ESA'S OPERATIONAL ATMOSPHERIC VALIDATION STRATEGY AND RESULTS

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ABSTRACT

Geophysical validation by independent means provides fundamental information on the overall quality of Earth Observation (EO) data. A comprehensive multi-mission validation program is an inherent component of ESA's atmospheric chemistry strategy which aims to create calibrated, accurate and consistent long-term atmospheric data records. The strategy includes validation using ground-based sounders, spectrometers, radiometers, lidars, balloon and aircraft campaigns, radio occultation data, as well as inter-comparisons with other space-borne missions. The program emphasizes instrument calibration and inter-calibration traceable to international standards and the harmonization of data processing and validation protocols for both ground and space-borne measurements. The ultimate goal is to provide operational and science data that meet the requirements for essential climate variables to support monitoring of global ozone, atmospheric pollution, and the effects of climate change in the atmosphere as well as for operational services.

1. INTRODUCTION

ESA's atmospheric composition program is concerned with global monitoring of stratospheric ozone, atmospheric pollution, chemistry-dynamics coupling in the UTLS region, processes in the upper atmosphere and the effects of climate change in the atmosphere. ESA aims to deliver climate-quality global-coverage ozone time series which now extends for one and a half decades. Other objectives are global high-resolution measurements and long-term monitoring of atmospheric pressure and temperature as well as numerous chemically active trace gases and chlorofluorocarbons in the lower and middle atmosphere. The gases include NOx, water vapor, O_2, CO, CH_4, CO_2, HNO_3, N_2O, OClO, BrO, and SO_2. Additionally, aerosols and clouds are of major interest with the goal to retrieve and monitor their impact on Earth's radiative processes using current and future remote sensing instrumentation.

ESA's remote sensing observations of atmospheric composition started with the Global Ozone Monitoring Experiment (GOME) aboard the European Remote Sensing satellite (ERS-2) which was launched in April 1995 and is still operational. GOME provides total column amounts of trace gases. The GOME time series is now complemented by three atmospheric chemistry instruments on board the Environmental Satellite (Envisat) launched in March 2002. The instruments are Global Ozone Monitoring by Occultation of Stars (GOMOS) [1], Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) [2], and Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) [3]. GOMOS operationally retrieves stratospheric vertical profiles of ozone, NO_2, NO_3, H_2O, O_2, high resolution temperature and aerosols. MIPAS provides vertical profiles of pressure, temperature, ozone, NO_2, HNO_3, N_2O, CH_4, and water vapor. SCIAMACHY presently derives operational profiles of ozone, NO_2, and BrO, as well as total columns of ozone, NO_2, OClO, BrO, water vapor, CO, SO_2, and information on cloud fraction, cloud top height, cloud optical thickness, absorbing aerosol index, and aerosol optical thickness. In addition to the operational data provided by ESA, the science community retrieves numerous other important products from the instruments. Envisat also carries the Medium Resolution Imaging Spectrometer (MERIS) which observes primarily marine biological productivity, but atmospheric properties are also derived, particularly for aerosols. Since October 2006, the ozone and NO2 column time series from GOME and SCIAMACHY has been supplemented with observations from GOME-2 on the MetOp-A satellite operated by EUMETSAT.

In the framework of the European program, Global Monitoring for Environment and Security (GMES), and GMES Atmosphere Services (GAS), Sentinel-4, -5 and -5 Precursor payloads will be devoted to atmospheric composition monitoring. Sentinel-4 payloads will be

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incorporated on two Meteosat Third Generation–Sounder (MTG-S) satellites in a geostationary orbit. Planned for launch in 2017 and 2024, they will measure at high temporal resolution columns of ozone, NO_2, BrO, SO_2, HCHO, CO, CH_4, and aerosols. The Sentinel-5 payloads will be flying on a post-EUMETSAT Polar System (EPS) spacecraft series and they are anticipated to launch in 2020. A Sentinel-5 precursor mission is planned for launch in 2014 to avoid the data gap between Envisat and Sentinel-5. The Process Exploration through Measurements of Infrared and millimeter-wave Emitted Radiation (PREMIER) mission is a candidate Earth Explorer 7 in ESA's Living Planet Programme. If selected, it would fill the gap in atmospheric limb sounding that emerges after 2015.

