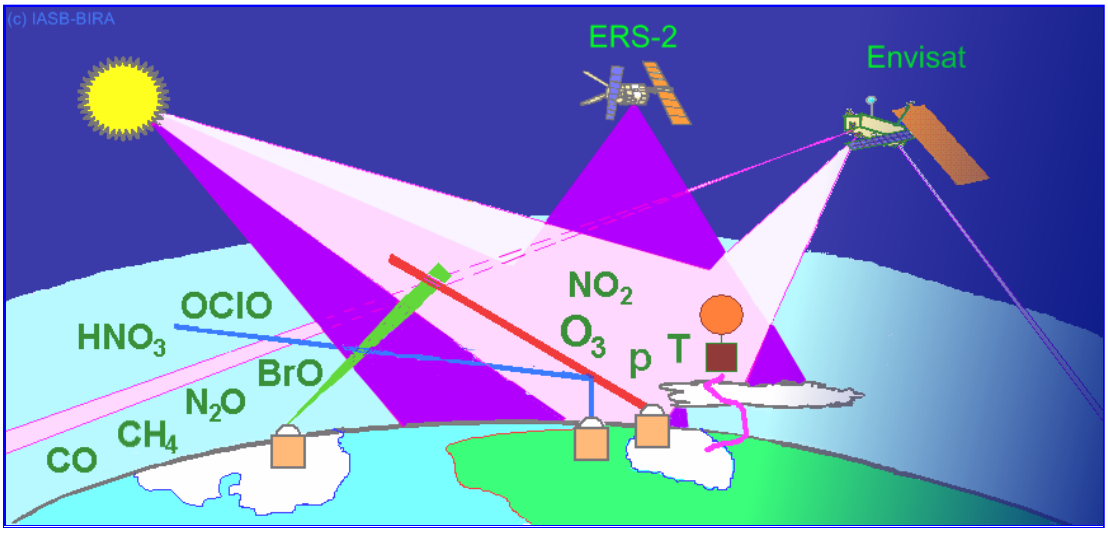
Multi-TASTE

MULTI-MISSION TECHNICAL ASSISTANCE TO ENVISAT AND TPMS VALIDATION BY SONDES, SPECTROMETERS AND RADIOMETERS

FINAL REPORT

OCTOBER 2008 – OCTOBER 2011



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NDACC teams contributing ground-based correlative measurements

Acronym	***Organisation***	***Country***
BAS-NERC	British Antarctic Survey – National Environment Research Council	United Kingdom
BIRA-IASB	Belgian Institute for Space Aeronomy	Belgium
CAO	Central Aerological Observatory	Russia
CNRS/LATMOS	CNRS, Laboratoire Atmosphères, Milieux, Observations Spatiales	France
DMI	Danish Meteorological Institute	Denmark
DWD	Deutsche Wetterdienst – Hohenpeissenberg	Germany
FMI-ARC	Finnish Meteorological Institute – Arctic Research Centre	Finland
IFE/IUP	Institut für Umweltphysik/Fernerkundung, University of Bremen	Germany
IMK/FZK	FZK/Institut für Meteorologie und Klimaforschung, U. Karlsruhe	Germany
INTA	Instituto Nacional de Técnica Aeroespacial	Spain
IPMet/UNESP	Instituto de Pesquisas Meteorológicas, Universidade Estadual Paulista	Brazil
JPL	Jet Propulsion Laboratory/California Institute of Technology	USA
KMI-IRM	Royal Meteorological Institute of Belgium	Belgium
KSNU	Geophysical Laboratory, Kyrgyz State National University	Kyrgyzstan
MeteoSwiss	MeteoSwiss, Aerological Station of Payerne	Switzerland
NILU	Norwegian Institute for Air Research	Norway
NIWA	National Institute of Water and Atmospheric Research	New Zealand
NOAA/ESRL	NOAA Earth System Research Laboratory	USA
U. Manchester	University of Manchester and University of Wales	United Kingdom
U. Réunion/LACY	Université de la Réunion	France

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1	B	01/06/2012	all	Implementation of 1st ESA revision
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CONTENT

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EXECUTIVE SUMMARY

The Multi-TASTE project

The present document is the final report of the three-year Multi-TASTE project (ESA contract No.21819/08/I-OL, from October 2008 through September 2011). Multi-TASTE has provided ESA with MULTI-mission Technical ASsistance To the validation of atmospheric composition data acquired by Envisat and Third Party Missions (TPM). Main tasks relate to: (a) the collection of ground-based correlative observations acquired by sondes, spectrometers and radiometers certified for the Network for the Detection of Atmospheric Composition Change (NDACC), the monitoring and verification of those data sets, and their delivery to the Envisat Cal/Val Data Centre (EVDC) operated at NILU on behalf of ESA; (b) geophysical validation studies of atmospheric composition (level-2) data products from Envisat (GOMOS, MIPAS and SCIAMACHY) and SCISAT-1 ACE-FTS based on comparisons with correlative data sets; (c) support to ESA for the development of validation and quality assurance strategies, among others in the GEO-CEOS context; and (d) the valorisation of the validation results and of the expertise through the Envisat Quality Working Groups (QWGs), Climate Change Initiative (CCI) projects, and more open scientific events.

Collected data

Ground-based correlative measurements of the following atmospheric species and parameters have been collected at several NDACC stations and delivered by project partners to the Envisat Validation Data Centre (EVDC) operated at NILU on behalf of ESA, accessible via http://nadir.nilu.no/calval: O_3, NO_2, BrO, OClO, CO, CO_2, CH_4, HNO_3, N_2O, HCl, H_2O, and ClO, as well as profiles of temperature and pressure. The actual geographical coverage and vertical range of the collected data varies with the instrument type, retrieval method and atmospheric species.

Validation activities

The **GOMOS** processor **IPF 5.00** – based on the prototype version GOPR 6.0cf – is the operational baseline since the end of July 2006. Within Multi-TASTE the validation of IPF 5.00 / GOPR 6.0cf vertical profiles of ozone and high-resolution temperature (HRTP) were consolidated, using the data set from 2002 to 2011. High-resolution temperature profiles exhibit a cold bias of –(2-3)K in the middle stratosphere at mid and low latitudes. At high latitudes we find a similar bias of –(2-3)K, although with more altitude dependence in the stratosphere, between 25-30km it becomes nearly 0K. In the Upper Troposphere/Lower Stratosphere (UTLS) we see a large warm bias of +10K, with increased spread of 10K in the comparisons. The O_3 profiles agree within ±7% with the correlative data. In the Arctic a permanent negative bias of -5% was seen, which remains under investigation in the Quality Working Group. The analysis of the comparison time series suggests a drift of –(10-20)% /decade at 20-30km for middle northern latitude, but this result needs further consolidation. The next GOMOS baseline processor **IPF 6.01** is based on prototype algorithm GOPR 7.0cd. The delta-validation of O_3 profiles from this prototype was reported in Project Technical Note [Vandenbussche et al., 2009]. The prototype shows a slight improvement of the bias in the lower stratosphere with respect to GOPR 6.0cf, and smaller error bars in the middle stratosphere.

The **MIPAS** processor **IPF 4.61/4.62** was the baseline at the beginning of the project, but unfortunately only able to process the nominal full resolution spectra measured in the first years of the mission. The comparisons (covering July 2002 to March 2004) to sondes and lidars indicate a cold bias of the temperature data in the lower and middle stratosphere, with a larger variability than explained by the combined precision estimates. Ozone data have a positive bias of +(10-15)% in the UTLS, but overall agree within ±7% of correlative measurements. In the course of the second year a new baseline **IPF 5.04** was released, which is able to process the entire mission. A validation of a partial data set (January 2005 to December 2008) of temperature, O_3, CH_4, N_2O and HNO_3 profiles was performed by the Multi-TASTE partners. The new HNO_3 data has a bias up to 50%, which is worse than for IPF 4.61/4.62. Methane and N_2O are respectively within 10% and 4% of the ground-based FTIR data. The very first processing of the entire mission was completed using **IPF 5.05**, a minor update of IPF 5.04, in the final year of the project. The comparisons to correlative data covered August 2002 to March 2011. Temperature data remain –(1-3)K too cold in the lower and middle stratosphere, increasing to 3-4K at the top and bottom of the profile. MIPAS ozone data agree to within ±5% with ground measurements, except for an increased positive bias in the UTLS, in the Antarctic ozone hole and a negative bias in the upper stratosphere. We advise to be cautious with data below the tropopause, also because the bias there increased with respect to the previous version. The comparison noise cannot be explained by the combination of the precision of the instruments entering the comparison, which indicates unaccounted for sources of variability in the comparison and/or an underestimation of the instrument precision. The differences in instrumental settings between the full resolution and optimal resolution parts of the mission lead to biases between the first and second parts of the data record, which are only partly removed by the use of the vertical averaging kernels provided wit the data product. This remaining bias will influence ozone trends derived from MIPAS IPF 5.05 data based the entire mission data record.

The **SCIAMACHY** processor **SGP 3.01** was the operational baseline at the start of the project. The validation work, initiated in TASTE, was continued and extended with new studies of e.g. the long-term stability. The SGP 3.01 validation covered August 2002 to March 2011. SGP 3.01 generates ozone column data generally consistent to ±1-2% on an average with ground-based data records. A negative drift in ozone column values has been noticed at numerous but not all stations. Differences between SGP 3.01 and ground-based ozone column data increase at large Solar Zenith Angle (SZA) and at low ozone column values as measured during the Antarctic ozone hole. SGP 3.01 generates NO_2 column data qualitatively consistent with NDACC/UV-visible and GOME GDP 4.1 data records. SGP 3.01 is low biased with respect to NDACC and GOME GDP 4.1 in the Southern Hemisphere, by about 5 10^{14} molec.cm^{-2}. This negative bias exhibits a seasonal cycle. The O_3 profiles exhibit a negative bias of -10% over the entire altitude range, and possibly a positive drift of 5-10% per decade in the lower stratosphere. These drift results need to be consolidated however with additional data. The new baseline, **SGP 5.01**, became operational in the second project year. The first validation results showed issues with the SO_2, OClO and CO nadir products, which pushed the reprocessing of the entire mission beyond the end of the Multi-TASTE project. The reported validation results are therefore based on a partial data set, mainly covering 2002-2003 and 2006. Ozone column differences between the two versions SGP 3.01 and 5.01 are small, usually in the form of a bias smaller than 0.6% on an average. Although slightly different, the drift detected with SGP 3.01 seems to persist with SGP 5.01. The introduction of the degradation correction improves on the drift in the tropics, but not on mid to high latitudes. Where SGP NO_2 column data are compared statistically to the NDACC/UV-visible network, SGP 3.01 usually is lower than SGP 5.01 by a few 10^{13} to 10^{14} molec.cm^{-2}, a value close to the detection limit of UV-visible spectrometers. Consequently SGP 5.01 remains low biased with respect to NDACC and GOME GDP 4.1 in the Southern Hemisphere, by about 5 10^{14} molec.cm^{-2} (that is, about 8% in summer but up to 50% in winter, due to the seasonal cycle of NO_2). The ozone profiles overestimate the correlative measurements with 5-10%, except in the UTLS, the tropical middle stratosphere and the Arctic lower stratosphere where a larger positive bias appears. The CO column data produced by SGP 5.01 is inadequate for use, even after filtering. The BrO column is -17% below the ground-based UV-visible data and has a stronger seasonal cycle. The 15-27km BrO partial columns show a large overestimation of +32% of the correlative data, mainly due to the lower part of the column. Some scientific products were analysed as well, such as IMAP/WFMD methane columns (small positive bias of 2-2.5%, although the seasonality does not correlate significantly with that of the FTIR data), KNMI/DOMINO nitrogen dioxide columns (small positive bias of +2%, roughly +4 10^{13} molec.cm^{-2}), and IUPB 3.2 BrO profiles (better than SGP 5.01, small bias of +1% in 15-27 partial column, smaller variability in comparisons, and trends in agreement with ground-based UV-visible data).

Since the massive **ACE-FTS** **v2.2** validation effort published in the ACE special issue of ACP, systematic intercomparisons with v2.2 data targeted by Multi-TASTE have been performed for ozone and temperature for the data from 2004 to 2011. The temperature data are within 2K of sonde and lidar measurements. In the upper stratosphere ACE-FTS is persistently 2K warmer than lidars, which might however be due to insufficient collocation of the probed air masses or due to atmospheric tides. ACE-FTS ozone profiles exhibit a bias smaller than 7% in the stratosphere, with good data quality down to the tropopause. A similar data quality is observed in the first studies of the new processor baseline **v3.0**, which became operational in the final project year.

Multi-TASTE efforts focused as well on the study of the consistency between ground-based instruments, and between space-based instruments using ground-based data as transfer standard. All Multi-TASTE project partners operating UV-visible instruments participated in the **CINDI campaign**, organized under the auspices of CEOS, GEOmon and NDACC. This led to a better understanding of the capabilities and accuracy of NO_2 measurements, along with ozone, aerosol, HCHO, CHOCHO and BrO.

The evaluation of the **multi-mission consistency** of GOME, SCIAMACHY and GOME-2 **NO_2 column** data using DOAS UV-visible spectrometers as transfer standard was continued and extended to the complete NDACC network of DOAS spectrometers, confirming from pole to pole the slight difference between SGP 3.01 and SGP 5.01, and that the validation results depend primarily on the latitude of the station (the behaviour of stratospheric NO_2) and on the presence of tropospheric NO_2 (to which the nadir-viewing satellites are much more sensitive than the zenith-sky NDACC spectrometers) A similar study was also carried out for various **ozone profilers** on Envisat, SCISAT-1 and SPOT-3/4. This showed that all ozone profile data records, apart from SCIAMACHY, remain within 7% ± 10% to the ozonesonde and lidar data in the stratosphere. Below 10-20km, depending on instrument and latitude, the data quality degrades rapidly. On an average, long-term stability with respect to correlative data meets usual requirements for ozone trend detection, except for GOMOS and SCIAMACHY which show drifts of roughly 10% per decade at some altitude levels.

Support to strategy specifications

The QA/QC experience available within NDACC in general and acquired by Multi-TASTE partners in particular has been instrumental in establishing and implementing principles of the GEO-CEOS Quality Assurance framework for Earth Observation (QA4EO). Among others, the Coordinator has participated actively in different QA4EO workshops and meetings (Ilhabela 2009, Moscow 2011, Harwell 2012). Different activities of Multi-TASTE partners have been directly relevant to the transposition of the high level QA4EO guidelines into practical implementations. A first one is the establishment and enforcement of ESA's PROMOTE C5 Service Validation Protocol (2009), which serves now as an endorsed basis for the Validation Protocols of three successors of PROMOTE, namely, the EC FP7 projects MACC (GMES Atmospheric Core Service), PASODOBLE (GMES Air Quality Downstream Services), and EVOSS (GMES Volcanic Observatory Services). Similarly, the expertise available within Multi-TASTE has been transposed directly into the Product Validation Plans of the ESA Climate Change Initiative (CCI) projects dealing with ozone and with greenhouse gases. Multi-TASTE scientists have provided scientific consultancy for the development and verification of ESA's Generic Environment for Cal/Val Analysis (GECA), which aims at establishing a harmonised environment suitable for the first-step validation of Earth Observation sensors performing atmospheric composition measurements, and also of SAR, land and ocean observations. They have contributed expertise on atmospheric validation methods, viewing procedures, metadata formats, data policy, traceability, and archiving of validation results, and access to peer data centres. In 2011, Multi-TASTE partners involved in ozone profile/column and NO_2 column validations have participated to the verification of the GECA prototype. In view of the exploitation of multi-mission data records in different initiatives like ESA's CCI and SPARC SI2N, the status of sampling and smoothing issues of data comparisons and merging has been assessed and multi-dimensional perspectives have been investigated and illustrated in a dedicated chapter of the ISSI Book on Atmospheric Water Vapour. Multi-TASTE partners have also been active in the analysis and formulation of a strategy for the validation of water vapour data products, of new challenges for NDACC instrumentation and methods in view of planned satellite missions for the next ten years, and of remaining SCIAMACHY validation requirements in the context of the Great SCIAMACHY Validation Assessment (TGSVA). Finally, Multi-TASTE partners have participated in developments of the Implementing Rules of the EU Directive INSPIRE, by representing peculiarities and interests of the atmospheric composition community.

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I INTRODUCTION

The present document reports on activities carried out during the three years of the Multi-TASTE project (ESA contract No.21819/08/I-OL), from October 2008 through September 2011. Multi-TASTE has provided ESA with Multi-mission Technical ASsistance To the validation of Envisat and Third Party Missions (TPM) by sondes, spectrometers and radiometers associated with the international Network for the Detection of Atmospheric Composition Change (NDACC). Precedented by the TASTE project (2004-2008), which focused on stratospheric species measured by the three individual atmospheric chemistry instruments carried by Envisat, the scope of Multi-TASTE has broadened to consider also new challenges raised by the joint assessment of data records acquired by different instruments, as well as new validation needs for tropospheric and climate measurements, in the evolving context of the GEOSS and GMES implementation. It paved the way to multi-mission validation tasks foreseen in ESA Climate Change Initiative projects (CCI) and gave quality assurance (QA) grounds for the future GMES Sentinel 4 and 5 missions and Sentinel 5 Precursor.

Validation support in Multi-TASTE is given by an international consortium gathering complementary expertise in remote sensing and satellite validation, all involved in the Network for the Detection of Atmospheric Composition Change (NDACC), namely: BIRA-IASB (Uccle, Belgium), CNRS/LATMOS (Guyancourt/Paris, France), FMI-ARC (Sodankylä, Finland), IFE/IUP (Bremen, Germany), FZK/IMK/KIT (Karlsruhe, Germany), INTA (Torrejón de Ardoz, Spain), NIWA (Lauder, New Zealand), and ULg (Liège, Belgium), and their collaborators. Main tasks relate to: (a) the collection of ground-based correlative observations acquired by NDACC-certified instruments, the monitoring and verification of those data sets, and their delivery to the Envisat Cal/Val Data Centre (EVDC) operated at NILU on behalf of ESA; (b) geophysical validation studies of atmospheric composition (level-2) data products from Envisat and Third Party Missions based on comparisons with correlative data sets; (c) support to ESA for the development of validation and quality assurance strategies, among others in the GEO-CEOS context; and (d) the valorisation of the validation results and of the expertise through the Envisat Quality Working Groups (QWGs), Climate Change Initiative projects, and more open scientific events.

I.1 Organisation of this document

A quick summary of Envisat and ACE-FTS validation results is presented in **Section II**. **Section III** reviews the acquisition, collection and quality control of correlative data records relevant to Envisat and Third Party Mission validation. **Section IV** presents an overview of the validation work performed during the reporting period, to which members of the consortium have contributed. It addresses the quality of the latest Envisat data versions and it includes validation results of major processor upgrades, progress with multi-mission validation of ozone and NO_2 data records, and support to algorithm development activities performed within the Envisat QWGs. **Section V** highlights advances regarding strategies for mission specific validation and multi-mission validation of key species, and also formulates current and future validation needs in terms of NDACC instrumentation and SCIAMACHY validation. Valorisation and outreach of the results are reported in **Section VI**. **Annex 1** (or **Section VII**) lists relevant peer-reviewed publications and conference proceedings, which constitute tangible deliverables of the project, as well as other relevant presentations. **Annex 2** (or **Section VIII)** lists the meetings, workshops, conferences and symposia attended by Multi-TASTE partners and to which they contributed. At last, the monthly data statistics of the correlative data sets delivered to the Envisat Validation Data Centre (EVDC) in the framework of both the Multi-TASTE and the preceding TASTE projects (covering 2006-2011) is described in **Annex 3** (or **Section X**).

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II SUMMARY OF ENVISAT AND ACE-FTS DATA PRODUCTS QUALITY

Some acronyms are used in the table below: UTLS (upper troposphere lower stratosphere), LS (lower stratosphere), MS (middle stratosphere), US (upper stratosphere), AK (averaging kernel).

II.1 Correlative data and validation best-practice

Species	*Correlative data*	*Validation best-practices*
O_3 col	Dobson, Brewer, DOAS/SAOZ	Lambert et al. (1999, 2000), Balis et al. (2007)
NO_2 col	UV-vis DOAS (incl. SAOZ)	Lambert et al. (2007), Celarier et al. (2008)
BrO col	UV-vis DOAS	Hendrick et al. (2011)
CH_4 col	FTIR	Dils et al (2006)
CO col	FTIR	Dils et al (2006)
T prof	PTU sonde and T lidar	Section IV.1.2 (or IV.2.2)
O_3 prof	O_3 sonde and O_3 lidar	Section IV.2.7 (or IV.3.10)
BrO prof	UV-vis DOAS	Hendrick et al. (2009)
CH_4 prof	FTIR	Vigouroux et al. (2007)
N_2O prof	FTIR	Vigouroux et al. (2007)
HNO_3 prof	FTIR	Vigouroux et al. (2007)

II.2 GOMOS

Species	Processor	Data set	Comparison results	Remark
T prof	IPF 5.00 / GOPR 6.0cf	full	• Negative bias -(2–3)K stratosphere, with ±4K spread • Altitude dependence at high latitude • Large bias (+10K) and noise (10K) in UTLS	• Data below the tropopause should be used with caution
O_3 prof	IPF 5.00 / GOPR 6.0cf	full	• Agreement within 7% ± 10% or better in stratosphere • But negative bias -5% in Arctic • Signs of -(10–20)% / decade drifts at 20–30 km for mid Northern latitude	• Data below the tropopause should be used with caution • Consolidation of drift results needed
	GOPR 7.0cd	partial	• Slight improvement in LS w.r.t. GOPR 6.0cf • Reduced error bars, mainly between 25–45 km	

II.3 MIPAS

Species	Processor	Data set	Comparison results	Remark
T prof	IPF 4.61 (FR)	full	• -(1–2) K in LS-MS • Observed variability (~3K) not explained by combined precision estimate (~0.6K)	
	IPF 5.04 (OR) / IPF 5.05 (FR+OR)	partial / full	• -(1–2) K in LS-MS, increasing to -(3–4) K in UTLS and US • Observed variability (~3K) not explained by combined precision estimate (<0.5K) • Use of vertical AK changes temporal behavior comparisons • Signs of seasonal cycle in differences at mid-high latitude	• Data below tropopause should be used with caution • Convolution of correlative data with MIPAS vertical AKs partly removes bias between FR and OR results • Possible missing source of variability in comparisons
O_3 prof	IPF 4.61 (FR) / IPF 4.62 (FR)	full	• Median agreement better than 7% ± 10% • But +(10–15)% bias in UTLS	
	IPF 5.04 (OR) / IPF 5.05 (FR+OR)	partial / full	• Bias within ±5%, spread 10% (not explained by combined precision estimate at top/bottom profile) • But increased bias in UTLS +40%, in US -20% and during Antarctic O3 hole +(20–30)% • Use of vertical AK changes temporal behavior comparisons • Signs of seasonal cycle in differences at mid-high latitude	• Data below tropopause should be used with caution • Convolution of correlative data with MIPAS vertical AKs partly removes bias between FR and OR results • Possible missing source of variability in comparisons
CH_4 prof	IPF 5.04 (OR)	partial	• Negative bias of less than 10% between 20–50 km	
N_2O prof	IPF 5.04 (OR)	partial	• In LS +4% bias, closer to 0% in MS	• Similar to IPF 4.61
HNO_3 prof	IPF 5.04 (OR)	partial	• Bias up to 50%, worse than IPF 4.61/4.62	• Worse than IPF 4.61 / 4.62 • More validation required

II.4 SCIAMACHY

Species	Processor	Data set	Comparison results	Remark
O_3 col	SGP 3.01	full	• Agreement of +1-2% ± 3-10% with ground-based networks • Negative drift at numerous but not all stations • SZA and column dependence typical of DOAS-based algorithms (e.g. GOME GDP4)	Most of features expected from DOAS based retrievals, except the drift which is more likely linked to calibration issues
	SGP 5.01	partial	• Similar results as with SGP 3.01 (see above) • Difference vs. SGP 3.01: usually a bias smaller than 0.6% on an average	Introduction of degradation correction reduces drift in the tropics, but not on mid to high latitudes
NO_2 col	SGP 3.01	full	• Qualitatively consistent with NDACC and GOME GDP 4.1 • Low biased with seasonal cycle, with respect to NDACC and GOME GDP 4.1 in Southern Hemisphere, by about 5 10^{14} molec.cm^{-2}.	
	SGP 5.01	partial	• Consistent with SGP 3.01, GOME GDP 4.1 and NDACC UVVIS • Slightly higher than SGP 3.01 by a few 10^{13} to 10^{14} molec.cm^{-2} • Low biased with seasonal cycle, with respect to NDACC and GOME GDP 4.1 in Southern Hemisphere, by about 5 10^{14} molec.cm^{-2}.	Difference between SGP 3.01 and 5.01 close to detection limit of NDACC/UV-visible spectrometers
	KNMI / DOMINO		• Small positive bias of +2% ± 11% (+4 10^{14} molec.cm^{-2})	At Jungfraujoch
BrO col	SGP 5.01	partial	• Negative bias of -17% ± 20% • Stronger seasonality than correlative data • Many negative values in 2002	At Harestua
CH_4 col	IMAP, WFMD	full	• Positive bias of +(2–2.5)%, independent of latitude • No correlation between annual cycle of FTIR and SCIA, amplitude of WFMD has much larger amplitude	
CO col	SGP 5.01	partial	• Large amount of extreme outliers, zeros and negative values • No seasonal cycle observed	• Inadequate in precision and accuracy

Species	Processor	Data set	Comparison results	Remark
O_3 prof	SGP 3.01	full	• Negative bias -10% • Positive drifts of 5–10% / decade at 26 km • Signs of seasonal cycle in differences	• Consolidation of drift results needed
	SGP 5.01	partial	• Positive bias +(5–10)%, with spread 10-50% • But increased bias in UTLS +40%, in Tropical MS +20%, in Arctic LS +(20–30)% • In UTLS and Polar LS-MS, observed variability not entirely explained by combined precision estimate • Signs of seasonal cycle in differences	• Possible missing source of variability in comparisons
BrO prof	SGP 5.01	partial	• 15–27 km partial col overestimates correlative data by +32% ± 31%	• At Harestua • Worse than IUPB 3.2
	IUPB 3.2	full	• 15–27 km partial col agrees within 1% ± 21% to correlative data • Trends for SCIAMACHY and correlative data in agreement	At Harestua and Kiruna

II.5 ACE-FTS

Species	Processor	Data set	Comparison results	Remark
T prof	v2.2	full	• In LS+MS bias less than 2K, in US positive bias +2K w.r.t. lidar • Vertical structure of differences oscillates, with amplitude of 1K in LS to 2K in MS	• Bias w.r.t. lidar might be due to temporal distance and atmospheric tides
O_3 prof	v2.2u	full	• Agreement within 7% ± 10% or better in stratosphere • Good data down to tropopause	• Data below the tropopause should be used with caution
	v3.0	full	• Agreement within 7% ± 10% or better in stratosphere • Good data down to tropopause	• Data below the tropopause should be used with caution

III Correlative Measurements

III.1 Overview

The following correlative measurements have been collected at NDACC stations and delivered by project partners to the Envisat Validation Data Centre (EVDC) operated at NILU on behalf of ESA, accessible via http://nadir.nilu.no/calval:

- O_3 vertical column data measured by Differential Optical Absorption (DOAS/SAOZ) visible spectrometers (hereafter VIS), by Dobson and Brewer ultraviolet spectrophotometers, and by Fourier Transform infrared spectrometers (FTIR);
- O_3 vertical profile data measured by balloon-borne electrochemical ozonesondes (O3S) and by millimetre wave radiometers (MWR);
- NO_2 vertical column data measured by DOAS/SAOZ visible spectrometers;
- BrO and OClO column data measured by DOAS ultraviolet spectrometers;
- NO_2, BrO and HCHO tropospheric data measured by MAX-DOAS UV-visible spectrometers;
- O_3, NO_2, CO, CH_4, HNO_3 and N_2O column data measured by FTIR spectrometers;
- O_3, CO, CH_4, HNO_3 and N_2O vertical profile data measured by FTIR spectrometers.

Correlative measurements have been collected at the geographical locations identified in Figure 1 and listed in Annexe 3 (Section IX.2). They address major atmospheric regimes in the polar and middle latitudes of both hemispheres and in the tropics. In addition to the measurements acquired in the timeframe of the project, Multi-TASTE, as an extension of the predecessor TASTE project, has also collected data since the beginning of the Envisat mission to bridge the gap between the Commissioning Phase of Envisat (2002-2003) and the main and long-term validation of Envisat (from 2004 onwards).

The project relies on quality standards and data formats in application within the NDACC, for which all contributing instruments are certified. It is fortunate that, while the NDACC remains committed to its original goal, that is, monitoring changes in the stratosphere with an emphasis on the long-term evolution of the ozone layer, its priorities have broadened considerably to encompass issues such as the detection of trends in overall atmospheric composition and understanding their impacts on the stratosphere and troposphere, and establishing links between climate change and atmospheric composition. Multi-TASTE benefited from new NDACC capabilities and expertise as they developed during the project. Tangible benefits are the validation of Envisat data products not considered in the original proposal, and the availability at EVDC of correlative data not foreseen in the original Multi-TASTE proposal, that is:

- CO_2, H_2O, HCHO and ClO column data measured by FTIR spectrometers;
- HCl, HCHO and NO_2 vertical profile data measured by FTIR spectrometers;
- pressure and temperature profile data measured by the balloon-borne PTU radiosonde to which electrochemical ozonesondes are coupled (p, T data are stored in O_3 profile data files).

Collected data records for which suitable variables and metadata exist, have been converted into the agreed HDF 4.1.3 data format and uploaded to EVDC. A few data sets for which suitable variables and metadata did not exist in the timeframe of the project and could not have submitted to the Envisat Cal/Val database for technical reasons, have been collected by the groups, distributed to interested Envisat partners in other formats, and used for Envisat validation. Detailed description of these data sets can be found in the station reports provided in annexe (Section IX.1). A few ground-based data products still in development at the beginning of the project, like NO_2 and BrO profiles from UVVIS measurements, have now been consolidated at pilot stations and used for Envisat validation. Further consolidation and possible extension to more stations is envisaged in the EC FP7 NORS (Network Of Remote Sensing) project.

