatory (BTO) measurement programme.

Parameter	Start date	Present Instrument	Data Frequency
Reactive Gases and ozonesondes			
Vertical profiles of O_3, PTU, and wind direction and speed, from sea level to ~33 km altitude	Nov 1992	ECC-A6+RS92/GPS radiosondes	1/week (Wednesdays)
Surface O_3	May 2011	UV Photometry Teco 49-C	1′
Radiation			
Global Radiation	May 2011	Pyranometer CM-11 Kipp & Zonen	1′
Column Water Vapour			
Precipitable Water Vapour (PWV)	Jan 2009	GPS/GLONASS GRX1200PRO receiver	15’ (ultra-rapid orbits) and 1 h (precise orbits)
Meteorology			
Temperature	Oct 2010	VAISALA F1730001	1′
Relative humidity	Oct 2010	VAISALA F1730001	1′
Wind direction and speed	Oct 2010	VAISALA WMT700	1′
Pressure	Oct 2010	VAISALA PMT16A	1′
Rainfall	Oct 2010	VAISALA F21301	1′

3.4 Teide Peak Observatory

The Teide Peak Observatory (TPO) is located at 3555 m a.s.l. at the Teide Cable Car terminal in the Teide National Park (Fig. 3.14). TPO was established as a satellite station of IZO primarily for radiation and aerosol observations at very high altitude. TPO station, together with Jungfraujoch (3454 m a.s.l.) in Switzerland, are the highest permanent radiation observatories in Europe.

This measurement site provides radiation and aerosol information under extremely pristine conditions and in conjunction with measurements at SCO and IZO allows us to study the variation of global radiation, UV-B and aerosol optical depth from sea level to 3555 m a.s.l. In addition to radiation and aerosol measurements, there is a meteorological station and a water vapour isotopologues analyser. Full details of the measurement programme are given in Table 3.6.

Figure 3.14. Measurements at Teide Peak Observatory.

Table 3.6. Teide Peak Observatory (TPO) measurement programme.

Parameter	Start date	Present Instrument	Data Frequency
Column aerosols			
AOD and Angstrom at 340, 380, 440, 500, 675, 870, 936 and 1020 nm	Jun 1997	CIMEL CE318 sun photometer (Co-managed with the University of Valladolid Atmospheric Optics Group)	~ 15′ (during Apr-Oct)
Fine/Coarse AOD Fine mode fraction	Jun 1997	CIMEL CE318 sun photometer (Co-managed with the University of Valladolid Atmospheric Optics Group)	~ 15′ (during Apr-Oct)
Radiation			
Global Radiation	Jul 2012	Pyranometer CM-11 Kipp & Zonen	1′
UVB Radiation	Jul 2012	Pyranometer Yankee YES UVB-1	1′
Water vapour			
Water vapour isotopologues (δD and δ^{18}O)	June 2013	Picarro L2120-I δD and δ^{18}O analyser	2″
Meteorology			
Wind direction and speed	Oct 2011	THIES CLIMA Sonic 2D	1′
Temperature	Aug 2012	VAISALA HMP45C	1′
Relative humidity	Aug 2012	VAISALA HMP45C	1′
Pressure	Aug 2012	VAISALA PTB100A	1′

3.5 Computing Facilities and Communications

The computing facilities and communications form an integral component of all measurement programmes and activities in the Izaña Atmospheric Research Center. In the IARC headquarters there is a temperature controlled room hosting server computers devoted to different automatic and continuous tasks (NAS, modelling, spectra inversion, etc.) for the research groups. Details of the computing facilities are given in Table 3.7.

Table 3.7. IARC computing facilities.

Computing Hardware				
	Storage	**Virtualization**	**Modelling**	**Total**
H.D.	34 TB	12 TB	10 TB	56 TB
Cores	7	28	68	105
RAM	12 GB	56 GB	46 GB	114 GB

The IARC headquarters has internet access through a double optical fibre connection (20 Mb/s) to AEMET headquarters in Madrid, one of them acting as back-up. IZO is real time connected to IARC headquarters through a wifi-radio link (54 Mb/s) of 34 km. An EUMETCast (EUMETSAT's Broadcast System for Environmental Data) reception station is available at SCO. It consists of a multi-service dissemination sy stem based on standard Digital Video Broadcast (DVB) technology. Most of the satellite information is received via this system (see Section 13 for more details).

An important communication advance in IZO was the establishment of a connection with the new network Iris Nova, which has some of its nodes in the facilities of the Instituto de Astrofísica de Canarias (IAC) Teide Observatory. However, although the Iris Nova network can provide a bandwidth of 1Gb, the current link is limited to 10Mb because there is a fiber optic section that is temporarily supplied by a microwave link of about 1500 m between the residence of the IAC and IZO. The definitive connection with high bandwidth will be completed in the near future.

3.6 Staff

Activities universal to all measurement programmes such as operation and maintenance of IARC facilities, equipment, instrumentation, communications and computing facilities are made by the following staff:

Ramón Ramos (AEMET; Head of Scientific instrumentation and infrastructures)

Enrique Reyes (AEMET; IT development specialist)

Néstor Castro (AEMET; IT specialist)

Antonio Cruz (AEMET; IT specialist)

Rocío López (AEMET; IT specialist)

Sergio Afonso (AEMET; Meteorological Observer-GAW Technician)

Concepción Bayo (AEMET; Meteorological Observer-GAW Technician)

Rubén del Campo Hernández (AEMET; Meteorological Observer-GAW Technician)

Virgilio Carreño (AEMET; Meteorological Observer-GAW Technician)

Cándida Hernández (AEMET; Meteorological Observer-GAW Technician)

Dr Fernando de Ory (AEMET; Meteorological Observer-GAW Technician)

4 Greenhouse Gases and Carbon Cycle

4.1 Main Scientific Goals

The main goal of this IARC programme is to carry out highly accurate atmospheric long-lived greenhouse gas (GHG) in situ continuous measurements at IZO in order to contribute to the GAW-WMO programme, following the GAW recommendations and guidelines. Additional goals are: 1) to study with precision the long-term evolution of the GHGs in the atmosphere, as well as their daily, seasonal and inter-annual variability; 2) to improve and develop the GHG measurement systems as well as the associated raw data processing software; 3) to carry out research to study the processes that control the variability and evolution of the GHGs in the atmosphere (e.g. Gomez-Pelaez et al., 2013; Dalsoren et al., 2016); and 4) to contribute to international research and its documentation via recommendations and guidelines.

4.2 Measurement Programme

Table 4.1 gives details of the atmospheric greenhouse gases measurements currently performed at IZO using in situ analysers (owned by AEMET) and some details about the measurement schemes. Carbon monoxide is not a greenhouse gas but affects the methane cycle. Details of the in situ measurement systems and data processing can be found in Gomez-Pelaez et al. (2006, 2009, 2011, 2012, 2013, 2014 and 2016).

Additional information can be found in the last IZO GHG GAW scientific audit reports: Scheel (2009), Zellweger et al. (2009), and Zellweger et al. (2013).

Additionally, weekly discrete flask samples have been collected for the National Oceanic and Atmospheric Administration-Earth System Research Laboratory-Global Monitoring Division Carbon Cycle Greenhouse Gases Group (NOAA-ESRL-GMD CCGG) Cooperative Air Sampling Network (since 1991). The participation consists of weekly discrete flask sample collection at IZO and subsequent shipping of the samples to NOAA-ESRL-GMD CCGG.

Figure 4.1. IZO Gas Chromatograph measurement system for CH_4, N_2O and SF_6.

Table 4.1. Atmospheric greenhouse gases measured in situ at IZO and measurement schemes used.

Gas	**Start Date**	**Analyser**	**Model**	**Ambient air measurement frequency**	**Reference gas/es and measurement frequency**	**Reference gas/es calibration frequency**
CO_2	1984	NDIR	Licor 7000 Licor 6252	Continuous Continuous	3 RG every hour 3 RG every hour	Biweekly using 4 LS
CH_4	1984	GC-FID	Dani 3800 Varian 3800	2 injections/hour 4 injections/hour	1 RG every 30 min 1 RG every 15 min	Biweekly using 2 LS
N_2O	2007	GC-ECD	Varian 3800	4 injections/hour	1 RG every 15 min	Biweekly using 5 LS
SF_6	2007	GC-ECD	Varian 3800	4 injections/hour	1 RG every 15 min	Biweekly using 5 LS
CO	2008	GC-RGD	Tr.An. RGA-3	3 injections/hour	1 RG every 20 min	Biweekly using 5 LS
CO_2 CH_4 CO	2016	CRDS	Picarro G2401	Continuous	2 RG every 21 hours to study performance	Every 3-4 weeks using LS

Reference gas/es (RG), Laboratory Standard (LS)

The air inside the flasks has been measured for the following gas specie mole fractions: 1) CO_2, CH_4, CO, and H_2 since 1991; N_2O and SF_6 since 1997 (both sets measured by NOAA/ESRL/GMD CCGG); 2) Isotopic ratios Carbon-13/Carbon-12 and Oxygen-18/Oxygen-16 in carbon dioxide since 1991 (measured by the Stable Isotope Lab of INSTAAR); 3) Methyl chloride, benzene, toluene, ethane, ethene, propane, propene, i-butane, n-butane, i-pentane, n-pentane, n-hexane and isoprene since 2006 (measured by INSTAAR). Two-week integrated samples of atmospheric carbon dioxide have also been collected for the Heidelberg University (Institute of Environmental Physics, Carbon Cycle Group) since 1984 to measure the C-14 isotopic ratio in carbon dioxide.

4.3 Summary of remarkable results during the period 2015-2016

This programme has continued performing continuous high-quality greenhouse gas measurements and annually submitting the data to the WMO GAW World Data Centre for Greenhouse Gases (WDCGG), where data are publicly available, and also global data summaries are published (e.g., WDCGG, 2016). The complete time series for CO_2 is shown in Fig. 4.2, while the CH_4, N_2O, SF_6 and CO time series at IZO are shown in Fig. 4.3. All the collected data are used for analysis and investigation of the carbon cycle and understanding of the role of anthropogenic and natural factors that control GHG variability.

IARC has also continued contributing to the data products GLOBALVIEW and OBSPACK led by NOAA-ESRL-GMD CCGG (e.g., Cooperative Global Atmospheric Data Integration Project, 2016), as well as collaborating with the associated CO_2 surface flux inversions CarbonTracker (e.g., CarbonTracker Team, 2016), CarbonTracker Europe and MACC, which follows the procedure described in Chevallier et al. (2010).

The PI of this IARC programme participated in the 18th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques, held in La Jolla, California, USA, September 13-17, 2015, where he gave the presentation Gomez-Pelaez et al. (2016).

IARC-AEMET participated in the "5th WMO/IAEA Round Robin Comparison Experiment" for the parameters CO_2, CH_4, N_2O, SF_6 and CO, and its measurement results showed a good compatibility with the WMO CCL (NOAA-ESRL-GMD CCGG) results and an excellent compatibility for CO_2.

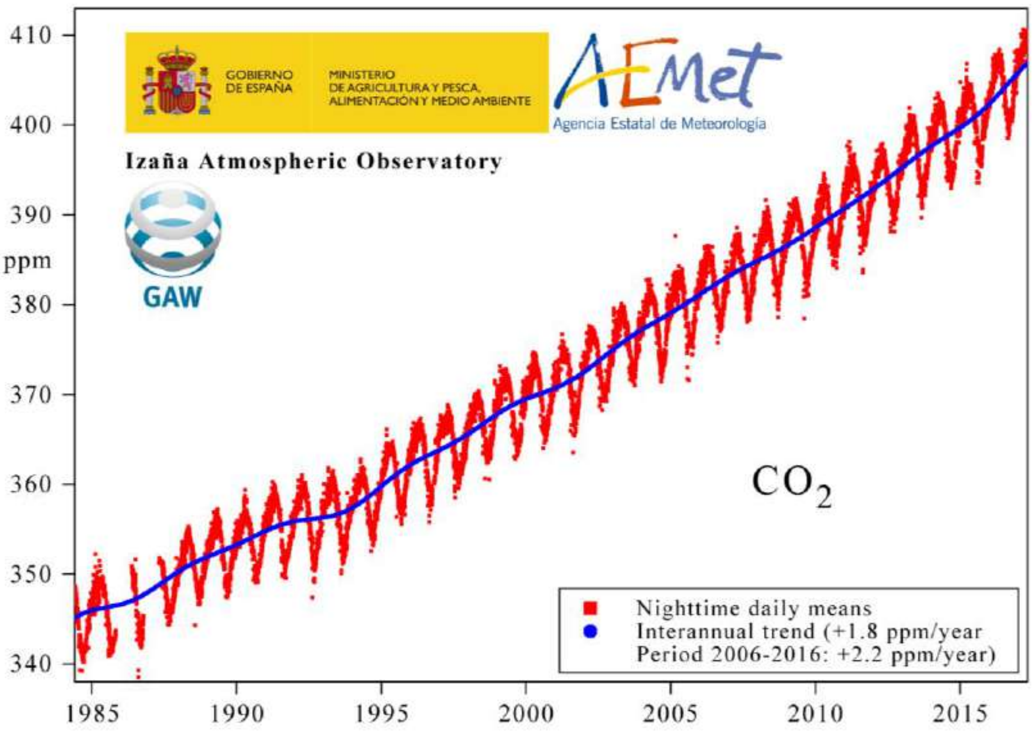

Figure 4.2. Izaña Atmospheric Observatory CO_2 time series.

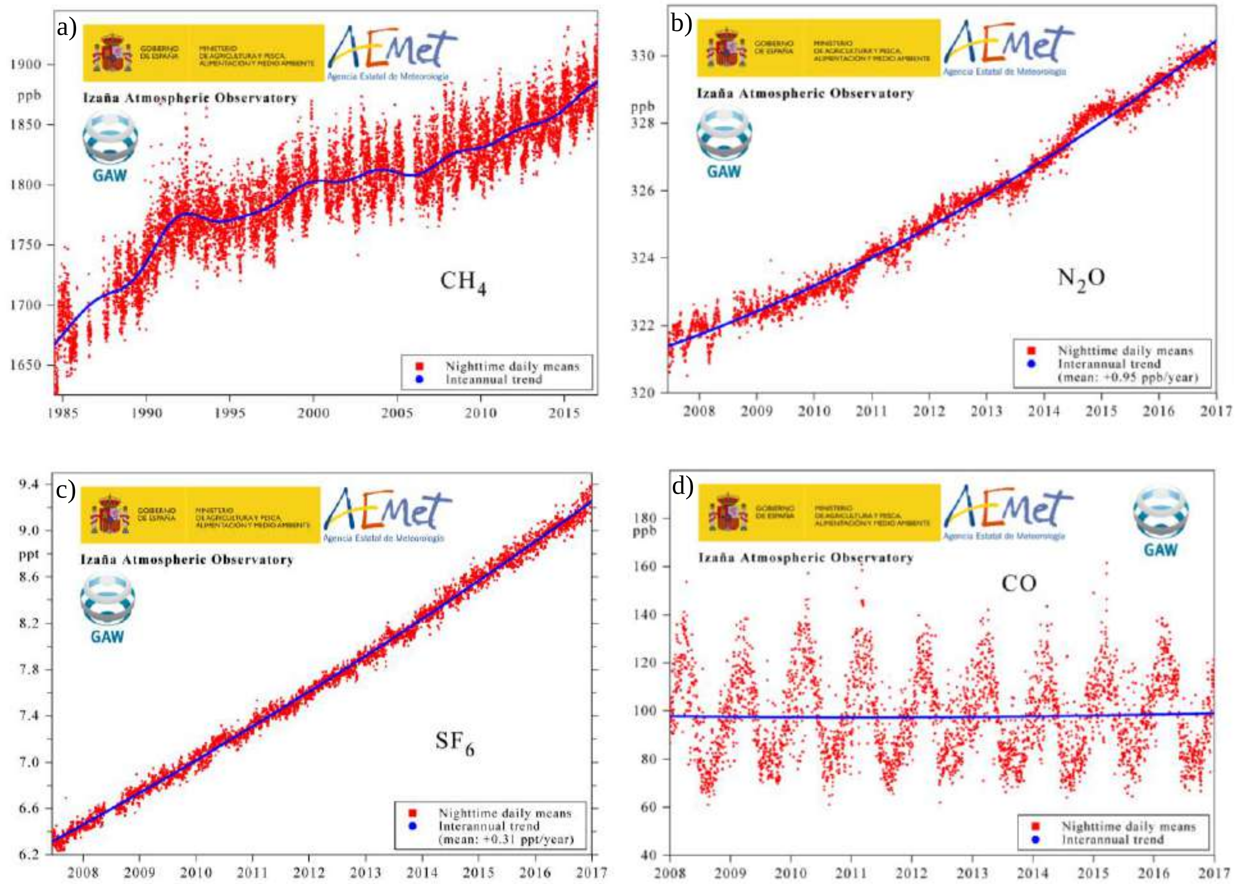

Figure 4.3. Izaña Atmospheric Observatory time series for a) CH_4, b) N_20, c) SF_6 and d) CO.

At the end of 2015, a CRDS Picarro G2401 for measuring CO_2, CH_4 and CO, belonging to AEMET, was installed at the Izaña Atmospheric Observatory using a provisional simple configuration for air/standard gas management. At the end of 2016, the plumbing design detailed in Gomez-Pelaez et al. (2016) was installed around this instrument for air/standard gas management (see also Fig. 4.4). The measurement system is performing well. Details about its performance will be published in the near future. This instrument was acquired through an infrastructure project (see details in next section).

Figure 4.4. CRDS for measuring CO_2, CH_4 and CO at the Izaña Atmospheric Observatory with the final plumbing design installed at the end of 2016.

An enumeration of the developments and changes introduced in the IARC GHG measurement systems and raw data processing software before September 2015 is reported in sections 2, 3 and 5 of Gomez-Pelaez et al. (2016), whereas those introduced after that date will be detailed in the extended abstract associated with an IARC presentation at the "19th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques (GGMT-2017)" (27-31 August 2017, Dübendorf, Switzerland).

4.4 Participation in Scientific Projects and Campaigns/Experiments

4.4.1 Participation in Scientific Projects

The IARC GHG measurement programme participated in the funded projects NOVIA and VALIASI, contributed to the research article García et al. (2016), and will participate in the project "ASI for Sounding Methane and Nitrous Oxide in the Troposphere", which was approved and funded at the end of 2016. All those projects are led by the IARC FTIR measurement programme (see more details about these projects in sections 5.5 and 8).

At the end of 2014, the project "Equipamiento para la Monitorización e Investigación de Gases de Efecto Invernadero y Aerosoles en la estación Global VAG (Vigilancia Atmosférica Global) de Izaña (Tenerife). AEDM13-3E-1773" was approved and funded by the Spanish "Ministerio de Economía y Competitividad" ("Fondos F.E.D.E.R."). A significant part of those funds was used to acquire a CO_2/CH_4/CO/H_2O CRDS analyzer for the IARC GHG measurement programme (see the previous subsection for more details).

At the end of 2016, the project "Equipamiento para la Monitorización e Investigación en la estación Global VAG (Vigilancia Atmosférica Global) de Izaña (Tenerife) de componentes atmosféricos que provocan y modulan el cambio climático.AEDM15-BE-3319" was approved and funded by the Spanish "Ministerio de Economía, Industria y Competitividad" ("Fondos F.E.D.E.R."). A significant part of those funds will be used to acquire a N_2O/CO QCL spectrometer for this measurement programme.

4.4.2 Participation in International Cooperative Scientific Studies

Modelling the atmospheric methane evolution during the last 40 years

This study of methane evaluation was led by researchers from the Center for International Climate and Environmental Research (CICERO) and the Norwegian Institute for Air Research (NILU). A researcher from the IARC and two researchers from the University of California also participated in it. This study models the atmospheric methane evolution during the last 40 years (Dalsoren et al., 2016). Observations at surface stations show an increase in global mean surface CH_4 of about 180 parts per billion (ppb) (above 10 %) over the period 1984–2012. Over this period, there are large fluctuations in the annual growth rate.

In this work, the atmospheric CH_4 evolution over the period 1970–2012 is investigated with the Oslo CTM3 global Chemical Transport Model (CTM) in a "bottom-up" approach. Surface measurements carried out at sites of international networks are used for comparisons with the output from the CTM to understand causes for both long-term trends and short-term variations.

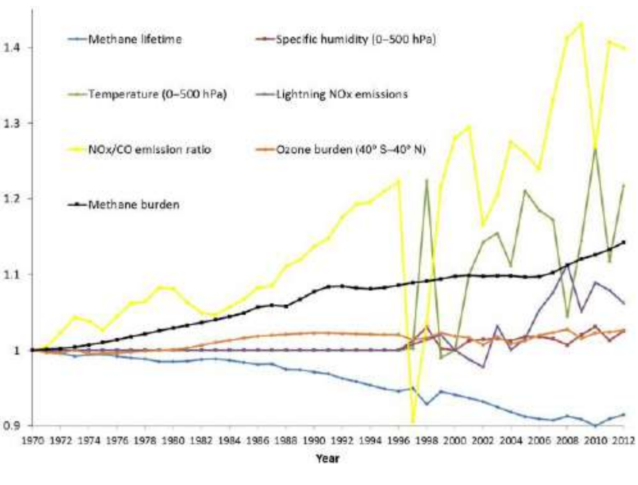

Figure 4.5. Development in atmospheric CH_4 lifetime and key parameters known to influence CH_4 lifetime. All variables values are relative to 1970. (To make it apparent in the figure, temperature variations are relative to the Celsius scale). Reprinted from Dalsoren et al. (2016).

The Oslo CTM3 model was able to reproduce the seasonal and year-to-year variations and shifts between years with consecutive growth and stagnation, both at global and regional scales. The overall CH_4 trend over the period is reproduced, but for some periods the model fails to reproduce the strength of the growth. The observed growth after 2006 is overestimated by the model in all regions. This seems to be explained by a too strong increase in anthropogenic emissions (of the inventories) in Asia in that period, having global impact. These findings confirm other studies questioning the timing or strength of the emission changes in Asia in the EDGAR v4.2 emission inventory over the last decades. For example, a recent publication by Ganesan et al. (2017) shows that EDGAR overestimates CH_4 emissions in India substantially.

The evolution of CH_4 is not only controlled by changes in sources, but also by changes in the chemical loss in the atmosphere and soil uptake. In the Oslo CTM3 numerical simulation, a large growth in atmospheric oxidation capacity over the period 1970–2012 is found: the CH_4 lifetime decreas es by more than 8% from 1970 to 2012 (Fig. 4.5), a significant shortening of the residence time of this important greenhouse gas. This results in substantial growth in the chemical CH_4 loss (relative to its burden) and dampens the CH_4 growth. The change in atmospheric oxidation capacity is driven by complex interactions between a number of chemical components and meteorological factors. The key factors are identified and simple prognostic equations for the relations between these and the atmospheric CH_4 lifetime are provided.

Adjoint of the global Eulerian-Lagrangian coupled atmospheric transport model (A-GELCA v1.0): development and validation

The main contributors to this study published in Geoscientific Model Developments (Belikov et al., 2016) were scientists of Japanese and Russian institutions. However, a researcher from IARC also participated in it contributing to the validation, interpretation of the results, and writing of the article (not in the development of the adjoint of the model). The transport model used belongs to the National Institute for Environmental Studies (NIES) of Japan. From the differences in the concentrations observed and those simulated by the forward run of the transport model, the improvements that need to be applied to the source/sink surface fluxes to minimize those differences can be deduced; and therefore, a more accurate a posteriori value for the surface fluxes can be obtained.

This "inversion" can be performed using the adjoint of the transport model. Developing the adjoint of a transport model is very complex. The adjoint model is like a backward run of the transport model but without inverting the dispersion due to the turbulence and convection (the dispersive phenomena are irreversible). The transport model used in this study is particularly complex and efficient due to the fact that it utilizes the coupling of an Eulerian and a Lagrangian model, continuously in time. Eulerian models are better for the global scale and long simulation times, whereas Lagrangian models are better for small scales and short simulation times. The GELCA model combines both types of model to obtain simultaneously the advantages of both of them: global coverage and high spatial resolution near the observation stations.

Development of CarbonTracker Europe-CH_4: global methane emission estimates and their evaluation for 2000-2012

A group of scientists working mainly in Finish and Dutch institutions (but also from Switzerland, USA, Spain, Australia, Malta, Italy, Germany and Japan) published this study in the scientific review Geoscientific Model Development (Tsuruta et al., 2017). The paper presents the evaluation of the model CarbonTracker Europe-CH_4 and the results of global methane flux inversions performed with that model. A researcher from IARC participated in this study contributing to the evaluation, flux inversion, interpretation of the results, and writing of the article (not in the development of the model).

Two main different configurations were used to assess the sensitivity of the CH_4 flux estimates to (a) the number of unknown flux scaling factors to be optimized which in turn depends on the choice of underlying land-ecosystem map (Fig. 4.6), and (b) on the parametrization of vertical mixing in the atmospheric transport model TM5. The posterior emission estimates were evaluated by comparing simulations to surface in-situ observation sites, to profile observations made by aircraft, and to dry air total column-averaged mole fraction observations.

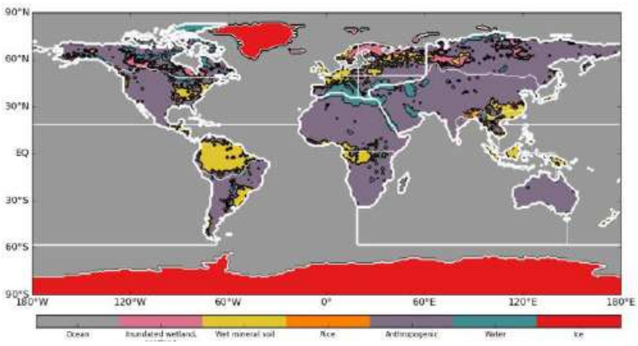

Figure 4.6. Land-ecosystem map used as regional definition in the optimisation performed by Tsuruta et al. (2017).

The posterior estimated Global methane emissions for 2000-2012 are 516±51 Tg CH_4 yr^{-1}, and emission estimates during 2007-2012 are 18 Tg CH_4 yr^{-1} greater than those from 2001-2006, mainly driven by an increase in emissions from the south America temperate region, the Asia temperate region and Asia tropics. The posterior estimates for the northern latitude regions show significant sensitivity to the choice of convection scheme in TM5. The Gregory et al. (2000) mixing scheme with faster inter-hemispheric exchange leads to higher estimated CH_4 emissions at northern latitudes, and lower emissions in southern latitudes, compared to the estimates using the Tiedtke (1989) convection scheme. The evaluation with non-assimilated observations showed that posterior mole fractions were better matched with the observations when the Gregory et al. (2000) convection scheme was used.

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5 Reactive Gases and Ozonesondes

5.1 Main Scientific Goals

The main scientific objectives of this programme are:

- Long-term high quality observations of reactive gases (CO, NO_x, SO_2) in both the free troposphere (FT) and the Marine Boundary Layer (MBL) to support other measurement programmes at IARC.
- Long-term high quality observations and analysis of tropospheric O_3 in the FT and in the MBL.
- Air quality studies in urban and background conditions.
- Analysis of long-range transport of pollution (e.g. transport of anthropogenic and wildfire pollution from North America).
- Study of the impact of dust and water vapour on tropospheric O_3.
- Analysis and characterization of the Upper Troposphere-Lower Stratosphere (UTLS).
- Analysis of Stratosphere-Troposphere Exchange processes.

5.2 Measurement Programme

The measurement programme of reactive gases (O_3, CO, NO_x and SO_2) (Figure 5.1) includes long-term observations at IZO, SCO and BTO (see Tables 3.2, 3.4 and 3.5) and ozonesonde vertical profiles at Tenerife (now at BTO). In addition, IARC (through AEMET and INTA) has a long-term collaboration with the Argentinian Meteorological Service (SMN) and in the framework of this collaboration, ozone vertical profiles are measured at Ushuaia GAW Global station (Argentina) (see Section 21). Surface O_3 measurements started in 1987, CO in 2004, and SO_2 and NO_x measurements were implemented in 2006 at IZO. At SCO, surface O_3 measurements started in 2001, and CO, SO_2 and NO_x programmes were also implemented in 2006.

Figure 5.1. Reactive gases analysers at Izaña Atmospheric Observatory.

The surface O_3 programme is considered a particularly important programme at IZO due to both free troposphere conditions of the site and the quality and length of the data series. Surface O_3 data at IZO have been calibrated against references that are traceable to the US National Institute for Standards and Technology (NIST) reference O_3 photometer (Gaithersburg, Maryland, USA). The surface O_3 programme at IZO has been audited by the World Calibration Centre for Surface Ozone, Carbon Monoxide, Methane and Carbon Dioxide (WCC-Ozone-CO-CH_4-CO_2-EMPA) in 1996, 1998, 2000, 2004, 2009 and 2013. EMPA's audit reports are available here, for example the 2013 report is available here. The audits were performed according to the "Standard Operating Procedure (SOP) for System and Performance Audits of Trace Gas Measurements at WMO/GAW Sites" (WMO GAW Report, 2007).

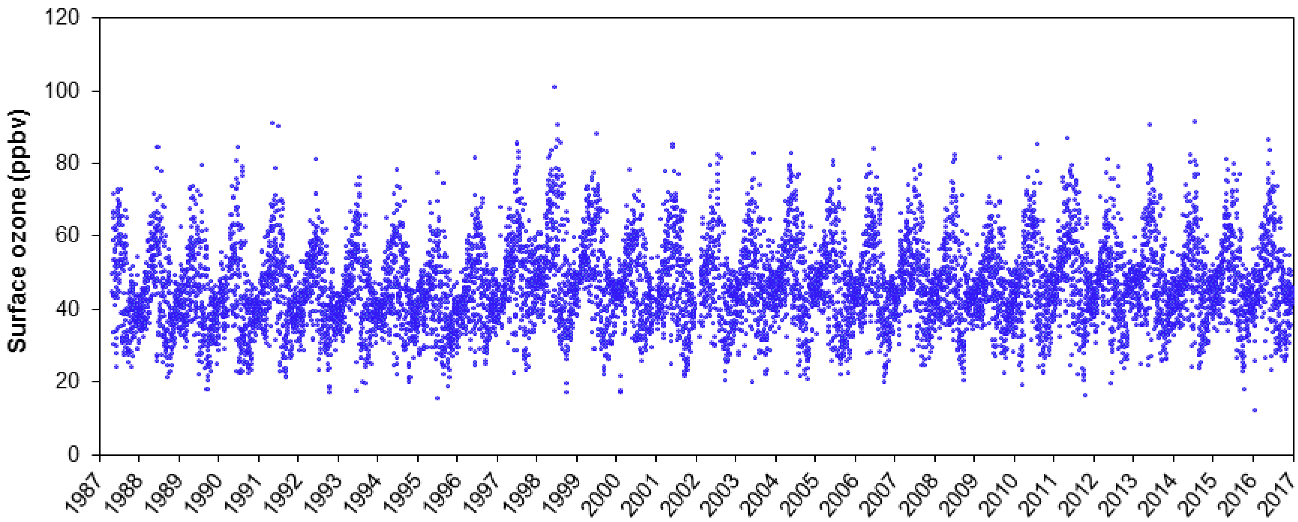

Figure 5.2. Long-term daily (night period) surface O_3 at IZO (1987-2016).

Details of the reactive gases and ozonesondes measurement programme are described in González (2012) and Cuevas et al. (2013). In 2016, an almost uninterrupted 30-year time series of surface O_3 was completed (see Figure 5.2).

The last audit held by EMPA at the Izaña Atmospheric Observatory in September 2013 reported that the station calibrator TEI 49C-PS #56084-306 had a problem with the electronics, resulting in an underestimation of the ozone values ~ 1% compared to the WCC-EMPA reference. This problem reoccurred at the end of 2016. The instrument was repaired at EMPA. After the repair, the instrument was compared and re-calibrated to the WCC-EMPA ozone reference (SRP#15). The instrument was fully functional after repair and can be used as an ozone reference in its current condition. Surface O_3 data from primary and secondary O_3 analyzers at Izana were properly corrected from small biases since all changes of the calibration settings were well documented.

Following the EMPA recommendations, a new surface ozone analyzer TEI 49i#1153030026 was purchased and started operation at IZO on 7 December 2015. Throughout 2016 the instrument was inter-compared with the primary and secondary O_3 analysers, and regularly (every 3 months) calibrated against the station calibration. This instrument will soon be designated the new primary analyser. The primary analyser will become the secondary instrument, and the current secondary instrument will be installed in the Teide Peak Observatory (TPO).

Concerning NO_x and SO_2, the measurement programmes have been implemented following methodologies established by the US Environmental Protection Agency (US EPA) and the European Union (2008/50/CE). These agencies have also established QA/QC protocols (e.g., US EPA, 600/4-77-027a, 1977; UNE-EN standards). These recommendations have been considered during the implementation of the reactive gases programme at SCO and IZO. We have also followed GAW protocols and procedures. The calibrations performed on the NO_x analyzer could not be applied before the end of 2016 due to lack of personnel in this programme. The SO_2 analyzer began to show signs of instability on 11 January 2016, finding out later that its optical part was damaged as the reflecting mirrors were burnt. During the rest of 2016, the failure could not be solved satisfactorily.

In relation to CO, this component is measured with high accuracy at IZO by the Greenhouse Gases and Carbon Cycle Programme, using the gas chromatography/reduction gas detection (GC/RGD) technique, and following the GAW recommendations (see Section 4). A detailed description of the programme can be found in Gómez-Peláez et al. (2013).

CO measurements at IZO are described in Section 4.2 within the Greenhouse Gases and Carbon Cycle Programme. CO measurements are also performed at SCO with non-dispersive IR absorption technique for air quality research.

Concerning NO_x and SO_2 measurements at IZO, the instruments are usually operating below the detection limit (50 pptv) during the night-time period when we can ensure background conditions. However, these measurements are quite useful for studies of local or regional pollution during daytime, when concentrations are modulated by valley-mountain breeze, and help to understand the impact of regional pollution. A detailed description of these measurement programmes, including quality control and quality assurance protocols is provided by González (2012).

The ozone vertical profiles measurements were initiated in November 1992 using the Electrochemical concentration cell (ECC) ozonesonde technique. The equipment and launching stations used in this programme are indicated in Table 5.1. Launches are performed once a week (Wednesday). At the start of the programme, the ozonesondes were launched from Santa Cruz Station (28.46°N-16.26°W; 36 m a.s.l.) and since 2011 they have been launched from BTO (28.41°N-16.53°W; 114 m a.s.l.). This programme provides ozone profiles from the ground to the burst level (generally between 30 and 35 km) with a resolution of about 100 metres. A detailed description of this programme and results can be found in Cuevas et al. (1994), Smit et al. (1995), and Sancho et al. (2001). The frequency of ozone soundings in this station is significantly increased during intensive campaigns.

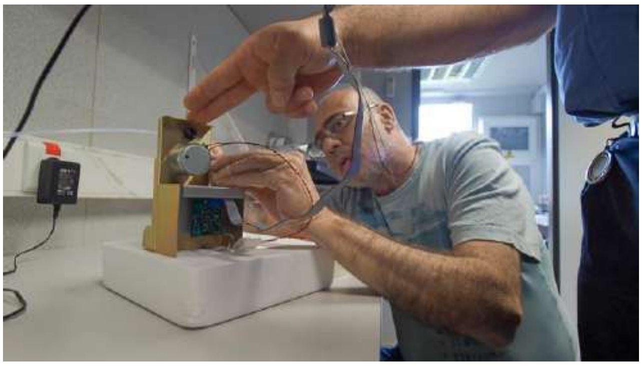

Figure 5.3. a) Preparation of an ozone electrochemical cell carried out by Sergio Afonso at the Ozonesonde Laboratory, BTO, b) launch of ozonesonde at BTO.

Table 5.1. Ozonesonde Programme equipment used in different time periods and launching stations since November 1992.

Instrument manufacturer and model	Frequency	Period/Launching station
OZONESONDES: Nov 1992 – Sep 1997: Science Pump Corp. Model ECC-5A Sep 1997 – present: Science Pump Corp. Model ECC-6A **GROUND EQUIPMENT:** Nov 1992 – Oct 2010: VAISALA DigiCora MW11 Rawinsonde Oct 2010 – present: VAISALA DigiCora III SPS 313 Workstation **RADIOSONDES:** Nov 1992 – Oct 1997: VAISALA RS80-15NE (Omega wind data) Oct 1997 – Sep 2006: VAISALA RS80-15GE (GPS Wind data) Sep 2006- present: VAISALA RS92-SGP (GPS Wind data)	1/week (Wed)	Nov 1992 – Oct 2010: From Santa Cruz Station (28.46°N-16.26°W; 36 m a.s.l.) Oct 2010 – Feb 2011: From Santa Cruz/ BTO (In alternate launches) Feb 2011 – present: From BTO Station (28.41°N-16.53°W; 114 m a.s.l.)

The main features of the ozonesonde system are the following:

- Sensor: ECC-6A
- Radiosonde: RS-92
- Balloon: TOTEX TA 1200
- Receiver: Digicora MW31
- Wind system: GPS

The ozonesondes are checked before launching with a Ground Test with Ozonizer/Test Unit TSC-1 (see Section 3.2.2 and Figure 5.3). A constant mixing ratio above burst level is assumed for the determination of the residual ozone if an altitude equivalent to 17 hPa has been reached.

Figure 5.4. Sergio Afonso and Marcos Damas go to the ozonesondes launching point at the Botanic Observatory (BTO).

5.3 Summary of remarkable results during the period 2015-2016

5.3.1 New software for reactive gases data evaluation (O_3, NO_x, SO_2)

A new software for reactive gases data evaluation was developed during 2015 and 2016. This new software makes it possible to carry out a simple and visual evaluation of the 1-minute data of reactive gases (surface O_3, NO_x, and SO_2). We can choose the desired component to evaluate and visualize its record along with that of another component and/or together with the meteorological information (temperature, relative humidity, pressure and wind) in order to have enough information to remove outliers and erroneous readings on the graph, by marking them, and cross-checking with the information provided by check-lists and log-books. Zeros, span and calibrations of the analysers can also be displayed and applied.

5.3.2 New World Data Center for Reactive Gases (WDCRG)

The new World Data Center for Reactive Gases (WDCRG) has been created utilizing the EBAS data infrastructure at NILU. EBAS is a database hosting observation data of atmospheric chemical composition and physical properties. The WDCRG is the data repository and archive for reactive gases of the GAW Programme. The WDCRG was established on 1 January 2016 and takes over the responsibility of RG data archiving from the Japan Meteorological Agency, which will continue to host the World Data Centre on Greenhouse Gases (WDCGG). The reactive gases to be hosted at WDCRG are: SO_2, oxidized nitrogen species, surface O_3 and VOCs.

We have developed the necessary software to edit data in the new format required by the WDCRG. Only surface O_3 data has been submitted up to now. To browse for data submitted to WDCRG, please visit http://ebas.nilu.no.

5.3.3 The Ozonesonde Data Homogenization project

Although there have not been any changes in ECC O3 manufacturer or changes in sensing solution type (Vaisala ECC-SPC5A/6A-1.0% KI full buffer) since the beginning of the Ozonesonde Programme (November 1992), some non-uniformity in data processing could have occurred through the programme time period. This can lead to some inhomogeneities in time series and records and thus may influence the trends derived from such records dramatically. The Assessment of Standard Operating Procedures for Ozonesondes (ASOPOS, Smit et al., 2013) demonstrated that, after standardization and homogenization improvement of precision and accuracy by about a factor of two might be yielded.

For these reasons, a WMO "Ozone Sonde Data Quality Assessment (O3S-DQA)" activity has been initiated recently with the following two major objectives:

1) Homogenization of selected ozonesonde data sets to be used for the ozone assessment with the goal to reduce uncertainty from 10-20% down to 5-10% (focus on transfer function).
2) Documentation of the homogenization process and the quality of ozonesonde measurements generally to allow the recent records to be linked to older records.

In the context of the WMO/GAW O3S-DQA activity, some O3-sounding stations, one of them the IZO station, were selected to be involved in the homogenization process, following the "Guide Lines for Homogenization of Ozone Sonde Data" (Smit et. al, 2012) prepared by the O3S-DQA panel members.

The reprocessing carried out in our station is being supervised by Dr Herman Smit (Jülich Forschung Zentrum, Germany), leader of the O3S-DQA panel. This work was initiated in 2016. An essential aspect of this homogenization will be the estimation of expected uncertainties and the detailed documentation of the reprocessing of the long term ozonesonde records.

In 2004, the Izaña Atmospheric Observatory joined NDACC and began routinely archiving the ozonesonde data into the NDACC database; in addition, all the ozonesonde records since 1995 were uploaded to the NDACC at this time. Currently 95% of the ozone soundings performed in the period 1995-2016 are in the NDACC network (Figure 5.5). Ozonesondes from the early period (November 1992-1994) need to be reprocessed and reanalysed carefully. Another aim of the homogenization is to recover these ozone soundings for the NDACC database. The ozonesonde data are also available at the World Ozone and Ultraviolet Data Center (WOUDC).

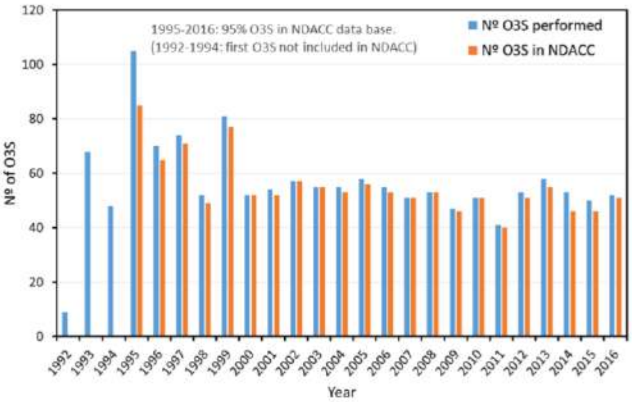

Figure 5.5. Number of ozone soundings (O3S) launched since the beginning of the programme and the number of ozonesondes recorded in NDACC network meeting the quality assurance criteria (1992-2016).

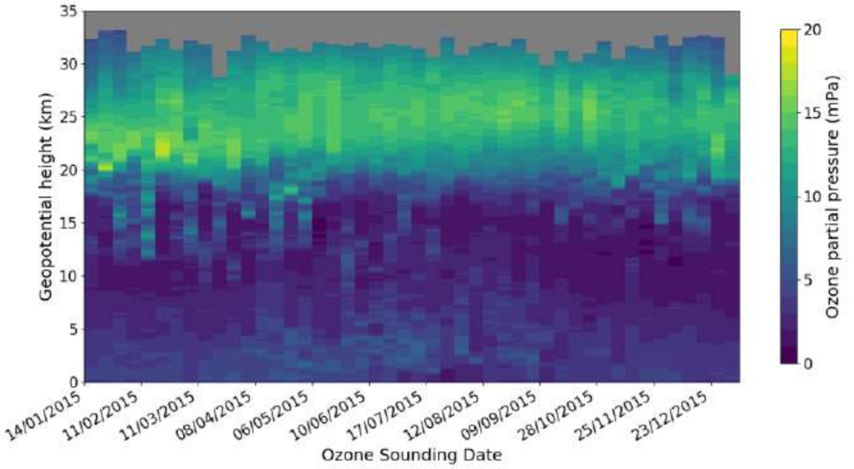

Figure 5.6. Time/height vertical cross-sections of ozone partial pressure corresponding to 2015 (in grey, balloon burst level).

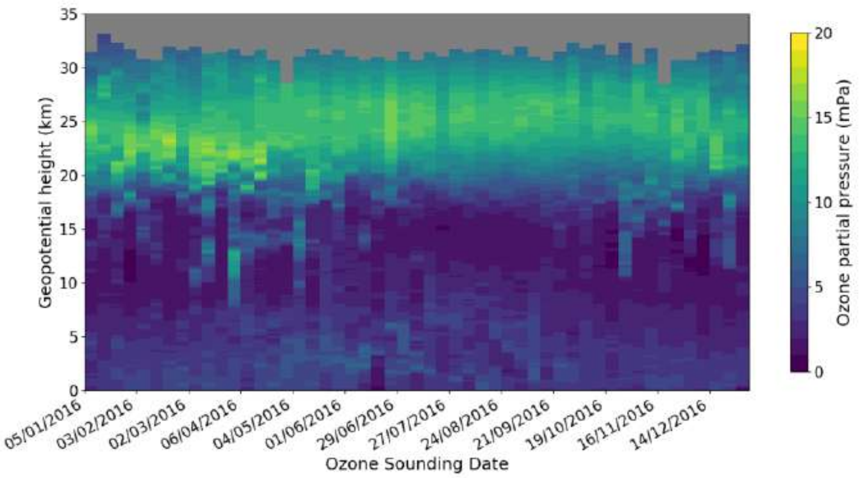

Figure 5.7. Time/height vertical cross-sections of ozone partial pressure corresponding to 2016 (in grey, balloon burst level).

The time/height vertical cross-sections of ozone partial pressure corresponding to the reporting period are shown in Figures 5.6 (2015) and 5.7 (2016).

The ECCs have individual characteristics, and a different ECC sensor is used in each ozonesonde. Despite a thorough pre-launch laboratory check, ECCs may deteriorate during flight and give poor readings for different reasons. In addition, long-term stability over many individual sondes is nearly impossible to maintain. Therefore, it is strongly recommended to normalize each sounding (WMO, 2008). This is accomplished by calibrating the vertically integrated sounding profile with a near-by coincident total ozone measurement, such as that provided by a Brewer spectrophotometer. The ratio between measured total ozone and the vertically integrated ozone from ozonesonde gives the correction factor (Cf). This factor must be applied to each value of the ozone profile, and this is one of the tasks which must be performed in the present homogenization work, reprocessing the historical ozonesondes series.

The values of Total Ozone Column (TOC) from Ozone Sounding (TOCs) were calculated from the integral of the Ozone Partial Pressure (correction factor not yet applied) of the ozonesondes from the Izaña Atmospheric Observatory altitude (2373 m) plus the Residual Ozone (calculated assuming a constant mixing ratio from the balloon burst level to 1 hPa). The near-by coincident total ozone measurement was taken from Brewer spectrometer (#157) located at the Izaña Atmospheric Observatory (TOCb). Both parameters present a similar behaviour (Figures 5.8 and 5.9) and are in close agreement in 2016 (Fig. 5.9). However, a slight bias, between 3 to 7% can be observed in 2015 (Fig. 5.8) which is being investigated. In addition, these figures demonstrate that the correction factor (Cf) is mostly between 0.95-1.05, the threshold that we established to consider a valid Ozone Sounding.

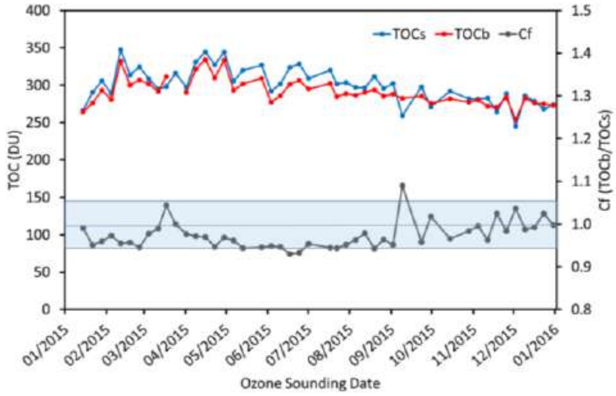

Figure 5.8. Temporal evolution of Total Ozone Column from Brewer (TOCb) and from Ozone Sounding (TOCs) on left axis, and their correction factor (Cf) on right axis, for 2015.

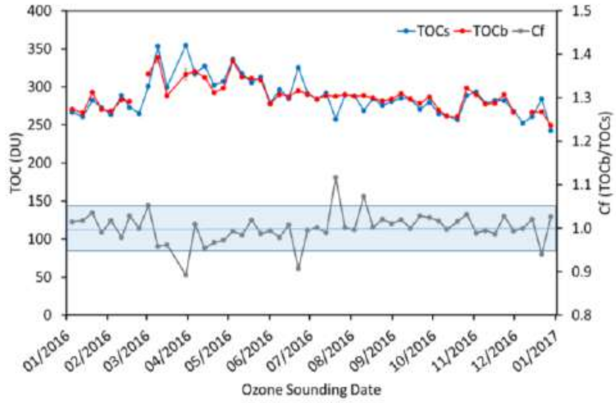

Figure 5.9. Temporal evolution of Total Ozone Column from Brewer (TOCb) and from Ozone Sounding (TOCs) on left axis, and their correction factor (Cf) on right axis, for 2016.

5.3.4 The TOAR project

The Tropospheric Ozone Assessment Report (TOAR): Global metrics for climate change, human health and crop/ecosystem research, is a new Activity of the International Global Atmospheric Chemistry Project (IGAC), approved by the IGAC Scientific Steering Committee on 13 March 2014. The mission of TOAR is to provide the research community with an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause.

The main two goals are: 1) Produce the first tropospheric ozone assessment report based on all available surface observations, the peer-reviewed literature and new analyses; and 2) Generate easily accessible, documented data on ozone exposure and dose metrics at thousands of measurement sites around the world (urban and non-urban), freely accessible for research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity.

We have been contributing to the "Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to climate and global model evaluation". Much of the work required to participate in TOAR has been the careful review of surface ozone data and its conversion to the format of the new global reactive gas data center (see section 5.3.2). A scientific paper titled "Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to climate and global model evaluation" is being prepared to be submitted to Elementa journal.

5.3.5 The Reactive gases Programme at the Ushuaia Global GAW station (Argentina)

The Ushuaia global GAW station (54.848334 °S, 68.310368 °W) is operated by the Argentinian National Meteorological Service (SMN). This station is mainly influenced by middle latitude air masses, but on certain occasions, the south polar vortex sweeps over the southern tip of the South American continent. On such occasions, Ushuaia can be on the edge of or even inside the ozone hole. The reactive gases programme carried out at the Ushuaia global GAW station is a joint project of SMN, the Government of Tierra del Fuego (Argentina) with contributions from the National Institute for Aerospace Technology (INTA, Spain) and the State Meteorological Agency (AEMET, Spain) through the Izaña Atmospheric Research Centre.

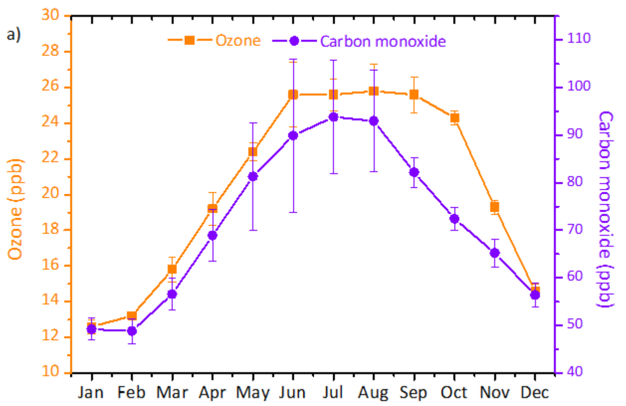

Figure 5.10. Annual variation of surface O_3 and CO at Ushuaia global GAW station. Reprinted from Adame et al. (2016).

Five years (2010-2014) of hourly surface measurements of surface O_3 and CO at the GAW-WMO Ushuaia station were analyzed and characterized. A meteorological study of the region was carried out using in situ observations and meteorological fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) global meteorological model. Atmospheric transport was investigated with air mass trajectories computed with the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) using ERA-Interim meteorological fields (Adame et al., 2016).

5.3.6 Confirmation of the unprecedented change in air quality in Santa Cruz de Tenerife from 2014

In 2015 and 2016, using data from the SCO station and air quality stations of the Government of the Canary Islands located in Santa Cruz de Tenerife, it was possible to verify the historical milestone of the improvement of air quality in the city. In July 2013, the Santa Cruz de Tenerife refinery ceased crude oil refining operations and resumed operation for a short time in December 2013. After this date, the refinery has not returned to activity.

Since 2014, the European air quality standards for SO_2 have not been exceeded at any time. The EU air quality standards set limit concentration values for 1-h averages (350 µg m^{-3}) not to be exceeded more than 24 times per year and for daily averages (125 µg m^{-3}) not to be exceeded more than three times per year. The significantly stricter WHO Air Quality Guideline (AQG) limit value (20 µg m^{-3} daily average) was exceeded on two occasions since 2014. This is clearly reflected in the SO_2 record of Santa Cruz at one of the stations with the longest time series (Tomé Cano) (Fig. 5.11). This is a new, cleaner air scenario for the SCO urban/local-research GAW station.

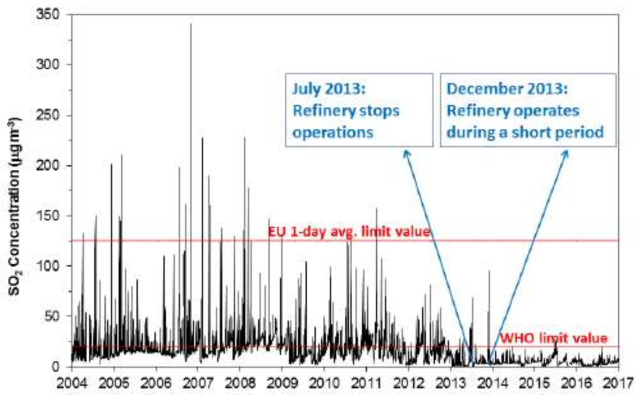

Figure 5.11. Daily average SO_2 at Tomé Cano station in Santa Cruz de Tenerife.

5.3.7 Other contributions

Dr Emilio Cuevas contributed to the validation of reactive gases and aerosols in the MACC global analysis and forecast system (Eskes et al., 2015). Dr Omaira García contributed to the study titled "Long-term trends of global tropospheric column ozone" (Gaudel et al., 2016) presented to the IGAC Conference held in Colorado (USA) in September 2016. This study addresses the following questions: Is ozone continuing to decline in nations with strong emission controls? To what extent is ozone increasing in the developing world? In response to these questions, the study showed results from IGAC's Tropospheric Ozone Assessment Report, and presented the first multi-instrument comparison of long-term tropospheric column ozone trends using co-located observations from satellites, FTIR and Umkehr. The study was aimed at evaluating the chemistry-climate models participating in the CCMI and TF-HTAP experiments.

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6 Total Ozone Column and Ultraviolet Radiation

6.1 Main Scientific Goals

The main scientific objective of this programme is to obtain the total ozone column (TOC) and ultraviolet (UV) spectral radiation with the highest precision and long-term stability that the current technology and scientific knowledge allows to achieve. To reach this objective the group uses three interconnected areas. The base is the instrumentation; this is supported by strict QA/QC protocols that require laboratory calibrations and theoretical modelling. Finally, web-oriented databases are developed for dissemination of the observational data.

6.2 Measurement Programme

Measurements of total ozone and spectral ultraviolet radiation began in May 1991 in IZO with the installation of Brewer spectrometer #033. Ozone profile measurements were added in September 1992 with two daily (sunrise and sunset) vertical ozone profiles obtained with the Umkehr technique. In July 1997, a double Brewer #157 was installed at IZO and it ran in parallel with Brewer #033 for six months. In 2003, a second double Brewer #183 was installed and it was designated the travelling reference of the Regional Brewer Calibration Center for Europe (RBCC-E).

Figure 6.1. Members of the Total Ozone and UV radiation programme with the RBCC-E Brewer spectrophotometer triad located at IZO.

In 2005, a third double Brewer #185 was installed and it completes the reference triad of the RBCC-E (Fig. 6.1). The measurement programme was completed with the installation of a Pandora spectroradiometer in October 2011. The technical specifications of both Brewer and Pandora instruments are summarized in Table 6.1.

Table 6.1. Spectrometer specifications.

Brewer	
Slit Wavelengths	O_3 (nm): 303.2 (Hg slit), 306.3, 310.1, 313.5, 316.8, 320.1
Mercury-calibration (O_3 mode)	302.15 nm
Resolution	0.6 nm in UV; approx 1nm in visible
Stability	±0.01 nm (over full temperature range)
Precision	0.006 ± 0.002 nm
Measurement range (UVB)	286.5 nm to 363.0 nm (in UV)
Exit-slit mask cycling	0.12 sec/slit, 1.6 sec for full cycle
O_3 measurement accuracy	±1% (for direct-sun total ozone)
Ambient operating temperature range	0°C a +40°C (no heater) -20°C a +40°C (with heater option) -50°C a +40°C (with complete cold weather kit)
Physical dimensions (external weatherproof container)	Size: 71 by 50 by 28 cm Weight: 34 kg
Power requirements Brewer and Tracker	3A @ 80 to 140 VAC (with heater option) 1.5A @ 160 to 264 VAC 47 to 440 Hz
Pandora	
Instrument spectral range	265-500 nm
Spectral window for NO_2 fit	370-500 nm
Spectral resolution	±0.4 nm
Total integration time	20 s
Number of scans per cycle	50-2500
Spectral sampling of the grating spectrometers	3 pixels per Full Width at Half Maximum (FWHM)

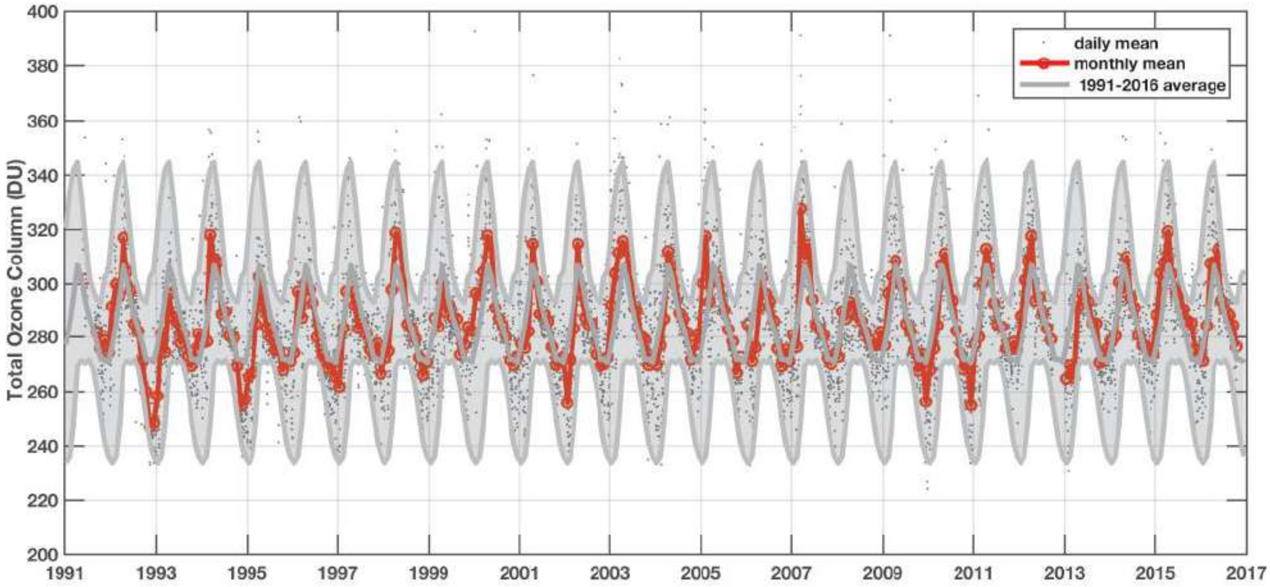

Figure 6.2. Total Ozone series at Izaña Atmospheric Observatory (1991-2016), daily mean (in grey dots) and monthly mean (in red), the long-term mean from the period 1991-2016 are also shown (grey line) with the shaded area corresponding to the standard deviation in the long term mean.

The spectral UV measurements are routinely quality controlled using IZO calibration facilities. The stability and performance of the UV calibration is monitored by 200W lamp tests twice a month. Every six months the Brewers are calibrated in a laboratory darkroom, against 1000W DXW lamps traceable to the Word Radiation Center (WRC) standards. The SHICrivm software tool is used to analyse quality aspects of measured UV-spectra before data transfer to the databases. In addition, model to measurements comparisons are regularly done. Every year the Brewer #185 is compared with the Quality Assurance of Spectral Ultraviolet Measurements (QASUME) International portable reference spectroradiometer from Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC).

Concerning total ozone, the Brewer triad has an exhaustive quality control in order to assure the calibration, with routine calibrations performed on a monthly basis. With this procedure, we have achieved a long-term agreement between the instruments of the triad with a precision of less than 0.25% in ozone.

The Total Ozone programme is a part of the NDACC programme. The total ozone series for 1991-2016 is shown in Fig. 6.2 and is available at the NDACC website and at the World Ozone and Ultraviolet Data Center (WOUDC). We show also in Fig. 6.3 the UV observations obtained from Brewer spectrophotometer #157, available also at the WOUDC.