As a part of ESA's Living Planet Programme, there are two forthcoming Earth Explorer missions dedicated to atmospheric measurements: Atmospheric Dynamics Mission (ADM-Aeolus) (http://www.esa.int/esaLP/ESAES62VMOC_LPadmaeolus_0.html), and Earth Clouds Aerosols and Radiation Explorer (EarthCARE) (http://www.esa.int/esaLP/ASESMYNW9SC_LPearthcare_0.html). ADM-Aeolus is planned for launch in 2011. The Aeolus satellite will carry one large payload, the Atmospheric Laser Doppler Instrument (ALADIN), which will probe the lowermost 30 km of the atmosphere to extract global vertical wind profiles for improving numerical weather forecasting. ADM-Aeolus will also provide direct observations of cloud and aerosol vertical stratification. EarthCARE is due for launch in 2013 as a joint European-Japanese mission that aims to improve Earth's radiation estimate in climate and numerical weather forecast models. EarthCARE will carry a high spectral resolution Backscatter Lidar (ATLID), Cloud Profiling Radar (CPR), Multi-Spectral Imager (MSI), and a Broadband Radiometer (BBR). ATLID will enable better separation between aerosol types, particularly dusts, and ice and water clouds.

2. CURRENT ATMOSPHERIC VALIDATION EFFORTS

ESA currently operates a number of validation projects for its own and third party mission (TPM) atmospheric chemistry measurements as well as in preparation for the Sentinels, ADM-Aeolus and EarthCARE observations of ozone, other trace-gases, aerosols and clouds.

Multi-mission Validation by Sounders, and Ground-based Spectrometers and Radiometers (Multi-TASTE) collects atmospheric trace gas data from well-controlled and calibrated balloon sondes and measurement networks, national and international, including the Network for the Detection of Atmospheric Composition Change (NDACC). Dobson and Brewer spectrophotometers are the primary instruments used in NDACC for ground-based measurements of total ozone. Other instruments include Infra-Red (IR) Fourier-transform spectrometers (FTIR), UV/visible (VIS) spectrometers and spectroradiometers, lidars, microwave radiometers, as well as ozone and aerosol sondes. Multi-TASTE is a continuation of the TASTE effort which started in 2004. Multi-TASTE identifies only measurements correlated with satellite observations and stores them in the Agency's validation database at the Norwegian Institute for Air Research (NILU) (http://nadir.nilu.no/calval/). The correlative measurements undergo a thorough quality screening suited to particular validation exercises and are used to derive accuracies of satellite trace gas retrievals including systematic trends and precision. The results are evaluated depending on a variety of factors such as geographical zones; time series trending; vertical profile altitudes; and satellite instrument and algorithm specifications, such as dark-limb and twilight illumination conditions, or hot versus colder stars in GOMOS.

ESA's satellite validation with lidar (VALID) is a continuation of the previous project, Envisat quality assessment with lidar (EQUAL), which operated from 2003 to 2007. VALID is concerned with validation of satellite-retrieved stratospheric ozone and stratospheric and mesospheric temperature profiles using differential absorption lidars (DIAL), as well as Rayleigh and Raman lidars from NDACC. Additionally, VALID is in charge of collecting data and building a strategy for validation of tropospheric aerosol and cloud products from current and future ESA missions and TPMs using the European Aerosol Research Lidar Network (EARLINET). The network is composed of multi- and single-wavelength Raman lidar stations and elastic backscatter lidar sites. A number of EARLINET stations are co-located with NASA's Aerosol Robotic Network (AERONET) of sunphotometers that jointly provide both column and vertically resolved aerosol and cloud data including optical thickness, single scattering albedo, size distribution, aerosol and cloud heights, planetary boundary layer structure and evolution, and profiles of extinction and backscatter. Current EARLINET validation work concentrates on the development of validation methodologies and datasets in preparation for ADM-Aeolus and EarthCARE. It uses aerosol and cloud products from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) [4]. Correlative EARLINET lidar observations are stored in the NILU database, and are screened and applied to validate the satellite products. Current validation efforts encompass aerosol optical thickness and attenuated lidar backscatter.