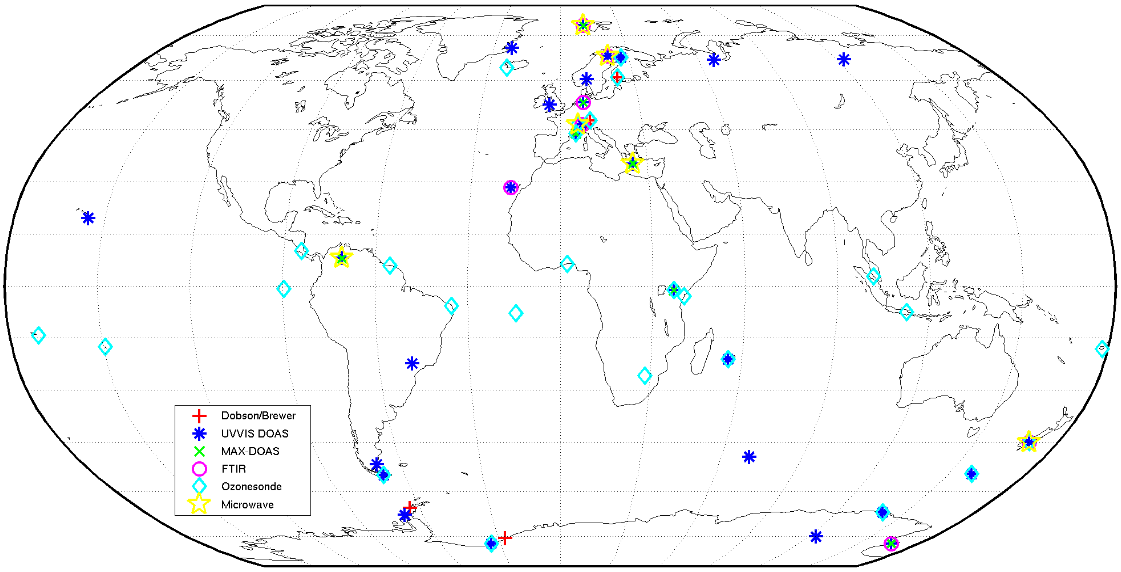

Figure 1: Ground-based instrumentation contributing to Multi-TASTE in 2008-2011: Dobson and Brewer UV spectrophotometers operating at selected NDACC stations, NDACC zenith-sky DOAS UV-visible spectrometers, MAX-DOAS UV-visible spectrometers, balloon-borne ozonesondes (including the SHADOZ contributing network), NDACC FTIR spectrometers, and NDACC millimetre wave radiometers.

Upload Status Tables in Annexe 3 (Section IX.2) display, year after year, an estimate of the number of measurement days per month that have been uploaded to EVDC. Nearly all instruments worked nominally. For a majority of them correlative data acquired directly by members of the consortium were uploaded within a few months after data acquisition. Uploads of data acquired partly by third parties, sometimes on a best effort basis, or acquired at very remote locations, require sometimes more time. Details by partner and station are given in Section IX.1. Note that data collected directly from archiving centres like NDACC, SHADOZ and WOUDC have been used for validation purposes within Multi-TASTE but they have not been submitted to EVDC, since data protocols forbid formally the distribution of archived data to third parties.

III.2 Quality assurance of correlative data

A large part of the contributing instruments are certified for the NDACC, a major contributor to WMO’s Global Atmosphere Watch programme (GAW). The NDACC Data Protocol is structured to ensure excellent data quality while providing ready data access. It recognises that, in order to produce a verifiable data product, sufficient time is needed to collect, reduce, calibrate, test, analyse, and inter-compare the streams of preliminary analyses at every NDACC site. Among others, seasonal analyses may be required for observations from both individual and multiple sites and it is expected that such a procedure shall yield the verifiable product referred to as "NDACC data" within a one-year period after acquisition.

In accordance with the NDACC Data Protocol, the error budget of each measurement is included in the uploaded data sets. In Table 1, we give a summary of the published studies that describe and discuss the measurement uncertainties for the instruments that contribute to the Envisat Cal/Val Data Centre within the Multi-TASTE project:

Table 1: Overview of measurement uncertainties for the correlative data produced within Multi-TASTE for the Envisat Cal/Val Data Centre

Instrument	*Species*	*Typical range bias*	*Typical range precision*	*Reference*
Brewer	O_3 vert. col.	~0-4%	~1%	Balis et al. (2007)
Dobson	O_3 vert. col.	~0-4%	~1%	Balis et al. (2007)
DOAS/SAOZ	O_3 vert. col. NO_2 vert. col.	~0-4% Total accuracy <15%	~1-3%	Hendrick et al. (2011) see text below
DOAS	BrO vert. col. BrO profile	Total accuracy 7-15% 11-18%	 18-38%	Hendrick et al. (2007) Hendrick et al. (2007)
MAX-DOAS	NO_2 tropo. col. BrO tropo. col. HCHO tropo. col.	20-30% depending on pollution ~37% 10%	 15% 20-25%	Wittrock et al. (2012) Theys et al. (2007) Vigouroux et al. (2009)
Ozonesonde	O_3 profile	5-10%	3-5%	Smit et al. (2007)
Microwave radiometer	O_3 profile	2% (surface) – 30% (100km)	2% (surface) – 50% (100km)	Palm et al. (2010)
FTIR	O_3 vert. col. O_3 profile CH_4 vert. col. CH_4 profile N_2O vert. col. N_2O profile CO vert. col. CO profile HNO_3 vert. col. HCL vert. col.	~5% 4-11% ~20% 20-26% ~5% 6-10% 3-5% 3-7% 15-34% 3-5%	~1% 7-23% ~1% 1-3% ~0.3% 1-2% 1-6% 1-13% 21-26% 7-11%	Senten et al (2008) Senten et al (2008), Schneider et al (2008) Senten et al (2008) *Idem* *Idem* *Idem* *Idem* *Idem* *Idem* *Idem*

The error budget of the ground-based UV-visible NO_2 measurements is obtained by considering error sources affecting the determination of the slant column densities (SCD), the residual amount in the reference spectrum (R), and the air mass factor (AMF). Results from intercomparisons exercises (e.g. Van Roozendael et al. (1998); Vandaele et al. (2005) and Roscoe et al. (2010)) show that state-of-the-art instruments hardly agree to better than a few percent regarding the determination of the NO_2 SCD, even using standardised analysis procedures. More conservatively, and including uncertainties of absorption cross-sections and their temperature dependencies, we quote an uncertainty of the order 5% for NO_2 SCDs. The accuracy on R is mostly limited by the method used to derive the vertical column at the time of the reference spectrum acquisition (most of the time a Langley-plot approach). The contribution from this error source to the total error budget is generally small (typically 1-2%), although it may become significantly larger when very low NO_2 abundances are monitored. In most conditions, the major contribution to the error budget of NO_2 vertical columns is the AMF calculation. Published studies indicate that the sensitivity of the AMF to stratospheric profiles of pressure, temperature and the constituent itself accounts for an uncertainty of 10 % maximum for NO_2. Much larger errors can be obtained when tropospheric NO_2 is produced or transported above the stations. Such pollution events are usually easily detected by inspection of the SZA dependency of the NO_2 SCDs and are filtered out in the analysis process. In summary the total accuracy on NO_2 vertical columns is estimated to be in most cases better than 15%.

The estimated MAX-DOAS error for tropospheric columns is 20% for polluted scenarios (e.g. NO_2 in Europe, HCHO with biogenic emissions, BrO during ozone depleting events in the Arctic). For background conditions like HCHO from methane oxidation it is roughly 30%. More details can be found in [Wittrock et al. (2012)] for NO_2 and [Vigouroux et al. (2009)] for formaldehyde.

The internal consistency and homogeneity in quality of the ground-based networks, in particular those contributing to NDACC, are documented in the literature. For the Dobson and Brewer total ozone data we refer to Fioletov et al. (2008). The station-to-station variability of the SHADOZ ozonesonde network has been studied by Thompson et al. (2007). The NDACC ozone and temperature lidar network was evaluated by Keckhut et al. (2004).

The faster data availability required by Multi-TASTE validation activities implies that only a limited time is available to recalibration, state-of-the-art processing or simply quality verification. Therefore we have developed and implemented verification procedures, described hereafter, to check first-order quality/consistency of the fresh fast-delivery data collected in the frame of the project. The quite large number of contributing instruments and stations implies the use of automated routines flagging non-standard events, which can be looked at more carefully once detected. In general the first step consists in scanning the data files in order to identify clearly aberrant data, e.g. negative species concentration values, impossible sunlight measurements during polar night, or sunrise NO_2 columns exceeding systematically sunset NO_2 columns. At ground stations where long enough time-series are available in the NDACC data archive and/or the WOUDC (for ozone data), the second step of the verification procedure consists in comparing fresh data to climatological means and standard deviations that we calculate on low-pass filtered time-series starting, if possible, in 1995. Column values deviating from the climatological mean by more than 2σ and 3σ are pointed out. Trains of consecutive values falling out of the $\pm 3\sigma$ interval are looked at to determine whether such persistent deviations may be due to data quality issues, to natural atmospheric variability, or to unexpected atmospheric features like the 2002 Antarctic vortex split. Single values falling out of the $\pm 3\sigma$ interval without belonging to a justifiable 2σ train are flagged accordingly but not rejected systematically since they could be associated e.g. to real events of extreme variability or to tropospheric pollution episodes enhanced by multiple scattering within clouds. For newer stations with shorter time-series, consistency checks are based on data already stored at the Envisat Cal/Val centre at NILU, acquired by other instruments at nearly collocated stations, or even by the same instrument. Results are reported in a log file. The climatological verification method is illustrated in the *TASTE Progress Report January-October 2004* issued in November 2004, available from ESA's Product Control Service (PCS)[1]. For total ozone data the verification procedure is the one described in Balis et al. [2007].

III.3 Techniques for analysing ground-based UV-visible long-term BrO and NO_2 observations for satellite validation and trend analysis

At the COSPAR Assembly 2010 NIWA presented examples of UV-visible DOAS data sets analysed using several different techniques, with a view to improve the validation and interpretation of long-term BrO and NO_2 data records acquired by satellites.

Zenith sky DOAS measurements

The observed DOAS slant columns are converted into total vertical columns using either air mass factors or a profile retrieval method. The latter is more sophisticated and can be used to obtain both profile information and partial and total vertical columns, e.g. [Schofield et al., 2004a; Schofield et al., 2004b; Hendrick et al., 2007; Hendrick et al., 2009]. Figures 2-3 show examples where measurements made at Lauder (45°S), New Zealand have been used for a comparison with satellite data [Hendrick et al., 2009; Salawitch et al., 2010].

[1] ESA Product Control Service: http://earth.eo.esa.int/pcs/

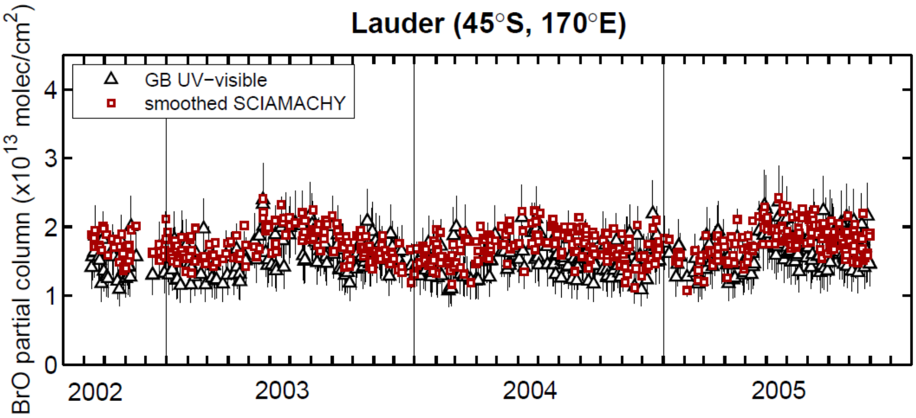

Figure 2: Comparison of the 15–27 km BrO partial columns calculated from the smoothed SCIAMACHY limb IUP 3.2 and ground-based UV-visible measurements at Lauder, New Zealand for 2002–2005 [Hendrick et al., 2009]. The mean relative difference is between both data sets is +11 ± 16%. About 10% of this offset is explained by the fact that different BrO cross sections have been used in the SCIAMACHY and ground-based UV-visible retrievals.

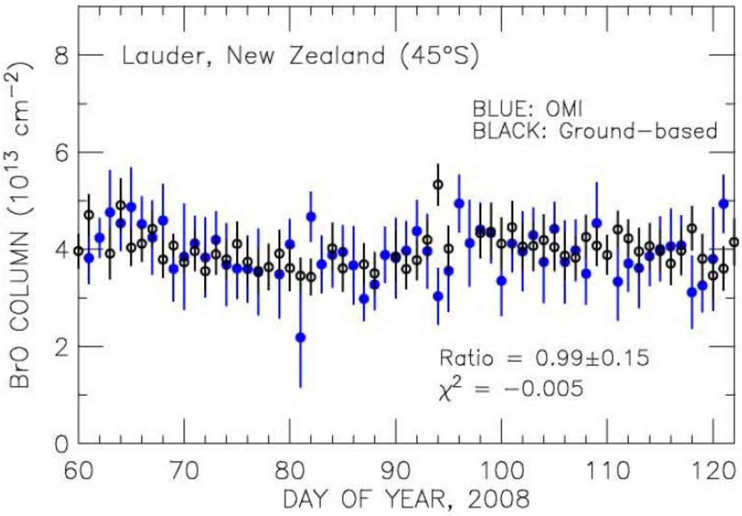

Figure 3: Comparison of BrO vertical columns measured by OMI (processor and version number not specified in paper by Salawitch et al.) during March and April 2008 over Lauder, New Zealand, with ground-based BrO measurements [Salawitch et al., 2010]. The total column BrO is inferred from vertical profiles retrievals [Hendrick et al., 2007]. The agreement is also very good: within 15% with no detectable bias.

Combination of zenith sky and direct sun measurements

The combination can also be used in a retrieval algorithm [Schofield et al., 2004a] to gain profile information. In this case the zenith sky observations provide predominantly the information on the stratospheric partial column and the direct sun observations on the tropospheric contribution. This has been discussed previously for observations made at Lauder and Arrival Heights, Antarctica [Schofield et al., 2004b, Schofield et al., 2006].

MAX-DOAS (Multi-Axis Differential Optical Absorption Spectroscopy) measurements

These are used for the retrieval of trace gas profiles in the lower troposphere, e.g. to measure pollution (relevant for trace gases such as NO_2) or bromine explosion events (relevant for BrO at high latitudes) in the boundary layer or lower troposphere. These time series can then be used for a comparison with satellite data directly or to remove the partial column measured by MAX-DOAS from the total column amount.
Figure 4 shows an example of NO_2 profiles measured during CINDI on June 18th and 25th in 2009. The profile retrieval algorithm applied here has been developed by PhD student Timothy Hay [Hay, 2010].

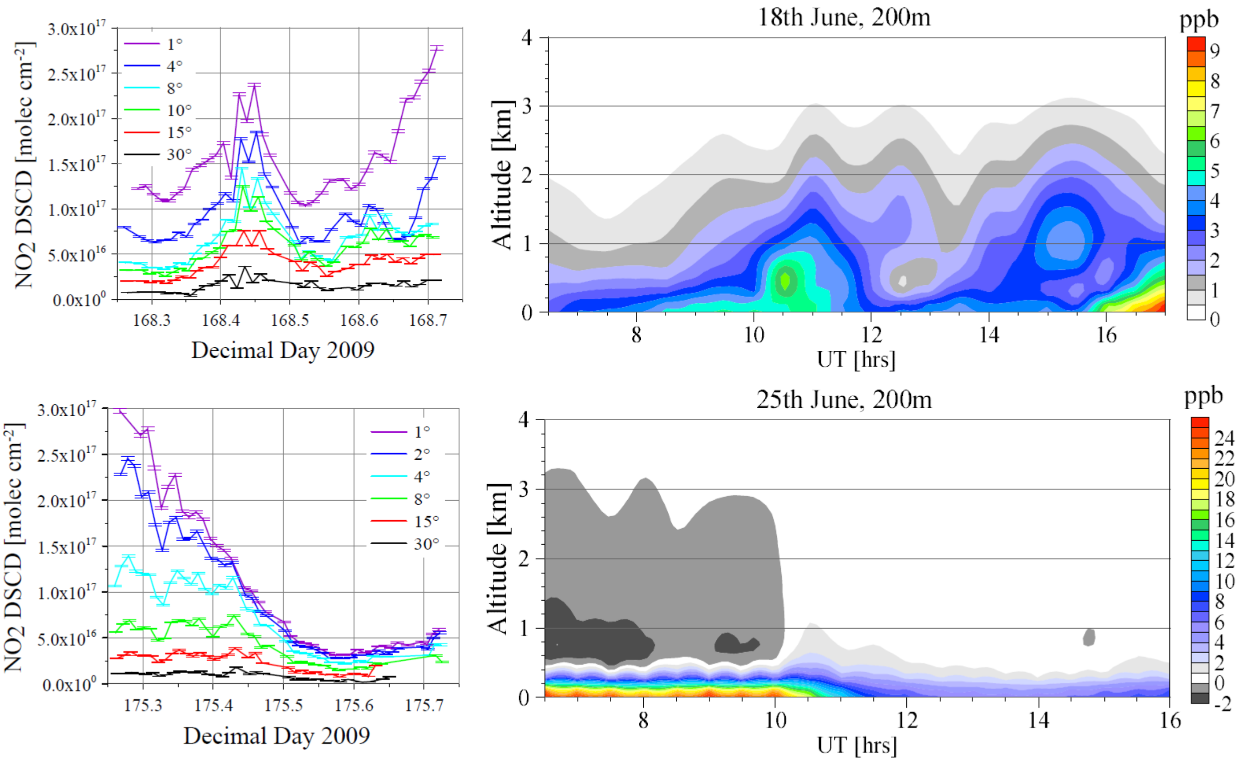

Figure 4: MAX-DOAS differential slant column densities (DSCDs) measured by the NIWA instrument and the corresponding NO2 profiles retrieved at 30 minute intervals for two days with ideal weather conditions are displayed. The contour plots show the NO2 mixing ratio profiles for the 200m layer retrievals.

The same retrieval algorithm has also been applied to MAX-DOAS observations made at Ross Island, Antarctica during a measurement campaign using a mobile Max-DOAS instrument. In general, the observations show that the retrieved BrO was concentrated within the layer from the surface to 50 m.

III.4 Improvements and homogenization of total ozone from twilight zenith-sky visible spectrometers

The NDACC UV-visible Working Group has issued recommendations for improving and homogenizing the retrieval of total ozone column from twilight zenith-sky visible measurements. These recommendations address both the DOAS spectral parameters and the calculation of air mass factors (AMF) needed for the conversion of O_3 slant column densities into vertical column amounts [Hendrick et al., 2011]. The most important improvement is the use of O_3 AMF look-up tables calculated using the TOMS V8 (TV8) O_3 profile database, that reduce the dependence of the O_3 AMF on the seasonal and meridian changes of the O_3 vertical distribution. With these new recommendations, the total accuracy of zenith-sky total O3 columns measurements in the visible reaches 6% [Hendrick et al., 2011].

To investigate their impact on the retrieved ozone columns, the recommendations have been applied to measurements from the NDACC/SAOZ network. The revised SAOZ ozone data (version V2) at Observatoire de Haute Provence (44°N, 5.5°E) and Sodankylä (67°N, 27°E) have been validated through comparison to collocated Dobson and Brewer instruments, respectively. A significantly better agreement is obtained between SAOZ and correlative reference ground-based measurements after applying the new O_3 AMFs and correcting the Dobson and Brewer measurements for their temperature dependence: a residual bias of less than 2% is obtained and the seasonality in the Dobson/Brewer – SAOZ differences is removed (see Figure 5).

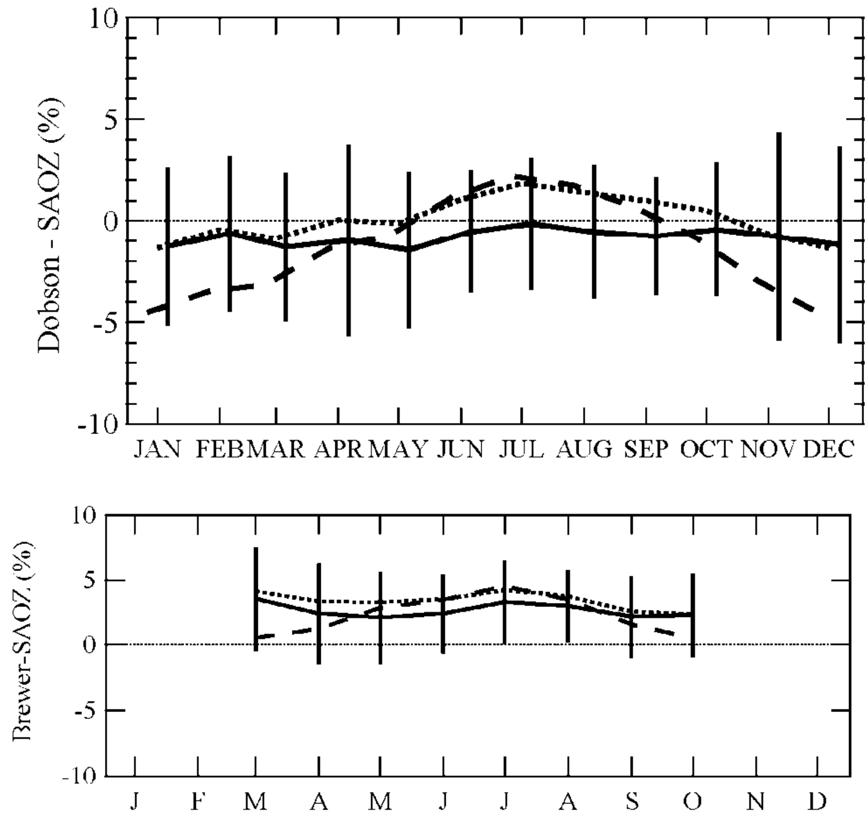

Figure 5: Seasonal variation of the Dobson/Brewer – SAOZ relative difference at OHP (upper plot) and Sodankylä (lower plot). Dashed and dotted lines correspond to old and new versions of the SAOZ data sets and solid line to new version of the SAOZ data sets and Dobson/Brewer observations corrected for temperature (from Hendrick et al., 2011).

The consistency between new SAOZ data at eight stations deployed at all latitudes and TOMS, GOME-GDP4, SCIAMACHY-TOSOMI, SCIAMACHY-OL3, OMI-TOMS, and OMI-DOAS satellite overpasses has been investigated. As shown in Figure 6, systematic seasonal differences between satellite and SAOZ instruments persist. These are attributed mainly to: (i) a possible problem in the satellite retrieval algorithms in dealing with the temperature dependence of the ozone absorption cross-sections in the Huggins band and the solar zenith angle (SZA) dependence, (ii) zonal modulations and seasonal variations of tropospheric ozone not accounted for in the TV8 database, and (iii) uncertainty on the stratospheric ozone profiles at high latitude in the winter in the TV8 database. For satellite measurements mostly sensitive to stratospheric temperature like TOMS, OMI-TOMS, or to solar zenith angle like SCIAMACHY-TOSOMI, the application of temperature and SZA corrections results in the almost complete removal of the seasonal difference with SAOZ, improving significantly the consistency between satellite and SAOZ total ozone observations. More details on this study can be found in Hendrick et al. (2011).

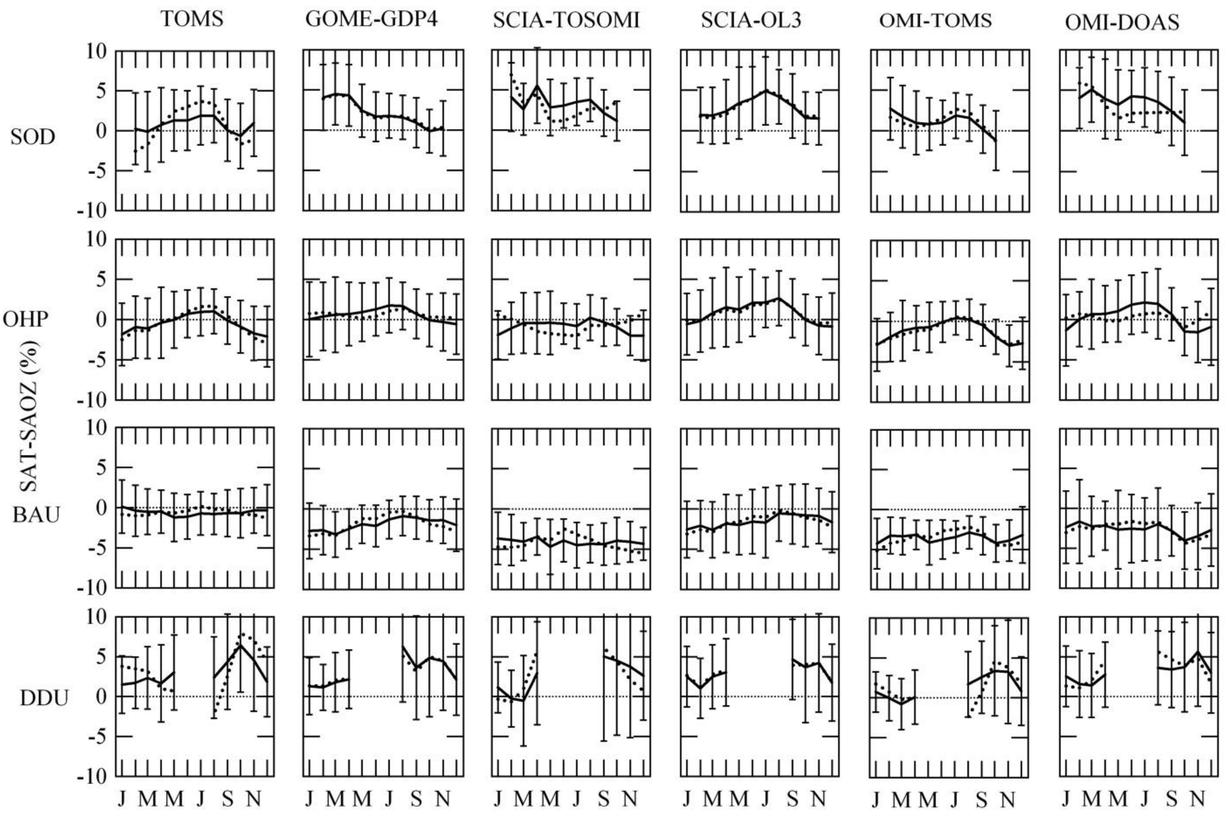

Figure 6: Seasonal variation of the satellite – SAOZ difference using the new NDACC recommendations for ground-based DOAS ozone analysis before (dotted lines) and after (solid lines) application of a temperature correction in satellite data. From top to bottom: Sodankylä, OHP, Bauru and Dumont d'Urville. From left to right: TOMS, GOME-GDP4, SCIAMACHY-TOSOMI, SCIAMACHY-OL3, OMI-TOMS, and OMI-DOAS. From Hendrick et al. (2011).

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IV VALIDATION RESULTS

During the project, the Multi-TASTE consortium was tasked to validate Envisat level-2 data products generated operationally, to support algorithm development activities carried out by the Envisat Quality Working Groups (QWGs), and to assess the quality of successive versions of level-2 data products from Envisat and Third-Party Missions like SCISAT-1 ACE and GOSAT TANSO. Envisat data products were generated both by Processing and Archiving Centres (PAC) operated at/on behalf of ESA, and by scientific institutes with their homemade retrieval software tools. Within Multi-TASTE, validation was carried out both independently by individual partners using their own methods, and by IASB-BIRA using a common method for all stations. This dual approach fostered constructive discussions and yielded a consolidated appreciation of Envisat data quality. Details of all the studies fall beyond the scope of this project report but they can be found in the reports and publications listed in Section **VII** (Annexe 1). Detailed quality assessments as well as feedback were provided to ESA and the Envisat QWGs. Where relevant, validation studies based on correlative data collected within Multi-TASTE were augmented with complementary data of similar nature, collected from archives of the NDACC, WOUDC and SHADOZ programmes.

This chapter gives an overview of the validation activities carried out during the entire project. The results and conclusions of the validation work of the final year are presented in detail below. The products validated during the first two years are summarized, we refer the reader to previous annual reports for complete information

IV.1 Envisat GOMOS

The GOMOS processor IPF 5.00 remained the operational baseline over the course of the Multi-TASTE project. Therefore the Multi-TASTE partners took the opportunity to consolidate the previous validation results, and to start a systematic multi-validation of limb sounders reported in Section IV.5.4 on multi-mission studies. A new operational processor, IPF 6.01, was released in the final project year. The validation analysis will be carried out as soon as the reprocessing of the full mission is completed. However, the ozone profiles produced by the prototype algorithm (GOPR 7.0cd) of IPF 6.01 were validated, and reported below.

IV.1.1 History of instrument operations and processor upgrades

The GOMOS Level-1b-to-2 processor IPF 5.00 – based on the prototype version GOPR 6.0cf – has been in operation since the end of July 2006. No changes have been made to the processor since its activation, except a minor modification (IPF 5.01) in the orbit handling software to support the lowering of the Envisat platform. This minor change has no effect on the retrieved species.

The latest L1b-L2 processor, IPF 6.01, was activated on June 7, 2011. It includes the following changes and improvements in the Level-1b part with respect to IPF 5.0x:

- New Reflectivity LUT: impact on all species
- New Slit width LUT: impact on all species
- Intra-pixel PRNU (Pixel Response Non Uniformity): Highly improves H_2O retrieval
- Star spectra location on the CCD: impact on all species
- New wavelength assignment: impact on all species
- Automatic DC bias correction: impacts O_3 (cold stars) and all other species
- Update of Cosmic Ray detection and correction algorithm (twilight): impact on all species, but mainly O_2
- SATU missing data correction: impact on all species
- Flag consolidation
- Attitude file written to DSD (MPH+SPH consolidation)
- Error due to DC included in the error budget of L1b (error on measured transmission)
- Threshold level of pixel saturation (bright limb) changed (lowered)
- New limb spectra error estimate

And in the Level-2 part:

- Full covariance matrix inversion: impact on error estimates and χ^2
- New HRTP (High Resolution Temperature Profile) algorithm: improves the High Resolution Temperature profiles
- New coding of the error bar (absolute value).