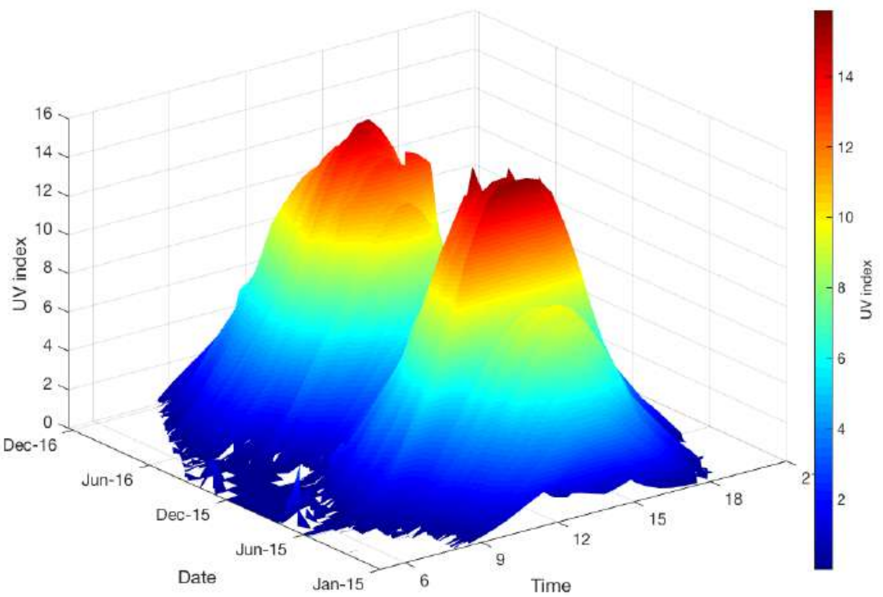

Figure 6.3. UV index during 2015-2016 obtained from Brewer #157 at Izaña Atmospheric Observatory.

6.3 Summary of remarkable results during the period 2015-2016

6.3.1 Effect of instrument temperature on the Brewer specrophotometer

A thorough study of the impact of temperature on Brewer measurements has been carried out in the framework of the European Metrology Research Programme (EMRP) ATMOZ Joint Research Project. We have performed a characterization of the temperature dependence in two experiments which were conducted at the PTB (March 2016, February 2017) and Kipp & Zonen (October, 2016) facilities to validate the standard methods for the determination of the temperature dependence of the Brewer measurements used to retrieve atmospheric TOC.

This work allows us to compare the measurements made through the different input ports of the instrument, the effect of temperature on the Brewer observations modes O_3, UV and AOD and the implications of this on measurements. It also allows us to compare and validate the temperature correction coefficients obtained in the laboratory and those obtained using the current standard procedure in EUBREWNET, which uses field data of the Brewer standard lamp. While various authors have studied the temperature effect on the global UV measurements of the Brewer spectrophotometer, so far no validation of the temperature sensitivity of the ozone retrieved from Brewer has been reported.

Figure 6.4. Experimental setup showing the Controlled Temperature Chambers used at the PTB facilities (left) and detailed view of the spectrometer inside the chamber (right).

The experiments showed some unexpected results, the temperature dependence of the absolute measurements did not show linear dependence in most of the cases and the measurements using the direct port showed a remarkable hysteresis.

Examining the ozone calculation which uses relative coefficients determined from laboratory or field data, we observe differences in the TOC < 0.08%. This result arises even though the values of the relative coefficients obtained by the different types of used lamps, and therefore different spectral irradiances, present wide differences. The algorithm used to retrieve TOC removes any linear effect with the wavelength, and the wavelength selection for the ozone calculation of the Brewer spectrophotometer is conducted to guarantee this condition.

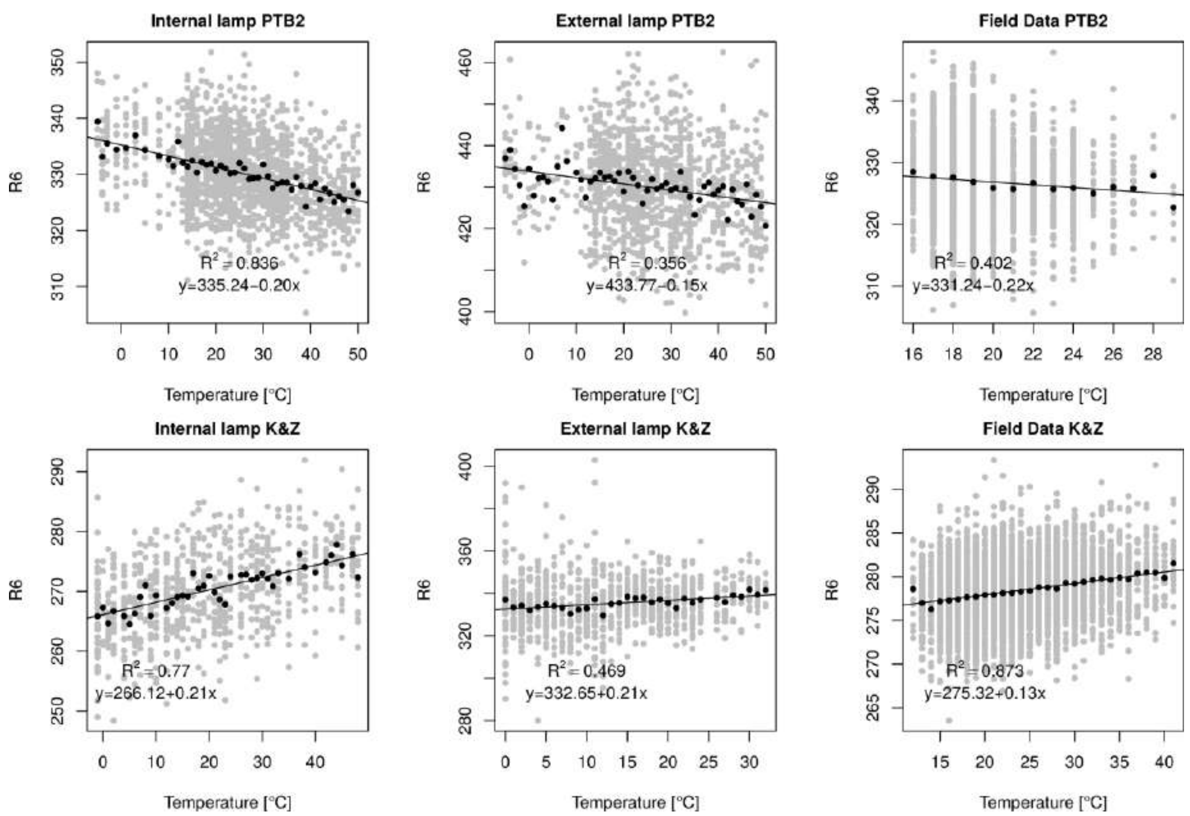

Figure 6.5. Impact of temperature on the total ozone measurements by Brewer spectrophotometers #185 and #233 obtained from laboratory (using an internal and an external lamp) and field data. Reprinted from Berjón et al. (2017).

While the behavior of the relative measurements is approximately linear with temperature, absolute measurements generally exhibit behaviors that may become difficult to model. This implies that the temperature coefficients used in the determination of TOC should not be directly used to correct the temperature sensitivity of AOD or UV Brewer measurements, which should be analyzed separately.

The difficulty of obtaining absolute coefficients from the measurements in the thermal chamber is probably due to the way the temperature changes affect the different elements in the Brewer spectrophotometer. Dilations in the fore optics affect the alignment of the system and cause a proportional change in all wavelengths. The effect on the monochromator causes small changes in the wavelength. The temperature affects the photomultiplier causing a nonlinear response mainly at high temperatures (Berjón et al., 2016, 2017).

Finally, it is noteworthy that temperature correction is usually applied to experimental measurements using a reference temperature close to the most frequent operation temperature. However, this is not the case with the Brewer spectrophotometer, which uses a reference temperature of 0°C while the mean operation temperature for example in EUBREWNET is 23°C with a median value of 22°C. A change of the reference temperature will reduce the error associated with the uncertainty of the temperature dependence calculation.

6.3.2 Development and validation of a Brewer AOD product for EUBREWNET

Within the framework of COST Action ES1207, and as part of the activities carried out at the WMO-CIMO Testbed for Aerosols and Water Vapor Remote Sensing Instruments at the Izaña Atmospheric Observatory, we have developed a Brewer Aerosol Optical Depth (AOD) product for the spectrophotometers integrated in the EUBREWNET network.

All the data necessary for the AOD determination can be obtained from the standard ozone measurements of the spectrophotometers and the instrumental calibration carried out by the Regional Brewer Calibration Center for Europe at the annual intercomparison campaigns. Furthermore, all the data are available at the EUBREWNET data server, making the calculations fast and easy to carry out.

In this new AOD product, the counts measured by the Brewer at the six standard wavelengths between 306 and 320 nm are used after performing corrections for filter and polarization effects. EUBREWNET's near-real-time level 1.5 product, with the Bass and Paur prescription for the ozone cross section, provides high-quality ozone data. Bodhaine's Rayleigh coefficients, and standard ozone and Rayleigh air masses are further used in our AOD algorithm. The aerosol air mass is currently approximated by the Rayleigh one, and for the pressure we use the climatological value at each Brewer station. Reference Brewers of the RBCCE triad are calibrated by the Langley method at IZO, and this calibration can then be transferred to other instruments integrated in the EUBREWNET network during e.g. intercomparison campaigns.

To validate our AOD product, we have compared the data of seven collocated Brewer and Cimel instruments operating at five different stations ranging from Tamanrasset (Algeria) to Kangerlussuaq (Greenland) during the 2013–2015 period. Data for the Izaña Atmospheric Observatory are presented in Fig. 6.6, and show a good correlation between the Brewer and Cimel instruments in the whole two-year period, with correlation coefficients > 0.94 (López-Solano et al., 2016a, 2017).

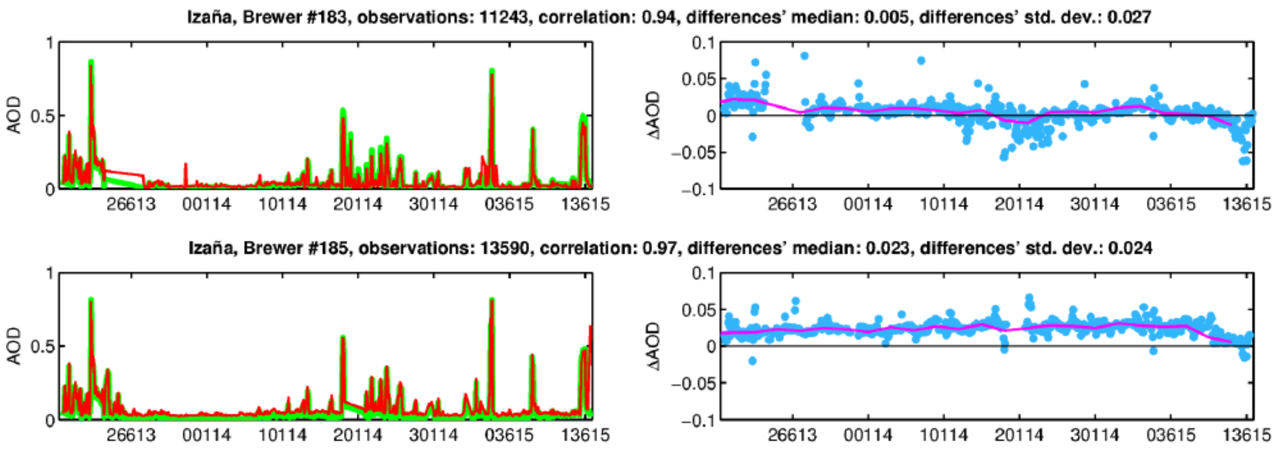

Figure 6.6. Brewer and Cimel AOD at the Izaña Atmospheric Observatory for the 2013–2015 period. AOD series shown on the left panel correspond to daily averages calculated from Brewer (red) and Cimel (green) observations within 1 minute. Daily (blue) and monthly (magenta) averages of AOD differences are shown on the right panel. For the Brewer instruments, we use the data for the longest measured wavelength at 320.1 nm, and for the Cimel, the 340 nm AERONET level 2.0 product extrapolated to 320 nm using the 340–440 Ångström exponent. Dates in the x axis are written as dddyy, where ddd is the day number and yy, the last two digits of the year. Reprinted from López-Solano et al. (2017).

For the whole set of stations considered we have found correlation coefficients of ≥ 0.90. We have further checked our new product by performing a comparison with the AOD provided by the UVPFR instrument operated by the PMOD/WRC during the 10th RBCC-E El Arenosillo 2015 intercomparison campaign, where more than 16 Brewer spectrophotometers were present. We have found Brewer-UVPFR correlation coefficients > 0.96, with median differences < 0.015.

6.3.3 Comparison with OMI O_3 and UV satellite products

Within the framework of the IDEAS+ project of the European Space Agency, and in collaboration with LuftBlick Earth Observation Technologies, we have carried out a comparison of Brewer ozone and ultraviolet data with the products provided by the Ozone Monitoring Instrument (OMI) onboard the NASA Aura satellite. Figure 6.7 shows a comparison of the OMTO3 and OMDOAO3 OMI ozone products with the measurements of the Brewer spectrophotometers operating during the 10th RBCC-E intercomparison campaign. For the Brewer instruments, we show averages of measurements taken within 30 minutes of the satellite overpass (López-Solano et al., 2016b).

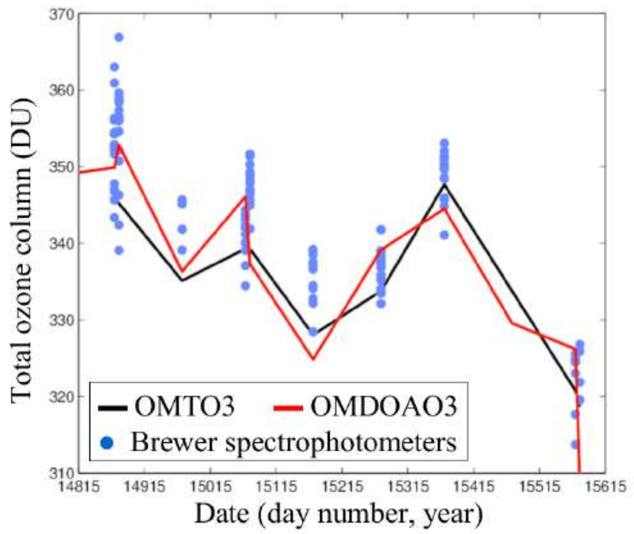

Figure 6.7. Brewer and OMI ozone data during the 10th RBCC-E El Arenosillo 2015 intercomparison campaign. Two satellite products (OMTO3 and OMODOAO3) are shown together with data from different Brewer instruments.

Overall, a good correlation between the satellite and Brewer data is clear. A comparison from June 2015 to June 2016 for eight EUBREWNET Brewer instruments operating at their own sites, from Tamarasset (Algeria) to Sodankylä (Finland), found relative differences < 5% in most cases between the Brewer and OMI ozone data. UV irradiances presented larger differences, reaching up to 15% in some cases. However, it should be noted that we used EUBREWNET's level 0 product, the only one available at the time of the comparison, for the Brewer UV data and it did not include any corrections or data filters.

6.3.4 Polarization investigation on the Brewer Spectrophotometer

Spectral measurements of the direct component of the UV solar radiation have recently gained more importance in the measurement programmes of various Brewer spectrophotometer monitoring stations, and have a wide range of applications, such as AOD retrieval, determination of aerosol properties and measurement of UV absorbing gases (Carreño et al., 2016).

The sensitivity of direct-sun measurements with Brewer spectrophotometers depends on the solar zenith angle (SZA) (Cede et al., 2006) due to Fresnel effects on the flat quartz window and polarization by the diffraction grating. To study the effect of the instrument internal polarization dependence on the SZA we have carried out a first group of measurements with a modified Brewer that allowed us to easily measure direct-sun count rates with and without the quartz window during the 10th RBCC-E El Arenosillo 2015 intercomparison campaign and a second set of measurements made at the Izaña Atmospheric Observatory. It is necessary to interpolate in time to calculate the ratio with and without window. A simple time interpolation would introduce spectral dependence. A better solution would be to apply a physical law (i.e., Bouguer-Lambert-Beer law): linear interpolation of log(I) vs. ozone airmass, removing the Rayleigh contribution before the regression, then reintroducing the interpolation.

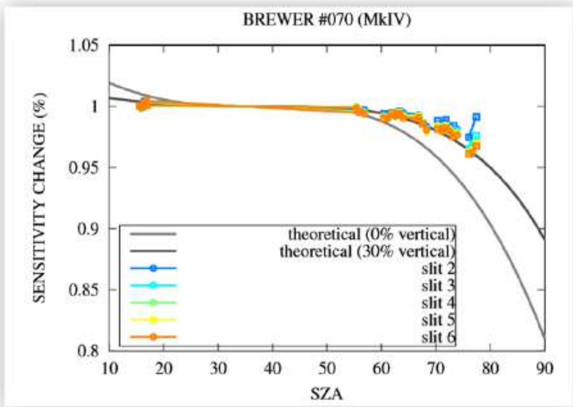

Figure 6.8. Combination of the effect of the flat quartz window and the effect of the diffraction grating (with no polarization and 30% vertical polarization).

The difference in the curvature from the theoretical curve can be explained by the fact that diffraction gratings are not necessarily linear polarisers. Applying a different polarisation degree we can adjust the theoretical curve to the data measured (Figure 6.8). The effect of the window and the corresponding correction for absolute spectral irradiances for all Brewer models (MkII, MkIII and MkIV) were calculated and the possible non-negligible wavelength dependence were determined.

6.4 Participation in Scientific Projects and Campaigns/Experiments

The participation in scientific projects of this measurement programme are intertwined with the activities of the Regional Brewer Calibration Center for Europe (RBCC-E) (see Section 17 for more details).

6.4.1 EUBREWNET

The Vienna Convention for the Protection of the Ozone Layer and the subsequent Montreal Protocol on Substances that Deplete the Ozone Layer have been among the most successful environmental agreements the nations of the world have entered into and have now almost completely eliminated the production of human-made "Ozone Depleting Substances". This has led to the halting of the rapid decline of ozone observed in the 1980s and 1990s, with some promising early indications of ozone recovery now being apparent. It is therefore important to continue to measure carefully the state of the global ozone layer in the coming decades, noting also that stratospheric conditions are expected to change with the projected increasing concentration of greenhouse gases, and the fact that stratospheric ozone itself has a significant effect on the atmospheric radiation balance and surface climate. For this reason, the Vienna Convention obliges signatory countries to maintain programmes to systematically monitor stratospheric ozone. The Brewer Ozone Spectrophotometer has, for the last 30 years, been the instrument of choice for ground station measurements of ozone and, in an effort to significantly improve the quality and timeliness of the data, a COST Action (ES1207) was initiated to form a European Brewer Network – EUBREWNET.

The COST Action is based in the two European calibration Centers (RBCC-E and WRC). The RBCC-E plays a key role in the EUBREWNET, coordinating the standardization of operation, characterization and calibration of the network instruments as well as providing the Brewer database. Now recognised by the WMO and the International Ozone Commission (IO3C), it represents an extremely valuable network of ground station data points without which the space-borne instruments would not be able to function with any degree of accuracy. In the current times when we are trying to identify ozone recovery rates of 1% per decade, it is highly important that data are both accurate and consistent across all stations.

The purpose of EUBREWNET is to harmonise observations, data processing, calibrations and operating procedures so that a measurement at one station is entirely consistent with measurements at all the others. Additionally, the Brewer spectrophotometer are also used to measure spectral UV irradiance, the sulphur dioxide column and aerosol optical depth. Some Brewer spectrophotometers are also able to measure the nitrogen dioxide column. This harmonised Brewer network (Fig. 6.9) constitutes the largest harmonised ground based UV network in the world, available for assimilation into satellite retrievals and models to greatly improve accuracy of the satellite data and forecasting. Another important point is the link to climate change where tropospheric ozone and aerosols are still regarded as having the largest effect on uncertainties in climate models. The Brewer instruments are suitable for the measurement of total column ozone which includes both tropospheric and stratospheric ozone whereas satellites struggle with the lower altitudes.

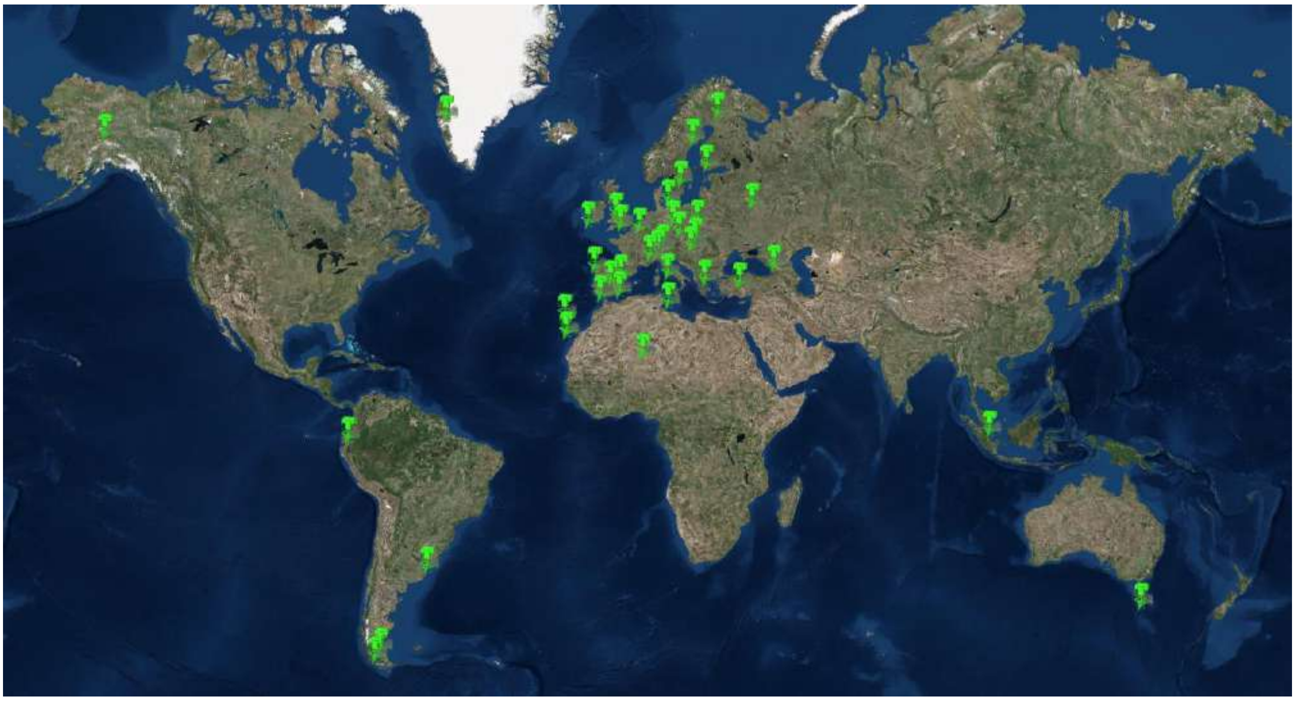

Figure 6.9. Location of Brewer stations currently participating in EUBREWNET. The network started as a European network but now includes more than 50 stations around the world.

The actual implementation of the network can be summarized as follows:

- Automated data transfers to central database hat started in September 2014. Data submission now became automatic with little operator involvement so improving overall submission rates.
- Calibration data are stored in a central database. This allows for central processing of all stations' data so ensuring consistency and use of up-to-date calibration and processing.
- Site characterisation. Central data processing in addition to station processing: including part of QC by comparison and state of the art algorithms.
- Central re-processing. Historical data or changes in constants recommended by WMO Ozone SAG.
- Central QA/QC systems (QA/QC validated in one place) stations with a problem can be easily identified.
- Near Real Time (NRT) data. Essential for NRT validation of satellite data and model assimilations.

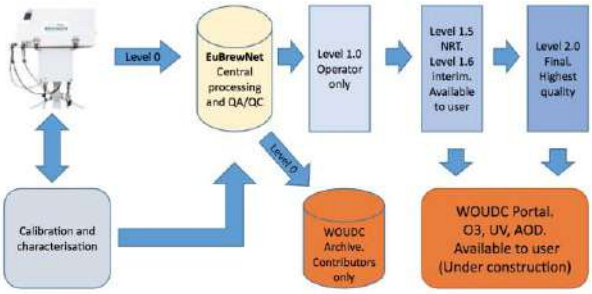

Figure 6.10. EUBREWNET database architecture.

EUBREWNET, in conjunction with WMO/UNEP, are very active in the areas of capacity building, particularly in Article 5 countries, by organising operator courses and workshops, which provide expert instruction and knowledge exchange using the considerable expertise within EUBREWNET.

Although EUBREWNET is intended as a database that processes the ozone measurements in real time, it has been taken into account that the Brewers measure the Ultraviolet radiation spectrum using its dome. In this sense, we are currently working on achieving an automatic processing of these measures for which the mathematical algorithms are being developed, as well as the interface necessary to introduce the configurations of the equipment (equipment response, temperature dependence, etc.) necessary for this kind of measurement. In addition, thanks to the collaboration with Dr Kaissa Lakalla, we wish to extend the algorithm for global ultraviolet correction implemented in the FMI to all Brewers of Eubrewnet. The angular responses of several Brewers were measured in previous RBCC-E calibration campaigns to achieve this objective.

In this new UV product, the measured UV spectrum are corrected taking into account the instrumental response that is obtained using 1000W lamp. This response is checked with respect to the QASUME portable reference spectroradiometer and can be uploaded to EUBREWNET by the Operator. With this information, EUBREWNET can process automatically all the UV measurements sent from the Brewer and calculate, for example, the UV-index. This first stage is considered as UV Product 1.0. On the other hand, and considering the angular dependence of these kind of measurements, we are working to devleop a methodology based on the FMI methodology to correct for this dependence.

The method developed in the FMI is based on comparison of the UV measurements with the database of theoretical measurements created using the Libradtran model, whose values have been obtained through the parameterization of various factors (ozone, albedo, clouds, etc.) that affect the final measured radiation. In EUBREWNET, in order to apply this model, it is necessary to receive these variables for each station as they reside in different climatological conditions. The variables include station altitude, the predominant type of aerosol or albedo. In fact, this last factor is very difficult to parametrize at stations like Izaña. This second stage of the UV product development has not been finalized yet due to the large number of parameters to be taken into account (León-Luis et al., 2016).

6.4.2 ATMOZ

The Joint Research Project Traceability for atmospheric total column ozone (ATMOZ) aims to significantly enhance the reliability of total ozone column measured at the Earth surface with Dobson instruments, Brewer-Spectroradiometer and Array-Spectroradiometer. New methods of observation (techniques, instruments and software) are developed to provide traceable total ozone column measurements with an uncertainty of < 1%.

The dissemination of the improved ozone traceability and the developed tools and methods was achieved via a large field intercomparison campaign of spectroradiometers held during 12-30 September 2016 at IZO in Tenerife. The participation of the RBCC-E has the objective to characterize the reference Brewer at the PTB facilities (Berjón et al., 2016, Redondas et al., 2016), and with this information develop the error analysis of the Brewer instrument. The improvements developed in this project will be transferred to the network instruments during RBCC-E campaigns. The publication of the calibration methodology for Brewer instruments (Brewer Calibration Standard Procedure) is the final objective for this project.

Sixteen instruments participated in the 2016 ATMOZ Total Ozone Intercomparison campaign: these included total ozone reference instruments from the World Dobson Calibration Center (WDCC), the Regional Dobson

Calibration Center–Europe (RDCC-E) and the RBCC-E; together with new CCD based instruments, Pandora, Phaeton and PBS, and new high-resolution array spectroradiometer systems developed in the framework of the ATMOZ project (for more details see Table 17.1). The objectives of the campaign were to compare the Total Ozone measurements of the participating instruments and to obtain a ground based high-resolution UV range extraterrestrial spectrum.

Two data sets are analyzed in this work; in the first one, we compare the operational algorithm. The second updated data-set is the best possible homogenized data-set, where all instruments use the same ozone cross section (Serduychenko et al., 2014) and apply the instrument characterization established during the ATMOZ project. This includes additional information such as profiles of effective temperature from ozonesonde and ancillary data usually not available in field measurements.

The comparison used the RBCC-E triad of Brewer spectrometers as the reference. There is a change of 2% in the reference Brewer between data set 1 and 2, 50% of the change is due to the change from the operative Bass & Paur to the Serdyuchenco cross section and 50% of the change is due to the adoption of the Nicolet Rayleigh. The effect of the use of effective temperature and height has a minor effect on the Brewer ozone observations data during the campaign conditions.

The preliminary results of the 16 participating instruments in the Izaña 2016 ATMOZ Intercomparison campaign are shown in Fig. 6.11 and Table 6.2 and can be summarized as follows:

- The Brewer-Dobson comparison shows results in agreement with previous comparisons (between 1 and 2%) which are improved on data set 2 to < 1% when new cross sections are used.
- There are significant differences between non-UV instruments like FTIR and RASAS. The difference is 2.9% with the FTIR which works in the infrared and -4.5% with the RASAS which works in the visible range.
- The Pandora instrument shows poor results on the operational algorithm which improves when the recently developed algorithm (QOS reference) is used showing similar differences to the PHAETON instrument. The ERMIS which also uses a QDOAS algorithm as the PHAETON shows similar agreement.
- Avodor, and QASUME from the PMOD-WRC, use the same algorithm on different instruments, the data set 2 use the extraterrestrial spectra obtained during the campaign.
- The BTS, CCD global spectrograph achieve promising results.

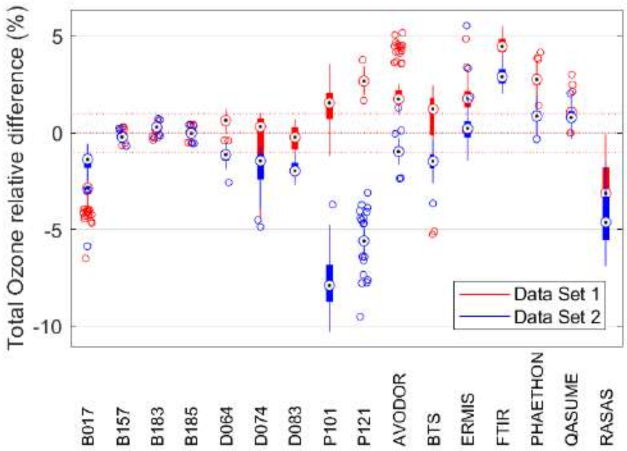

Figure 6.11. Izaña 2016 ATMOZ campaign preliminary results. Total Ozone relative differences (%) to the RBCC-E Brewer Triad reference, using hourly values to include twilight instruments.

Table 6.2. Izaña 2016 ATMOZ Intercomparison campaign preliminary results. Relative differences (%) of the participating instruments to the RBCC-E Brewer Triad reference.

Instrument	Institution	data_set_1 (%)	data_set_2 (%)
Brewer017	IOS/EC	-1.6	-3.1
Brewer157	AEMET	-0.2	-0.2
Brewer183	AEMET	0.3	0.2
Brewer185	AEMET	0.0	0.0
Dobson D064	RDCC-E	-1.2	0.6
Dobson D083	NOAA	-2.0	-0.6
Dobson D074	RDCC-E	-2.0	-0.3
Pandora101	Sieltec	-7.7	1.4
Pandora121	Luzblick	-5.6	2.7
Avodor	PMOD	-0.9	2.2
BTS	PTB /Gigaherzt	-1.5	0.4
ERMIS	PMOD	0.2	1.8
FTIR	AEMET	2.9	4.5
Phaethon	Thessaloniki University	0.9	2.7
QASUME	PMOD	0.8	1.1
RASAS	INTA	-4.5	-3.0

6.4.3 EarthCare Ground Base - Spectrometer Validation Network (Pandonia)

The aim of this project is to establish a network of Pandora instruments "Pandonia". The main instrument of Pandonia will be Pandora-2S, which is currently being developed under this project as an evolution of the existing Pandora spectrometer system. The Pandonia network emphasizes: homogeneous calibration of instrumentation, low instrument manufacturing and operation costs, central data processing and formatting and quick delivery of final data products. The planned data products of Pandonia are: Total and tropospheric ozone (O_3) column, Total and tropospheric nitrogen dioxide (NO_2) column and Spectral aerosol optical depth (AOD) in the ultraviolet (> 300nm) and visible range.

The reference instruments of Pandonia will be at IZO, which is also an instrument test site together with the observation platform of the Biomedical Physics Department, Medical University Innsbruck, Austria. All network instruments will be traceable to reference instruments, through intercomparison with a mobile reference unit visiting network locations. The LuftBlick team and RBCCE team working together with the latest 2016 ATMOZ campaign at IZO, have developed improvements in the main gas retrieval processing algorithms, decreasing considerably the offset in the TOC, and the known Pandora O_3 effective temperature dependence in the long term with respect to the Izaña Brewer Triad.

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7 Fourier Transform Infrared Spectroscopy (FTIR)

7.1 Main Scientific Goals

Earth observations are fundamental for investigating the processes driving climate change and thus for supporting decisions on climate change mitigation strategies. Atmospheric remote sounding from space and ground are essential components of this observational strategy. In this context, the Fourier transform infrared spectroscopy (FTIR) programme at the IARC was established with the main goals of long-term monitoring of atmospheric gas composition (ozone related species and greenhouse gases) and the validation of satellite remote sensing measurements and climate models. In particular, within the FTIR programme much effort has been put in developing new strategies for observing tropospheric water vapour isotopologues from ground and space-based remote sensors, since these observations play a fundamental role for investigating the atmospheric water cycle and its links to the global energy and radiation budgets.

The FTIR programme at the IARC is the result of the close and long lasting collaboration of more than a decade between the IARC-AEMET and the IMK-ASF-KIT (Institute of Meteorology and Climate Research-Atmospheric Trace Gases and Remote Sensing, Karlsruhe Institute of Technlogy, Germany). The IMK-ASF has operated high-resolution ground-based FTS systems for almost two decades and they are leading contributors in developing FTIR inversion algorithms and quality control of FTIR solar measurements. As a result of this collaboration, the FTIR experiment at IZO has contributed to the prestigious international networks NDACC and TCCON since 1999 and 2007, respectively.

7.2 Measurement Programme

A ground-based FTIR experiment for atmospheric composition monitoring has two main components (Figure 7.1): a precise solar tracker that captures the direct solar light beam and couples it into a high resolution interferometer (IFS). IARC's FTIR activities started in 1999 with a Bruker IFS 120M spectrometer, which was replaced by a Bruker IFS 120/5HR spectrometer in 2005 (see technical specifications in Table 7.1).

In order to derive trace gas concentrations from the recorded FTIR solar absorption spectra, synthetic spectra are calculated by the line-by-line radiative transfer model PRFWD (Schneider and Hase, 2009). Then, the synthetic spectra are fitted to the measured ones by the software package PROFFIT (PROFile FIT, Hase et al., 2004).

Figure 7.1. The ground-based FTIR experiment at the IARC (scientific container, upper panel, hosting the Michelson interferometer, lower panel).

PROFFIT allows to retrieve volume mixing ratio (VMR) profiles and to scale partial or total VMR profiles of several species simultaneously. There have been a lot of efforts for assuring and even further improving the high quality of the FTIR data products: e.g., monitoring the instrumental line shape (Hase et al., 1999), monitoring and improving the accuracy of the applied solar trackers (Gisi et al., 2011), as well as developing sophisticated retrieval algorithms (Hase et al., 2004). The good quality of these long-term ground-based FTIR data sets has been extensively documented by theoretical and empirical validation studies (e.g., Schneider et al., 2008a,b; Schneider et al., 2010; García et al., 2012; Sepúlveda et al., 2012a, 2014a).

The FTIR programme at the IARC is complemented by two Picarro L2120-I water vapour isotope analysers for high-precision δD and δ^{18}O measurements (see Fig. 7.2) installed at IZO and TPO within the European project MUSICA.

Figure 7.2. Intercomparison of the two Picarro L2120-I δD and δ^{18}O analysers at the IARC.

Table 7.1. Technical Specifications for Bruker IFS 120/5HR (in brackets, if different for 120M).

Manufacturer, Model	Bruker, IFS 120/5HR [IFS 120M]
Spectral range (cm^{-1})	700 - 4250 (NDACC) and 3500 - 9000 (TCCON) Optional: 20 - 43000
Apodized spectral resolution (cm^{-1})	0.0025 [120M: 0.0035]
Resolution power ($\lambda/\Delta\lambda$)	$2 \cdot 10^5$ at 1000 cm^{-1}
Typical Scan velocity (cm/s)	2.5 (scan time about 100 s @ 250 cm of Optical Path Difference)
Field of view (°)	0.2
Detectors	MCT and InSb (NDACC); InGaAs (TCCON)
Size (cm)/Weight (kp)/Mobility	320 x 160 x 100 [120M: 200 x 80 x 30] 550 + 70 (Pump) [120M: 100 + 30 (Electronics)] Installed inside container, limited mobility
Quality assurance system	Routine N_2O and HCl cell calibrations to determinate the Instrumental Line Shape

These instruments are based on the Wavelength-Scanned Cavity Ring-Down Spectroscopy (WS-CRDS) technology and are calibrated by injecting liquid standards in a Standard Delivery Mode (SDM) from Picarro. The 0.6 Hz-precision of the analyser on δD is <13.5‰ at 500 ppmv H_2O and is <2‰ for 4000 ppmv. The absolute uncertainty for δD is <13.7‰ at 500 ppmv and <2.3‰ at 4500 ppmv. The error estimation accounts for instrument precision as well as errors due to the applied data corrections (SDM effects + instrumental drifts <1‰, liquid standard bias <0.7‰, calibration bias <0.5‰) for δD.

7.3 Summary of remarkable results during the period 2015-2016

The FTIR activities from 2015 to 2016 have been focused on ground and space-based remote sensing FTIR spectrometry as well as in-situ spectrometry.

7.3.1 Ground-based remote sensing FTIR spectrometry

The ground-based FTIR observations have a large potential for monitoring and investigating the composition of the troposphere, the stratosphere and exchange processes between them. This is fundamental to monitor and study, for example, the sources and sinks of greenhouse gases or the evolution of the ozone layer. For this purpose, our activities have addressed the optimisation, development and validation of the new strategies for monitoring the long-term evolution of trace gases, such as greenhouse gases and ozone, in the framework of NDACC and TCCON networks (García et al., 2015a). The IARC FTIR have routinely contributed to NDACC with C_2H_6, $ClONO_2$, CO, CH_4, COF_2, HCl, HCN, HF, H_2CO, HNO_3, N_2O, NO_2, NO, O_3 and OCS observations (total column amounts and VMR vertical profiles) since 1999, while total column-averaged abundances of CO_2, N_2O, CH_4, HF, CO, H_2O and HDO have been measured within TCCON since 2007 (see Fig. 7.3).

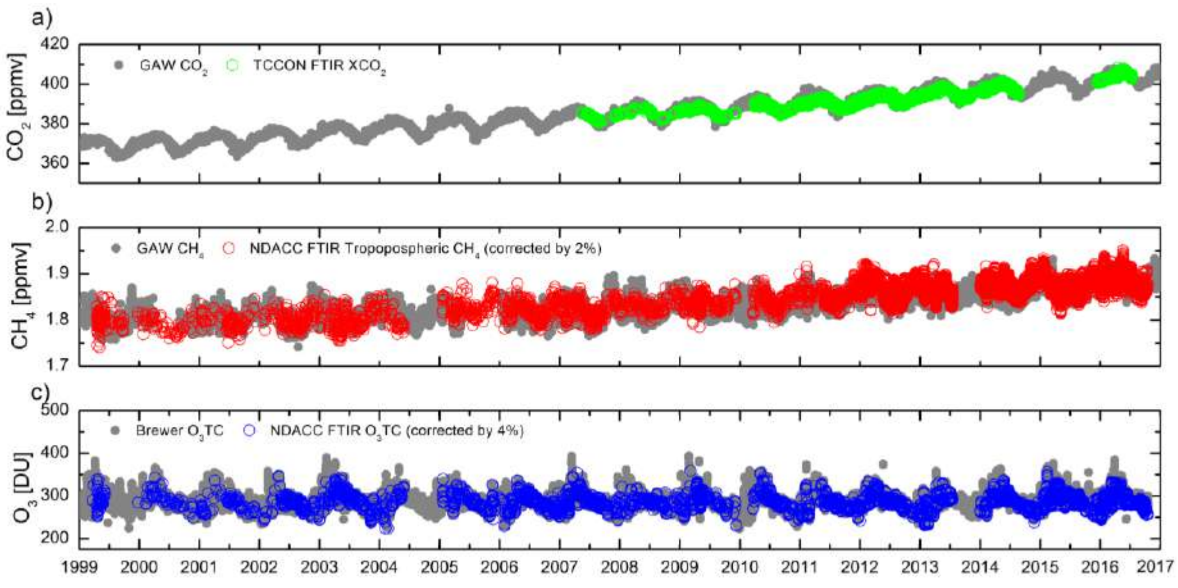

Figure 7.3. Time series of the total column-averaged abundances of a) carbon dioxide (XCO_2) in the framework of TCCON, b) tropospheric methane (CH_4) and c) ozone total column (O_3TC) amounts in the framework of NDACC as observed by the IARC FTIR. For comparison, the time series of these trace gases as observed by other high-quality measurement techniques available at the IARC are also displayed (GAW in-situ records for CO_2 and CH_4, and Brewer O_3TC amounts for O_3).

However, such investigations require data that are very consistent throughout many years and between the different sites. To address this issue, Barthlott et al. (2015) presented a method that allows an assessment of the consistency of any mid-infrared high-resolution solar absorption measurement (2600–3000 cm^{-1} spectral region) made since the late 1950s. The method uses the difference between XCO_2 retrieved from the spectra and as simulated by a model. Both the retrieval and the model are designed in a way that allows their easy adoption to any measurement site. The method was applied to the NDACC/FTIR spectra that have so far been contributing to the project MUSICA, including IZO among them. The scatter found between the yearly mean NDACC data and the model was ~ 3 ‰, this provides strong evidence for the very good long-term data consistency among these NDACC/FTIR sites. This is also a good reliability and consistency test for the long-term trends of tropospheric species measured at these sites.

With these refined time series we have participated in numerous studies at a global scale. For example, the IARC FTIR time series have been used to investigate the long-term changes in the methane total column amounts across the globe (Bader et al., 2016, Fig. 7.4). This study found that, combining FTIR and model estimations, allowed to estimate the contribution of natural sources such as wetlands and biomass burning to the inter-annual variability of methane. However, anthropogenic emissions, such as coal mining, and gas and oil transport and exploration, which are mainly emitted in the Northern Hemisphere and act as secondary contributors to the global budget of methane, have played a major role in the increase of atmospheric methane observed since 2005.

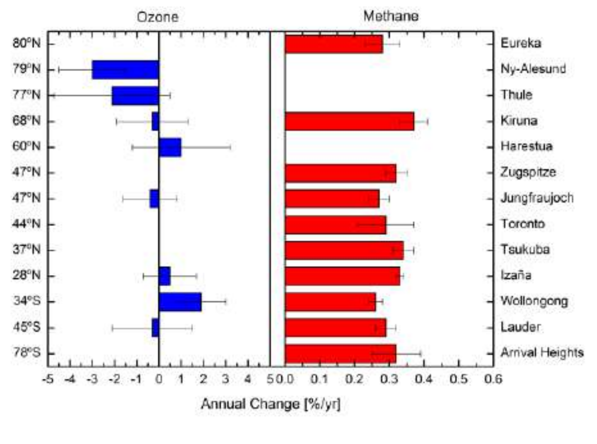

Figure 7.4. Annual changes [in %/yr] of the ozone total column amounts (left panel, reprinted from Vigouroux et al., 2015), and methane total column amounts (right panel, reprinted from Bader et al., 2016) for different FTIR stations covering from 80ºN to 80ºS.

In addition, we have investigated the long-term changes in the ozone vertical distribution and in the total ozone column amounts (García et al., 2012; Vigouroux et al., 2015; Gaudel et al., 2016; Tarasick et al., 2016). These works contribute to the SI2N Initiative (SPARC, 2015) of the Stratosphere-troposphere Processes And their Role in Climate (SPARC) project of the World Climate Research Programme, (continued in 2016 by the project LOTUS, Long-term Ozone Trends and Uncertainties in the Stratosphere) and to the first Tropospheric Ozone Assessment Report (TOAR) to be published in 2017. These studies report that, at least at subtropical latitudes, there is not a clear ozone total column recovery (Fig. 7.4), since the stratospheric ozone increase could partially be compensated by the ozone decrease in the tropopause and troposphere regions.

Understanding and predicting the long-term ozone evolution is a very difficult task, since ozone is affected by an interplay of chemical reactions and atmospheric dynamics. Monitoring and investigating the O_3 isotopologue composition can help us to disentangle this complex scenario, giving us novel insights into the ozone transport, the current ozone recovery and their links to global warming. Sanromá et al. (2016) presented, for the first time, the long-term series of the stratospheric $\delta^{50}O_3$ isotopologue ratios as observed by the IARC FTIR. By analysing these long-term series at different time scales, we explore the intra-annual variability (Fig. 7.5) and the long-term evolution of $\delta^{50}O_3$ ratios at subtropical latitudes.

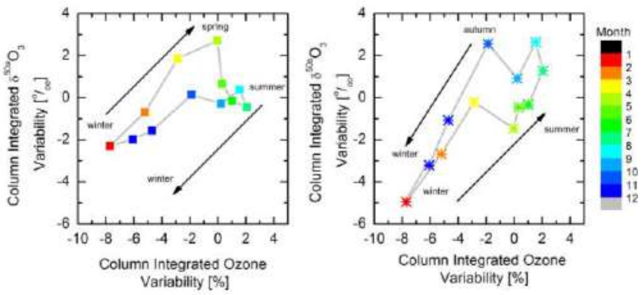

Figure 7.5. Intra-annual variability of the {$\delta^{50a}O_3$, $^{48}O_3$} and {$\delta^{50s}O_3$, $^{48}O_3$} pairs as observed by the IARC FTIR. Reprinted from Sanromá et al. (2016).

7.3.2 Space-based remote sensing FTIR spectrometry

Within space-based FTIR spectrometry, IARC's high quality FTIR data has been extensively applied for many years for the validation of trace gases measured by different satellite instruments (ILAS, MIPAS, ACE-FTS, GOME). Currently, our activities are focused on the Infrared Atmospheric Sounding Interferometer (IASI) on board MetOp/EUMETSAT satellites through the European projects MUSICA and VALIASI (Validation of the EUMETSAT products of atmospheric trace gases observed from IASI using ground-based Fourier Transform Infrared spectrometry), and the Spanish project NOVIA (Towards a Near Operational Validation of IASI level 2 trace gas products).

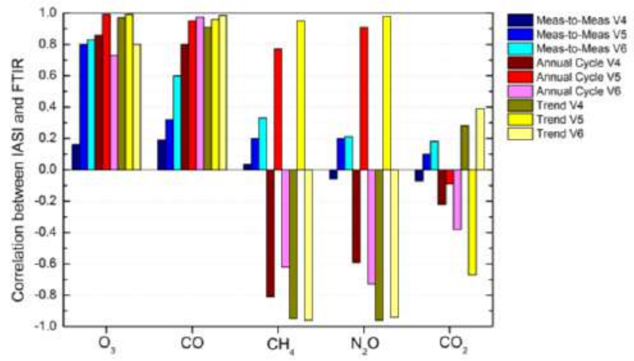

Figure 7.6. Summary of the comparison between IASI/MetOp-A versus FTIR at IZO for all the IASI trace gas products and IASI processors (version 4, V4, version 5, V5, and version 6, V6) at different time scales: measurement-to-measurement (Meas-to-Meas), Annual Cycles and long-term trends. Reprinted from Sepúlveda et al. (2016).

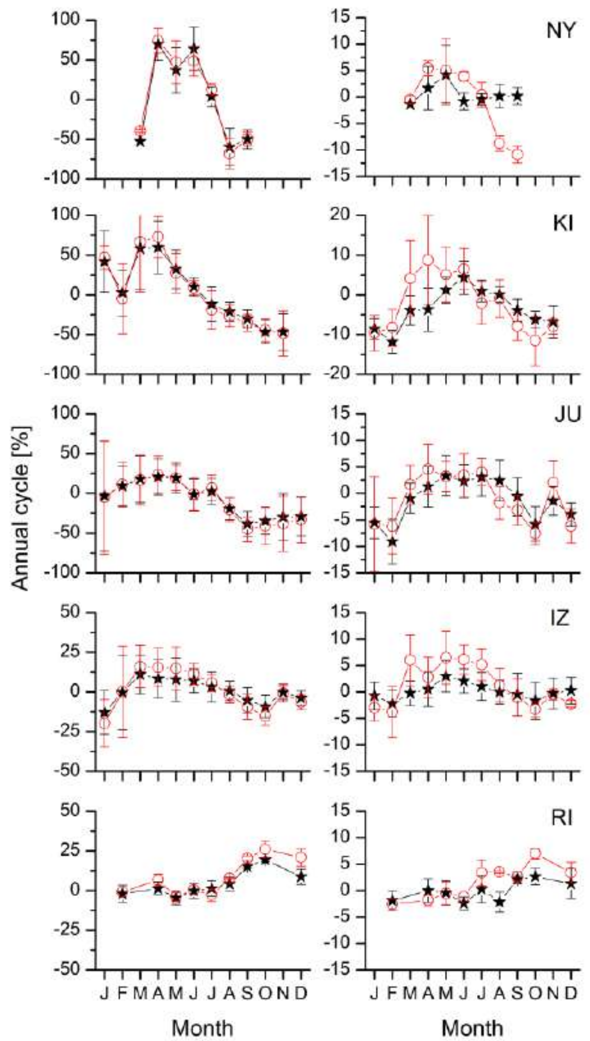

Figure 7.7. Comparison of the annual cycles of the ozone total column amounts (left panels) and tropospheric partial column amounts (right panels) for the IASI-A Level 2 V5 (black stars) and FTIR (red circles) at different NDACC sites covering from 80ºN to 21ºS: NY=Ny-Alesund (79ºN), KI= Kiruna (68ºN), JU=Junfraujoch (47ºN), IZ=Izaña (28ºN) and RI=Reunion Island (21ºS). Reprinted from Sepúlveda et al. (2016b).

By means of VALIASI and NOVIA projects, the long-term validation of the IASI operational atmospheric trace gas products (O_3, CO, CO_2, CH_4 and N_2O) for different IASI processors is being carried out (e.g., García et al., 2015a, 2015b; García et al., 2016a; Sepúlveda et al., 2015a, 2015b; Sepúlveda et al. 2016a, see Fig. 7.6). Special attention has been paid to the quality assessment of the IASI ozone products (total column amounts and vertical profiles) (e.g., Peindado-Galán et al., 2015; Peinado-Galán et al., 2016; Sepúlveda et al., 2016b). An example of the IASI-FTIR comparison for the ozone annual cycles at different NDACC FTIR stations is displayed in Figure 7.7.

We also participate in the validation of other space-based remote platforms, like the OMI, SCIAMACHY or OCO-II (Scheepmaker et al., 2015; Robles-Gonzalez et al., 2016; Wunch et al., 2016).

7.3.3 MUSICA (Multiplatform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water)

In addition to ozone and greenhouse gases, one key element in the Earth's climate is the water cycle. Remote sensing observations of tropospheric water vapour isotopologue composition can give novel opportunities for understanding the different water cycle processes and their link to the climate. In particular, in the lower/middle troposphere, {H_2O, δD} pairs have proved to be good proxies for moisture pathways (Risi et al., 2012). However, their observation, when using remote sensing techniques, is challenging.

The project MUSICA addresses this challenge by integrating the remote sensing with in situ measurement techniques. The aim is to retrieve calibrated tropospheric {H_2O, δD} pairs from the middle infrared spectra measured from ground by NDACC/FTIR spectrometers and from space by MetOp/IASI sensors (Barthlott et al., 2016; Schneider et al., 2016). Special effort has been made to experimentally validate and proof the added value of the MUSICA tropospheric remote sensing products (Wiegele et al., 2014; Schneider et al., 2015, Schneider et al., 2016a). This has been done by combining the water vapour isotolopogue profiles taken within MUSICA/AMISOC aircraft campaign in 2013 in the surrounding of Tenerife (Canary Island) (Dyroff et al., 2015) and the in-situ continuous water vapour measurements made at IZO and TPO since 2012 (González et al., 2016).

As observed in Figure 7.8, the {H_2O, δD} pair distributions obtained from the different remote sensors are consistent and allow distinct lower/middle tropospheric moisture pathways to be identified in agreement with multi-year in situ references (Schneider et al., 2016a).

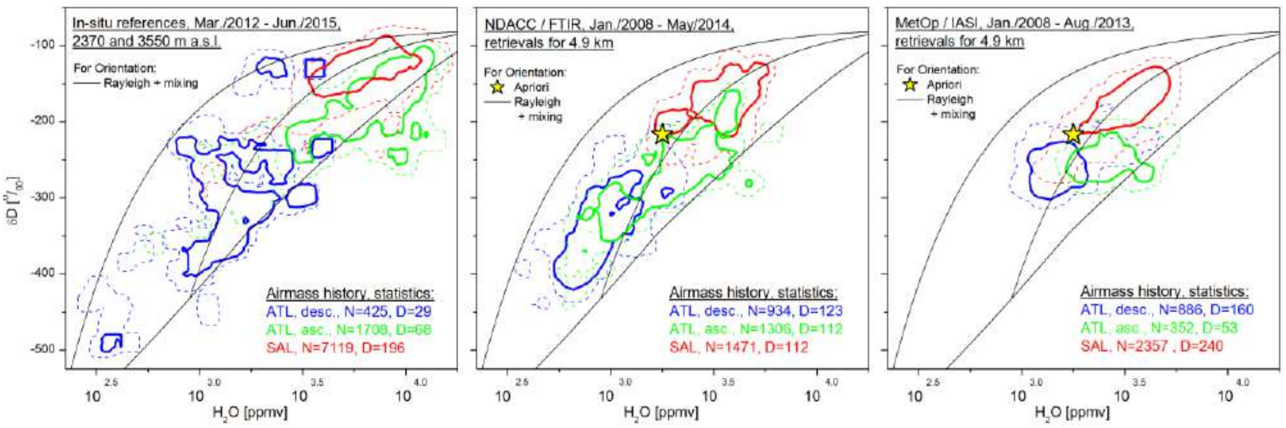

Figure 7.8. Free tropospheric {H_2O, δD} pair distributions as obtained by different measurement techniques in the surroundings of Tenerife. The contour lines indicate areas with the highest densities of the {H2O, δD} pairs: red denotes air masses that are clearly affected by dry convection over the African continent; blue and green denote Atlantic air masses with different pathways. The thin dashed and thick solid lines mark the areas that include 95% and 66% of all data, respectively. Left: two Picarro in-situ instruments (L2120-i) measuring during nighttime at 2390 and 3550 m a.s.l. (IZO and TPO). Middle: ground-based NDACC/FTIR located at Izaña. Right: space-based MetOp/IASI-A and MetOp/IASI-B observing in a 2ºx2º area south of the island. The yellow star marks the a priori value used for the remote sensing retrievals at 4.9 km. Reprinted from Schneider et al. (2016).

MUSICA also document the possibilities of the NDACC/FTIR instruments for climatological studies (due to long-term monitoring) (Schneider et al., 2012, Schneider et al., 2016a) and of the MetOp/IASI sensors for observing diurnal signals on a quasi-global scale with high horizontal resolution, and for validating tropospheric moisture pathways in atmospheric models (Schneider et al., 2016a; 2017).

The in-situ continuous water vapour measurements performed at IZO and TPO also allow us to investigate the moisture pathways to the subtropical free troposphere of the subtropical northern Atlantic. González et al. (2016) identified four principally different transport pathways. The air mass transport from high altitudes and high latitudes shows two different scenarios. The first scenario brings dry air masses to the stations, as the result of condensation events occurring at low temperatures. The second scenario brings humid air masses to the stations, due to cross-isentropic mixing with lower-level and more humid air during transport since last condensation (LC). The third pathway is transportation from lower latitudes and lower altitudes, whereby we can identify rain re-evaporation as an occasional source of moisture. The fourth pathway is linked to the African continent, where during summer dry convection processes over the Sahara very effectively inject humidity from the boundary layer to higher altitudes. As shown in Figure 7.8 (right panel), the different pathways leave distinct fingerprints on the measured H2O-δD pairs.

The MUSICA/IASI retrieval focuses on water vapour isotopologues, but also provides upper tropospheric CH_4 and N_2O as side products (Figure 7.9) (García et al., 2016b, 2016c). By comparing to coincident high precision aircraft vertical profiles taken within the HIAPER Pole-to-Pole Observations (HIPPO) project, we document that MUSICA/IASI products can capture the upper tropospheric CH_4 and N_2O variability (at ~300-350 hPa) with a precision of 2.1% (38.2 ppbv) for each individual IASI CH_4 observation. The precision is improved to 1.7% (32.1 ppbv) for IASI data that have been averaged within 2ºx2º boxes. For N_2O the empirically estimated precision is 2.7% (8.7 ppbv) for each individual observation and 2.1% (6.9 ppbv) for the 2ºx2º averages.

Moreover, we explore how the co-retrieved N_2O estimates could be successfully used for reducing common errors in the CH_4 retrievals. For the combined CH_4 product, the comparison with HIPPO data gives an empirical precision estimate of 1.5% (26.3 ppbv), when considering all individual IASI observations, and of 1.2% (21.8 ppbv) for the 2ºx2º averages. The quality of the MUSICA/IASI products allow us to identity the well known latitudinal gradients of CH_4 and N_2O, with a tendency to higher concentrations in low latitudes than in high latitudes (Figure 7.9).

In future work it should be examined as to what extent IASI observations of upper tropospheric CH_4 and N_2O variations can help to investigate the emission source patterns, transport pathways and sinks of CH_4 and N_2O, and whether the provision of a highly precise product ("CH_4 combined with N_2O") offers additional benefits for such research purposes.

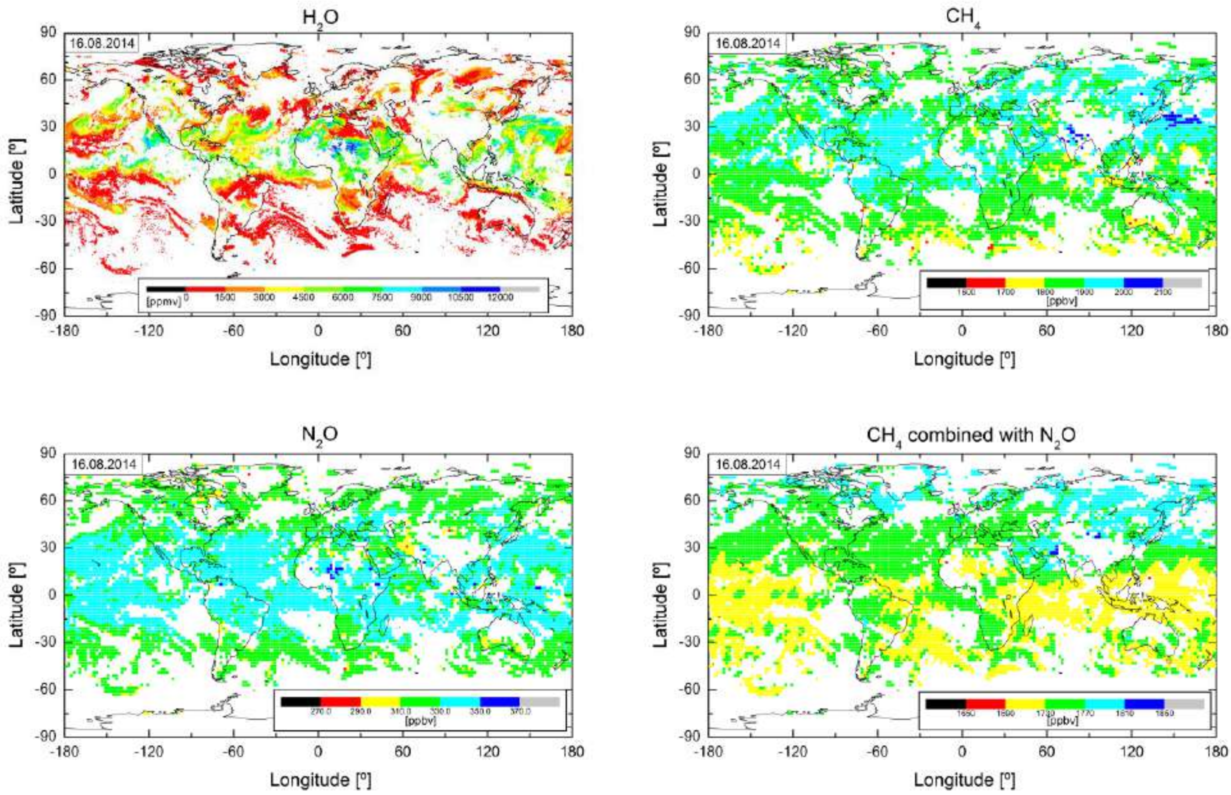

Figure 7.9. Example of the MUSICA/IASI-A VMR global maps for H_2O (upper left panel) at ~4.9 km for all individual IASI observations, and CH_4 (upper right panel), N_2O (bottom left panel), and CH_4 combined with N_2O (bottom right panel) at ~10 km for 2ºx2º averages on 16/08/2014. The H_2O global map is reprinted from Schneider et al. (2016), while the remaining maps are reprinted from García et al. (2016b).

7.4 Participation in Scientific Campaigns

7.4.1 ATMOZ campaign, September 2016

Together with the IARC's Brewer group (see Section 6), the FTIR spectrometer participated in the campaign ATMOZ (Traceability for atmospheric total column ozone, https://projects.pmodwrc.ch/atmoz/), carried out at the IARC during September 2016. This project aims to significantly enhance the reliability of total ozone column measured at the Earth surface with Dobson instruments, Brewer-Spectroradiometer and Array-Spectroradiometer. Our role was to provide coincident ozone measurements (total column amounts and vertical VMR profiles), used as auxiliary data.