Long-term Validation of SCIAMACHY data (SciLoV) is primarily concerned with comparisons of SCIAMACHY atmospheric trace gases and its different operational and scientific algorithms with products from other satellites. Limb profiles of ozone and NO2 are evaluated using NASA's Microwave Limb Sounder (MLS) on Aura, the Halogen Occultation Experiment (HALOE), the Stratospheric Aerosol and Gas Experiment (SAGE), as well as the Canadian Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) and balloon measurements. Nadir ozone total columns are assessed with the Dutch-Finnish Ozone Monitoring Instrument (OMI) operated by NASA. Long-term trends in ozone columns are derived from matchups with Brewer and Dobson spectrophotometers and with the GOME instrument. Multi-year inter-comparisons with MIPAS and GOMOS are anticipated. SCIAMACHY limb water vapor validations have been also initiated, principally, with HALOE and frost hygrometer data.

Multi-mission validation by satellite radio occultation (RO) is another ESA validation project. It creates a long-term database of altitude profiles of reflectivity, derived temperature, specific humidity, pressure, and density. For generating the database, a number of satellite RO instruments are employed, including German-US research satellite program CHAMP, Taiwanese/US RO constellation Formosat-3/COSMIC, and EUMESAT/ESA's weather satellite program MetOp/GRAS. The datasets overlap the time series and coverage of Envisat MIPAS and GOMOS as well as the main ground validation sites defined in Multi-TASTE and VALID. The correlative RO data will be stored at NILU and used to validate MIPAS and GOMOS standard and scientific data products.

ESA has been supporting balloon, aircraft, and ground campaigns providing atmospheric chemistry measurements for its satellite validations. Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere (SCOUT-O_3) is a European Commission Integrated Project. The campaigns measured ozone, temperature, water vapor, and nitrogen dioxide, as well as CFCs and other halocarbon tracers by spectroscopy and solar and Moon occultations in the UV/VIS and in the IR. Cloud altitude, optical thickness, and brightness temperatures were observed with a downward looking micro-lidar and IR radiometers. The instruments included Michelson Interferometer for Passive Atmospheric Sounding (MIPAS-B2), mini-Differential Optical Absorption Spectroscopy (DOAS), Limb Profile Monitor of the Atmosphere (LPMA) / DOAS, Terahertz and submillimeter Limb Sounder (TELIS), UV/VIS spectrometers with the moon as light source (SOLOMON), infrared absorption spectroscopy by tunable diode lasers (SPIRALE), Stratospheric and Tropospheric Aerosols Counter (STAC), Cryosampler, ClO/BrO sensor, tunable diode laser H2O instrument (pico-SDLA), particle counters and Infrared Atmospheric Sounding Interfererometer (IASI).

An independent ESA contract also supports Envisat validation with balloon-borne measurements from well-established payloads of LPMA / DOAS, MIPAS-B2, and from cryosamplers. The project contributes to the long-term validation of level-2 operational and science atmospheric products as well as of level-1 products such as the spectral solar irradiance and skylight radiance (SCIAMACHY, level-1), and calibrated IR spectra (MIPAS, level-1). A number of campaigns have a special focus on validating upper tropospheric and lower stratospheric trace gases in the tropics and at high latitudes. Numerous campaigns address different aspects of atmospheric chemistry including uncertainties in trace gas estimations, particularly NO_2, in the lower stratosphere in the polar vortex and wintertime polar ozone depletion.