Unfortunately the reprocessing of the full mission with IPF 6.01 was still under way during the redaction of this final report.

IV.1.2 Validation of temperature profile [IPF 5.00 / Prototype 6.0cf]

The High Resolution Temperature Profiles (HRTP) of version IPF 5.00 were compared to sondes and lidars in the first project year. The analysis and its results were consolidated in the second year. The validation approach is identical to that in Section IV.2.4.

Main conclusions:

- In the tropics and at mid-latitudes, a negative bias of -2 to -3K is observed from 20 km up to the burst point of the balloon.
- At high northern and southern latitudes, the median of the differences depends on altitude. There is a negative bias of about -3K at 15-20 km, which diminishes with increasing altitude. From about 25-30 km altitude, the median bias is close to 0K. Above 30 km, the differences increase again to reach about -2 to -3K in median.
- The half 68% inter-percentile is about 4K in the stratosphere at all latitudes.
- In the UTLS, absolute differences increase to more than +10K in some cases and are much noisier; the half 68% inter-percentile exceeds 10K.

A complete validation report can be found in Multi-TASTE annual report #1 [Lambert et al., 2009], which was updated in Multi-TASTE annual report #2 [Hubert et al., 2010].

IV.1.3 Validation of ozone profile [IPF 5.00 / Prototype 6.0cf]

Monthly statistics of the agreement between Envisat GOMOS Prototype Processor v6.0cf / IPF 5.00 ozone profile data and correlative measurements from ozonesonde stations contributing to the Multi-TASTE project are provided as an electronic annex.

The results are detailed in Section IV.5.4 on multi-mission studies.

IV.1.4 Validation of ozone profile [Prototype 7.0cd]

The verification of the GOMOS ozone processor upgrade from version 6.0cf to version 7.0cd (also referred to as baseline algorithm 2008) was undertaken in the first project year. For this study the GOMOS data acquired under dark conditions (PCD_ILLUM = 0, 'dark limb' or 3, 'straylight') were compared to correlative observations collected from ozonesonde and lidar stations. The validation methodology is identical to that of Section IV.2.7.

The general conclusions for this delta-validation study were the following:

- With respect to the previous version 6.0cf, the new GOPR prototype 7.0cd seems to improve slightly (a few percent maximum, not uniformly) the retrieval of GOMOS ozone profile data in the lower stratosphere (from 15-20 km to about 25 km).
- For all other data, the new prototype 7.0cd seems to offer, in the limits of this verification study, the same data quality as the one achieved with the reference version 6.0cf.
- The error bars on the data provided in the GOMOS data files have improved, mainly between 25 and 45 km altitude.

The complete validation report can be found in Multi-TASTE annual report #1 [Lambert et al., 2009] and in the Project Technical Note [Vandenbussche et al., 2009].

IV.2 Envisat MIPAS

The MIPAS processor IPF 4.61/4.62 was the baseline at the beginning of the project. It was only able to process the nominal full resolution (FR) spectra measured during the first part of the mission, i.e. before March 2004. In the first project year, the temperature and ozone profiles were validated. In the course of the second year an improved version of the MIPAS processor, IPF 5.04, provided data sets to the validation teams. This processor retrieves geophysical observables from optimized resolution (OR) data, which allows, for the first time, to process the complete mission. A subset of the complete mission was reprocessed with IPF 5.04, and it served as input to the validation of the vertical profile of temperature, ozone and other products by the Multi-TASTE partners. The reprocessing of the entire mission with IPF 5.05 was completed in the final year of the project. The validation reports of ozone and temperature profiles of the full MIPAS mission can be found below. In addition, MIPAS is included in the systematic multi-mission validation of limb sounders; as reported in Section IV.5.4 on multi-mission studies.

IV.2.1 History of instrument operations and processor upgrades

MIPAS operated at nominal resolution from July 2002 to March 2004, when the interferometer experienced a major anomaly and stopped operation. In January 2005 instrument operations were resumed in an optimized resolution mode with reduced spectral but finer vertical sampling. The complete set of full resolution spectra was processed with the operational processor IPF 4.61/4.62 and has been available for several years. The Level 1b-2 processors, IPF 5.04 and soon after IPF 5.05, enable the production of profiles for both resolution modes. This allowed the restart of the operational processing at the ESA Ground segment on June 10, 2010, for near real-time production (at ESRIN and Kiruna) and on June 21, 2010, for off-line production (at D-PAC).

The following changes and improvements were implemented in the L1b-L2 processor IPF 5.04 (which is fully aligned with its scientific prototype ORM 1):

- The instrument misalignment matrix is now partly taken into account, which reduces the observed offset and gradient of the difference between engineering and true tangent altitudes of the previous L1b processor. (Pressure remains the recommended altitude proxy.)
- A-posteriori regularisation to compensate for the ill-conditioned situation due to the finer vertical measurement grid in the optimized resolution mode. It is applied for the main target parameters (temperature, O_3, HNO_3, CH_4, N_2O and NO_2), except for H_2O and pressure.
- Inclusion of the averaging kernel matrix of the regularized profile in the output Level 2 product
- Computation of conditioning parameter (information about the stability of the matrix inversion)
- Bug correction in continuum derivatives and T/VMR derivatives
- Update of the partitioning functions of HNO_3
- Option for more accurate FOV convolution, which impacts H_2O profiles near the tropopause

Version 5.05 was a minor upgrade of IPF 5.04 with no impact on the ozone and temperature profiles.

It is important to keep in mind that the full resolution and optimized resolution retrievals are characterized by different measurement scenarios, different L1 files, different Level-1-to-2 retrieval algorithms, and different spectral microwindows.

IV.2.2 Validation of temperature profile [IPF 4.61]

The complete validation report can be found in Multi-TASTE annual report #1 [Lambert et al., 2009]. Here we list the key points. The validation methodology follows that found in Section IV.2.4.

- In the troposphere and the stratosphere, the general median agreement is within 2K. At about two thirds of the radiosonde stations, the comparison with correlative temperature profiles yields a median difference close to zero. At the other third of the stations, we observe a median negative bias of -1 to -2K.
- There seem to be more stations with a negative bias at low latitudes, however it is unclear whether this is correlated with latitude.

IV.2.3 Validation of temperature profile [IPF 4.61 and IPF 5.04]

The report in which the validation results of full resolution IPF 4.61 profiles are compared to those of a subset of the optimized resolution IPF 5.04 profiles can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation methodology follows that found in Section IV.2.4.

The main results were

- No significant temporal features (cycles, drifts, …) were found in the comparison time series. But the data set is too small to be statistically conclusive.
- Between 10 hPa (≈ 30 km) and 100-200 hPa (≈ 16-11 km), the IPF 5.04 temperature profiles underestimate the correlative data by 1-2 K, almost independent of altitude and latitude. At these altitudes the comparisons are similar for both processors, except at polar latitudes where the bias of IPF 4.61 is less pronounced.
- However, below the tropopause (>100-200 hPa) the IPF 5.04 cold bias gradually increases and reaches -5 K at the bottom of the profile. The vertical analysis of IPF 4.61 did not indicate such a gradually increasing disagreement.
- The precision of the MIPAS L2 algorithms has decreased from 0.4-0.8 K (IPF 4.61) to 0.2-0.5 K (IPF 5.04). However, when combined with the 0.1 K precision of the correlative measurements, the expected error is significantly smaller than the observed 2-4 K half 68% inter-percentiles of the comparisons. Previous studies [Ridolfi et al., 2007] drew a similar conclusion for IPF 4.61; insufficient cloud-flagging and spatial smoothing errors were suggested contributions to the unexplained random error component.
- Apart from the -5 K underestimation at the bottom of the profiles, the observed bias of the comparisons is consistent with MIPAS systematic error, which is around 2-3 K and up to 5 K at polar latitudes.

IV.2.4 Validation of temperature profile [IPF 5.05]

We present the results of comparisons between full mission IPF 5.05 (August 2002 – March 2011) MIPAS temperature profiles and a data set of correlative temperature profiles provided by PTU radiosondes launched as part of GAW (including NDACC and SHADOZ) network activities, and NDACC temperature lidars. The full mission reprocessing led to an amount of co-locations superior to those of the IPF 4.61 - IPF 5.04 validation analysis carried out in the second year of the project. The improved spatial and temporal sampling of the atmosphere was essential to uncover previously unreported features (seasonal cycle, possible time dependence of vertical averaging kernel …) in the IPF 5.05 data set.

We found that the MIPAS data set co-located with profiles recorded at 74 radiosonde and 7 lidar stations. The co-location criteria were chosen as the best compromise between a sufficient amount of comparison points and a sufficient co-location of the probed air masses. First, a maximum distance of 500 km between the ground-based station and the MIPAS tangent point for the scan at 30km altitude, and, second, a maximum time difference of 6h (for both day-time radiosonde and night-time lidar data). Tightening the spatial criteria reduces the amount of co-locations strongly and hence limits the statistical relevance of the results. MIPAS data points with a temperature retrieval error larger than 500% were rejected, and, when more than five grid points satisfied this condition, the entire profile was removed. Then, the correlative profiles were smoothened to the satellite resolution, using two methods. The first, designated by $T_{corr,BOX}$, is a simple per-layer average (layers of ~1.5 km thickness). The second method, leading to $T_{corr,VAK}$, smoothens using the MIPAS vertical averaging kernel. Finally all data (satellite and ground-based) were linearly interpolated to a common pressure grid between 450-0.06 hPa.

Monthly statistics of the agreement between MIPAS IPF 5.05 temperature profile data and radiosonde measurements from stations contributing to the Multi-TASTE project are provided as an electronic annexe.

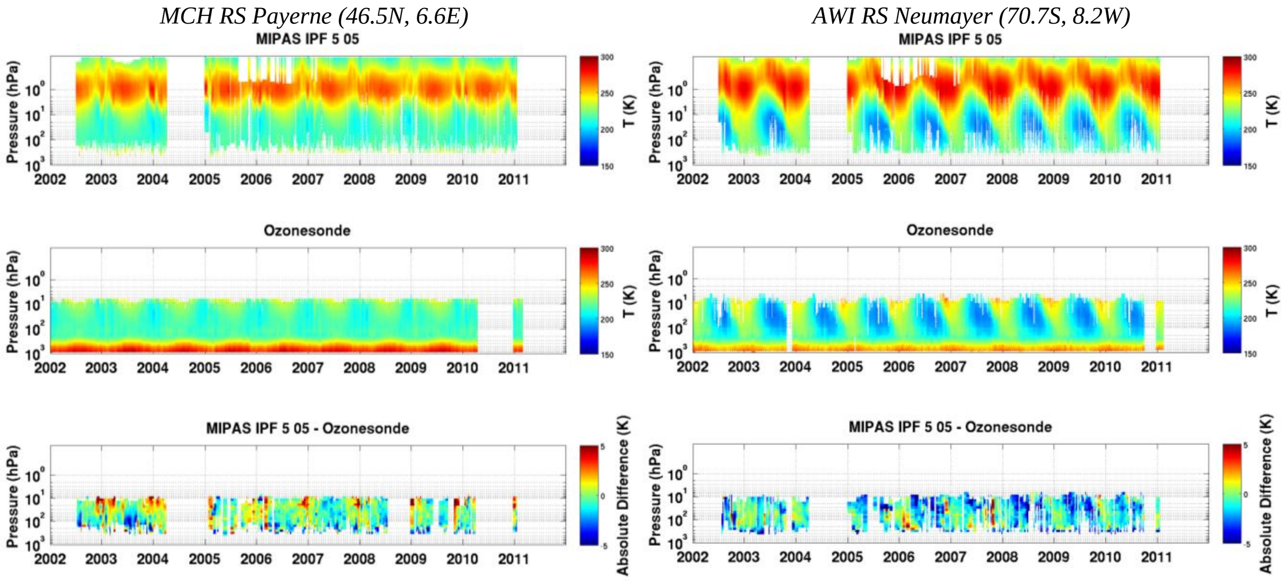

Figure 7: Time series of the vertical temperature profile as retrieved by MIPAS IPF 5.05 (top panels) and by the radiosondes launched at Payerne, Switzerland (left) and Neumayer, Antarctica (right). The bottom panels show the absolute temperature difference between the co-located profiles.

Figure 7 illustrates the first part of the validation study, which consisted of the visual inspection and the statistical study of temperature profile time series at each station. The figure shows the time series of temperature profiles at the radiosonde station at Payerne, Switzerland (left) and Neumayer, Antarctica (right). The objective is to identify possible global features, cyclic errors and long-term drifts. The top and central panels show the profiles as retrieved respectively by the MIPAS IPF 5.05 processor and by the ground-based measurements, while the bottom panel presents their absolute difference, calculated as $\Delta T_{BOX}(p,t) \equiv T_{MIPAS}(p,t) - T_{corr,BOX}(p,t)$. For a better visibility a one-month running mean was applied to all time series. The empty areas p < 1 hPa for the IPF 5.05 time series in 2005-2006 correspond to UTLS-1 measurement mode periods. This mode has a maximum scan altitude of 51.5 km, opposed to 68 km in the nominal measurement mode. The time series shown in Figure 7 are typical for most ground stations: the qualitative temporal and vertical behaviour of IPF 5.05 is in agreement with the correlative data for a wide range of atmospheric phenomena.

Figure 8 shows the $\Delta T_{BOX}(p,t)$ difference time series (left column) at various pressure levels, for Neumayer (high latitude), Payerne (mid latitude) and Paramaribo (Tropics). When the time series satisfied some basic quality criteria (sufficient number of points, small spreads, …), it was subjected to a robust linear regression. The sensitivity to outliers was reduced by weighting each observation with Tukey's bisquare function. The parameter of interest is the slope of the regression line, which represents the (linear) drift of the satellite data with respect to the correlative data. We adopted the usual 2σ significance level to reject the no-drift hypothesis. All satellite drift estimates are reported in K per year and with 2σ error bars (corresponding to 95% confidence level). This analysis was performed for all ground stations.

The time series unveiled a seasonal cycle in the differences, which is most pronounced for stations at mid and high latitudes above the 100 hPa level, see e.g. Payerne or Neumayer. This was previously not observable, due to the much lower number of comparisons available for analysis. The linear model in our drift analysis does not yet include this effect. However, ignoring seasonalities should not alter the estimated value of the drift, but rather make the drift error estimation too conservative. Our choice hence limits the statistical power to detect drifts, but does not increase the number of false detections. We intend to quantify the impact of the seasonal cycle on the drift estimation in the future. Convolution of the correlative data with the MIPAS vertical averaging kernels reduces the bias between the FR and OR validation results. From

Figure 8 it is clear that the $\Delta T_{VAK}(p,t) \equiv T_{MIPAS}(p,t) - T_{corr,VAK}(p,t)$ time series have a different slope than that of $\Delta T_{BOX}(p,t)$, which does not incorporate vertical AK information.

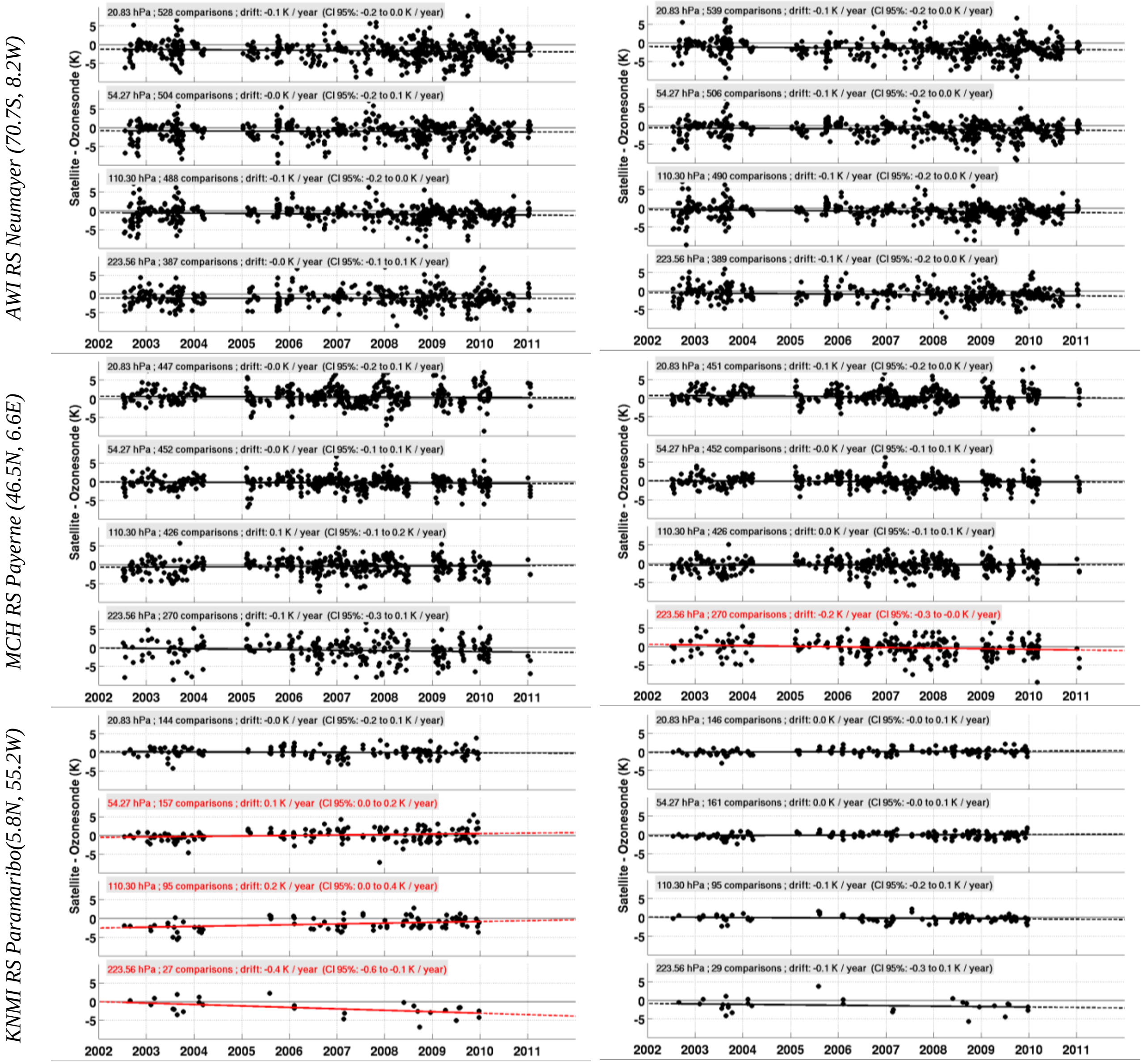

Figure 8: Time series of absolute temperature differences $\Delta T_{BOX}(p,t)$ (left, radiosonde smoothed with per-layer average) and $\Delta T_{VAK}(p,t)$ (right, radiosonde smoothed with MIPAS averaging kernels) between MIPAS IPF 5.05 and radiosonde data at Neumayer, Antarctica (top), Payerne, Switzerland (centre) and Paramaribo, Suriname (bottom) at selected pressure levels. A linear regression was fitted to the data when more than 20 co-located pairs were found and the spread in their relative differences was less than 30%. Black lines are not significant, red lines are significant at 95% confidence level. The annual slope and 95% confidence interval are indicated in each subplot.

Figure 8 shows the $\Delta T_{VAK}(p,t)$ time series beside those of $\Delta T_{BOX}(p,t)$. Figure 9 presents the latitudinal cross-section of the drift results at all stations, for $\Delta T_{BOX}(p,t)$ (left) and $\Delta T_{VAK}(p,t)$ (right). The reduction in the slope is especially clear in the tropical UTLS (~100 hPa level), where drifts drop from ~0.25 K/yr (box) to ~0 K/yr (AK). This indicates that smoothing the correlative data with MIPAS vertical AK changes the temperature with a time-dependent magnitude, which is expected from the fact that the instrumental settings for the FR and OR part of the mission are quite different, and the differences in vertical sampling for the various MIPAS measurement modes. The impact at other latitudes is smaller, if any at all.

Further investigation is required to make a solid statement about the presence of drifts. For the moment we expect no or only a small drift of MIPAS with respect to correlative data, not more than 0.3-0.5 K/year.

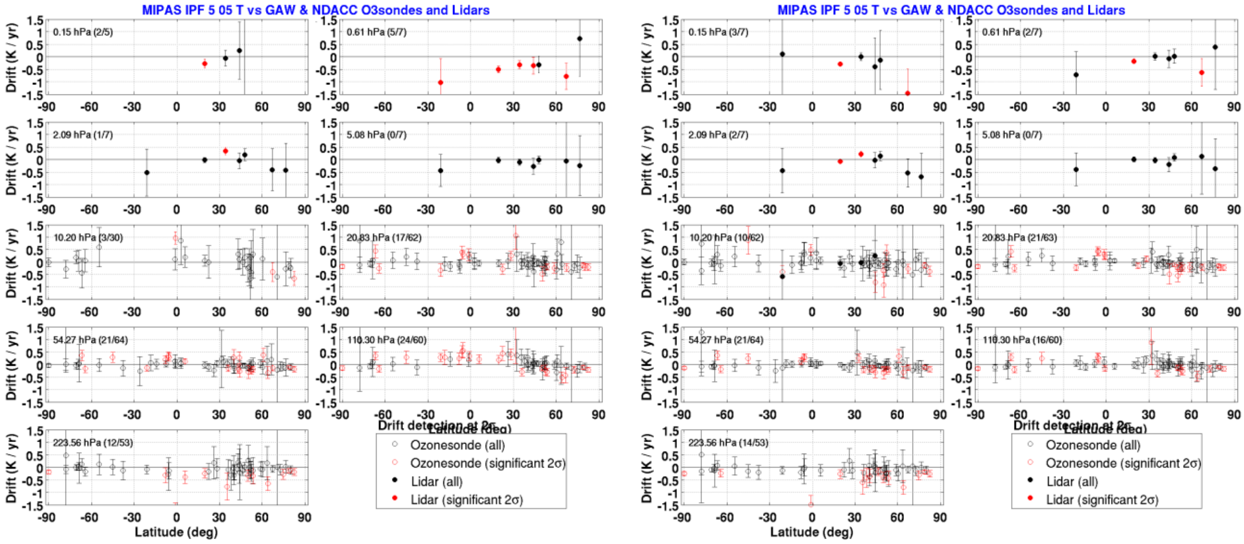

Figure 9: Slope of the multi-year linear trend fitted to time series of the absolute differences $\Delta T_{BOX}(p,t)$ (left) and $\Delta T_{VAK}(p,t)$ (right) between MIPAS IPF 5.05 and ground-based (ozonesonde=open circle and lidar=closed circle) temperature measurements at each station, plotted as a function of latitude and at different pressure levels. The error bars represent 95% confidence level. Drifts with statistical significance (95% confidence level) are shown in red.

In most cases the absence of significant dependencies on time permitted the statistical study of the vertical structure of the absolute temperature differences between pairs of co-located profiles. This was done for each ground station; Figure 10 presents the results at the station of Sodankylä, Finland. The left panel shows the median (solid) and 68% inter-percentile (dashed) of the absolute differences $\Delta T_{BOX}(p,t)$ (blue) and $\Delta T_{VAK}(p,t)$ (cyan) between MIPAS IPF 5.05 and radiosonde measurements. The right panel shows the median absolute precision (dashed) and bias (solid) for MIPAS (blue) and for the correlative data (grey). Three additional stations (Eureka, OHP and Hilo) are shown in Figure 11; these results are representative for the other ground-based stations.

Between 10 hPa (≈ 30 km) and the tropopause (100-200 hPa ≈ 16-11 km), the IPF 5.05 temperature profiles show a small cold bias of roughly 0.7 K, almost independent of altitude and latitude. Below the tropopause (>100-200 hPa) the cold bias increases gradually and reaches -3 K at the bottom of the profile. Above the 10 hPa level, the bias increases with altitude, reaching -2 to -3 K around 1 hPa (≈ 45 km) and -5 K at 0.5 hPa (≈ 50 km). These observed biases are in agreement with the combined systematic error of the co-located measurements. In the UTLS, the comparisons with $T_{corr,VAK}$ have a median bias about 1 K smaller in magnitude than that of ΔT_{BOX}. This is visible for all latitudes.

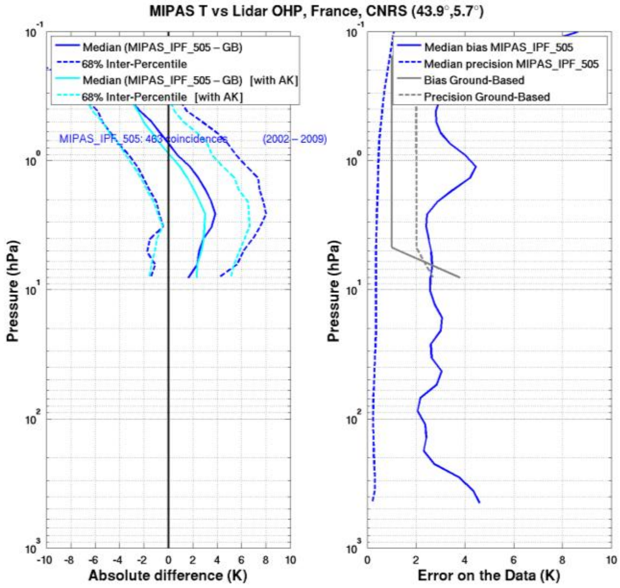

Figure 10 – left: vertical dependence of median (solid) and 68% inter-percentile (dashed) of the absolute temperature differences $\Delta T_{BOX}(p,t)$ (blue) and $\Delta T_{VAK}(p,t)$ (cyan) between MIPAS IPF 5.05 and CNRS lidar data at Observatoire de Haute-Provence, France. Right panel: median absolute precision (dashed) and bias (solid) for MIPAS and correlative data.

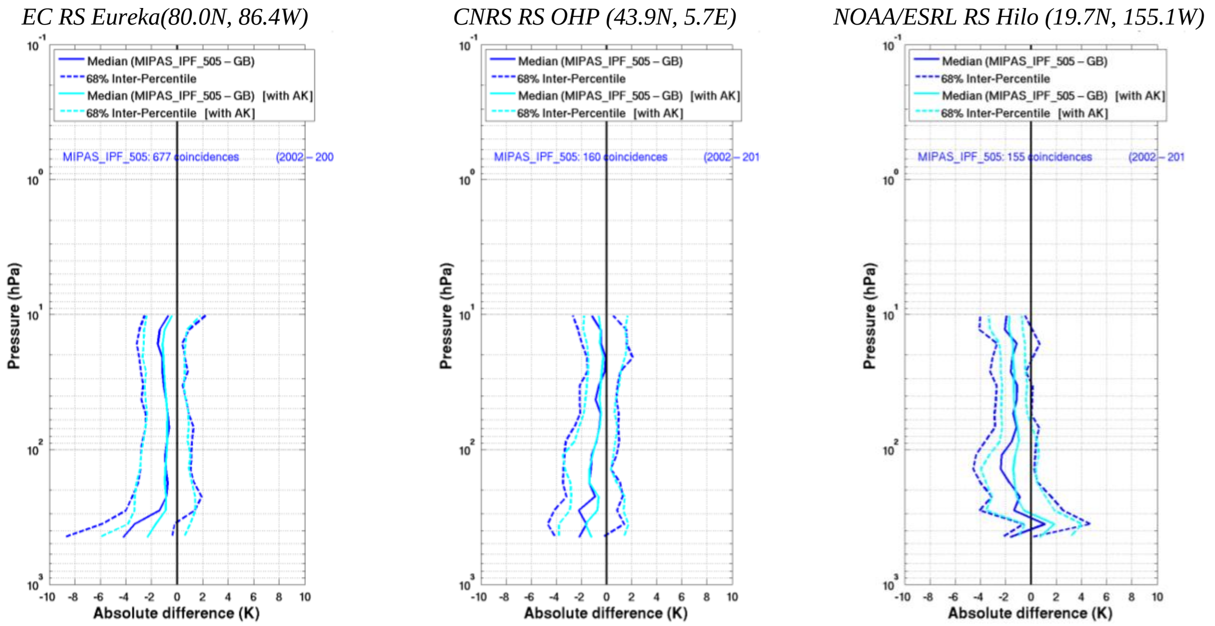

Figure 11: Vertical dependence of median (solid) and 68% inter-percentile (dashed) of the absolute temperature differences $\Delta T_{BOX}(p,t)$ (blue) and $\Delta T_{VAK}(p,t)$ (cyan) between MIPAS IPF 5.05 and correlative data at three radiosonde stations.

The spread in the comparisons is larger than expected from the <0.5 K combined random error of MIPAS and the correlative measurements. The observed spread decreases from 4 K above 3 hPa, to 2-3 K for 3-10 hPa, to 1.5-2 K from 10 hPa to the tropopause. Below the tropopause, the spread increases again to 3-4 K. Previous studies [Ridolfi et al., 2007] drew a similar conclusion for IPF 4.61; insufficient cloud-flagging and spatial smoothing errors were suggested contributions to the unexplained random error component. Using the MIPAS vertical AK to smoothen the correlative profile slightly reduces the spread in the comparisons, as expected.