7.4.2 ATOM campaign, July-September 2016

Within the Atmospheric Tomography Mission (ATom) the first mission out of the four planned ones was carried out during summer 2016 (July-September). ATom will study the impact of human activity on the levels of greenhouse gases and chemically reactive gases in the atmosphere. For this purpose, ATom deploys an extensive gas and aerosol payload on the NASA DC-8 aircraft for systematic, global-scale sampling of the atmosphere, profiling continuously from 0.2 to 12 km altitude. Flights will originate from the Armstrong Flight Research Center in Palmdale, California, fly north to the western Arctic, south to the South Pacific, east to the Atlantic, north to Greenland, and return to California across central North America. During the transect over the Atlantic Ocean in August 2016, the IARC FTIR was measuring in coincidence with the ATom DC-8 aircraft.

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7.6 Staff and collaborators

The FTIR research group (listed below) is composed of researchers and specialist technicians from the IARC-AEMET, from IMK-ASF-KIT, and from GOA-UVA:

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Dr Andreas Wiegele (IMK-ASF-KIT; Research Scientist, MUSICA group)

8 In situ Aerosols

8.1 Main Scientific Goals

Atmospheric aerosol is constituted by a mixing of natural (e.g. sea salt, desert dust or biogenic material) and anthropogenic (e.g. soot, industrial sulphate, nitrate, metals or combustion linked carbonaceous matter) airborne particles whose size range from a few nanometres (nm) to tens of microns (µm). Aerosols impair air quality with impacts on human health due to cardiovascular, cerebrovascular and respiratory diseases such as asthma and chronic obstructive pulmonary disease; they also influence climate by scattering and absorbing radiation and by influencing cloud formation and rainfall.

The activities of the In situ Aerosols programme are developed within the scientific priorities of the Global Atmosphere Watch programme. One of the main tasks of our group is to maintain the long-term observations of aerosols at IZO. These measurements improve the understanding of the potential long-term multi-decadal changes and trends of aerosols. Our investigations are focused on: 1) Long-term multi-decadal variability and trends of aerosols; 2) Aerosols and climate and 3) Aerosols and air quality.

8.2 Measurement Programme

The long-term in situ aerosols observation program of Izaña Atmospheric Observatory includes measurements of aerosol mass and number concentrations, chemical composition, size distribution and optical properties by in-situ techniques. Instruments are placed in the Aerosols Research Laboratory (ARL) (Fig. 8.1), a building equipped with a whole air inlet for conducting the aerosol sample to the on-line analysers (CPCs, SMPS, APS, MAAP, aethalometer, nephelometer) and two additional PM_{10} and $PM_{2.5}$ inlets for the aerosol samplers. In December 2015, two new instruments were acquired with economical support of the European Regional Development Fund (Table 3.2): a beta attenuation based PM_{10} monitor (Thermo 5014i) and a dichotomous microbalance based $PM_{2.5}$ and $PM_{2.5-10}$ analyser (TEOM™ 1405-DF). The interior of the PARTILAB is maintained at 22 ºC. Because of the low relative humidity (RH) in the outdoor ambient air (RH percentiles 25^{th}, 50^{th} and 75^{th} are 15%, 31% and 55%, respectively) driers are not needed. Measurements of number concentration, size distributions and optical properties of aerosols are performed with high time resolution (Table 3.2).

Figure 8.1. Aerosol Research Laboratory at Izaña Atmospheric Observatory.

For these automatic instruments, the QA/QC activities include:

- <daily checks> of the data and status of the instruments.
- <weekly checks> of the airflows and leak tests for some instruments (e.g. SMPS).
- <quarterly checks> includes measurements of the instrumental zero (24h filtered air) for all the instruments (CPCs, SMPS, APS, MAAP, aethalometer nephelometer) and calibration checks (e.g. nephelometer).
- <annual intercomparisons> for some instruments.
- participation in intercomparisons, e.g. those performed annually between 2010 and 2012 for CPCs and SPMS at El Arenosillo - Huelva (Gómez-Moreno et al., 2011, 2013) and those in the World Calibration Centre for Aerosols Physics in Leipzig – Germany for CPCs (Sep 2012) and absorption photometers (Nov 2005; Müller et al., 2011).

The procedure for these activities follows the recommendation of the GAW programme for aerosols.

The aerosols chemical composition programme is based on:

- the collection of aerosol samples on filters. Samples are collected at night to avoid the diurnal upslope winds that may bring material from the boundary layer,
- the determination of the aerosol mass concentrations by the gravimetric method. Filters are weighed, before and after sampling, at 20 ºC temperature and 30-35 % relative humidity in the Aerosol Filters Laboratory (Fig. 8.4) of the Izaña Atmospheric Research Centre (see Section 3.2.1). The procedure for weighing filters is similar to that described in EN-14907, except that we use a lower relative humidity (30-35 %) due to the relative humidity of the ambient air at IZO being much lower than the 50% stated by EN-14907.
- the determination of chemical composition which currently includes elemental composition (those

detected by IPC-AES, i.e. Al, Ca, Fe, Mg, K, Na,…), salts (SO_4^{2-}, NO_3^-, NH_4^+, Cl^-), organic carbon, elemental carbon and trace elements (those detected by IPC-MS, i.e. P, V, Ni, Cd, As, Sb, Sn,...).

The QA/QC procedure for the aerosol chemical composition programme includes:

- airflow checks and calibrations.
- the collection of blank field filters for gravimetry and chemical analysis.
- intercomparison exercises.

For the QA/QC activities, the group is equipped with four bubble flow-meter Gilibrators™ for measuring airflows from a few to tens of litres per minute (e.g. CPCs, SMPS, APS, MAAP, aethalometer nephelometer) and three pressure drop flow-meters for measuring airflows of tens of cubic metres per hour (e.g. samplers).

The World Calibration Centre for Aerosol Physics audited the IZO aerosol programme in Nov 2006 (Tuch and Nowak, 2006). An updated report dated March 2014 is available (Rodríguez et al., 2014a).

8.3 Summary of remarkable results during the period 2012-2014

During the 2015-2016 biennium, the In situ Aerosols group focused mostly on their research activities on desert dust and climate. Additional activities included urban air quality, black carbon (Milford et al., 2016, Domínguez-Rodríguez et al., 2015, 2016), ammonia (Reche et al., 2015), ultrafine particles (Fernández-Camacho et al., 2015; Gómez-Moreno et al., 2015) and water vapour research in collaboration with other groups of the IARC (González et al., 2016; Schneider et al., 2015, 2016).

Air quality studies on black carbon were performed in collaboration with the University of Huelva, Hospital Univeristario de Canarias and the US National Oceanic and Atmospheric Administration. Studies included measurements in several cities of Spain (Santa Cruz de Tenerife, Huelva and Seville) and high-resolution modelling with CAMx air quality coupled with MM5 meteorological model (Fig. 8.2; Milford et al., 2016). Investigations on the connection between exposure to black carbon and cardiovascular diseases were performed in collaboration with the Hospital Univeristario de Canarias (Domínguez-Rodríguez et al., 2015, 2016). The overall results indicate that continued reduction of black carbon from diesel on-road sources in these urban areas is indeed a priority in order to mitigate the impacts of black carbon on human health and on climate.

Dust research included dust long-term variability (Rodríguez et al., 2015), impact on visibility (Camino et al., 2015), fertilization of the ocean with iron (Ravelo-Pérez et al., 2016), ice nuclei (Conen et al., 2015; Boose et al., 2016) and new mineralogy schemes of global dust models (Pérez et al., 2016).

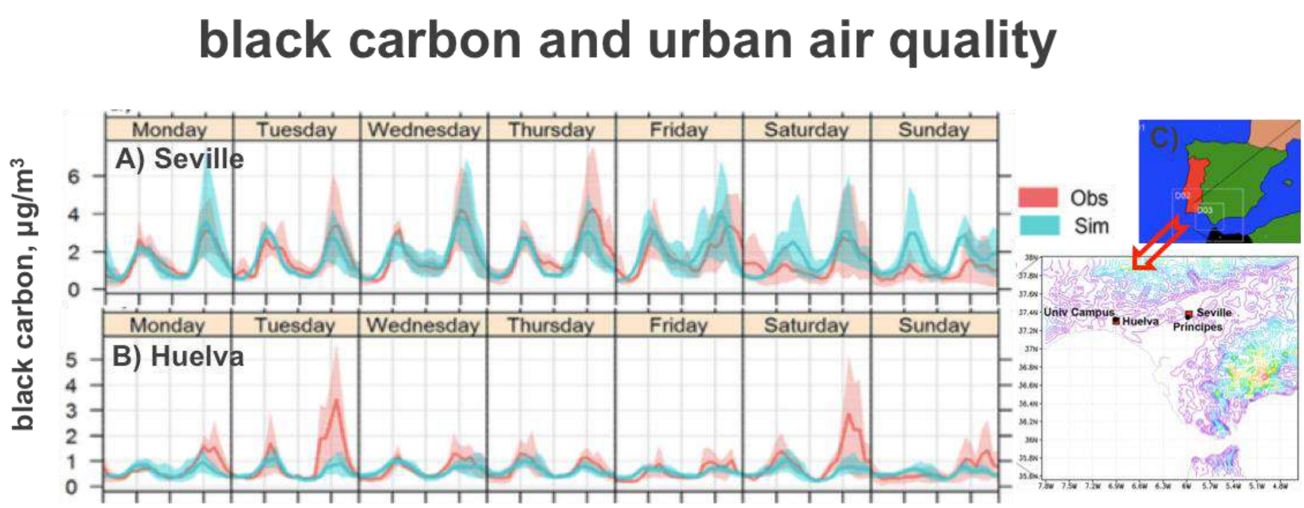

Figure 8.2. Mean daily evolution of black carbon concentrations for every day of the week in Seville and Huelva according to experimental data (obs) and modelling (sim). Reproduced from Milford et al. (2016).

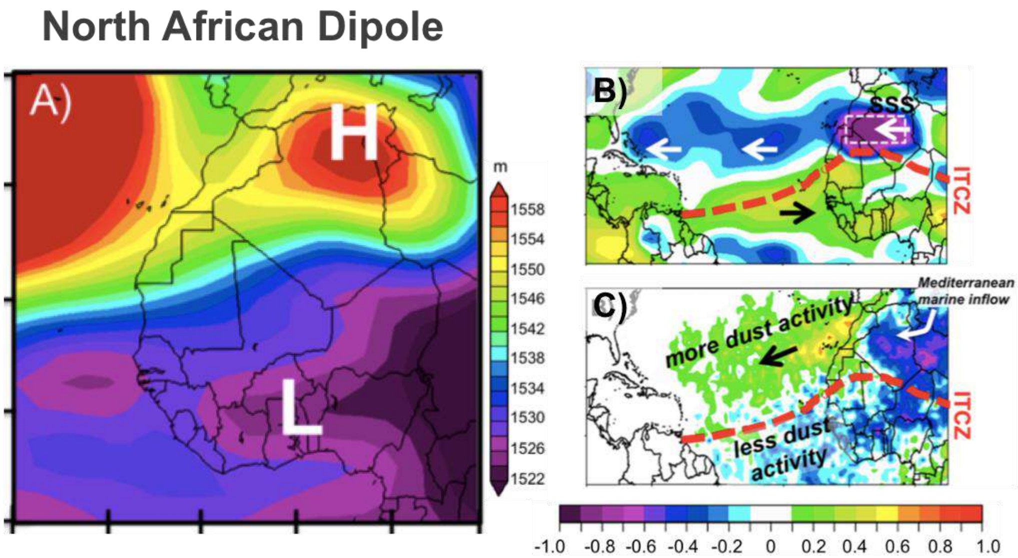

Figure 8.3. Average of the 850 hPa geopotential height for August (1987-2014) illustrating the High to Low configuration of the North African Dipole (A). Correlation coefficient of the mean value of the North African Dipole Intensity with zonal wind (A) and with Major Dust Activity Frequency (B) for August from 1987 to 2014. Reproduced from Rodríguez et al. (2015).

The long-term record of dust concentrations at Izaña was used, by the In situ Aerosols group and the University of Miami, for studying the summer-to-summer variability in dust export to the North Atlantic in the so-called Saharan Air Layer (Rodríguez et al., 2015). This variability was related to the summer meteorological conditions in North Africa, which is characterised by high pressures over northern Sahara and low pressure over the tropics linked to the monsoon (Fig. 8.3A); a condition to which we refer as North AFrican Dipole (NAFD) and whose Intensity (NAFDI) was measured as the difference of the anomaly of the 850hPa geopotential height over subtropics (Morocco) and over the tropic (Nigeria; Cuevas et al., 2016).

The high correlation between the three decades record of dust at Izaña with NAFDI (Fig. 8.4A) illustrates how dust export is highly related to the variability in meteorology, as described in detail in studies of the aerosol group, including its connection to the Saharan Heat Low (Rodríguez et al., 2015; Cuevas et al., 2016). Summers with high values of the NAFDI are associated with intense Harmattan winds in inner Sahara (Fig. 8.4B) and with a northward shift of the Saharan Air Layer (Fig. 8.3C). Throughout 3 decades, dust at Izaña has been significantly correlated with the zonal wind component of Harmattan winds in the inner Sahara (Fig. 8.4B). The low dust concentrations linked to a southern shift of the Saharan Air Layer during EL Niño periods and vice-versa during La Niña (Fig. 8.4A), point to a tele-connection with ENSO that is a subject being studied by the aerosol group.

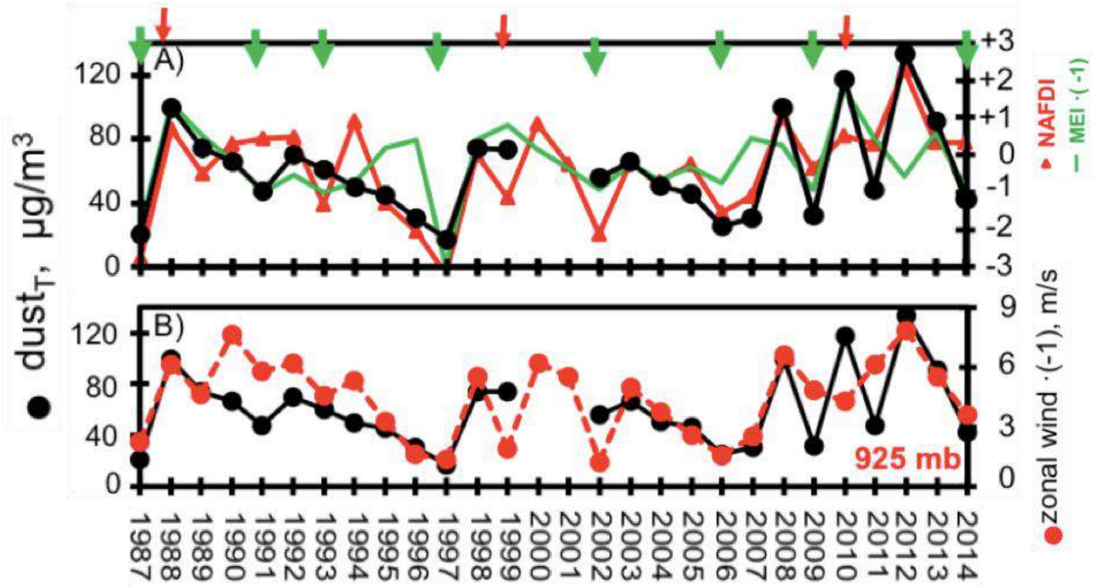

Figure 8.4. Mean values of dust concentrations at Izaña, North African Dipole Intensity (NAFDI), Multivariate ENSO Index (MEI) and zonal wind at 925 hPa levels in inner Algeria (Subtropical Saharan Stripe 25–28N, 7W–2E) for August from 1987 to 2014. Green and red arrows on the top indicate El Niño and La Niña conditions, respectively.

soluble iron study

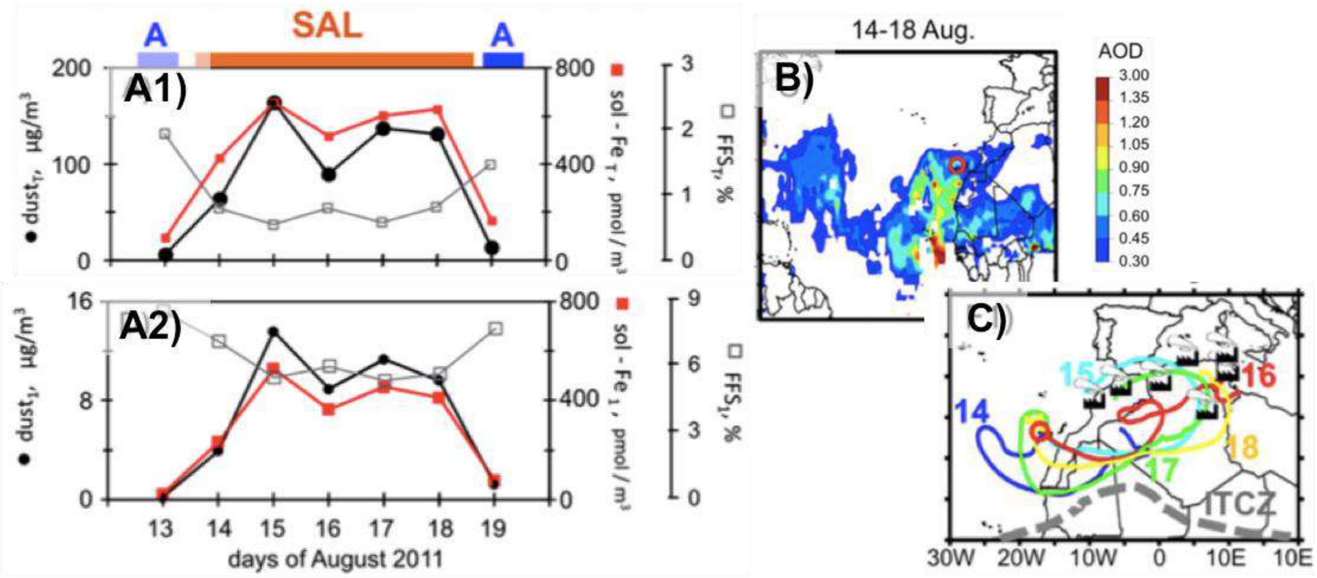

Figure 8.5 Concentrations of Saharan dust and soluble iron and fractional iron solubility (FFS) in total (A1) and in submicron (A2) aerosols at Izaña, Saharan Air Layer as detected in terms of Aerosol Optical Depth by MODIS (B) and backtrajectories (C) during the iron solubility study at Izaña. Reproduced from Ravelo-Pérez et al. (2016). Samples collected in the Saharan Air Layer (SAL) and Atlantic westerly airflow (A) are differentiate

The potential of Saharan dust to fertilize the ocean with soluble iron, and its implications on the ocean - atmosphere exchange of CO_2 (Schultz et al., 2012), was a matter of study at Izaña Atmospheric Observatory by the In situ Aerosols group in collaboration with the University of La Laguna (Ravelo-Pérez et al., 2016). Results showed that soluble iron in the Saharan Air Layer is linked to desert dust, mostly to the dissolution of submicron dust mineral (Fig. 8.5A and 8.5B).

The Fractional Fe Solubility (FFS = soluble iron to total iron ratio) plotted versus dust observations at Izaña show the inverse relationships identified in previous studies (Fig. 8.6A and 8.6B), with higher values in the submicron fraction than in total dust. However the new data evidences that there is a correlation between FFS and the ammonium-sulphate / dust ratio and this indicates that acid processing of dust, due to mixing with pollutants, may have enhanced the availability of soluble iron from the dust to the ocean (Fig. 8.6C). Previous studies of the aerosol group (Rodríguez et al., 2011) had already identified the presence of acids in the Saharan Air Layer, connected to industrial emissions (Fig. 8.5C). Because of the synoptic scale of the Saharan Air Layer, this role of the acid processing may have large scale implications.

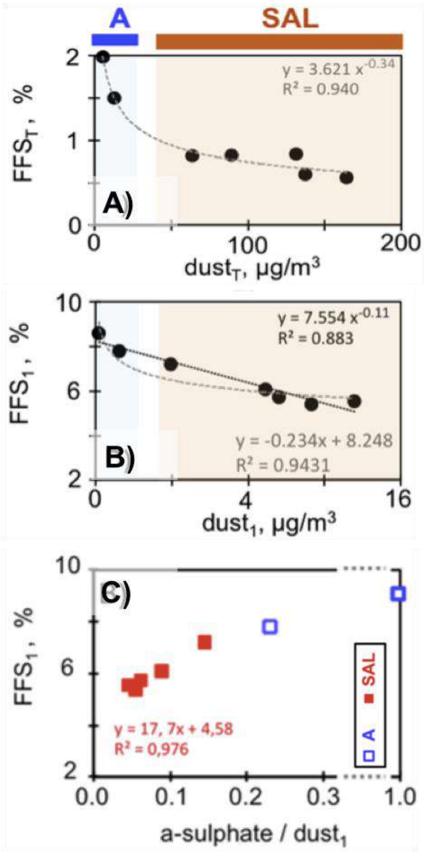

Figure 8.6. Fractional total Iron Solubility (FFST) versus total dust (A) and Fractional submicron Iron Solubility (FFS1) versus submicron dust (B) and versus the submicron ammonium-sulphate / dust ratio (C). Reproduced from Ravelo-Pérez et al. (2016). Samples collected in the Saharan Air Layer (SAL) and Atlantic westerly airflow (A) are differentiated)

8.4 Participation in Scientific Campaigns

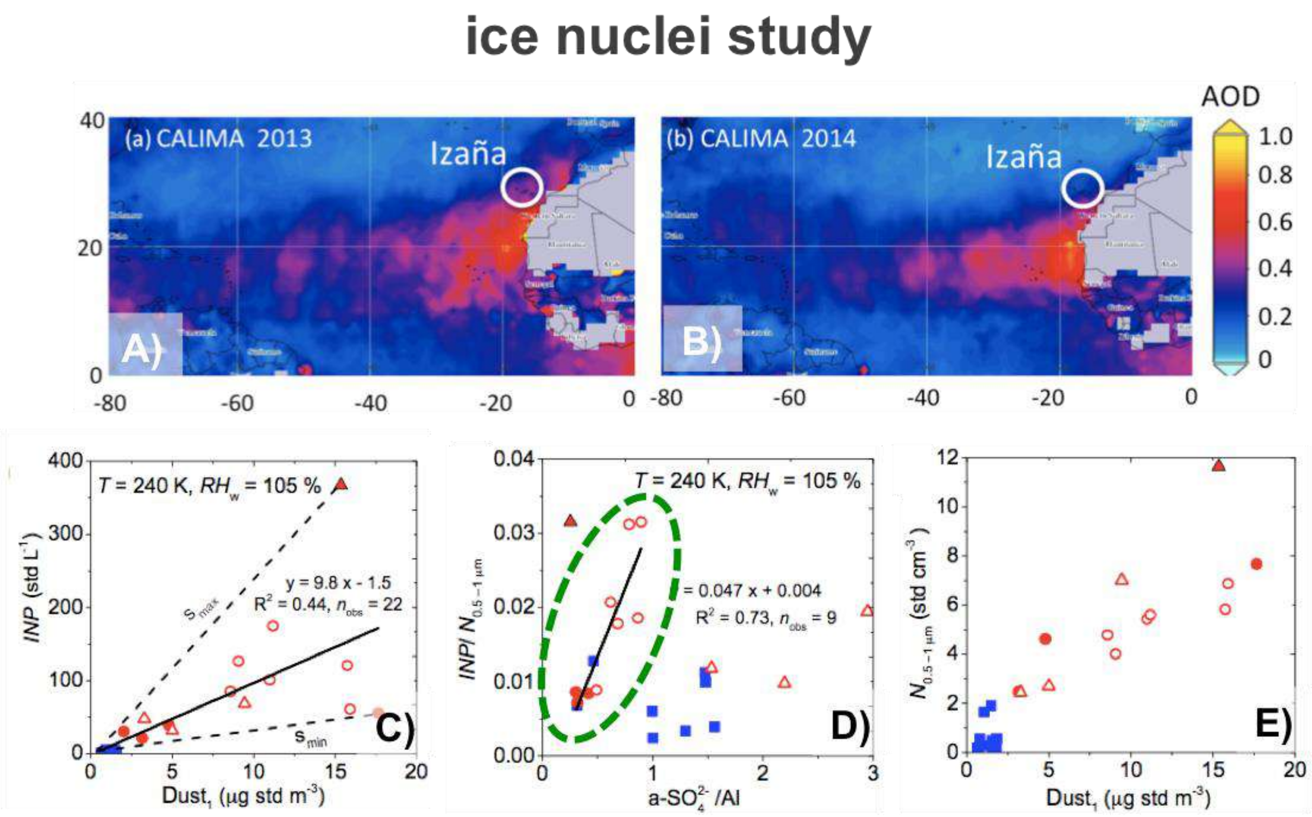

Figure 8.7 Saharan Air Layer as detected in terms of Aerosol Optical Depth (AOD) by MODIS in the 2013 (A) and 2014 (B) CALIMA studies. Concentrations of Ice Nuclei Particles (INP) versus dust in the submicron fraction (C). Ice Nuclei Particles to number of particles (N) of 0.5 to 1 µm diameter ratio versus ammonium sulphate to Aluminium ratio (D). Number of particles (N) of 0.5 to 1 µm versus submicron dust concentrations (E). Reproduced from Boose et al. (2016).

The objective of the Cloud, Aerosols and Ice Measurements in the Saharan Air Layer (CALIMA) study was to measure the ability of Saharan dust particles to act as nuclei for ice and cloud droplets (Fig. 8.7A and 8.7B). This field measurement campaign was performed at IZO by scientists of the Institute for Atmospheric and Climate Science of Zürich and of the In situ Aerosols group of the Izaña Atmospheric Research Centre (Boose et al., 2016). Ice nuclei particle concentrations were measured in the deposition and condensation mode at temperatures between 233 and 253 K with the Portable Ice Nucleation Chamber. Additional aerosol measurements included bulk chemical composition, concentration of fluorescent biological particles and particle size distribution.

The concentrations of ice nuclei particles showed a good correlation with bulk dust concentrations (Fig. 8.7C), especially with the abundance of aluminium, iron, magnesium and manganese and a lower correlation with calcium, sodium or carbonate; this is consistent with earlier laboratory studies which showed a higher ice nucleation efficiency of certain feldspar and clay minerals compared to other types of mineral dust. An increase of the ammonium sulphate abundance (linked to anthropogenic emissions in upwind distant anthropogenic sources) mixed with the desert dust has a small positive effect on the condensation mode of ice nucleation particles per dust mass ratio but no effect on the deposition mode (Fig. 8.7D). Overall results suggest that atmospheric aging processes in the Saharan Air Layer can lead to an increase in ice nucleation ability of mineral dust from the Sahara.

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9 Column Aerosols

9.1 Main Scientific Goals

The main scientific goals of this programme are:

- Long-term high quality measurements of column aerosol properties in the FT and the MBL.
- Aerosol characterization in the Saharan Air Layer and Marine Boundary Layer.
- Development of new methodologies and instrumentation for column aerosols and water vapour observations, as well as new calibration techniques.
- Mineral dust model validation.
- Satellite borne aerosol data validation.
- Provision of accurate sun and lunar photometer calibrations and intercomparisons.

9.2 Measurement Programme

The measurement programme is very extensive and includes remote sensing sensors at three of the IARC stations, IZO, SCO and TPO (see Tables 3.2, 3.4 and 3.6) and in collaborative stations abroad. At present, the IARC is one of three partners of the AERONET-EUROPE Calibration Service (Fig. 9.1) (see Section 16 for more details). The AERONET-EUROPE Calibration Service was financed by the Aerosol Cloud and TRace gas InfraStructure (ACTRIS) European Research Infrastructure Action until April 2015. Since May 2015, AERONET-EUROPE Calibration Service has been financed by the project ACTRIS-2 Integrating Activities, receiving funding from the European Union's Horizon 2020 research and innovation programme.

The IARC manages the AERONET sites of IZO, SCO, Tamanrasset (Algeria), Cairo (Egypt), and Tunis (Tunisia). This unique network provides dust information near dust sources over the Sahara and is a key observational facility, within the SDS-WAS Regional Center (see Section 18), for dust modelling, verification and validation of the satellite-based aerosol products.

Figure 9.1. Cimel masters of the AERONET-EUROPE Calibration Facility at Izaña Atmospheric Observatory.

Figure 9.2. Cimel at Teide Peak Observatory (TPO).

Another important quality assurance activity is the annual calibration, since 2011, of the Cimel sun photometer Masters of the China Aerosol Remote Sensing NETwork (CARSNET) managed by the China Meteorological Administration (CMA; Key Laboratory of Atmospheric Chemistry, Centre for Atmosphere Watch and Services, Chinese Academy of Meteorological Sciences). CARSNET has 37 operational sites including the Waliguan global GAW station (Che et al., 2009).

Langley calibrations of AERONET Cimel sun photometers are complemented with laboratory radiance calibration using the integrating sphere of the Optical calibration facility at IZO (Guirado et al., 2012). IZO, besides being a station of the GAW-PFR network is one of the pristine conditions sites, together with Mauna-Loa, to perform Langley calibrations of the World Radiation Center PFR-Master (Wehrli, 2000; Kouremeti et al., 2016).

The IARC and the Spanish Institute for Aerospace Technology (PI: Dr Margarita Yela) co-manage a Micropluse lidar (MPL) aerosols programme, which started a long-term observation programme in 2005. The instrument is part of the NASA MPLNET worldwide aerosol lidar network. It operates in full-time continuous mode (24 hours a day / 365 days a year) except around noon time periods during the summer solstice. The instrument operated at SCO is the unique aerosol lidar in Northern Africa that provides information about the vertical structure of the Saharan Air Layer over the North Atlantic. The main characteristics of the MPL are detailed in Table 9.1.

Table 9.1. Technical characteristics of the Micro-Pulse Lidar (MPL) at Santa Cruz de Tenerife Observatory.

Micro-Pulse Lidar version 3 (MPL-3)	
Transmitter	
Laser	Nd:YLF
Wavelength	523 nm
Pulse repetition rate	2500 Hz
Pulse energy	7-10 µJ
Receiver	
Type	Schmidt-Cassegrain
Diameter	20 cm
Focal	200 mm
Field of view	100 µrad
Detector	
Type	Avalanche photodiode (APD)
Mode	Photocounting

The IARC has acquired a new lidar, the CE376, from Cimel Electronique, which works at two wavelengths (532 & NIR < 850 nm) with two depolarization channels. This lidar was purchased as part of the project "Equipment for greenhouse gases and aerosols monitoring and research at the Izaña Global Atmospheric Watch observatory", financed by the Ministry of Economy and Competitiveness (MINECO) of Spain (specific competitive call for research infrastructures). The project is supported (80%) by MINECO using European Regional Development Funds, and (20%) by AEMET.

This new lidar, which was installed at SCO in late December 2015 (Figure 9.3), complements the existing MPL, its main mission is to characterize the Saharan Air Layer (SAL) and cloudiness (mainly cirrus and altostratus associated to the top of the SAL) using synergy with a network of AERONET photometers located at three altitudes (SCO, IZO and PT O).

During 2016, the CE376 was incorporated into the IARC Column Aerosol observation programme, and the corresponding measurement, calibration and maintenance protocols have been implemented.

The main technical characteristics of the CE376 lidar are shown in Table 9.2.

Table 9.2 Technical characteristics of the CE376 Lidar at Santa Cruz de Tenerife Observatory.

Cimel CE376 lidar	
Transmitter	
Laser	Green laser: frequency doubled Nd:YAG NIR laser: pulsed laser diode
Wavelength	Green: 532 nm NIR: < 850 nm
Pulse repetition rate	5000 Hz
Pulse energy	Green: 5-10 µJ NIR: 3-5 µJ
Receiver	
Type	Galilean
Diameter	10 cm for both emission and reception
Focal	200 mm
Total beam divergence	Emission: Green: 100 µrad, NIR: <250 µrad Reception : Green: 200 µrad, NIR: <300 µrad
Detector	
Type	Avalanche photodiode (APD) APD QE 55% / 70%
Mode	Photocounting

As part of the WMO Commission for Instruments and Methods of Observations (WMO-CIMO) Izaña Testbed for Aerosols and Water Vapour Remote Sensing Instruments some activities related to column aerosol measurements, and specifically with methodological and instrument developments have been undertaken (see Sections 21 and 22).

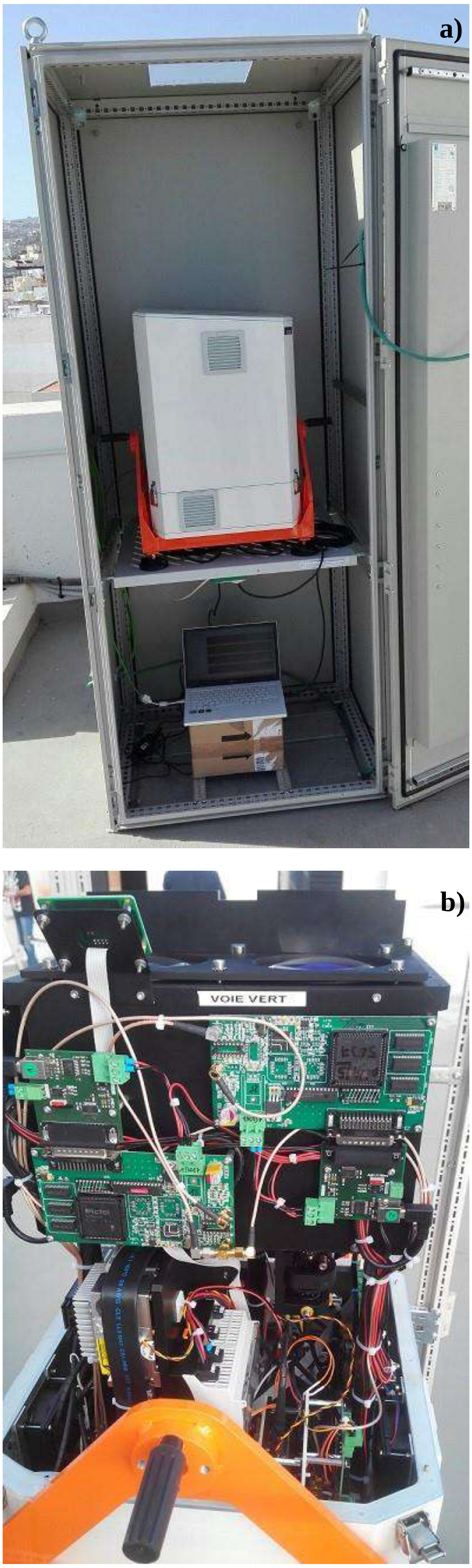

Figure 9.3 The new Cimel CE376 lidar: a) in the thermostatized enclosure on the Santa Cruz Observatory instrument terrace and b) different details of the instrument.

9.3 Summary of remarkable results during the period 2015-2016

The most relevant results obtained during the reporting period are summarized hereinafter.

9.3.1 Characterization of aerosols in the subtropical region

"Characterization of the total column aerosol properties in the subtropical region" was the title of the PhD Thesis defended by Dr Carmen Guirado and supervised by Dr Emilio Cuevas and Dr Ángel de Frutos at the University of Valladolid in June 2015. The characterization of atmospheric aerosols performed in this study focused on a wide area from the subtropical region of the northern hemisphere, encompassing the Sahara desert and the subtropical North East Atlantic. Firstly, the design and implementation of an optical calibration lab at the Izaña Atmospheric Observatory was described. Secondly, properties of atmospheric aerosols in the Saharan continental layer, the marine boundary layer and clean conditions of the free troposphere, from a relatively long series of data obtained from sun photometry and auxiliary information, were analyzed and characterized. For more details, see section 26.

9.3.2 Aerosol optical depth retrievals between 1941 and 2013

A 73-year time series of the daily AOD at 500 nm has been reconstructed at IZO (Figure 9.4). For this purpose, we have combined AOD estimates from artificial neural networks (ANNs) from 1941 to 2001, and AOD measurements from a Precision Filter Radiometer (PFR) between 2003 and 2013. The analysis is limited to summer months (July–August–September), when the largest aerosol load is observed at IZO (Saharan mineral dust particles).

The ANN AOD time series has been comprehensively validated against coincident AOD measurements performed with a solar spectrometer Mark-I (1984–2009) and AERONET CIMEL photometers (2004–2009) at IZO, obtaining a rather good agreement on a daily basis: Pearson coefficient, R, of 0.97 between AERONET and ANN AOD, and 0.93 between Mark-I and ANN AOD estimates.

In addition, we have analysed the long-term consistency between ANN AOD time series and long-term meteorological records identifying Saharan mineral dust events at IZO (synoptical observations and local wind records). Both analyses provide consistent results, with Pearson coefficient (R) > 0.85 (Figure 9.5).

Therefore, we can conclude that the reconstructed AOD time series captures well the interannual AOD variations and dust-laden Saharan air mass outbreaks on short-term and long-term timescales and, thus, it is suitable to be used in climate analysis (Garcia et al., 2016).

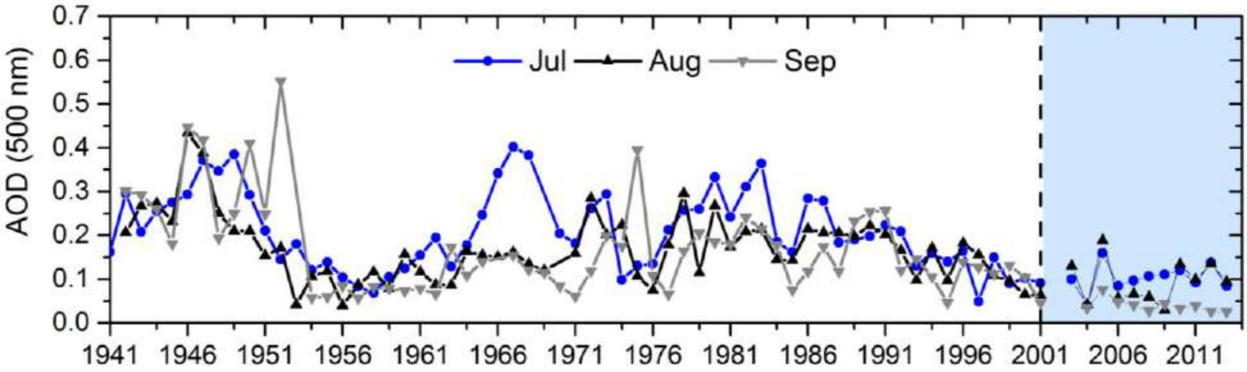

Figure 9.4 Times series of the AOD estimates from artificial neural networks from 1941 to 2001, and AOD measurements from a Precision Filter Radiometer between 2003 and 2013 at IZO. AOD are monthly medians (July, August and September) at 500 nm.

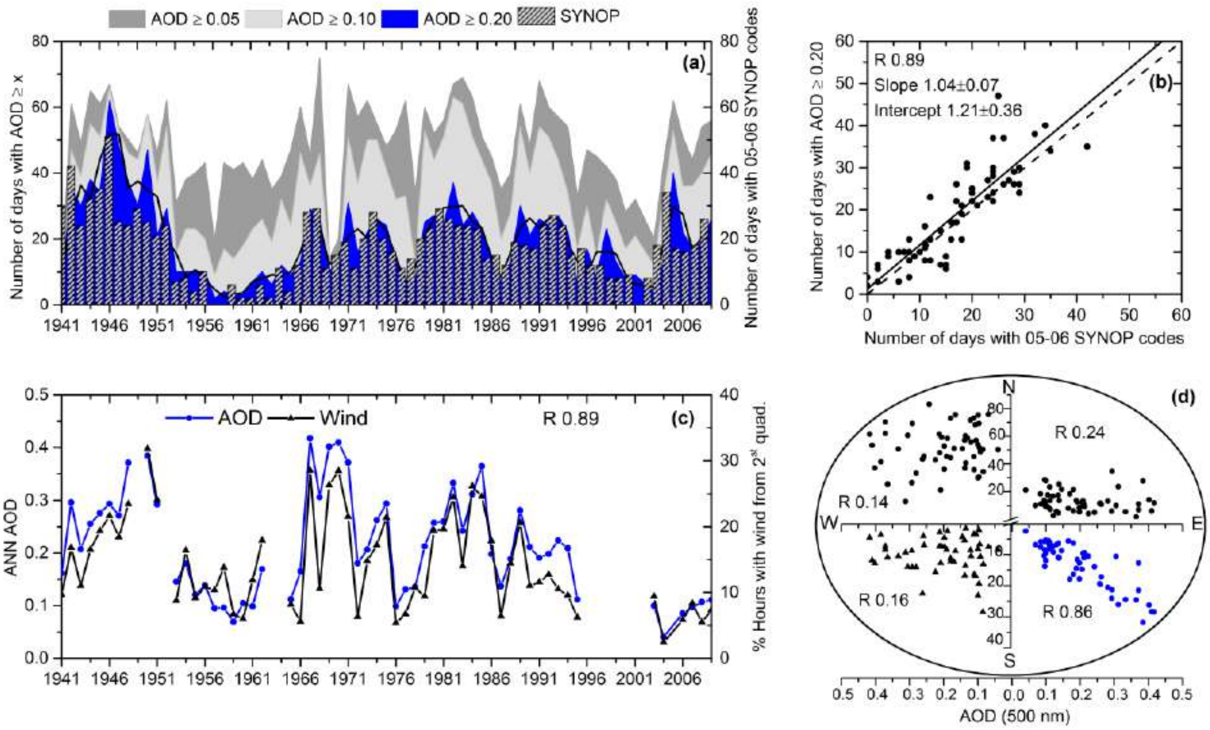

Figure 9.5 (a) Time series of the number of days grouped into ANN AOD intervals (AOD≥0.05; AOD≥0.10; AOD≥0.20) on the left axis, while on the right axis, the bars indicate the number of days with SYNOP data reporting dust in suspension (05–06 SYNOP codes) for the period 1941–2009. The 5-year running mean are shown in black. (b) Scatterplot of number of days with ANN AOD≥0.20 and number of days with 05–06 SYNOP codes. The least-square fit parameters are shown in the legend. (c) Time series of the ANN AOD monthly medians (blue line) and monthly percentage of time the wind blows from the second quadrant (E–S; 90°-180°) (black line) at IZO in July in the period 1941–2009. (d) Percentage of time (y axis) the wind blows from in each one of the four quadrants vs. the ANN AOD monthly medians (x axis). R indicates the Pearson coefficient. Reprinted from Garcia et al., 2016.

9.3.3 Studies on aerosol AOD model evaluation

A new study on validation of mineral dust products from the Monitoring Atmospheric Composition & Climate, Phase II (MACC-II) model from the European Centre for Medium-Range Weather Forecasts (ECMWF) was conducted (Cuevas et al., 2015). This work evaluated the quality of different mineral dust products from a reanalysis of the MACC-II/ECMWF model, which was specially optimized for atmospheric mineral dust parameters for the period 2007-2008 in a large region covering northern Africa, the Middle East and Europe.

The evaluation was carried out in a geographical domain of great interest because it includes two of the most important mineral dust sources in the world: the Sahara-Sahel and the Middle East (Arabian Peninsula and surrounding countries). This evaluation is one of the most comprehensive that has been made to date.

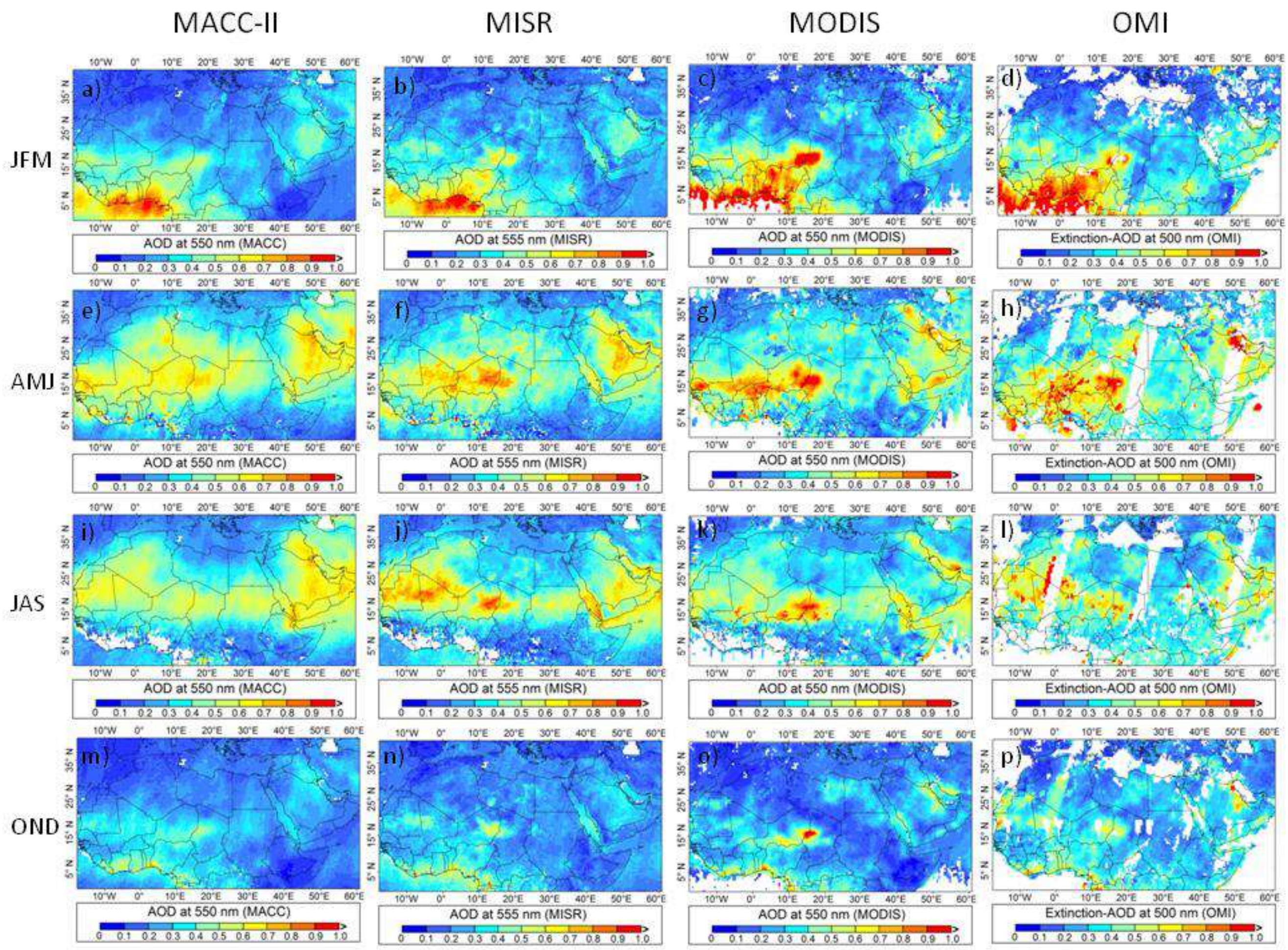

Figure 9.6. Spatial distribution of seasonal AOD averages from MACC-II, MISR, MODIS and OMI for the period 2007–2008. Winter (JFM), spring (AMJ), summer (JAS) and autumn (OND). Reprinted from Cuevas et al., 2015.

We used spatial distributions of AOD from three sensors flying aboard satellites (MISR, MODIS and OMI) using MISR (Multi-angle Imaging Spectroradiometer) as a reference. In addition we used in-situ measurements in 26 AERONET stations located in eight geographically distinct regions, PM_{10} in-situ concentrations (surface dust concentration) at three stations in the Sahel, part of the African Monsoon Multidisciplinary Analysis (AMMA) project, vertical extinction profiles at two ground lidar sites located in Tenerife (Spain) and M'Bour (Senegal), respectively, and CALIOP (Cloud-Aerosol lidar with Orthogonal Polarization) aboard CALIPSO.

Daily, monthly, seasonal and interannual variability of different parameters accounting for atmospheric dust content were analyzed, and a critical analysis of the limitations of the observations used in this validation exercise, was made since mineral dust is not measured directly by any of the observation techniques.

The results of this study show that the spatial and temporal variability (seasonal and interannual) of aerosol optical depth shows excellent agreement between model simulations and satellite retrievals. The ability of MACC-II to reproduce AOD, Ångström exponent (AE) and dust optical depth (DOD), on both a daily and a seasonal scale, is very good in all studied regions, although the correlation is significantly higher in dust transport regions (Mediterranean basin and North Atlantic) than in dust source regions (Sahara and Arabian peninsula). MACC-II also resolves well the dust vertical distribution above the marine mixing layer, and shows a fairly good agreement with the daily, seasonal and interannual variations of PM_{10} at the three stations forming the Sahelian transect.

Dust data from MACC-II reanalysis may play an important role in health and energy (solar energy) related activities in regions where little observational data on-site are available and where satellites have great difficulty to provide accurate observations due to high ground reflectivity (desert areas).

This work was performed as part of the MACC-II project activities in which AEMET actively participates representing the "Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)" Regional Center for Northern Africa, Middle East and Europe, operated jointly with the BSC (see Section 18).

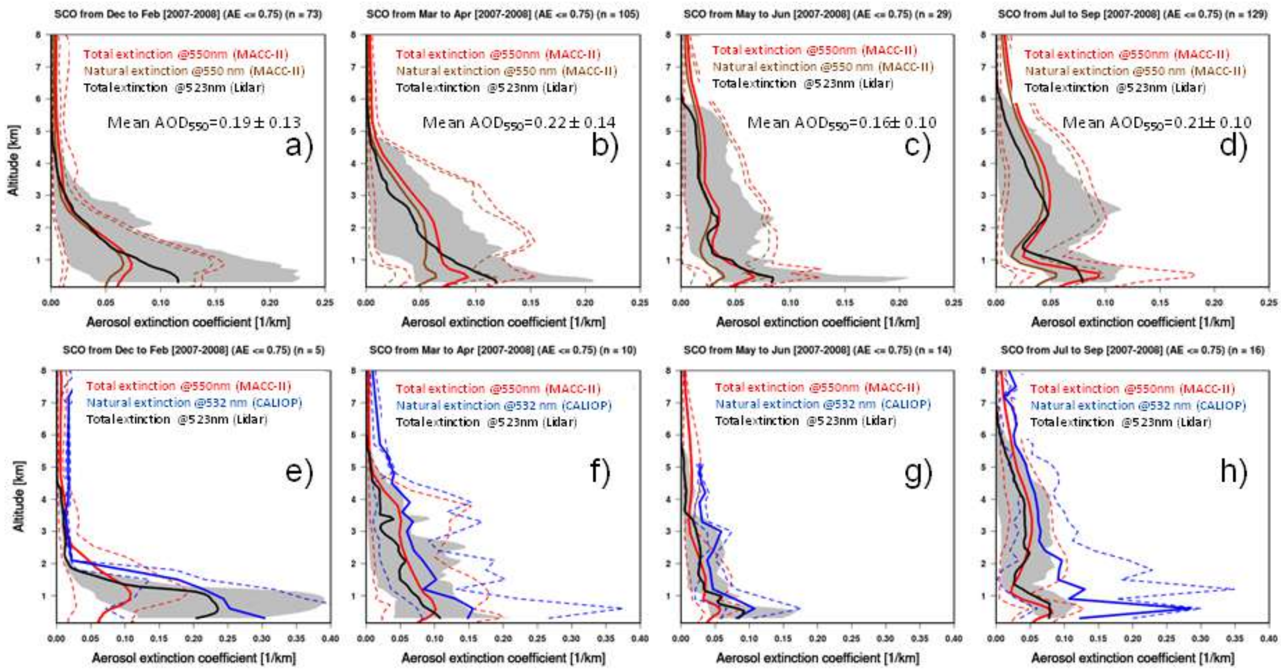

Figure 9.7. Vertical profiles of averaged optical extinction, for different seasons, from MACC-II (red), the MPL lidar at Santa Cruz de Tenerife (black), and CALIOP / CALIPSO (blue). Reprinted from Cuevas et al., 2015.

Also in the framework of the WMO SDS-WAS we participated in a study aimed to evaluate the predictions of five state-of-the-art dust forecast models during an intense Saharan dust outbreak affecting western and northern Europe in April 2011 (Huneeus et al., 2016). The capacity of the models to predict the evolution of the dust cloud with lead-times of up to 72 h using observations of AOD from AERONET and the Moderate Resolution Imaging Spectroradiometer (MODIS), and dust surface concentrations from a ground-based measurement network was assessed.

9.3.4 A new empirical equation relating visibility to PM_{10} concentration in North Africa

A new empirical equation to estimate surface mineral dust concentration (PM_{10}) from in situ visibility observations in Northern Africa was published in the journal Aeolian Research (Camino et al., 2015).

The determination of a new empirical equation (IZO-Eq) relating horizontal visibility and mineral desert dust concentration (PM_{10}) was obtained at the Izaña Atmospheric Observatory (IZO), using data recorded during Saharan dust intrusions between 2003 and 2010. This equation was validated in the Sahel region during the dry and wet seasons (2006-2008) using data from two PM_{10} monitoring stations from the African Monsoon Multidisciplinary Analysis project, and data from the nearest synoptic weather stations.

The PM_{10} estimated by IZO-Eq has been compared with PM_{10} estimated by other empirical equations and with surface dust concentrations simulated by the NMMB/BSC-Dust model. IZO-Eq demonstrates a better performance than the other equations. IZO-Eq is also able to reproduce the variability of surface dust concentration simulated by NMMB/BSC-dust.

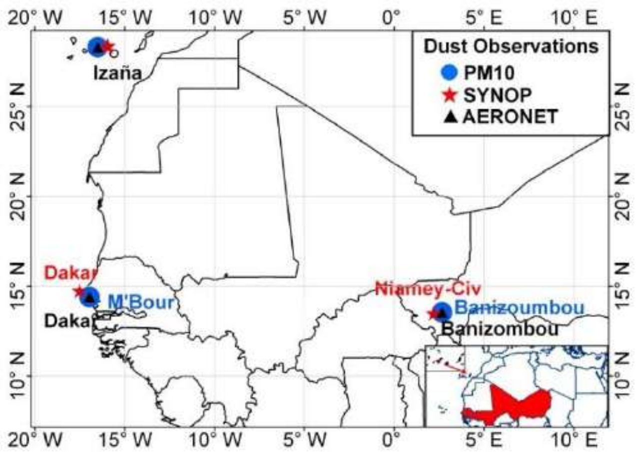

Figure 9.8. Location of the PM_{10} monitoring sites (blue circles), meteorological stations (red stars) and AERONET stations (black triangles) used in the analysis. Reprinted from Camino et al., 2015.

For visibilities > 10 km, empirical equations cannot be used to estimate PM_{10}, since above this threshold the equations estimate a nearly constant PM_{10} value regardless of the visibility range. This article also provides a performance review of the visibility-PM_{10} empirical equations most widely used today. This work was performed within the framework of the European project MACC-II.

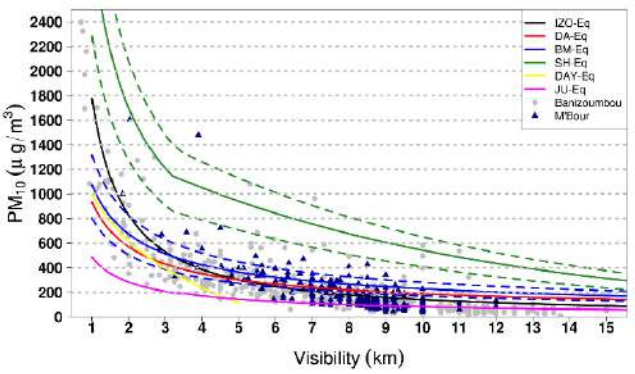

Figure 9.9. PM_{10} daily means (μg/m3) versus visibility daily means (km) for each AMMA site during the dry season for the period 2006-2008. Banizoumbou and M'Bour are represented by grey dots and blue triangles, respectively. Lines represent the estimated PM_{10} by IZO-Eq (black), DA-Eq (red), BM-Eq (yellow), SH-Eq (green) and DAY-Eq (purple). Since BM-Eq and SH-Eq provide TSP, the estimated values are converted to PM_{10} using an averaged TSP/PM_{10} ratio of 0.80 obtained at Banizoumbou station. Reprinted from Camino et al., 2015.

9.3.5 Satellite products evaluation

The aerosol radiative effects that influence the accuracy of retrieval of shortwave ground net radiation between 400 and 900 nm, from the Operational Land Imager (OLI), the new generation sensor of the Landsat mission, were assessed and published in Bassani et al. (2016). The analysis of the aerosol effects on the shortwave net radiation was carried out on a spectrally-homogeneous desert area located in the southwestern Nile Delta. The results reveal that the shortwave net radiation available for energy exchange between the land and atmosphere reduces the accuracy when the local aerosol microphysical properties are not considered during the space data processing. Consequently, these findings suggest that the aerosol type should be considered for variables retrieved from satellite observations that are related to the energy exchange in the natural ecosystems, such as Photosynthetically-Active Radiation (PAR). This will also improve the accuracy of land monitoring and of estimates of the solar energy availability for power generation when space data are used.

9.3.6 Aerosol vertical profiles

The vertical profiles of extinction obtained with MPL over Tenerife have been used in various studies, for example: to obtain preliminary statistics of the vertical structure of aerosols in the subtropical region, to validate the MACC-II reanalysis (Cuevas et al., 2015; see section 9.3.3.) and for validation of nocturnal AOD Lunar-Cimel (Barreto et al., 2016).

A study about the impact of Saharan dust intrusions on the vertical distribution of aerosol mass concentration was published by Córdoba-Jabonero et al., 2016. This study is based on simultaneous ground-based, remote-sensing and airborne in-situ measurements performed during the AMISOC-TNF campaign over the Tenerife area in summertime from 1 July to 11 August 2013. The synergy between Lidar observations and airborne measurements was established in terms of the Mass Extinction Efficiency (MEE) to calculate the vertical distribution of aerosol mass concentration of Saharan dust particles. Both the optical and microphysical profilings showed dust particles mostly confined in a layer of 4.3 km thickness from 1.7 to 6 km height. Lidar Ratio (LR) ranged between 50 and 55 sr, typical values for Saharan dust particles. In addition, it was observed that dust events mostly affected the Free Troposphere, being less intense in the Boundary Layer, which is mostly affected by gravitational settling. The use of an assumed averaged MEE value can be especially critical for estimating the mass concentration of particular layers. Moreover, the potential of MAXDOAS retrieval for aerosol extinction profiling is also evidenced by showing a relatively good agreement with the Lidar-derived extinction profiles, once a particular smoothing procedure is applied to Lidar measurements.

We also participated in a study on Cirrus cloud (Ci) features observed in late autumn/early winter season at both subtropical and polar latitudes (See Córdoba-Jabonero et al., 2017). Lidar measurements were carried out in three stations: São Paulo (MSP, Brazil), and Tenerife (SCO), as subtropical sites, and the polar Belgrano II base (BEL, Argentina) in the Antarctic continent. The backscattering ratio (BSR) profiles and the top and base heights of the Ci layers together with their Cirrus Cloud Optical Depth (CCOD) and Lidar Ratio for Ci clouds were derived. In addition, temperatures at the top and base boundaries of the Ci clouds were also obtained from local radiosoundings to verify pure ice Ci clouds occurrence using a given temperature top threshold (−38 °C).

9.3.7 Development of new methodologies and techniques to derive AOD and AE and column water vapour

Two important methodological and instrumental developments were carried out in the reporting period. One was the comprehensive performance evaluation of the new sun-sky-lunar C318-T multiband photometer (Barreto et al., 2016), and the other one was the development of the new zenith-looking narrow-band radiometer-based system (ZEN) for Dust AOD determination (Almansa et al., 2016). For further details see Section 22 (Technological Projects).

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10 Radiation

The radiation programme, and specifically the implementation of its core component, the Baseline Surface Radiation Network (BSRN) programme, has been performed in close collaboration with the University of Valladolid Atmospheric Optics Group.

10.1 Main Scientific Goals

The main scientific goals of this programme are:

- To conduct high quality measurement of radiation parameters.
- To investigate the variations of the solar radiation balance and other solar energy parameters in the three radiation stations managed by the IARC.
- To investigate aerosols radiative forcing with a particular focus on the role played by dust taking advantage of the privileged situation of the Canary Islands to analyse dust outbreaks over the North Atlantic and the unique local radiation network with stations at different altitudes (from sea level to 3555 m a.s.l.).
- To recover, digitize and analyse historical radiation data in order to reconstruct long-term radiation series that allow us to make precise studies concerning sky darkening and brightening, and relate radiation to cloud cover and solar flux.
- To conduct the spectral characterization of the solar radiation: impacts of different types of clouds, aerosols, especially mineral dust, and precipitable water vapour.

10.2 Measurement Programme

Direct radiation records from an Abbot silver-disk pyrheliometer are available since 1916, although this information has not yet been analysed. Global solar radiation records from a bimetallic pyranograph are available both in bands and as daily integrated values in printed lists, since 1977. This information has been digitized, recalibrated and processed. The results show an excellent agreement between the bimetallic pyranograph and the BSRN CM21 pyranometer, which allowed the successful reconstruction of a long-term global radiation data series (since 1977), after a careful analysis of historical data (see section 10.3.1).

Global and direct radiation measurements started in 1992 as part of a solar radiation project of the Canary Islands Government. In 2005, IZO joined the Spanish radiation network managed by the AEMET National Radiation Center (CNR). Since 2009, IZO has been a BSRN station providing the basic set of radiation parameters. In addition, other parameters, including shortwave and long wave upward radiation, UV-A and UV-B radiation are also measured within the BSRN Programme. Later, some basic radiation measurements were implemented at the other three IARC measurement stations (SCO, TPO and BTO).