ESA, NASA, and other participating institutes and networks cofund inter-calibration of ground-based spectrometers and lidars in the frame of Committee on Earth Observation Satellites (CEOS) projects. The objective of this task is to ensure the consistency among global ground-based validation networks to support the quality of satellite retrievals of ozone, radiances, and aerosols. The scheme focuses on ground sensor calibrations and inter-calibrations, and on the uniformity of auxiliary data and processing algorithms. For spectrophotometers, detailed objectives include characterization and correction of seasonal differences between simultaneous Dobson and Brewer observations, characterization and correction of Brewer deviations at high solar zenith angles, and Dobson deviations at higher slant column densities. The impact of straylight on cross-section estimations is also explored, as well as the dependency of the inter-calibration accuracy on a wide range of operation conditions. Every two years campaigns will validate air-quality measurements in areas with intense but homogeneous pollution. In support of EARLINET, inter-calibrations and inter-comparisons will be accomplished with traveling lidar round-robins. The campaigns will perform approximately 3 collocations per year to achieve near-complete network coverage over a 5-year period. Collocated datasets will be delivered to the NASA and ESA validation data centers. In this context, the Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring Instruments (CINDI) took place in June-July 2009 in the Netherlands. CINDI resulted in improvements in calibration and measurement protocols for participating in-situ and remote sensing instruments from 13 countries around the globe. It also provided evaluations of uncertainties in ground observations of

NO_2 tropospheric columns and profiles which are vital for satellite validation. Apart from NO_2, other parameters were also measured and inter-compared, including O_3, aerosol, HCHO, CHOCHO, and BrO.

The extended validation of Envisat operational and scientific data (ExVal) is an ESA and PROgramme de Développement d'EXperiences scientifiques (PRODEX) project concerned with validation of ozone, air density, and temperature profiles from a DIAL lidar at the Arctic Lidar Observatory for Middle Atmospheric Research (ALOMAR) in northern Norway. ExVal is also anticipated to contribute to EARLINET validations with its tropospheric aerosol lidar.

3. OPERATIONAL ATMOSPHERIC VALIDATION STRATEGY

ESA's atmospheric science aims at ensuring long-term continuity and global coverage of Earth atmospheric composition observations including ozone, pressure, temperature, aerosols, clouds, and numerous chemically active and passive trace gases. These observations enable integrated research incorporating data assimilation and modeling in order to understand the impact of human activities on global climate and chemistry and to predict their evolution. The goal is to provide complete multi-decadal time series of the atmospheric constituents at high and consistent quality throughout the measurement lifetime. The time series encompass numerous satellite missions, in-situ and remote sensing observations from field campaigns and long-term ground monitoring networks. It is therefore of outmost importance to bridge the missions and ensure mission-to-mission inter-calibration and harmonization of geophysical products combined with inter-calibration and harmonization of ground observations. A comprehensive satellite calibration and validation program thus operates beyond the lifetime of individual missions and supports not only the provision of mission validation data but also knowledge centers and laboratories, new instrumentation and science, ground sensor networks and campaigns, and regular reanalyses and reprocessings of satellite and ground data. This effort is driven by the requirement to create a high quality, long term dataset that allows trend analysis for atmospheric Essential Climate Variables for ESA's Climate Change Initiative in support of the Global Climate Observing System.

ESA supports a comprehensive validation program for its atmospheric composition space-borne sensors. The program includes independent geophysical evaluations of measurement time series using ground, balloon and aircraft observations, and inter-comparisons with other satellite sensors. The validations give information on instrument characterization and calibration including on-orbit long-term temporal degradation and on the performance of the processing algorithms. Thus, the quality of final atmospheric products can be determined. Next to providing product accuracies, ground observations support development of regional and global atmospheric models and algorithms, data assimilation, and evaluation of the consistency of long-term measurement time series which may span several independent and possibly not overlapping missions. Inter-comparisons with other space instruments take advantage of global and uniform satellite coverage where there may not be enough statistics from ground point collocations to assess some aspects of the measurement quality such as temporal trends and dependencies on particular geographical locations and observation conditions.