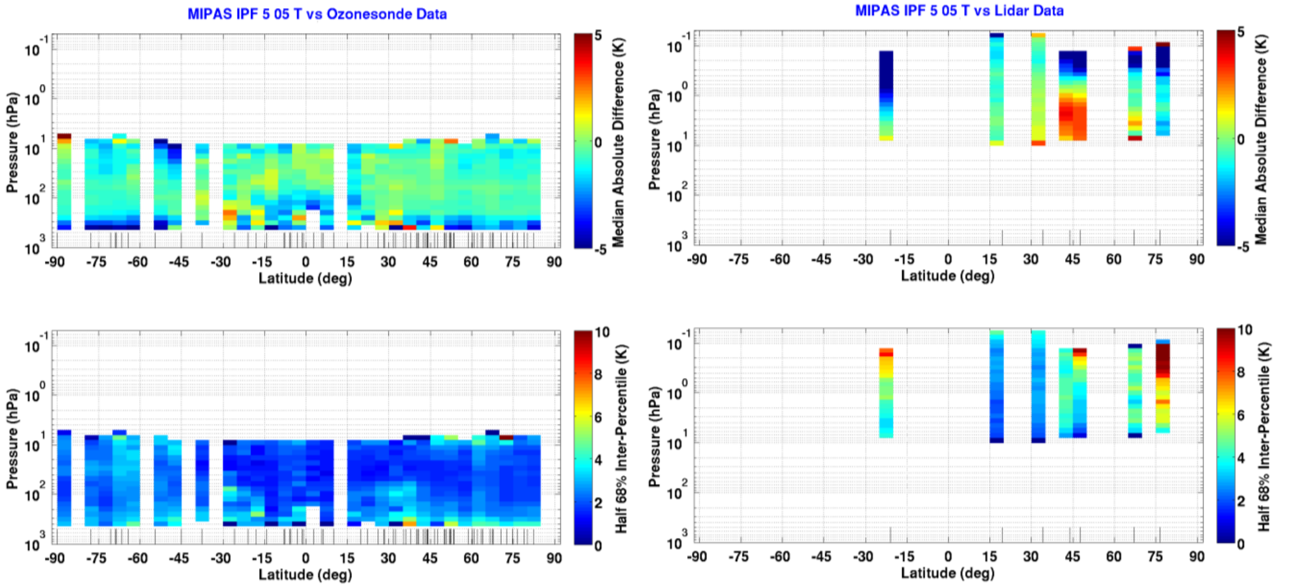

Figure 12: Median (top) and half 68% inter-percentile (bottom) of the absolute difference $\Delta T_{BOX}(p,t)$ between MIPAS IPF 5.05 and correlative data as a function of pressure and latitude; for radiosondes (left) and lidars (right).

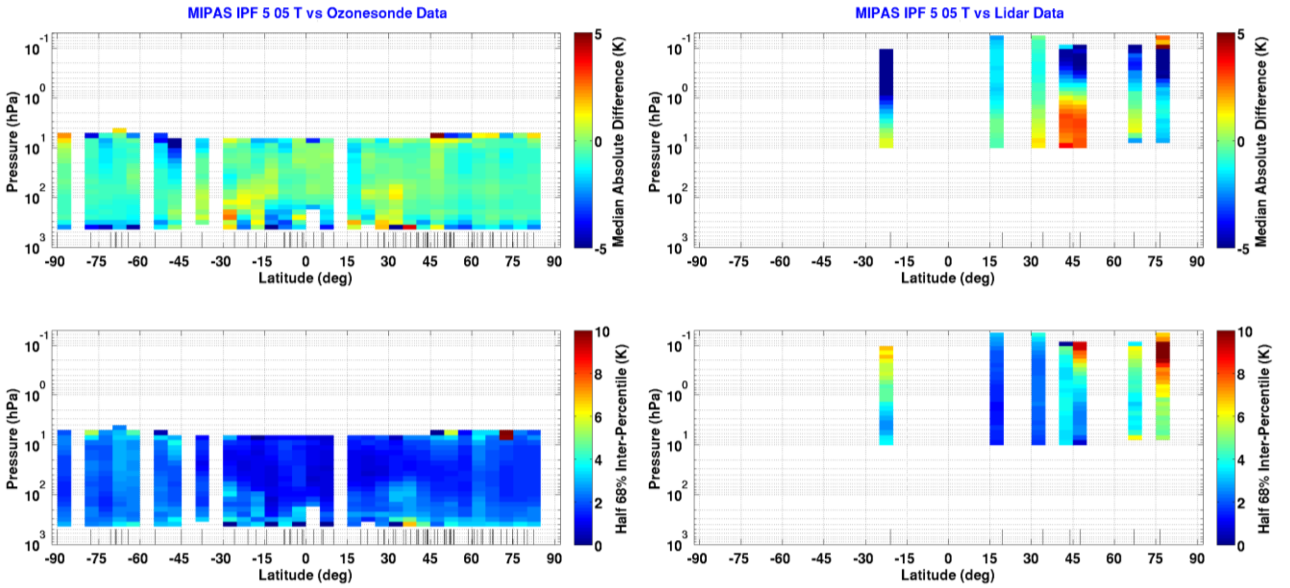

Figure 13: Median (top) and half 68% inter-percentile (bottom) of the absolute difference $\Delta T_{VAK}(p,t)$ between MIPAS IPF 5.05 and correlative data as a function of pressure and latitude; for radiosondes (left) and lidars (right).

Given the long-term stability and the similarity of the results for stations close in latitude, we derived multi-year and zonal statistics for radiosonde and lidar stations. Figure 12 presents the medians (top) and half 68% inter-percentiles (bottom) of the absolute differences $\Delta T_{BOX}(p,t)$, computed for all co-located temperature profiles within 5° latitude bands. Figure 13 shows the same, but for the $\Delta T_{VAK}(p,t)$ absolute differences.

Summary

Our previous conclusions are confirmed by Figure 12 and Figure 13. The MIPAS IPF 5.05 temperature profile exhibits a cold bias at all latitudes and altitudes. It is -(1-2) K in the middle stratosphere, increasing to -(3-4) K in the upper troposphere and stratosphere, in agreement with the combined systematic errors of the co-located measurements. The observed spread ranges from 2 to 4 K, above the expected combined random error. This suggests the existence of additional sources of variability in the comparisons.

We observed a seasonal cycle in the stratosphere at mid and high latitudes stations. However, no large drifts were detected. A study is planned to quantify the effect of including a seasonal component in the current, linear drift model.

Using MIPAS vertical averaging kernel reduces the bias of the comparisons. Our results suggest that the vertical AK is time-dependent, at least in the tropical UTLS this was clearly observable from the comparisons. Such a time dependence is caused by the different instrumental settings between the FR and OR part of the mission, and between the different measurement modes of MIPAS.

IV.2.5 Validation of ozone profile [IPF 4.61/4.62]

The validation was undertaken as part of the multi-mission studies reported in Multi-TASTE annual report #1 [Lambert et al., 2009]. The validation methodology follows that found in Section IV.2.7.

Main conclusions were:

- The timespan of available data is extremely short for the detection of long term trends. Therefore the detected drifts are “noisy”, i.e. they are not consistent from station to station.
- In the middle and high latitude stratosphere, the median agreement between MIPAS IPF 4.61/4.62 and correlative ozone profiles is usually better than 7% ± 10%.
- The main exception is a permanent bias of +10 to +15 % observed in the inter-tropical upper troposphere and lower stratosphere.

IV.2.6 Validation of ozone profile [IPF 4.61/4.62 and IPF 5.04]

The report in which the validation results of full resolution IPF 4.61/4.62 profiles are compared to those of a subset of the optimized resolution IPF 5.04 profiles can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation methodology follows that found in Section IV.2.7.

Key results:

- The comparisons for the IPF 5.04 and the IPF 4.61/4.62 processors are very similar in the stratosphere.
- In the stratosphere, between 10 hPa (≈ 30 km) and 50-100 hPa (≈ 20-15 km), the IPF 5.04 ozone profiles are within ±5% of the correlative data, almost independent of altitude and latitude. The exception is a 20-30% overestimation of Antarctic ozone hole events.
- In the Upper Troposphere Lower Stratosphere (p >50-100 hPa), IPF 5.04 overestimates ground-based measurements by 20% to 50%. Such a positive bias, although of smaller magnitude, has been reported for the previous processor as well [Cortesi et al., 2007].
- The precision of the MIPAS L2 algorithms has improved from 5-10% to 2-5%. After combination with the 5-7% precision of the correlative measurements, this is in agreement with the generally observed 5-10% half 68% inter-percentiles of the comparisons.

IV.2.7 Validation of ozone profile [IPF 5.05]

We present the results of comparisons between full mission IPF 5.05 (August 2002 - March 2011) MIPAS ozone profiles and a data set of correlative ozone profiles provided by ozonesondes and lidars operating in the NDACC, SHADOZ and GAW networks. The full mission reprocessing led to collocation statistics superior to those of the IPF 4.61 - IPF 5.04 validation analysis carried out in the second project year. The improved spatial and temporal sampling of the atmosphere was essential to uncover previously unreported features (seasonal cycle, possible time dependence of vertical averaging kernel, …) in the IPF 5.05 data set.

We found that the MIPAS data set co-located with profiles recorded at 74 ozonesonde and 11 lidar stations. The co-location criteria were chosen as the best compromise between a sufficient amount of comparison points and a sufficient co-location of the probed air masses. First, a maximum distance of 500 km between the ground-based station and the MIPAS tangent point for the scan at 30km altitude, and, second, a maximum time difference of 6h (for both day-time ozonesonde and night-time lidar data). Tightening the spatial criteria reduces the amount of co-locations strongly and hence limits the statistical relevance of the results. MIPAS data points with a ozone retrieval error larger than 500% were rejected, and, when more than five grid points satisfied this condition, the entire profile was removed. Then, the correlative profiles were smoothened to the satellite resolution, using two methods. The first, designated by $O_{3_{corr,BOX}}$, is a simple per-layer average (layers of ~1.5 km thickness). The second method, leading to $O_{3_{corr,VAK}}$, smoothes using the MIPAS vertical averaging kernel. Finally all data (satellite and ground-based) were linearly interpolated to a common pressure grid between 450-0.06 hPa.

Monthly statistics of the agreement between MIPAS IPF 5.05 ozone profile data and ozonesonde measurements from stations contributing to the Multi-TASTE project are provided as an electronic annex.

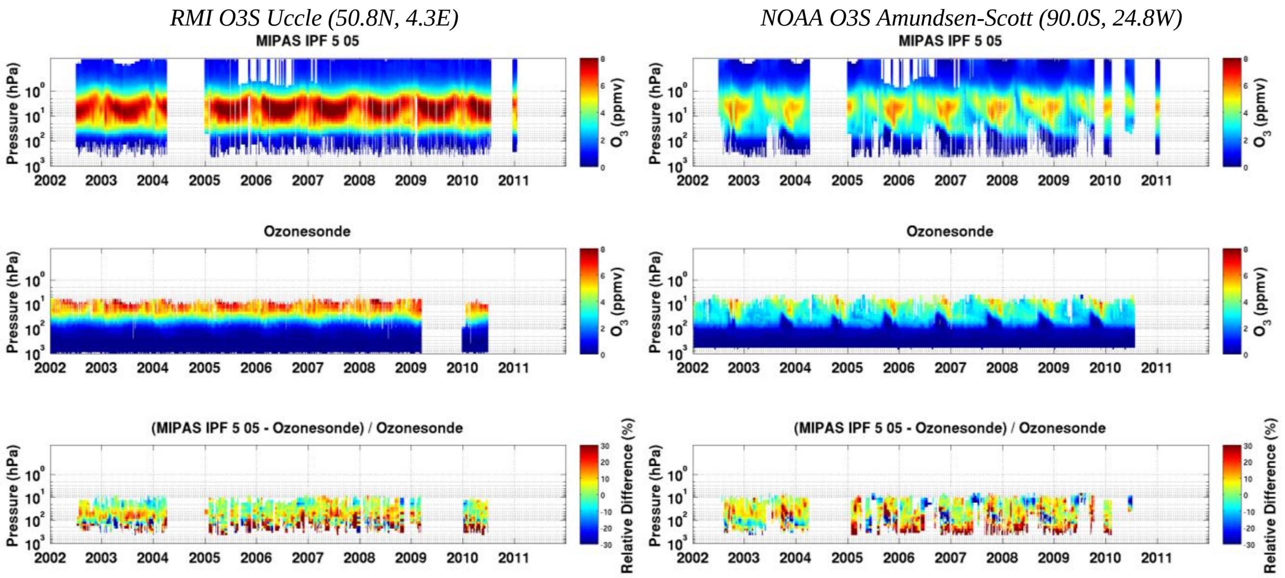

Figure 14: Time series of the vertical ozone profile as retrieved by MIPAS IPF 5.05 (top panels) and by the ozonesondes launched at Uccle, Belgium (left) and Amundsen-Scott, Antarctica (right). The bottom panels show the relative ozone difference between the co-located profiles.

Figure 14 illustrates the first part of the validation study, which consisted of the visual inspection and the statistical study of ozone profile time series at each station. The figure shows the time series of ozone profiles at the ozonesonde station at Uccle, Belgium (left) and Amundsen-Scott, Antarctica (right). The objective is to identify possible global features, cyclic errors and long-term drifts. The top and central panels show the profiles as retrieved respectively by the MIPAS IPF 5.05 processor and by the ground-based measurements, while the bottom panel presents their relative difference, calculated as $\Delta O_{3_{BOX}}(p,t) \equiv \left(O_{3_{MIPAS}}(p,t) - O_{3_{corr,BOX}}(p,t)\right) \,/\, O_{3_{corr,BOX}}(p,t)$. For a better visibility a one-month running mean was applied to all time series. The empty areas p < 1 hPa for the IPF 5.05 time series in 2005-2006 correspond to UTLS-1 measurement mode periods. This mode has a maximum scan altitude of 51.5 km, opposed to 68 km in the nominal measurement mode.

The time series shown in Figure 14 are typical for most ground stations: the qualitative temporal and vertical behaviour of IPF 5.05 is in agreement with the correlative data for a wide range of atmospheric phenomena, except during Antarctic ozone hole conditions. Figure 15 shows the $\Delta O_{3_{BOX}}(p,t)$ difference time series (left) at various pressure levels, for Ny-Alesund (high latitude), Uccle (mid latitude) and Mauna Loa (Tropics). When the time series satisfied some basic quality criteria (sufficient number of points, small spreads, …), it was subjected to a robust linear regression. The sensitivity to outliers was reduced by weighting each observation with Tukey's bisquare function. The parameter of interest is the slope of the regression line, which represents the (linear) drift of the satellite data with respect to the correlative data. We adopted the usual 2σ significance level to reject the no-drift hypothesis. All satellite drift estimates are reported in percent per year and with 2σ error bars (corresponding to 95% confidence level). This analysis was performed for all ground stations.

The time series unveiled a seasonal cycle in the differences, which is most pronounced for stations at mid and high latitudes above the 100 hPa level, see e.g. Uccle or Ny-Ålesund. This was previously not observable, due to the much lower number of comparisons available for analysis. The linear model in our drift analysis does not yet include this effect. However, ignoring seasonalities should not alter the estimated value of the drift, but rather make the drift error estimation too conservative. Our choice hence limits the statistical power to detect drifts, but does not increase the number of false detections. We intend to quantify the impact of the seasonal cycle on the drift estimation in the future.

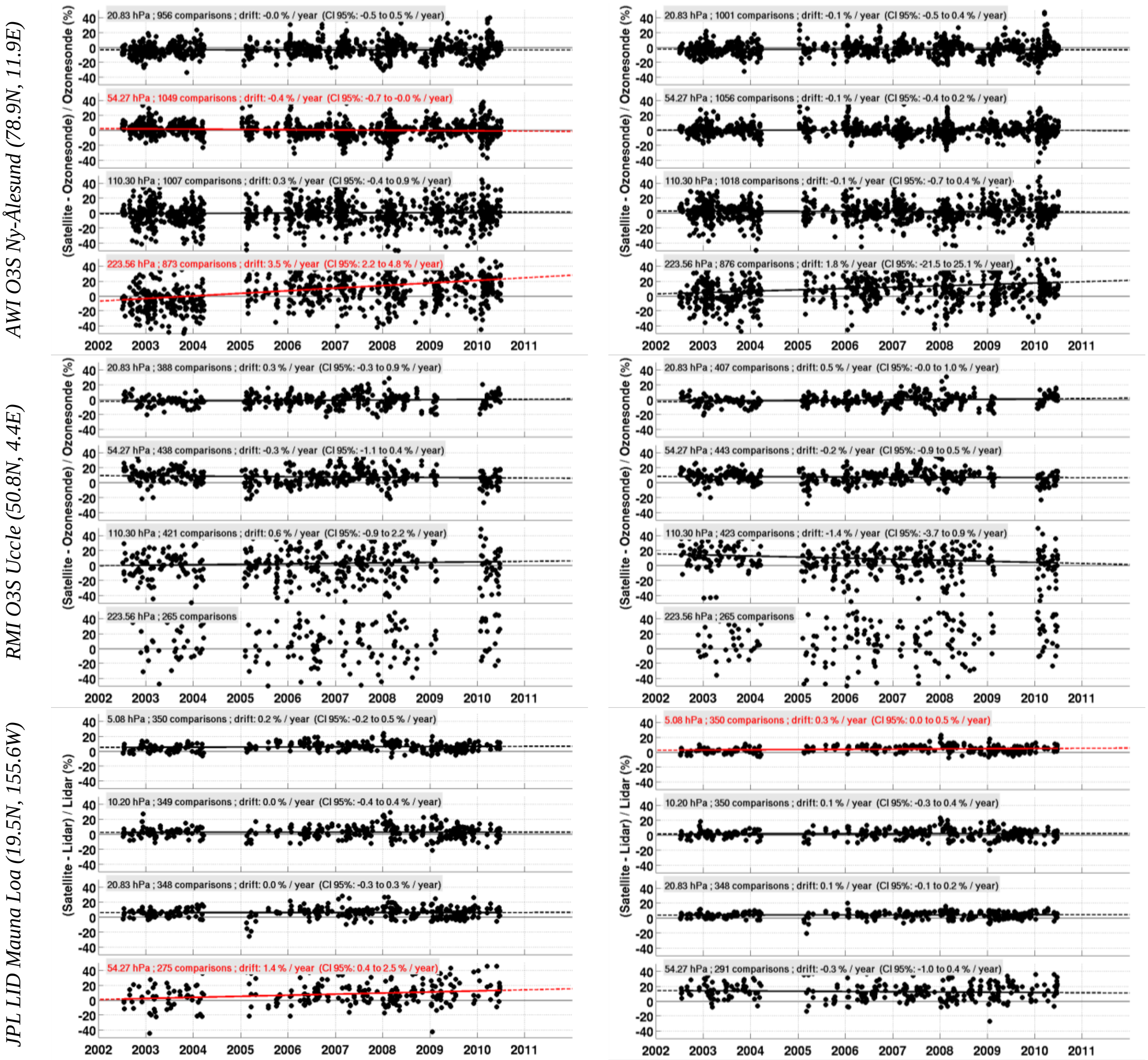

Figure 15: Time series of relative ozone differences $\Delta O_{3\,BOX}(p,t)$ (left) and $\Delta O_{3VAK}(p,t)$ (right) between MIPAS IPF 5.05 and correlative data at Ny-Ålesund, Svalbard and Jan Mayen (top), Uccle, Belgium (centre) and Mauna Loa, Hawaii (bottom) at selected pressure levels. A linear regression was fitted to the data when more than 20 co-located pairs were found and the spread in their relative differences was less than 30%. Black lines are not significant, red lines are significant at 95% confidence level. The annual slope and 95% confidence interval are indicated in each subplot.

The $\Delta O_{3VAK}(p,t) \equiv \left(O_{3\,MIPAS}(p,t) - O_{3\,corr,VAK}(p,t)\right) \,/\, O_{3\,corr,VAK}(p,t)$ time series have a different slope than that of $\Delta O_{3\,BOX}(p,t)$, which does not incorporate vertical AK information. Figure 15 shows the $\Delta O_{3VAK}(p,t)$ time series beside those of $\Delta O_{3\,BOX}(p,t)$. Figure 16 presents the latitudinal cross-section of the drift results at all stations, for $\Delta O_{3\,BOX}(p,t)$ (left) and $\Delta O_{3VAK}(p,t)$ (right).

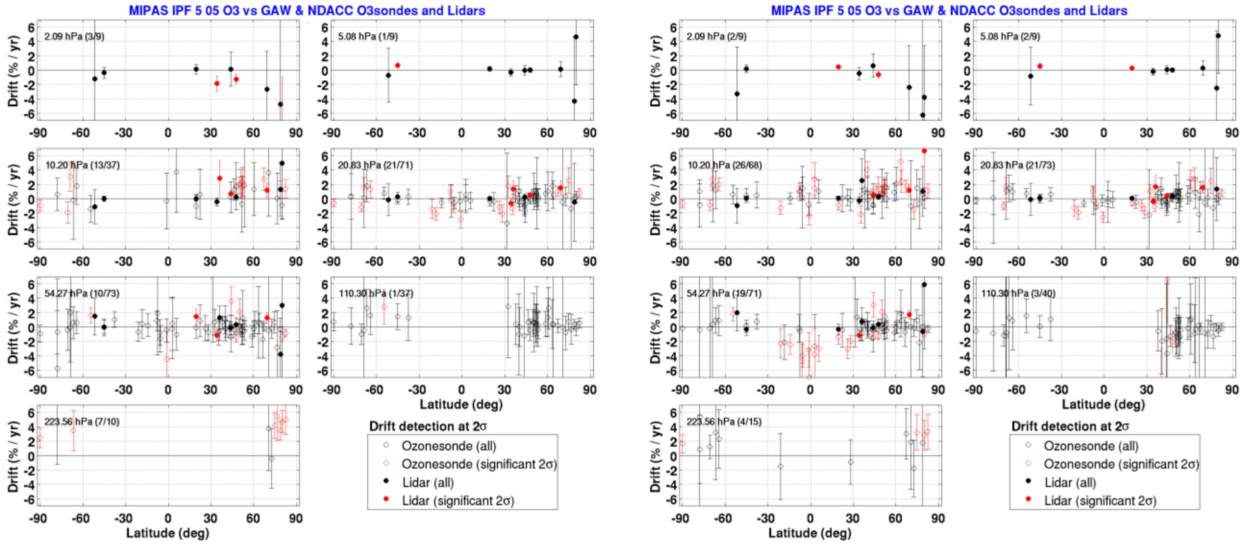

Figure 16: Slope of the multi-year linear trend fitted to time series of the relative differences $\Delta O_{3\,BOX}\ (p,t)$ (left) and $\Delta O_{3VAK}\ (p,t)$ (right) between MIPAS IPF 5.05 and ground-based (ozonesonde=open circle and lidar=closed circle) ozone measurements at each station, plotted as a function of latitude and at different pressure levels. The error bars represent 95% confidence level. Drifts with statistical significance (95% confidence level) are shown in red.

The change in the slope is especially clear in the Tropics in the lower stratosphere (~50 hPa level), where drifts increases from ~0%/yr (box) to ~-2%/yr (AK). This indicates that smoothing the correlative data with MIPAS vertical AK changes the ozone VMR with a time-dependent magnitude, which is expected from the fact that the instrumental settings for the FR and OR part of the mission are quite different, and the differences in vertical sampling for the various MIPAS measurement modes. Differences due to different vertical smoothing methods manifest themselves more where the ozone gradient is large. The lower stratosphere ozone gradient is higher in the Tropics than at other latitudes. The change in slope is therefore less pronounced at mid and high latitudes than in the Tropics. Further investigation is required to make a solid statement about the presence of drifts. For the moment we expect no or only a small drift of MIPAS with respect to correlative data, not more than 2%/year.

In most cases the absence of significant variation with time enables statistical studies of the vertical structure of the relative differences between pairs of co-located profiles. This was done for each ground station; Figure 17 presents the results at the station of Ny-Ålesund. The left panel shows the median (solid) and 68% inter-percentile (dashed) of the relative differences $\Delta O_{3\,BOX}\ (p,t)$ (blue) and $\Delta O_{3VAK}\ (p,t)$ (cyan) between MIPAS IPF 5.05 and ozonesonde measurements. The right panel shows the median relative precision (dashed) and bias (solid) for MIPAS (blue) and for the correlative data (grey). Three additional stations (Sodankylä, Lauder and Maxaranguape Natal) are shown in Figure 18; these results are representative for the other ground-based stations. Between 4 hPa (≈ 36 km) and 20 hPa (≈ 26 km) the IPF 5.05 profiles lie within ±5% of the correlative data. In the lower stratosphere, from 20 hPa down to the tropopause, the comparisons have a positive bias of +(5-7)%. In the upper troposphere, MIPAS overestimates the ozone VMR; the bias increases with decreasing altitude and becomes as large as +40% at the bottom of the profile. Lidar comparisons in the upper stratosphere (>4 hPa) suggest a negative bias of the MIPAS profiles of up to -20% at some stations. The observed biases are in agreement with the combined systematic error of the co-located measurements, except in the extratropical UTLS. The combined systematic error in this part of the atmosphere is too small to explain the bias in the comparisons, especially at higher latitudes.

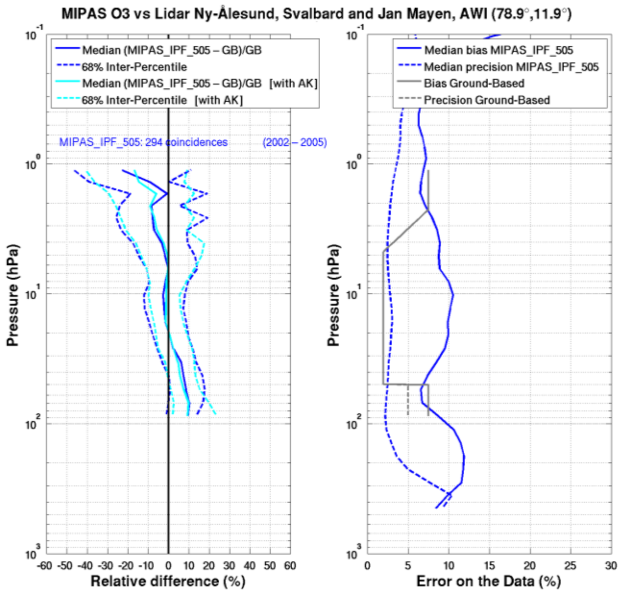

Figure 17 – left: vertical dependence of median (solid) and 68% inter-percentile (dashed) of the relative ozone differences $\Delta O_{3\,BOX}(p,t)$ (blue) and $\Delta O_{3VAK}(p,t)$ (cyan) between MIPAS IPF 5.05 and AWI lidar data at Ny-Ålesund, Svalbard and Jan Mayen. Right panel: median relative precision (dashed) and bias (solid) for MIPAS and correlative data.

FMI O3S Sodankylä (67.4N, 26.7E) | *NIWA O3S Lauder (45.0S, 169.7E)* | *NASA O3S Maxaranguape Natal (5.4S, 35.4W)*

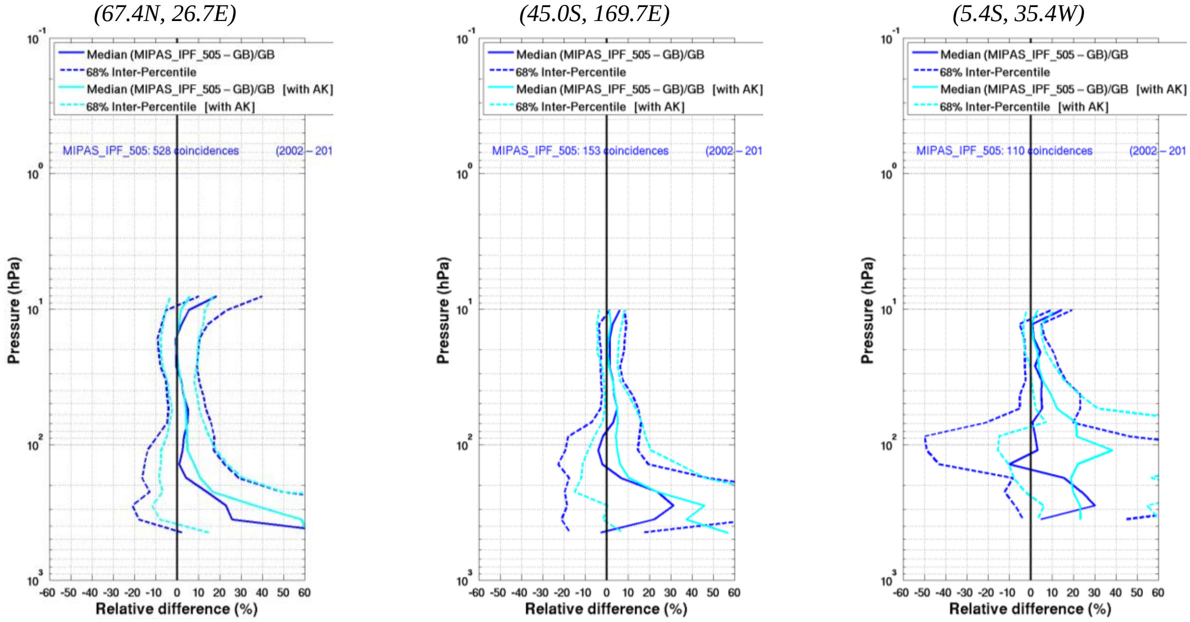

Figure 18: Vertical dependence of median (solid) and 68% inter-percentile (dashed) of the relative ozone differences $\Delta O_{3\,BOX}(p,t)$ (blue) and $\Delta O_{3VAK}(p,t)$ (cyan) between MIPAS IPF 5.05 and correlative data at three ozonesonde stations.

The observed spread is 10% between 4 and 20 hPa, increasing to 10-20% above 4 hPa and between 20 hPa and the tropopause. In the upper troposphere the comparison spread varies between 20-50%. These are larger than expected from the combined random error of MIPAS and the correlative measurements, especially at the top and the bottom of the profile. [Cortesi et al., 2007] drew a similar conclusion for IPF 4.61/4.62; insufficient cloud-flagging and spatial smoothing errors were suggested contributions to the unexplained random error component. Using the MIPAS vertical AK to smoothen the correlative profile reduces the spread in the comparisons only marginally. Figure 18 also shows the impact on the relative differences when smoothing the correlative ozone profile with the MIPAS vertical AK rather than the simple layer-smoothing. The difference between both smoothing methods is larger where the gradient of the ozone profile is larger.

This is especially clear at 100 hPa in the Tropics (cfr. Maxaranguape Natal), and to a lesser degree at mid (Lauder) and high latitudes (Sodankylä).