Radiation measurements are tested against physically possible and globally extremely rare limits, as defined and used in the BSRN recommended data quality control. Shortwave downward radiation (SDR) measurements are compared daily with SDR simulations, which are modelled with the LibRadtran model. This information has been implemented and shared in the web page http://bsrn.aemet.es/, where real time measurements of global, direct, diffuse and UV-B radiation are shown.

Measurements of spectral direct solar radiation (spectral direct normal irradiance) performed with an EKO MS-711 spectroradiometer (Fig. 10.1) started in 2016. This instrument covers a wavelength range from 300 to 1100 nm, exhibiting a Full Width at Half Maximum < 7 nm. It is equipped with its own built-in entrance optics, and the housing is temperature-stabilized at 25°±5° (Egli et al., 2016). The main specifications of the EKO MS-711 are given in Table 10.1.

Table 10.1. Main specifications of the EKO MS-711 spectroradiometer

EKO MS-711 spectroradiometer	
Wavelength range	300 to 1100 nm
Wavelength interval	0.3 - 0.5nm
Optical resolution FWHM	< 7 nm
Wavelength accuracy	+/- 0.2 nm
Cosine Response (Zenith: 0 ~ 80°)	< 5%
Temp. dependency (-10ºC to 50°C)	< 2 %
Temp. Control	25ºC ± 2ºC
Operating temperature	-10 to 50ºC
Exposure time	10msec - 5sec Automatic adjustment
Dome material	Synthetic Quartz Glass
Communication	RS-422 (Between sensor and power supply)
Power requirement	12VDC, 50VA (from the power supply)

The EKO MS-711 spectroradiometer has been mounted on an Owel INTRA 3 sun-tracker (Fig. 10.2), an intelligent tracker which combines the advantages of automatic-tracking operation (automatic alignment with the system of astronomical coordinates follows after a few days), and actively-controlled tracking (a 4-quadrant sun sensor). It is constructed for use under extreme weather conditions; its operational temperature range is between -20 and +50 °C.

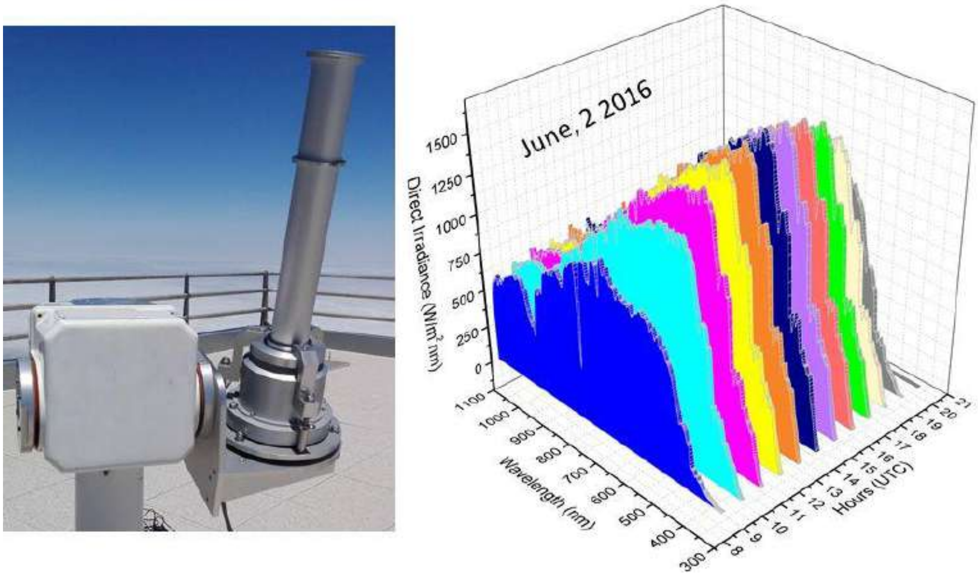

Figure 10.1. The EKO MS-711 spectroradiometer (left) and a spectrum obtained on 2 June 2016 (right).

It can sustain about 50 kg of a carefully balanced load. The tracker motors have a special grease for use in low temperatures. The drive unit has an azimuth rotation > 360°. It moves back to the start (morning) position at the corresponding midnight. The drive unit has a zenith rotation > 90°. The unit has an angular resolution ≤ 0.1°, an angular repeatability of ≤ ± 0.05° and an angular velocity ≥ 1.5°/s on the outgoing shafts. The maximum speed is 2.42°/s.

Figure 10.2. The Owel INTRA 3 sun tracker used for the EKO MS-711 spectroradiometer.

The atmospheric transmission was a new product implemented in 2014 and processed retrospectively back until 2009. It has now been updated until 31 December 2016 (Fig. 10.3). It is available at the IZO BSRN web page. The atmospheric transmission is derived from broadband (0.2 to 4.0µm) direct solar irradiance BSRN observations. Data are for clear-sky mornings between solar elevations of 11.3° and 30°.

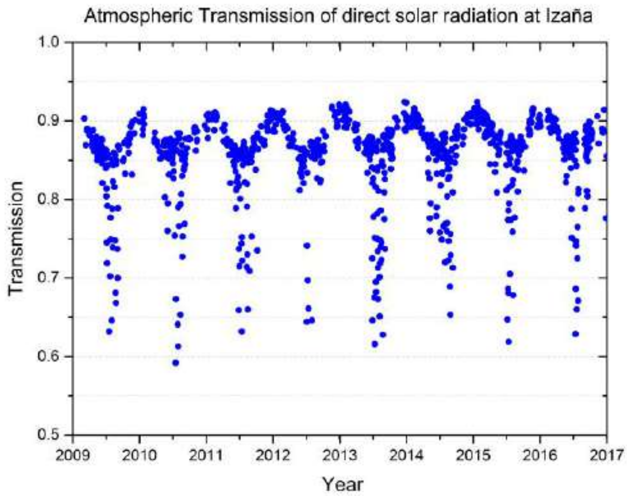

Figure 10.3. Daily atmospheric transmission data (2009-2016) at IZO computed in clear-sky mornings between solar elevations of 11.3° and 30°.

Sky images from SONA total-sky cameras at IZO and SCO, meteorological vertical profiles from radiosondes, AOD and AE from Cimel and PFR sunphotometers, column water vapour from Cimel and GPS/GLONASS, column NO_2 from DOAS, and total O_3 from Brewer spectrophotometer are used as ancillary data and/or as input data in LibRadtran simulations.

A summary of the radiation measurement programme managed by the IARC is shown in Table 10.2.

Table 10.2. Details of IARC radiation measurement programme.

Instrument	Measurements	Spectral Range
Izaña historical records (2373 m a.s.l.) Start Date: Different dates		
Abbot silver-disk pyrheliometer	Direct Radiation (1916)	~0.3 to ~3.0 µm
Bimetallic pyranograph (analog.)	Global Radiation (Jan 1977)	~0.3 to ~3.0 µm
YES Multi Filter Rotating Shadow-band Radiometer	Global, diffuse and estimated direct radiation (Feb 1996)	300-1200 nm
K&Z CM5 pyranometer	Global radiation (Jan 1992)	310-2800 nm
Izaña BSRN Station (2373 m a.s.l.) Start Date: March 2009		
Pyranometer K&Z CM-21, EKO MS-801	Global and Diffuse Radiation	285-2600 nm
Pyrheliometer K&Z CH-1, EKO MS-56	Direct Radiation	200-4000 nm
Pyrgeometer K&Z CG-4	Longwave Downward Radiation	4500-42000 nm
Net Radiometer, EKO MR-60	Net Radiation	
Pyranometer K&Z UV-A-S-T	UV-A Radiation	315-400 nm
Pyranometer Yankee YES UVB-1	UV-B Radiation	280-400 nm
Absolute Cavity Pyrheliometer PMO6	Direct Radiation	-
Spectroradiometer EKO MS-711	Spectral Direct Radiation	300-1100 nm
Izaña National Radiation Center (CNR) Station (2373 m a.s.l.) Start Date: August 2005		
Pyranometer K&Z CM-21	Global and Diffuse Radiation	285-2600 nm
Pyrheliometer K&Z CH-1	Direct Radiation	200-4000 nm
Pyrgeometer K&Z CG-4	Longwave Downward Radiation	4500-42000 nm
Pyranometer Yankee YES UVB-1	UV-B Radiation	280-400 nm
Pyranometer K&Z PQS1	Photosynthetically Active Radiation (PAR)	400-700 nm
SCO (52 m a.s.l.) Start Date: February 2006		
Pyranometer K&Z CM-11	Global and Diffuse Radiation	310-2800 nm
Pyrheliometer EPPLY	Direct Radiation	200-4000 nm
BTO (114 m a.s.l.) Start Date: 2009		
Pyranometer K&Z CM-11	Global and Diffuse Radiation	310-2800 nm
TPO (3555 m a.s.l.) Start Date: July 2012		
Pyranometer K&Z CM-11, CM-21	Global and Diffuse Radiation	310-2800 nm
Pyranometer Yankee YES UVB-1	UV-B Radiation	280-400 nm

10.3 Summary of remarkable results during the period 2015-2016

10.3.1 Comparison of measured and modelled spectral UV. Estimation of the underlying effective albedo.

A comparison study between measured and modelled direct and global ultraviolet (300–400 nm) spectral irradiances and the determination of the effective surface albedo at IZO was performed and published by García et al. (2015).

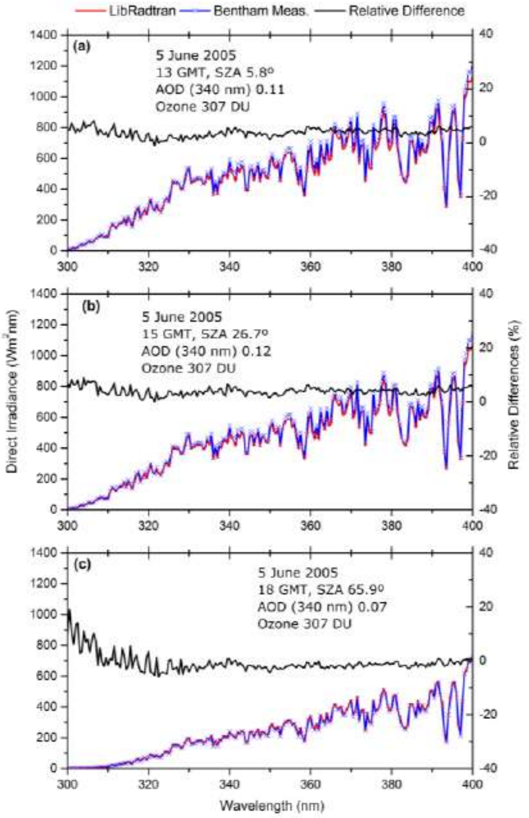

Figure 10.4. Comparison between UV spectral direct irradiance measurements (black line) and the simulations performed with LibRadtran model (grey line) on 5 June 2005 at (a) SZA 5.8° (13 GMT, AOD (340 nm) 0.11) (b) SZA 26.7° (15 GMT, AOD (340 nm) 0.12) and (c) SZA 65.9° (18 GMT, AOD (340 nm) 0.07). Reprinted from García et al. (2015).

The spectral measurements were performed with a Bentham spectroradiometer during the Quality Assurance of Solar Ultraviolet Spectral Irradiance Measurements comparison campaign in June 2005. The simulations were obtained with the LibRadtran radiative transfer model. The model input parameters, such as total ozone and aerosol optical depth, were measured at IZO. The comparison between measured and modelled direct solar radiation component was made at 0.5 nm spectral resolution, showing excellent agreement, with differences below 5% for solar zenith angle (SZA)<60° (Fig. 10.4) and 10% for global radiation.

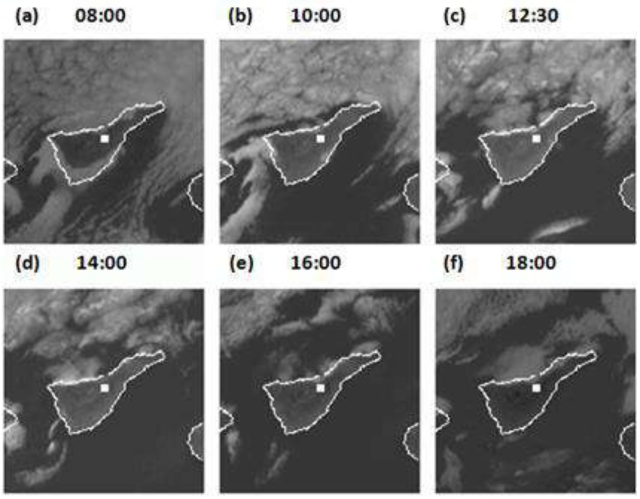

Figure 10.5. High resolution visible images from MSG (Meteosat Second Generation) over Tenerife on 9 June 2005 at 0800, 1000, 1230, 1400, 1600 and 1800 UTC. The white line marks the Tenerife Island contour and the white point indicates the IZO location. Reprinted from García et al. (2015).

These differences were mainly attributed to surface albedo due to the presence of the sea of clouds, in particular, its extent and location in relation to the altitude of the Izaña station (Fig. 10.5). The effective surface albedo was determined by using two methods: 1) Kylling's method (Kylling et al., 2000) and 2) a Lookup-Table (LUT) performed with the LibRadtran model. The results show that the surface albedo depends on the sea of clouds coverage around IZO (Fig. 10.5, Table 10.3).

Table 10.3. Summary of surface albedo obtained from the Kylling's method and Lookup-Table (LUT) based on radiative transfer models (RTM) on 9 June 2005 at 0800, 1000, 1230, 1400, 1600 and 1800 UTC (SEM as standard error of the mean).

Time (UTC)	SZA (°)	Kylling's method	LUT
08:00	67.8	0.58±0.06	0.50±0.11
10:00	41.8	0.28±0.03	0.22±0.06
12:30	9.6	0.20±0.04	0.19±0.06
14:00	13.6	0.19±0.02	0.15±0.04
16:00	39.7	0.09±0.01	0.06±0.01
18:00	65.8	0.07±0.01	0.06±0.01
Total	-	**0.24±0.02**	**0.20±0.05**

10.3.2 Compatibility of different techniques for global solar radiation measurements and application for long-term observations

A one-year inter-comparison of classical and modern radiation and sunshine duration (SD) instruments has been performed at IZO starting on 17 July 2014. We compared daily global solar radiation (GSR_H) records measured with a Kipp & Zonen CM-21 pyranometer, within the framework of the BSRN, with those measured with a Multifilter Rotating Shadowband Radiometer (MFRSR), a bimetallic pyranometer (PYR), and GSR_H estimated from sunshine duration measured with a Campbell-Stokes sunshine recorder (CS) and a Kipp & Zonen sunshine duration sensor (CSD) (Fig. 10.6). The BSRN GSR_H measurements were used as the reference in the intercomparison study as these measurements have passed strict quality controls (based on principles of physical limits and comparison with the LibRadtran model.

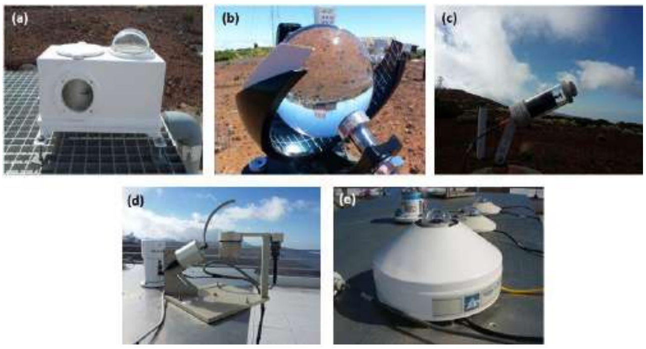

Figure 10.6. (a) Bimetallic pyranometer (PYR), (b) Campbell-Stokes sunshine recorder (CS), (c) Kipp & Zonen sunshine duration sensor (CSD), (d) Multifilter Rotating Shadowband Radiometer (MFRSR) and (e) Kipp & Zonen CM-21 pyranometer installed at IZO during the one-year intercomparison.

We obtained an overall root mean square error (RMSE) of ≈ 0.9 MJm^{-2} (4%) for PYR and MFRSR GSR_H, 1.9 MJm^{-2} (7%) and 1.2 MJm^{-2} (5%) for CS and CSD GSRH, respectively. Factors such as temperature, relative humidity and the solar zenith angle have been shown to moderately affect the GSR_H observations. As an application of the methodology developed in this work, we have re-evaluated the GSR_H data time series obtained at IZO with two PYRs between 1977 and 1991. Their high consistency and temporal stability have been proved by comparing with GSR_H estimates obtained from SD observations.

These results demonstrate that 1) the continuous-basis intercomparison of different GSR_H techniques offers important diagnostics for identifying inconsistencies between GSR_H data records, and 2) the GSR_H measurements performed with classical and more simple instruments are consistent with more modern techniques and, thus, valid to recover GSR_H data time series and complete worldwide distributed GSR_H data. The inter-comparison and quality assessment of these different techniques have allowed us to obtain a complete and consistent long-term global solar radiation series (1977-2015) at Izaña (Fig. 10.7).

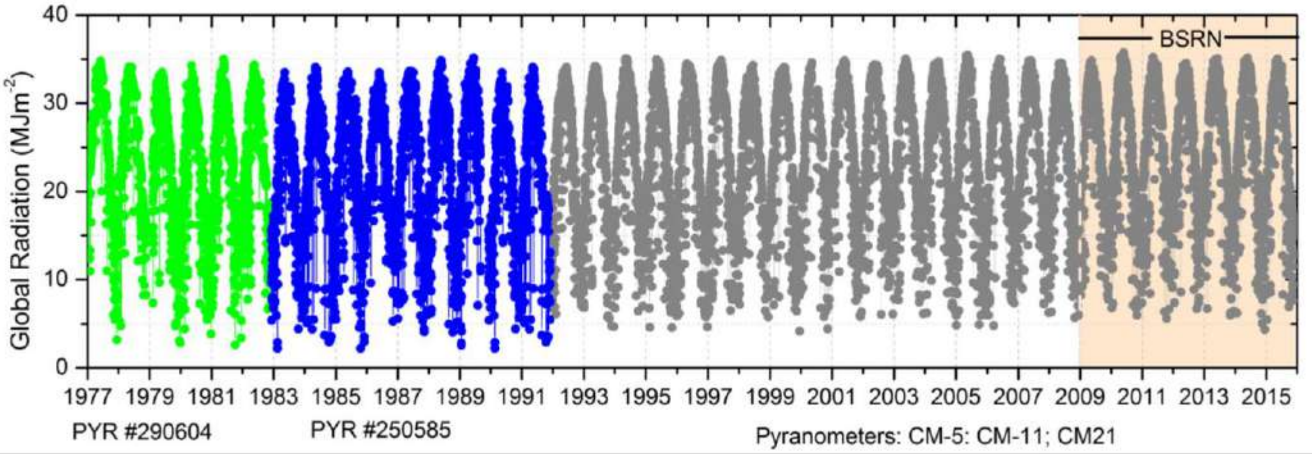

Figure 10.7. Daily GSR_H data time series between 1977 and 2015 at IZO. The green and blue dots correspond to the measurements performed with PYR #290609 and #250585, respectively, between 1977 and 1991, and the grey dots represent the measurements performed with different pyranometers (CM-5, CM-11 and CM-21) between 1992 and 2015.

10.4 Participation in Scientific Projects and Campaigns/Experiments

10.4.1 Calibration campaign of BSRN instruments with a PMO6 Absolute Cavity Pyrheliometer

As part of the radiation quality assurance system a calibration campaign of BSRN pyranometers and pyrheliometer was performed during summers 2015 amd 2016 using an Absolute Cavity Pyrheliometer PMO6 as reference (Fig. 10.8). The PMO6 was calibrated in the World Radiation Center, Davos. The BSRN instruments were calibrated following the ISO 9059:1990 (E) and ISO 9846:1993(E), delivering the corresponding official calibration certificates.

Figure 10.8. Absolute cavity radiometer (PMO6) installed at IZO during summers 2015 and 2016 in the BSRN sun-tracker.

10.5 Future activities

The main on-going and future activities of the radiation programme are focused on:

- Reconstruction and accurate analysis of a new long GSR data series (since 1916) in which newly recovered observation data are being incorporated. Long-term records of aerosols (AOD), cloudiness, and solar flux will be compared with GSR data.
- Comparison of observed and modeled longwave downward radiation (LDR) at BSRN Izaña between 2009 and 2016. The LDR observations are performed with a Kipp & Zonen CG-4 pyrgeometer, and the simulations are obtained with LibRadtran and Modtran radiative transfer models.
- Apparent transmission data recovery from direct radiation measured with ancient Abbot silver-plate pyrheliometers (since 1916) and comparison with present results.
- Accurate determination of cloud attenuation impact on global radiation using GSR from SCO and BTO.
- Accurate analysis of UV-B broadband data from the vertical transect formed by SCO (52 m a.s.l.), IZO (2373 m a.s.l) and TPO (3555 m a.s.l.) observatories, with complementary information on cloudiness, AOD and O_3 vertical profiles (ECC O_3 sondes).

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11 Differential Optical Absorption Spectroscopy (DOAS)

11.1 Main Scientific Goals

Differential Optical Absorption Spectroscopy (DOAS) and Multi Axis Differential Optical Absorption Spectroscopy (MAXDOAS) techniques allow the determination of atmospheric trace gases present in very low concentrations. The long term monitoring of atmospheric trace gases is of a great interest for trend studies and satellite validation. The detection of gases using DOAS or MAXDOAS technique allows the study of mutual interaction between gases even when detection limits of the gases are low.

The main scientific goals of the DOAS and MAXDOAS programme are:

- To improve the knowledge of the distribution, seasonal behaviour and long term trends of minor constituents related to ozone equilibrium such as NO_2, BrO and IO and their distribution in the subtropical atmosphere.
- To obtain a climatology of stratospheric NO_2 and BrO in subtropical regions and its dependence on environmental and climatic variables.
- To study the seasonal variation of NO_2, O_3, formaldehyde (HCHO) and IO in the free troposphere and its interaction with environmental factors such as Saharan dust amongst others.
- To contribute to validation of NO_2 and Ozone satellite products (GOME, GOME2, SCIAMACHY, OMI, TROPOMI) and in the improvement of the methodology to perform such comparisons.

11.2 Measurement Programme

The DOAS technique (Platt and Stutz, 2008) is a method to determine the atmospheric trace gases column density by measuring their absorption structures in the near ultraviolet and visible spectral region.

Figure 11.1. RASAS II and ARTIST II MAXDOAS (UV-VIS) spectroradiometers at IZO.

Figure 11.2. DOAS instruments outdoor optics with sky trackers.

The technique is based on measurement of atmospheric absorption of solar radiation at selected wavelength bands where the gas under consideration shows a structured and known absorption cross-section. For stratospheric observations the instrument is pointed at zenith during the twilights.

Although the DOAS technique was developed for stratospheric research, during the last few years it has been largely employed in tropospheric environment and pollution episodes studies. In particular, the so called Multi Axis Differential Optical Absorption Spectroscopy approach allows to infer vertical distribution of minor species from spectrometric measurements of solar scattered light at given angles of elevation (off-axis measurements). The analysis technique makes use of the Optical Estimation Method (Rodgers, 2000) by putting together the off-axis measurements and a radiative transfer algorithm to get the best solution for all used elevation angles.

The instruments automatically take spectra from an AM SZA = 96º to PM SZA = 96º, every day. As the instrument must work with a stabilized room temperature and also with a stabilized internal temperature and humidity, those parameters are monitored and recorded in data files. Calibration of the instrument grating is performed approximately every year. Calibration of the elevation angle is performed once a month. After the spectral inversion, a quality control of data is carried out. The acquired data are filtered on the basis of the analysis and instrumental error, aerosol optical thickness and the solar zenith angles, to ensure quality.

INTA has performed measurements of stratospheric O_3 and NO_2 at IZO since 1993. Data have been used for the study of stratospheric O_3 and NO_2 distribution in the subtropical region (Gil et al. 2004, Gil et al., 2008) and for validation of satellite products (Meijer et al., 2004, Lambert et al., 2007, Hendrick et al., 2011, Robles-Gonzalez et al., 2016). In 2003, the installation of an ultraviolet DOAS spectrometer expanded the measurements of stratospheric gases to the near ultraviolet region, allowing the monitoring of stratospheric BrO and the estimatation of the concentration of BrO in the free troposphere (Puentedura, 2004). More recently, in 2010, the instruments were adapted to MAXDOAS measurements, allowing the detection of free tropospheric trace gases, such as IO and NO_2 (Puentedura et al, 2012, Gomez et al., 2014, Gil-Ojeda et al., 2015). In the case of BrO, its tropospheric concentration was confirmed to a lower limit of 1 pptv. Prior to the installation at IZO in 2009, the VIS-MAXDOAS instrument participated in the international blind NO_2 MAXDOAS intercomparison campaign CINDI (Cabauw Intercomparison campaign Nitrogen Dioxide measuring Instrument) (Roscoe et al., 2010, Piters et al., 2012, Pinardi et al., 2013). During the AMISOC campaign in 2013, extensive measurements of IO were performed at three different altitude levels on Tenerife. Data are currently under revision

11.3 Summary of remarkable results during the period 2012-2014

11.3.1 Measurements of Free Tropospheric IO

The installation of Vis-MAXDOAS in 2009 allowed the detection of IO in the free troposphere. This was the first time that this specie was detected and measured in in the free troposphere, yielding slant column densities consistent with a background concentration of 0.2-0.4 pptv in the free troposphere of marine regions and opening the question about the origin of IO in this layer (Puentedura et al., 2012).

11.3.2 Reanalysis of stratospheric NO_2 and O_3 data series

In the frame of the European NORS project, the long-term data series of NO_2 and O_3 have been reanalysed adapting the analysis consistent with NDACC recommendations. Re-processed NO_2 data set is shown in Fig. 11.3, and results for O_3 (Gil et al., 2012) are shown in Fig. 11.4.

11.3.3 Seasonal evolution of background NO_2 in the free troposphere

Gomez et al (2015) have presented a simple method based on a Modified Geometrical Approximation to estimate the tracers concentration at the level of IZO from MAXDOAS measurements. Gil-Ojeda et al. (2015) used 3 years (2011-2013) spectra to analyse the seasonal evolution of the NO_2 volume mixing ratio. MAXDOAS presents two main advantages with respect to the in situ instrument at this location, both related to the very long optical path of the measurements over 60 km. Firstly, it minimizes the potential NO_2 which may be upwelled from the marine boundary layer. The breeze layer has a limited vertical extension and its relative contribution to the MAXDOAS long path is small. Secondly, it allows concentrations below the detection limit of in situ instrument to be retrieved.

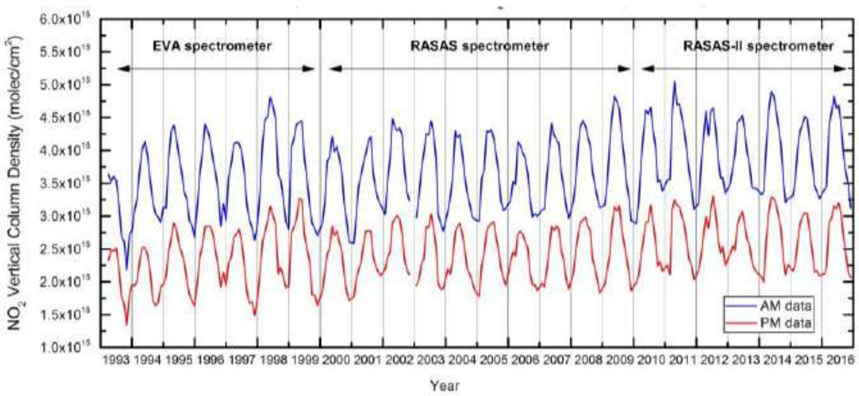

Figure 11.3. Time series of reanalyzed stratospheric NO_2 1993-2016.

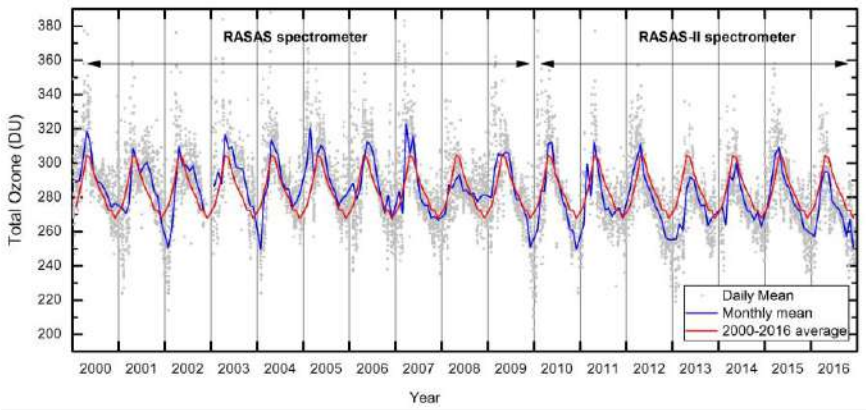

Figure 11.4. Time series of reanalyzed stratospheric O_3 2000-2016.

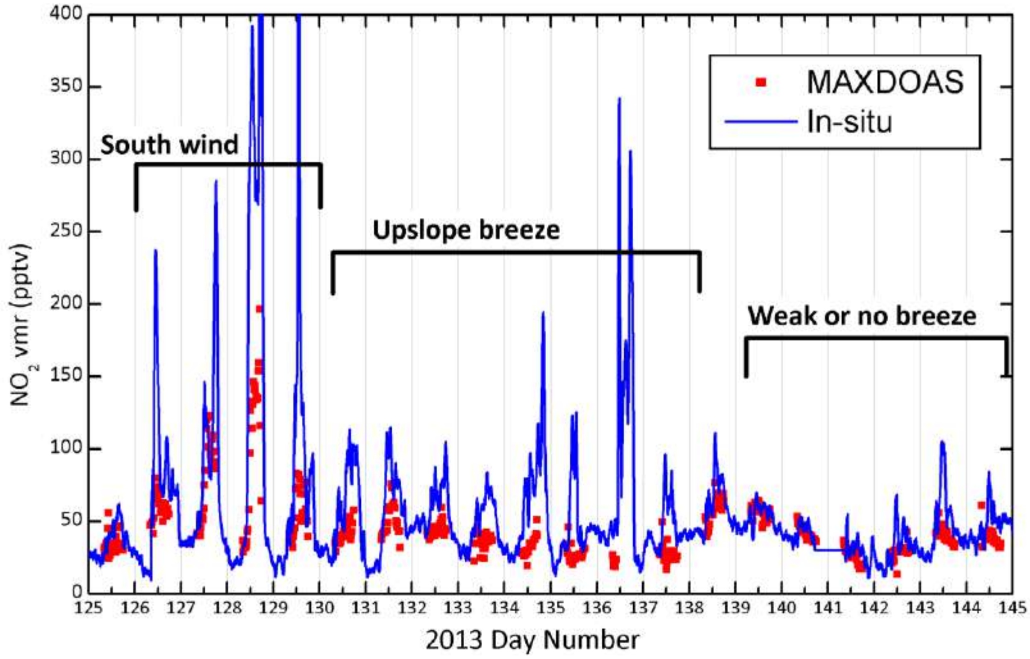

Figure 11.5. Izaña Atmospheric Observatory MAXDOAS versus minutal in-situ NO_2 volume mixing ratio for a period of time representative of three different wind regimes. Figure reprinted from Gil-Ojeda et al. (2015).

Results from Gil-Ojeda et al. (2015) illustrate the differences in concentration between the in-situ local sampling and the MAXDOAS long-path average (Fig. 11.5). On days when the breeze is inhibited, the in-situ data are representative of the free troposphere, and the agreement between instruments is very good (days 139-145). On days when anabatic winds are present, NO_2 volume mixing ratio increases are seen in in-situ data whereas the MAXDOAS signal remains at FT levels (days 130-137). The upslope wind counteracts the subtropical subsidence and the intensity can be very variable. In general, the depth of the mixing layer is not enough to contaminate the MAXDOAS path. This situation is the one most commonly observed at IZO. A third set of measurements is shown when MAXDOAS data also show large increases in NO_2 (days 127-129) caused by a 980 MW thermal power plant located 25 km south of IZO.

11.4 Participation in Scientific Projects and Campaigns/Experiments

11.4.1 S5P NItrogen Dioxide and FORmaldehyde Validation using NDACC and complementary FTIR and UV-Vis DOAS ground-based remote sending data (NIDFORVal).

The aim of this project is to stablish a network of observations supporting validation for tropospheric products of the Sentinel-5 Precursor (Sentinel-5P). The INTA-MAXDOAS instruments installed at Izaña Atmospheric Observatory are part of the Sentinel-5P Calibration and Validation Team for HCHO and NO_2.

This is an ESA proposal (ID28607) led by the Belgian Institute of Spatial Aeronomy that started in 2016 and extends to 2024.

11.4.2 Aviation and Atmosphere: an Aerospatiale study on aerosols and gases (AVATAR)

AVATAR is a funded Project from the Spanish Ministry of Economy, Industry and Competitiveness (CGL2014-55230-R). This project is mainly focused on analysis of the aerosol impact on climate through the study of the gas-aerosol interaction, study of gas and aerosol distribution in airport areas, aerosol and cloud radiative effects and the performance of comparisons between satellite and ground-based measurements of aerosol.

This project is also focused on the monitoring of the free troposphere and stratosphere with the aim to extend the previous results of AMISOC of the seasonal variation of IO and BrO in the free troposphere. Activities within AVATAR support trace gas monitoring and NIDFORVal activities at Izaña Atmospheric Observatory. This project is operated in collaboration with the In Situ Aerosol Programme.

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12 Water Vapour

12.1 Main Scientific Goals

The main scientific goals of this programme are:

- High quality observations and study of precipitable water vapour (PWV) total column content and vertical profile.
- Analysis of daily, seasonal and annual cycles of PWV for different locations and altitudes of Tenerife and La Palma islands.
- Study of radiative forcing due to water vapour and clouds.
- Tests of low-cost IR sensors for PWV and cloud height estimation.

12.2 Measurement Programme

Several measurement techniques are used in this programme.

12.2.1 RS-92 radiosondes

From the vertical profiles of relative humidity obtained with RS-92 radiosondes, precipitable water content in the atmospheric column is calculated by integrating numerically (using the trapezoidal rule) the density function of atmospheric water vapour for the base and top of each atmospheric stratum. The integration is performed from ground level to 12 km altitude. By default, the PWV profile is supplied for the following layers: 1) from ground up to 1.5 km; 2) from 1.5 km to 3 km altitude in layers of 0.5 km thickness; 3) from 3 km altitude up to 12 km in layers of 1 km thickness.

12.2.2 Radiometric technique

Precipitable total water content in the atmospheric column is estimated from the absorption of water vapour in a narrow band around 941 nm from a MFRSR (Yankee Environmental Systems, Model MFR-7). From the PWV value deduced from RS92, we can characterize, on the one hand, the filter parameters of the water vapour channel using the Campanelli technique (Campanelli et al, 2010; Romero-Campos et al., 2011), and on the other hand, through the Langley-modified technique, we can obtain the extraterrestrial irradiances for 941 nm, from which we extract the corresponding calibration constant. Finally, 1-minute PWV is obtained.

12.2.3 Global Navigation Satellite System technique

The Global Navigation Satellite System (GNSS) technique consists in determination of PWV in the atmospheric column from the observed delay in radio signals at two different frequencies emitted by a network of Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) satellites received in our GNSS receiver (Fig. 12.1).

Figure 12.1. Global Navigation Satellite System receiver at Izaña Atmospheric Observatory.

Currently, we work with nine GNSS receiver stations (Fig. 12.2) at different heights, eight of them in Tenerife and one in La Palma island. La Orotava-Parque Nacional is the name of the last GNSS receiver station, which was incorporated into the network on 10 April 2015.

The atmospheric pressure in places where the GNSS antennas are located is a key parameter for obtaining the PWV from the zenith total delay (ZTD) and zenith hydrostatic delay (ZHD).

The four reference meteorological stations used to obtain accurate surface pressure records with GNSS stations are: Reina Sofía Airport-Tenerife South, IZO, SCO and La Palma Airport. The GNSS network and data acquisition are managed by the Spanish National Geographic Institute (IGN).

The ZTD calculation from GNSS signals for both ultra-rapid orbits and precise orbits is performed by the IGN using Bernese 5.0 software. Since 23 September 2015, the Bernese software version 5.2 was used. This fact has produced some non-homogenous data, especially significant in high-mountain stations due to the low PWV.

In general, during the comparison period (1-23 September 2015) of the two Bernese versions, slightly larger ZTD and PWV values were obtained with version 5.2. The differences of ZTD are within ±1.5% (Fig. 12.3) and differences of PWV fall in the ±5mm range (Fig. 12.4). Most of these differences were found within the ±3.5mm interval, which is the estimated error of GNSS PWV measurements (Schneider et al., 2010).

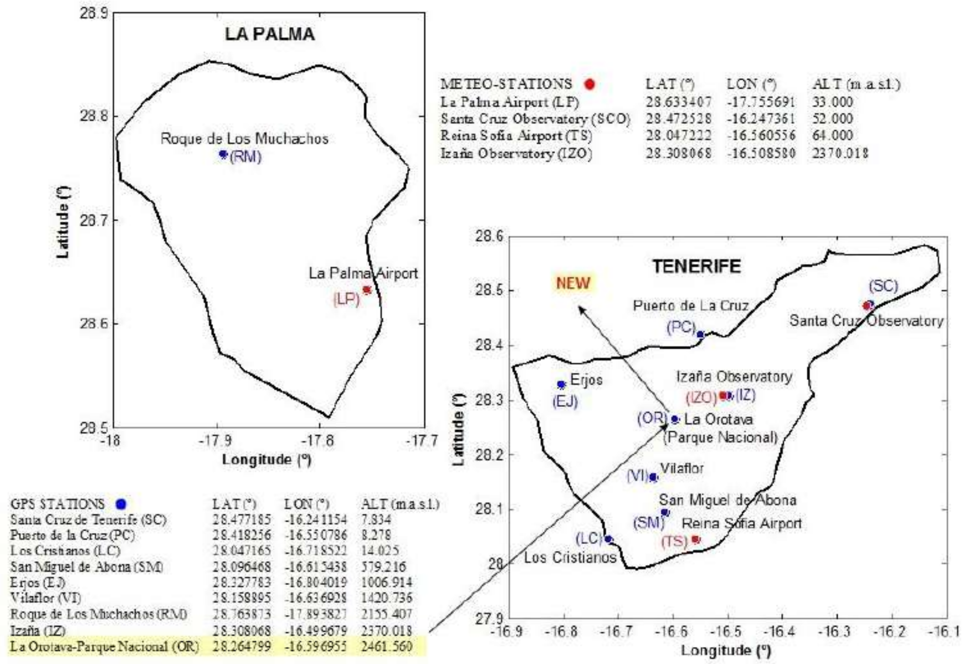

Figure 12.2. Locations of Global Navigation Satellite System stations.

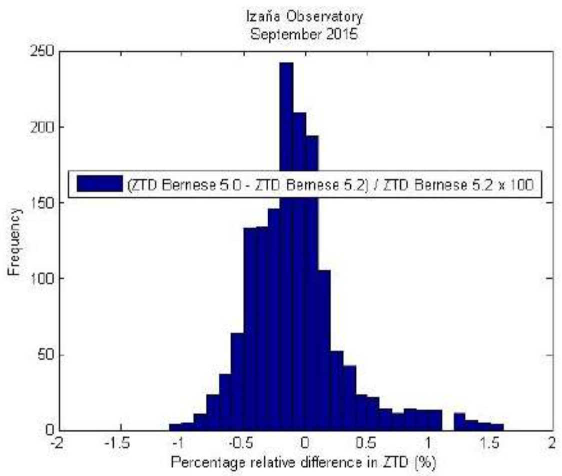

Figure 12.3 ZTD differences between Bernese 5.0 and 5.2.

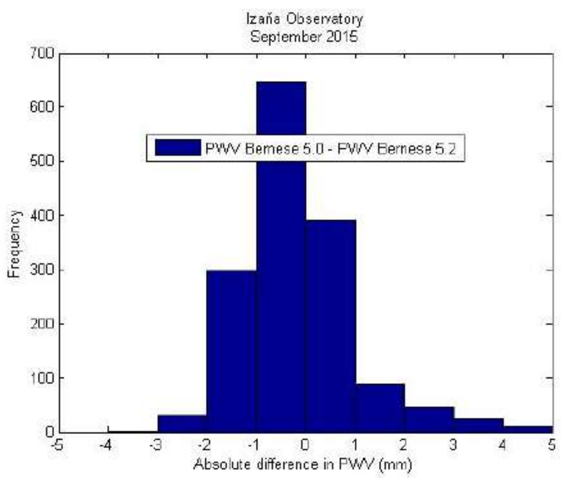

Figure 12.4 PWV differences between Bernese 5.0 and 5.2.

The PWV is calculated at IZO from ZTD and pressure values at the stations. An important task we do is estimate the pressure in the GNSS sites where measurements of surface pressure are not available. To do this, we calculate, based on the hydrostatic equation, a mean density (weighted by gravity) of the air in the air column between the nearest reference weather stations and our GNSS station located at different altitude on the field.

The final evaluation of the PWV obtained by the three techniques described above is performed by comparing the results with each other. At IZO these techniques have been evaluated using the FTIR as reference instrument. A detailed analysis is provided in Schneider et al. (2010).

12.3 Summary of remarkable results during the period 2015-2016

12.3.1 Daily cycle of PWV from GNSS

The averaged daily cycles of PWV for the period 2008-2016 are shown for GNSS stations at SCO and at IZO (Fig. 12.5). The daily cycles have been calculated from averaged hourly anomalies. For these statistics, we have selected only those hourly average values with, at least, 60% of high quality intra-hours values. The daily time anomalies were obtained by subtracting from the value of the corresponding hourly average, the value of the daily average. Then, for each hour, the averages for all of the available data anomalies within the time period of evaluation are calculated. The diurnal variations are quite similar at IZO and SCO, and a mínimum is observed at around 10UTC at these stations.

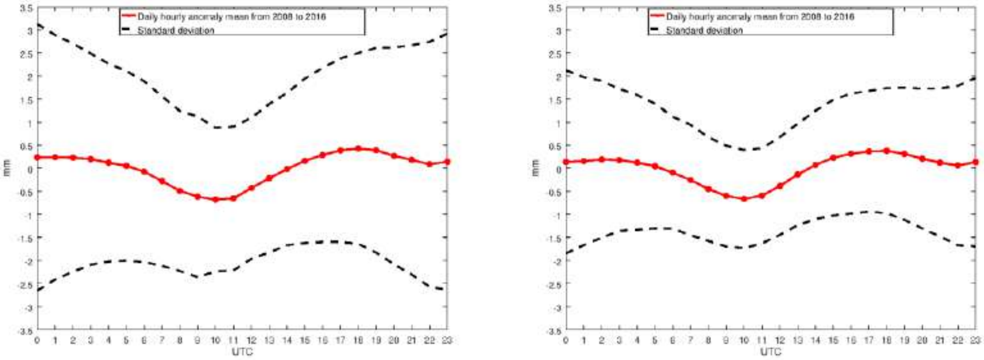

Figure 12.5. PWV averaged daily cycles at SCO (left) and IZO (right).

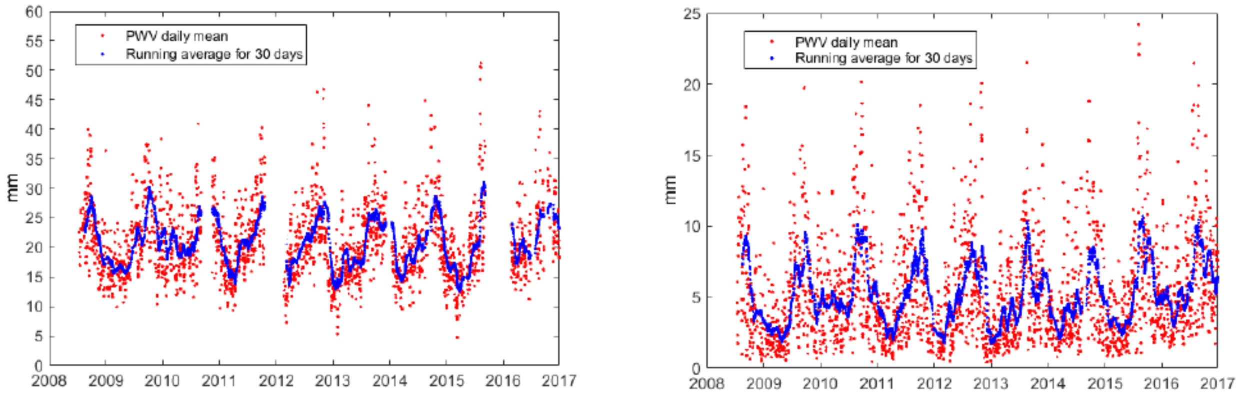

Figure 12.6. PWV series at SCO (left) and IZO (right) for 2008–2016.

12.3.2 PWV data series from GNSS

Daily PWV derived from hourly mean PWV data series calculated using ZTD for ultra-rapid GPS orbits on days in which we have, at least, 15 (60%) of all the daily possible hourly means are shown in Fig. 12.6. These series are calculated for IZO and SCO for the period 2008-2016. Gaps are caused by the absence of ZTD data. The maximum values are observed in summer-autumn and the minimum values are in winter.

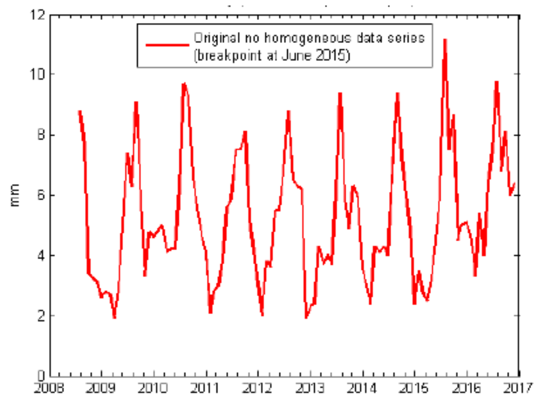

Figure 12.7. Non-homogenized PWV monthly data series at IZO (2008-2016).

12.3.3 Monthly PWV data series from GNSS

Following a similar procedure to that of other authors (Botey et al., 2013), monthly PWV data series were calculated from daily mean PWV by averaging within the months in which we have, at least, 17 (60%) of all possible daily data. These averaged monthly data series are shown for the period 2008-2016 in Fig. 12.7 and Fig. 12.8 for IZO. In the case of IZO, a breakpoint in series homogeneity was found in June 2015 due to the change of the Bernese software version implemented in September 2015. In Fig. 12.7, the monthly and non-homogeneous original data series is shown. In Fig. 12.8, the corresponding homogenised data series is shown. The homogenization was performed following the Lanzante iterative method based on Wilcoxon-Mann-Whitney test (Lanzante, 1996) and applying it as described in (Romero-Campos, P.M. et al., 2011).

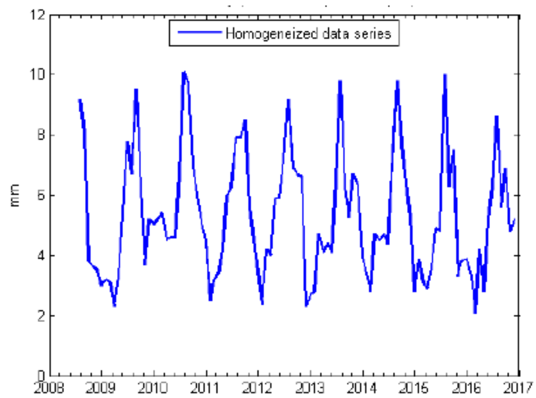

Figure 12.8 Homogenized PWV monthly data series at IZO (2008-2016).

12.3.4 PWV in near-real time and its 24-hour prediction

Near-real time and 24-hour prediction of PWV column content and vertical distribution present valuable information both for operations at airports, astronomical and meteorological observatories, and severe weather nowcasting. To provide this information, maps and graphs showing in near-real time (with a delay of two hours, approximately) PWV distribution and vertical profiles over Tenerife Island for different locations and altitudes have been produced (Romero-Campos et al., 2016).

PWV maps (Fig. 12.9) and graphs are computed from ultra-rapid GPS orbits ZTD, which have a resolution of 15 minutes and are available each two hours, approximately. The 24-hour prediction is based on the atmospheric refractivity and ZTD using the GNSS equations. Input values are predicted values of pressure, temperature, specific humidity, and geopotential from ECMWF, and latitude, longitude and time, associated with each station of our GNSS network.

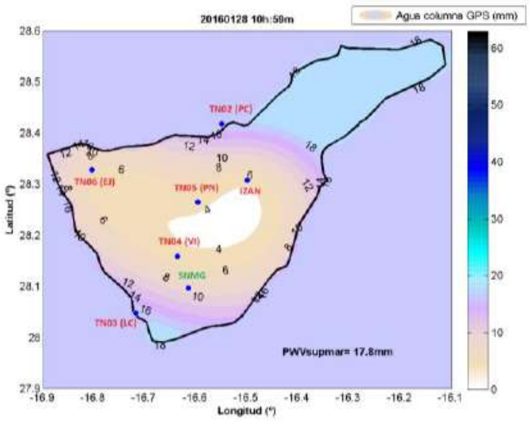

Figure 12.9 Example PWV distribution from the GNSS network over Tenerife.

A validation analysis of predicted PWV values was performed from June 2013 to January 2016, both for 0UTC and 12UTC for the coastal stations and for IZO station. In all the cases, high correlations (R Pearson >0.9) between predicted and measured values were obtained.

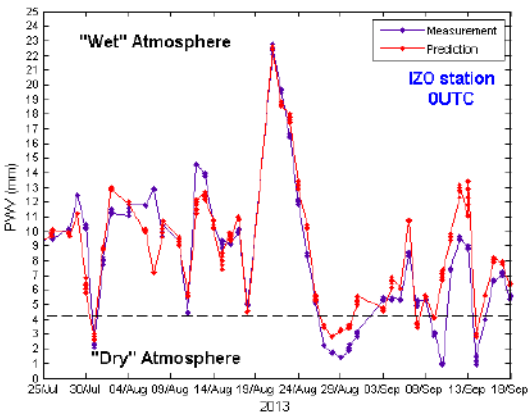

Figure 12.10 Comparison between predicted (24 ahead) and observed (GNSS) PWV at 00UTC for IZO.

In addition, a good qualitative and quantitative agreement is observed between predictions and measurements for transition periods between "wet" and "dry" atmospheres (Fig. 12.10) although predicted values show a slight overestimation, especially in dry atmospheres.

12.3.5 Daily PWV from radiosondes at Tenerife

Relatively long PWV data series are available from the radiosondes launched on Tenerife. PWV obtained from radiosondes at SCO and IZO are shown for the period 1994-2016 (Fig. 12.11).

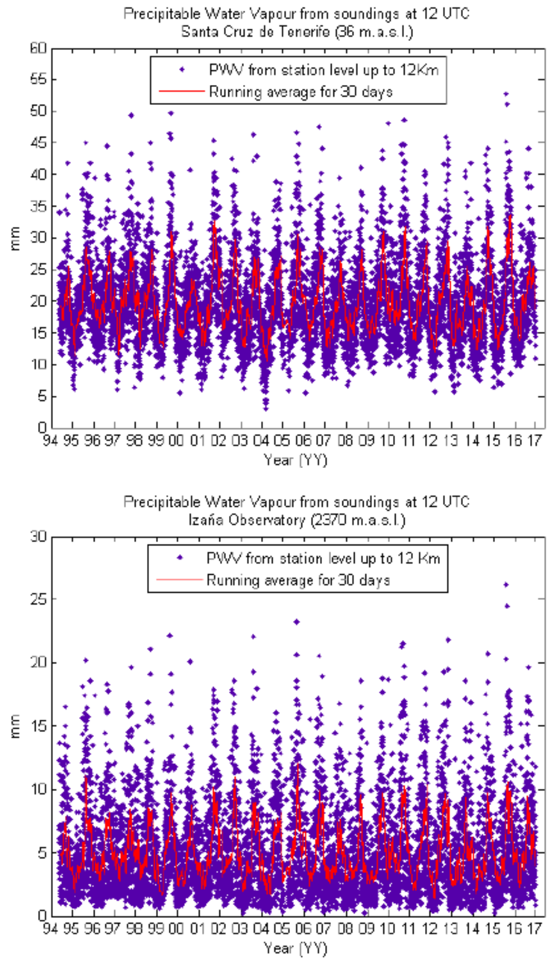

Figure 12.11. Daily PWV series from Tenerife radiosondes for SCO and IZO (1994–2016).

These are the values of PWV calculated over the duration of the radiosonde flight (about 2 hours or so) from the time of its release, and assuming that, in this period of time, the PWV remains constant. We can observe annual cycles with peaks in summer-autumn and minimum values in winter. Lower values of PWV are observed at IZO in comparison with SCO.

12.3.6 PWV vertical stratification monthly statistics

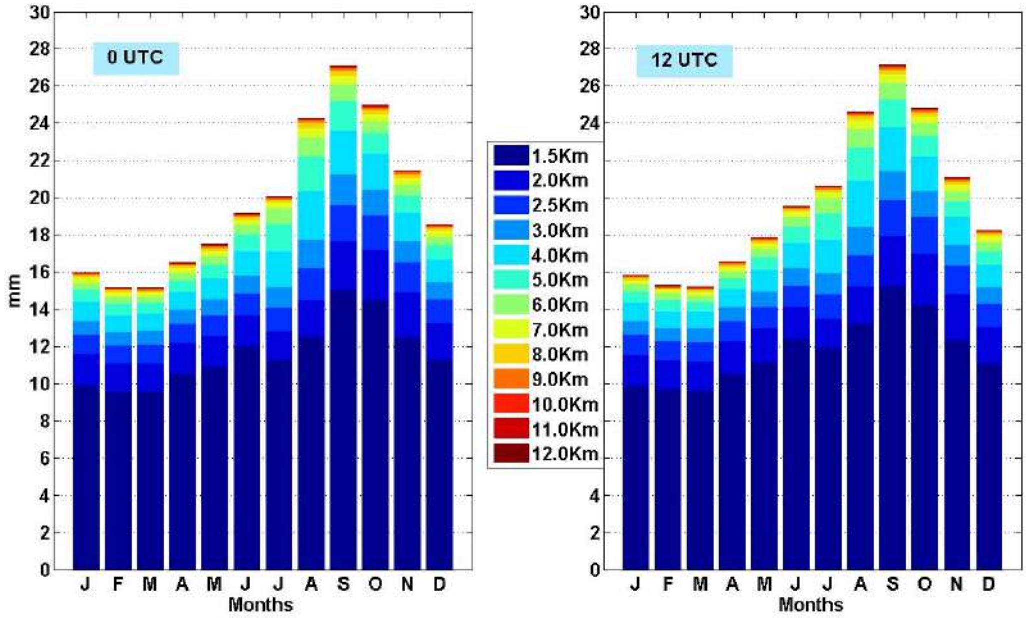

Figure 12.12. Monthly statistics of precipitable water vapour vertical distribution from radiosondes, Tenerife (1995-2016).

The monthly average of PWV vertical distribution over Tenerife, obtained from radiosondes data at 0 and 12UTC in the period 1995-2016, are depicted in Fig. 12.12. No significant differences are found between 00 and 12UTC. Most of the PWV is concentrated within the first 1.5 km altitude. There is a wet season from August to October, with a maximum in September, and a "dry" season that corresponds to the months from January to April with a minimum in February-March. The total height of each column corresponds to the total monthly averaged PWV at sea level. The minimum monthly averaged PWV is about 15 mm in February while the maximum (27 mm, approximately) is recorded in September.

12.4 References

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13 Meteorology

13.1 Main Scientific Goals

The main goals of this programme are:

- To provide diagnosis and operational weather forecasting to support routine operation activities at the IARC observatories and issue internal severe weather alerts and special forecasts for planned field campaigns, outdoor calibrations, repairs, etc.
- To implement and configure High Resolution Numerical Weather Prediction Models capable of capturing the complex meteorology of the mountain observatory, as an aid to improve the supporting forecasts.
- To maintain meteorological parameter observations according to WMO specifications, and in the framework of AEMET's Synoptic and Climatological Observation networks.
- To measure conventional meteorological parameters at different stations on the island of Tenerife, to support other observation programmes.
- To develop non-conventional meteorological parameters programmes.
- To provide meteorological analysis information to document and support results from other observation programmes and scientific projects.

13.2 Measurement Programme

The Izaña Atmospheric Research Center directly manages six weather observation stations located at IZO (3), SCO, BTO and TPO (see Section 3 for more details of the IARC facilities).

Izaña Atmospheric Observatory

IZO has three fully automatic weather stations, two of them are located in the weather garden (C430E/60010 and Meteo-STD), which includes a network of five cloud observation webcams, and the third station is on the instrument terrace of the observation tower (Meteo-Tower) at 30 m above ground level. Instrumentation for manual observations (staffed by personnel) with temperature, humidity, pressure and precipitation analog recorders (bands), is also maintained at IZO in order to preserve the historical series that started at Izaña Atmospheric Observatory in 1916.

Santa Cruz Observatory

SCO has a fully automatic weather station located on the instrument terrace.

Botanic Observatory

BTO has a fully automatic weather station installed at the ozonesounding station at the Botanic Garden in Puerto de la Cruz.

Teide Peak Observatory

TPO has an automatic very high altitude weather station with temperature, humidity and pressure sensors, supplemented with data from a wind sensor installed at the Cable Car tower No.4, managed by the Cable car company.

The meteorology programme also has access to meteorological soundings data of pressure, temperature, humidity and wind from the Tenerife station (Id: WMO 60018) located in the town of Güimar. This station belongs to AEMET's upper-air observation network and is managed by the Meteorological Center of Santa Cruz de Tenerife (AEMET).

13.3 Meteorological Resources

To accomplish the objectives of this programme we have the following tools:

Man Computer Interactive Data Access System (McIDAS)

LINUX Workstations (Fedora Core) with the Man Computer Interactive Data Access System (McIDAS) application provide access, exploitation and visualization of meteorological information from different geo-referenced observations, modelling and remote sensing (satellite, radar) platforms.

The application provides access to all data in real time in the AEMET National Prediction System, including the following data and products:

- Global synoptic surface observation and upper-air networks.
- Outputs of numerical prediction models from ECMWF (IFS) and AEMET (HIRLAM).
- METEOSAT satellite imagery.
- Images of AEMET's Weather Radar Network.
- Data from AEMET's Electrical Discharge Detection network.
- Products derived from SAF (Satellite Application Facilities) Nowcasting MSG images.

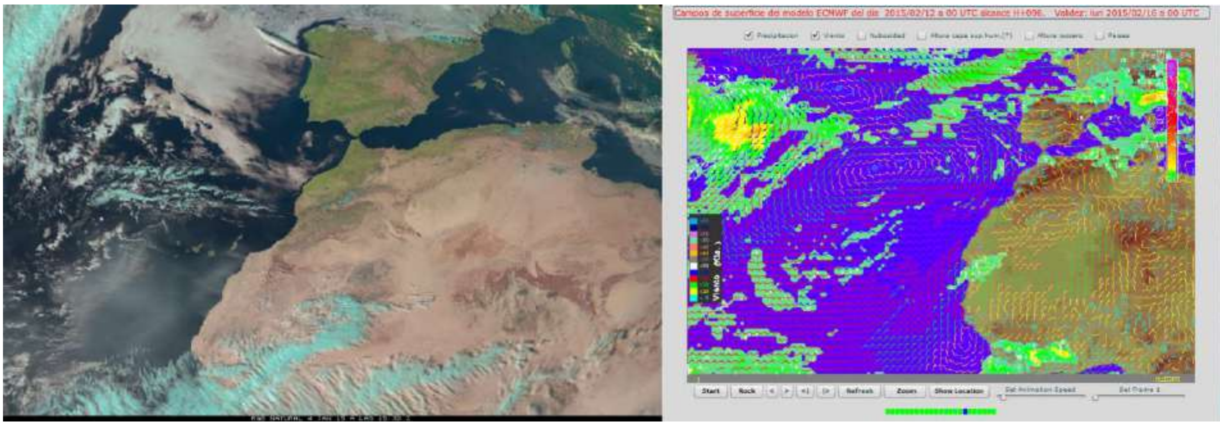

Figure 13.1. Left: natural RGB composite image with the (R) channel 1 (B), 2 (G) and 3 satellite Meteosat-10 (MSG-3) for 4/1/2015 15:30 UTC. Right: graphical output of the predicted fields to 96 h, of the ECMWF IFS model for surface wind (coloured barbs) and precipitation in 6 h (filled in colour) for 16/02/2015 00 UTC.

Utilising this application different automated processes for the exploitation of meteorological information have been developed, among which we can highlight:

1) Automatic generation of graphical products from specific models and images from derived MSG products (RGB combinations), for consultation through an internal website (see Fig. 13.1).

2) Calculation of isentropic back trajectories of air masses from analysis outputs (4 cycles per day) and prediction (every 12 hours and range up to 132 hours) for Tenerife and other places in the Canary Islands and the rest of Spain, at different vertical levels (Fig. 13.2).