Quality Assurance Framework for Earth Observation

Table 1. Envisat range of operational and scientific atmospheric products

T **Temperature**	P **Pressure**	H_2O **Water Vapour**	O_2 **Oxygen**	Cloud Fraction	Aerosol
O_3 **Ozone**	CO_2 **Carbondioxid**	N_2O **Nitrous oxide**	NO_2 **Nitrogendioxide**	HCOH **Formaldehyde**	BrO **Bromine monoxide**
OClO **Chlorite**	HNO_3 **Nitric Acid**	CH_4 **Methane**	SO_2 **Sulphur dioxide**	CTH **Cloud Top Height**	COT **Cloud Optical Thickness**
N_20_5 **Dinitrogen pentoxide**	ClO **Hypochlorite**	CFC-12 **Chlorofluoro Carbon**	CH_3Cl **Chloromethane**	OCS **Carbonyl sulfide**	HCN **Hydrogen cyanide**
$ClONO_2$ **Chlorine nitrate**	HOCL **Hypochlorous acid**	CFC-12 **Chlorofluoro Carbon**	CFC-113 **Chlorofluoro Carbon**	SF_6 **Sulphur Hexafluoride**	PSCs **Polar Stratospheric Clouds**
HNO_4 **Peroxynitric acid**	CO **Carbon Monoxide**	HCFC-22 **Hydrochlorofluorocarbons**	COF2 **Carbon oxyfluoride**	C_2H_6 **Ethane**	Cirrus
NO **Nitric oxide**	NH_3 **Ammonia**	CCl_4 **Carbon tetrachloride**	CF_4 **Tetrafluoromethane**	PAN **Peroxyacyl nitrates**	HDO **Heavy Water**

data (QA4EO) are community-established processes to facilitate harmonization and interoperability of Earth observation data. They are proposed by the CEOS Working Group on Calibration and Validation (WGCV) (http://calvalportal.ceos.org/CalValPortal/qa4eoInfo.do) . In the realm of atmospheric composition validation, QA4EO addresses the following issues:

1. calibration of the validation sensors that is traceable to international standards with documented accuracies and temporal consistencies;
2. uniform calibration of validation instruments, calibration round robins, and coherent measurement and data processing methodologies which also correspond to satellite data processing, e.g. trace gas cross-sections;
3. uniform calibration and data processing of satellite missions;
4. harmonization of protocols for validating satellite observations from individual missions, including methodologies and common ground diagnostic sites;
5. comprehensive and standardized processing and validation environments and tools which meet the needs of multi-mission long-term calibration and validation;
6. common data formats and data sharing principles.

The overall quality of validation sensors and instrument networks is tackled by the CEOS inter-calibration of ground-based spectrometers and lidars, by individual validation contracts, and by supporting validation and inter-calibration campaigns such as CINDI. Global and European atmospheric monitoring networks including NDACC, EARLINET, AERONET, and largely collocated with AERONET NASA's Micro-Pulse Lidar Network (MPLNET), play an important role in the standardization of measurements and data processing protocols. These network data are regularly reprocessed when new calibration and algorithm protocols are available. Data processing consistency is also addressed by ESA's own projects, for example Harmonization of GOME, SCIAMACHY, and GOME-2 ozone and nitrogen dioxide cross-sections (HARMONICS). The Agency is currently developing Generic Environment for Calibration and validation Analysis (GECA) [5]. GECA will host correlative validation datasets, provide pre-processing, co-location engines, satellite extractions, and enable comparisons, statistics, and trend analyses that are compatible with existing ESA satellite toolkits. GECA will become a comprehensive and standardized tool for atmospheric composition validations and will support consistent correlative data sets and data access. It will be accessible from the Cal/Val Portal (http://calvalportal.ceos.org/CalValPortal/welcome.do). ESA projects provide further integration of space-borne and ground-based observations via the inter-calibration and validation processes followed by modeling, data assimilation, and scientific exploitation of derived atmospheric time series.

ESA is committed to the acquisition and analyses of atmospheric composition data from TPMs in order to augment its atmospheric time series and coverage and to aid its calibration and validation activities. The current TPMs include the Swedish-Canadian-French-Finnish Odin satellite launched in 2001; the Canadian ACE-FTS instrument operating since 2003 on board SCISAT-1; and CALIPSO. In the future, the OMI sensor onboard of NASA's Aura platform will become a TPM as well as JAXA's Greenhouse Gases Observing Satellite (GOSAT), which is operational since January 2009 and provides CO_2, CH_4, and other climate observations. ESA is also committed to maintaining archives of atmospheric composition data from ground networks and field campaigns for satellite measurement validation, assimilation, modeling, and scientific exploitation. The NILU database will soon be complemented by GECA which will enable consolidated access to validation data and techniques.