Given the long-term stability and the similarity of the results for stations close in latitude, we derived multi-year and zonal statistics for ozonesonde and lidar stations. Figure 19 presents the medians (top) and half 68% inter-percentiles (bottom) of the relative differences $\Delta O_{3\,BOX}(p,t)$, computed for all co-located ozone profiles within 5° latitude bands. Figure 20 shows the same, but for the $\Delta O_{3VAK}(p,t)$ relative differences.

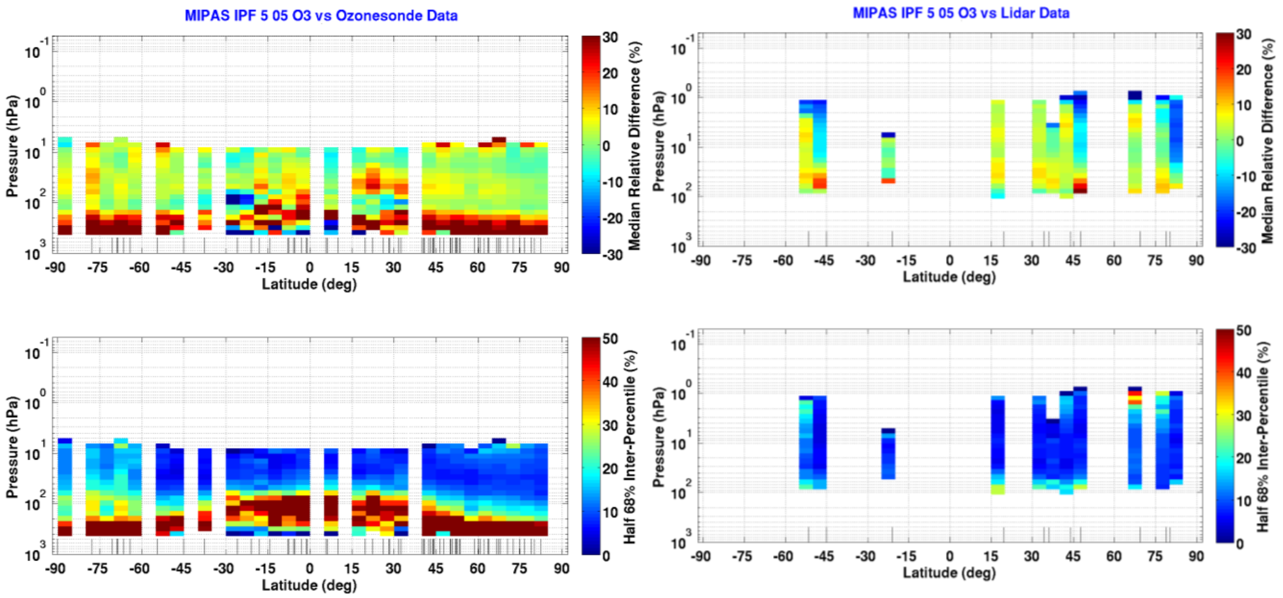

Figure 19: Median (top) and half 68% inter-percentile (bottom) of the relative difference $\Delta O_{3\,BOX}(p,t)$ between MIPAS IPF 5.05 and correlative data as a function of pressure and latitude; for ozonesondes (left) and lidars (right).

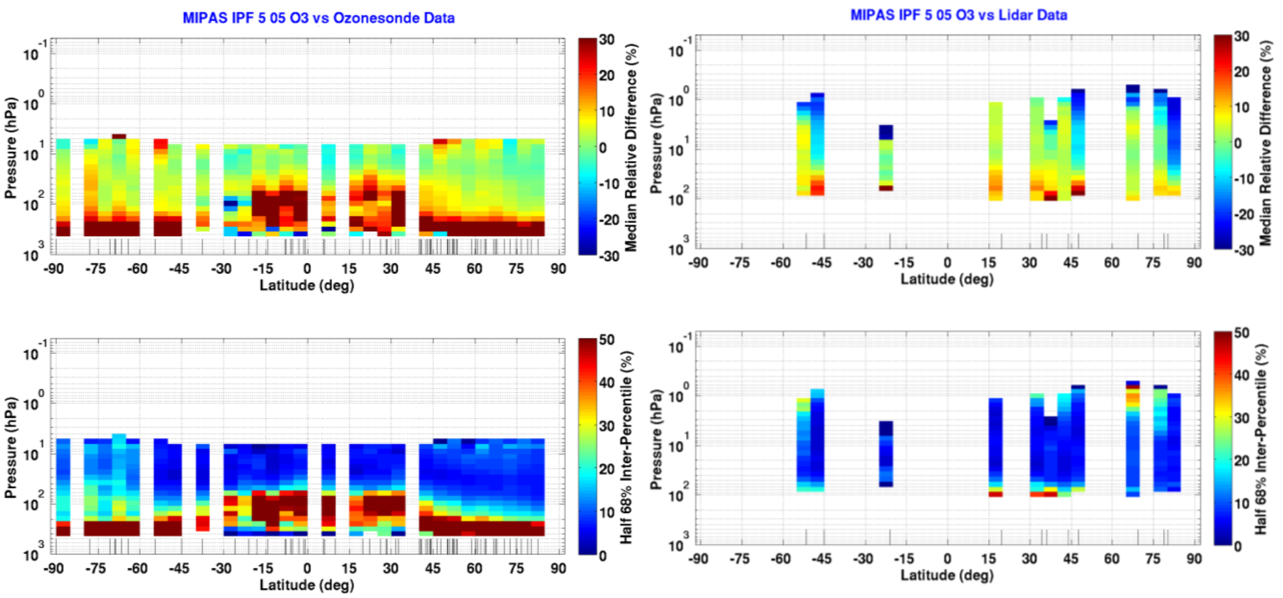

Figure 20: Median (top) and half 68% inter-percentile (bottom) of the relative difference $\Delta O_{3VAK}(p,t)$ between MIPAS IPF 5.05 and correlative data as a function of pressure and latitude; for ozonesondes (left) and lidars (right).

Summary

Our previous conclusions are confirmed by Figure 19 and Figure 20. The MIPAS IPF 5.05 ozone profile remains within 5% of the ozonesonde and lidar observations, in agreement with the combined systematic errors. The exceptions are the UTLS with a +40% bias, and the upper stratosphere with -20% bias with respect to the correlative measurements. The observed spread ranges from 10% to 50%, and are larger than the expected combined random error at the top and bottom of the profile. This suggests the existence of additional sources of variability in the comparisons.

We observed a seasonal cycle in the stratosphere at mid and high latitudes stations. However, no large drifts were detected. A study is planned to quantify the effect of including a seasonal component in the current, linear drift model.

Our results reflect the fact that the MIPAS vertical AKs are time-dependent, at least in the tropical UTLS (and possibly at higher latitudes). Such a time dependence is caused by the different instrumental settings between the FR and OR part of the mission, and between the different measurement modes of MIPAS.

IV.2.8 Validation of CH_4, N_2O and HNO_3 profiles [IPF 5.04]

Methane, nitrous oxide and nitric acid profile data from the MIPAS prototype processor IPF 5.04 have been validated in the second project year against ground-based FTIR data at Jungfraujoch, Kiruna and St Denis at Ile de La Réunion. For each of the products the validation approach follows Vigouroux et al. (2007). Key findings of the validation report can be found in Multi-TASTE annual report #2 [Hubert et al., 2010].

- For methane (CH_4) a small underestimation was observed for IPF 5.04, typically smaller than 10% in the altitude range 20-50 km. The previous processor IPF 4.61 slightly overestimated the CH_4 ground-based data [Payan et al., 2009].
- For nitrous oxide (N_2O) the preliminary comparison results for IPF 5.04 look very close to what was reported for IPF 4.61 [Payan et al., 2009], with differences between the MIPAS and the ground-based data close to zero, except for Kiruna at altitudes above 25 km where the N_2O volume mixing ratio becomes very small.
- The preliminary nitric acid (HNO_3) validation results show discrepancies up to 50%, which is worse than the validation results of the previous processor IPF 4.61/4.62 [Wang et al., 2007]. However, the relevant partial column differences remain to be compared more precisely, taking into account the limited number of degrees of freedom in the ground-based profile data (i.e. very coarse vertical resolution).

IV.3 Envisat SCIAMACHY

The SCIAMACHY processor SGP 3.01 was the baseline at the beginning of the project. A detailed validation study was carried out and reported in the Multi-TASTE Annual Report #1 [2009], available from ESA's Product Control Service (PCS)[2]. In the course of the second year an improved version of the processor, SGP 5.01, was provided to the validation teams. A subset of the complete mission was reprocessed with SGP 5.01, and delivered to the Multi-TASTE partners for the validation of total columns of ozone, nitrogen dioxide, bromine monoxide and carbon monoxide and profiles of ozone. The reprocessing of the entire mission with SGP 5.01 was not yet completed by the end of the final year of the project. But the validation analyses were updated including the operational SGP 5.01 since beginning 2010. The validation reports of various SCIAMACHY products can be found below. In addition, SCIAMACHY SGP 3.01 is included in the systematic multi-mission validation of limb sounders, as reported in Section IV.5.4 on multi-mission studies.

IV.3.1 History of instrument operations and processor upgrades

The latest versions of SCIAMACHY's Level-0-to-1b and Level-1b-to-2 operational processors were activated on 4th February 2010 at the near real-time processing centres and five days later at the D-PAC offline processing centre. The Level-0-to-1b processor, IPF 7.03, introduces a new limb state in the mesosphere (with scan altitudes between 60 and 150 km) and offers improved stray light correction for spectral channel 2. With respect to its predecessor SGP 3.01, the new Level-1b-to-2 processor, SGP 5.01, includes substantial updates and upgrades:

- M-factor correction, impacting nadir O_3 retrievals and AAI retrievals
- Change of NO_2 retrievals now using not radiometrically calibrated data
- New AAI algorithm
- Improvements of cloud fraction retrieval
- New forward model in limb retrievals using Picard iteration
- Optimized settings for limb profile retrieval of NO_2 and O_3
- Usage of the Limb Cloud Flag in O_3 profile retrieval
- Update of the usage of aerosols in O_3 profile retrieval
- Reduction of the step size of the vertical retrieval grid from 3.5 km to 1.75 km between 14-42km

Several new trace gas data products were introduced as well:

- Nadir products: SO_2 total column for normal and volcanic conditions, BrO total column, OClO slant column, H_2O total column and CO total column.
- Limb products: BrO profiles and cloud flags for PSC and tropospheric clouds.

The data quality of the various trace gas data products was evaluated before establishing IPF 7.03 and SGP 5.01 as the new operational processors. The BIRA-IASB validation team identified and delivered to DLR the list of all SCIAMACHY orbits that co-located in space and time with measurements in the correlative data set between 2002 and 2010. Due to reprocessing time constraints, a total of 1900 orbits (mainly during 2002, 2003 and 2006) were processed with IPF 7.03 and SGP 5.01 and made available to the validation teams.

[2] ESA Product Control Service: http://earth.eo.esa.int/pcs/

IV.3.2 Validation of nadir ozone column [SGP 3.01 / SGP 5.01]

SCIAMACHY ozone column data sets available for delta validation of SGP upgrades have been compared to correlative data sets provided by ground-based networks of Dobson and Brewer spectrophotometers and of DOAS/SAOZ UV-visible spectrometers associated with WMO's Global Atmosphere Watch (GAW). The validation methodology is described basically in Lambert et al. [1999,2000], with updates in Balis et al. [2007]. Both SGP 3.01 and SGP 5.01 generate ozone column data generally consistent with GAW ground-based data records. As shown in Figure 21, where SCIAMACHY data available with the two SGP versions (2002, 2003, 2004 and 2006) are compared statistically to the Dobson and Brewer networks, differences between the two SGP versions are small, usually in the form of a bias smaller than 0.6% on an average. With SGP 3.01 a negative drift in ozone column values had been noticed at numerous but not all stations. Although slightly different, this drift seems to persist with the current SGP 5.01 data set available for delta validation. The introduction of the degradation correction improves on the drift in the tropics, but not on mid to high latitudes. Differences between SGP 3.01/5.01 and ground-based networks increase at large Solar Zenith Angle (SZA), as illustrated in Figure 22 at Arctic and Antarctic stations, and at low ozone column values as measured during the Antarctic ozone hole, as illustrated in Figure 23 at two Antarctic stations.

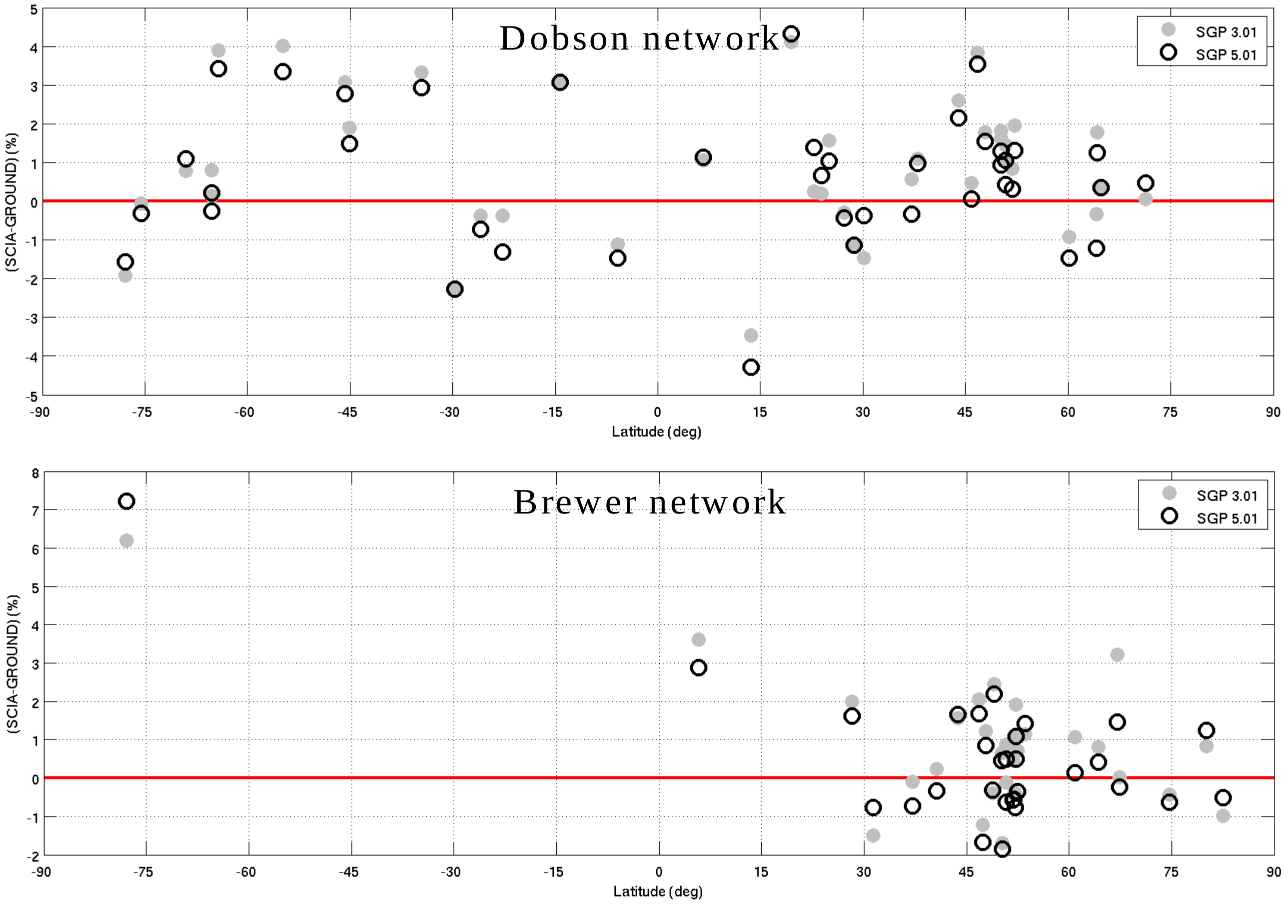

Figure 21: Mean percent relative difference between SCIAMACHY SGP (3.01 and 5.01) and ground-based total ozone measured from pole to pole by the Dobson (top) and Brewer (bottom) networks.Time period: 2002, 2003 and 2006.

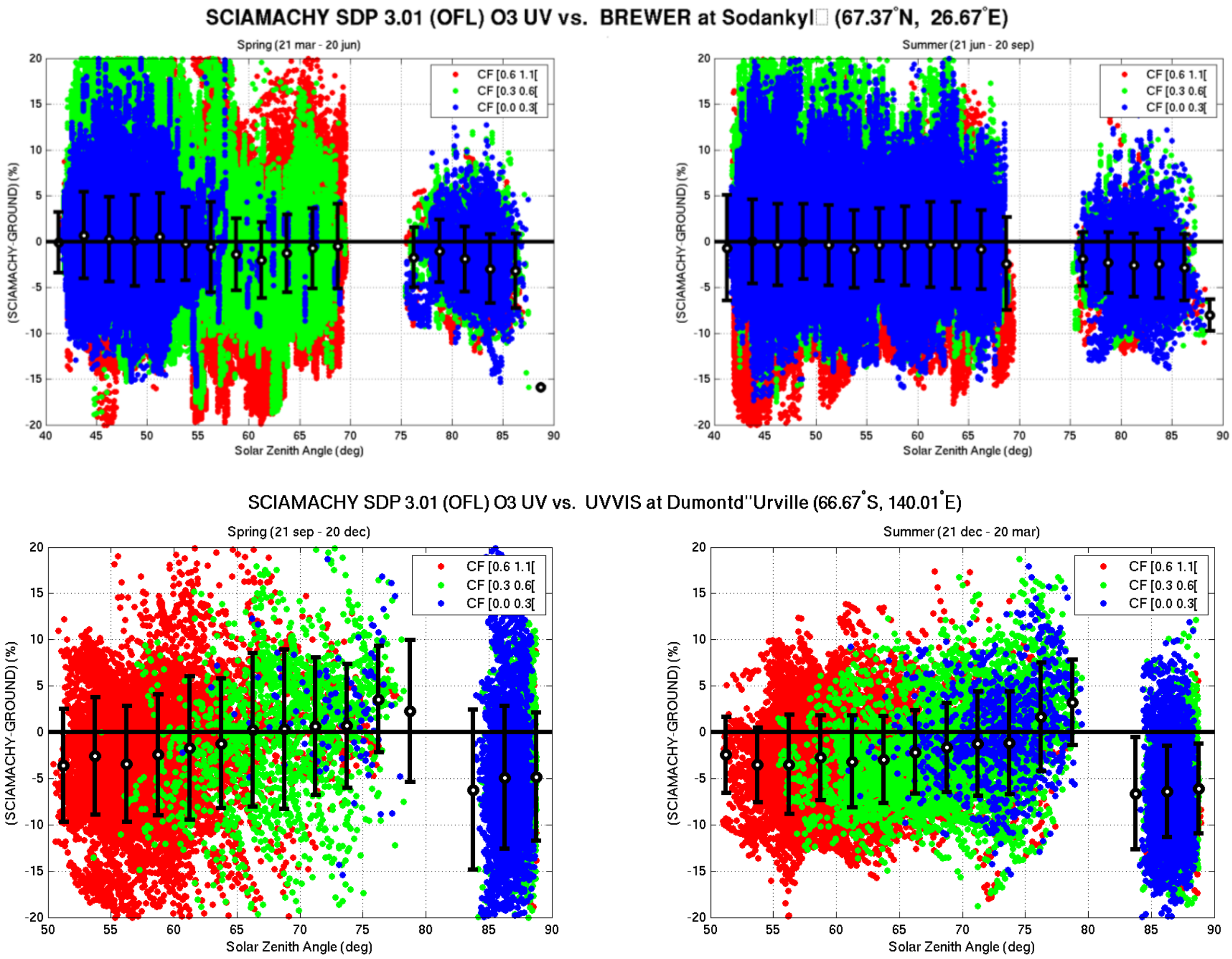

Figure 22: Percent relative difference between SCIAMACHY SGP 3.01 ozone column data and ground-based correlative measurements acquired from 2002 to 2009 by the FMI Brewer at Sodankylä in Finland (top), and the CNRS SAOZ at Dumont d'Urville in Antarctica (bottom). Differences are reported as a function of the SCIAMACHY solar zenith angle and by season (left: spring; right: summer), and sorted by range of cloud fraction (colour code defined in figure caption). Mean and standard deviations have been calculated for 2.5-deg bins of SZA.

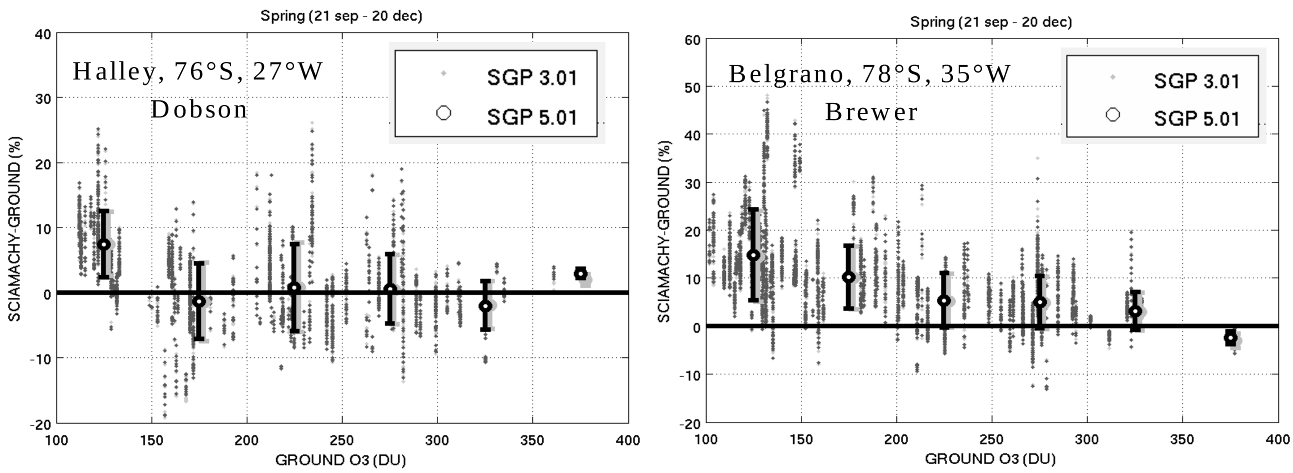

Figure 23: Percent relative difference between SCIAMACHY SGP (3.01 and 5.01) and ground-based total ozone measured in the Antarctic ozone hole at Halley by the BAS-NERC Dobson (left) and at Belgrano by the INTA Brewer (right), as a function of the ground-based total ozone value.

Clouds remain an important source of uncertainty for total ozone retrieval from nadir ultraviolet measurements. The SGP data files contain the fractional cloud cover of the SCIAMACHY ground pixel, the cloud top pressure, and the cloud optical depth. Examples of the dependence of SCIAMACHY ozone data on the cloud fraction are given in Figure 25 at three different stations. Usually this dependence is small, within 1-4%, with in general the best agreement at low cloud fractions and a variable agreement at high cloud fractions. The dependence on the cloud optical depth is more striking: at all low and middle latitude stations with a sufficient amount of comparison pairs, the scatter of the differences increases dramatically as the optical depth decreases, as illustrated in Figure 24. At higher latitudes the optical depth dependence becomes dominated by other sources of uncertainties – e.g. the SZA dependence - and does not appear so clearly.

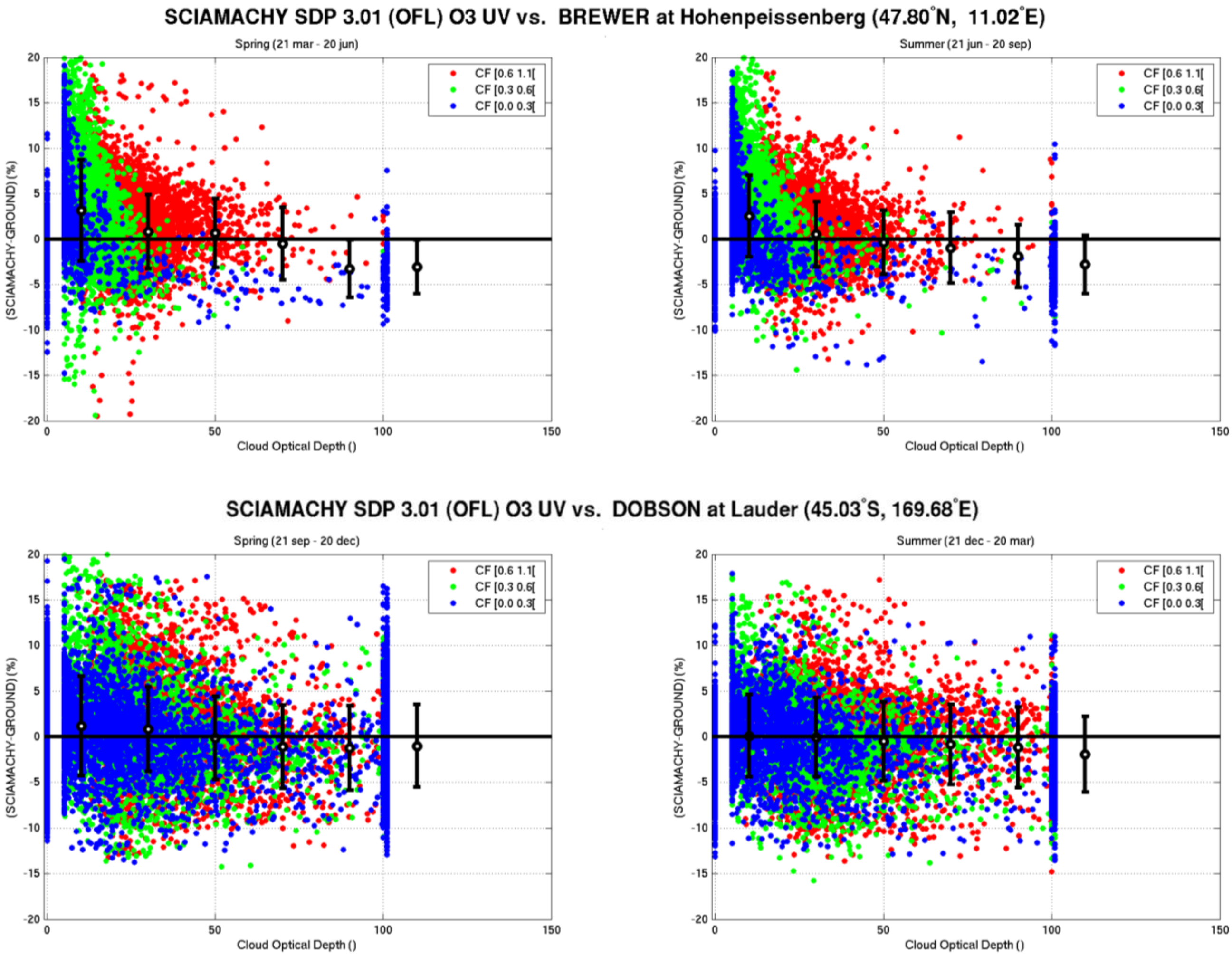

Figure 24: Percent relative difference between SCIAMACHY SGP 3.01 and NDACC ozone column measurements by the DWD Brewer at Hohenpeißenberg and the NIWA Dobson at Lauder, depicted as a function of the cloud optical depth, and sorted by cloud fraction range (colour code in figure caption).

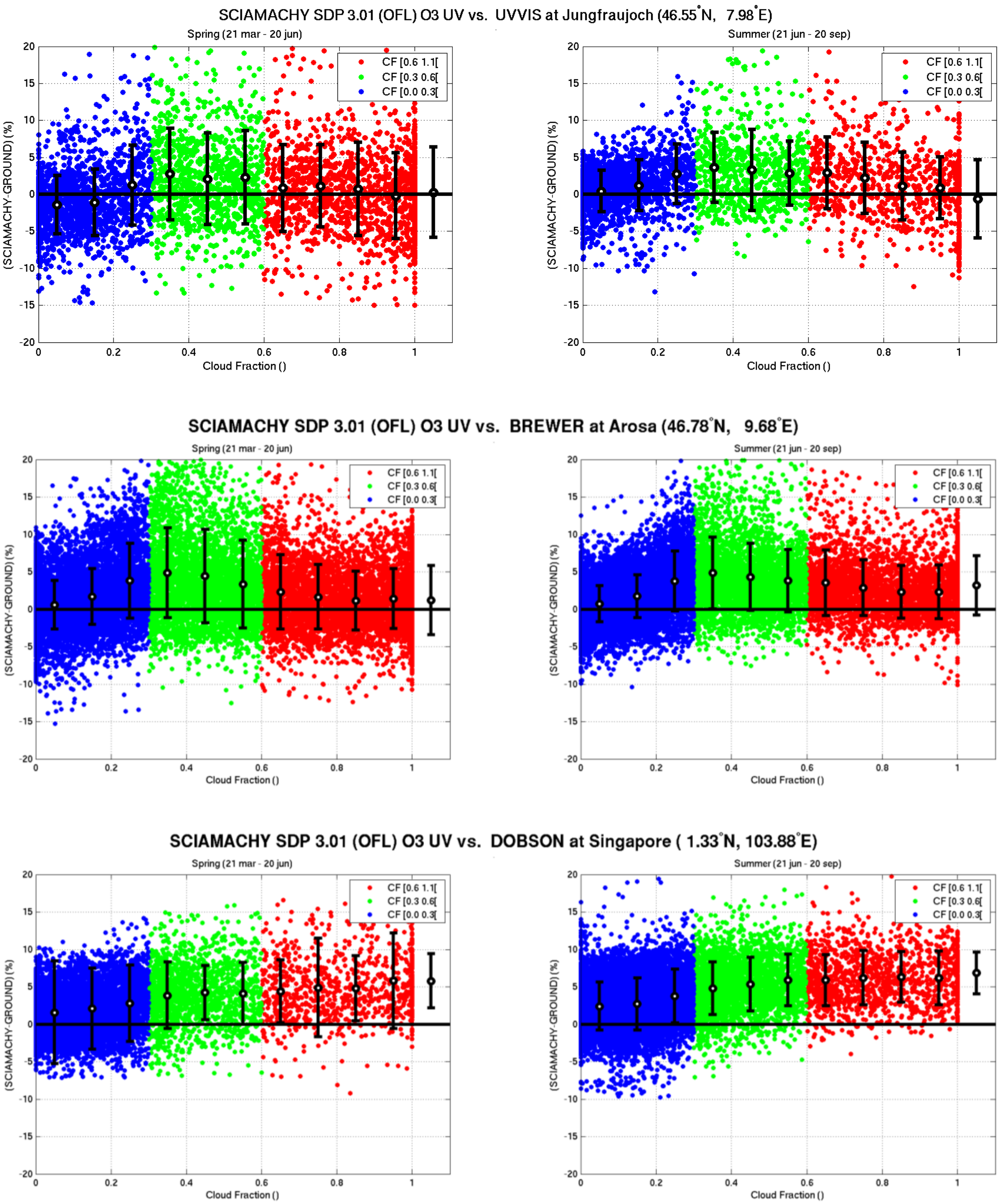

Figure 25: Percent relative difference between SCIAMACHY SGP 3.01 and NDACC ozone column measurements by the IASB-BIRA SAOZ at the Jungfraujoch, the MCH Brewer at Arosa, and the MSS Dobson in Singapore, depicted as a function of the fractional cloud cover of the SCIAMACHY ground pixel.