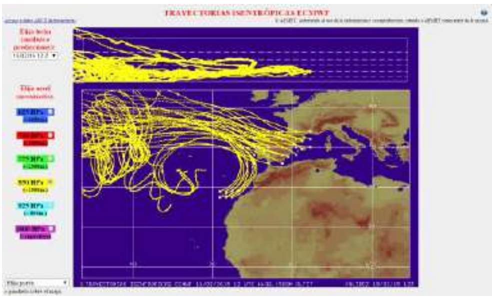

Figure 13.2. Screenshot of isentropic back-trajectories for several points of Spain with 96 h forecasted on day 15/02/2015 12 UTC at the level of 850 hPa.

3) Lightning strikes in situ detection and AEMET lightning detection network warning system, for taking preventive action to avoid damages in the facilities.

4) Automatic seven day Meteogram generation of temperature, humidity, wind, pressure and clouds for Izaña Observatory using standard isobaric grid points interpolated to 2400 m a.s.l. The statistics have been weighted using the inverse distance to the validity forecast time taking into account the last five available model runs (Fig. 13.3).

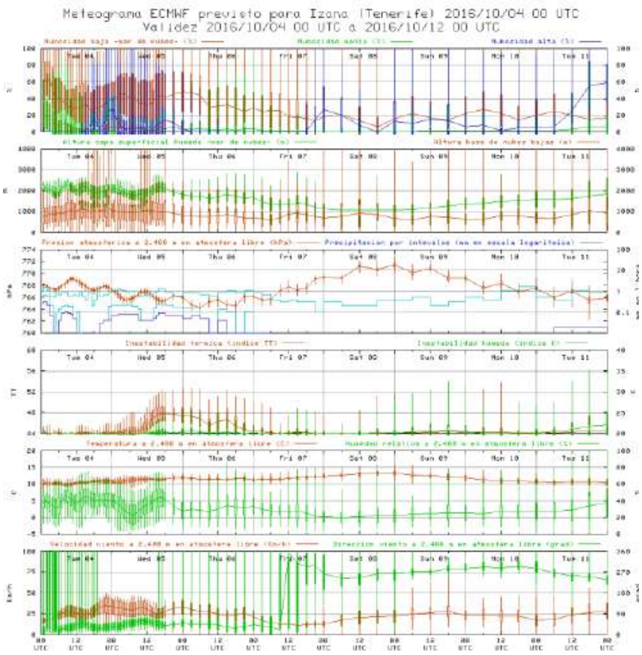

Figure 13.3. Ensemble week length meteogram forecast at IZO on 04/10/2016 at 00 UTC.

EUMETCast receiving system

The EUMETCast real-time receiving system for aerial imagery and meteorological satellite data distributed by EUMETSAT has its own internal web interface for displaying images received, and mass storage system for archiving images of compressed MSG segments in native format.

EUMETSAT Data Center

We have access to the EUMETSAT Data Center for retrieval of images and historical products of Meteosat satellites.

AEMET Server Meteorological Data System

We have access to numerical models databases, observations, bulletins, satellite and radar images is available on the AEMET Server Meteorological Data System (SSDM).

ECMWF products and MARS archive

In addition, we have access to the European Centre for Medium-Range Weather Forecasts (ECMWF) computer systems and consultation of the Meteorological Archival and Retrieval System (MARS), which is the archive of all operational products generated in ECMWF. From this system we have developed different exploitation processes such as:

- Routine extraction in two cycles per day of meteorological analysis and prediction fields of IFS model, which are decoded in a compatible format for exploitation from McIDAS, and for the integration of the high resolution model.
- Monthly extraction of ERA-Interim reanalysis outputs for updating large data series for different projects.
- Extraction of previous analysis fields calculation for computing back trajectories with FLEXTRA.
- Routine extraction in two cycles per day from Copernicus Atmosphere Monitoring Service (CAMS) system (Fig. 13.4).

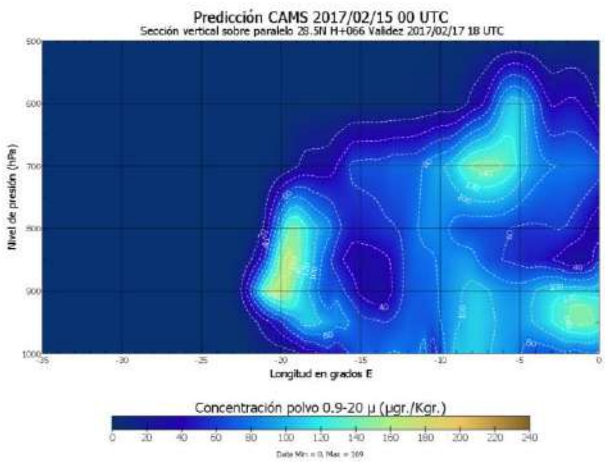

Figure 13.4 Latitudinal dust concentration vertical section forecast on February 15th 2017 as an example of routine output cycles from CAMS.

AEMET National Climatological Data Base (BDCN)

We have access to the AEMET National Climatological Data Base (BDCN) for data extraction of observations from the AEMET principal and secondary climatological networks.

13.4 Numerical Models

Non-hydrostatic high resolution weather model (MM5)

The meteorology programme has access to a clusters system in LINUX environment of parallel processors for the integration of a non-hydrostatic high resolution weather model (MM5) for the area of the Canary Islands. The initial and boundary conditions are from the ECMWF model IFS, and nested grids of 18, 6 and 2 km resolution are outputted with a forecasting range up to 144 hours. The outputs of this model offer the added value of dynamic downscaling of the IFS model predictions in the complex topography of the Canary Islands. Various types of post-processed numerical fields permit a better understanding of the atmospheric situations. In addition to these outputs a neural network has been implemented that improves the prediction of local variables of temperature and wind at the observatory, granting additional accuracy to the in situ forecast. All these results are presented using a web server installed in the same cluster.

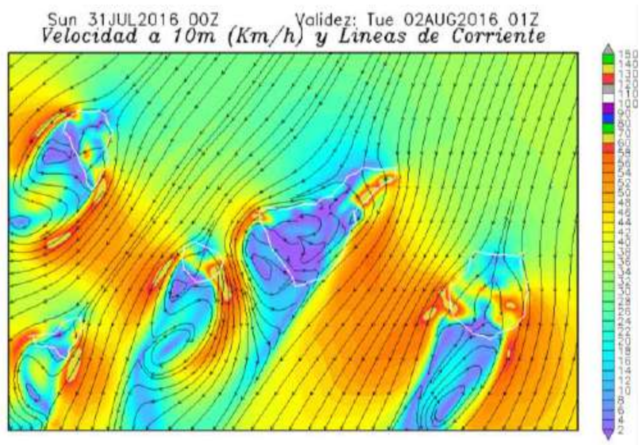

Figure 13.5. Example of graphics presented in MM5 web page. This shows the plot of the forecasted wind speed shaded in colours and overlapped with the streamlines on August 2 2016 at 01 UTC.

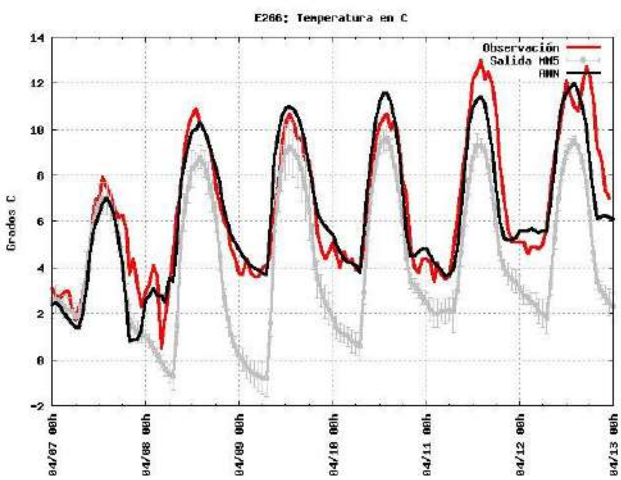

Figure 13.6. Example of the Artificial Neural Network 2 m forecast temperature improvement from 7-13 April 2016. Black lines represent the ANN values, while grey and red lines represent direct MM5 output and observation, respectively.

FLEXible TRAjectory (FLEXTRA) model

The FLEXTRA model has been installed in a dedicated server in order to simulate the backward-trajectories arriving at Izaña Atmospheric Observatory calculated at several levels. The backward-trajectories are routinely updated each month. Additional graphic information representing the track and its height is shown using a web server as a quick reference in order to select particular episodes. A later more exact representation can be requested using a McIdas web based server (Figure 13.7).

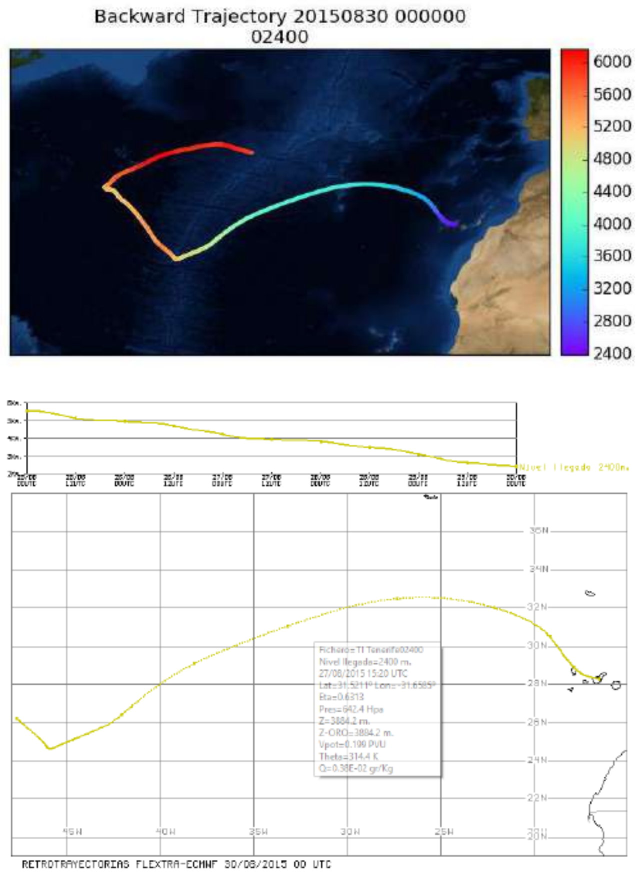

Figure 13.7. Quick reference and detailed plot of a backward-trayectory with track ending on 10/08/1979 at 00 UTC.

HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model

The HYSPLIT model has been installed on the same server as the FLEXTRA model in order to simulate trajectories using the GFS model as data input.

It has also been installed in the cluster system using MM5 output data and run in dispersion mode using the parallel program configuration (Figure 13.8).

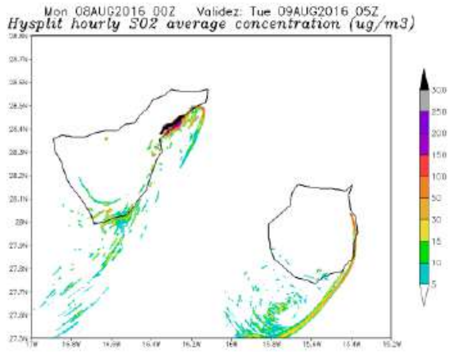

Figure 13.8. Average Hysplit SO_2 concentration shading contours forecasted on day 09/08/2016 at 05 UTC.

13.5 Summary of activities during the period 2015-2016

Activities of this operational and research meteorology programme during 2015-2016 include:

1) Maintenance of meteorological instrumentation to ensure quality and continuity of observations within national and international meteorological and climatological observation networks in which IZO participates. These include the Synoptic Observation Network (WMO Region I, ID: 60010), included in the surface observation network of Global Climate Observing System (GCOS), the AEMET Climatological Monitoring Network (ID C430E) and the Baseline Surface Radiation Network (BSRN; station # 61).

2) Supervising and quality checking of meteorological data from IZO, SCO, BTO and TPO.

3) Analysis and prediction of severe weather events that may affect operations of the observation programmes at the four IARC observatories. Special attention is paid to IZO, which is frequently affected by adverse events such as very strong winds, rain and heavy snow, lightings, frost, and frozen rime, which can cause significant damages to facilities. We highlight some of the most important episodes during 2015-2016:

- From 22 to 24 March 2015, there was a wind, snow and rainstorm with a snow accumulation of 47.0 mm, wind gusts of 108.0 km/h at 04:10 UTC on 23 March and a minimum temperature of -5.1ºC at 03:30UTC on 24 March.

Figure 13.9. Left image shows corrected reflectance (bands 7-2-1) from Aqua MODIS on day 25/03/2015. It shows the accumulated snow layer (cyan). Ref. NASA Worldview (https://worldview.earthdata.nasa.gov) Right image: Snow truck carrying IARC staff.

- On 10, 13 and 14 August 2015, an unusual episode of tropical storms in Canary Islands, combined with a dust intrusion, accumulated 66.2 mm of rain (Fig. 13.10).

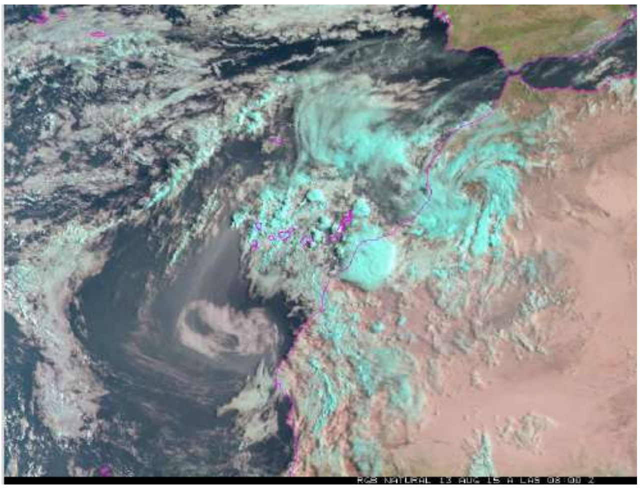

Figure 13.10. Meteosat RGB natural (bands 3-2-1) image on 13/08/2015 08:00 UTC. © EUMETSAT 2015.

- Wind storm on 16 October 2015 with a gust of 109.8 km/h at 17:50 UTC.
- Wind storm and heavy snow from 18 to 22 February 2016 with 135 mm snow height and a minimum temperature of -4.9 ºC and maximum of -3.2ºC. At 08:20 UTC we recorded a wind gust of 128.9 km/h and a 95.4 km/h maximum continuous wind speed in 10 minutes.

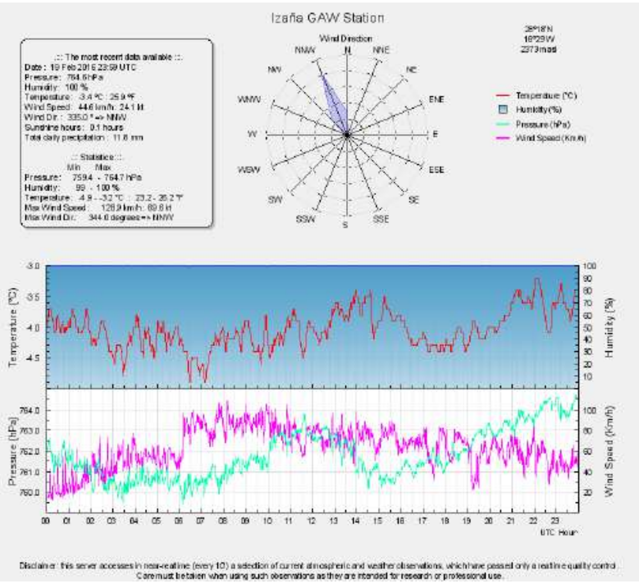

Figure 13.11. Wind, temperature and pressure graphics recorded on 19 February 2016 showing extreme wind and temperature data.

4) Analysis of extreme weather events that occurred during 2015 and 2016 at IZO in comparison with the long term meteorological records. For example, December 2015 broke the record for the highest December maximum and minimum temperature (Table 13.1).

Table 13.1 Extreme events in 2015 and 2016 at IZO in comparison with meteorological records.

Extreme Event	Data	Date
Highest May minimum temperature at 15 cm depth	16.1 °C	11/5/2015
Highest May maximum 10′ mean velocity	87 km/h	15/5/2015
Highest June minimum temperature at 15 cm depth	18.5 °C	29/6/2015
Maximum August daily precipitation	59.2 mm	13/8/2015
Maximum September 10′ precipitation intensity	8.4 mm/h	24/9/2015
Highest December maximum temperature	20.1 °C	17/12/2015
Highest December minimum temperature	12.7 °C	18/12/2015
Highest February minimum pressure	778.7 hPa	9/2/2016
Highest August maximum 10′ mean velocity	76 km/h	9/8/2016

13.6 Outstanding collaborations with other scientific programmes

Collaborations with other scientific programmes during 2015-2016 included the following:

- Extraction of sunshine duration, clouds, visibility and various meteorological parameters from the AEMET National Climatological Data Base, in order to update the historical aerosol optical depth series for the Radiation Programme (García et al., 2016a, b).
- Extraction and upgrade of meteorological data over Tenerife from isobaric levels fields (from surface to 0.1 hPa) from operational models and ECMWF ERA-Interim reanalysis since 1990 to obtain vertical profiles of the atmosphere for analysis of the vertical stability its implication for the atmospheric water vapour isotopes cycle (González et al., 2016).
- Extraction of hourly temperature and specific humidity data over Tenerife from isobaric levels fields (from 1000-1 hPa) of the operational ECMWF model to obtain data for the Water Vapour Programme (Romero-Campos et al., 2015).
- Aerosol Modelling with CAMx air quality model and HYSPLIT model coupled with MM5 meteorological model (Milford et al., 2016a, b) (see Section 8).
- Simulation of 10-day back-trajectories arriving at Izaña Atmospheric Observatory for several levels with the HYSPLIT model from 1949 to 2016 and with the FLEXTRA model from 1979 to 2016. The back-trajectories provide relevant information on transport and source regions of air masses affecting the various components and parameters measured at IZO.

13.7 Summary of remarkable results during the period 2015-2016

13.7.1 Meteorological long term records

In 2015 and 2016 we have updated the long-term climate series of monthly mean temperature and annual accumulative precipitation at Izaña Atmospheric Observatory since 1916. In addition to these variables, we have also recovered the sunshine duration, humidity and pressure from 1916. This constitutes a century of meteorological data and is the oldest uninterrupted climate series in the Canary Islands.

In the series of annual mean temperature at IZO (Fig. 13.12a) a positive linear trend is observed at a rate of 1.47 ºC per century, quite similar to the values of the global warming trend This series is especially relevant since the station is at altitude and is representative of conditions of quasi free troposphere. It is remarkable that temperature in the year 2015 is in the 4th quintile (warm) and 2016 is in the 5th quintile (very warm), although both are less than the extreme event in the year 2010. Total annual precipitation in the years 2015 and 2016 is less than 300 mm and is positioned in the 2nd quintile of the series (dry) (Fig. 13.12b). The total annual sunshine duration of over 3800 hours in the year 2015 is also remarkable and constitutes the maximum value in the series from 1916 (Fig. 13.12c).

All of Izaña's historic observational data since 1916 have now been digitized and stored in the AEMET National Climatological Data Base. Digitization of the remaining historic data from 1909 to 1916, corresponding to the first period of the Izaña Atmospheric Observatory in its previous location in the "Cañada de la Grieta" is currently being conducted and will be completed by the end of 2018. All of the original observer logbooks since 1909 have been classified and stored safely at the observatory.

13.7.2 WMO Long-term Observing Stations

Today, supercomputers and sophisticated models and satellites are important tools for climate scientists. However, long-term, high quality continuous observations from thermometers, rain gauges and other instruments remain essential. Without them, we could not be certain that the Earth has warmed by one degree centigrade over the past century. These long-term observations are vital to our scientific understanding of climate variability and change and essential for model and satellite validation activities.

To promote the recovery and continuation of these records, governments are nominating Long-term Observation Stations for formal recognition by WMO. Many Long-term Observation Stations are also of outstanding historical and cultural interest, recalling previous eras and the birth of modern meteorology. Taken together as a network, Long-term Observation Stations are uniquely able to tell the story of recent climatic history. More information about the WMO Long-term Observing Stations project, can be found here.

AEMET officially requested in 2016 the WMO recognition of Izaña Atmospheric Observatory as a Long-term or centennial observation station, providing documentation on meteorological/atmospheric records, a historical review and photographs.

13.7.3 Characterization of the Marine Boundary Layer and the Trade-Wind Inversion over the Sub-tropical North Atlantic

A comprehensive analysis of the stability of the lower troposphere along the east side of the sub-tropical North Atlantic has been performed by using upper air meteorological long-term records at the Canary Islands (Tenerife), Madeira (Madeira) and Azores (Terceira) archipelagos. The main results have been published in Carrillo et al. (2015).

In summertime a stability strengthening centred at levels near 900 and 800 hPa is found in a significant percentage of soundings (ranging from 17 % in Azores to 33 % in Güimar, Canary Islands). Carrillo et al. (2015) show that this double structure is associated with the top of the marine boundary layer (MBL) and the trade-wind inversion (TWI) respectively. The top of the MBL coincides with the base of the first temperature inversion (≈900 hPa) where a sharp change in water vapour mixing ratio is observed. A second temperature inversion is found near 800 hPa, which is characterized by a large wind shear just above the inversion layer, tied to the TWI (see Figure 13.13). This is a novel result since the temperature inversion associated with the trade wind was traditionally considered as a single inversion, when in fact, two temperature inversions spaced approximately 1 km of altitude are detected in a significant percentage of summer days.

A second interesting result is that the seasonal and latitudinal variations of the height and strength of both temperature inversions are driven by large-scale air flow subsidence from the upper troposphere associated with the descent branch of the Hadley cell. Increased general subsidence in summertime enhances stability in the lower troposphere, more markedly in the southern stations, where the inversion-layer heights are found at lower levels enhancing the main features of these two temperature inversions. A simple conceptual model that explains the lower tropospheric inversion enhancement by subsidence is proposed in Carrillo et al. (2015).

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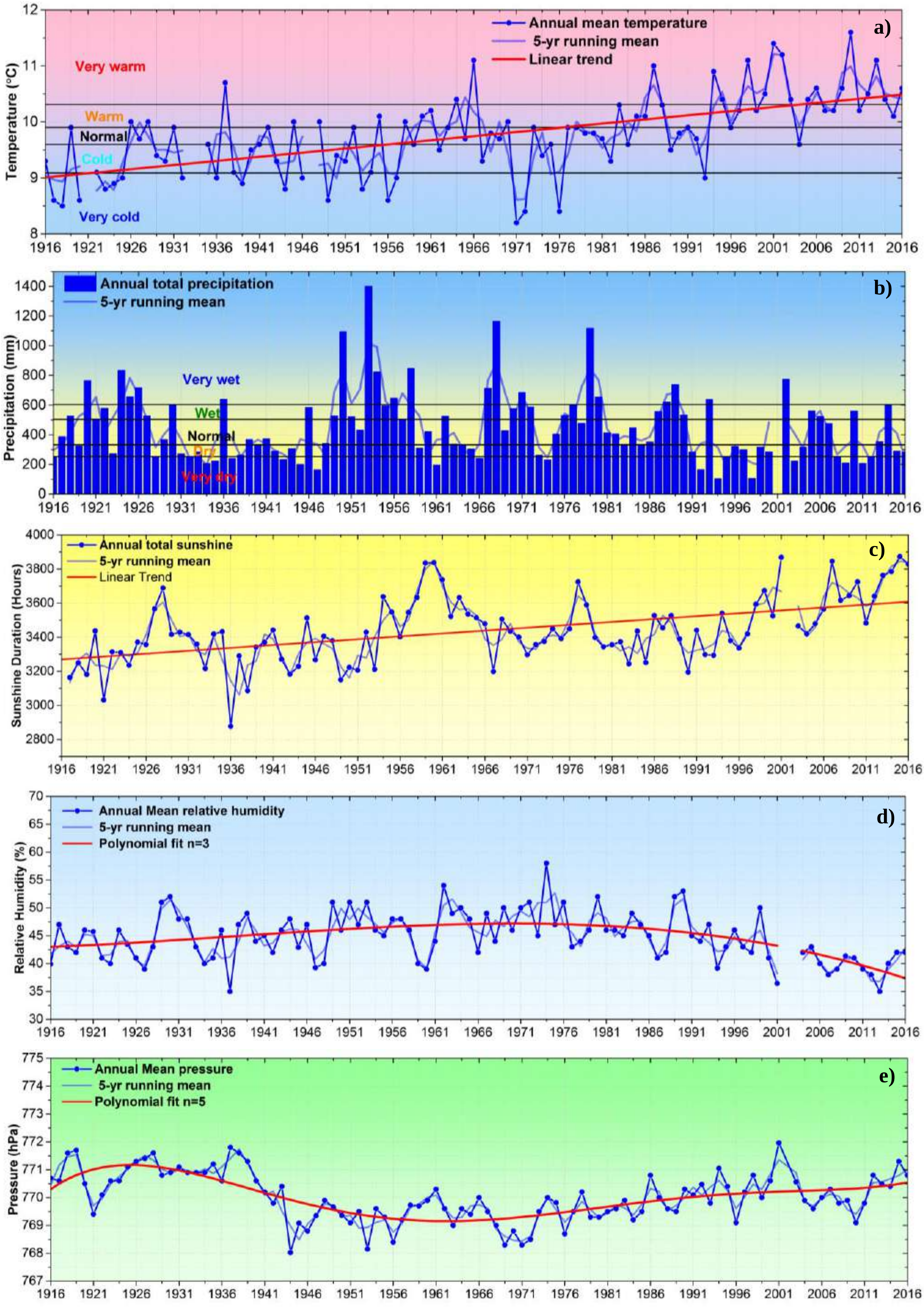

Figure 13.12. Time series (1916-2016) of a) annual mean temperature, b) total annual precipitation, c) annual sunshine duration, d) annual mean relative humidity and e) annual mean pressure at Izaña Atmospheric Observatory.

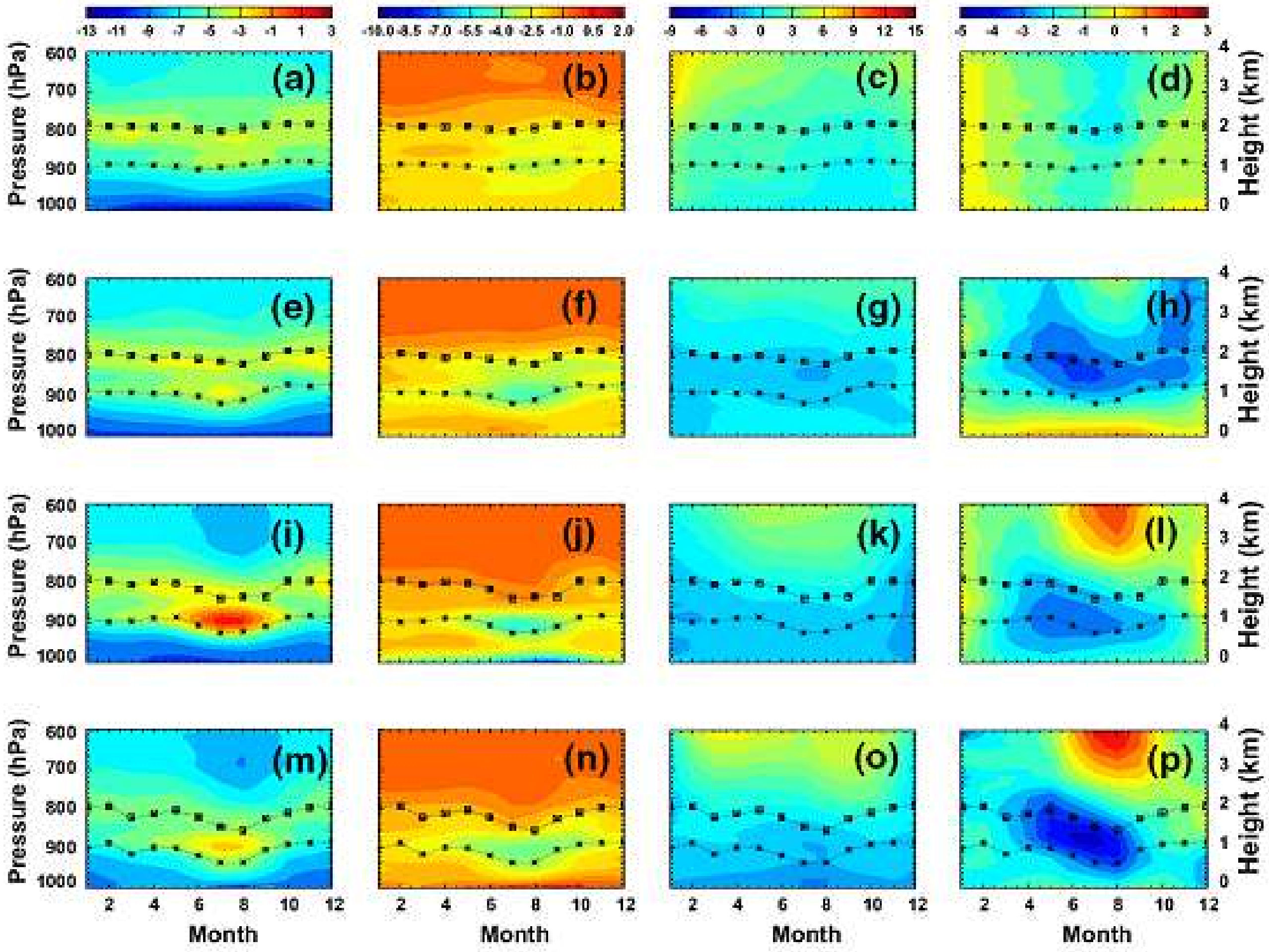

Figure 13.13 Annual cycle of the lapse rate (K km^{-1}), first column; gradient of mixing ratio dr/dz (g kg^{-1} km^{-1}), second column; and zonal and meridional wind speed (m s^{-1}), third and fourth columns, respectively. All of the figures have been calculated using only data from soundings with two inversions detected in the 1000–700 hPa range, at Azores (a–d), Madeira (e–h) and Canary Islands: Santa Cruz (i–l) and Güimar (m–p). Dotted lines indicate the average height of the base of the first (*) and second (_) inversion layer. Error bars represent the standard error. Figure reprinted from Carrillo et al. (2015).

13.8 References

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14 Aerobiology

The Aerobiology programme at the IARC is carried out jointly by IARC-AEMET and the Laboratori d'Anàlisis Palinològiques (LAP) of the Universidad Autónoma de Barcelona (UAB) with partial financing from Air Liquide España S.A through the Eolo-PAT project. This programme started in 2004 at SCO with the aim of improving the knowledge of the pollen and spore content in the air of Santa Cruz de Tenerife and its relation with the prevalence of respiratory allergy. A second aerobiological station was implemented at IZO thanks to the financial support of the R+D National Plan CGL-2005-07543 project ("Origin, transport and deposition of African atmospheric aerosol in the Canaries and the Iberian Peninsula based on its Chemical and Aerobiological Characterization"). These two projects also contribute to improve the knowledge of the biological fraction of aerosols within the GAW program.

14.1 Main Scientific Goals

The main scientific goals of this programme are:

- To produce high quality standardized data on the biological component of the atmospheric aerosol.
- To establish the biodiversity and quantity of pollen and fungal spores registered in the air of Santa Cruz de Tenerife and Izaña.
- To establish the distribution pattern over the course of the year of the airborne pollen and fungal spores at Santa Cruz de Tenerife and Izaña, through the daily spectra.
- To put the Canary islands on the map of the global aerobiological panorama, along with the Spanish (REA; SEAIC) and European networks (EAN).
- To provide information useful for medical specialists and allergic patients.
- To set up the list of the allergenic pollen and spore taxa in the air of Santa Cruz de Tenerife and Izaña that will help doctors to diagnose the allergy aetiology and to rationalize the use of the medication.
- To produce weekly alerts on the allergenic pollen and spores for the days ahead to help doctors in the allergy detection and to help people suffering from allergies with a better planning of their activities and to improve the quality of their life.

A detailed description of this programme can be found in Belmonte et al. (2011).

14.2 Measurement Programme

The sampling instrument is a Hirst, 7-day recorder VPPS 2000 spore trap (Lanzoni S.r.l.) (Fig. 14.1) and the analysing instrument is a Light microscope, 600 X (Table 3.2). The pollen and spore analysis is conducted using palynological methods following the recommendations of the Spanish Aerobiology Network management and quality manual. The sampling programme at SCO is continuous through the year, whereas samples are only collected at IZO from April-May to November because of adverse meteorological conditions during the rest of the year.

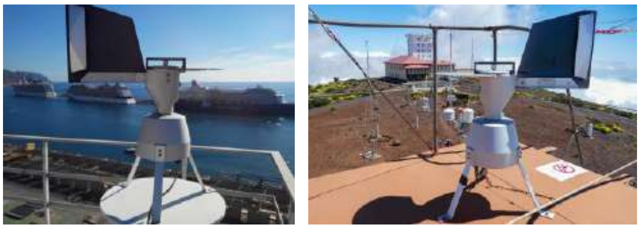

Figure 14.1. Hirst, 7-day recorder VPPS 2000 spore trap at SCO (left) and at IZO (right).

14.3 Summary of remarkable results during the period 2015

The annual dynamics of the total pollen and total fungal spores taxa in Santa Cruz de Tenerife and Izaña are shown in Figs. 14.2 and 14.3. Data shown correspond to mean weekly concentrations.

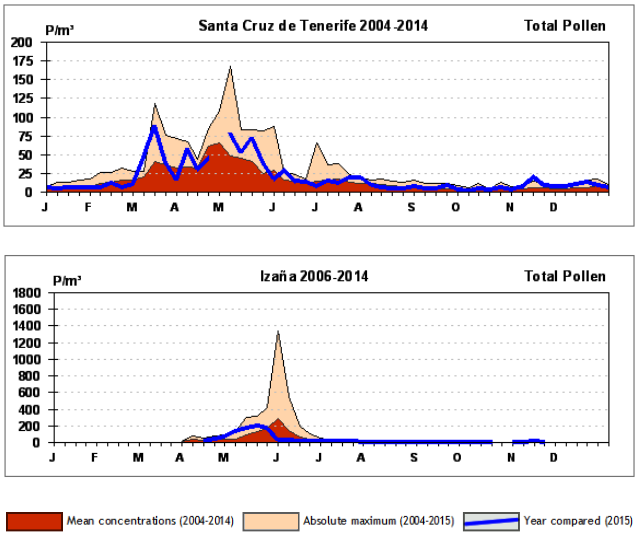

Figure 14.2. Dynamics of the mean weekly Total Pollen concentrations in Santa Cruz de Tenerife (upper) and Izaña (lower) during 2015 in comparison with 2004-2014 mean data.

Table 14.1. Airborne pollen and spore spectrum for SCO, year 2015.

SANTA CRUZ DE TENERIFE

1 January 2015 - 31 December 2015

	YEAR		WEEK		DAY	
	Total Pollen	Percentage %	Maximum P/m^3	Week nr. Nr.	Maximum P/m^3	Date of the Maximum dd/mm/yyyy
TOTAL POLLEN	6518	100.0	89.6	11	254.1	03/05/2015
POLLEN FROM TREES	2482	38.1	37.8	20	132.3	03/05/2015
Acacia	0	0.0	0.0	-	0.0	-
Ailanthus	3	0.0	0.4	11	2.8	13/03/2015
Alnus	1	0.0	0.1	8	0.7	18/02/2015 - 19/03/2015
Castanea	18	0.3	1.1	27	2.8	01/07/2015
Casuarina	17	0.3	0.9	52	5.6	24/12/2015
CUPRESSACEAE	179	2.7	4.9	46	18.2	10/11/2015
Eucalyptus	28	0.4	0.6	11	4.2	15/03/2015
Ilex	0	0.0	0.0	-	0.0	-
MORACEAE	400	6.1	16.7	23	69.3	01/06/2015
Myrica	661	10.1	33.1	18	121.8	03/05/2015
OLEACEAE	202	3.1	10.1	20	31.5	18/05/2015
PALM TREES	607	9.3	9.6	30	22.4	05/03/2015
Pinus	177	2.7	10.8	14	41.3	02/04/2015
Platanus	14	0.2	0.8	47	5.6	17/11/2015
Populus	1	0,0	0.1	10	0.7	05/03/2015 - 15/04/2015
Quercus total	96	1.5	5.0	20	16.1	17/05/2015
Salix	13	0.2	0.5	4	2.8	15/03/2015
Schinus	53	0.8	0.8	30	2.8	17/06/2015 - 21/07/2015
Tilia	0	0.0	0.0	-	0.0	-
Ulmus	1	0.0	0.2	10	0.7	06/03/2015 - 08/03/2015
Other pollen from trees	11	0.3	-	-	-	
POLLEN FROM SHRUBS	1187	18.2	69.5	11	15.5	12/03/2015
CISTACEAE	0	0.0	0.0	-	0.0	-
ERICACEAE	1133	17.4	69.0	11	149.8	12/03/2015
Ricinus	38	0.6	0.4	18	2.1	14 and 28/04/ and 01/12/2015
Pistacia	6	0.1	0.5	14	1.4	03/04/2015
Other pollen from shrubs	10	0.1	-	-	-	-
POLLEN FROM HERBS	2634	40.4	32.5	14	76.3	18/05/2015
COMPOSITAE total (incl. *Artemisia*)	688	10.6	15.3	18	35.7	18/05/2015
Artemisia	661	10.1	15.3	18	32.9	18/05/2015
BORAGINACEAE	20	0.3	0.7	15	2.1	10/04/2015
CYPERACEAE	11	0.2	0.6	46	1.4	13/11/2015 - 15/11/2015
CRASSULACEAE	0	0.0	0.0	-	0.0	-
CRUCIFERAE	28	0.4	1.0	10	2.8	08/03/2015
Euphorbia	1	0.0	0.1	20	0.7	14/05/2015 -18/07/2015
GRAMINEAE (Grasses)	477	7.3	5.5	21	21.0	18/05/2015
Mercurialis	62	1.0	1.4	9	4.9	26/02/2015
Plantago	141	2.2	2.9	10	7.7	06/03/2015
Rumex	181	2.8	3.8	11	13.3	12/03/2015
CHENOPODIACEAE/AMARANTHACEAE	221	3.4	2.2	46	7.0	16/12/2015
URTICACEAE	643	9.9	14.7	14	27.3	02/04/2015
Other pollen from herbs	161	2.3	-	-	-	-

	YEAR		WEEK		DAY	
	Total Spores	Percentage %	Maximum S/m^3	Week nr. Nr.	Maximum S/m^3	Date of the Maximum dd/mm/yyyy
TOTAL SPORES	141876	100.0	4962.8	43	13666.8	24/10/2015
Alternaria	1257	0.9	16.0	14	28.0	30/03-18/05 and 20/06/2015
Ascospores	76980	54.3	3788.0	43	11214.0	24/10/2015
Aspergillus/Penicillium	2209	1.6	37.2	45	109.2	06/11/2015
Clasdosporium	42311	29.8	534.8	25	1131.2	20/06/2015
Ustilago	5894	4.2	79.6	21	198.8	17/05/2015
Other fungal spores	13225	9.2	-	-	-	-

Table 14.2. Airborne pollen and spore spectrum for IZO, year 2015.

IZAÑA
6 April 2015 - 22 November 2015

	YEAR		WEEK		DAY	
	Total Pollen	Percentage %	Maximum P/m³	Week nr. Nr.	Maximum P/m³	Date of the Maximum dd/mm/yyyy
TOTAL POLLEN	6704	100.0	201.7	20	476.7	20/05/2015
POLLEN FROM TREES	2313	34.5	119.2	18	242.9	28/04/2015
Acacia	0	0.0	0.0	-	0.0	-
Ailanthus	0	0.0	0.0	-	0.0	-
Alnus	0	0.0	0.0	-	0.0	-
Castanea	62	0.9	3.2	29	11.2	04/07/2015 - 11/07/2015
Casuarina	1	0.0	0.1	36	0.7	05/09/2015
CUPRESSACEAE	27	0.4	2.2	46	11.2	10/11/2015
Eucalyptus	2	0.0	0.1	18	0.7	28/04/-31/05/ and 30/06/2015
Ilex	0	0.0	0.0	-	0.0	-
MORACEAE	4	0.1	0.2	42	1.4	17/10/2015
Myrica	363	5.4	26.0	19	83.3	07/05/2015
OLEACEAE	48	0.7	4.0	20	9.8	14/05/2015
PALM TREES	5	0.1	0.1	16	0.7	17/04/2015 - 14 and 19/06/2015
Pinus	1620	24.2	103.2	18	237.3	28/04/2015
Platanus	1	0.0	0.2	18	1.4	01/05/2015
Populus	0	0.0	0.0	-	0.0	-
Quercus	8	0.1	0.8	20	2.8	13/05/2015
Salix	0	0.0	0.0	-	0.0	-
Schinus	0	0.0	0.0	-	0.0	-
Tilia	0	0.0	0.0	-	0.0	-
Ulmus	0	0.0	0.0	-	0.0	-
Other pollen from trees	172	2.6	-	-	-	-
POLLEN FROM SHRUBS	140	2.1	5.4	17	18.9	13/04/2015
CISTACEAE	0	0.0	0.0	-	0.0	-
ERICACEAE	134	2,0	5.4	17	18.9	13/04/2015
Ricinus	5	0.1	0.2	15	0.7	09 and 12/04/2015 - 06/05/2015
Pistacia	0	0.0	0.0	-	0.0	-
Other pollen from shrubs	1	0.0	-	-	-	-
POLLEN FROM HERBS	4176	62.3	187.8	20	468.3	20/05/2015
COMPOSITAE total (incl. *Artemisia*)	65	1.0	3.2	20	9.8	15/05/2015
Artemisia	39	0.6	1.2	15	3.5	22/04/2015 - 06/05/2015
BORAGINACEAE	13	0.2	0.6	17	2.8	22/04/2015
CYPERACEAE	6	0.1	0.4	46	2.1	14/11/2015
CRASSULACEAE	1	0.0	0.1	39	0.7	22/09/2015
CRUCIFERAE	3453	51.5	178.2	20	464.1	20/05/2015
Euphorbia	0	0.0	0.0	-	0.0	-
GRAMINEAE (Grasses)	132	2.0	3.2	20	14.7	21/06/2015
Mercurialis	9	0.1	0.4	15	2.1	08/04/2015
Plantago	13	0.2	0.5	20	2.1	14/05/2015
Rumex	56	0.8	2.4	19	5.6	09/05/2015
CHENOPODIACEAE/AMARANTHACEAE	58	0.9	1.6	46	3.5	14/11/2015
URTICACEAE	337	5.0	7.5	17	23.1	06/05/2015
Other pollen from herbs	33	0.5	-	-	-	-

	YEAR		WEEK		DAY	
	Total Spores	Percentage %	Maximum S/m³	Week nr. Nr.	Maximum S/m³	Date of the Maximum dd/mm/yyyy
TOTAL SPORES	34258	100.0	658.4	45	1033.2	02/11/2015
Alternaria	473	1.4	7.5	20	19.6	13/05/2015
Ascospores	13272	38.7	459.2	45	851.2	02/11/2015
Aspergillus/Penicillium	448	1.3	11.2	45	56.0	03/07/2015
Clasdosporium	13860	40.5	215.0	22	596.4	28/05/2015
Ustilago	1929	5.6	38.0	27	201.6	29/06/2015
Other fungal spores	4276	12.5	-	-	-	-

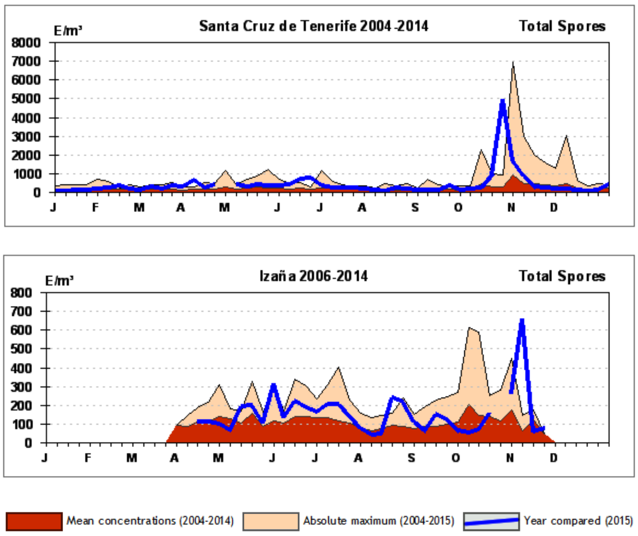

Figure 14.3. Dynamics of the mean weekly Total Fungal Spore concentrations in Santa Cruz de Tenerife (upper) and Izaña (lower) during 2015 in comparison with 2004-2014 mean data.

Similar graphs for each particular taxa can be generated on the webpage.

The plots show that the annual course of total concentration of pollen and fungal spores at SCO is very different from that observed at IZO, which presents a great interannual variation depending on weather conditions such as temperature and precipitation. While in SCO concentration of pollen shows a broad maximum covering an extensive spring season (February to June), in IZO concentration of pollen concentrates in almost one month (usually from late May to late June; during May in 2015) with values that can be very high, much higher than those recorded for SCO, although this was not the case in 2015. Year 2015 showed early pollinations with regard to the mean data and concentrations higher than the mean ones during an important part of the year, especially in SCO (Fig. 14.2).

The total concentration of fungal spores shows a contrasting seasonal variation to that of total pollen. In SCO the highest concentrations that usually occur between October and December took place in October-November in 2015 and reached values higher than the mean ones during most of the year. At IZO, significant values are usually observed from April to December and year 2015 showed concentrations higher than the mean values and over the absolute maximum concentration in November. There is a big difference, of the order of magnitude, of the concentrations recorded in SCO (higher) and IZO (Fig. 14.3).

These results refer to total concentration of pollens and fungal spores. However individual pollens and fungal spores might have a quite different seasonal behaviour at each station (see Tables 14.1 and 14.2).

A number of products, such as current levels and forecasts of the main allergenic pollens and fungal spores, historical and current data and pollen calendar for SCO can be found at the Tenerife Aerobiology information (Proyecto EOLO-PAT) web page.

14.4 Future Activities

- Continuation of pollens and fungal spores sampling, and aerobiological data analysis.
- Update of the airborne pollen and spores databases.
- Improvement of the information provided through the webpage and services to its users.
- Trend analysis.
- Internannual variability in connection with meteorology.

14.5 References

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15 Phenology

15.1 Main Scientific Goals

Phenology is the study of biological phenomena that occur periodically coupled to weather-related seasonal rhythms and to the annual course of the weather, in a particular place. These phenomena (migratory birds' phases, appearance of flowers or fruit ripening in plants, etc.) are sensitive to changes in weather and climate; hence, its detailed study may help better understand how these environmental variations affect living things. Therefore, WMO recommended to the National Meteorological Services to implement a phenological observations programme.

IZO is an excellent location for conducting phenological observations since it is located in a high mountain area on an island with a large number of endemic species. The endemic species are adapted to specific environmental conditions, which make them particularly sensitive to small environmental changes, and therefore their study is of great interest.

AEMET has operated a programme of phenological observations since the 1940s, but its focus has been largely on agricultural applications. However, in 2014 IZO joined AEMET's network of phenological stations in order to better understand the relationship between the life cycles of endemic wildlife of the environment and the specific and unique climate of the area. The programme started in collaboration with the Teide National Park authority.

The programme of phenological observations at IZO was established with the commitment to maintain long-term observations; we can only obtain valuable information if observations are performed systematically for many years. The clearest examples are the weather observations.

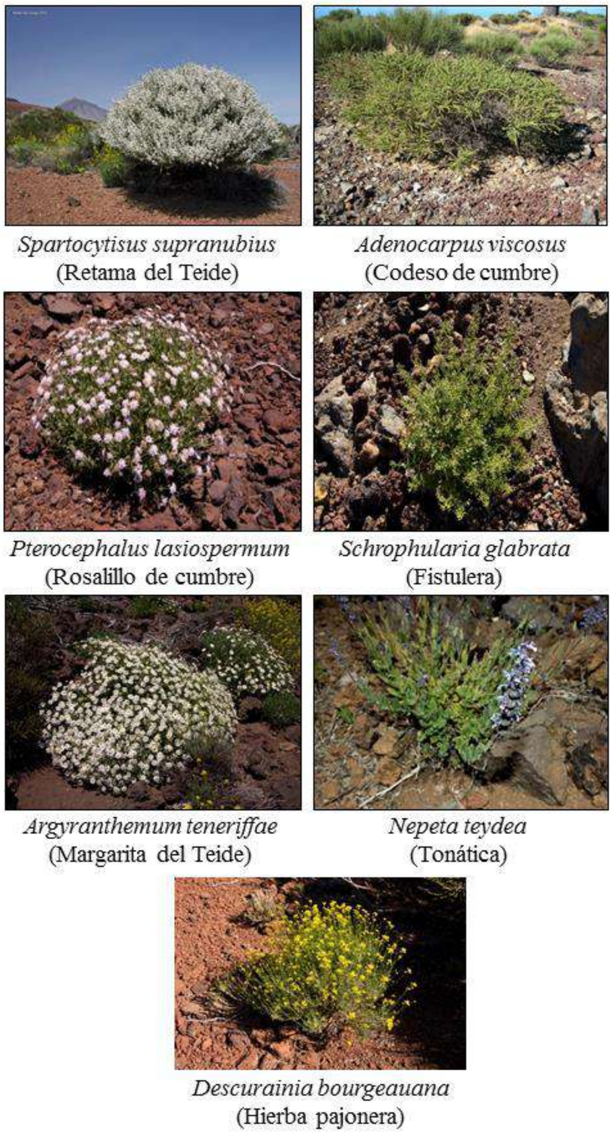

Figure 15.1. Endemic taxa typical from high lands of the island of Tenerife, which are analysed in the Phenology programme.

15.2 Measurement Programme

Currently we are studying the taxa shown in (Fig. 15.1), all of them endemic, corresponding to the higher elevations of the island of Tenerife. We study, for each taxon, the emergence of the inflorescence, or the appearance of flower buds, flowering, and fruit development according to the BBCH code (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) adopted by AEMET. The phenological stages that are taken into account are detailed in Table 15.1.

We also employ another encoding (Table 15.2), used by the technicians of the Teide National Park and based on the model proposed by Anderson and Hubricht (1940) within the joint phenological project with this institution. In this methodology, three biological phases (inflorescence emergence or development of flower buds; flowering and fruit development) and their percentage in the population development of each taxa are considered. Phenological observations are visual, so we chose nine sampling points around IZO where there is a good representation of healthy adult specimens of the studied taxa. For each observation point we estimate the percentage of phenological phases, translating this percentage to the aforementioned codes. The selected sampling points are marked in Fig. 15.2.

The phenological observations are made on a weekly basis at the time of the appearance of buds, flowering and fruit growth and every fortnight in pre- and post-development weeks of these stages, and on a monthly basis during the winter months.

Table 15.1. Phenological stages: BBCH code.

BBCH code	Description
551	10% of visible petals closed, 10% "tip petals"
55	Emergence of the corolla, visible petals closed, "tip petals"
60	First flowers open
61	10% of flowers open (beginning of flowering).
63	Flowering to 30%
65	Bloom 50% (full bloom)
79	End of fruit formation (practically reach their final size)
89	The fruits are mature; They detach easily from the plant

Table 15.2. Phenological stages: Anderson & Hubricht code.

Code	Description (valid for each stage: inflorescence, flowering and fruit)
A	Absent
B	From the first specimens up to 10%
C1	from 10 to 30% of buds / flowers / fruits
C2	Between 30 and 50%
D	More than 50%
E1	Between 50 and 30%
E2	Between 30 and 10%
F	Less than 10% of specimens

Figure 15.2. Aerial view of the surroundings of the Izaña Atmospheric Observatory indicating the selected sampling points, those on the north-west slope are marked in blue and those on the south-east slope are marked in yellow.

15.3 Summary of remarkable results during the period 2012-2014

The three years of observations (Fig. 15.3) allow us to distinguish different patterns of flowering in the studied species: while some remain in full bloom for many weeks (as in the case of the Daisy flower), other species have a more explosive flowering, probably adapting to the few days when environmental conditions are favourable to do so without too much heat or cold, and the ground still wet.

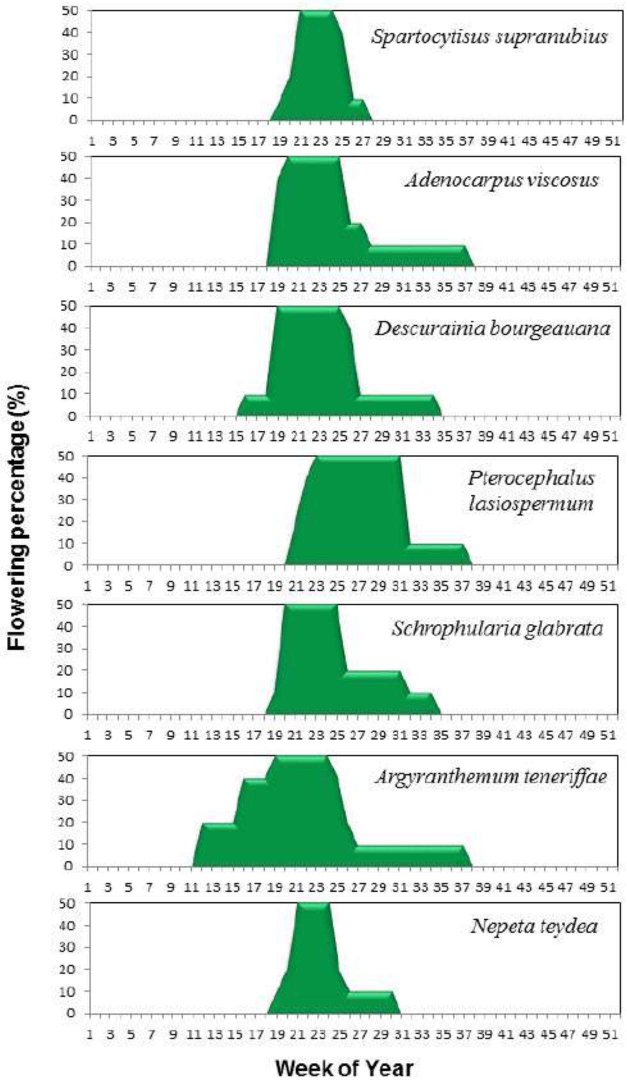

Figure 15.3. Duration of the flowering stage in different taxa at Izaña, 2014.

15.4 Development of a gauge for measuring the water from fog

In the summits of Tenerife the annual precipitation is around 430 mm, but there are large inter-annual variations. Fog is thought to provide a significant additional contribution of water to vegetation in drought years, as the vegetation is able to capture some of the water contained in the fog droplets. In order to have data on the amount of water that can be obtained from the fog, a rain gauge was adapted following the guidelines of the WMO technical note (2008) and installed in 2009. The gauge comprises a metal mesh above a cylinder of 10 cm diameter and 22 cm height, and a frame of 0.2 cm x 0.2 cm, which mimics the capture of fog droplets by the plants, although we assume this is quite difficult to achieve because much depends on the leaf morphology, orientation of the plant, wind, etc. The adapted rain-gauge and a close-up of the wire mesh installed are shown in Fig. 15.4.

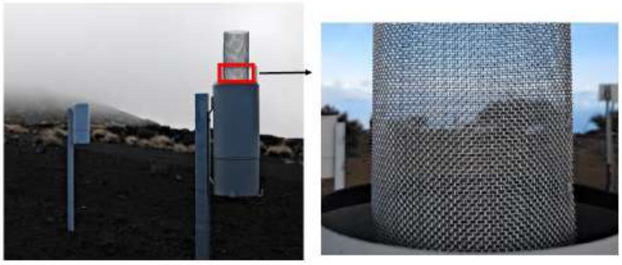

Figure 15.4. Adapted rain-gauge and a close-up of the wire mesh.

The results obtained so far show that the contribution of water due to the fog is important, since the rain gauge adapted for the collection of fog-water collected approximately 5 times more precipitation than the conventional rain gauge (Fig. 15.5). Also noteworthy is the extremely dry period 2011-2012, in which the total water collected by the fog gauge was almost 13 times higher than the standard gauge.

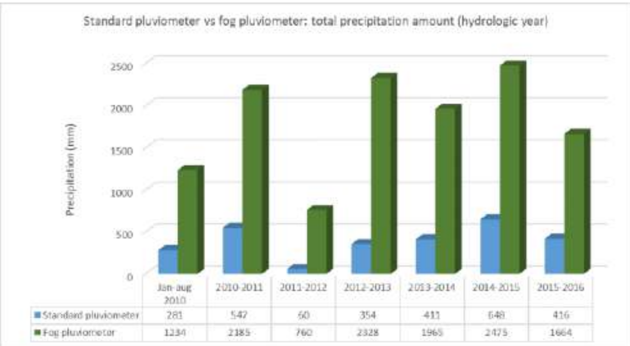

Figure 15.5. Comparison of the precipitation collected with standard rain gauge and the modified fog-rain gauge for the last seven hydrometeorological years. The 'hydrometeorological year' used here is the period from September 1 to August 31.

In March 2015, another rain gauge adapted for the collection of fog-water was installed southeast of the observatory, in an area sheltered from the northwest winds predominant at Izaña. The objective was to establish if there is a difference in fog precipitation according to the location, and if this difference in the availability of fog water could have any influence on the phenology of the vegetation located in that zone.

In addition, an experiment was conducted to quantify the amount of fog-water collected by a mature Teide broom (Spartocitysus supranubius) specimen. A several decades old specimen located near zone 1 of observations was selected, and four devices were installed around it, one in each cardinal point (north, south, east and west). Each device consisted of a funnel of 120 cm^2 of catchment area, to which a drainage hose was added to a plastic bottle buried in the soil beneath the broom to avoid evaporation as much as possible, since the collection of water for quantification was conducted on a monthly basis.

Figure 15.6 Specimen of Teide broom chosen for the experiment.

Figure 15.7 Broom rain gauge

Table 15.3 Precipitation collected with the various rain gauges from 1 March 2015 – 30 September 2016.

Rain gauge	Precipitation (mm)
Standard rain gauge	308
Meteorological garden fog gauge	2070
Fog gauge (southeast)	1415
Broom rain gauge (north)	537
Broom rain gauge (west)	179
Broom rain gauge (south)	119
Broom rain gauge (east)	288
Total amount of broom rain gauges	1123

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International Cooperation Programmes

16 ACTRIS TransNational Access

16.1 AERONET-EUROPE Calibration Service

The AERosol RObotic NETwork (AERONET) is a ground-based standardized automatic sun/sky-photometer network devoted to the characterization and monitoring of aerosol properties. AERONET sites are located worldwide, with also a high number in Europe. AERONET is practically the only facility available worldwide to satellite and atmospheric modelling communities to verify and validate both near real time and long-term aerosol products. It was widely used in the various Monitoring Atmospheric Composition and Climate (MACC) projects and in the current Copernicus Atmosphere Monitoring Service (CAMS). AERONET is also used by the Climate Change Initiative (CCI) and the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) for Northern Africa, Middle East and Europe.

The AERONET-EUROPE Calibration Service was financed by the Aerosol Cloud and TRace gas InfraStructure (ACTRIS) European Research Infrastructure Action (FP7/2007-2013) until April 2015. Since May 2015, AERONET-Europe has been financed by the project ACTRIS-2 Integrating Activities, receiving funding from the European Union's Horizon 2020 research and innovation programme. AERONET-EUROPE Calibration Service offers to the scientific community a unique sun-photometer facility for calibration and maintenance, operating within the AERONET federation (Goloub et al., 2012; 2013; 2014). Since 2015, one additional value from AERONET-EUROPE Calibration Service is providing lunar calibration and nighttime AOD from the new Triple photometer (Cimel CE318T; for sun, sky and lunar observations).

This TransNational Access (TNA) handles a calibration service for instruments operated at current and future AERONET sites, thus, complementing the NASA calibration center based in Washington-USA. AERONET-Europe Calibration Service is a multi-site infrastructure (Fig. 16.1) with facilities at Lille (LOA, France) and Valladolid (GOA, Spain), devoted to inter-calibration of field instruments, and at IZO, a unique facility for absolute calibration of Master Cimel instruments.

IZO hosts a set of eight reference instruments continuously in operation and available for the needs of the LOA and GOA facilities. AERONET-EUROPE master instruments from LOA and GOA are recalibrated every three months at IZO in order to assure measurement accuracy.

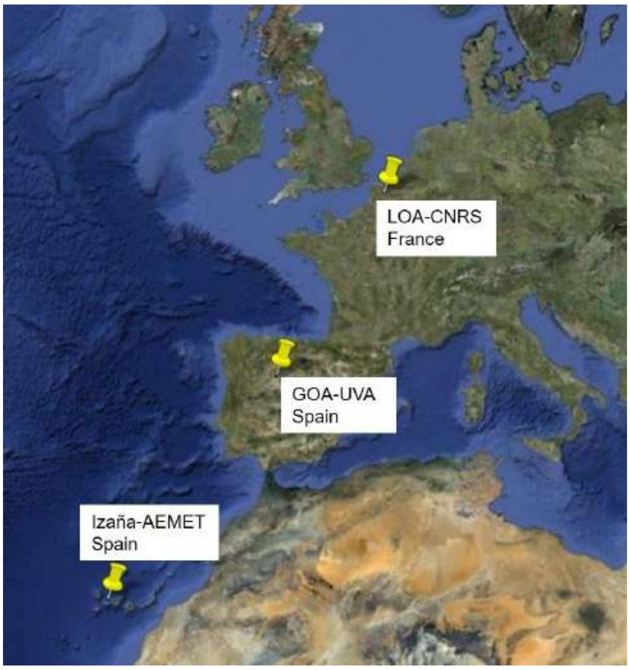

Figure 16.1. Location of the three calibration facilities of AERONET-Europe.