Table 2. GOMOS product accuracies

GOMOS processing version 5.0 (dark limb)			
Parameter	Precision	Bias	Comment
T	n.a.	<5 K	HRTP 23-30km
O_3 18-22 km	20 %	[-5%,1%]	Ozonesonde, lidar
O_3 22-41 km	10 %	[-2%,1%]	Ozonesonde, lidar
O_3 41-45 km		[-5%,0%]	Lidar
NO_2 20-50 km	20%	10%	Balloon, HALOE
O_2 15-35 km	14%	-6%	ECMWF analysis
NO_3 25-45 km	30%	15%	Balloon
Aerosols		20%	SAGE II/III, POAM III

Table 3. MIPAS product accuracies

MIPAS processing version 4.61 / 4.62			
Parameter	Precision	Bias	Comment
P			No geophysical comparisons
T 6-65 km	[1K,2 K]	[1K,1.5 K]	Balloon, lidar, PTU
O_3 18-23 km	[15%,30%]	[5%,20%]	Ozonesonde, lidar, FTIR
O_3 23-52 km	10%	~ 0%	Ozonesonde, lidar, satellite
HNO_3 17-34 km	[20%,30%]	[10%,15%]	FTIR, balloon, satellite
NO_2 23-35 km	10 %	~ 0 %	Balloon, GB-DOAS, satellite
NO_2 35-50 km	10 %	10 %	satellite
CH_4 12-40 km	< 20 %	10 %	FTIR, balloon
N_2O 12-40 km	< 20 %	~ 0 %	FTIR, balloon

Table 4. SCIAMACHY product accuracies

SCIAMACHY processing version 3.01		
Parameter	Columns (Nadir)	
	Precision	Bias
O_3	< 2 %	1 %
NO_2	[5%,30%]	[5%,30%]
Cloud Fraction	0.08	0.02
CTH	1.9 km	1.2 km
	Profiles (Limb)	
O_3 20-35 km	[10%,20%]	[-15%,0%]
O_3 35-40 km	[20%,40%]	± 25 %
NO_2 20-40 km	< 25%	[10%,18%]

With the advent of new knowledge, instrumentation, measurement techniques, and scientific algorithms, ESA expands its accuracy and scope of atmospheric parameters which are routinely derived from satellite data. Improvements are made in the vertical and horizontal resolution of global observations of multiple chemical species and aerosols from the boundary layer to the stratopause. The goal is to better fulfill recognized needs in the areas of air quality, UV exposure, climate change, and global circulation modeling for climate and weather predictions. A list of operational and scientific products is displayed in Table 1. Particular attention is now paid to water vapor retrievals and validation in order to reduce knowledge gaps of the processes affecting water vapor at the interface between the troposphere and stratosphere where water vapor concentrations are small. In overall, there is an emphasis on building the capacity for precise validation of current and upcoming data products and on supporting instrument laboratory studies, calibration standards, and laboratory and field inter-comparisons. It is also recognized that producing measurements with the needed combination of coverage, accuracy, precision and resolution requires a multi-spectral capability that covers microwave, thermal-, short-wave-, and near-IR, VIS and UV spectral regions as well as nadir and limb sounding technology.

4. ATMOSPHERIC VALIDATION RESULTS

Tables 2, 3 and 4 show accuracies achieved by ESA's operational GOMOS, MIPAS and SCIAMACHY algorithms as of the first half of 2009. SCIAMACHY total column ozone has a maximum 1% bias and 2% precision uncertainty, while ozone profiles from GOMOS are at most 5% biased, depending on the altitude, and have less than 20% uncertainty. MIPAS temperature profiles possess about 1K bias and 1 to 2K precision. NO_2 profiles from GOMOS and MIPAS are extracted up to 50km altitude with bias up to 10% and precision less than 20%. Further trace gas profiles are included in the standard product list: NO_3 and O_2 from GOMOS, and HNO_3, N_2O, CH_4, and H_2O from MIPAS. In 2009, SCIAMACHY is ready to provide nadir total columns of BrO, CO, SO_2, and H_2O, nadir slant columns of OClO, limb BrO profiles, nadir H_2O, and polar stratospheric and noctilucent cloud limb products, cloud top height, cloud fraction, aerosol optical thickness, and absorbing aerosol index.