IV.3.3 Validation of nadir nitrogen dioxide column [SGP 3.01 / SGP 5.01]

Initial validation of SCIAMACHY SGP 3.01 NO_2 column data can be found in Multi-TASTE Annual Report #1 [Lambert et al., 2009]. An update of SGP 3.01 validation is reported below in Section IV.5.3 on multi-mission validation. Delta-validation results of the SGP upgrade from version 3.01 to 5.01 are reported in Multi-TASTE Annual Report #2 [Lambert et al., 2010], and main results are reproduced hereafter.

SGP 3.01 and SGP 5.01 (available in 2002, 2003, 2004 and 2006) generate NO_2 column data mutually consistent and consistent also with NDACC/UV-visible and GOME GDP 4.1 data records. Figure 26 shows the statistical comparison of SGP total column data with stratospheric column data measured by the NDACC/UV-visible network. The methodology of comparison is detailed in Section IV.5.3. SGP 3.01 usually is lower than SGP 5.01 by a few 10^{13} to 10^{14} molec.cm^{-2}, a value close to the detection limit of UV-visible spectrometers. In the Northern Hemisphere direct comparisons between SCIAMACHY total column data with NDACC stratospheric column data yield apparent biases of up to several 10^{15} molec.cm^{-2}, actually due to their difference in sensitivity to large amounts of tropospheric NO_2 (over Europe and Japan). In the Southern Hemisphere, where low levels of tropospheric NO_2 enable direct comparisons between SCIAMACHY and ground-based data, SCIAMACHY SGP 3.01/5.01 is low biased with respect to NDACC and GOME GDP 4.1, by about 5 10^{14} molec.cm^{-2}. This negative bias exhibits a seasonal cycle, as illustrated in Figure 26.

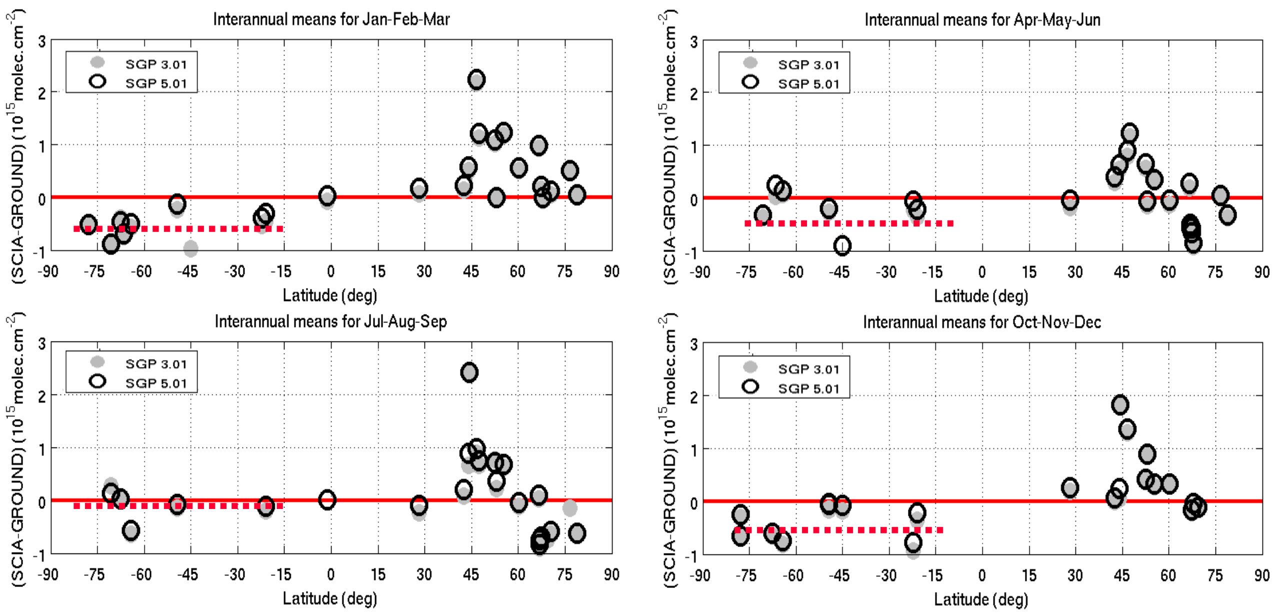

Figure 26: Mean absolute difference between SCIAMACHY SGP (3.01 and 5.01) and ground-based total NO_2 measured from pole to pole by NDACC UV-visible spectrometers. Results are presented by season. At NDACC stations the difference between SGP 3.01 and 5.01 falls within the error bar of the ground-based measurements. Large differences between SGP and NDACC data over Northern middle latitudes (affected by pollution in Europe and Japan) are not accurate and should not be interpreted quantitatively.

Main conclusions:

- SGP 3.01 and SGP 5.01 generate NO_2 column data mutually consistent and also with NDACC/UV-visible and GOME GDP 4.1 data records.
- Where SGP data are compared statistically to the NDACC/UV-visible network, SGP 3.01 usually is lower than SGP 5.01 by a few 10^{13} to 10^{14} molec.cm^{-2}, a value close to the detection limit of UV-visible spectrometers.
- SCIAMACHY SGP 5.01 is low biased with respect to NDACC and GOME GDP 4.1 in the Southern Hemisphere, by about 5 10^{14} molec.cm^{-2}. This negative bias exhibits a seasonal cycle.

IV.3.4 Validation of KNMI/DOMINO nadir nitrogen dioxide column

Stratospheric NO_2 columns retrieved from SCIAMACHY nadir, GOME, and GOME-2 measurements using the KNMI/BIRA DOMINO algorithm have been compared to ground-based SAOZ observations at the NDACC station of Jungfraujoch (46.5°N, 8.0°E). All pixels falling within a radius of 300 km around the station were selected. To ensure photochemical matching, sunrise ground-based UV-visible data were converted to the satellite overpass SZA using a stacked box photochemical model. A very good agreement is found with mean satellite–SAOZ relative differences of +1±9 % (about +2 10^{13} molec.cm^{-2}), +2±11 % (about +4 10^{13} molec.cm^{-2}), and +2±10 % (about +4 10^{13} molec.cm^{-2}) for GOME, SCIAMACHY, and GOME-2, respectively (see Figure 27). This comparison exercise as well as trend analyses of stratospheric NO_2 using both satellite and SAOZ data sets are presented in Hendrick et al. (2012).

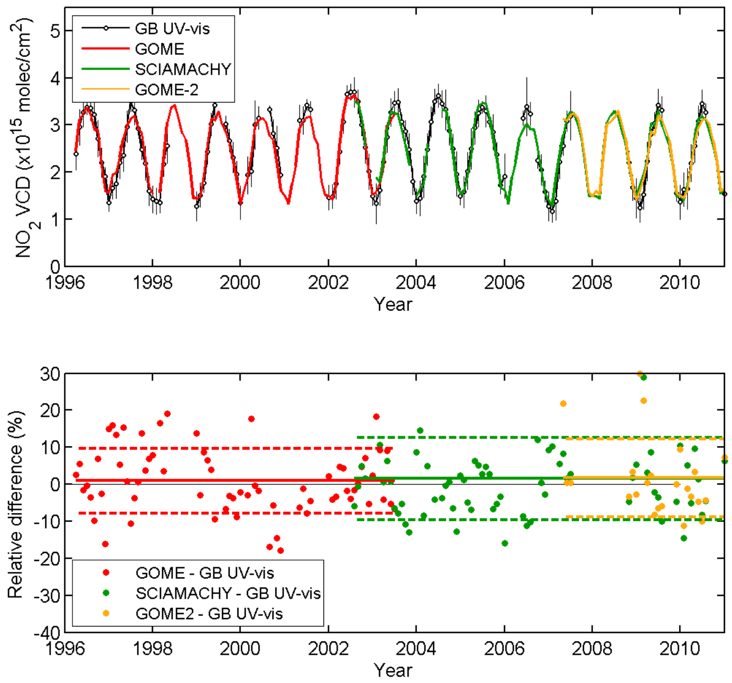

Figure 27: Comparison between stratospheric NO_2 columns retrieved from SCIAMACHY nadir, GOME and GOME-2 measurements (KNMI/DOMINO product) and ground-based SAOZ observations at the NDACC station of Jungfraujoch (46.5°N, 8.0°E).

IV.3.5 Delta-validation of nadir bromine monoxide column [SGP 5.01]

The UV-VIS Group of BIRA-IASB has been also involved in the 2010 SCIAMACHY delta-validation (the new processing baseline 7.03/5.01). The nadir BrO product has been verified through comparisons with total BrO columns retrieved from ground-based UV-visible observations at Harestua (60°N, 11°E). A description of the ground-based UV-visible data set can be found in Hendrick et al. (2007) and the validation approach is similar to the one used for the nadir NO_2 columns (see Section IV.3.4). A reasonably good agreement is found in 2003 and 2006 with a mean SCIAMACHY – ground-based relative difference of -17±20 % (see Figure 28). The comparison also revealed a more marked BrO seasonality in the SCIAMACHY data set and a problem in SCIAMACHY data in 2002 with a lot of negative column values.

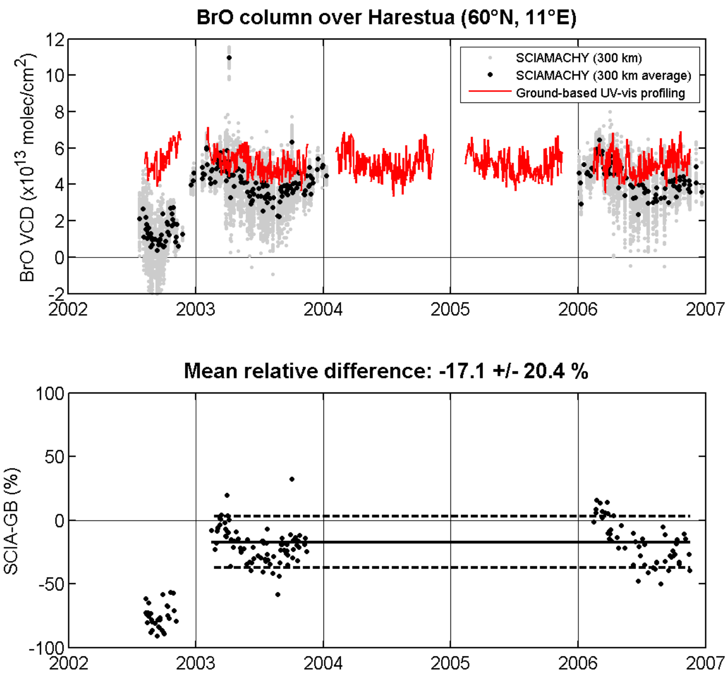

Figure 28: Comparison of the total BrO columns retrieved from SCIAMACHY nadir (SGP 5.01) and ground-based UVVIS measurements at the NDACC station of Harestua (60°N, 11°E).

IV.3.6 Validation of nadir methane column [IMAP, WFMD]

The validation report can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation methodology is based on Dils et al (2006).

Main results:

- The precision of SCIAMACHY XCH4 from IMAP v4.9 and WFM-DOAS v1.0 has strongly improved since 2005 (WFM-DOAS v0.41). Due to this improvement it is now possible to retrieve via a relatively small 200 km pixel selection radius realistic values on the day-to-day variability of XCH4.
- There is a high bias of SCIAMACHY IMAP v4.9 and WFM-DOAS v1.0 of 2 to 2.5% relative to the global FTIR data set.
- There is no significant latitudinal dependency of the bias.
- Still no significant correlation of the annual cycles between FTIR and SCIA can be found. Comparisons of the seasonality of XCH4 between the FTIR and the SCIAMACHY WFM-DOAS and IMAP data, show that IMAP-DOAS has a similar amplitude as FTIR but with a noticeable phase shift while WFM-DOAS exhibits an even stronger seasonality but also exhibits a much larger scatter.

IV.3.7 Delta-validation of nadir carbon monoxide column [SGP 5.01]

The validation report can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation methodology is based on Dils et al (2006).

Main conclusions:

- The SGP 5.01 CO total column data set suffers from a large amount of extreme outliers, zeros and negative values.
- Even after the elimination of these noisy data, no seasonal cycle is visible for SGP 5.01.
- The CO column data are both inadequate in precision and accuracy.

IV.3.8 Validation of limb ozone profile [SGP 3.01]

Previous validation results can be found in Multi-TASTE annual report #1 [Lambert et al., 2009], and an update in Multi-TASTE annual report #2 [Hubert et al., 2010]. The results were updated recently and are detailed in Section IV.5.4 on multi-mission studies.

Monthly statistics of the agreement between SCIAMACHY limb SGP 3.01 ozone profile data and correlative measurements from ozonesonde stations contributing to the Multi-TASTE project are provided as an electronic annex.

IV.3.9 Delta-validation of limb ozone profile [SGP 5.01]

The validation report can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. This delta-validation captured the main points of the analysis carried out on a more complete data set, which is reported in Section IV.3.10. The validation approaches of the two analyses are identical.

Key findings:

- Comparison to ozonesondes and lidars of a partial SGP 5.01 data set covering 2002-2003 and 2006.
- Sign of seasonal cycle and drift in the differences at various stations, but data set too small to be conclusive.
- Median agreement of SGP 5.01 with correlative data is within ±(5-10)%, increasing to ±(10-20)% in the southern hemisphere.
- With respect to SGP 3.01 version 5.01 removes the permanent -10% bias at high northern latitudes, but has a higher bias in the Tropics.
- The observed 10% variability in the comparisons is explained by the combined precision expectation. However, there is an interesting oscillating feature of the SGP 5.01 precision between 20-35km.

IV.3.10 Validation of limb ozone profile [SGP 5.01]

We present the results of comparisons between SGP 5.01 (August 2002 to March 2011) SCIAMACHY ozone profiles and a data set of correlative ozone profiles provided by ozonesondes and lidars operating in the NDACC, SHADOZ and GAW networks. We repeated the analysis of Section IV.3.9 with additional data. The SGP 5.01 data set of the delta-validation round was augmented with all data since beginning of February 2010, when the SGP 5.01 processor was switched on at the offline processing centre. The additional data allowed to strengthen the evidence for a seasonal cycle in the comparisons, but lacks the temporal sampling needed to arrive at firm conclusions about e.g. long-term drifts. This analysis will be accessible once the complete mission has been reprocessed.

We found that the SCIAMACHY data set co-located with profiles recorded at 58 ozonesonde and 11 lidar stations. The co-location criteria were chosen as the best compromise between a sufficient amount of comparison points and a sufficient co-location of the probed air masses. First, a maximum distance of 500 km between the ground-based station and the SCIAMACHY tangent point, and, second, a maximum time difference of 12h. Tightening the spatial criteria reduces the amount of co-locations strongly and hence limits the statistical relevance of the results. SCIAMACHY data points with an ozone number density error larger than 500% were rejected, and, when more than five grid points satisfied this condition, the entire profile was removed. Then, the correlative profiles were box-averaged to the satellite resolution. Finally all data (satellite and ground-based) were linearly interpolated to a common altitude grid between 14 and 100 km. Monthly statistics of the agreement between SCIAMACHY SGP 5.01 ozone profile data and ozonesonde measurements from stations contributing to the Multi-TASTE project are provided as an electronic annex.

FMI O3S Sodankylä (67.4N, 26.6E) *MCH O3S Payerne (46.8N, 7.0E)*

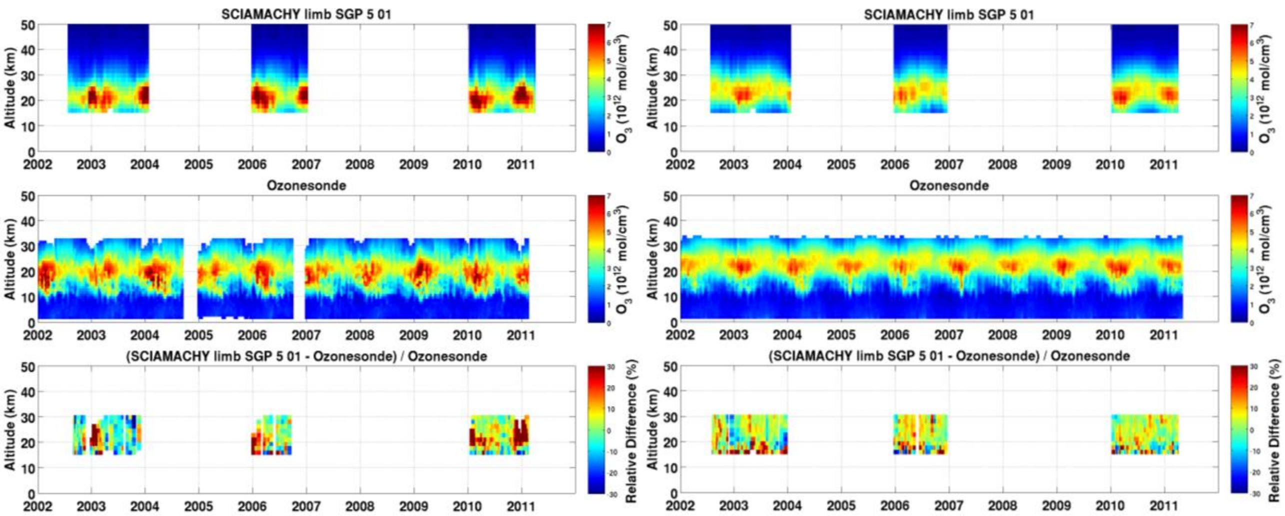

Figure 29: Time series of the vertical ozone profile as retrieved by SCIAMACHY SGP 5.01 (top panels) and by the ozonesondes launched at Sodankylä, Finland (left) and Payerne, Switzerland (right). The bottom panels show the relative ozone difference between the co-located profiles.

Figure 29 illustrates the first part of the validation study, which consisted of the visual inspection and the statistical study of ozone profile time series at each station. The figure shows the time series of ozone profiles at the ozonesonde station at Sodankylä, Finland (left) and Payerne, Switzerland (right). Even though the SCIAMACHY mission is only partly processed, these figures indicate possible global features, cyclic errors and, to a lesser extent, long-term drifts. The top and central panels show the profiles as retrieved respectively by the SCIAMACHY SGP 5.01 processor and by the ground-based measurements, while the bottom panel presents their relative difference, calculated as $\Delta O_3(z,t) \equiv \left(O_{3\,SCIA}(z,t) - O_{3\,corr}(z,t)\right) \;/\; O_{3\,corr}(z,t)$. For a better visibility a one-month running mean was applied to all time series.

The time series shown in Figure 29 are typical for most ground stations: the qualitative temporal and vertical behaviour of SGP 5.01 is in reasonable agreement with the correlative data for a wide range of atmospheric phenomena. Figure 30 shows the $\Delta O_3(z,t)$ difference time series at various altitude levels, for Sodankylä, Finland (high latitude) and Payerne, Switzerland (mid latitude). When the time series satisfied some basic quality criteria (sufficient number of points, small spreads, …), it was subjected to a robust linear regression. The sensitivity to outliers was reduced by weighting each observation with Tukey's bisquare function. The parameter of interest is the slope of the regression line, which represents the (linear) drift of the satellite data with respect to the correlative data. We adopted the usual 2σ significance level to reject the no-drift hypothesis. All satellite drift estimates are reported in percent per year and with 2σ error bars (corresponding to 95% confidence level). This analysis was performed for all ground stations.

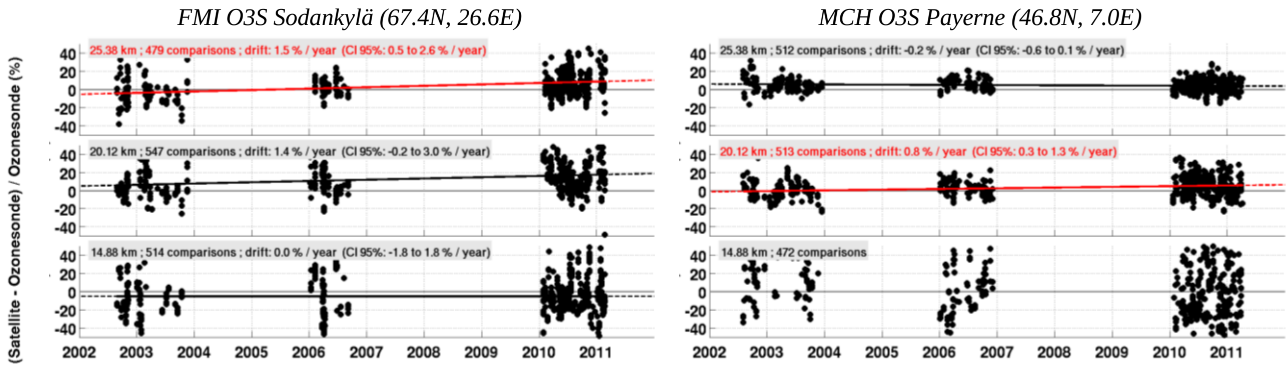

Figure 30: Time series of relative ozone differences $\Delta O_3(z,t)$ between SCIAMACHY SGP 5.01 and correlative data at Sodankylä, Finland (left) and Payerne, Switzerland (right) at selected altitude levels. A linear regression was fitted to the data when more than 20 co-located pairs were found and the spread in their relative differences was less than 30%. Black lines are not significant, red lines are significant at 95% confidence level. The annual slope and 95% confidence interval are indicated in each subplot.

The time series unveiled a seasonal cycle with a considerable amplitude (up to 10% in the Arctic) in the differences, probably at all stations and altitudes, similar to that found in the comparisons of the SGP 3.01 processor with correlative data (see Section IV.3.8). Unfortunately the comparison data set currently lacks the statistics to be conclusive. The linear model in our drift analysis does not yet include seasonalities. However, ignoring this should not alter the estimated value of the drift, but rather make the drift error estimation too conservative. Our choice hence limits the statistical power to detect drifts, but does not increase the number of false detections. We intend to quantify the impact of the seasonal cycle on the drift estimation in the future.

Figure 31 presents the latitudinal cross-section of the SGP 5.01 drifts at all stations. Some stations show significant drifts at the 2σ level, but overall the uncertainty is too large to detect drifts smaller than 2-4% per year in the current SGP 5.01 comparison data set. This is entirely due to the sparse comparison time series. A solid statement about the presence of drifts will be possible once the full mission has been reprocessed.

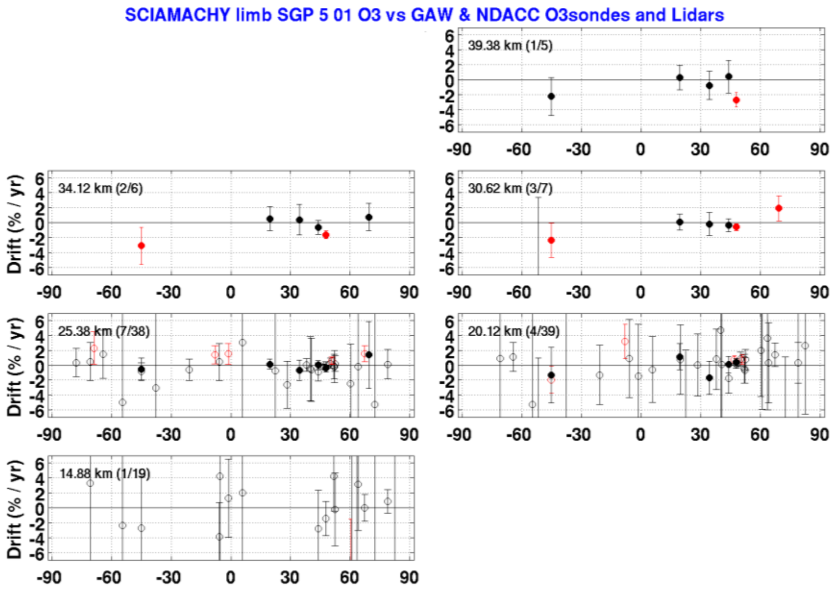

Figure 31: Slope of the multi-year linear trend fitted to time series of the relative differences $\Delta O_3(z,t)$ between SCIAMACHY SGP 5.01 and ground-based (ozonesonde = open circle and lidar = closed circle) ozone measurements at each station, plotted as a function of latitude and at different altitude levels. The error bars represent 95% confidence level. Drifts with statistical significance (95% confidence level) are shown in red.

In most cases the absence of significant dependencies on time permitted the statistical study of the vertical structure of the relative ozone differences between pairs of co-located profiles. This was done for each ground station; Figure 32 presents the results at the station of Ny-Ålesund, Svalbard and Jan Mayen. The left panel shows the median (solid) and 68% inter-percentile (dashed) of the relative differences $\Delta O_3(z,t)$ (blue) between SCIAMACHY SGP 5.01 and ozonesonde measurements. The right panel shows the median relative precision (dashed) and bias (solid) for SCIAMACHY (blue) and for the correlative data (grey). Unfortunately the bias is not provided in the SCIAMACHY data set. Three additional stations (Payerne, Ascension Island and Neumayer) are shown in Figure 33; these results are representative for the other ground-based stations.

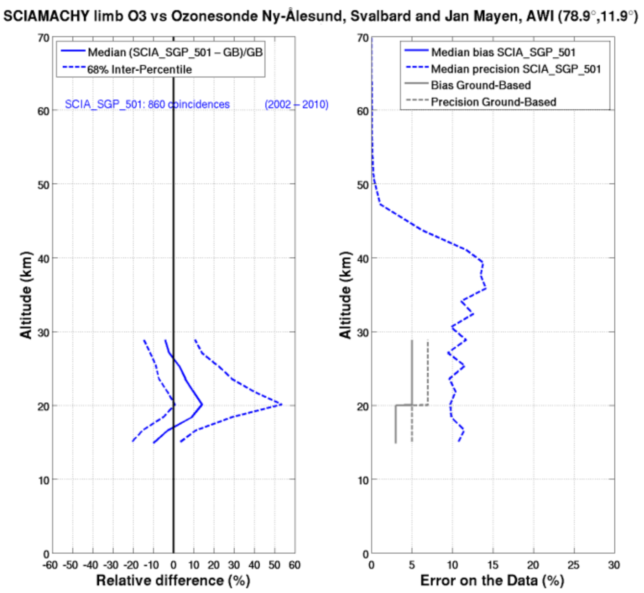

Figure 32 – left: vertical dependence of median (solid) and 68% inter-percentile (dashed) of the relative ozone differences $\Delta O_3(z,t)$ between SCIAMACHY SGP 5.01 and AWI ozonesonde data at Ny-Ålesund, Svalbard and Jan Mayen. Right panel: median relative precision (dashed) and bias (solid) for SCIAMACHY and correlative data. No bias is provided in the SCIAMACHY data.

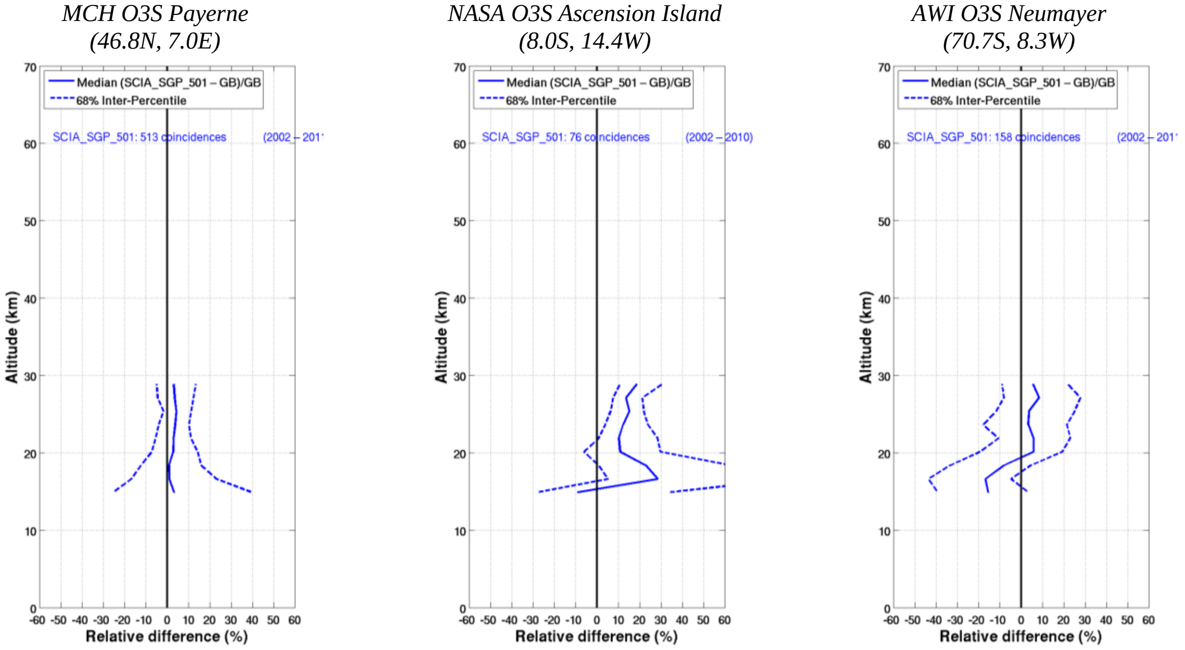

Figure 33: Vertical dependence of median (solid) and 68% inter-percentile (dashed) of the relative ozone differences $\Delta O_3(z,t)$ between SCIAMACHY SGP 5.01 and correlative data at three ozonesonde stations.