Master instruments from other networks as CARSNET (China Aerosol Remote Sensing NETwork) and IRSA (Institute of Remote Sensing Applications) are also recalibrated at IZO on a regular basis (Fig. 16.2). Furthermore, under certain conditions, some field instruments have been calibrated at IZO where their maintenance and repair work was performed.

All users operating for their research activity either a standard or a polarized CIMEL sun/sky or triple (sun/sky/lunar) photometer located in Europe or run out of Europe in the framework of international cooperation agreements can submit a proposal to AERONET-EUROPE Calibration Service at any time. The instrument calibration and maintenance is performed free of charge, and proposals are granted on the basis of a TNA selection panel review process. Instrument shipping expenses from and to the user site are not included and must be covered by the user institution.

Most of the accesses provided under AERONET-EUROPE allow to assure quality of data on sites operating not only a sun or triple photometer but also multiple complementary in situ and remote sensing instruments. This aspect provides a clear integration of sun or triple photometers, LIDARs and in situ aerosol instruments. The number of total accesses provided by AERONET-EUROPE in 2015-2016 was 195, specifically 93, 58 and 44 for LOA, GOA and IZO, respectively.

Figure 16.2. Cimel Masters at the Izaña Atmospheric Observatory AERONET-Europe Calibration facility.

In addition to the calibration activity provided by AERONET-EUROPE to European users for European sites, several accepted proposals involved European users deploying their instruments during either field experiments or in a more permanent manner out of Europe, for example, in Northern Africa, South East-Africa, Central Asia, Asia and Antarctica. These calibrations also provided a good opportunity for linking the AERONET network to other sun or lunar photometer networks operating or starting operation in the world. Several proposals involved other existing technologies and new technologies under evaluation.

Data quality, instrument performance and well-trained site managers are, after calibration, the keys of success to be considered by AERONET-EUROPE. Thanks to these activities, several sites/instruments previously managed/calibrated by NASA and insufficiently managed by the users, have been renovated.

Quality-assured data from AERONET-EUROPE are widely used by modelling and satellite communities through several European programs and initiatives (ESA, MACC-II, GMES, AEROCOM, etc). By the end of 2012, around 40 AERONET sun-photometers were used for near real time validation by the SDS-WAS Regional Center for North Africa, Middle East and Europe, most of them were calibrated by AERONET-EUROPE. CAMS also performs near real time use of AERONET data for specific model aerosol products verification.

16.2 Physical access to observational facilities

The ACTRIS-2 project offers free of charge hands-on access of researchers to 18 world-class observing platforms in Europe within the transnational access (TNA) programme. The observational facilities offering TNA are representative for their uniqueness within Europe, offering a comprehensive measurement programme at the forefront of the advancement of research in the specific domains covered within ACTRIS (e.g. vertical aerosol distribution, in-situ aerosol properties, trace gases) together with state-of-the-art equipment, high level of services, and capacity to provide research-driven training to young scientists and new users. One of these 18 observational facilities is the Izaña Atmospheric Research Center under the acronym of ISAF (Izaña Subtropical Access Facility). ISAF is the only existing infrastructure for observations in the free troposphere of the subtropical North Atlantic. Three TNA types are available: 1) training, 2) mobility of expert and 3) combination of training/expert mobility. In the period 2015-2016, two TNA proposals to ISAF were applied for and approved.

16.2.1 TNA 20-27 June 2016

Raúl D'Elía a technician from the Laser and Applications Research Center (CEILAP) (Argentina) was the first researcher to apply for access to ISAF. During his stay, from 20 to 27 June 2016, Raúl had the opportunity to be trained on AERONET master photometer calibrations, including solar, sky and lunar calibrations, which are performed at Izaña Atmospheric Observatory as part of the AERONET-EUROPE Calibration Centre. Furthermore, Raúl was introduced to other permanent programmes at Izaña (Radiation, Total Column Aerosols and Water Vapour, Surface Aerosols, Ozone and UV, and FTIR). This visit was also part of the IARC activities as WMO-CIMO Testbed for Aerosols and Water Vapor Remote Sensing Instruments.

Figure 16.3. Raúl D'Elía undertaking training activities during his TNA, 20-27 June 2016.

16.2.2 TNA 12-30 September 2016

The second TNA proposal involved the mobility of experts from PMOD/WRC (Dr Julian Gröbner, Dr Natalia Kouremeti and Dr Luca Egli). They participated in an intercomparison campaign hosted at Izaña Atmospheric Observatory from 12 to 30 September 2016. As part of the campaign activities, they aimed at obtaining a calibration of aerosol optical depth for the standard, ultraviolet and lunar precision filter radiometers (PFR) operated within the GAW PFR global network. This calibration will allow AOD measurements at the Izaña Subtropical Access Facility to become traceable to the AOD world reference, represented by a Triad of PFR instruments stationed at the World Optical Depth Research and Calibration Center (WORCC).

Figure 16.4. Dr Julian Gröbner, Dr Natalia Kouremeti and Dr Luca Egli during the TNA, 12-30 September 2016.

16.3 Future activities

AERONET-EUROPE will be reinforced and expanded within ACTRIS-2 by providing a fast and efficient calibration and standard maintenance service for sun/sky/polar/lunar photometers, and through the instrument status monitoring with Quality Check during operation in the field, and Quality Assurance.

16.4 References

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17 Regional Brewer Calibration Center for Europe (RBCC-E)

17.1 Background

In November 2003 the WMO/GAW Regional Brewer Calibration Center for Europe (RA-VI region) (RBCC-E) was established at IZO. The RBCC-E reference is based on three double Mark-III Brewer spectrophotometers (the IZO triad): a Regional Primary Reference (Brewer 157), a Regional Secondary Reference (Brewer 183) and a Regional Travelling Reference (Brewer 185) (Fig. 17.1). As described in Section 3.1, IZO is located in a subtropical region (28ºN) on a mountain plateau (2373 m a.s.l.) with pristine skies and low ozone variability. This location allows routine absolute calibrations of the references in similar conditions to the Mauna Loa Observatory (MLO), Hawaii, USA. The establishment of the RBCC-E Triad allows the implementation of a self-sufficient European Brewer calibration system that respects the world scale but works as an independent GAW infrastructure.

There are two European Calibration Centers for the two types of ozone spectrophotometers in use: Dobson and Brewer. The Regional Dobson Calibration Center for Europe (RDCC-E) is located at the Meteorological Observatory Hohenpeissenberg (Germany). Since 2009, the RBCC-E activities have largely been funded by the ESA project, "CEOS Intercalibration of Ground-Based Spectrometers and Lidars" which includes the participation of the two European Calibration Centers (RBCC-E and RDCC-E).

17.2 Objectives

The main objectives of this Cooperation programme are:

- To implement a system for routine absolute calibrations of the European Brewer regional reference instruments at IZO, fully compatible with absolute calibrations of the world reference triad at MLO.
- To perform periodical calibration campaigns using the Regional Primary Reference B157 (during intercomparisons held at IZO) and the Regional Travelling Reference B185 spectrophotometer (traceable to B157) in continental campaigns.
- To perform regular comparisons of the Regional Brewer Primary Reference B157 with the Regional Dobson Reference D074 to monitor the relationship between both calibration scales in the RA-VI region.
- To study the sources of errors of the absolute calibrations and to determine the accuracy of total ozone measurement achievable by the Brewer spectrophotometer under different atmospheric conditions or instrumental characteristics.

Figure 17.1. RBCC-E team and RBCC-E Brewer spectrophotometer triad located at Izaña Atmospheric Observatory (Photo: Alberto Redondas).

17.3 Tasks

The main tasks of this Cooperation programme are:

- To develop quality control procedures and Standard operating Procedures (SOPs) for traceability of measurements to the reference standards.
- To maintain laboratory and transfer standards that are traceable to the reference standards.
- To perform regular calibrations and audits at GAW sites.
- To provide, in cooperation with Quality Assurance/Science Activity Centres, training and technical assistance for stations.

17.4 GAW Scientific Advisory Group for Ozone

The GAW Scientific Advisory Group for Ozone (GAW SAG Ozone) monitors the activities in the stratospheric ozone programme, overlooks and gives guidance to the World Ozone and UV Data Centre and the Calibration Centres, and establishes and helps publish standard operating procedures. In addition, it helps with capacity building activities, makes recommendations about measurement techniques, calibration schedules and relocation of redundant instruments, and provides recommendations for all participants of the Ozone Network. The group consists of 19 international experts. Alkiviadis Bais (Greece) has been the chair of the GAW SAG Ozone since 2013. Alberto Redondas (IARC) as site manager of the RBCC-E has been a member of the GAW SAG Ozone since 2005.

17.5 Main activities of the RBCC-E during the period 2015-2016

17.5.1 Absolute calibration transfer

The RBCC-E Brewer triad transfers the calibration from the world reference triad, located in Toronto (Canada) and managed by Environment and Climate Change Canada, Meteorological Service of Canada (ECCC-MSC). The RBCC-E travelling reference Brewer#185 ensures the world reference transference to the WMO-Region VI Brewer netwok. The link of the RBCC-E triad to the world reference has been performed in the past using the travelling standard Brewer#017 managed by the International Ozone Service (IOS). The WMO GAW SAG ozone in 2011 authorized RBCC-E to conduct the transference of its own absolute calibration, based on Langley analysis at IZO. The link to the world reference is by direct intercomparison with the world triad in Toronto or by common Langley campaigns at MLO or at IZO (Redondas 2014a).

At present, the RBCC-E maintains a triad of reference instruments. The Regional Primary Reference Spectrophotometer (B#157), Secondary Reference Spectrophotometer (B#183) and the Regional Travelling Reference Spectrophotometer (B#185). Each spectrophotometer is calibrated independently with the standard Langley method at IZO and since 2011 transfer their own calibration and are regularly compared with the Toronto Triad. Redondas et al. (2016) studied the stability of the RBCCE triad during the period 2005-2015, using a mathematical method where the ozone values are fitted to a 2nd grade polynomial (Fioletov et al., 2005) or an extended 3rd grade polynomial (René et al., 2014).

Redondas et al. (2016) took into account two conditions: a) only days with at least 15 measurements distributed between, before and after the solar noon and with standard deviation < 0.5 were selected and b) data from Brewer #185 measured during campaigns were removed. In addition to this study, the stability of the RBCCE triad during the period 2010-2016 is presented in this report. The distribution of the difference between the ozone daily mean obtained by each Brewer with respect to the Triad mean O_3 value (O_{3_mean}) was calculated as follows:

$$O_{3\_mean} = (O_{3\_157} + O_{3\_183} + O_{3\_185})/3. \quad (1)$$

A good Gaussian profile can be observed in the distribution of the differences (Fig. 17.2) which confirms the stability of the IZO Brewer Triad during the period 2010-2016.

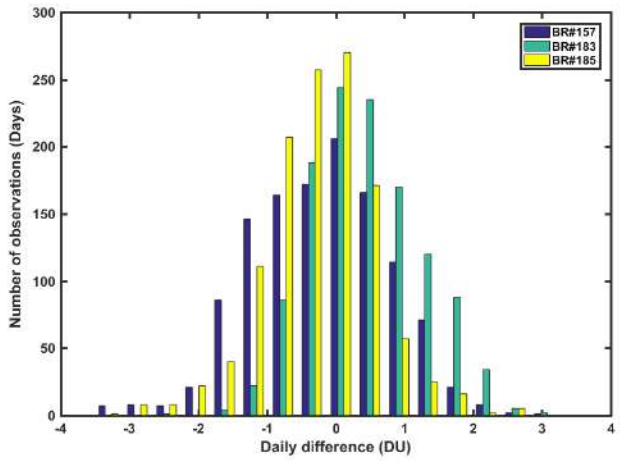

Figure 17.2. Distribution of the differences between the ozone daily mean obtained by each Brewer in the Triad with respect to the mean O_3 value of the RBCC-E Brewer Triad located at IZO for the period 2010-2016.

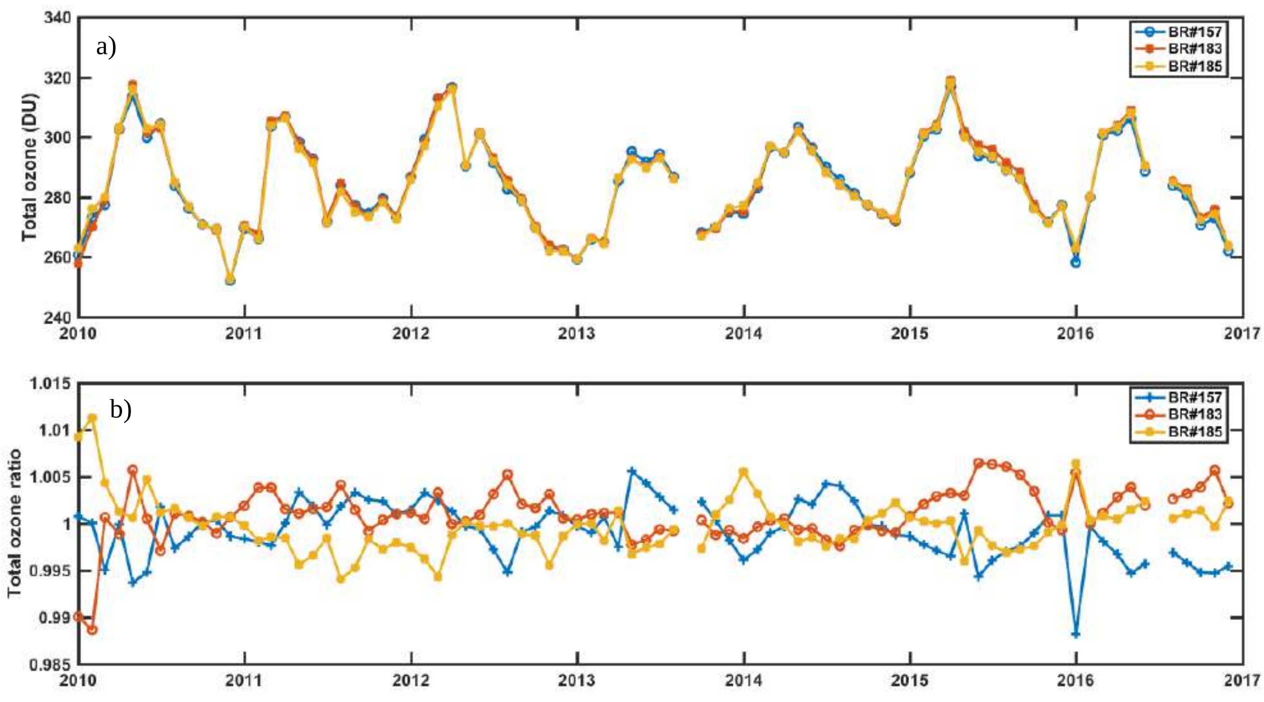

Figure 17.3. a) Monthly mean Total Ozone Column values measured at Izaña Atmospheric Observatory by the RBCC-E triad and b) Total ozone ratio of each Brewer in comparison to the RBCC-E Triad mean during the period 2010-2016.

Figure 17.3 shows the relative deviations from the RBCC-E triad monthly mean TOC for each individual Brewer. This plot is used as a benchmark to identify if an instrument of the Triad needs to be recalibrated or for checking that a current calibration applied to a Brewer is good enough. The standard deviation of the relative deviations from the RBCC-E Triad monthly mean have values of 0.33%, 0.34% and 0.23% (B\#157, B\#183 and B\#185) for the period 2010-2016, slightly lower than those reported for the Canada Triad (Fieletov, et al. 2005).

17.5.2 RBCC-E Intercomparison campaigns

Brewer intercomparisons are held annually, alternating between Arosa in Switzerland and the El Arenosillo Sounding Station of the INTA at Huelva in the south of Spain. The aim is for a number of Brewers from invited organizations to collect simultaneous ozone data so that their calibration constants can be transferred from the reference instruments. Two regular intercomparison campaigns were organized by the RBCC-E during this reporting period (2015-2016), the Tenth RBCC-E intercomparison campaign held at Arosa-Davos (Switzerland, 16-27 July 2015) and the Eleventh RBCC-E intercomparison campaign held at El Arenosillo (Spain, 10-21 June 2016) (Table 17.1). The geographical origin of the Brewers calibrated by the RBCC-E is shown in Fig. 17.4 and the number of calibrations performed by the RBCC-E every year is shown in Fig. 17.5. In 2015 and 2016, 25 and 18 calibrations were performed, respectively. These routine intercomparison campaigns provide the Brewer community with the opportunity to assess the European network instruments status.

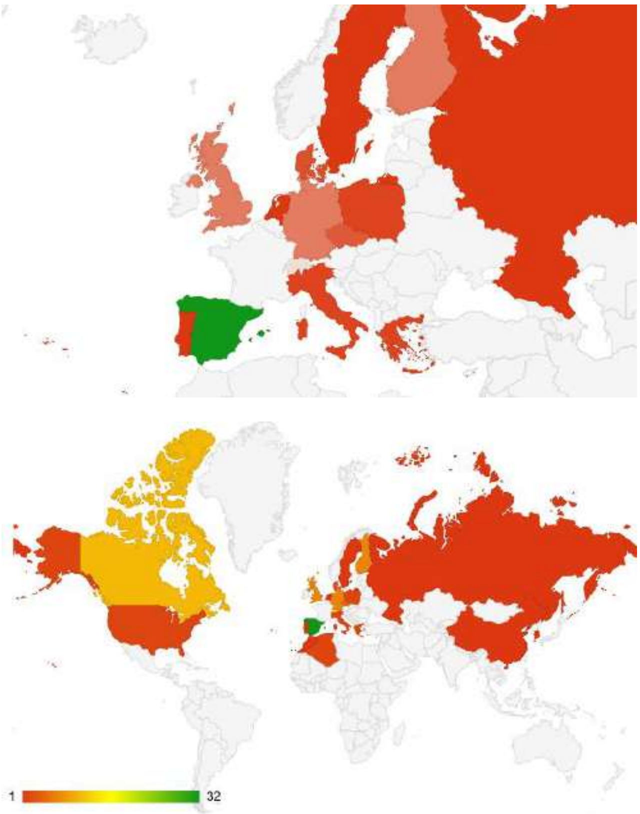

Figure 17.4. Geographical origin of the Brewers calibrated by the RBCC-E.

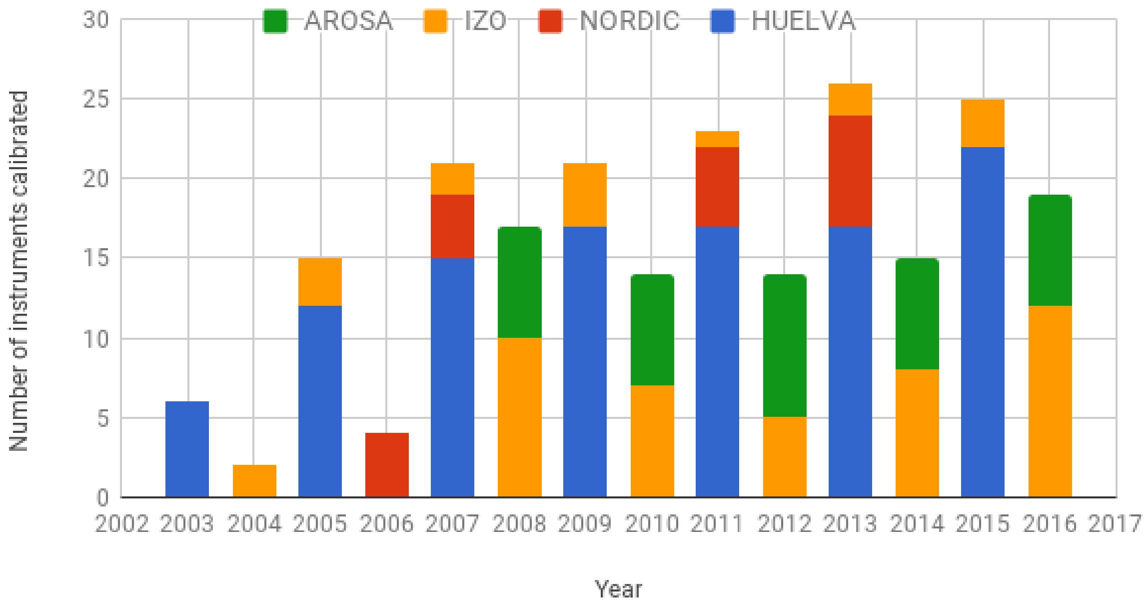

Figure 17.5. Calibrations performed by the RBCC-E per year.

Table 17.1. Campaigns performed during the period 2015–2016 organized by the RBCC-E.

Institution	Participants	Instrument	Country
Arenosillo 2015 (Spain, 10-21 June) RBCC-E			
IARC-AEMET	Alberto Redondas Sergio Leon Virgilio Carreño Javier Lopez Bentorey Hernández	Brewer #185-MKIII	Spain
International Ozone Services (IOS)	Martin Stanek Volodya Savastiouk	Brewer #017-MKII	Canada
Kipp & Zonen (K&Z)	Pavel Baba l Oleskii Marianenko	Brewer #158-MKIII	The Netherlands
Instituto Nacional de Técnica Aeroespacial (INTA)	Jose Manuel Vilaplana	Brewer #150-MKIII	Spain
IARC-AEMET	J.R. Moreta González Daniel Moreno J.M San Atanasio Angel Miguel Boned Francisco Escribá Francisco García	Brewer #033-MKIV Brewer #070-MKIV Brewer #186-MKIII Brewer #166-MKIV Brewer #117-MKIV Brewer #151-MKIV	Spain
Algerian Meteorology Service (WMO)	Ouchene Bouziane Ferroudj Mohammed Salah	Brewer #201-MKIII	Algeria
UK Meteorological Office (UKMO)	John Rimmer Peter Kelly	Brewer #075-MKIV Brewer #126-MKII Brewer #172-MKIII	U.K.
Direction de la Météorologie Nationale (DMN)	Hamza Rachidi Mohammed Jamaleddine Abdelkarim Faquih	Brewer#165-MKIII	Morocco
Demmark	Paul Erikson Niss Jepsen	Brewer #202-MKIII Brewer #228-MKIII	Denmark
World Radiation Center (WRC)	Luca Egli Christian Thomann Julian Gröbner	Brewer #163-MKIII QUASUME	Switzerland
Institute of Experimental Meteorology	Vadim Shirokov	Brewer #044-MKIV	Rusia
FMI	Tomi Karpinen Tapani Koskela	Brewer #214-MKIII	Finland
Universidad de Extramadura	Marisa Cancillo Ana Alvarez Antonio Serrano		Spain
Arosa-Davos 2016 (Switzerland, 16-27 July 2016) RBCC-E			
IARC-AEMET	Alberto Redondas Sergio León Luis Virgilio Carreño	Brewer #185-MKIII	Spain
Arosa Lichtklimatisches Observatorium (LKO)	René Stübi Herbert Schill Werner Siegrist	Brewer #040-MKII Brewer #072-MKII Brewer #156-MKIII	Switzerland
Kipp & Zonen (K&Z)	Alexander Visser Pavel Babal	Brewer #158-MKIII Brewer #230-MKIII	Netherland
World Radiation Center (WRC)	Julian Gröbner Luca Eggli Gregor Huelsen	Brewer #163-MKIII	Switzerland

Institution	Participants	Instrument	Country
Izaña ATMOZ campaign 2016 (Spain, 12-30 September) RBCC-E/RDCC-E			
IARC-AEMET	Alberto Redondas Virgilio Carreño Sergio León Luis Alberto Berjón Daniel Santana Iballa Hernández Bentorey Hernández Javier López	Brewer #185-MKIII Brewer #183-MkIII Brewer #157-MkIII Pandora	Spain
Meteorological Observatory of Hohenpeissenberg (MOHp)	Ulf Koehler Herbert Munier	Dobson #064	Germany
NOAA	Glen McConville	Dobson #083	EEUU
RDCC-E	Michael Heinen Martin Stanek	Dobson D#074 Dobson D#017	Germany
PMOD	Julian Gröebner Luca Egli Natalia Kournemeti	UV PFR Lunar PFR QASUME AVODOR UV PSR	Switzerland
University of Thessaloniki	Alkis Bais Fani Gkertsi	Phaethon	Greece
PTB	Ingo Kröger Stefan Riechelmann Peter Spefeld	UV-FT GIgahertz BTS2048-UV-S	Germany
Universidad de Valladolid	Carlos Toledano Ramiro González Victoria Cachorro	Irradiance Calibration	Spain
Dutch Metrology Institute	Omar el Gawhary Natasha	Wavelength ruler, LDLS	Netherland
AEMET	Rosa García	EKO CCD radiometer	Spain
Manchester University	John Rimmer		United Kingdom

17.5.3 Brewer Calibration: Stray Light

The Brewer instrument measures the intensity of direct sunlight at six wavelengths (λ) in the UV (303.2, 306.3, 310.1, 313.5, 316.8, and 320.1 nm) each covering a bandwidth of 0.5 nm (resolution power λ/δλ of around 600). The spectral measurement is achieved by a holographic grating in combination with a slit mask, which selects the channel to be analyzed by a photomultiplier. The longest four wavelengths are used for the total ozone concentration calculation. Based on the Lambert-Beer law, the total ozone column in the Brewer algorithm can be expressed as:

$$\boldsymbol{X} = \frac{\boldsymbol{F-ETC}}{\boldsymbol{\alpha\mu}} \qquad (2)$$

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 extra-terrestrial constant. The F, α and ETC parameters are weighted functions at the operational wavelengths with weighting coefficients w:

$$F = \sum_i^4 w_i F_i - \frac{p}{p_0}\beta_i\mu \qquad (3)$$

$$\alpha = \sum_i^4 w_i \alpha_i \qquad (4)$$

$$ETC = \sum_i^4 w_i F_{0_i} \qquad (5)$$

where, βi are the Rayleigh coefficients, p is the climatological pressure at the measurement site, p_0 is the pressure at sea level, and F_0 are the individual extra-terrestrial constants at each wavelength. The weights w = [1, −0.5, −2.2, 1.7] have been chosen to minimize the influence of SO_2 and verify:

$$\sum_i^4 w_i = 0 \qquad (6)$$

$$\sum_i^4 w_i \lambda_i = 0 \qquad (7)$$

This procedure widely eliminates absorption features, which depend, in local approximation, linearly on the wavelength, like for example the contribution from aerosols.

We can divide the calibration into three steps: instrumental, wavelength, and ETC transfer:

1) The instrumental calibration includes all the parameters that affect the measured counts (F), in particular dead time correction, temperature coefficients and filter attenuation.

2) The wavelength calibration determines the ozone absorption coefficient: the so-called "dispersion test" is used to obtain the particular wavelength for the instrument and the slit, or instrumental function, of each spectrophotometer. Note that the precise wavelengths of every Brewer spectrophotometer differ slightly from instrument to instrument.

3) Finally, the ETC transfer is performed by comparison with the reference or, in the case of the reference instruments, by the Langley method.

The calibration process is an iterative process. The instrumental and/or wavelength calibration will affect the final ETC. For this reason, the calibration campaigns are scheduled in three different periods:

1) Initial or Blind period: the first days of the campaign are dedicated to determine the current status of the instrument, during this period modifications of the instrument are not allowed.

2) Characterization period: after the determination of how the instrument is measuring, the next days are dedicated to characterization of the instrument and performance of the necessary adjustments and maintenance. The instrumental and wavelength calibration must be finished at the end of this period.

3) Final period: the period where the ETC transfer is performed when the instrument is fully characterized and stable.

The transfer of the calibration scale (namely ETC) is done side by side with the reference instrument. Once we have collected enough near-simultaneous direct sun ozone measurements, we calculate the new extraterrestrial constant after imposing the condition that the measured ozone will be the same for simultaneous measurements. In terms of Equation 2, this leads to the following condition:

$$ETC_i = F_i - X_i^{reference}\alpha\mu \quad (8)$$

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 a tail at the lower ETC values for high Ozone Slant Column (OSC, the product of the total ozone content by the airmass) (see Fig. 17.6).

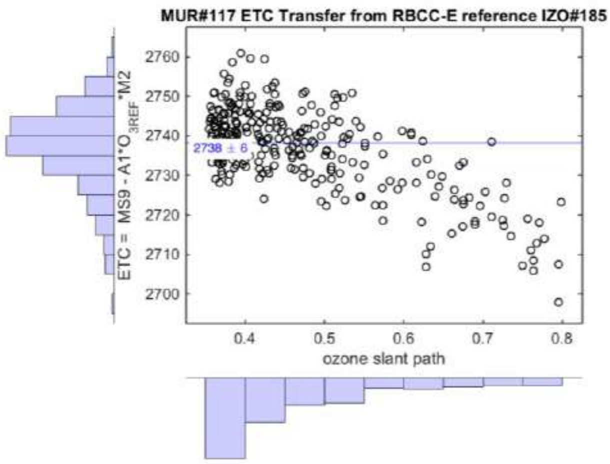

Figure 17.6. Distribution of individual ETC values determined by simultaneous measurements. In the x axis, the ozone slant column is shown divided by 1000 (OSC are expressed in cm). In this particular Brewer, the stray light is clearly shown at values above 0.6 for the scaled ozone slant column. Reprinted from Redondas et al. (2017).

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:

$$F = F_o + k(X\mu)^s \quad (9)$$

$$ETC_i = ETC_o + k(X\mu)^s \quad (10)$$

where ETC_o is the ETC for the stray light free OSC region and k and s are retrieved from the reference comparison (Fig. 17.7). 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:

$$X_{i+1} = X_i + \frac{k(X_i\mu)^s}{\alpha\mu} \quad (11)$$

Only one iteration is needed for 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 total ozone column (Fig. 17.8). These stray light corrections are now implemented in the standard processing of EUBREWNET (Redondas et al., 2017).

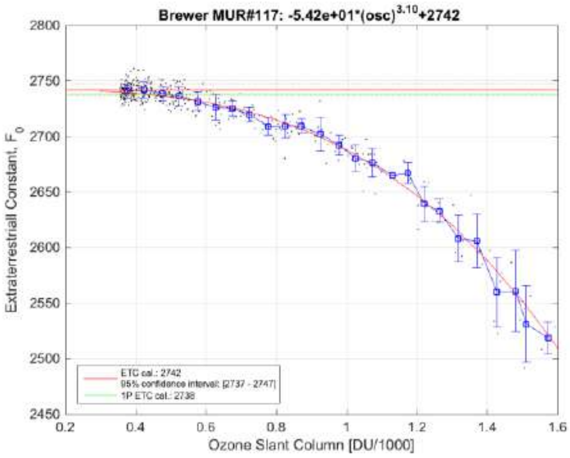

Figure 17.7. The stray light parameters k and s are determined by a nonlinear fit using the ETC determined from the stray-light free region as first guess parameters. The red horizontal line indicates the ETC constant retrieved from the fit whereas the green line shows the initial guess. Reprinted from Redondas et al. (2017).

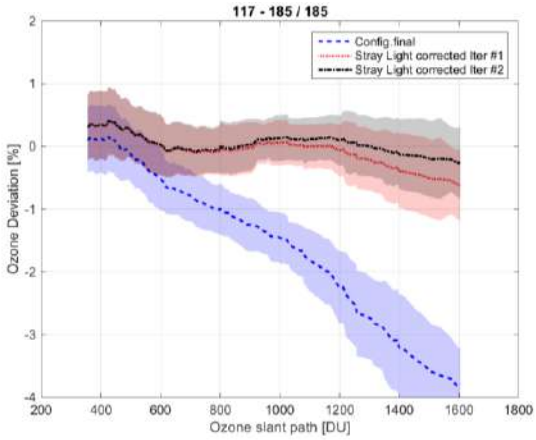

Figure 17.8. Percentage differences in total ozone column with respect to the reference vs. Ozone Slant Path. The blue line shows the results using the final configuration constants, and the red and black lines show the results after the stray light correction has been applied, with one and two iterations, respectively. Data are averaged in ± 50 DU intervals; the shaded area represents one standard deviation. Reprinted from Redondas et al. (2017).

17.5.4 Intercomparison Results

The initial comparison (blind period), using the instruments' original calibration constants, showed that all of the operational Brewer instruments were in the +/- 1.5% range if we consider the stray light free region (OSC < 900), 75% (16 instruments) of them were within 1% range and 50% (10 instruments) showed a perfect agreement of +/- 0.5% after two years calibration period (Figure 17.9). It is worth noting that these results are obtained without the Stray Light correction. Large errors of up to 4% (see for example Fig. 17.8) can be expected for single-monochromator Brewer instruments operating at OSC > 1000 DU. After the implementation of the Stray Light correction the single monochromator Brewers improved their performance and with the final calibration, all participating Brewer spectrophotometers were within the ± 0.5% agreement range (Figure 17.10).

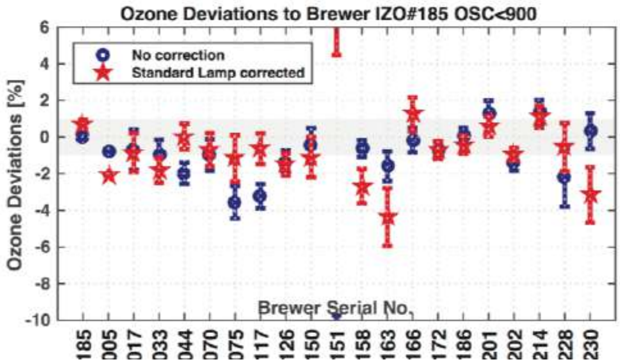

Figure 17.9. Initial period percentage mean difference for the simultaneous direct sun measurements with the reference for all the participating instruments, with and without the standard lamp correction, in the stray-light free OSC region (OSC < 900). Reprinted from Redondas et al. (2017).

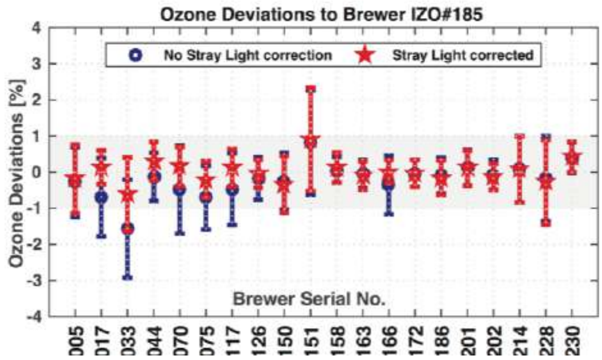

Figure 17.10. Final period percentage mean difference for the simultaneous direct sun measurements with the reference for all the participating instruments, blue symbols show results without the stray light correction and red ones are with the correction applied to single Brewer spectrophotometers. Reprinted from Redondas et al. (2017).

17.5.5 Training activities

The RBCC-E, in conjunction with WMO/UNEP and the EUBREWNET action are very active in the areas of training and capacity building, by organizing operator courses and workshops which provide expert instruction and knowledge exchange using the considerable expertise available. We also actively support the monitoring programs in developing countries. There have been various training activities during the 2015-2016 period (see below).

Brewer workshop during the 10th RBCC-E Calibration Campaign, Huelva, 25 May 2015

This workshop was focused on the EUBREWNET COST ACTION activities, mostly related with the WG-1 instrument characterization. This includes Brewer angular response, stray light determination by laser measurements, polarization effects, dead time characterization and radiative transfer modelling. All the sessions are available at the COST web-page.

Figure 17.11. Participants of the Brewer workshop during the 10th RBCC-E Calibration Campaign, Huelva 2015.

EUBREWNET Brewer Ozone Spectrophotometer open workshop in conjunction with the EMRP ATMOZ project and the 15th Biennial WMO-GAW Brewer Users Group Meeting. Ponta Delgada, Portugal, 17-20 May 2016

The event was organized as a collaboration of EUBREWNET (COST Action ES1207) and WMO-GAW. The event was hosted by the Instituto Português do Mar e da Atmosfera (IPMA) in Ponta Delgada, Portugal, 17 to 20 May 2016. The workshop focused on the operational, scientific and technical issues of the Brewer instrument and its role in the global ozone, aerosol and UV monitoring networks, as well as the development of new instruments and characterisation methods. The workshop also provided an opportunity for formal and informal exchange of information by those involved in the use of Brewer UV and ozone spectrophotometers, as well as others who have a general interest in atmospheric spectroscopy in the visible and ultraviolet. The presentations are available here (as links on the programme).

Figure 17.12. Brewer Ozone Spectrophotometer/Metrology Open Workshop Participants, Ponta Delgada, 17-20 May 2016.

EUBREWNET Brewer Ozone Spectrophotometer training school as side event of the Quadrennial Ozone Symposium 2016. Edinburgh, UK, 4-9 September 2016

The event was organized as a collaboration of EUBREWNET (COST Action ES1207) and WMO-GAW and took place back-to-back to the Quadrennial Ozone Symposium in Edinburgh, United Kingdom on 4-9 September 2016 with the participation of 20 students from America (4), Asia (2) and Europe (14) (Table 17.2) . The training school focused on operational, scientific and technical issues of the Brewer instrument with emphasis on the EUBREWNET products O_3, UV and AOD. The program of the course and the slides of the lectures are available at the EUBREWNET web site (http://www.eubrewnet.org/cost1207/2016/06/13/eubrewnet-wmo-gaw-brewer-operator-course-in-edinburgh/).

Figure 17.13. Participants at the Brewer Training School, Edinburgh, UK, 4-9 September 2016.

Table 17.2. Participants of the 2015 EUBREWNET workshop, 10th RBCC-E campaign, Huelva, Spain, 25 May - 5 June 2015.

Institution	Participants	Country
Thesaloniki University	Alkis Bais Dr Kostas Fragkos D Illias Fountitakis Theano Drosoglou	Greece
International Ozone Services	Vladimir Savastiouk Martin Stanek	Canada
Enviromental Canada	Mike Brohart	Canada
York University, Canada	Tom McElroy Omid Moeini	Canada
Izaña Atmospheric Research Center (AEMET), and University of La Laguna	Alberto Redondas Juan José Rodríguez Virgilio Carreño Sergio León Luis Javier López Bentorey Hernández	Spain
INTA	J. M. Vilaplana	Spain
Universidad de Extremadura	Antonio Serrano	Spain
AEMET	J.M. San Atanasio Juan R. Moreta Daniel Moreno Francisco Escribá Francisco García Carlos Marrero	Spain
Tasmania University	Manuel Nuñez	Australia
Manchester University	John Rimmer Peter Kelly Eric Gonzalez	UK
PMOD- World Radiation Center	Julian Groebner Christian Thomann Luca Egli Thomas Carlund	Switzerland
Kipp & Zonen	Oleksii Marianenko Keith M. Wilson Pavel Babal	The Netherlands
Danish Meteorological Institute	Paul Eriksen Niss Jepsen	Denmark
Finish Meteorological Institute	Tomi Karprinen Tapani Koskela	Finland
	Vadim Shirotov	Russia
Rome University	Ana Maria Siani	Italy
ARPA	Henri Diemoz	Italy

Figure 17.14. Participants of the Brewer workshop during the 10th RBCC-E Calibration Campaign, Huelva 2015.

Table 17.3. Participants of the EUBREWNET Brewer Ozone Spectrophotometer Training School, Quadrennial Ozone Symposium, Edinburgh, UK, 4-9 September 2016.

Institution	Participants	Country
CEILAP (Laser and Application Research Center)	Elian Wolfram Jonathan Javier Quiroga	Argentina
Institute for Meteorology, University of Natural Resources and Life Sciences, Vienna	Astrid Kainz Daniel Rauter	Austria
Royal Meteorological Institute of Belgium	Veerle De Bock Van Malderen Roeland	Belgium
Federal University of Santa Maria	Lucas Vaz Peres	Brazil
Universidad de Magallanes	Claudio Casiccia	Chile
Finnish Meteorological Institute	Rigel Kivi	Finland
Met Eireann	Mike Donegan	Ireland
Department of Physics - University of Turin	Amedeo Romagnolo	Italy
INAF-OAC	Valerio Marinelli	Italy
Malaysian Meteorological Department	Mohd Firdaus Jahaya	Malaysia
Instituto Português do Mar e da Atmosfera	Linda Moniz	Portugal
Izaña Atmospheric Research Center (AEMET), and University of La Laguna	Esther Sanromá Javier López Solano Bentorey Hernandez Cruz	Spain
University of Geneva	Arianna Religi	Switzerland
Thai Meteorological Department	Sumridh Sudhibrabha	Thailand

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Bentorey Hernandez Cruz (ULL; Research Scientist)

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18 Sand and Dust Storm Centres

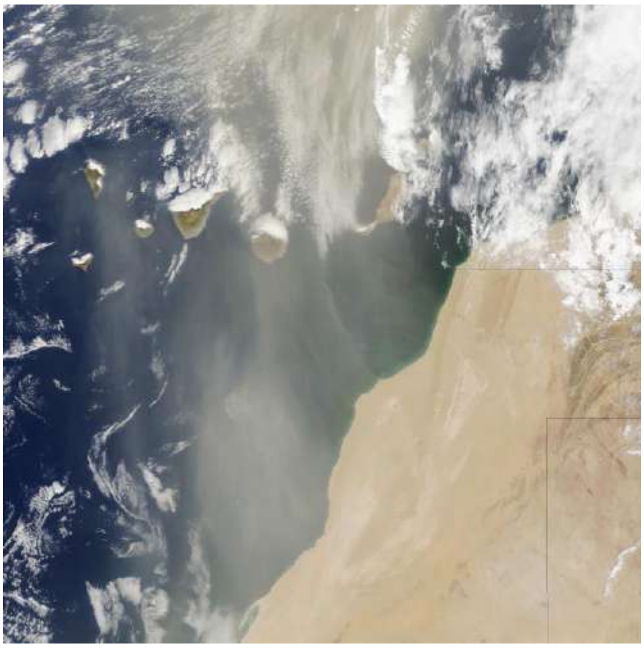


Figure 18.1. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite acquired this natural-color image of dust sweeping off the coast of Western Sahara and Morocco, and impacting the Canary Islands at mid-levels, on 7 August 2015. In lower levels the stratocumulus associated with trade winds are observed.

The IARC is actively involved in the strategic planning of activities, scientific advice on aerosols and dust observation, as well as in initiatives on capacity building and training of two Centers dedicated to Sand and Dust Storm activities: 1) the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Center for Northern Africa, Middle East and Europe, and 2) the Barcelona Dust Forecast Centre (BDFC).

18.1 WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Center

The Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) is a programme of the World Meteorological Organization with the mission to enhance the ability of countries to deliver timely and qualitative information related to sand and dust storm forecasts, observations to end users, and improve the knowledge of this phenomena.

The Regional Centre for Northern Africa, Middle East and Europe (NA-ME-E) was established in 2007 to coordinate SDS-WAS activities within this region. The Centre, as a consortium of the Spanish State Meteorological Agency (AEMET) and the Barcelona Supercomputing Centre – National Supercomputing Centre (BSC-CNS), soon evolved into a structure that hosted international and interdisciplinary research cooperation between numerous organizations in the region and beyond, including national meteorological services, environmental agencies, research groups and international organizations.

The Center's web portal (Fig. 18.2) became a place where visitors could find the latest dust-related observations and the most up-to-date experimental dust forecasts. The activities carried out by the SDS-WAS Regional Centre have been broadly disseminated in international workshops and conferences (Basart et al., 2015b; Basart et al., 2016a; 2016b; 2016c; Cuevas et al., 2016a, 2016b). A detailed description of the main activities of the SDS-WAS regional Centre can be found in Terradellas et al. (2016).

A global observational network is crucial to any forecast and early warning system for real-time monitoring, validation and evaluation of forecast products, as well as for data assimilation. The main data sources are in-situ aerosol measurements performed in air quality monitoring stations, indirect observations (visibility and present weather) from meteorological stations, sun photometric measurements (e.g. AERONET network), lidar and ceilometers and satellite products.

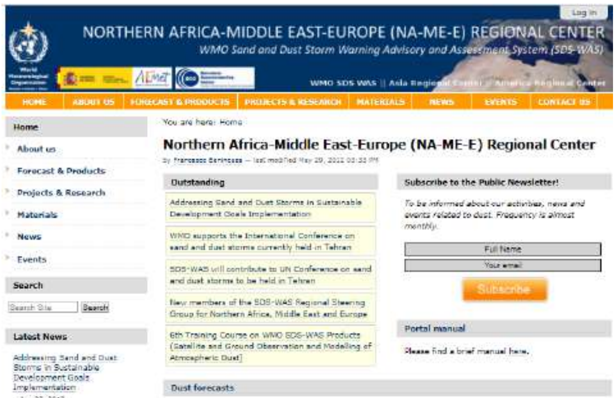


Figure 18.2. SDS-WAS Regional Center Web portal.

The exchange of forecast products is a core part of the WMO SDS-WAS programme and the basis for the joint visualization and evaluation initiative. The web portal offers side-by-side dust forecasts (dust surface concentration and dust optical depth at 550 nm) generated by 12 modelling systems as well as the multi-model median. The models are BSC-DREAM8b_v2, CAMS-ECMWF, DREAM8-NMME-MACC, NMMB/BSC-Dust, NASA GEOS-5, NCEP-NGAC, EMA RegCM4, UK Met Office, DREAM ABOL, NOAA-WRF-CHEM, SILAM and LOTOS-EUROS.

An important stage of any forecasting system is the evaluation of the products. The main goal of this process is to assess whether the modelling systems successfully simulate the evolution of dust-related parameters. In addition, the evaluation improves the understanding of the models capabilities, limitations, and appropriateness for the purpose for which they were designed. The evaluation is performed by comparing the models forecasts with observational data. The individual models and multi-model median forecsts of the dust optical depth (DOD) at 550 nm are compared with AERONET observations of aerosol optical depth (AOD) for 40 selected dust-prone stations. In addition to this near real time evaluation, a system to assess quantitatively the performance of the different models has been implemented. It yields evaluation scores computed from the comparison of the simulated DOD with the AERONET retrievals of AOD.

The SDS-WAS Regional Centre works toward strengthening the capacity of countries to use the observational and forecast products distributed in the framework of the WMO SDS-WAS programme in the partnership with National Meteorological and Hydrological Services (NMHSS) in the region and other relevant organizations.

18.1.1 Relevant activities and milestones in 2015-2016

The kick-off meeting of the WMO SDS-WAS Steering Committee was held in Amman, Jordan, on 6 and 7 November 2015, in connection with the 1st Africa/Middle East Expert Meeting and Workshop on the Health Impact of Airborne Dust. The kick-off meeting was attended by representatives of the three regional nodes and the WMO Secretariat. Enric Terradellas, Technical Director of the RC NAMEE was elected as chair for the next two years.

The Science and Implementation Plan 2015-2020 for the WMO SDS-WAS, was drafted and published (Nickovic et al., 2015) in the frame of the WMO World Weather Research Programme (WWRP). The article entitled “Airborne Dust: A Hazard to Human Health, Environment and Society” was published in the WMO Bulletin Vol 64 (2), 2015.

The WMO SDS-WAS was presented at the First International Conference on Dust, held at the Shahid Chamran University in Ahvaz, capital city of the Iranian province of Khuzestan. The conference took place between 2-4 March 2016 and was mainly focused on strategies to control natural and anthropogenic dust emissions, methods to mitigate the impacts and the relationship between dust storms and climate change.

Basart et al. (2016c) presented activities of the WMO SDS-WAS in the “8th International Workshop on Sand/Duststorms and Associated Dustfall”, which was held in Lisbon (Portugal) from 1-4 May 2016. The goal of the workshop was to present results and to discuss how to enhance our understanding of dust storm mechanisms and the links and feedbacks between desert dust, air quality, radiation, clouds, water budget and health impacts.

A resolution proposed by Iran and backed by Pakistan and Iraq that aims to enlist the aid of Middle East countries to tackle dust storms in the region was approved at the second UN Environment Assembly. The assembly was held in the headquarters of the United Nations Environment Programme in Nairobi, Kenya on 23-27 May 2016 (Fig. 18.3).

Figure 18.3. UN Environment Assembly approves Dust Storm Resolution at the the headquarters of the United Nations Environment Programme in Nairobi, Kenya on May 23-27, 2016.

Dust forecasts produced by the WMO SDS-WAS RC NAMEE and the Barcelona Dust Forecast Center are also disseminated via UNEPLive, a platform managed by the United Nations Environment Program.

The second meeting of the SDS-WAS Steering Committee and the 2016 Meeting of the Asian SDS-WAS Regional Node were held on 20 September 2016 in Jeju, Korea. The current status and progress with implementation in three Regional Nodes as well as coordination of further plans were discussed and reported. Invited representatives of WMO, UNEP, WHO and UNCCD discussed coordination of SDS activities among the UN Agencies. It was agreed to build a joint plan and extend the SDS-WAS Steering Committee by involving representatives of other UN Agencies.

In October 2016, UNEP published the “Global Assessment of Sand and Dust Storms” report, jointly written by UNEP, WMO and the United Nations Convention to Combat Desertification (UNCCD). The report, with foreword by the

UN Secretary-General Ban Ki-Moon, has been included in the documentation of the 71st session of the UN General Assembly.

In October 2016, WMO SDS-WAS presented our suggestions for UN consultations regarding the developing Sand and Dust Storms UN resolution being put forward by the G77 political grouping.

18.1.2 SDS-WAS Regional Center Scientific contributions

IARC and AEMET contribute to the scientific activities of the SDS-WAS Northern Africa, Middle East and Europe Regional Centre through various multidisciplinary projects. For example, one such project is focused on understanding the variability of the export of mineral dust from the Sahara to the Mediterranean and Atlantic. The summer Saharan dust export is highly dependent on the variability of the large-scale meteorology in North Africa, which is characterized by a high over the subtropical Sahara and a low over the tropics. We referred to this high–low dipole-like pattern as the North African Dipole (NAFD) and its variability is parameterized in terms of the NAFD intensity (NAFDI) (Rodríguez et al., 2015; ACP) (See Section 8). Currently, the role played by NAFDI in dust mobilization over the Sahara and dust transport toward the Mediterranean and the Atlantic, through its close relationship with the Saharan Heat Low (SHL) and mid-latitude Rossby waves, is being investigated (Cuevas et al., 2016c).

An additional scientific contribution includes the determination of a new empirical equation relating horizontal visibility and mineral desert dust concentration (PM_{10}) obtained at IZO, using data recorded during Saharan dust intrusions between 2003 and 2010 (Camino et al., 2015). This equation has been validated in the Sahel region during the dry and wet seasons (2006-2008) using data from two PM_{10} monitoring stations from the African Monsoon Multidisciplinary Analysis (AMMA) project, and weather data from the nearest synoptic stations.

In the framework of the WMO SDS-WAS, the results of five state-of-the-art dust forecast models during an intense Saharan dust outbreak affecting Western and Northern Europe in April 2011 were analysed in detail. A paper on this study was published (Huneeus et al., 2016).

Figure 18.4. Haboob, bears down on Tehran on 2 June 2014. (Photo: Alireza Naseri).

Increasing frequency and spatial distribution of the severe dust storm weather events motivated researchers to initialize development of the operational dust storm forecasting tool for the broader user community. The multi-disciplinary and multi-institutional joint project within the framework of the WMO SDS-WAS includes group of experts from BSC (Spain), KIT (Germany), TROPOS (Germany), SEEVCCC (Serbia), NOA (Greece), MetOffice (UK), NOAA/NWS/NCEP (USA), CNR (Italy), EMA (Egypt), IRIMO (Iran) and CIAI-AEMET (Spain). The main objective of the project is to perform an in-depth case study of the small-scale, short-lived extreme dust storm that occurred in Tehran on 2 June 2014, which caused at least five deaths, 82 injured people and left 50,000 residential units without power (Fig. 18.4). This is a collaborative project in the framework of the SDS-WAS Regional centre.

18.1.3 SDS-WAS and MACC project

macc
Monitoring atmospheric composition & climate

Monitoring Atmospheric Composition and Climate (MACC) operates and improves data-analysis and modelling systems for a range of atmospheric constituents that are important for climate, air quality and surface solar radiation. Product line include data records of atmospheric composition for recent years, data for assessment of the current conditions and forecasts of the distribution of key constituents for a few days ahead. MACC was funded under the 7th Framework Programme of the European Union and provides the pre-operational atmospheric environmental service of the GMES initiative. This service complemented the weather analysis and forecasting services provided by European and national organizations by adding services related to the chemical composition of the atmosphere.

To provide air quality and atmospheric composition services, MACC-II uses a comprehensive global monitoring and forecasting system that estimates the state of the atmosphere on a daily basis, combining information from models and observations, and it provides a daily 5-day forecast. The global modelling system is also used to provide the boundary conditions for an ensemble of more detailed regional air quality models that are used to zoom in on the European domain and produce 4-day forecasts of air quality. The collaboration with MACC has enabled SDS-WAS to incorporate the MACC prediction system to the intercomparison and joint evaluation of dust models (Basart et al., 2015a). On the other hand, SDS-WAS has provided a valuable external evaluation of the dust component of the MACC prediction system that has led to new ways for improvement.

SDS-WAS participated (through AEMET and BSC-CNS) in the MACC project providing information in three reports in 2015 (Eskes et al., 2015a; 2015b; MACC, 2016). In addition to this important participation in the MACC-II quarterly reports, the SDS-WAS was responsible for the publication of the results of MACC-II reanalysis validation using numerous independent satellite borne and ground-based dust observations (Cuevas et al., 2015a; 2015b).

18.1.4 SDS-WAS and Copernicus CAMS-84 Service

The Copernicus programme, previously known as GMES (Global Monitoring for Environment and Security), consists of a complex set of systems, which collect data from multiple sources: earth observation satellites and in situ sensors such as ground stations, airborne and sea-borne sensors. It processes these data and provides users with reliable and up-to-date information through a set of services related to environmental and security issues.

The Copernicus Atmosphere Monitoring Service (CAMS) has been developed to address environmental concerns, providing data and processed information, aiming at supporting policymakers, business and citizens with enhanced atmospheric environmental information.

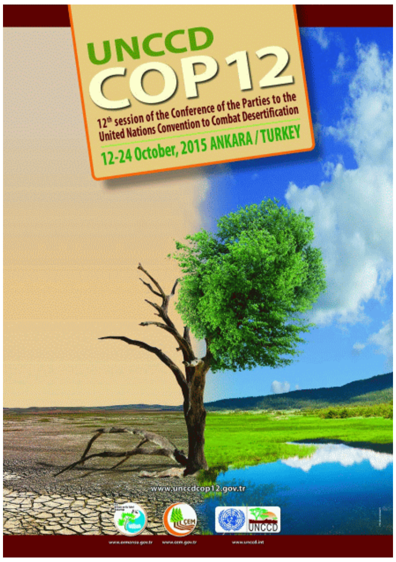
CAMS-84 is a global and regional a posteriori validation activity, with focus on the Arctic and Mediterranean areas. The SDS-WAS Regional Centre, through BSC-CNS as the main parter and AEMET as a third-party, participates in CAMS-84 providing validations and evaluation of dust and aerosols products. In the period 2015-2016, the SDS-WAS participated in the preparation of observations characterization and validation methods (Eskes et al., 2016), and in periodical validation reports (Eskes et al., 2016b).

Mineral dust validation activities carried out under different MACC projects, from mid-2015 onwards, were carried out as CAMS-84 services and published as Quarterly Reports. The SDS-WAS Regional Centre participated in the preparation of six reports during the period 2015-2016 (Huijnen et al., 2015a; 2015b, 2016a; 2016b; 2016c; and Eskes, 2016b).

18.1.5 Workshops and Capacity building activities

During 2015-2016 the following capacity building activities were carried out:

- “On the Edge of Crisis: Dust and Sand Storms", side event at the 12th session of the Conference of the Parties to the UN Convention to Combat Desertification (UNCCD) (Ankara, Turkey, 12-23 October 2015).



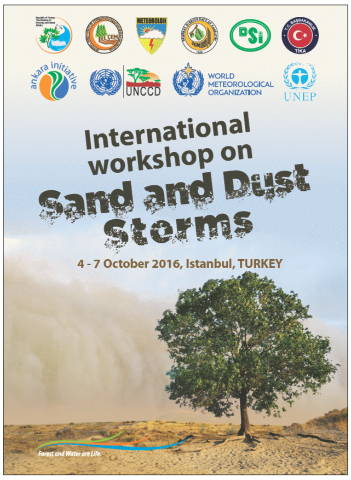
- The 1st Africa/Middle East Expert Meeting and Workshop on the Health Impact of Airborne Dust (Amman, Jordan, 2-5 November 2015).

- Training Course on “Ground Observation of Dust”, 5th Regional Conference on Climate Change (Tehran, Iran, 25-26 January 2016).

- "Achieving land degradation neutrality and combating sand and dust storms for healthy planet and healthy people", side event at the United Nations Environment Assembly (Nairobi, Kenya, 26 May 2016). S.Nickovic, delivered a talk on the role of the SDS-WAS. Partners of the side event were Department of Environment, Islamic Republic of Iran, Mongolian Ministry of Environment, Green Development and Tourism, and the Islamic Development Bank, Saudi Arabia.

- The SDS-WAS representative participated in the 2016 WMO-GAW SAG-Aerosol meeting presenting the dust-aerosols activities and observational requirements at the SDS-WAS RC NAMEE (Seoul, Korea, 31 May – 3 June 2016).

- The International Workshop on Sand and Dust Storms (SDS) hosted by the Turkish Ministry of Forestry and Water General Directorate of Combating Desertification and Erosion (ÇEM) and the Turkish Meteorological Service (TSMS) with technical corporation from WMO, UNEP and UNCCD (Istanbul, Turkey, 4-7 October 2016).



- 5th Training Course on WMO SDS-WAS Products (Satellite and Ground Observation and Modelling of Atmospheric Dust) (Tehran, Iran, 5-9 November 2016).

18.2 The Barcelona Dust Forecast Centre

In May 2013, in view of the demand of many national meteorological services and the good results obtained by the SDS-WAS related to operationalization, the 65th Session of the WMO Executive Council designated the consortium formed by AEMET and the BSC-CNS to create in Barcelona the first Regional Specialized Meteorological Centre with activity specialization on Atmospheric Sand and Dust Forecast (RSMC-ASDF). The Centre shall operationally generate and distribute predictions for Northern Africa (north of equator), Middle East and Europe.

The Barcelona Dust Forecast Centre (BDFC) prepares regional forecast fields using the NMMB/BSC-Dust model continuously throughout the year on a daily basis (Terradellas et al., 2015). The model consists of a numerical weather prediction model incorporating on-line parameterizations of all the major phases of the atmospheric dust cycle. It is run at a horizontal resolution of 0.1 degrees longitude per 0.1 degrees latitude for a domain covering Northern Africa, Middle East and Europe (25ºW-65ºE, 0º-65ºN). This domain covers the main dust source areas in Northern Africa and Middle East, as well as the main transport routes and deposition zones from the equator to the Scandinavian Peninsula.

Following its efforts to make the predictions reach all potential users and, in particular, the national meteorological and hydrological services, the BDFC started to broadcast dust forecast through the EUMETCast service in November 2015.

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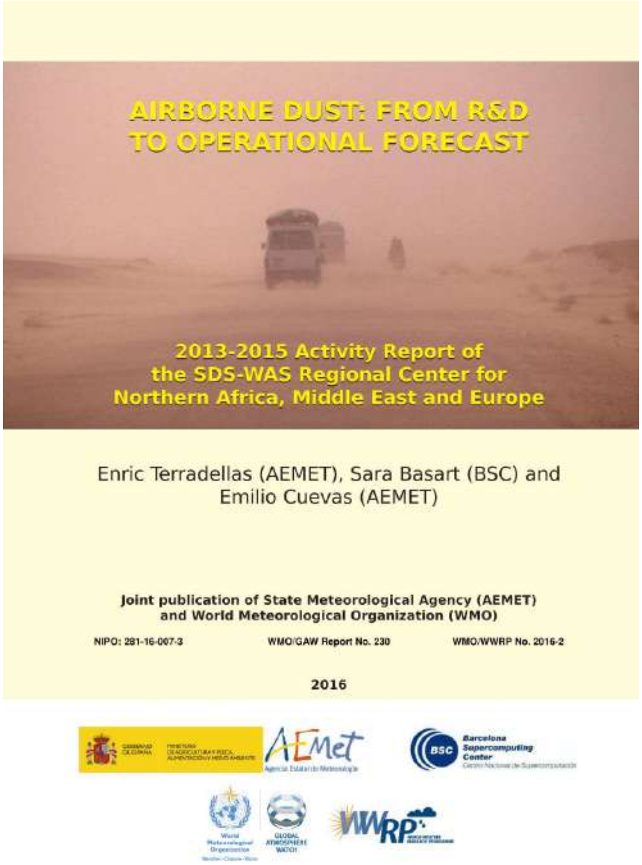

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19 GAW Ushuaia twinning programme

The State Meteorological Agency of Spain, through the Izaña Atmospheric Research Center, the Argentinian Meteorological Service (SMN), the Spanish National Institute for Aerospace Technology (Instrumentation and Atmospheric Research Branch) and the Government of the province of Tierra del Fuego (Argentina), initiated a programme on 14 April 2008 for total column atmospheric ozone monitoring from the Global GAW station Ushuaia (Argentina; 55°S and 68°W). This programme complements the ozonesonde programmes performed on the Antarctic Peninsula by the Finnish Meteorological Institute at Marambio station (Argentinian Base; 64°S, 57°W), and by the INTA at Belgrano station (Argentinian Base; 78ºS, 34ºW).