The accuracies are partly derived by Multi-TASTE and VALID programs. The distribution of Multi-TASTE validation sites is displayed in Fig. 1. VALID ozone and temperature lidar sites are shown in Fig. 2.

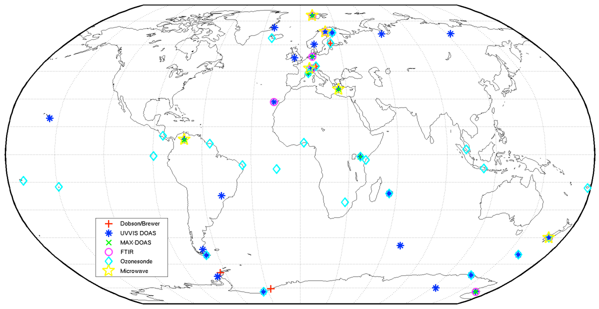

Figure 1. Multi-TASTE site distribution

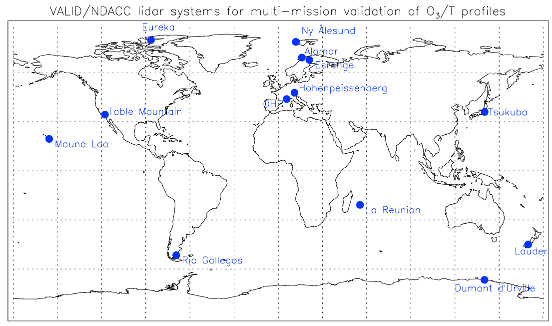

Figure 2. VALID lidar site distribution

The quality of GOMOS ozone profiles is confirmed by multiple validation programs. Results from Multi-TASTE and VALID are displayed in Fig. 3.

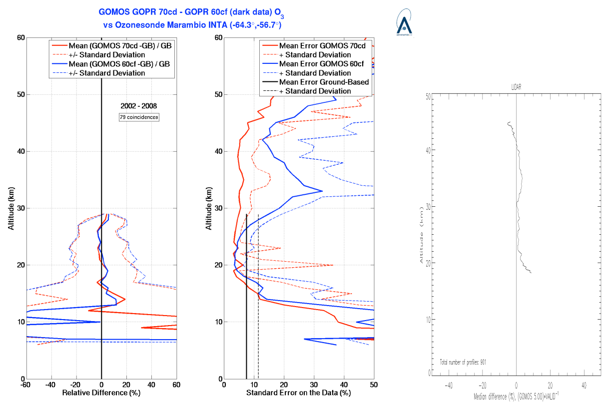

Figure 3. GOMOS ozone profile validations, mean differences with ozonesonde at Marambio, Antarctica, their standard deviation, and median global differences with lidar measurements

Detailed results of MIPAS validation can be found in the *Atmospheric Chemistry and Physics* Special Issue, MIPAS: Potential of the experiment, data processing and validation of results, Editors: P. Hartogh and P. J. Espy, 2006-7 (http://www.atmos-chem-phys.net/special_issue70.html). Fig. 4 presents MIPAS temperature profile accuracy in comparison with global lidars in the VALID network.

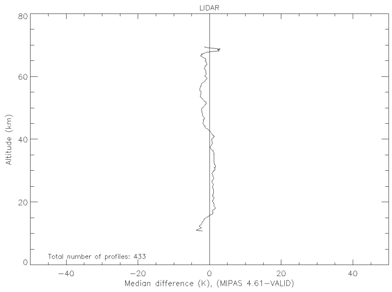

Figure 4. Median of MIPAS temperature profile differences with globally distributed lidar measurements

SCIAMACHY 2009 reprocessing is expected to bring significant improvements in the long-term time series of instrument-derived trace gases and in their vertical profiles [6,7]. Fig. 5 illustrates the differences in Dobson and Brewer measurements in comparison with GOME and SCIAMACHY time series obtained by the SciLoV program [8]. A seasonal trend in Dobson differences is clearly visible and is one of the topics of the CEOS inter-calibration effort.