At high northern latitudes (e.g. Ny-Ålesund) there is a +10% bias between 18-25 km. The lidar data indicate a similar overestimation at 40 km as well. At other altitudes, the bias is smaller. SGP 5.01 performs best at mid northern latitudes (e.g. Payerne), where the bias is smaller than 5% over the whole altitude range. In the Tropics (e.g. Ascension Island) the station-to-station variability is larger due to smaller comparison data sets. We observe a large positive bias (up to +40%) in the UTLS and a +20% overestimation around 30 km, at other altitudes the bias is smaller, but always positive. At mid southern latitudes we notice a +10% bias between 25 and 35 km. In the Southern polar region (e.g. Neumayer) the comparisons indicate a +5% bias above 20 km and a -10% bias below. We could not interpret whether the observed biases can be explained by the combined systematic error of the co-located instruments, since the latter is not provided in the SCIAMACHY data set.

The observed spread ranges from 10% to 50%. In the UTLS and at higher altitudes in the Polar atmosphere the spread in the comparisons is larger than the expected combined random error of correlative and SCIAMACHY data. This suggests the existence of additional sources of variability in the comparisons (e.g. errors due to smoothing or spatial mismatch) and/or the underestimation of the random errors of the co-located instruments.

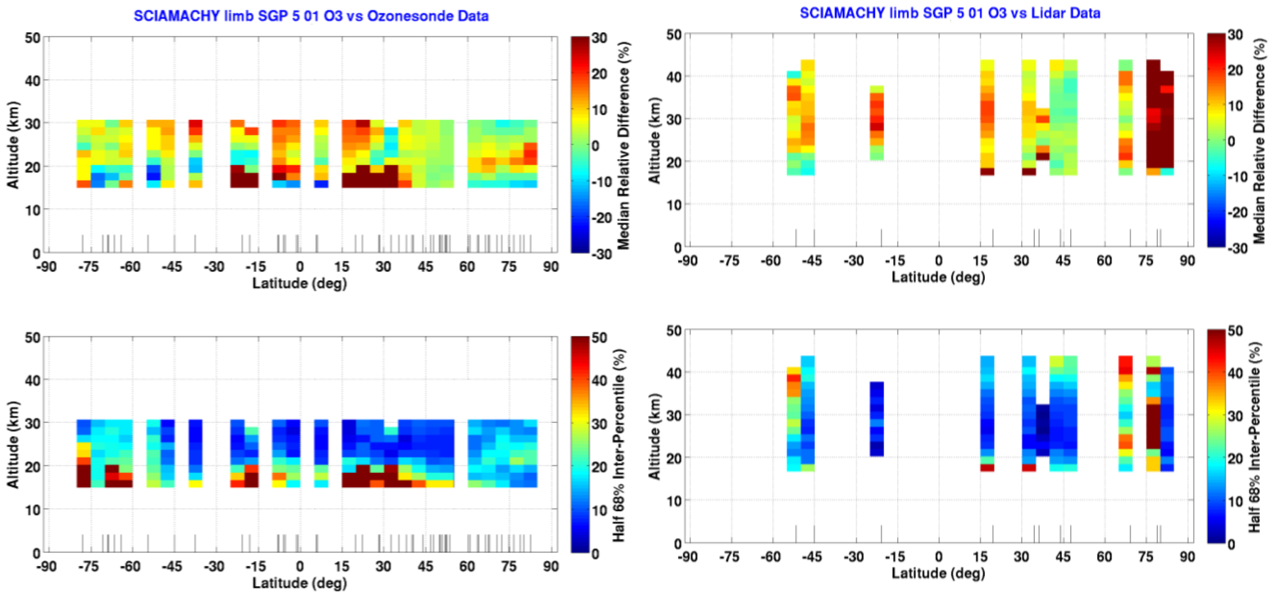

Figure 34: Median (top) and half 68% inter-percentile (bottom) of the relative difference $\Delta O_3(z,t)$ between SCIAMACHY SGP 5.01 and correlative data as a function of altitude and latitude; for ozonesondes (left) and lidars (right).

Given the long-term stability and the similarity of the results for stations close in latitude, we derived multi-year and zonal statistics. Figure 34 presents the medians (top) and half 68% inter-percentiles (bottom) of the relative differences $\Delta O_3(z,t)$ with respect to ozonesonde (left) and lidar stations (right), computed for all co-located ozone profiles within 5° latitude bands. In the altitude region where ozonesondes and lidar measurements overlap, there is a good agreement between both types of validating instruments. The apparent disagreement at the O_3 lidar sites of Eureka (80° N, 3 collocations) and Ny-Ålesund (79° N, 32 collocations) is due to the poorer temporal sampling of the comparison time series because of the short Polar night.

<u>Summary</u>

The SGP 5.01 ozone profiles are in reasonably good agreement with the correlative data, with a median overestimation between 5 to 10%. The bias is much larger in the UTLS, up to 40%. Regions of the atmosphere that require special attention are the Tropical middle stratosphere and the lower stratosphere at high northern latitudes. SCIAMACHY seems to overestimate ozone by 20% in the Tropics at 30 km. In the Arctic there is +(20-30)% bias at 20 km during winter time. The observed spread ranges from 10% to 50%, but is not entirely explained by the combined random error in the UTLS and at higher altitudes in the Polar atmosphere.

We observed a seasonal cycle in the comparisons, probably at all latitudes and altitudes. The currently available data set does not allow the detection of drifts at the few percent per year level. At the moment we can only conclude that drifts are smaller 5% per year, and possibly even smaller than 2% per year. The full mission data set is required to reach firm conclusions on the short and long-term stability of the SGP 5.01.

IV.3.11 Validation of limb bromine monoxide profile [IUPB 3.2]

The following report is an update of the validation analysis in Multi-TASTE annual report #1 [Lambert et al., 2009].

The comparison of the 15-27 km BrO partial columns calculated from SCIAMACHY limb (version 3.2 of the IUP-Bremen scientific product) and ground-based UVVIS profiles over Harestua (60°N, 11°E) has been updated till August 2010, see Figure 35. The validation approach is described in Hendrick et al. (2009). In brief, the following spatial coincidence criterion was chosen for the selection of the SCIAMACHY profiles: the average latitude and longitude at tangent point should fall within latitude of the station ± 5° and longitude of the station ± 10°. This corresponds to a maximum distance between SCIAMACHY and ground-based UV-visible observations of about 750 km. To ensure photochemical matching, sunrise ground-based UV-visible data were converted to the SZA at satellite tangent point using a stacked box photochemical model., SCIAMACHY profiles were smoothed using coincident ground-based UVVIS averaging kernels in order to reduce comparison errors arising from differences in vertical smoothing of the vertical profile.

SCIAMACHY and ground-based UVVIS columns are in good agreement, with SCIAMACHY columns lower than ground-based columns by +1±21%. Both data sets display also a very good consistency regarding the seasonality of the BrO column.

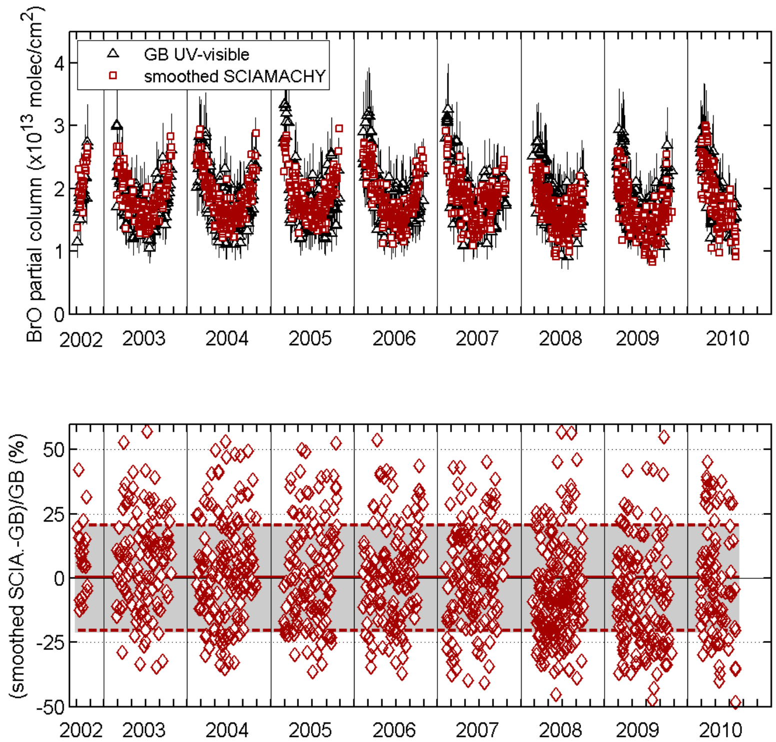

Figure 35: Comparison of the 15-27 km BrO partial column calculated from SCIAMACHY limb measurement (IUPB v3.2) and from ground-based UVVIS profiling at the NDACC station of Harestua (60°N, 11°E), for 2002-2010 (morning coincidences). See [Hendrick et al., 2009] for more details.

Ground-based UV-visible BrO profiles at Harestua have been also used to validate other SCIAMACHY limb BrO scientific (MPI-Mainz) and operational (DLR) retrieval algorithms [Rozanov et al., 2011]. Comparison results for Kiruna, also including balloon-borne observations, are shown in Figure 36. A good overall agreement is found between the different data sets.

The trend analysis of stratospheric BrO columns retrieved from SCIAMACHY limb and ground-based UV-visible observations over Harestua has been also updated till 2010. Since stratospheric BrO shows a marked seasonality with a maximum in winter and a minimum in summer (related to the NO_2 seasonal cycle), a statistical model with a linear trend and seasonal components is used to fit the SCIAMACHY limb and ground-based UV-visible columns [Hendrick et al., 2009b]. The trend analysis results are presented in Figure 37. Before 2001, a positive trend of +2.1±0.5% per year is inferred from ground-based observations while after 2001, a negative trend of -0.8±0.2% per year and -1.1±0.4% per year is found in both the ground-based and the SCIAMACHY data sets. Given the mean age of air in the stratosphere, this decline is consistent with the decrease of long-lived bromine source gases (CH_3Br and halons) observed at the Earth's surface since 1998. These comparison results provide therefore further evidences that the effects of the Montreal Protocol restrictions on brominated substances have now reached the stratosphere.

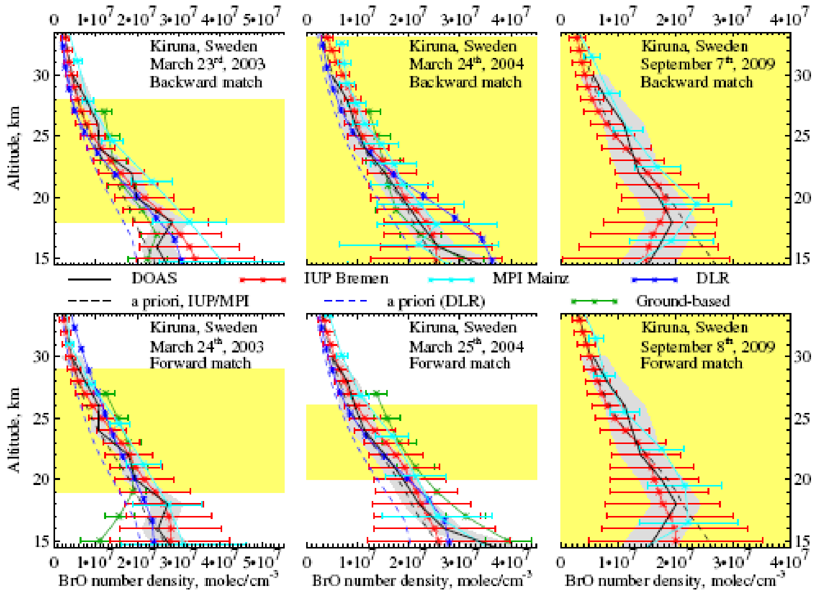

Figure 36: Comparison of BrO vertical distributions retrieved from SCIAMACHY limb measurements using different retrieval algorithms to coinciding balloon-borne DOAS observations. When available, ground-based UV-visible BrO profiles from the Harestua station are also shown. All balloon launches are in Kiruna (high latitude). Left panels: 23 March 2003. Middle panels: 24 March 2004. Right panels: 7 September 2009. Grey shadings depict the uncertainties of DOAS results (1-σ). Yellow areas mark vertical ranges where according to trajectory model calculations both instruments probe the same air mass. From [Rozanov et al., 2011].

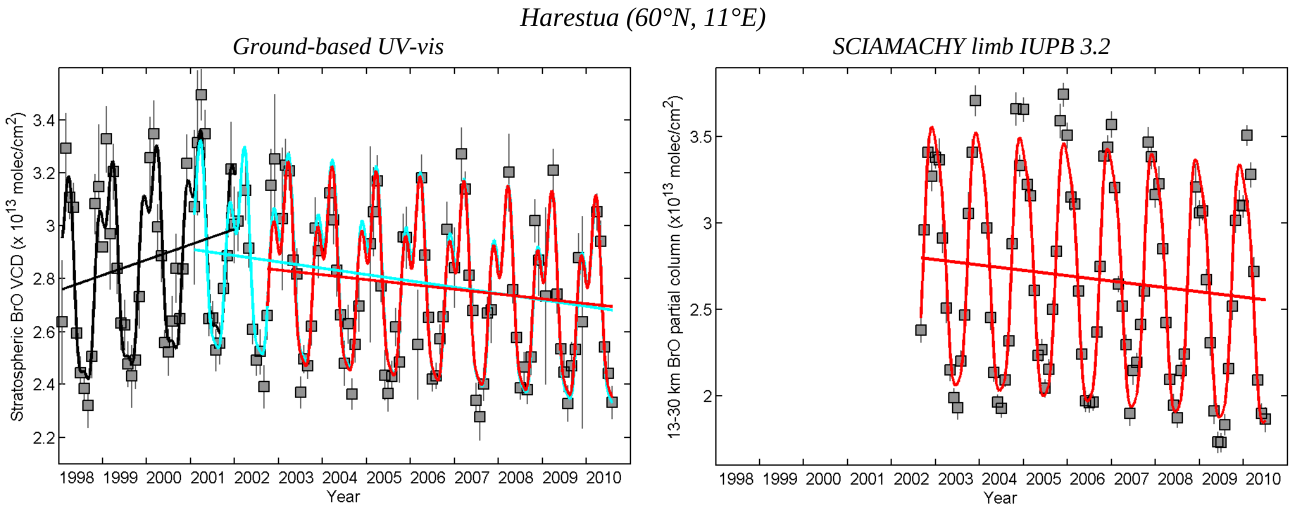

Figure 37: Trend of stratospheric BrO estimated from ground-based UV-vis (left) and SCIAMACHY limb BrO observations (right) over Harestua (60°N, 11°E). For this study, 80°SZA (solar zenith angle) sunset ground-based UV-vis stratospheric BrO vertical columns are used.

IV.3.12 Validation of limb bromine monoxide profile [SGP 5.01]

The validation report can be found in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation approach is described in Hendrick et al. (2009).

Key findings:

- SCIAMACHY 15-27km column overestimates UVVIS at Harestua, with a mean bias of +32% and accuracy of 31%. The operational processor performs worse than the scientific processor at IUP-Bremen.
- The overestimation is most notable (up to 50%) between 15-21km.

IV.4 Third Party Missions: ACE-FTS and GOSAT-TANSO

IV.4.1 SCISAT-1 ACE-FTS

Since the massive ACE v2.2 validation effort published in the ACE special issue of ACP, systematic intercomparisons with v2.2 data targeted by Multi-TASTE have been performed for ozone and temperature, as well as for OCS, HF and HCN [Li et al., 2009; Duchatelet et al., 2010, Lejeune et al., 2010, Mahieu et al., 2010].

Validation efforts are on-going for the recently released version 3.0, but out of scope of the present project.

IV.4.1.1 Validation of temperature profile [v2.2]

A validation report can be found in Multi-TASTE annual report #1 [Lambert et al., 2009], and an update in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation approach is identical to that of Section IV.2.4.

Key findings:

- Between 10-30km agreement with radiosonde within ±2K. The apparent +2K bias with respect to lidar in the upper stratosphere may be explained by the difference in measurement time and atmospheric tides.
- Oscillation pattern in altitude of the differences, with increasing amplitude of 1K at 10km to 2K at 30km.

IV.4.1.2 Validation of ozone profile [v2.2 updated]

Validation results can be found in the multi-mission studies reports in Multi-TASTE annual report #1 [Lambert et al., 2009], and an update in Multi-TASTE annual report #2 [Hubert et al., 2010]. The validation methodology is identical to that of Section IV.2.7.

Main conclusions

- Mean agreement within 7% or better in stratosphere, with standard deviation of about 10%.
- Data quality remains good (i.e. bias below 20% and variability below 30%) down to tropopause.

IV.4.1.3 Validation of ozone profile [v3.0]

Monthly statistics of the agreement between ACE-FTS v3.0 ozone profile data and correlative measurements from ozonesonde stations contributing to the Multi-TASTE project are provided as an electronic annex.

The results are detailed in Section IV.5.4 on multi-mission studies.

IV.4.1.4 Validation of CH_4, $^{13}CH_4$, ^{12}CO and ^{13}CO profile [v2.2]

A few papers dealing with the validation of ACE v2.2 and v4.61 of MIPAS CH_4 have been finalised and published, with due participation of the Multi-TASTE FTIR groups. In addition, further comparisons of improved ^{12}CO, ^{13}CO and $^{13}CH_4$ FTIR products with ACE-FTS v2.2 data have been performed (see participation to symposia).

IV.4.2 GOSAT-TANSO

Many of the Multi-TASTE partners operating NDACC-affiliated FTIR instruments have expanded/are expanding their measurement capabilities to the near infrared (NIR), in an effort to join TCCON (http://www.tccon.caltech.edu/), the Total Carbon Column Observatory Network. Some instruments are already working in time sharing between regular NDACC-type measurements and TCCON/GOSAT activities, like the Bruker 120HR operated at Lauder. NIWA has had a dedicated near-infrared (NIR) ground-based FTS measurement program at the Lauder site within the framework of TCCON since 2004. FMI-ARC has installed a new Bruker 125 HR FTIR instrument in Sodankylä, operational since 2009. IASB-BIRA has installed a new Bruker 125 HR FTIR instrument at La Reunion, to be fully operational by the end of 2011.

Developed initially to support the validation of NASA's Orbiting Carbon Observatory (OCO), TCCON is also intended to support the geophysical validation and algorithm verification of CO_2 column data acquired by GOSAT, successfully launched by JAXA in January 2009. It will also support the validation of the future OCO-2 satellite, currently scheduled for launch in February 2013.

IUP and NIWA coordinate each a proposal submitted in response to the GOSAT Research Announcement. The proposal coordinated by IUP aims at performing GOSAT validation and exploiting potential synergies with SCIAMACHY SWIR validation. This GOSAT validation project includes the FTIR sites in Spitsbergen and Bremen plus two new sites in Bialystok (Poland) and Orléans (France).

NIWA collaborates with the NIES GOSAT validation team and TCCON partners at the University of Wollongong on GOSAT validation in the Southern Hemisphere. This is a GOSAT RA project (1st RA) led by New Zealand TCCON PI Dr Vanessa Sherlock. Dr Sherlock is also a co-investigator on the European Space Agency Climate Change Initiative greenhouse gas project ('GHG-cci') led by Dr Michael Buchwitz (IUP). A characterisation of NIES GOSAT retrieval error characteristics in the Australasian region and identification of likely shortcomings in the NIES retrieval algorithm was presented at the 7th International Workshop on Greenhouse Gas Measurements from Space and the 3rd GOSAT RA Principal Investigators meeting in Edinburgh (May 2011). NIWA has an on-going contract with the National Institute for Environmental Studies (NIES, Japan) for expedited delivery of ground-based data (NIR FTS, lidar, sun-photometer, all sky camera imagery) for GOSAT validation. These data contributed to a preliminary validation of GOSAT measurements (Morino et al., 2011). TCCON data from Lauder, NZ have also been used by the US Atmospheric Carbon Observations from Space (ACOS) team to derive a bias correction for ACOS GOSAT carbon dioxide retrievals (Wunch et al., 2011). NIWA's TCCON data have been used by Dr Max Reuter and co-workers at the University of Bremen to validate a new algorithm for retrieving carbon dioxide abundances from SCIAMACHY data (Reuter et al., 2011).

It is important to note that several TCCON data sets – including those from IUP and NIWA – were submitted to the ESA GHG-cci project database in June 2011 and will contribute to specific climate-oriented validation of GOSAT and SCIAMACHY carbon dioxide and methane retrievals in those projects.

IV.5 Multi-mission studies

IV.5.1 CINDI intercomparison campaign

This report appeared in Multi-TASTE annual report #1 [Lambert et al., 2009]. All Multi-TASTE partners operating UV-visible DOAS instruments participated in the Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring instruments (CINDI), carried out in June-July 2009 in Cabauw, Netherlands, under the auspices of CEOS, GEOmon and NDACC, with support from ESA, NASA, ACCENT TROPOSAT-2, and a list of national agencies. A major objective of this campaign was to better understand capabilities and accuracy of the NO_2 measuring instruments that can be used for validation of tropospheric NO_2 from satellites. The accuracy of the NO_2 tropospheric columns and profiles for the participating instruments has been studied under different atmospheric conditions (clouds/aerosols) and viewing geometries. A dedicated NO_2 profiling workshop took place, which is driving the development of profile retrieval based on MAX-DOAS measurements. Apart from NO_2, other parameters were measured and intercompared, among which ozone, aerosols, HCHO, CHOCHO and BrO. Results were discussed during the CINDI Workshop (Cabauw, 6-8 July 2009), the EOS Aura Science Team Meeting (KNMI, 14-17 September 2009), and the CINDI Workshop organised during the 5th International DOAS Workshop (Mainz, Germany, 12-15 July 2011).

IV.5.2 Multi-mission consistency of ERS-2, Envisat and MetOp-A O_3 column data

In Multi-TASTE Annual Report #2 [Hubert et al., 2010] we had mentioned that several Multi-TASTE partners had started a systematic evaluation of successive ozone column satellite missions using long-term ground-based data records as a standard transfer, namely, for ozone column data from ERS-2 GOME, Envisat SCIAMACHY, EOS-Aura OMI-TOMS and OMI-DOAS, and MetOp-A GOME-2. In 2009-2011 the ozone column retrieval algorithms for several of those sensors have been revisited and improved algorithms and settings are being implemented. In particular, the GDP5/GODFIT project has entered a last phase of maturation and verification, before the anticipated reprocessing of the complete GOME data record and subsequent validation. In the framework of the Ozone_cci project an adaptation of GODFIT to SCIAMACHY and GOME-2 is also foreseen, again followed by reprocessings. Multi-mission consistency studies for total ozone data records from these satellites should be envisaged after reprocessing of the respective data sets.

IV.5.3 Multi-mission consistency of ERS-2, Envisat and MetOp-A NO_2 column data

In Multi-TASTE Annual Report #2 [Hubert et al., 2010] we had mentioned the start of a systematic evaluation of satellite NO_2 column data records, using long-term NDACC UVVIS stratospheric NO_2 data records as a reference. Most of the studies concentrate on mid-morning satellites, namely, ERS-2 GOME, Envisat SCIAMACHY, and MetOp-A GOME-2. In 2010-2011 the corresponding NO_2 retrieval algorithms experienced only minor changes. New calibrations of the level-1 data sets impacted hardly the level-2 NO_2 data records. Therefore we have continued the evaluation of the multi-mission consistency of GOME, SCIAMACHY and GOME-2 NO_2 column data, and extended it to the whole NDACC network of DOAS spectrometers. Hereafter we report results for the following NO_2 column data versions:

- GOME data from 1995 to 2010 processed routinely with version 4.1 of the GOME Data Processor (GDP) established at DLR on behalf of ESA [Van Roozendael et al., 2006].
- SCIAMACHY data from 2002 to 2010 processed routinely with version 3.01 of the SCIAMACHY Ground Processor (SGP) established at DLR. In 2010 a limited data set of SCIAMACHY NO_2 column data processed with version 5.01 of SGP was tested using the same NDACC ground-based measurements. Since the two SGP versions don't produce significantly different NO_2 column data [Multi-TASTE Annual Report #2, 2010], only SGP 3.01 data are studied here.
- GOME-2 from 2007 to 2010, processed routinely with versions 4.3 (operational since 28 May 2008) and 4.4 (operational since March 2010) of the GDP established at DLR on behalf of EUMETSAT [Valks et al., 2011]. Changes between version 4.3 and 4.4 do not affect the quality of NO_2 retrievals, therefore the two data sets are not distinguished in this study.

A pole-to-pole overview of the comparisons is presented in Figure 42 for GOME, in Figure 43 for SCIAMACHY, and in Figure 44 for GOME-2. In these colour plots several families of behaviours appear, which can be explained qualitatively as follows.

Illustration of typical results at Arctic and Antarctic latitudes is given in Figure 38 at the Antarctic station of Marambio. Antarctic stations of the NDACC/UVVIS network are all characterised by negligible tropospheric pollution. Pollution at Arctic stations ranges from negligible to low, depending on the vicinity of emission sources and the transport of pollutants. The total column of NO_2 is thus predominantly of stratospheric origin, except in rare cases of tropospheric pollution that can be filtered out. As a result, satellite weighting functions resemble those of the UVVIS observations, enabling direct comparisons between GOME and UVVIS column data from the perspective of measured information content. Also, the diurnal cycle of NO_2 is relatively well understood near the equinoxes. Modelling studies carried out at IASB-BIRA in collaboration with U. Leeds [Lambert *et al.*, 2002, 2003] indicate that sunrise values measured by NDACC/UVVIS instruments might be reasonably close – within a few 10^{14} molecule.cm^{-2} – to the mid-morning values acquired by the three satellites. In those cases the mean agreement with NDACC/UVVIS data usually is within the range of ±0.5 10^{15} molecule.cm^{-2}. During polar summer, the diurnal cycle of NO_2 exhibits a different behaviour. Although the permanent illumination of the stratosphere prevents the formation of night-time species, the variation in solar illumination between noon and midnight is sufficient to modify significantly the photochemical equilibrium between NO and NO_2. As a consequence, the stratospheric column of NO_2 alternates smoothly between a minimum around noon and a maximum under midnight sun conditions, with an amplitude of 0.5 10^{15} to 1.5 10^{15} molecule.cm^{-2}. This particular cycle must be taken into account properly since the satellites overpasses polar stations several times a day. Here we adjust ground-based NO_2 data to the satellite local time using photochemical box modelling results (described in Lambert et al. [2002]). Thanks to this adjustment we observe an agreement again within the range of ±0.5 10^{15} molecule.cm^{-2}. During polar springtime, strong and/or sudden changes of temperature and of NOy partitioning (e.g. resulting from denoxification or denitrification processes) can alter unpredictably the amplitude and the shape of the diurnal cycle and comparison results are to be taken with care.

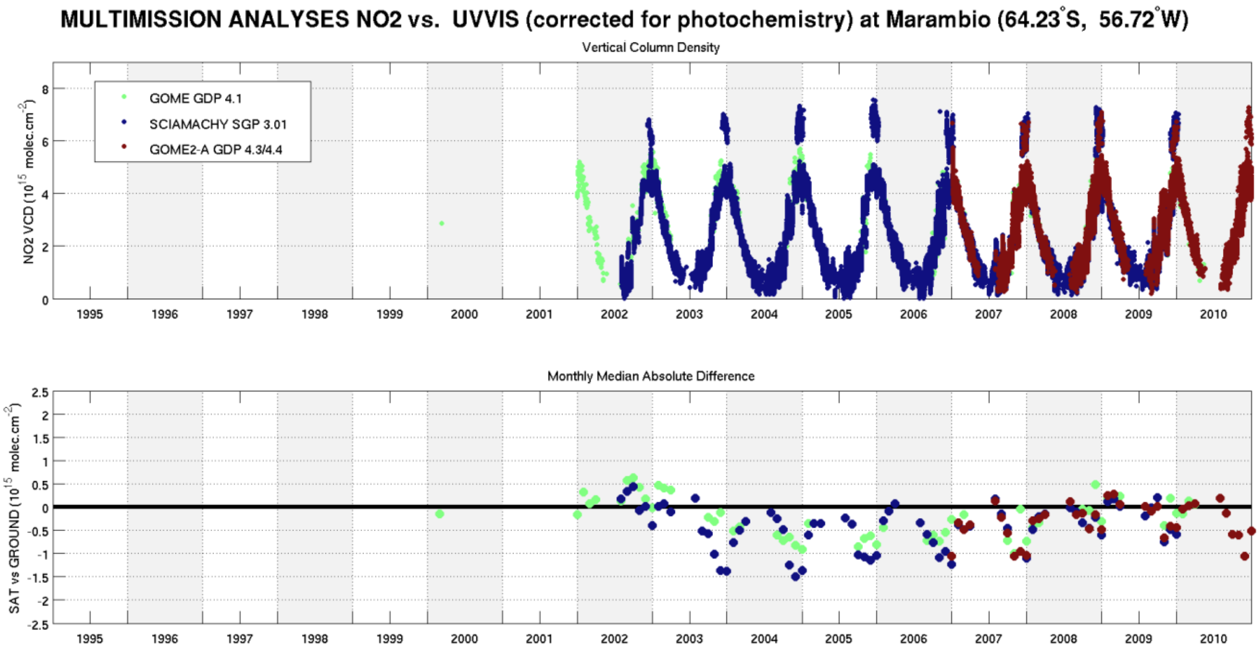

Figure 38: Comparison of multi-mission satellite NO_2 column data with respect to ground-based correlative measurements by the UVVIS instrument operated by INTA at Marambio (Antarctic Peninsula). Top: time series of NO_2 vertical column density measured by the three mid-morning satellites GOME (GDP 4.1), SCIAMACHY (SGP 3.01) and GOME-2 (GDP 4.3/.4.4). Bottom: monthly median of the absolute difference between satellite and sunrise UVVIS data, corrected in summer for polar day photochemistry.