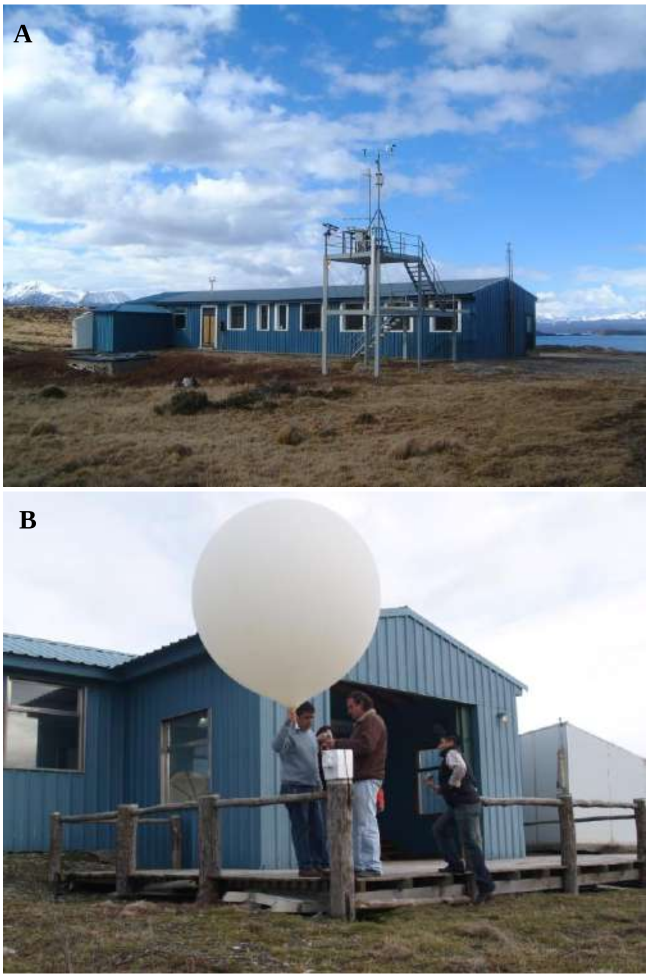

Figure 19.1. A) The GAW global station Ushuaia facilities and B) our colleague Ricardo Sánchez (SMN; Argentina) holds the balloon before the ozonosonde launch.

This programme provides information about the impact of the Antarctic ozone hole on the vertical ozone distribution over the southern part of South America. The data from Ushuaia are transmitted to the WMO World Ozone and UV Data Centre in Toronto, Canada, and are available to the ozone international community of scientists and other interested parties. The Ushuaia ozonesonde station has contributed to the WMO Antarctic Ozone Bulletins, published at roughly two-three week intervals from August to November every year.

Normally Ushuaia is outside the Antarctic polar vortex, but sometimes the vortex elongates northward impacting the city of Ushuaia, causing values below 220DU, typical of ozone hole conditions, to be measured, as occurred on 12 and 27 September 2016 and on 9 October 2016 (Fig. 19.2).

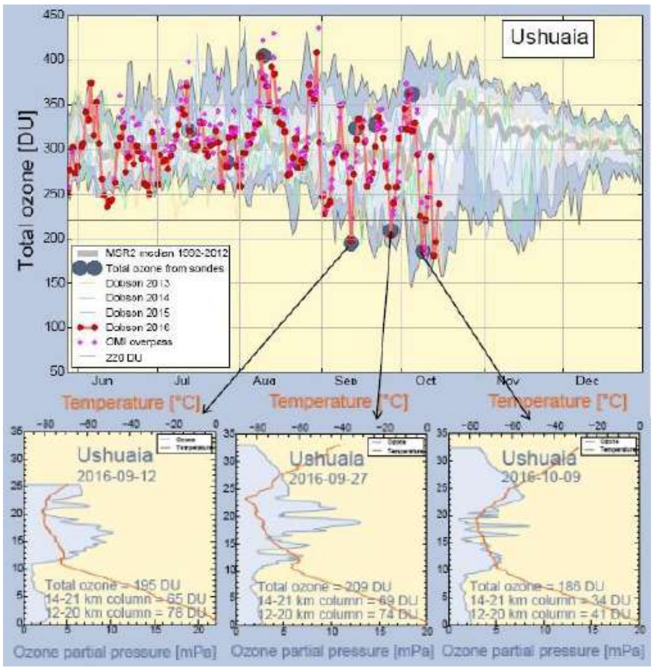

Figure 19.2. Total ozone column over Ushuaia from June to December in 2013 to 2015, and from June to October in 2016 (top panel). Three ozone and temperature profiles over Ushuaia (Argentina) with total ozone lower than 220 DU in Spring 2016 (lower panel). Information extracted from the WMO Antarctic Ozone Bulletin 2016.

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20 GAW Tamanrasset twinning programme

In 2006, the "GAW-Twinning" between IZO and Tamanrasset GAW stations was initiated with the Saharan Air Layer Air Mass characterization (SALAM) project. This was part of a cooperation programme between the l'Office Nationale de la Météorologie (ONM, Algeria) and AEMET. In September 2006, the AERONET Tamanrasset-AEMET Cimel station was installed (Fig. 20.1).

Figure 20.1. The AERONET Cimel at Tamanrasset on the terrace of the Regional Meteorological Centre.

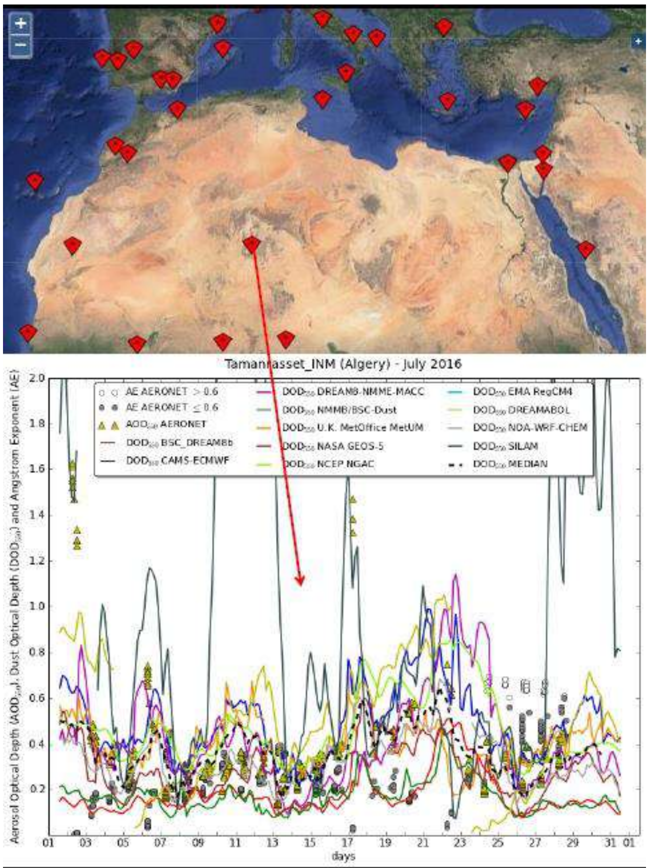

Figure 20.2. Map of the AERONET stations in Northern Africa used by the Sand and Dust Storm Warning Advisory and Assessment System Regional Centre (top panel), and AERONET dust AOD comparison with 12 dust models at Tamanrasset in July 2016 (lower panel).

The GAW station Tamanrasset is in the south of Algeria, in the heart of the Sahara, and provides unique and precious data in a region with a surface area greater than Europe. As can be seen from the map of AERONET stations in Northern Africa (Fig. 20.2) Tamanarasset station is the only AERONET observation site in the heart of the Sahara region. This station is strategic not only for the characterization of atmospheric composition over the Sahara desert in the frame of the GAW Programme, but also to evaluate atmospheric models and validate satellite data. In fact, it is a key station to assess the performance of mineral dust prediction models in a challenging region where there are numerous nearby dust sources. The scientific community regularly uses data from Tamanrasset in various studies, for example for assessment of model development (Heinold et al., 2016) and for analysis of aerosol properties and aerosol transport (Farahat et al., 2016).

Tamanrasset is a singular station of special attention for the Sand and Dust Storm Warning Advisory and Assessment System Regional Center (e.g. Terradellas et al., 2016) (see Section 18 for more details). AOD data from Tamanrasset are routinely used by Copernicus to validate the Copernicus-CAMS aerosols model. This AERONET photometer is calibrated by the IARC on an annual basis. Details of this programme are provided in Guirado et al. (2014).

The twinning was reinforced with the installation at Tamanrasset of a double Brewer Spectrophotometer #201 (MARK-III) in October 2011 (Fig. 20.3), thanks to the project entitled "Global Atmosphere Watch in the Maghreb-Sahara Region" (GAW-Sahara) financed by the Spanish Agency for International Development Cooperation (AECID).

Figure 20.3. Brewer#201 at Tamanrasset on the terrace of the Regional Meteorological Centre.

An operational Dobson (#11; WMO station code 002) spectrophotometer has been operated at Tamanrasset since April 1994. This station is now one of the few sites in the world where permanent and long-term intercomparison between the Dobson, the Brewer and the present and future satellite-based sensors could be performed on a routine basis. This initiative has been strongly recommended by the WMO Ozone Scientific Advisory Group and will be a unique contribution to the total ozone global network Quality Assurance. In addition, the Brewer instrument provides spectral ultraviolet radiation data.

Tamanrasset, with the Brewer Spectrophotometer #201, plays an important role in the context of other global observation networks, e.g. in the EUBREWNET network (Fig. 20.4) (see Section 6.4.1 for more details) providing near-real time data of column ozone, spectral radiation and AOD in the UV range. This equipment is periodically calibrated by the Regional Brewer Calibration Center for Europe (RBCC-E; PI: Alberto Redondas) hosted by the IARC taking advantage of the biannual intercomparisons that are held at the INTA station at El Arenosillo-Huelva (Southern Spain).

Figure 20.4. The Brewer spectrophotometer of Tamanrasset as part of the EUBREWNET network.

A multifilter radiometer from the Norwegian Institute for Air Research (NILU) has been operating at the high-altitude Assekrem GAW station (2730 m a.s.l) 80 km north of Tamanrasset (Fig. 20.5) since October 2011. The high mountain Assekrem station is also a facility of the ONM managed by the Meterological Centre of the Algerian South-Region.

Figure 20.5. The NILU-UV6 radiometer at Assekrem. In the background, mountains of the Hoggar massif.

The NILU multifilter radiometer at Assekrem station provides UV radiation, Photosynthetic Active Radiation (PAR) and total column ozone data at a high-altitude site in the middle of the Sahara.

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21 WMO CIMO Testbed for Aerosols and Water Vapour Remote Sensing Instruments

The mission of the Commission for Instruments and Methods of Observations (CIMO) is to promote and facilitate international standardisation and compatibility of instruments and methods of observations used by Members, in particular within the WMO Global Observing System, to improve quality of products and services delivered to/by Members and to meet their requirements (see Report from the President to Cg-XV (2007), Report from the President to Cg-XVI (2011) and Report from the President to Cg-XVII (2015).

CIMO-XV (2010) decided to establish CIMO Testbeds and Lead Centres to promote collaboration between CIMO and relevant NMHSs in testing, development and standardization of meteorological instruments and in assessing systems performance. It would utilize and build on both existing and state-of-the-art facilities and specific expertise available at NMHSs for the provision of guidance to all WMO Members.

CIMO XVI nominated Izaña Atmospheric Observatory as WMO-CIMO Testbed for Aerosols and Water Vapour Remote Sensing Instruments. The CIMO aim to promote the advancement of observing systems of WMO member countries through its WMO Integrated Global Observing System (WIGOS). It is also expected that Testbeds centres can play a decisive role in the effort of WMO to reduce the differences between countries, favouring the completion of training and capacity building through specific collaborations with stations and observatories in developing countries. The General Terms of Reference for the CIMO Testbeds for Ground based Remote-sensing and In-situ Observations (CIMO TB) can be found at the Terms of Reference of CIMO Testbeds.

21.1 Main objectives and activities of the Izaña Testbed

The main ongoing activities of the Izaña Atmospheric Observatory Testbed are related to instrument validation, development of new methodologies and devices for aerosol observations (Fig. 21.1).

21.1.1 The reconstruction of a 73-year time series of AOD at 500 nm by using artificial neural networks

The reconstruction of a 73-year time series of AOD at 500 nm at IZO has been achieved by using artificial neural networks (ANNs) from 1941 to 2001 and AOD measurements directly obtained with a Precision Filter Radiometer (PFR) between 2003 and 2013.

Figure 21.1. Contrasting atmospheric conditions covering a broad range of aerosols burden make Izaña Atmospheric Observatory a key site for aerosol remote sensing instruments testing and calibration: pristine conditions (upper panel) and significant dust load (lower panel) (Courtesy of S. Rodríguez).

The ANN method has proved to be a very useful tool for the reconstruction of daily AOD values at 500 nm from meteorological input data, such as the horizontal visibility, fraction of clear sky, and relative humidity, recorded at IZO. This methodology could be extrapolated to other sites, especially those affected by high dust loads. See Section 9.3.2 and García et al. (2016) for more details.

21.1.2 Development and testing of several lunar-photometer prototypes and the new Triple (Sun-Lunar-Sky) CE318-T photometer

Development and testing of several lunar-photometer prototypes (i.e. modified CE318-N and CE318-U) capable of measuring aerosols and column water vapour during the night period, has been performed at IZO in collaboration with Cimel Electronique (http://www.cimel.fr). The final version, the CE318-T, is able to perform daytime and nighttime photometric measurements using the sun and the moon as light source. This new device permits a complete cycle of diurnal aerosol and water vapour measurements valuable to enhance atmospheric monitoring.

Figure 21.2. View of the radiation/aerosol instruments on the IZO instrument terrace (Photo: C. Bayo).

Two new methodologies to transfer the calibration from a reference instrument using only daytime measurements (Sun Ratio and Sun-Moon gain factor techniques) have been developed and evaluated. These methods reduce the previous complexities inherent to nocturnal calibration. A quantitative estimation of CE318-T aerosol optical depth uncertainty by means of error propagation theory during daytime and night period has been assessed. A subsequent performance evaluation including CE318-T and collocated measurements from independent reference instruments has served to assess the CE318-T performance, day and night, as well as to confirm its estimated uncertainty. The CE318-T has been recently adopted by NASA AErosol RObotic NETwork (AERONET) as the new standard instrument of the network, see Barreto et al. (2016) for more details. A detailed description of this project can be found in Section 22 Technological Projects).

21.1.3 Research on water vapor isotopologues with Fourier Transform Infrared Technique

Development of methodologies envisaged to obtain vertical profiling of $HDO/H_2{}^{16}O$, and corresponding validation and comparison with in-situ airborne and ground-based observations during the MUSICA remote sensing validation campaign were performed during 2014 and 2015. The project MUSICA (MUlti-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water, http://www.imk-asf.kit.edu/musica), supported by the European Research Council within the Seventh Framework Programme, has as its main goal the generation of a high-quality database on a global scale of tropospheric water vapour isotopologues ($H_2{}^{16}O$ y $HD^{16}O$) from ground-based remote measurements (Fourier Transform InfraRed spectrometers) and space-based platforms (Infrared Atmospheric Sounding Interferometer, IASI, on board the satellites EUMETSAT/MetOp-A and MetOp-B). The Izaña Testbed has played a very active role in MUSICA being the main station supporting different experiments. The results of this project will contribute to a better understanding of the different processes affecting the cycle of atmospheric water and its link to the energy balance at a global scale.

The main results achieved up to now have been published by Dyroff et al. (2015), González et al. (2015), Scheepmaker et al. (2015), and Schneider et al. (2015; 2016; 2017) in the reporting period.

21.1.4 The Izaña Testbed site supporting different field campaigns of radiation/aerosol prototypes

The Izaña Testbed site has been used for different field campaigns of radiation/aerosol prototypes, such as the new Precision Solar Spectroradiometer (PSR), developed at PMOD/World Radiation Centre (Davos Switzerland), which will replace current filter sunphotometers for long term AOD and absolute solar irradiance measurements. This instrument has been absolutely calibrated at IZO and compared with other reference photometers. Preliminary stellar measurements have also been performed.

21.1.5 Design, development and testing of a new low-cost and robust zenith-looking multi narrow-band radiometer for AOD retrieval.

A look-up table methodology for AOD retrieval from zenithal sky radiance has been developed and applied to AERONET Cimel sunphotometers from Santa Cruz de Tenerife, Izaña and Tamanrasset (Algeria) validating the results against AERONET AOD. The methodology has been applied to a new low-cost and robust zenith-looking multi narrow-band radiometer developed in collaboration with SIELTEC S.L. company (http://www.sieltec.com.es/). Estimated AOD with the new prototypes demonstrated good results when validated against reference AOD from AERONET (see Almansa et al., 2016). For a detailed description of this project see Section 24 (Technological Projects).

21.1.6 Long-term comparability between column aerosol sensors

A comprehensive intercomparison of daily aerosol optical depth and Angstrom exponent (AE) retrievals over Izana Testbed from multiple ground-based radiometers, such as a PFR (Precision Filter Radiometer) from the GAW-PFR (Global Atmospheric Watch-Precision Filter Radiometer) Network (acting as the reference instrument), several AERONET CIMEL sun-photometers, a MFRSR (Multifilter Rotating Shadowband Radiometer), and a PMOD/Rocket (Physikalisch-Meteorologisches Observatorium Davos), as well as space-borne sensors including MODIS (on Terra and Aqua satellites), MISR, OMI, and SeaWIFS was conducted during the period 2001-2015.

21.1.7 AERONET-EUROPE quality assurance linked to the PMOD-WRC international reference

AERONET is a global aerosol network providing information on atmospheric column aerosols at more than 400 stations globally, allowing adequate spatio-temporal characterization of aerosols. The GAW-PFR network was started in 1999 as a pilot project. The GAW Scientific Advisory Group for Aerosols selected a number of existing GAW stations as candidates for the deployment of 12 Precision Filter Radiometers (PFR). The network is based on mutual collaboration between GAW stations. AOD observation programmes using PFR instruments are now operating at 24 additional locations in Europe, Japan and Antarctica. The GAW-PFR network is managed by PMOD-WRC. Additional information about GAW-PFR stations can be found at the WORCC portal. Both these global networks are of great importance for assessing AOD obtained from models and satellite retrievals; the Izana Atmospheric Observatory participates in both networks.

Figure 21.3 Precision Filter Radiometers (PMOD/WRC) at the Izaña Atmospheric Observatory testbed platform.

In the framework of the WMO-CIMO Testbed for Aerosols and Water Vapour Remote Sensing Instruments, at the Izaña Atmospheric Research Center, we are performing a comprehensive assessment of AERONET/GAW-PFR long-term AOD measurements. The main objective of this study is to provide consistent, detailed and accurate information on the degree of agreement between AERONET-Cimel and GAW-PFR observations. For this, a long-term intercomparison of Cimel/AERONET –GAW/PFR instruments at Izaña in the period January 2005 – November 2014 (10 years) has been performed in collaboration with PMOD-WRC using 1’ minute simultaneous Cimel-PFR AOD data at 500 and 870 nm channels. A total of 15 Cimel sunphotometers and three PFR were used during this period. Preliminary results indicate that more than 93% of 1-minute AOD differences at 500 and 870 nm (more than 81,000 data in each channel) fell within the AOD 95% uncertainty limits defined by WMO. Statistics of the traceability and possible explanations to non-traceable data have been investigated. This study will be published as an AEMET Technical note (Romero-Campos et al.) and as a scientific paper in an international journal.

In addition, we are working on the establishment of permanent traceability between Cimel masters at Izaña, used to transfer calibration to station Cimel instruments from AERONET-EUROPE and GAW-PFR reference. We are leading several actions on this important issue. The first activity was the participation with two masters (CE318-N and the new CE318-T) in the 4th WMO Filter Radiometer Comparison (FRC-IV) which was held from 28 September – 16 October 2015 in Davos, Switzerland. More than 99% of 1-miniute AOD differences at 500 nm between AERONET and PFR reference fell within the AOD 95% uncertainty limits defined by WMO. The good agreement between the Cimel Masters and the GAW-PFR triad is shown in the Campaign Report (Kazadzis et al., 2016).

At present we are working, in close collaboration with PMOD-WRC, in designing procedures, and corresponding protocols, to ensure traceability of the AERONET-Cimel Masters calibrated at IZO with GAW-PFR Masters which form part of the PMOD-WRC PFR triad and that are, in each moment, at Izaña. An AERONET CE318-T Master, acquired within an R+D national programme Infrastructure project will be installed permanently at Izaña as reference and will be intercompared on a continuous-basis (in the common channels) with PFR-Masters. This will allow the transfer of these calibrations to Cimel travel Masters. Calibration and traceability procedures between PMOD-PFR and Cimel AERONET-EUROPE are planned to be implemented within the next two years.

21.1.8 Assessment of nocturnal Aerosol Optical Depth at high altitude. Refinement of the Izaña RObotic Lunar Observatory (ROLO) model outputs

The original United States Geological Service Robotic Lunar Observatory (ROLO) provides radiometric calibration and sensor stability monitoring for space-based remote sensing instruments using the Moon as a reference source. We have developed at Izaña Testbed our own ROLO in order to be used for nocturnal AOD and water vapor observations with the Lunar Cimel photometers.

We have studied the evolution of AOD at nighttime in 61 clean and stable nights at Izaña Atmospheric Observatory, based on extinction vertical profiles from the Micropulse lidar installed at SCO. We detected a significant bias with moon's phase and zenith angles, especially in longer wavelength channels. Working under the assumption of stable AOD conditions, we have parameterized this residual dependence in nocturnal AOD in terms of moon's phase and zenith angles through an empirical regression model. Our results show that the corrected AOD at nighttime has averaged errors < 0.01, which are of the same order as the typical daytime CE318-T photometer measurement uncertainty. This improvement of Izaña’s ROLO outputs provides more accurate calibrations and AOD observations during the nighttime.

21.1.9 Preliminary validation of AOD in UV range using double Brewer spectrophotometers.

A new AOD product in the UV range has been developed and assessed using the Izaña Testbed facilities and ancillary data (Rodríguez-Franco, 2015; López-Solano et al., 2016a; 2016b). This new algorithm is being implemented in EUBREWNET to produce AOD on an operational basis. It will allow real-time aerosols monitoring at more than 20 Brewer stations, from Algeria to Finland.

21.1.10 Development of synergy photometer/lidar/ceilometer methodologies for retrieving vertical aerosol extinction

A preliminary two-layer approach to obtain vertical atmospheric extinction (α) at Santa Cruz de Tenerife station (Canary Islands, Spain) using Micropulse lidar (MPL-3 Lidar) and CL-51 Vaisala ceilometer has been developed. Uncertainties commonly associated with the estimation of Lidar Ratio (LR) are notably reduced by using a two-layers inversion model, in which AOD is extracted from two different sun-photometers located at two different layers: one at SCO and another one at IZO, representative of both free troposphere and Saharan conditions.

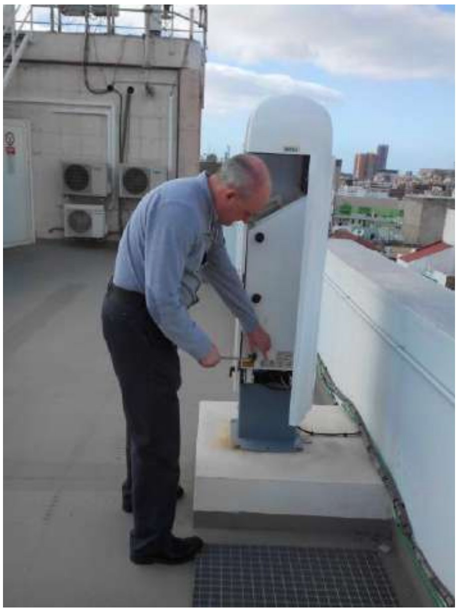

Figure 21.4. Pedro Miguel Romero-Campos making adjustments to the Vaisala CL-51 ceilometer.

Figure 21.5. Alberto Redondas and colleagues in the dark-room, an IZO testbed facility of the Izaña Atmospheric Observatory (Photo: LuzLux-Quadrado Verde).

21.2 Forthcoming projects

21.2.1 Using GRASP algorithm to obtain aerosol properties with the new ZEN-R41 radiometer and CE318-T photometer

The Generalized Retrieval of Atmosphere and Surface Properties (GRASP) algorithm, developed at the Laboratoire d'Optique Atmosphérique (LOA) (CNR-Université de Lille; France), infers a large number of aerosol and surface parameters including particle size distribution, the spectral index of refraction, the degree of sphericity and absorption. The algorithm is designed to retrieve aerosol properties from spectral, multiangular polarimetric remote sensing observations.

Figure 21.6. Sieltec ZEN-R41 radiometer.

We have agreed with the GRASP team to implement and test GRASP in nocturnal observations with the new CE318-

T (see section 21.1) at Izaña Testbed and at the Santa Cruz measurement station at sea level. GRASP will also be implemented to obtain inversion products with the ZEN-R41 instrument (see section 22)

21.2.2 AOD from PANDORA photometer

The first PANDORA photometer was designed to monitor the atmospheric column of trace gases. However, a new Pandora dual spectrometer system (Pandora-2S) is being developed by Luftblick company (Austria), as an evolution of the existing Pandora. Pandora-2S will contain two spectrometers, capable of covering the full wavelength range up to 900 nm, and will be able to obtain spectral AOD over the entire range 300-900nm (SpecAOD) within ±0.05. This will extend its capability as a ground based instrument for satellite observations evaluation.

Development and evaluation of new algorithms for aerosol retrieval with the new PANDORA-2S spectrometer, in collaboration with Luftblick company (Austria) and PMOD-WRC, will be a future activity of the Izaña Testbed. This instrument will form the new PANDONIA global network and the Reference Triad will be maintained at Izaña.

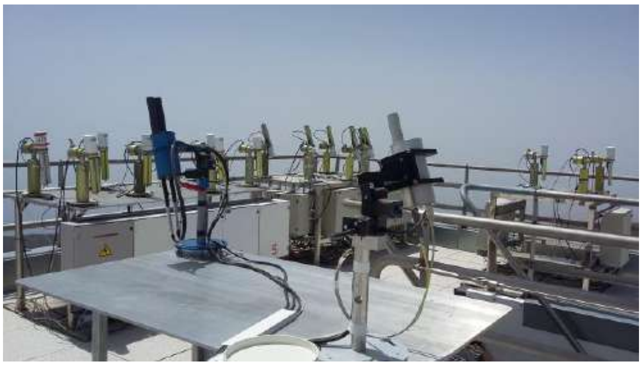

Figure 21.7. The original Pandora (in the foreground), the new Pandora-2S and several Cimel photometers (background).

21.3 Other calibration and validation related activities

TENUM is a French company that has designed and manufactured a small educational sun-photometer named Calitoo. This instrument has been developed under the scientific and technical supervision of Dr. Phillipe Goloub and Eng. Luc Blarel from LOA (CNRS-University of Lille). Calitoo sun-photometers are used in the Global Learning and Observations to Benefit the Environment (GLOBE) program, which is a worldwide hands-on, primary and secondary school-based science and education program.

After manufacturing, the sun-photometers must be periodically calibrated to provide AOD measurements. In the period 15-21 June 2015, 110 Calitoo sun-photometers were calibrated using the Langley method at IZO.

Figure 21.8. Calitoo sun photometer calibration campaign in June 2015 at Izaña Atmospheric Observatory. Frederic Bouchar, Stéphane Villeneuve, and Nicolas Lherm during the calibration activity at Izaña's calibration platform (courtesy of TENUM).

One of these Calitoo instruments has been utilized since November 2016 in a pilot project in Tehran (Iran), in collaboration with the Islamic Republic of Iran Meteorological Organization (IRIMO), to monitor aerosol pollution and the impact of dust outbreaks on the city.

21.4 Future activities

- Establishment of permanent traceability with PMDO/WRC world reference for AERONET sunphotometer references at IZO.
- Development of synergy photometer/lidar/ceilometer methodologies for retrieving vertical aerosol extinction.
- Accurate and comprehensive evaluation of the new algorithm to retrieve operational AOD in the UV range from Brewer spectrophotometers within EUBREWNET Cost Action 1207.
- Development and evaluation of new algorithms for aerosol retrieval with the new PANDORA-2 spectrometer in collaboration with Luftblick company (Austria). This instrument will form the new PANDONIA global network.
- Characterization of the new lidar prototype namely CE376, from Cimel Electronique, which works at two wavelengths (532 & 800nm) with two depolarization channels.
- Comprehensive assessment of the potential use of the very low-cost Calitoo-TENUM hand-held sunphotometer for operational dust model and satellite observation validation activities within the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS).
- Training course on sunphotometry to operators of PHOTONS/AERONET in Egypt, Tunisia, and Algeria and Morocco in 2016-2017.

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22 Technological Projects

22.1 The new sun-sky-lunar Cimel CE318-T multiband photometer

The Lunar Photometer technological and scientific project, established in 2011 between Cimel Electronique and the Izaña Atmospheric Research Center, was focused on the design and implementation of new strategies to tackle the problems to monitor atmospheric aerosols and water vapor content at night. The most important obstacles to overcome are the low incoming energy from the Moon, the variation of the Moon's illumination inherent to the lunar cycle, as well as the non-lambertian reflectance properties of this celestial body.

The use of the RObotic Lunar Observatory (ROLO) model, developed by Kieffer and Stone (2005), has recently emerged to take the continuous change of the Moon's brightness over the cycle into account. This model is a unique tool for Moon photometry (Berkoff et al., 2011; Barreto et al., 2013a, b, 2016), providing precise knowledge of the Moon's spectral irradiance. In the frame of this project, the first collaborative efforts in 2013/2014 were focused on the development of calibration techniques and methodologies for aerosol and column water vapor retrieval at nighttime using the lunar photometer prototypes (trade name CE318-U), as presented by Barreto et al. (2013a,b).

In this regard, the Lunar-Langley Method (Barreto et al., 2013a) has emerged as a useful tool to perform an accurate calibration of lunar photometers, and the CE318-U prototype was developed as an instrument capable to obtain aerosol optical depth (AOD) and precipitable water vapor (PWV) with similar accuracy to daytime measurements. Further efforts led to the development of the first sun-sky-lunar photometer (trade name CE318-T) in 2014. This new instrument is able to perform daytime and nighttime photometric measurements using both the Sun and the Moon as light source, allowing the extraction of a complete diurnal cycle of aerosol properties and water vapor content, valuable to enhance atmospheric monitoring.

IARC CE318-T observations started in 2014, with three prototypes installed at IZO: one reference instrument and two secondaries. The reference, assumed as CE318-T master, is currently working as IZO master. The two CE318-T secondaries were used to develop and check new procedures to transfer the absolute Lunar Langley calibration technique to field instruments. The information extracted from these three years of CE318-T observations has allowed the comprehensive assessment of the CE318-T performance, and in addition, has served to identify other sources of problems related to lunar photometry.

Figure 22.1. The CE318-T photometer tracking the moon at IZO.

A quantitative estimation of AOD uncertainty by means of error propagation theory, performed by Barreto et al. (2016), revealed similar CE318-T AOD uncertainties at daytime (u^{D}_{AOD}) as those expected for previous sunphotometer versions. AOD uncertainties at nighttime (u^{N}_{AOD}) depend strongly on the Moon's illumination conditions, ranging between 0.011 and 0.018 for reference instruments, and between 0.012 and 0.021 in case of field instruments. This estimation was calculated assuming a ROLO relative lunar extraterrestrial irradiance accuracy of ≈ 1%, independent of any orbital parameter (Kieffer and Stone, 2005)

Barreto et al. (2016) assessed the CE318-T performance during daytime using measurements from collocated independent reference instruments. Daytime AOD evaluation, performed at IZO from March to June, 2014, encompassed measurements from the CE318-T master, the CE318 Aerosol RObotic NETwork (CE318-AERONET) master, a Precision Filter Radiometer (PFR) and a Precision Solar Spectroradiometer (PSR) prototype. This comparison analysis is summarized in Fig. 22.2, where the number of measurements (N), mean bias (MB), root mean square error (RMSE) and Pearson correlation coefficient (r) for 870 nm and 500 nm channels are included.

This analysis reported low AOD discrepancies between the four instruments (≤ 0.003). These results demonstrated that the new CE318-T provides measurements, equivalent or better than those provided by the current standard CE318-AERONET master.

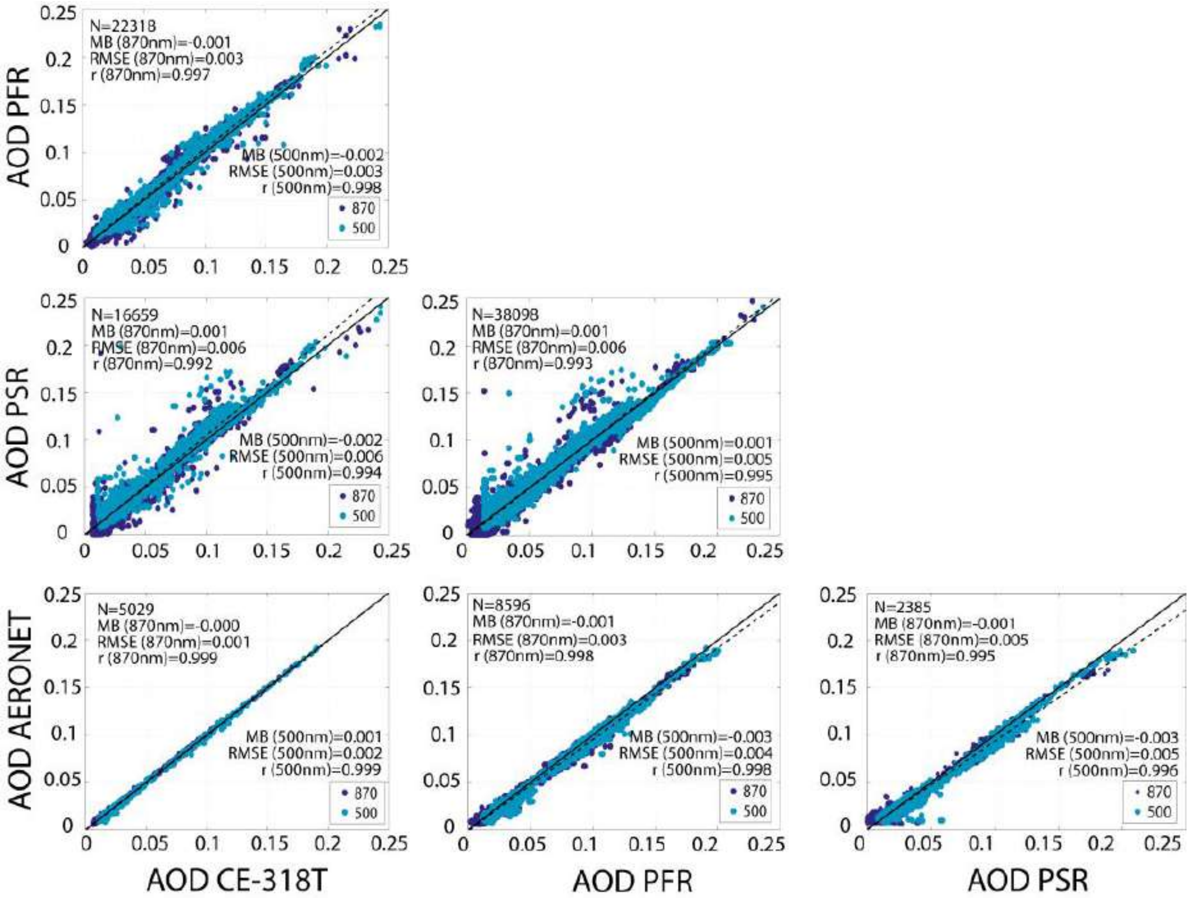

Figure 22.2. Scatterplots of AOD at 870 nm (blue) and 500 nm (cyan) using four different and independent measurements (CE318-T, CE318-AERONET, PFR and PSR) during March, April, May and June, 2014 at IZO. In each figure, the dotted line represents the linear regression line, and the solid line is the diagonal. Figure reprinted from Barreto et al. (2016).

As a result of this analysis, the AERONET team accepted this new Cimel version henceforth in AERONET, once the homogeneity of the network was ensured, suggesting the replacement of CE318-N instruments by the new CE318-T as far as possible (see the news published on 2 Oct. 2016, on the AERONET webpage).

The nocturnal AOD evaluation was performed by Barreto et al. (2016) using CE318-T and star photometer collocated measurements and also by means of a day/night coherence transition test using the master CE318-T and the CE318 daytime data from the CE318-AERONET master. Results showed low discrepancies with star photometer at 870 nm and 500 nm channels (≤ 0.013). Differences with AERONET daytime data (1-h after sunrise and 1-h before sunset) are in agreement with the estimated u^{N}_{AOD} values for all illumination conditions for the visible spectral range. A good agreement is also found for near infrared channels when the Moon's illumination is high.

Precipitable water vapor (PWV) validation showed a good agreement between CE318-T and Global Navigation Satellite System (GNSS) PWV values for all illumination conditions, within the expected precision for sun photometry.

Some case studies have also been included to highlight the ability of the new CE318-T to capture the diurnal cycle of aerosols and water vapor as well as their short-term atmospheric variations, critical for climate studies. Results from one of the case studies are presented in Fig. 22.4. From this figure we can see that the CE318-T has sufficient accuracy to capture the diurnal variations of AOD, Angström exponent (AE) as well as PWV during a sequence of three dust outbreaks at IZO.

One significant conclusion extracted from this study is the important dependence found in the AOD uncertainty with phase angle and also the faint nocturnal cycle found on AOD, indicating a possible dependence of AOD uncertainty on the Moon's zenith (θ) and phase angles. As it is claimed in this work, the reason for these discrepancies remain unclear, although it is likely to be due to a sum of causes, such as inaccurate instrument calibration, possible systematic errors in the ROLO model, and uncertainties in night-time AOD calculation.

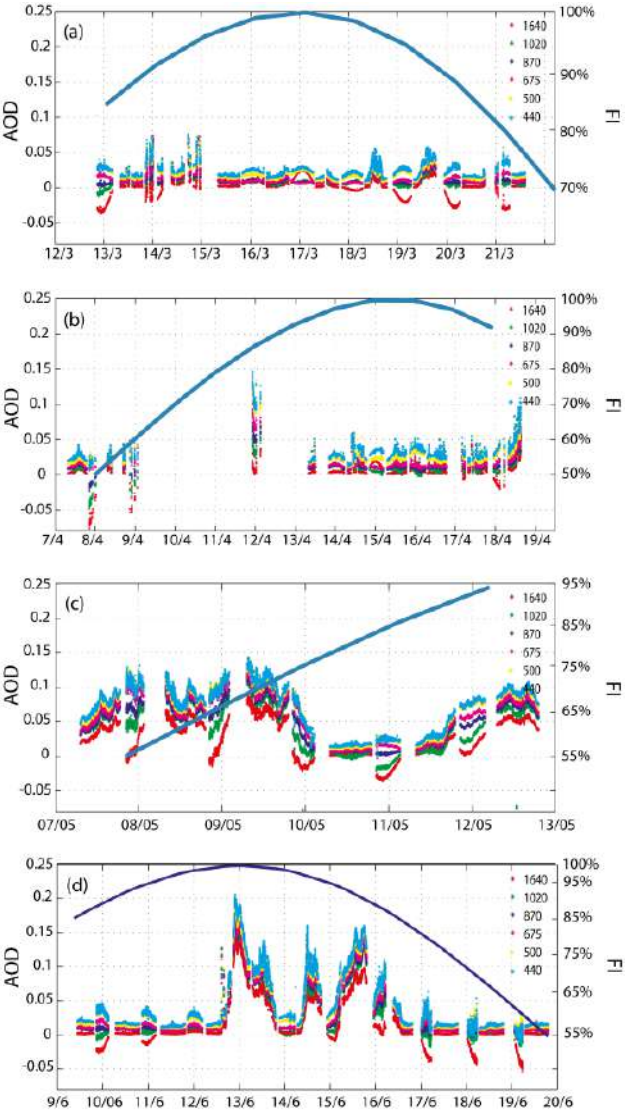

Figure 22.3. Diurnal CE318-AERONET/CE318-T AOD evolution during (a) March, (b) April, (c) May and (d) June, 2014 at IZO. The blue line and right y-axis correspond to the evolution in this period of the Moon's factor of illumination (FI). Figure reprinted from Barreto et al. (2016).

Finally, further investigations should be focused on accurately estimating the precision of the Moon's extraterrestrial irradiances extracted from the ROLO model. Since the phase angle dependence of the ROLO model as well as the asymmetry of this model within the Moon cycle have also been reported by Lacherade et al. (2013) and Viticchie et al. (2013), the uncertainty involved in the ROLO model should be revised.

Many projects have been developed in this context, such as the European Space Agency (ESA) intended invitation to tender (ITT) to the project 16.197.24 "Lunar spectral irradiance measurement and modelling for absolute calibration of EO optical sensors" and the expected EUMETSAT project on lunar calibration for operational instruments.

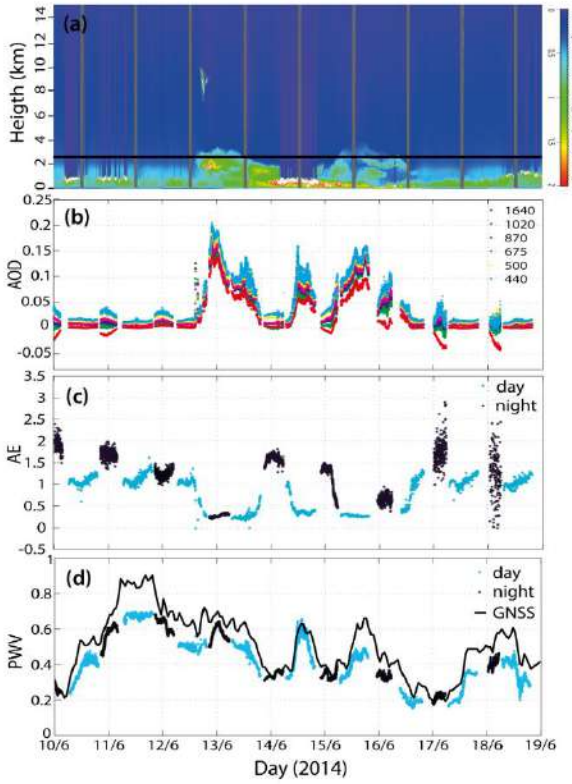

Figure 22.4 Case study at IZO in June, 2014, including information for (a) Micropulse Lidar MPL-corrected backscatter cross section obtained from Santa Cruz de Tenerife station (60 ma.s.l.). The black horizontal line in (a) represents the altitude of IZO station. Grey vertical lines in (a) represent the absence of measurements. The evolution of CE318-T AOD, AE and PWV from 10 to 19 June 2014 is shown in (b), (c) and (d). PWV values from GNSS precise orbits are plotted with a black solid line. Figure reprinted from Barreto et al. (2016).

The polar community is also investing significant efforts in the improvement of the ROLO model. The POLARMOON project, starting in 2017 as a collaboration between AEMET and University of Valladolid, is a good example of these efforts.

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22.2 The ZEN System Project

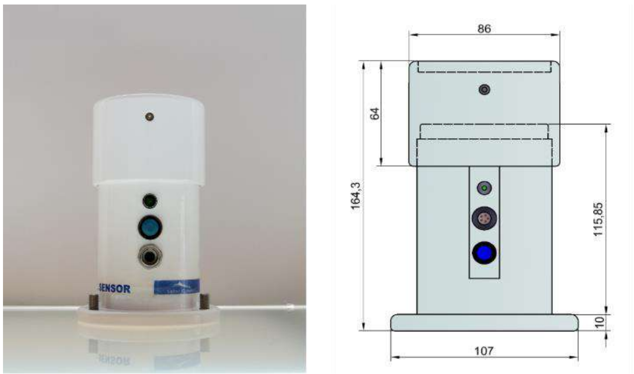

Figure 22.5. ZEN-R41 scheme and dimensions.

The ZEN system project has arisen as a collaboration between Sieltec Canarias S. L. and the Izaña Research Atmospheric Center to fill observational gaps in aerosol monitoring, especially in remote desert regions. This project started in 2014 with the development of the first zenith looking radiometer prototype, named SIELTEC Digital Sky Color Radiometer (DSCR).

At present, different remote sensing techniques are employed to monitor atmospheric aerosols all over the world by means of satellite and ground based instrumentation. Aerosol observation from satellite platforms introduces the advantage of excellent spatial coverage but is affected by surface reflectance, which is especially important in bright regions such as deserts. This technique also has the drawback of low temporal resolution (around one measurement per day).

Ground based photometers can provide accurate aerosol optical and microphysical properties. For example, these instruments retrieve aerosol optical depth with an estimated accuracy ≤ 0.02 in the visible spectral range, suggested as a goal by WMO. Such instrumentation can provide high temporal resolution aerosol coverage but with a low spatial coverage. To cover bigger areas, they are normally deployed in different locations creating networks of ground based photometers. The Aerosol Robotic Network (Holben et al., 1998) is the most widespread network, with over 1100 stations distributed across five continents, routinely and automatically providing information on aerosol optical and microphysical properties, using the Cimel Electronique 318 (CE318) photometer as the standard instrument.

However, given the operational needs of the instruments commonly used in this type of network, their stations require an almost permanent support, so they are usually deployed in locations near populated areas.

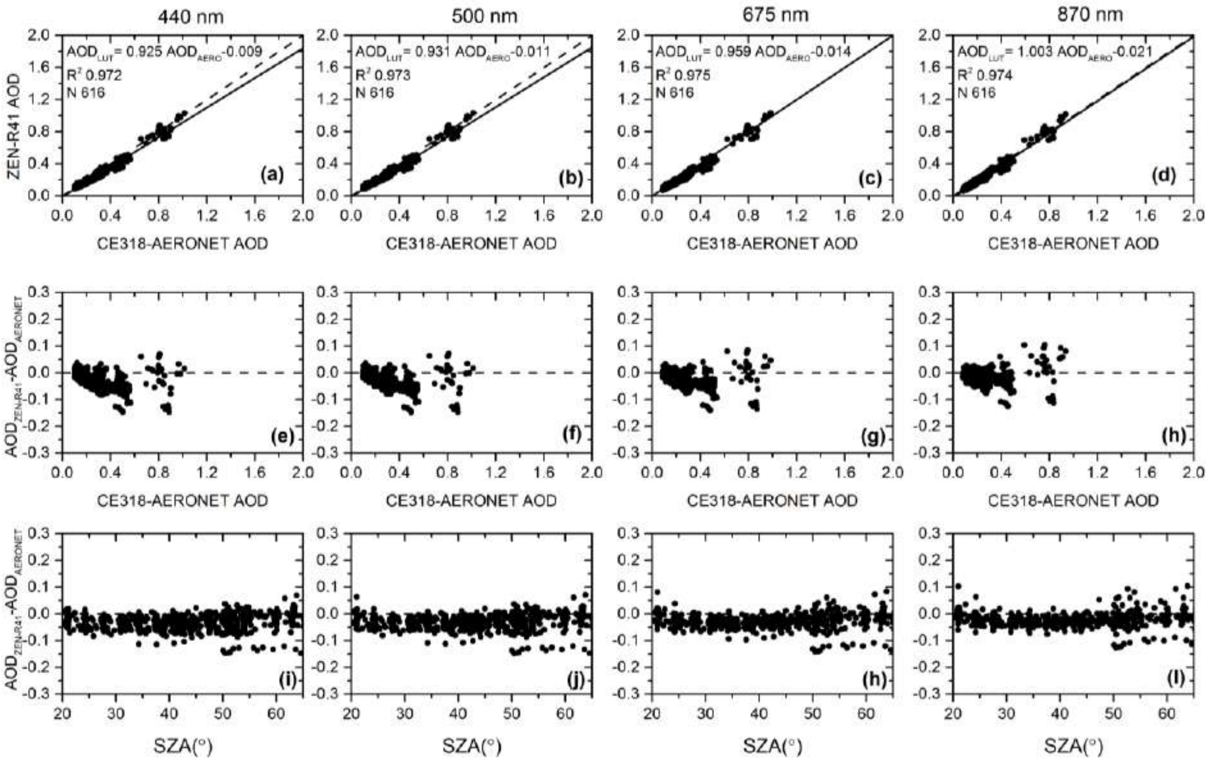

Figure 22.6. AOD comparisons between CE318-AERONET and ZEN-R41 for four different spectral bands (440, 500, 675 and 870 nm) performed at IZO in 2015. In the upper panel (a–d) AOD scatter plots AERONET/ZEN41 are presented.). The black solid lines are the least-square fits, and the dashed lines are the diagonals (y=x). The least-square fit parameters are shown in the legend (slope, intercept, coefficient of determination (R^2) and number of data (N)). The middle panel (e–h) shows the AOD ZEN-AOD AERONET differences versus AERONET AOD. AOD differences versus solar zenith angle (SZA in °) are shown in the lower panel (i–l). Reprinted from Almansa et al., 2016.

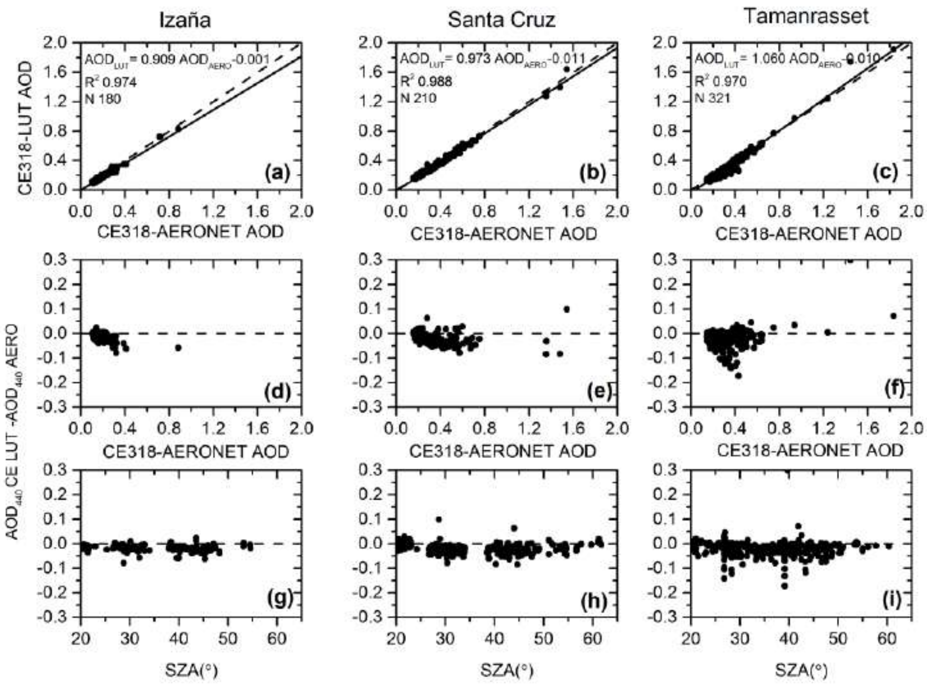

Figure 22.7. Scatter plot of AOD at 440 nm between CE318-AERONET and CE318-LUT for Izaña (a), Santa Cruz (b) and Tamanrasset (c) stations in 2013 for 20° < SZA < 65° (a, b, c). AOD at 440 nm difference between CE318-AERONET and CE318-LUT respect to CE318-AERONET (d, e, f) and SZA (°) (g, h, i), respectively. Reprinted from Almansa et al., 2016.

In addition, the high cost of this type of instrument reduces its use to those countries or organizations with limited resources to fund their purchase and maintenance. Consequently, there is a significant loss of information in unpopulated desert and low-income regions. An obvious example is the lack of measurement stations in the African continent, which is the most important source region of mineral dust in the world.

The reasons mentioned above have motivated the development of the ZEN system, presented in Almansa et al. (2016), a system capable of supplying the present deficiencies in mineral dust aerosol monitoring. The ZEN system comprises the ZEN-R41 radiometer (Fig. 22.5), which measures downwelling zenith sky radiance (ZSR) at four channels (870, 675, 500 and 440 nm), and a methodology for AOD retrieval (ZEN-LUT).

The ZEN-R41 radiometer is a rather compact radiometer. It has been designed to be stand-alone and without moving parts, making it a low-cost, robust and automated instrument with lower maintenance than classical sun-photometers, appropriate to be deployed in remote and unpopulated desert areas. The ZEN-LUT is a look-up table (LUT)-based method to estimate AOD, specifically designed for desert aerosols. The LUTs are composed of a set of simulated ZSR and AOD values obtained with the radiative transfer code LibRadtran (Mayer and Kylling, 2005). The AOD is then inferred by minimizing the difference between simulated and measured ZSR at all used wavelengths.

The first prototype (DSCR) was installed at IARC in 2014. The preliminary assessment of this new device was presented in Cuevas et al. (2015). Subsequent improvements gave rise to the second prototype, trade name ZEN-R41, installed at IZO in 2015.

Almansa et al. (2016) tested the ZEN system at Izaña station in 2015 covering different aerosol conditions (from AOD>0.01 to AOD<1). AOD results were validated through comparison with a collocated CE318 AERONET photometer. The results of the AOD comparison between AERONET and the ZEN system are shown in Fig. 22.6. The comparison showed a good agreement between ZEN-R41 and AERONET (coefficient of determination, R^2, of 0.97), with observed AOD differences up to 0.15, and ZEN-R41 AOD was systematically underestimated (mean bias ranging from -0.020 to -0.030). A subsequent sensitivity analysis of the ZEN system was performed to identify the systematic errors (instrumental and radiative transfer inputs) exerting the most influence on the final AOD. This study showed the instrumental errors and the aerosol model as the most important contributors to the final AOD uncertainty. This analysis estimated an AOD combined standard uncertainty in the ZEN system ≤ 0.06 in the case of AOD_{500nm} ~ 0.5, and 0.15 for AOD_{500nm} ~ 1.0, provided instrumental errors are minimized (≈5 %).

Finally, in this study the ZEN-LUT method was applied to CE318 ZSR measurements (CE318-LUT) and therefore it confirmed this method can be used to retrieve AOD in other locations affected by mineral dust, such as SCO (Tenerife, Spain) and Tamanrasset (Algeria). The comparison between AOD from AERONET and CE318-LUT AOD, in a common period in which AERONET level 2.0 data was available at three stations (IZO, SCO and Tamanrasset), is shown in Fig. 22.7. These results show a good agreement between AERONET and CE318-LUT AOD, with R^2 ranging from 0.99 to 0.97 and RMSE values from 0.011 (at IZO) to 0.032 (at Tamanrasset).

In view of the results obtained, we concluded that the ZEN system is appropriate to monitor mineral dust aerosols in remote desert locations with little maintenance and with a reasonable accuracy, allowing us to enhance the operational capability of global aerosol networks for dust monitoring, data assimilation and dust model and satellite validation nearby dust source regions. As a consequence, this instrument could play a key role in dust model data assimilation in near dust source regions, satellite validation and early warning within the WMO (SDS-WAS).

Future work is oriented on the implementation of a cloud screening method to remove the cloud contaminated data, water vapor estimation and the application of the ZEN system to other types of aerosols.

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23 Capacity Building Activities

During 2015-2016 IARC participated in various capacity building activities. For further details of these activities, see individual sections or the IARC webpage.

2015

Training course to CIFP- Los Gladiolos students at the Izaña Atmospheric Observatory facilities, 25 Feb 2015

On 25 February 2016 the students of the Higher Level of Professional Training in Environmental Education and Control, taught in the CIFP "Los Gladiolos" at Santa Cruz de Tenerife, attended a training course at the Izaña Atmospheric Observatory on in situ monitoring techniques for the chemical composition of the atmosphere as performed within the WMO GAW Programme.

Operation of international organizations and international cooperation in the field of meteorology: AEMET Headquarters, Madrid, 12 March 2015

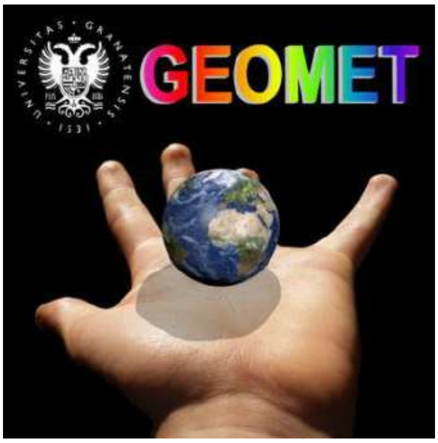
Dr Emilio Cuevas presented IARC´s scientific and operational activities in the field of Atmospheric Composition, performed in collaboration with international institutions and groups in this course, AEMET, Madrid, 12 March 2015.

Brewer workshop during the 10th RBCC-E Calibration Campaign, Huelva, 25 May 2015

This workshop, focused on the EUBREWNET COST Action activities, provided training to new Brewer operators on technical aspects of Brewer calibration.

Inaugural lecture, Master degree in Geophysics and Meteorology (GEOMET), University of Granada, 14 Oct 2015

Dr Emilio Cuevas gave the inaugural lecture on atmospheric research and monitoring, of the Master degree in Geophysics and Meteorology (GEOMET) of the University of Granada on 14 October 2015.



Sun-photometry Training Course: Izaña, Tenerife, 19-23 Oct 2015

Mr Lahouari Zeudmi and Mr Mohamed Kharef (Office National de la Météorologie-Tamanrasset station) and Mr. Souhayel Belhouane and Mr. Hichem Fehri (Institut National de la Météorologie de Tunisie –Tunis Carthage station) attended a 20-hour training course on Cimel sun-photometer operations given by Dr Carmen Guirado-Fuentes and Mr Ramón Ramos, under the supervision of Dr Emilio Cuevas during 19-23 October 2015.

Sun-photometry Training Course: Izaña, Tenerife, 30 Nov-4 Dec 2015

Mr Hassan Ousha and Mr Abderrahim Kini (Direction de la Météorologie Nationale du Maroc) attended a 20-hour training course on Cimel sun-photometer operation given by Dr Carmen Guirado-Fuentes, under the supervision of Dr Emilio Cuevas during 30 November - 4 December 2015.

CIAI collaboration with University of La Laguna Undergraduate Internship Program: Nov-Dec 2015

IARC collaborated, for the third consecutive year, with the University of La Laguna, Tenerife, by offering external work experience in the framework of the Undergraduate Internship Program, during 23 November-18 December 2015. The students Adrián José Jorge-Trujillo and Eduardo Coello-Rodríguez participated in the programme under the supervision of Dr Emilio Cuevas (IARC-AEMET) and Dr Carmen Guirado-Fuentes (IARC-AEMET, GOA-UVA), respectively, together with Dr Manuel Arbelo-Pérez (ULL) as academic supervisor. The practical training focused on the operation and calibration of reactive gas analysers, and the validation of hand-held sun-photometer measurements.

2016

Training Course on “Ground Observation of Dust”, 5th Regional Conference on Climate Change, Tehran, Iran, 25-26 January 2016

Dr Emilio Cuevas gave a class on ground-based observation techniques and methodologies (in-situ and remote sensing) to University students and air quality managers during the 5th Conference on Climate Change which was held in Tehran (Iran) on 25-26 January 2016.

Training course for University of La Laguna, Chemistry and Environmental Sciences Undergraduate students: Izaña Atmospheric Observatory, 17 Feb 2016

A group of 25 undergraduate students, of the University of La Laguna Departments of Chemistry and Environmental Sciences, attended a one-day training course held at the Izaña Atmospheric Observatory on 17 February 2016. The training course described the instrumentation of the different research programmes of the observatory, including greenhouse gases, reactive gases, radiation, aerosols, meteorology, stratospheric ozone and UV radiation and FTIR.

EUBREWNET Brewer Ozone Spectrophotometer open workshop in conjunction with the EMRP ATMOZ project and the 15th Biennial WMO-GAW Brewer Users Group Meeting. Ponta Delgada, Portugal, 17-20 May 2016

The event was a collaboration of EUBREWNET (COST Action ES1207), the EMRP ATMOZ project and WMO-GAW. One of the highlights of the workshop was the exchange of formal and informal information between experts and new researchers and Brewer operators (for more details, see Section 17.5.5).

ACOMET Seminar "Basic Concepts in Atmospheric Composition": Izaña Atmospheric Observatory, 18 June 2016

The seminar entitled "Basic Concepts in Atmospheric Composition" was given to the members of the Meteorology Communicators Association (ACOMET) from Spain during its IV ACOMET Seminar on 18 June 2016 (for more details, see Section 24.3).

EUBREWNET Brewer Ozone Spectrophotometer training school as side event of the Quadrennial Ozone Symposium 2016: Edinburgh, UK, 4-9 September 2016

The training school, organized by EUBREWNET and WMO-GAW, was held in Edinburgh, UK, 4-9 September 2016. Twenty students from America, Asia and Europe attended the training school, which focused on operational, scientific and technical aspects of the Brewer instrument and on the use of EUBREWNET O_3, UV and AOD products (for more details, see Section 17.5.5).

Training Course “Observation and Prediction of Air Quality”: Santa Cruz de la Sierra, Bolivia, 5-9 September 2016

Dr Sergio Rodríguez (IARC-AEMET) participated in a training course, organized and coordinated by AEMET and AECID, entitled: “Observation and Prediction of Air Quality” held in Santa Cruz de la Sierra, Bolivia, during 5-9 September 2016.