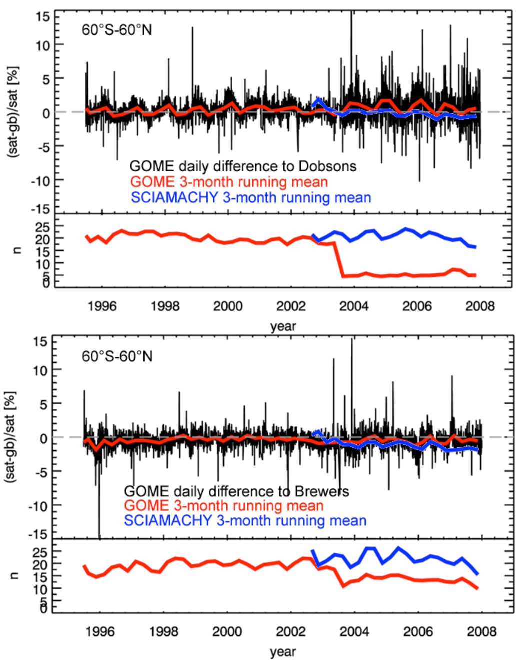

Figure 5. GOME and SCIAMACHY WFDOAS column ozone validations against global Dobsons and Brewers within 60° latitude, mean differences, and mean numbers of collocated ground stations. After 2003 GOME lost global coverage which reduced the number of collocations, particularly for Dobsons

Fig. 6 shows locations of the European lidar network for aerosol validation, EARLINET.

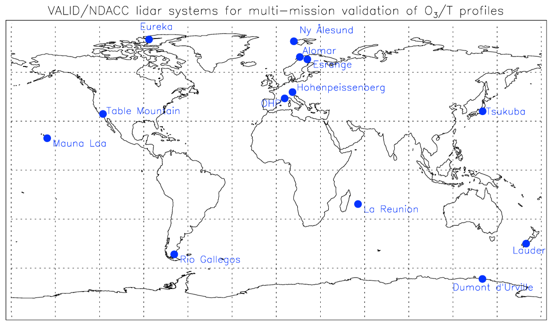

Figure 6. EARLINET aerosol lidar sites

Initial validations of CALIPSO level-1 attenuated backscatter profiles at 532nm with EARLINET proved very encouraging [9]. Only night-time and cloud-free measurements were considered and independent extinction and backscatter EARLINET profiles. Fig. 7 shows the inter-comparisons for three lidar stations.

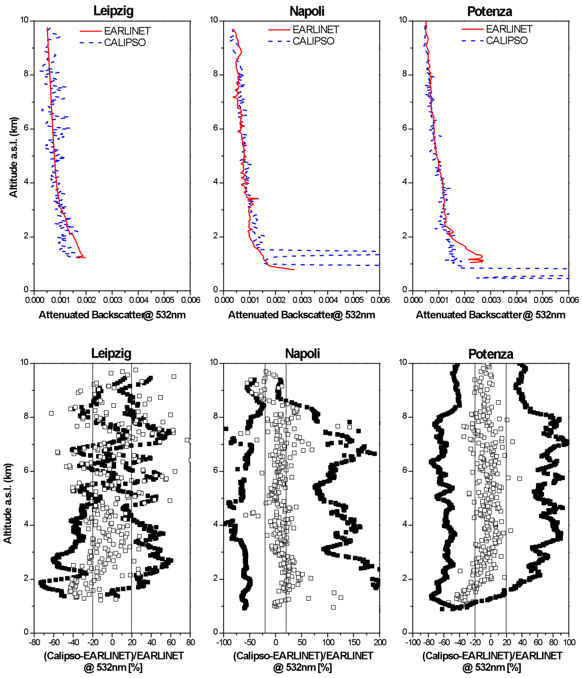

Figure 7. Validations of level-1 CALIPSO attenuated backscatter at three EARLINET stations, profiles and percent differences

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