5th Training Course on WMO SDS-WAS Products: Tehran, Iran, 5-9 November 2016

The 5th Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust) was held during 5-9 November 2016 in Tehran, Iran. Dr Sergio Rodríguez (IARC-AEMET) participated in the course with a lecture on ground based observations and health effects of airborne dust.

Permanent capacity building

Capacity building: Brewer Spectrophotometer

RBCC-E has provided specific training and calibration services to the double Brewer installed in the GAW Tamanrasset station (Algeria). RBCC-E has remotely assisted numerous operators of EUBREWNET Brewer instruments when requested.

AERONET-EUROPE Calibration Facility

The Izaña Atmospheric Research Center node of the ACTRIS AERONET-EUROPE Calibration Facility provides regular capacity building to Cimel AERONET operators, mainly for those stations in Northern Africa.

24 Izaña Atmospheric Observatory Centenary Activities

24.1 "Izaña: 100 years of atmospheric observations" seminar: 7 April 2016

On 7 April 2016, the seminar "Izaña: 100 years of atmospheric observations", which was part of the Izaña Atmospheric Observatory centenary celebrations, was held in Santa Cruz de Tenerife.

The objective of the seminar was to discuss the future of atmospheric observation programmes especially in the context of climate variability and change, and to answer the following question: What can scientists do today to help future scientists assess climate variability and its socio-economic impacts?

This seminar consisted of a series of lectures given by invited scientists from universities and organizations that are linked to the Izaña Atmospheric Observatory research programmes. Issues such as the connection between climate variability, the composition of the atmosphere and its greenhouse gas content, Saharan dust, ozone depleting gases, and climate prediction were addressed.

The seminar, organized and coordinated by Dr. Sergio Rodríguez was open to the public. The presentations were as follows:

An overview of 50 years of research on African dust transport to the Caribbean, Professor Joseph M. Prospero, University of Miami.

Long-term aerosol observations in the Mediterranean, Dr Andrés Alastuey, CSIC, Barcelona.

Remote sensing of aerosol properties in the context of AERONET-EUROPE, Dr Victoria Cachorro, University of Valladolid.

Airbourne microorganisms. What's in the air we breathe? Dr Cristina González, Institute of tropical diseases, University of La Laguna, Tenerife.

Climate prediction in the North Atlantic basin, Dr Francisco J. Doblas-Reyes, BSC, Barcelona.

Long-term observations of trace gases by remote sensing, Dr Olga Puentedura. INTA, Madrid.

High resolution infrared remote sensing for research on the stratosphere, greenhouse gases and the water cycle, Dr Matthias Schneider, IMK-ASF, Karlsruhe.

24.2 Official Centenary Ceremony: 8 April 2016

In 2016 the Izaña Atmospheric Observatory celebrated the 100-year anniversary with several notable activities, among which, the Official Centenary Ceremony held on 8 April 2016 at the observatory, was the principal event.

This event was attended by the world's foremost meteorological authorities. The President and the Secretary-General of the World Meteorological Organization, Dr David Grimes and Dr Petteri Taalas, respectively, the Director General of European Centre for Medium-Range Weather Forecasts (ECMWF), Dr Florence Rabier, the Director General of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Dr Alain Ratier, the Director of the Group on Earth Observations (GEO), Dr Barbara Ryan, the Executive Director of the European Meteorological Services Network (EUMETNET), Mr Eric Petermann, and the Director of the German Meteorological Service (DWD), Dr Gerhard Adrian. The ECOMET (an economic interest grouping of the National Meteorological Services of the European Economic Area) Chief Executive, Mr Willie McCairns, and the Directors of 16 national weather services in Europe also attended the ceremony (see Table 24.1 and 24.2). The list of guests, up to a hundred, was completed with representatives of scientific institutions, universities and other technical centres with which the Izaña Atmospheric Observatory collaborates closely

The event began with the intervention of the President of AEMET, accompanied by the director of the German Meteorological Service, who emphasized the fundamental role played by the German Government in the installation of the Izaña Atmospheric Observatory, inaugurated on 1 January 1916, in the frame of the collaboration between the two countries.

Here below we give a brief snapshot of some of the presentations during the official centenary ceremony at the Izaña Atmospheric Observatory

The German scientists were pioneers, beginning in as early as 1909, observations and atmospheric investigations using a portable construction provided by the German Emperor William the Second, which was settled in a location near the present observatory, in La Cañada de la Grieta, in the foothills of Teide. For this reason, the Consul of Germany in Tenerife as well as the Director of the German Meteorological Service, participated in the opening of the centenary ceremony.

Dr Emilio Cuevas, director of the Izaña Atmospheric Research Centre, who acted as master of ceremony introducing guest researchers, explained Izaña Atmospheric Observatory's measurement programme and its outstanding role in monitoring climate change.

Figure 24.1. Izaña Atmospheric Observatory centenary celebration, 8 April 2016.

Manuel Palomares, Coordinator of Programmes and Projects of EUMETNET, emphasized the great scientific interest of the site at Izaña, which led to the construction of the Atmospheric Observatory in this location.

WMO recognized the importance of the Izaña Atmospheric Observatory in the Global Atmosphere Watch Programme. This was emphasized by the WMO President, Dr David Grimes, who stated that "understanding of the atmosphere is fundamental to life on Earth, and in this case, thanks to the vision of nations like Spain through the establishment of the Izaña Atmospheric Observatory, we have improved our knowledge in this area. The Izaña Atmospheric Observatory collaborates crucially with the Global Atmosphere Watch Program that was created in 1989, which aims to monitor concentrations of carbon dioxide and other atmospheric components."

In this regard, Dr Petteri Taalas, Secretary General of WMO, stressed that "thanks to the long-term monitoring of stations such as Izaña, we can know how greenhouse gas concentrations are evolving." These stations will form the backbone of WMO's Integrated Global Greenhouse Gas Information System (IG^3IS), which will combine observations, modeling and analysis to improve understanding of GHG fluxes. "Through this system we will understand the effectiveness of efforts to reduce greenhouse gas emissions, which will be a key tool for the implementation of COP21," Taalas said.

Dr Alain Ratier, Director General of EUMETSAT, spoke on the complementarity of on-site observation in the face of remote sensing and highlighted the role of Izaña in these moments in which "there are new space programs with new instruments that will need to be calibrated in Supersites such as this."

Table 24.1 List of speakers at the Izaña Atmospheric Observatory centenary celebration, 8 April 2016, in order of appearance.

Name	Affiliation	Position
Mr Miguel Ángel López	President	AEMET, Spain
Dr Gerhard Adrian	Director	DWD, Germany
Mr Ángel Hernández	Honorary Consul	Honorary Consul of Germany in Tenerife
Dr Emilio Cuevas	Director	IARC-AEMET
Mr José Antonio Valbuena	Councilor of Environment	Cabildo of Tenerife
Mr Manuel Palomares	Coordinator of Programmes and Projects	EUMETNET
Prof Joseph M. Prospero	Prof. Emeritus	RSMAS, Univ. of Miami
Prof Johannes Orphal	Head	IMK-ASF, KIT, Germany
Mr Julio González-Breña	Head	AEMET International Relations Department
Dr Petteri Taalas	Secretary General	WMO
Dr Florence Rabier	Director General	ECMWF
Dr Alain Ratier	Director General	EUMETSAT
Dr Barbara Ryan	Director	GEO
Eric Petermann	Executive Director	EUMETNET
Dr David Grimes	President	WMO

Figure 24.2. Izaña Atmospheric Observatory centenary celebration, 8 April 2016: a) Dr Gerhard Adrian, b) Prof Joseph M. Prospero, c) Prof Johannes Orphal, d) Dr Petteri Taalas, e) Dr Florence Rabier, f) Dr Alain Ratier, g) Dr Barbara Ryan and h) Dr David Grimes.

The Director of GEO (Group on Earth Observations), Dr Barbara Ryan, highlighted the in-situ observation resources of the atmosphere and their interest to build the Global Earth Observation System of Systems (GEOSS).

Eric Peterman, executive director of EUMETNET, stressed that "not only is it important to note the role of observatories with very long series, but also the steps taken by their staff to make the data usable." During his presentation he highlighted the importance of centennial observatories and instrumental climatic series within the European meteorological infrastructure.

Centennial observatories are also key in observing the climate system for better weather prediction, according to the director general of the European Centre for Medium-Range Weather Forecasts (ECMWF), Dr Florence Rabier, for whom "Izaña's contribution is fundamental for validation of data, climate research and atmospheric mineral dust transport research in collaboration with the Barcelona Supercomputing Center."

Table 24.2 List of NMHS Presidents and other participants at the Izaña Atmospheric Observatory centenary celebration, 8 April 2016.

NMHS Presidents and other participants	
Name	**Country**
Dr Gerhard Adrian	Germany
Michael Staudinger	Austria
Daniel Gellens	Belgium
Marianee Thyrring	Denmark
Prof. Juhani Damski	Finland
Jean Marc Lacave	France
Gerhard van der Steenhoven	Holland
Liam Campbell	Ireland
Hafdis Karlsdóttir	Iceland
Silvio Cau	Italy
Martina Reckwerth	Luxembourg
Miguel Miranda	Portugal
Robert Varley	United Kingdom
Peter Binder	Switzerland
Ivan Cacic	WMO AR VI President
Silvia Castañer	EUMETSAT Administration Director
Willie McCairns	ECOMET Executive Chief

The relevant role of the Izaña Atmospheric Observatory in the history of studies on transatlantic transport of African dust was another outstanding subject, thanks to the participation of the University of Miami Rosenstiel School Professor Emeritus Joseph Prospero, one of the pioneers of aerosol dust research, now known as the "grandfather of dust".

Figure 24.3. Dr Sergio Rodríguez presents a commemorative plaque to Professor Emeritus Joseph M. Prospero as a tribute to being a pioneer of the aerosol programme at the Izaña Atmospheric Observatory.

Professor Emeritus J. M. Prospero started long-term studies on aerosol dust in the early 1960s in the Caribbean and in the mid 1970s at Izaña Atmospheric Observatory. He performed long-term observations of aerosol chemistry at Izaña throughout three decades (1970s and 1987-1999), producing a data set that has been incorporated to the Izaña Observatory database. Prof. Emeritus J. M. Prospero has played a key role contributing to the scientific activities of aerosol research at Izaña Atmospheric Observatory and is nowadays an active scientific collaborator of the Izaña team.

During the celebration of the Izaña 1916-2016 Centenary, a commemorative plaque was given to Prof. Emeritus J. M. Prospero and another plaque was attached to the aerosols laboratory, which is the original building of the Izaña Atmospheric Observatory, built in the mid 1910s. This building was renamed the "Joseph M. Prospero Aerosol Research Laboratory".

Figure 24.4. Upper panel, Professor Emeritus J. M. Prospero with his honoury plaque at the Izaña Atmospheric Observatory Aerosol Research laboratory. Lower panel: several pictures of this building throughout the last century.

The Izaña Atmospheric Observatory has also been designated as a WMO CIMO Testbed for aerosols and water vapour remote sensing instruments measurements, a feature highlighted by Prof. Johannes Orphal, director of the Institute of Meteorology and Climate Research Atmospheric Trace Gases and Remote Sensing (KIT, Germany), who highlighted the role of the observatory as a remote sensing and calibration supersite for satellite sensors that measure different atmospheric components with spectroradiometric techniques.

Since much of the merit of what is now Izaña is due to those who previously worked at the observatory and are no longer in it, and as a homage to them, a video with short messages of congratulations, from different parts of the world, of people who have worked or maintained a special collaboration with this observatory was presented. As a tribute to all those who worked in the past at the Izaña Atmospheric Observatory, Dr Emilio Cuevas presented a plaque of recognition (Fig. 24.5, 24.6) that was collected on behalf of all absentees by Ms Carmen Rus, Director of Planning, Strategy and Commercial Development, direction of the IARC.

Figure 24.5 Dr Emilio Cuevas delivers a commemorative plaque to Ms Carmen Rus, Director of Planning, Strategy and Commercial Development of AEMET, in homage to all those who worked in the past at the Izaña Atmospheric Observatory.

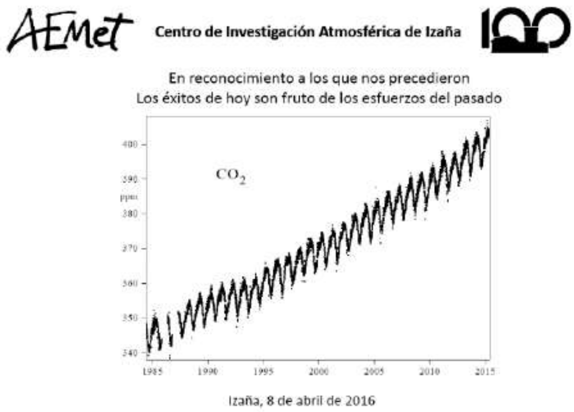


Figure 24.6. Plaque motto: "In recognition of those who preceded us. Today's successes are the result of past efforts"

Finally, the President and the Secretary General of WMO unveiled a plaque at the entrance of the Observatory in commemoration of its 100-year anniversary.

Figure 24.7. Unveiling the plaque commemorating the Izaña Atmospheric Observatory centenary, Dr David Grimes (WMO President) and Dr Petteri Taalas (WMO Secretary General), accompanied by Mr Miguel Ángel López (AEMET President).

Figure 24.8. Izaña Atmospheric Observatory centenary celebration, 8 April 2016.

After the official events, guided visits to the Izaña Atmospheric Observatory facilities were organized.

A summary video of the ceremony acts can be found here.

A full video of the ceremony acts can be found here.

A photo gallery of the anniversary act can be found here.

Other related links:

https://public.wmo.int/en/media/news/iza%C3%B1a-observatory-celebrates-100-years

24.3 Meteorology Communicators Association (ACOMET) activities in conmemoration of the Izaña Observatory Centenary

On 18 June 2016, members of the Meteorology Communicators Association (ACOMET) visited the Izaña Atmospheric Observatory. The visit was part of the ACOMET IV Seminar, which was held on the island of Tenerife coinciding with the Izaña Atmospheric Observatory centenary.

Figure 24.9 Participants of the ACOMET meeting, during the visit to Izaña Atmospheric Observatory, 18 June 2016.

During the visit to the Izaña Atmospheric Observatory the seminar entitled "Basic Concepts in Atmospheric Composition" was given. The lecturers were researchers from the Izaña Atmospheric Research Centre: Dr Emilio Cuevas, Ángel Gomez, Alberto Redondas, Dr Omaira García, and Dr Sergio Rodriguez. Topics such as greenhouse gases and global warming, ozone and ultraviolet radiation, reactive gases and global air quality, atmospheric aerosols and their impact on health, and atmospheric mineral dust were addressed in this course. Dr Fernando de Ory, gave a talk about the history of the observatory. See the following link for some photos of the ACOMET visit to IZO).

In the afternoon of 18 June 2016, members of ACOMET visited the Teide Cable Car (Teleférico de Pico del Teide), where they had the opportunity to see the instruments managed by the IARC at the cable car terminal station, (Teide Peak Observatory, 3,555 m a.s.l.), one of the highest atmospheric measurement stations in Europe.

Participants also had the opportunity to visit the “Teide Clouds Laboratory” project, which is intended to show the importance of the Teide as an area of huge scientific research interest to the public. The Teide Clouds Laboratory project started in December 2015, with the main aim of registering atmospheric phenomena in Teide National Park using photographic images and high definition time-lapse videos. The project is the result of a collaboration between the IARC, the Teide Cable Car Company, and the renowned Astrophotographer Daniel Lopez.

On 19 June 2016, ACOMET held an event at the Museum of Nature and Man (Santa Cruz de Tenerife) in which members of the IARC staff participated: Rubén del Campo Hernández, technician of the Izaña Atmospheric Observatory GAW Programme and member of ACOMET, gave a talk on clouds and meteors observations. Dr Emilio Cuevas, IARC director, participated in a panel discussion on climate change and weather communication with Victoria Palma, meteorologist of Radio Television Canaria, José Luis Martín Esquivel, a biologist of the Teide National Park, and José Miguel Viñas, president of ACOMET. The moderator was Juan José Martin; a journalist specialized in science communication.

24.4 Internal meeting to commemorate the Izaña Observatory Centenary: 2 December 2016

On 2 December 2016, an internal event was held at the Izaña Atmospheric Observatory in commemoration of its centenary. This meeting was devoted to people who currently work and worked in the past in the observatory.

This commemorative meeting focused on the Human Factor of the observatory, the most important factor, which has provided the true character to the Izaña Atmospheric Observatory throughout its history. The people of Izaña work at a remote site, but at the same time, these people have always had a close contact with people from other countries and cultures that has enriched the life and history of the observatory.

We had the honour of being visited by former colleagues, now retired, who had to work in much more difficult conditions and with less resources than at present. We also wanted to pay homage to those who preceded us, and to those who currently work at Izaña, handling very sophisticated equipment and involved in complex atmospheric research programmes.

The meeting on 2 December 2016 started with a talk about the history of Izaña Atmospheric Observatory, given by the IARC Director, Emilio Cuevas, which quickly became a casual, but very endearing and interesting colloquium from which we learned many things. Former colleagues such as Gilberto Naranjo, Fernando Clavijo, and Pili Sálamo who began working at Izaña in the 1950s and early 1960s were in the meeting room. Having several generations of Izaña people together was enormously gratifying and moving. We also had the pleasure of welcoming colleagues from the AEMET Delegation in the Canary Islands, specifically the Las Palmas Centre, who made the effort to come to Izaña on personal initiative.

Figure 24.10. Participants of the Izaña Atmospheric Observatory internal meeting, 2 December 2016. Past and present together.

During this day, we made an informal visit to the facilities where there were constant references to the past, and comparisons with the present. Our retired colleagues were pleasantly surprised to find that we had preserved, with great affection, tools, equipment, objects, and documents with which they worked. Respect for our history and for the work of our elders has been a constant feature at the Izaña Amospheric Observatory. The meeting also served to set a date in January 2017 to meet each other and gather first-hand information on instruments and activities from past decades from which, unfortunately, there is little written information.

We missed many of Izaña's former colleagues who currently work in different AEMET centres in Santander, Valladolid, Madrid, Alicante, Valencia, Almería, Málaga and Tenerife. Nacho Abad (Alicante airport meteorological office) sent us a beautiful drawing and a moving poem about Izaña that are now framed in the observatory dining room along with fond memories and photos of the staff.

We also had time to show the new projects and instruments that we currently manage, and make a toast all together for a prosperous future.

24.5 Other meetings to commemorate the Izaña Observatory Centenary

Throughout 2016, informative lectures on the history of the Izaña Atmospheric Observatory and its current activities were presented in different institutions on the island of Tenerife:

Dr Emilio Cuevas, El Centro de Investigación Atmosférica de Izaña: 100 años observando la atmósfera, Día Meteorológico Mundial, Subdelegación del Gobierno en Santa Cruz de Tenerife, 17 March 2016.

Dr Emilio Cuevas and Dr Fernando de Ory, El Centro de Investigación Atmosférica de Izaña: 100 años observando la atmósfera, Real Sociedad Económica de Amigos del País de Tenerife, La Laguna, 12 May 2016.

Dr Emilio Cuevas and Dr Fernando de Ory, El Centro de Investigación Atmosférica de Izaña: 100 años observando la atmósfera, Museo de la Naturaleza y el Hombre, Santa Cruz de Tenerife, 17 May 2016.

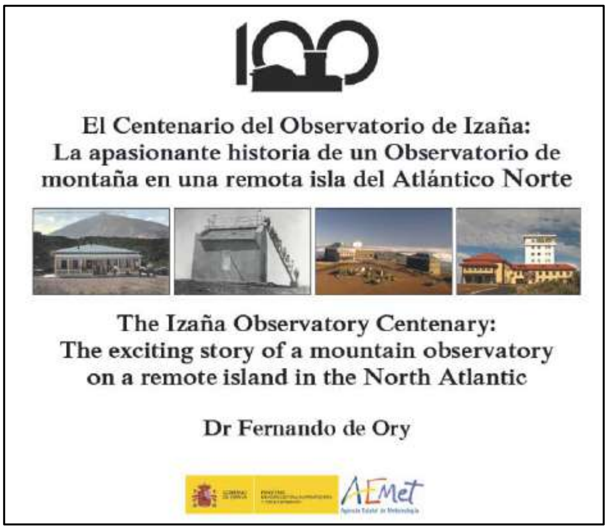
Dr Emilio Cuevas, 100 años del Observatorio de Izaña: su historia y actividades actuales, Real Casino de Tenerife, 4 October 2016.

24.6 Outreach documents

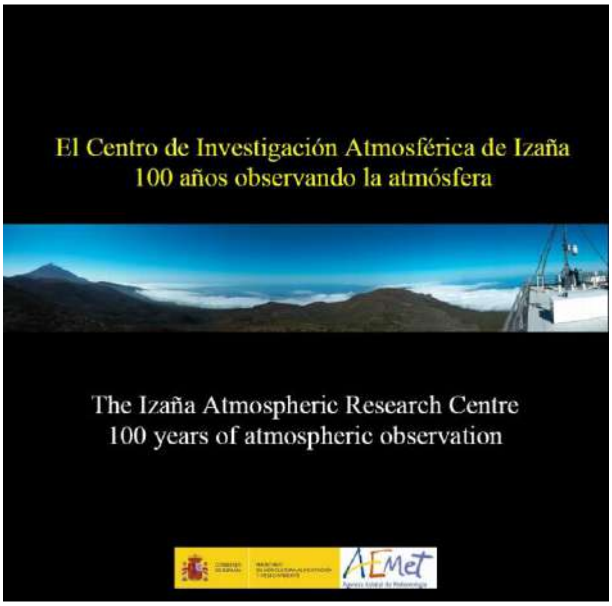
As part of the actions undertaken in 2016 to commemorate the centenary of the Izaña Atmospheric Observatory, two informative booklets and the first activity report of the Izaña Atmospheric Research Centre (2012-2014) were published.

The activity report describes the activities carried out at IARC in the period 2012 to 2014. These activities are the result of efforts of all those working in the IARC, in administration, technical staff and researchers, as well as technicians and researchers from other collaborative institutions. Therefore, this report constitutes recognition to the team-effort of each and every one of them. The report was published in both digital and hard copy formats. It is available here.

The booklet entitled "The Izaña Observatory Centenary: The exciting story of a mountain observatory on a remote island in the North Atlantic", written by Dr Fernando de Ory Ajamil was published in both digital and hard copy versions.



The booklet gives a brief historical overview, spanning four centuries, of the first meteorological and atmospheric observations conducted in Tenerife, the events leading up to the creation of the Izaña Observatory and the 100 years since its inauguration. The booklet is available here.



A 44-page booklet entitled "The Izaña Atmospheric Research Center: 100 years of atmospheric observation" has been published in which, in a simple but rigorous way, the activities currently carried out by the Center are summarized. The booklet contains numerous photographs and graphics, it is available here.

24.7 Photography Centenary Contest

A photo contest convened by IARC staff has given rise to a series of magnificent photographs. The winning photographs, according to the votes received, were the following: "Teide and Kevin-Helmholtz waves" by Rubén del Campo Hernández; "Phantom Clouds" by Conchy Bayo and "Let yourself be seen" by Toño Perdigón.

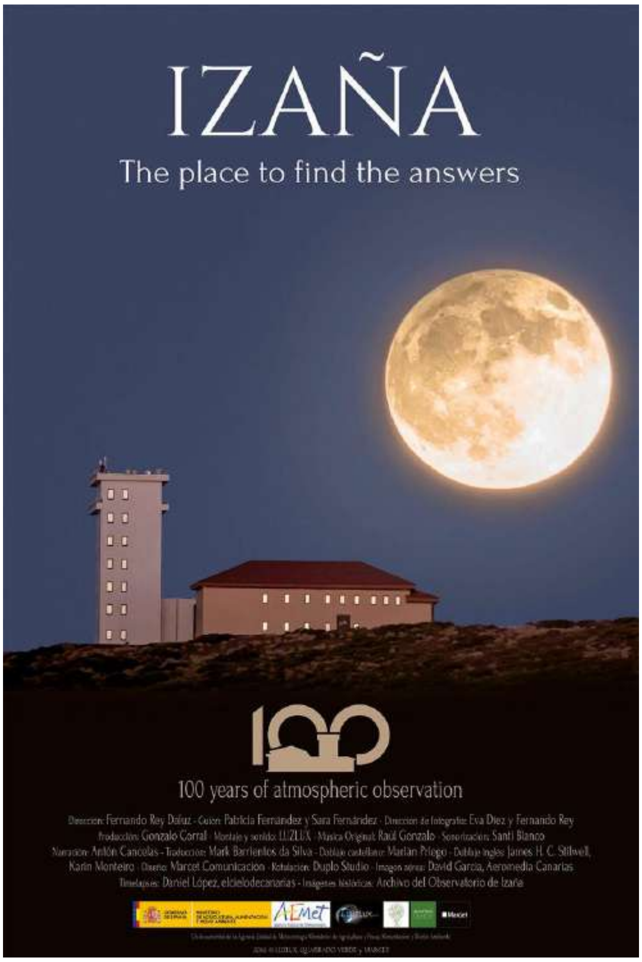
The 11 best photographs can be seen here.

24.8 Centenary Web Page

To commemorate the centenary of the Observatory, a specific web page with a special logo was designed (http://izana100.aemet.es/).

In this web a summary of the history of the Izaña Atmospheric Observatory, the documents described in the previous section, the photography contest, a section of the tweets related to the centenary, and a carousel of historical photographs of the last 100 years separated by decades were included. This last activity involved a huge effort to recover historical graphic documents, their scanning and editing, and their documentation when possible.

24.9 Izaña Atmospheric Observatory documentary



The documentary, "Izaña, the place to find the answers" was commissioned to commemorate the Izaña Atmospheric Observatory centenary. The documentary describes in an informative way the main problems and atmospheric challenges: such as greenhouse gases and global warming; the deterioration of the ozone layer; global air pollution and its monitoring; and climate change, and how it is approached by the scientific community, in general, and by Izaña Atmospheric Observatory, in particular.

The documentary is available in both Spanish and English.

24.10 Activities for the recovery of the Observatory's historical legacy

Last but not least were the activities aimed at recovering and documenting old instruments, equipment and tools, antique furniture, restoration and exhibition of photographs taken in the observatory over 100 years, and historical books and documents. These activities enthusiastically involved a large number of IARC staff and served those who work today at the observatory to learn more about its history and the work of our predecessors.

Figure 24.11 Mosaic of photographs showing the recovery of historical material from Izaña Atmospheric Observatory.

25 Publications

25.1 List of peer-reviewed papers

2016

Bader, W., Bovy, B., Conway, S., Strong, K., Smale, D., Turner, A. J., Blumenstock, T., Boone, C., Coulon, A., Garcia, O., Griffith, D. W. T., Hase, F., Hausmann, P., Jones, N., Krummel, P., Murata, 5. I., Morino, I., Nakajima, H., O'Doherty, S., Paton-Walsh, C., Robinson, J., Sandrin, R., Schneider, M., Servais, C., Sussmann, R., and Mahieu, E.: Ten years of atmospheric methane from ground-based NDACC FTIR observations, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-699, 2016.

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Bolsée, D., Pereira, N., Cuevas, E., García, R., Redondas, A., Comments to the Article by Thuillier et al. "The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer Onboard the International Space Station" on the Interpretation of Ground-based Measurements at the Izaña Site, Solar Physics, 291, 2473–2477, 2016.

Borges, M.E., M. Sierra, E. Cuevas, R.D. García, P. Esparza, Photocatalysis with solar energy: Sunlight-responsive photocatalyst based on TiO_2 loaded on a natural material for wastewater treatment Solar Energy, Volume 135, October 2016, Pages 527-535, ISSN 0038-092X, http://dx.doi.org/10.1016/j.solener.2016.06.022, 2016.

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26 PhD Theses

This section briefly describes the Doctoral Theses that have been supervised and co-supervised by researchers at IARC in the period 2015-2016.

Figure 26.1. Dr Carmen Guirado Fuentes (UVA/AEMET) with her supervisors Dr Emilio Cuevas (AEMET), on the left, and Dr Ángel de Frutos Baraja (UVA), on the right, after her PhD defense at the Faculty of Science of the University of Valladolid, on 19 June 2015.

Carmen Guirado Fuentes defended her PhD Thesis entitled "Characterization of the total column aerosol properties in the subtropical region" on 19 June 2015 at the University of Valladolid (UVA). The thesis was supervised by Dr Emilio Cuevas (IARC-AEMET) and Dr Ángel de Frutos Baraja, Director of the Department of Theoretical and Atomic Physics and Optics at the University of Valladolid. This Doctoral Thesis work has been developed at IARC and it has been possible thanks to the collaboration agreement between IARC and Atmospheric Optics Group (UVA).

Dr Carmen Guirado-Fuentes was honoured with the maximum qualification "Excellent Cum Laude" by the panel of expert examiners composed by Dr Santiago Mar Sardaña (UVA), Dr Victoria Cachorro Revilla (UVA), Dr Philippe Goloub (University of Lille), Dr Pablo Ortiz de Galisteo Marín (AEMET), and Dr Manuel Pujadas Cordero (Research Centre for Energy, Environment and Technology-CIEMAT).

This Doctoral Thesis work focused on the characterization of atmospheric aerosols over a large area in the subtropical region of the Northern Hemisphere covering the Sahara desert and the eastern North Atlantic region. The approach used in the analysis of atmospheric aerosol optical properties is the solar photometry technique, which provides aerosol content and properties in the atmospheric column.

Firstly, this study includes the development and deployment of an optical calibration facility at the IARC. This facility is essential for IARC as a fully AERONET (AErosol RObotic NETwork) sun photometer calibration facility. Secondly, an accurate analysis of relatively long data series of aerosol optical properties was performed in the Saharan continental convective layer, the marine boundary layer, and the clean free troposphere, using data from AERONET and ancillary information.

Tamanrasset (Algeria) is a strategic AERONET station in the heart of the Sahara desert, which plays a key role in dust model and satellite borne sensor evaluation. The deployment and operation of this station is the result of a joint effort of IARC, the Atmospheric Optics Group (University of Valladolid), and the Laboratoire d' Optique Atmosphérique (University of Lille).

More information on the Thesis defence can be found here.

Download the Thesis manuscript here.

Figure 26.2. From left to right: Prof. Pedro Abreu-González, Dr Alberto Domínguez-Rodríguez, Dr Rubén Alfonso-Juárez Prera and Dr Sergio Rodríguez-González, after the PhD defense at the Faculty of Medicine of the University of La Laguna, on 30 October 2015.

Rubén Alfonso Juárez Prera defended his PhD Thesis entitled "Impact of air pollution on inflammation, oxidative stress and 1-year prognosis in patients hospitalized for acute coronary ischemic pathology" at the University of La Laguna (Tenerife) on 30 October 2015.

This research was supervised by Prof. Pedro Abreu González, University of La Laguna, Dr Alberto Domínguez Rodríguez, Hospital Universitario de Canarias, and Dr Sergio Rodríguez González (IARC-AEMET). The dissertation was given in the Faculty of Medicine of the University of La Laguna and was evaluated by Profesor Armando Torres Ramírez, Universidad de La Laguna, Dr. Remedios Alemán Valls, Hospital Universitario de Canarias,and Dr. Pablo Avanzas Fernández, Hospital Universitario Central de Asturias, who awarded this research with the maximum qualification "Excellent CumLaude".

About 8 million people die prematurely every year due to exposure to air pollution according to the World Health

Organization. Ischemic heart disease accounts for about 40% of such deaths. In this scientific research, Rubén Alfonso Juárez Prera showed that there is an association between exposure to soot black carbon particles (typically emitted by diesel vehicle exhaust, ships and other industrial sources) and the presence of molecules biomarkers of oxidative stress that may prompt some hearth diseases. This research allowed to identify the profile of people that may suffer a new heart disease due to exposure to air pollution in a short time period (about weeks). This research was performed with experimental data collected in Tenerife Island: (i) ambient air pollutants and (ii) biomarkers in the blood of patients affected by heart diseases. This research was performed with funds provided by Health Research Funds (Fondo de Investigación Sanitaria), Institute of Health Carlos III and FEDER (PI12/00092).

More information on the Thesis defence can be found here.

Download the Thesis manuscript here.

Figure 26.3. From left to right: Dr María del Sol Manzano Arellano (UPCT), Dr Elisa Sosa Trujillo (ULL/IARC-AEMET), Dr Axel Ritter Rodríguez (ULL) and Dr Emilio Cuevas (IARC-AEMET) after the PhD defence at the Faculty of Science of the University of La Laguna, on 1 February 2016.

Elisa Sosa Trujillo (IARC-AEMET) defended her PhD Thesis entitled "Isotopic composition study of the precipitation and the water vapour in the subtropical region, Canary Islands" on 1 February 2016 at the University of La Laguna. The thesis was supervised by Dr Juan Carlos Guerra García and Dr María Teresa Arencibia Pérez (University of La Laguna). This Thesis has been possible thanks to the collaboration between the University, IARC-AEMET and the Spanish Airports and Air Navigation (AENA). The dissertation was performed in the Faculty of Science, Physics Department of the University of La Laguna and was evaluated by Dr Emilio Cuevas (IARC-AEMET), Dr María del Sol Manzano Arellano (University of Cartagena) and Dr Axel Ritter Rodríguez (University of La Laguna). This research was awarded with the maximum qualification "Excellent Cum Laude".

Isotope hydrology is an emerging field of research. Since the relation between oxygen and hydrogen stable isotopes with climatic parameters and atmospheric circulation patterns was established, it became apparent that using the change in the isotopic composition of precipitation is a sensitive tool for studying climate in the present, past and future. The analysis of stable isotopes in precipitation, groundwater, surface water and atmospheric water vapour, has served to better understand the overall functioning of the hydrological cycle and allows us to study the history of air masses.

In the Canary Islands, studies based on isotopic composition have been made as a support of hydrogeological studies, where the main topic was the characterization of groundwater. Although there have been studies of the isotopic composition on the islands, none of them have a period of study as long as it is presented in this thesis, sampling both precipitation and atmospheric water vapour. This thesis fills a gap on this subject in a poorly studied region of the world, of great scientific interest because of its geographical location and weather conditions. The main objective is isotopic composition of atmospheric water characterization in the liquid (precipitation) and vapour phases. Three sampling stations were used in this study, two of them are located in the marine boundary layer (El Rayo and Taborno stations) and the third one is located in the free troposphere (Izaña Atmospheric Observatory).

More information on the Thesis defence can be found here.

Download the Thesis manuscript here.

26.1 On-going PhD Theses

The theses that are currently in progress in the Izaña Atmospheric Research Center are:

1. Fernando Almansa: "Atmospheric aerosols detection by measuring the scattered solar radiation and emission in the thermal infrared spectral range", University of Valladolid, Supervisors: Dr Emilio Cuevas (IARC-AEMET) and Prof. Dr Angel de Frutos (University of Valladolid).
2. Judit Carrillo: "Study on the Subtropical North Atlantic Troposphere Thermodynamic Structure", University of La Laguna; Supervisors: Dr Juan Carlos Guerra (University of La Laguna) and Dr Emilio Cuevas (IARC-AEMET).
3. María Isabel García: "Sources and processes that contribute to the levels and physicochemical properties of anthropogenic aerosols observed in the free troposphere over the North Atlantic", University of La Laguna; Supervisors: Dr Sergio Rodríguez, (IARC-AEMET), Andres Alastuey (IDAEA-CSIC), and Barend Van Drooge (IDAEA-CSIC).
4. Niobe Peinado: "Validation of the IASI ozone retrievals with ground based measurements and other

satellite data", University of Valencia, Supervisors: Prof. Ernesto López-Baeza (University of Valencia), Dr Xabier Calbet (EUMETSAT), and Dr Omaira García (IARC-AEMET).

5. Ángel J. Gómez-Peláez: "Measurement and transport of greenhouse gases, carbon monoxide and Saharan dust, with special emphasis on the free troposphere of the subtropical Northeast Atlantic", University of Granada; Supervisors: Dr Emilio Cuevas (IARC-AEMET) and Prof. Fernando Moreno-Insertis (IAC-ULL).
6. Yballa Hernández Pérez: "Characterization of the aerosols vertical distribution over the North-Eastern subtropical Atlantic region", University of La Laguna, Supervisors: Dr África Barreto Velasco, Dr Alberto Berjón Arroyo, and Dr Manuel Arbelo Pérez.

27 IARC Seminars

IARC scientific seminars have been held on an approximately monthly basis since March 2015. These seminars are primarily targeted at IARC researchers. External researchers working in meteorology and atmospheric sciences, and in IARC activities are also invited to attend. The seminars held during the period 2015-2016 are detailed below (for more information see the webpage).

"The phenological observation programme of the Izaña Atmospheric Observatory". Speaker: Rubén del Campo Hernández (IARC-AEMET). Date: 24 November 2016.

"Summary of the site testing results at the Roque de los Muchachos Observatory". Speaker: Dr. Casiana Muñoz-Tuñón (IAC). Date: 15 November 2016.

“An error estimation technique for PWV derived from atmospheric radiosonde data” Speaker: Julio A. Castro-Almazán (IAC-ULL). Date: 17 October 2016.

“Novelties and review of the Meteorological Products for Internal Support to the CIAI activities” Speaker: Juan José de Bustos Seguela (CIAI-AEMET). Date: 6 October 2016.

“Classification of clouds and meteorological phenomena”. Speaker: Rubén del Campo Hernández (CIAI-AEMET). Date: 10 June 2016.

“Free barotropic Rossby waves as drivers of the NAFDI variations, the Saharan Heat Low and the dust outbreaks towards the Atlantic and the Mediterranean”. Speaker: Ángel J. Gómez-Peláez (CIAI-AEMET). Date: 19 May 2016.

“Aerosol optical depth retrievals at the Izaña Atmospheric Observatory from 1941 to 2013 by using artificial neural networks”. Speaker: Dr Rosa García Cabrera (CIAI-AEMET-Air Liquide). Date: 21 April 2016.

“Climatology of aerosol composition in the North Atlantic free troposphere westerly airflows”. Speaker: María Isabel García Álvarez (CIAI-AEMET) Date: 16 March 2016.

“Arctic UV measurements”. Speaker: Dr Kaisa Lakkala (Finnish Meteorological Institute). Date: 8 March 2016.

“First centenary of the Izaña Atmospheric Observatory establisment (1916-2016). A brief historic overview”. Speaker: Dr Fernando de Ory Ajamil (CIAI-AEMET). Date: 26 February 2016.

“Isotopic composition study of the precipitation and the water vapour in the subtropical region, Canary Islands”. Speaker: Elisa Sosa Trujillo (ULL). Date: 26 January 2016.

“Preliminary results of a detailed analysis of the role played by the North African Dipole in the dust export into the subtropical Atlantic and the Mediterranean. Climatological aspects”. Speaker: Dr Emilio Cuevas Agulló (CIAI-AEMET). Date: 17 December 2015.

“Brewer-OMI comparison using EUBREWNET”. Speaker: Dr. Javier López Solano (FGULL-AEMET). Date: 26 November 2015.

"Error budget estimation of the Total Ozone measurements by Dobson and Brewer spectrophotometers proposed in the ATMOZ project (- Traceability for Atmospheric Total Column Ozone-)". Speaker: Alberto Redondas Marrero (CIAI-AEMET). Date: 27 October 2015.

“A look-up table methodology for aerosol optical depth retrieval from zenithal sky radiance. Application on a new developed zenith looking radiometer” Speaker: Antonio Fernando Almansa Rodríguez (CIAI-AEMET and Cimel Electronique). Date: 24 September 2015.

“The new sun-sky-lunar Cimel CE318-T multiband photometer. A comprehensive performance evaluation”. Speaker: Dr África Barreto (CIAI-AEMET y Cimel). Date: 2 July 2015.

“Characterization of the total column aerosol properties in the subtropical region”. Speaker: Carmen Guirado Fuentes (Univ. Valladolid & CIAI-AEMET). Date: 10 June 2015.

“A methodology to evaluate the fog water catchment potential and its exploitation: natural or man-made”. Speaker: Juan José Braojos (ex-civil servant of CIATF). Date: 20 May 2015.

“Modulation of Saharan dust export by the North African dipole”. Speaker: Dr. Sergio Rodríguez (CIAI-AEMET). Date: 6 May 2015.

“Brewer aerosol optical depth (AOD) calibration and retrieval in the UV-B”. Speaker: Juan José Rodríguez-Franco (CIAI-AEMET). Date: 22 April 2015.

“Long-term Monitoring of Atmospheric Trace Gases by using ground-based Fourier Transform Spectrometer at the Izaña Atmospheric Observatory”. Speaker: Dr. Omaira Elena García (CIAI-AEMET). Date: 25 March 2015.

Organizer of the IARC seminars: Ángel J. Gómez-Peláez (AEMET; Research Scientist).

28 List of scientific projects

Table 28.1. List of scientific projects at IARC during 2015-2016.

Project Title	Duration	Funding Agency	Project Website	Principal Investigator/ Contact
Aerosols, Clouds, and Trace gases Research InfraStructure (ACTRIS-2)	2015-2019	H2020-INFRAIA-2014-2015 (H2020)	http://www.actris.eu/	PI (CNR-IMAA): Dr Gelsomina Pappalardo PI (IARC-AEMET): Dr Emilio Cuevas
Multidecadal variability and trends of aerosol properties in the North Atlantic (AEROATLAN)	2016-2018	Spanish Ministry of Economy and Competitiveness	http://aeroatlan.aemet.es/	PI (IARC-AEMET): Dr Sergio Rodríguez
Equipamiento para la Monitorización e Investigación en la estación Global VAG (Vigilancia Atmosférica Global) de Izaña (Tenerife) de componentes atmosféricos que provocan y modulan el cambio climático	2016-2017	Spanish Ministry of Economy and Competitiveness	—	PI (IARC-AEMET): Dr Emilio Cuevas
Traceability of the Atmospheric total column ozone (ATMOZ)	2014-2017	EURAMET/EMRP	http://projects.pmodwrc.ch/atmoz/	PI (WRC): Dr Julian Gröbner PI (IARC-AEMET): Alberto Redondas
EGB-SVN EarthCare Ground Base-Spectromenter Validation Network (Pandonia network)	2014-2017	European Space Agency/LuftBlick	http://www.pandonia.net/	PI (ESA/LuftBlick): Dr Alexander Cede PI (IARC-AEMET): Alberto Redondas
Validation of IASI Level 2 products (VALIASI)	2013-2014 2015-2017	EUMETSAT	—	PI (IARC-AEMET): Dr Omaira García
COST ES-1207 EUBREWNET	2013-2016	EU COST Action	http://www.cost.eu/COST_Actions/essem/Actions/ES1207	PI (University of Manchester): Dr John Rimmer PI (IARC-AEMET): Alberto Redondas
WATER-GOA	2013-2016	Spanish Ministry of Economy and Competitiveness Spain National R&D /CGL2012-33576	—	PI (UVA): Dr Ángel M. de Frutos Contact (IARC-AEMET): Pedro Miguel Romero Campos
MUlti-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water (MUSICA)	2011-2016	European Research Council under FP7/2007-2013 No. 256961	http://www.imk-asf.kit.edu/english/musica.php	PI (IMK-ASF-KIT): Dr Matthias Schneider PI (IARC-AEMET): Dr Omaira García
Towards a Near Operational Validation of IASI level 2 trace gas products (NOVIA)	2013-2015	Spanish Ministry of Economy and Competitiveness	http://www.novia.aemet.es/	PI (IARC-AEMET): Dr Omaira García

Equipamiento para la Monitorización e Investigación de Gases de Efecto Invernadero y Aerosoles en la estación Global VAG (Vigilancia Atmosférica Global) de Izaña (Tenerife)	2013-2015	Spanish Ministry of Economy and Competitiveness No. AEDM13-3E-1773	—	PI (IARC-AEMET): Dr Emilio Cuevas
Integrated non_CO2 Greenhouse gas Observing System (InGOS)	2011-2015	Integrating Activity of European Union	http://www.ingos-infrastructure.eu/	PI (ECN): Dr Alex Vermeulen Contact (IARC-AEMET) Dr Omaira García
MACC and MACC-II—Monitoring Atmospheric Composition and Climate (Working Package; "Dust model validation")	2011-2015	7th EU Framework Project (FP7) (FP7-SPACE-2011-1)	https://www.gmes-atmosphere.eu/	PI (ECMWF): Dr Vincent-Henry Peuch PI (IARC-AEMET): Dr Emilio Cuevas
Aerosols, Clouds, and Trace gases Research Infrastructure Network (ACTRIS)	2011-2015	EU FP7/2007-2013 No. 262254	http://www.actris.net/	PI (CNR-IMAA): Dr Gelsomina Pappalardo PI (IARC-AEMET): Dr Emilio Cuevas
CEOS intercalibración of ground based spectrometers and Lidars	2010-2015	European Space Agency through the Finnish Meteorological Institute ESRIN/Contract No. 22202/09/1EC	http://calvalportal.ceos.org/	PI (BIRA/IASB): Dr van Roozendael PI (IARC-AEMET): Alberto Redondas
SDS-Africa	2007-ongoing	Spanish Agency for International Development Cooperation	—	PI (IARC-AEMET): Dr Emilio Cuevas
GAW-Sahara	2007-ongoing	Spanish Agency for International Development Cooperation	—	PI (IARC-AEMET): Alberto Redondas

For a definition of the acronyms used in the above table, see Section 31.

29 List of major national and international networks, programmes and initiatives

The Izaña Atmospheric Research Center participates in the following national and international networks, programmes and initiatives:

ACTRIS — Aerosols, Clouds, and Trace gases Research InfraStructure Network

AERONET — AErosol RObotic NETwork

BSRN — Baseline Surface Radiation Network

CarbonTracker — CO_2 measurement and modeling system developed by NOAA to keep track of sources and sinks of carbon dioxide around the world

CarbonTracker Europe

EAN — European Aeroallergen Network

EARLINET — European Aerosol Research Lidar Network

E-GVAP — EUMETNET GPS water vapour Programme

EPN — EUREF Permanent Network

EUBREWNET — European Brewer Network

GAW — WMO Global Atmosphere Watch Programme

GCOS — Global Climate Observing System

GEOMON — Global Earth Observation and Monitoring of the Atmosphere

GLOBALVIEW-CO2

GLOBALVIEW-CH4

GLOBALVIEW-CO

GLOBALVIEW-CO2C13

GURME — WMO GAW Urban Research Meteorology and Environment project

ICOS — Integrated Carbon Observation System

LOTUS — Long-term Ozone Trends and Uncertainties in the Stratosphere

MACC — Monitoring Atmospheric Composition and Climate

MPLNet — Micro-Pulse Lidar NETwork

NDACC — Network for the Detection of Atmospheric Composition Change

NOAA/ESRL/GMD CCGG Cooperative Air Sampling Network

PHOTONS — PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire

RBCC-E — Regional Brewer Calibration Center for Europe

REA — Red Española de Aerobiología

REDMAAS — Red Española de DMAs Ambientales

SDS-WAS — WMO Sand and Dust Storm Warning, Advisory and Assessment System

SPALINET — Spanish and Portuguese Aerosol Lidar Network

SPARC — Stratosphere-troposphere Processes And their Role in Climate

TCCON	Total Carbon Column Observing Network
TOAR	Tropospheric Ozone Assessment Report
WCCAP	World Calibration Centre for Aerosol Physics
WDCGG	WMO GAW World Data Centre for Greenhouse Gases
WDCRG	WMO GAW World Data Center for Reactive Gases
WOUDC	World Ozone and Ultraviolet Data Center
WRC-WORCC	World Radiation Centre-World Optical Depth Research and Calibration Cente
WRC-WCC-UV	World Radiation Centre-World Calibration Center-Ultraviolet Section
WRDC	WMO World Radiation Data Centre

30 Staff

Research Staff			
Name	**Position**	**Email**	**Personal Web Page**
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Ángel J. Gómez-Peláez	Greenhouse Gases and Carbon Cycle Programme: Head	agomezpATaemet.es	ResearchGate Google Scholar
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31 List of Acronyms

ACE-FTS - Atmospheric Chemistry Experiment - Fourier Transform Spectrometry

ACMAD - African Centre of Meteorological Application for Development

ACOMET - Meteorology Communicators Association

ACS - Acute Coronary Syndrome

ACSO - Absorption Cross Sections of Ozone

ACTRIS - Aerosol Cloud and TRace gas InfraStructure

ADF - aerosol radiative forcing

AE - Angstrom Exponent

AECID - Spanish Agency for International Development Cooperation

AEMET - State Meteorological Agency

AEROCOM - Aerosol Comparisons between Observations and Models

AF - Radiative Forcing

AMISOC - Atmospheric MInorSpecies relevant to the OzoneChemistry at both sides of the Subtropical jet

AMMA - African Monsoon Multidisciplinary Analysis

ANN - Artificial Neuronal Networks

AOD - Aerosol Optical Depth

APS - Aerosol Polarimetry Sensor

ATMOZ - Traceability for atmospheric total column ozone

AQG - Air Quality Guideline

BBCH - Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie

BC - Black Carbon

BDCN - National Climatological Data Base

BDFC - Barcelona Dust Forecast Centre

BIRA-IASB - Royal Belgian Institute for Space Aeronomy

BSC-CNS - Barcelona Supercomputing Centre – National Supercomputing Centre

BSRN - Baseline Surface Radiation Network

BTO - Botanic Observatory

CALIMA - Cloud, Aerosols and Ice Measurements in the Saharan Air Layer

CAMS - Copernicus Atmosphere Monitoring Service

CARSNET - China Aerosol Remote Sensing NETwork

CBL - Convective Boundary Layer

CCD - Charge-coupled device

CCGG - Carbon Cycle Greenhouse Gases group

CCI - Climate Change Initiative

CCLs - Central Calibration Laboratories

CEILAP - Laser and Applications Research Center

CEOS - Committee on Earth Observation Satellites

CICERO - Center for International Climate and Environmental Research

CIEMAT - Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

CIMO - Commission for Instruments and Methods of Observations

CINDI - Cabauw Intercomparison campaign Nitrogen Dioxide measuring Instrument

CMA - China Meteorological Administration

CRN – Centro radiométrico Nacional (Spain)

CNR - National Research Council of Italy

CNRS - Centre National de la Recherche Scientifique

COST - European Cooperation in Science and Technology

CPCs - Condensation Particle Counter

CPT - Cold Point Tropopause

CRDS - Cavity Ring-Down Spectroscopy

CRR - Convective Rainfall Rate

CSIC - Consejo Superior de Investigaciones Científicas

CWT - Concentration Weighted Trajectory

DBM - Daumont, Brion & Malicet

DMN - Direction de la Météorologie Nationale

DOAS - Differential Optical Absorption Spectroscopy

DOD - Dust Optical Depth

DREAM - Dust REgional Atmospheric Model

DSCR - Digital Sky Colour Radiometer

DT - Dynamical Tropopause

DU - Dobson Unit

DVB - Digital Video Broadcast

EAN - European Aeroallergen Network

ECC - Electrochemical concentration cell

ECCC-MSC - Environment and Climate Change Canada Meteorological Service of Canada

ECMWF - European Centre for Medium-Range Weather Forecasts

ECMWF-IFS - European Centre for Medium-Range Weather Forecasts - Integrated Forecasting System

ECN - Energy research Centre of the Netherlands

EGVAP - EUMETNET GPS Water Vapour Programme

EMA - Egyptian Meteorological Authority

EMPA - Eidgenössische Materialprüfungs- und Forschungsanstalt

EMRP - European Metrology Research Programme

Eolo-PAT EOLO-Predicción Aerobiológica para Tenerife

EPA - Environmental Protection Agency

EPAU - Evaluación integral del impacto de las emisiones de partículas de los automóviles en la calidad del aire urbano

ERA-Interim – ECMWF global atmospheric reanalysis from 1979

ESA - European Space Agency

ESA-CALVAL – European Space Agency Calibration and Validation project

ESRL - Earth System Research Laboratory

ETC - Extraterrestrial constant

EU COST - European Cooperation in Science and Technology
EUMETSAT - European Organisation for the Exploitation of Meteorological Satellites
EURAMET - European Association of National Metrology Institutes
FCS - Fraction Clear Sky
FLEXTRA - FLEXible TRAjectories
FMI - Finnish Meteorological Institute
FNL - Final Analysis Data
FOV - Field Of View
FP7 - European Community's Seventh Framework Programme
FT - Free Troposphere
FTIR - Fourier transform infrared spectroscopy
FTS - Fourier Transform Spectrometry
FWHM - Full Width at Half Maximum
GAW - Global Atmosphere Watch
GAW -PFR - Global Atmosphere Watch - Precision Filter Radiometer
GCOS - Global Climate Observing System
GC-RGD - Gas Chromatography Reduction Gas Analyser
GDAS - Global Data Assimilation System
GEO – Group on Earth Observations
GEOS-5 -Goddard Earth Observing System model
GFS - Global Forecast System
GHG - Greenhouse Gas
GLOBE - Global Learning and Observations to Benefit the Environment
GLONASS - Global Navigation Satellite System
GMD - Global Monitoring Division
GMES - Global Monitoring for Environment and Security
GNSS - Global Navigation Satellite System
GOA - Atmospheric Optics Group
GOA-UVA - University of Valladolid Atmospheric Optics Group
GOME - Global Ozone Monitoring Experiment
GPS - Global Positioning System
GSR - Global Solar Radiation
HARMONICS - Harmonised Assessment of Reliability of MOdern Nuclear I&C Software
HIRLAM - High Resolution Limited Area Model
HUC - Hospital Universitario de Canarias
HYSPLIT - Hybrid Single Particle Lagrangian Integrated Trajectory Model
IAC - Instituto de Astrofísica de Canarias
IAEA - International Atomic Energy Agency
IAMAS - International Association of Meteorology and Atmospheric Sciences
IARC - Izaña Atmospheric Research Center
IASI -Infrared Atmospheric Sounding Interferometer
ICIA - Instituto Canario de Investigaciones Agrarias
ICOS - Integrated Carbon Observation System
ICP-AES - Inductively Coupled Plasma Atomic Emission Spectroscopy
ICP-MS - Inductively Coupled Plasma Mass Spectroscopy
IDAEA - Institute of Environmental Assessment and Water Research
IGACO - Integrated Global Atmospheric Observations
IGN - Spanish National Geographic Institute
ILAS - Improved Limb Atmospheric Spectrometer
IMAA - Institute of Methodologies for Environmental Analysis
IMK-ASF - Institut für Meteorologie und Kimaforschung - Atmosphärische Spurengase und Fernerkundung
INM - Institut National de la Météorologie
INSTAAR - Institute of Arctic and Alpine Research
INTA - Instituto Nacional de Técnica Aeroespacial
IO3C - International Ozone Commission
IPMA - Instituto Português do Mar e da Atmosfera
IR – Infrared
ISAF - Izaña Subtropical Access Facility
IUP - Institut für Umweltphysik / Institute of Environmental Physics
IZO - Izaña Atmospheric Observatory
KIT - Karlsruhe Institute of Technology
LABEC - Laboratorio di Tecniche Nucleari per i Beni Culturali
LAP - Laboratori d'Anàlisis Palinològiques
LIDAR - Laser Imaging Detection and Ranging
LOA - Laboratoire d'Optique Atmosphérique
LR - Lidar Ratio
LSCE - Laboratoire des Sciences du Climat et de l'Environnement
LUT – Look Up Table
MAAP - Multi Angle Absorption Photometer
MARS - Meteorological Archival and Retrieval System
MAXDOAS - Multi Axis Differential Optical Absorption Spectroscopy
MBL - Marine Boundary Layer
MCAR - Mean Concentrations At Receptor
McIDAS - Man Computer Interactive Data Access System
MetUN - Met Office Unified Model
MEE - Mass Extinction Efficiency
MFRSR - Multi Filter Rotating Shadow-Band Radiometer
MGA - Modified Geometrical Approach
MIPAS - Michelson Interferometer for Passive Atmospheric Sounding
MIR - Middle Infrared
MISR - Multi-angle Imaging SpectroRadiometer
MLO - Mauna Loa Observatory
MM5 - Mesoscale Model

MODIS - Moderate Resolution Imaging Spectroradiometer

MPL - Micro Pulse Lidar

MSG - Meteosat Second Generation

MUSICA - MUlti-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water

NA-ME-E - The Regional Centre for Northern Africa, Middle East and Europe

NAO - North Atlantic Oscillation

NAS - Network-Attached Storage

NASA - National Aeronautics and Space Administration

NASA MPLNET - The NASA Micro Pulse Lidar Network

NCDB National Climatological Data Base (AEMET)

NCEP - National Centers for Environmental Prediction

NDIR - Non Dispersive

NEMS - NOAA Environmental Modeling System

NGAC - NEMS GFS Aerosol Component

NIES - National Institute for Environmental Studies

NILU - Norwegian Institute for Air Research

NIR - Near Infrared

NIST - National Institute for Standards and Technology

NMHSS - National Meteorological and Hydrological Services

NMMB - Nonhydrostatic Multiscale Model on the B-grid

NMME - North American Multi-Model Ensemble

NOA - National Observatory of Athens

NOAA - National Oceanic and Atmospheric Administration

NORS - Demonstration Network Of ground-based Remote Sensing Observations in support of the Copernicus Atmospheric Service

NOVIA - Towards a Near Operational Validation of IASI level 2 trace gas products

NPF - New Particle Formation

NRT - Near Real Time

ODSs - Ozone Depleting Substances

OMI - Ozone Monitoring Instrument

ONM - Office National de la Météorologie

OLI - Operational Land Imager

OSC - ozone slant column

OT - Ozone Tropopause

PAR - Photosynthetic Active Radiation

PFR - Precision Filter Radiometer

PI - Principal Investigator

PIXE - Particle-Induced X ray Emission

PLASMA - Photomètre Léger Aéroporté pour la Surveillance des Masses d'Air

PM - Particle Matter

PMOD - Physikalisch-Meteorologisches Observatorium Davos

POLLINDUST - Studying the dust and pollutants in the Saharan Air Layer

PSR - Precision Solar Spectroradiometer

PTB - Physikalisch-Technische Bundesanstalt

PV - Potential Vorticity

PWV - Precipitable Water Vapour

QA - Quality Assurance

QASUME - Quality Assurance of Spectral Ultraviolet Measurements

QC - Quality Control

R&D - Research and Development

RBCC-E - Regional Brewer Calibration Center for Europe

REA - Red Española de Aerobiología

REDMAAS - Red Española de DMAs Ambientales

RGB - composite - Red Green Blue composite

RH - Relative Humidity

RMSE - Root Mean Square Error

ROLO - RObotic Lunar Observatory model

RSMC-ASDF - Regional Specialized Meteorological Centre with activity specialization on Atmospheric Sand and Dust Forecast

RTM - Radiative Transfer Model

SAF - Satellite Application Facilities

SAG - Scientific Advisory Group

SAL - Saharan Air Layer

SALAM - Air Layer Air Mass characterization

SAUNA - Sodankylä Total Column Ozone Intercomparison

SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric Chartography

SCO - Santa Cruz Observatory

SD - Sunshine Duration

SDM - Standard Delivery Mode

SDR - Shortwave downward radiation

SDS - Sand and Dust Storm

SDS-WAS - Sand and Dust Storm Warning Advisory and Assessment System

SEAIC - Sociedad Española de Aerobiología e Inmunología Clínica

SeaWIFS - Sea-Viewing Wide Field-of-View Sensor

SEM - standard error of the mean

SMN - Argentinian Meteorological Service

SMPS - Scanning mobility particle sizer

SOL - Significant Obstructive Lesions

SONA - Sistema de Observación de Nubes Automático

SOP - Standard Operating Procedure

SPARC - Stratosphere-troposphere Processes And their Role in Climate

SPC - Science Pump Corporation

SSDM - Server Meteorological Data System

STJ - Subtropical Jet Stream

STS - Sky Temperature Sensor
STT - stratosphere-to-troposphere
SYNOP - Surface Synoptic Observation
SZA - Solar Zenith Angle
TNA - Trans National Access
TOC - Total Ozone Column
TPO - Teide Peak Observatory
TSP - Total Suspended Particles
TT - Thermal Tropopause
UAB - Universidad Autónoma de Barcelona
UFPs - Ultrafine Particles
ULL - University of La Laguna
UNEP - United Nations Environment Programme
UN-GESAMP - United Nations - Group of Experts on the Scientific Aspects of Marine Environmental Protection
UPC - Universitat Politècnica de Catalunya
UPS - Uninterruptible Power Supply
USGS - U.S. Geological Survey
UTC - Coordinated Universal Time
UTLS - Upper Troposphere Lower Stratosphere
UV - Ultraviolet
UVA - University of Valladolid
VALIASI - Validation of the EUMETSAT products of atmospheric trace gases observed from IASI using ground-based Fourier Transform Infrared spectrometry
VIS - Visible
VMR - Volume Mixing Ratio
WCC - World Calibration Center
WCRP - World Climate Research Programme
WDCGG - World Data Centre for Greenhouse Gases
WDCRG - World Data Center for Reactive Gases
WIGOS – WMO Integrated Global Observing System
WMO - World Meteorological Organization
WORCC - World Optical Depth Research and Calibration Center
WOUDC - World Ozone and Ultraviolet Data Center
WRC - World Radiation Center
WS-CRDS - Wavelength-Scanned Cavity Ring-Down Spectroscopy
WWRP - World Weather Research Programme
XS - Cross Section
ZHD - Zenith Hydrostatic Delay
ZTD - Zenith Total Delay

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