At other latitudes modelling studies indicate that sunrise values measured by UVVIS instruments might be used year-round since reasonably close – within a few 10^{14} molecule.cm^{-2} – to the mid-morning values acquired by the satellites. But another problem can alter the interpretation of comparisons. Initially, to enhance the detection of subtle changes in stratospheric composition, NDACC stations were installed in remote areas far away from pollution sources, and in the facts NDACC/UVVIS measurements usually are hardly affected by pollution. Practically, satellite validation results at European and Japanese sites show that, although these sites are usually located in a relatively clean environment, large satellite pixels of 320 x 40 km^2 for GOME and 80 x 40 km^2 for GOME-2 are nevertheless under the influence of neighbouring regions with urban and industrial emissions. This is the case for the NDACC station of Harestua in Norway, illustrated in Figure 39, where the excellent agreement between the three satellites contrasts nevertheless with a seasonally varying bias with respect to the ground-based UVVIS data. In principle, the discrepancy between satellite total columns and NDACC stratospheric columns should be a measure of the tropospheric column seen by the satellite: the total column detected by the satellite contains a tropospheric component, which superimposes on the stratospheric column measured by NDACC instruments. This principle forms the basis of the residual techniques developed to derive tropospheric column values from total column measurements. In general, at such stations, satellites are found to report NO_2 values larger on an average by 0.5 10^{15} to 2.5 10^{15} molec.cm^{-2}, which is an indication of the difference in sensitivity to the troposphere. This discrepancy exhibits an annual cycle as tropospheric NO_2 varies with the season, being at its maximum in winter and minimum in summer. Different possibilities exist, e.g., validation of the stratospheric column retrieved from satellite data (usually by a residual method) or validation of satellite columns filtered according to the fractional cloud cover (assuming that most of the pollution is below clouds). These possibilities are out of the scope of this project report.

In Figure 40 and Figure 41 comparisons are illustrated at the (sub-)tropical stations of Izaña (Tenerife Island, 28°N) and Saint Denis (Reunion Island, 22°S). While the annual mean agreement with ground-based data remains – for the three satellites – within the +2/-5 10^{15} molec.cm^{-2} range, the results for GOME appear noisier, especially at Saint Denis.

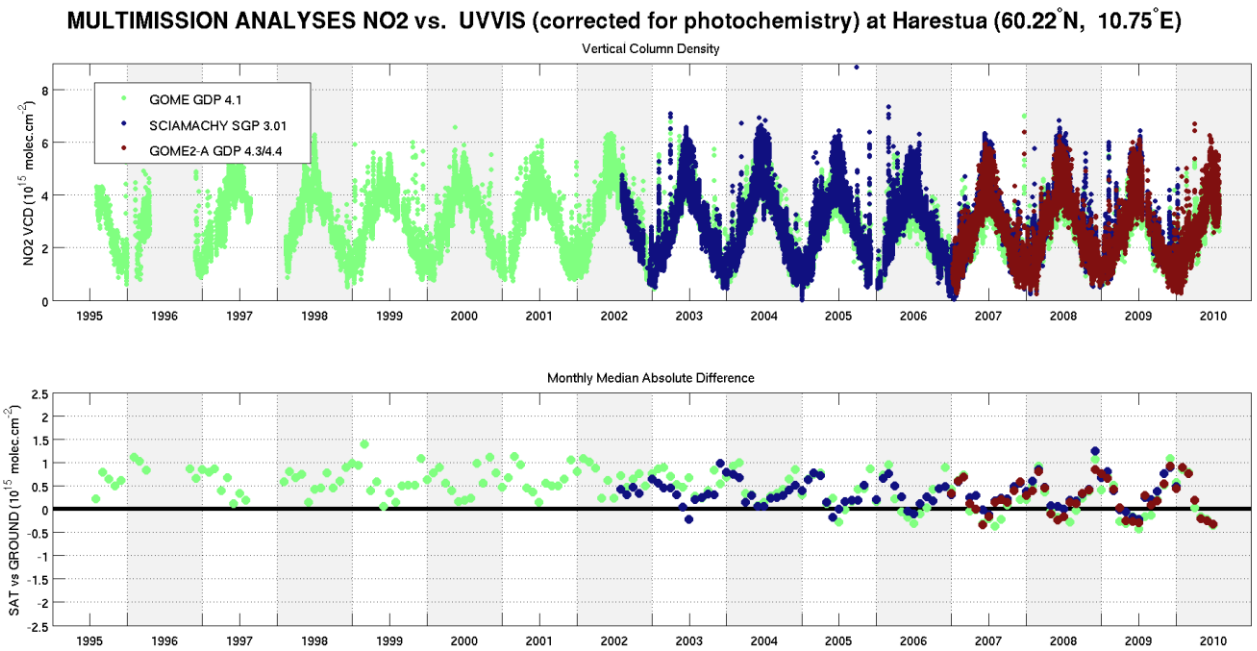

Figure 39: Same as Figure 38, but with respect to correlative measurements by the UVVIS instrument operated by BIRA-IASB at the NDACC station of Harestua (Norway).

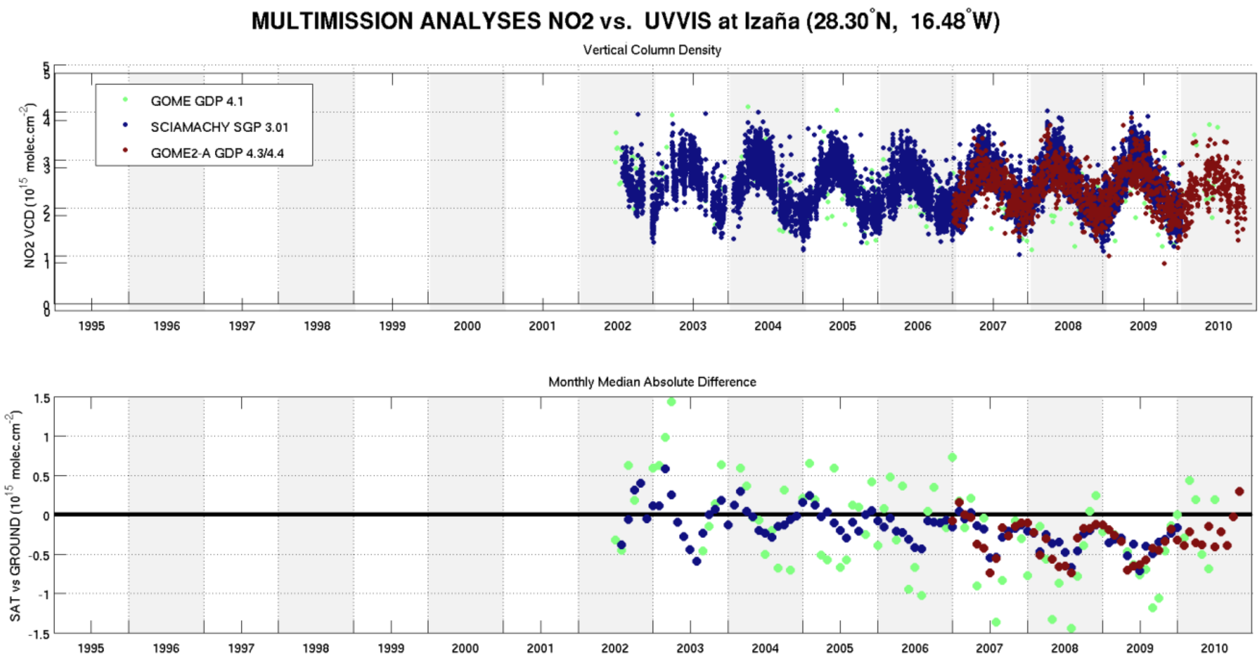

Figure 40: Same as Figure 39, but with respect to correlative measurements by the UVVIS instrument operated by INTA at Izaña (Tenerife Island).

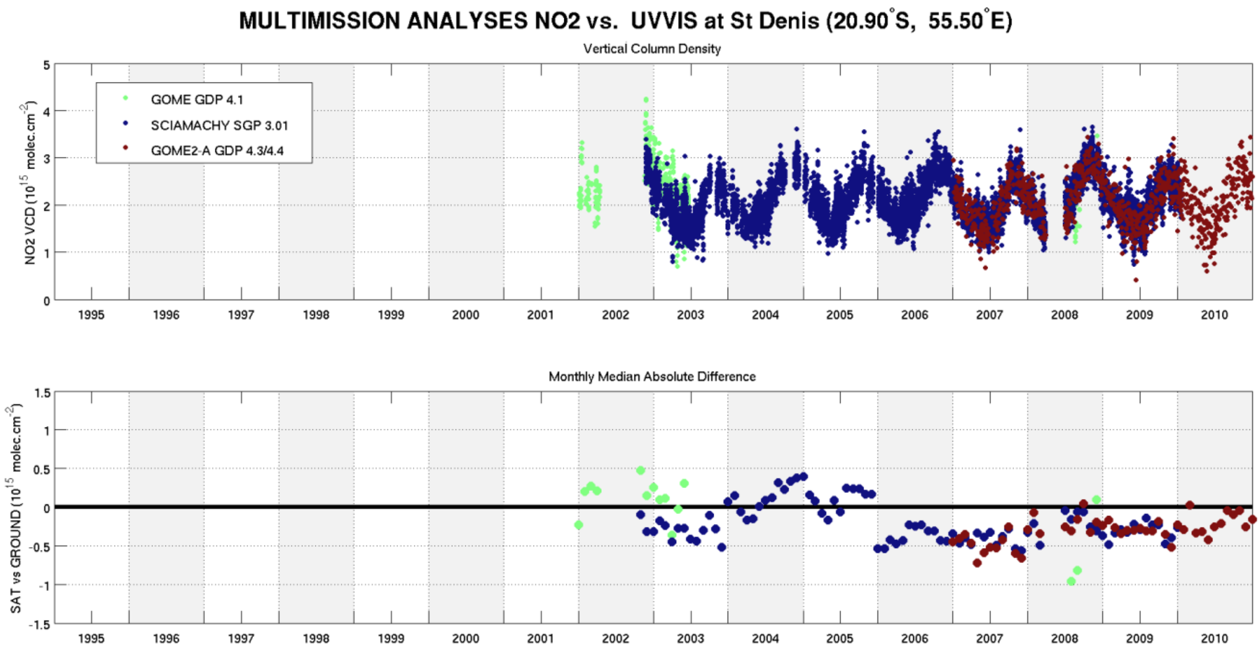

Figure 41: Same as Figure 39, but with respect to correlative measurements by the UVVIS instrument operated by CNRS and U. Réunion at Saint Denis (Reunion Island).

Figure 38 to Figure 41 illustrate the major classes in which comparison results can be grouped. These results are summarised in the following Figure 42 to Figure 44, which display monthly medians of the absolute difference between the satellites and NDACC/UVVIS total NO_2 data (in 10^{15} molec.cm^{-2}, one line by station from North to South). Based on these groups of comparison results, the following conclusions can be drawn.

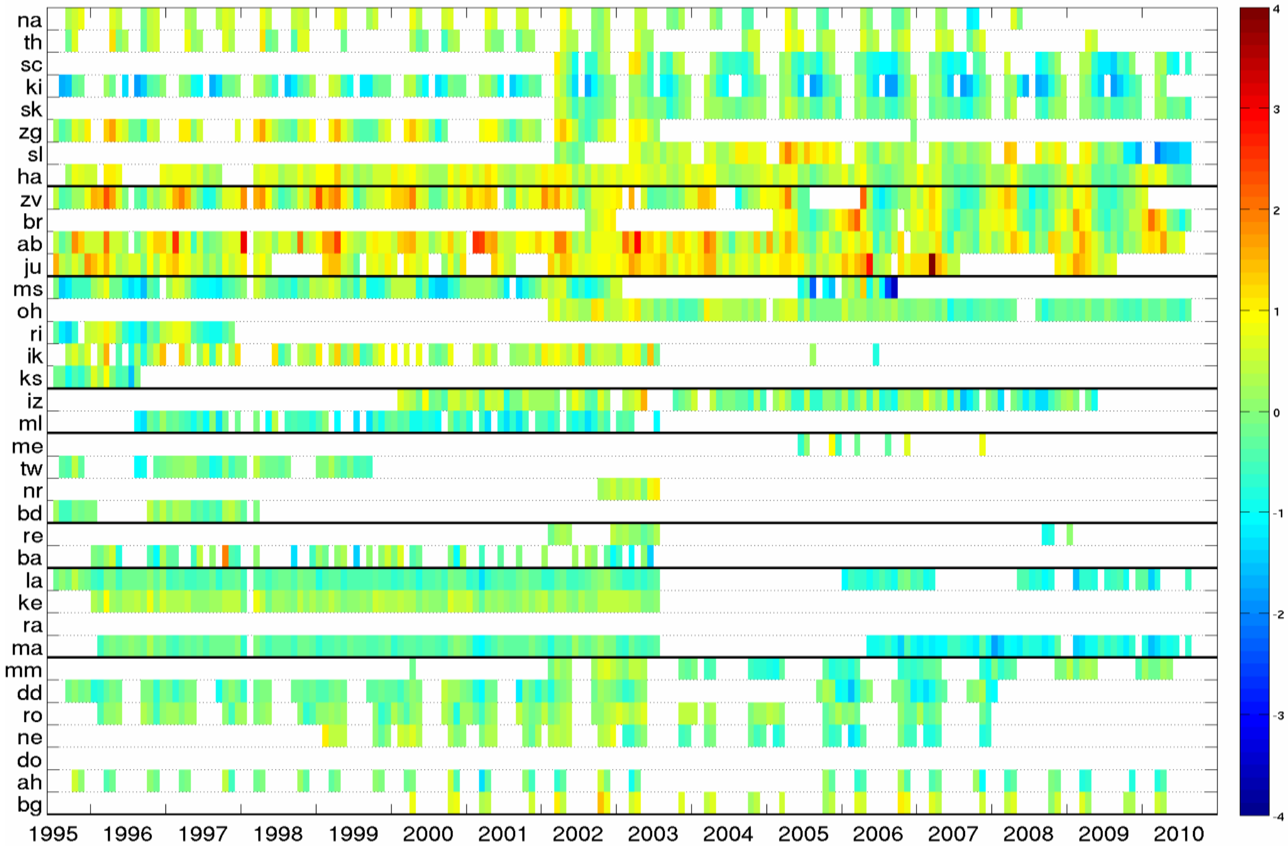

Figure 42: Monthly medians of the absolute difference between GOME GDP 4.1 and NDACC/UVVIS total NO_2 column data (in 10^{15} molec.cm^{-2}). One line by station, from North to South. Photochemical adjustment in polar day conditions.

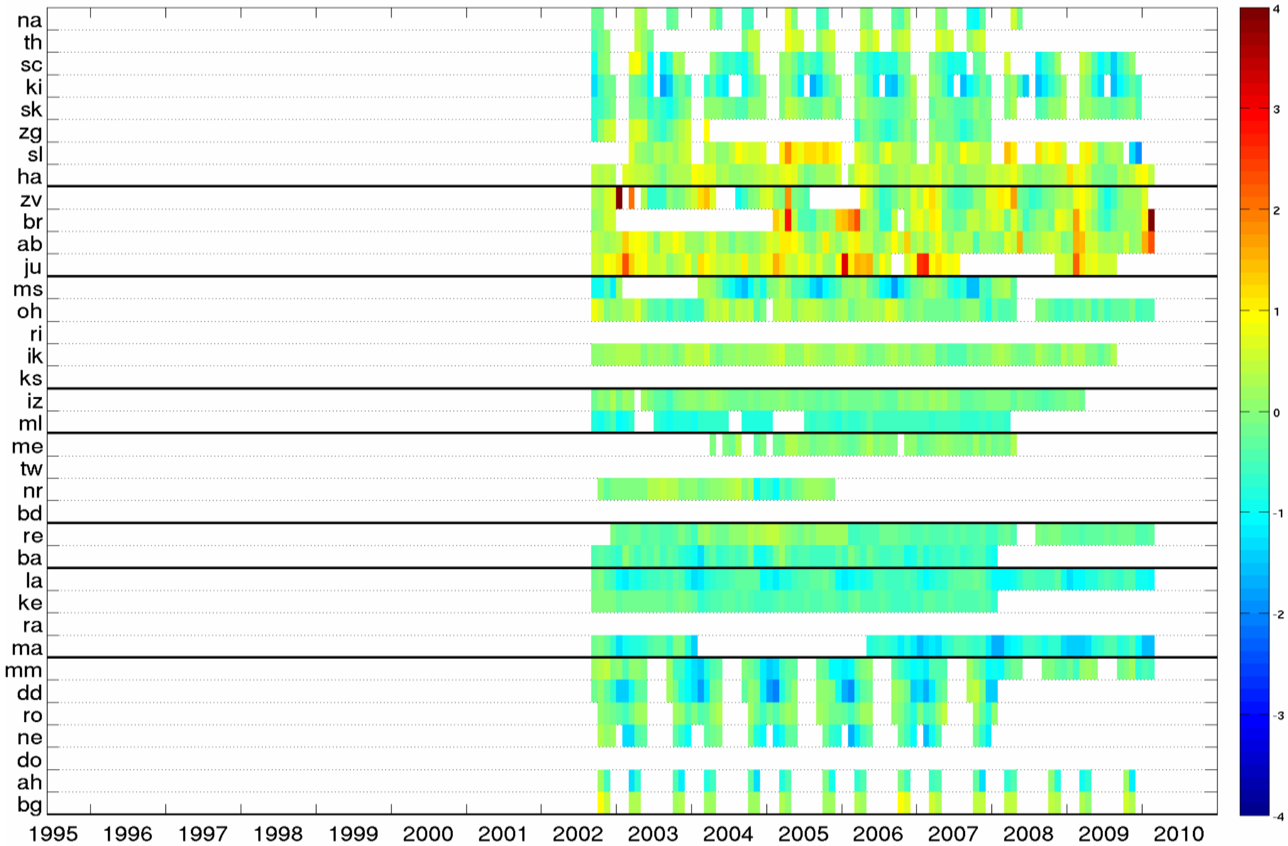

Figure 43: Same as Figure 42, but between SCIAMACHY SGP 3.01 and the NDACC/UVVIS network.

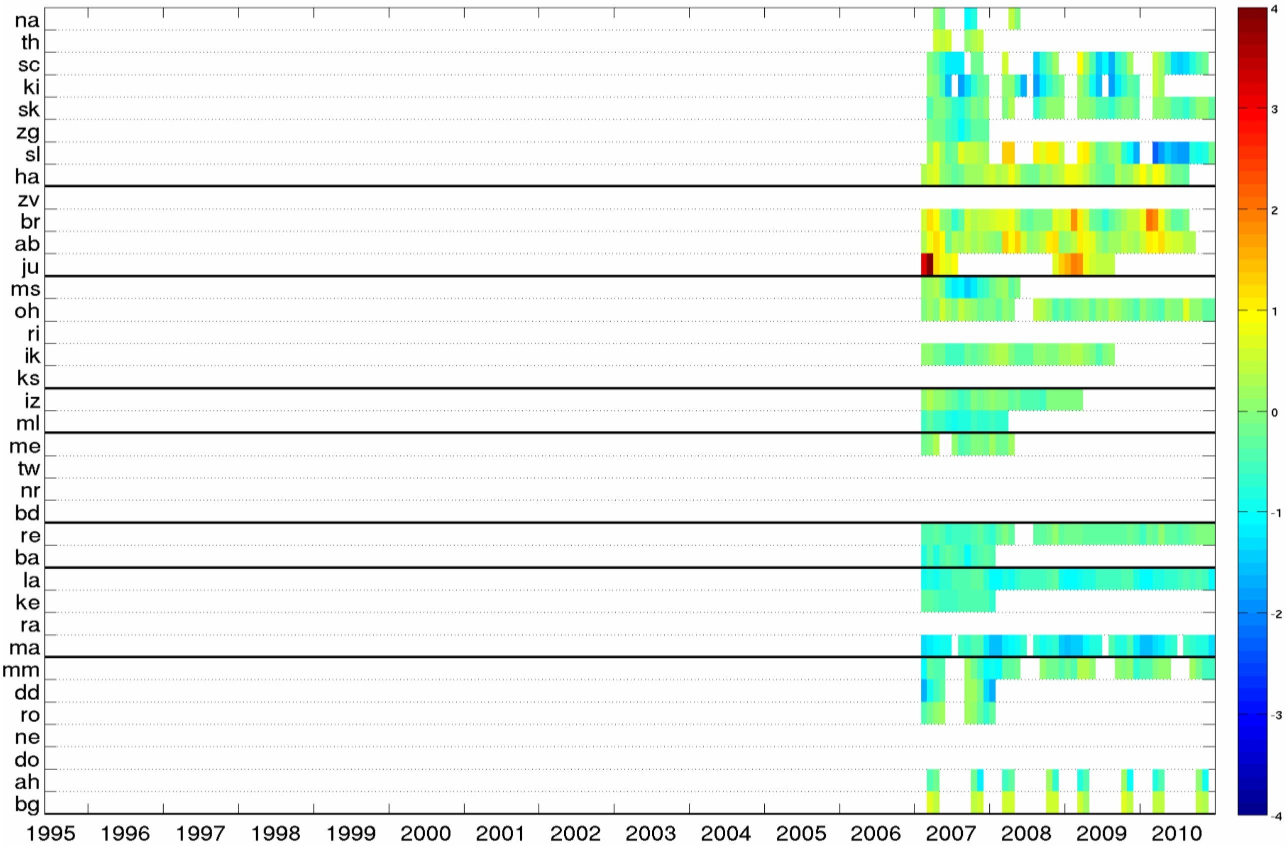

Figure 44: Same as Figure 42, but between GOME-2 GDP 4.3/4.4 and the NDACC/UVVIS network

Main conclusions

At stations free of pollution and where the diurnal cycle can be accounted for accurately, that is, where direct comparisons between satellite nadir and ground-based zenith-sky measurements provide the most quantitative results, the median agreement ranges between a few $+10^{14}$ molec.cm^{-2} and $-7\ 10^{14}$ molec.cm^{-2}. A few 10^{14} molec.cm^{-2} of agreement is equivalent to a few percent up to about 10%, that is, within the error bar of the satellite and ground-based retrievals [e.g. Vandaele et al., 2005; Roscoe et al., 2010]. A systematic difference of $-7\ 10^{14}$ molec.cm^{-2} in polar summer (with stratospheric columns of about $6\ 10^{15}$ molec.cm^{-2}), exceeds the 10% level and reaches the limits of the retrieval error bars. Outside of polar summer, values of $-7\ 10^{14}$ molec.cm^{-2} are more to be considered as a negative bias between the satellite and the ground-based instruments. In the Southern Hemisphere such a bias is not observed for GOME GDP 4.1 but well for SCIAMACHY SGP 3.01 and GOME-2 GDP 4.3/4.4. At some stations free of pollution, the median agreement for the three satellites exhibits also temporal features like an annual cycle, and at most stations a temporary negative offset of a few 10^{14} molec.cm^{-2} during the years 2004-2008 with a return in 2009-2010 to the pre-2004 levels. At the time being the origin of this temporary systematic difference between the satellites and NDACC is unexplained. Finally, at low latitudes, where the GOME signal-to-noise ratio degrades due to the shorter optical path and the lower amount of NO_2, GOME data are noisier with respect to NDACC data, with increased DOAS fit residuals. This low latitude effect does not appear for SCIAMACHY and GOME-2.

NDACC stations surrounded by pollution sources visible by the satellites – like all Northern middle latitude sites (Europe and Japan) – and polar sites where the diurnal cycle is less predictable in spring and winter, make appear larger deviations and/or larger noise attributable partly to the difference in vertical sensitivity and/or to residual diurnal cycle effects.

IV.5.4 Multi-mission consistency of Envisat and Third-Party Mission limb ozone profiles

Previous results of multi-mission studies (with older versions of satellite processors) can be found in Multi-TASTE annual report #1 [Lambert et al., 2009] and Multi-TASTE annual report #2 [Hubert et al., 2010].

IV.5.4.1 Introduction

In the framework of the Multi-TASTE project and of external projects like Belgian Science Policy Office/ProDEX SECPEA and EC FP6 IP GEOmon, networks of ozonesonde and lidar stations have been used as a standard transfer to investigate the consistency of Envisat ozone profile data, of data records from historical satellites, and of more contemporary sensors like ACE-FTS. These results have been updated and presented publicly at the SPARC/IOC/WMO-IGACO workshop on. *Past Changes in the Vertical Distribution of Ozone* (Geneva, January 25-27 2011) and the GEOmon Final Assembly (Brussels, February 2-4, 2011). Hereafter we present a summary of the main validation results of ESA Envisat GOMOS IPF 5.00 / GOPR v6.0cf, MIPAS IPF 5.05, SCIAMACHY limb SGP 3.01, of CSA SCISAT-1 ACE-FTS v3.0 and of NRL/CNES/ONR SPOT-3 POAM-II v6 and SPOT-4 POAM-III v4 ozone profile data.

Monthly statistics of the agreement between ozone profiles from GOMOS, MIPAS, SCIAMACHY and ACE-FTS, and correlative ozonesonde data from stations contributing to Multi-TASTE, are provided as an electronic annex.

IV.5.4.2 Description of ozone profile data sets

GOMOS operates successfully since July 2002 except for an anomaly in 2005 that resulted in a gap in the data. Previous validation studies of successive GOMOS ozone profile data versions have shown that only data acquired on dark limb are of sufficient quality for scientific use [Meijer et al., 2004; De Clercq et al., 2004]. Comparisons between dark limb profiles of the latest reprocessed version 6.0cf and ground-based ozonesondes and lidars have shown a typical agreement within 10% from 20 km up to 50 km [De Clercq et al., 2006]. In this report we use GOMOS ozone data from the latest reprocessing (version 6.0cf) and its operational implementation IPF 5.00. Only dark limb data have been selected (including straylight data).

MIPAS operated at full resolution (FR) from July 2002 till March 2004, when the instrument experienced a major anomaly. In January 2005 operations were resumed in an optimized resolution (OR) mode. The latest MIPAS processor IPF 5.05 is the first processor able to digest both FR and OR spectra and produce ozone profiles for the entire mission. The results of an initial validation can be found in Section IV.2.7. They are roughly in line with those of the previous operational processors, IPF 4.61/4.62, able to retrieve FR spectra only. The IPF 4.61/4.62 MIPAS profiles were the subject of an extensive validation effort, in which they were compared to those of several other satellites, balloons and ground-based instruments [Cortesi et al., 2007]. This coordinated study concluded to a typical agreement within ±10% from 20 to 50 km and highlights a significant positive bias of up to +25% in the Upper Troposphere Lower Stratosphere (UTLS).

Previous SCIAMACHY Ground Processor retrievals suffered from pointing errors [De Clercq et al., 2004; De Clercq et al., 2006; von Savigny et al., 2003] and the retrieved ozone profiles exhibited an altitude shift of up to 1.5 km. Accordingly, comparisons concluded to an altitude-dependent bias of up to ±20%. SGP version 3.01 retrieves ozone profiles on an altitude grid between 15 and 40 km and includes a pointing correction that should reduce the altitude uncertainty to less than 500 m, and thus the bias. Retrievals from the recently activated processor version, SGP 5.01, are not considered here since only part of the mission was reprocessed at the time of writing, the results of an initial validation effort can be found in Section IV.3.9.

CSA's Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) on-board SCISAT-1 uses the infrared solar occultation technique from an orbit at 75° inclination. The previous ACE-FTS processor, version 2.2 updated, has been the subject of a coordinated international validation [Dupuy et al., 2009] involving comparisons with satellite, ground- and balloon-based instruments. The study concluded to a typical agreement of the ACE-FTS profile data within 5% between 15 and 45 km, with a small positive bias in ACE-FTS data with respect to correlative data. Version 3.0 of ACE-FTS ozone profiles was recently released, and is used in this study. No validation results have been published so far, but preliminary studies indicate that the bias above 35 km is reduced by about 5% [Waymark et al., 2011].

Operating from a polar orbit, NRL's Polar Ozone and Aerosol Measurement II and III (POAM-II and III) aboard the polar orbiting French platforms SPOT-3/4, measured ozone profiles, from 1993 to 1996 and from 1998 to 2005 respectively, with coverage of the polar zones but no measurement at latitudes below about 56°. POAM-II v5 ozone profiles have been compared to measurements from satellites and from ozonesondes [Rusch et al., 1997; Deniel et al., 1997]. The POAM-II data show a typical mean agreement within 5-7% above 22 km, with in general a negative bias of a few percents with respect to correlative measurements. Studies based on the current version 6, used for this work, show similar results and also depict a negative bias [Danilin et al., 2002]. The latest version of POAM-III ozone profile data is v4. The previous version 3 had been extensively validated using observations from aircrafts, balloons and satellite instruments [Randall et al., 2003]. These studies showed a typical agreement of ±5% from 13 to 60 km. Minor changes have been implemented in the current v4 for ozone retrieval and comparisons with correlative data show a similar agreement than for v3 [Atmospheric Science Data Center, 2005 and 2006].

For this preliminary study we have adopted basic coincidence criteria based on the maximum distance between the tangent point at the ozone maximum and the location of the ground-based stations. Even though more accurate selection methods exist, given the horizontal resolutions of the satellite and ground-based measurements, a maximum distance of 500 km was found as the best compromise between a sufficient coincidence of the air masses to be compared and a sufficient amount of co-located pairs of profiles. While the selection of horizontal coincidence criteria can offer some flexibility, temporal distance criteria are constrained directly by the measurement time of the data being compared, which depend on parameters like the radiation source and the orbit inclination. In this exercise, the time difference between ground-based and satellite measurements varies from 0 to maximum 12 hours. Co-locations of satellite and ground-based profiles have been identified according to the above criteria for up to 74 ozonesonde and 11 lidar stations.

IV.5.4.3 Comparison results

IV.5.4.3.1 Seasonal and long-term features

In this first part of our study, we analyse time series of the relative differences between satellite and correlative data at selected altitude/pressure levels. In particular, we look for any seasonal cycle or long-term drift. To determine if a long-term drift exists, a robust linear regression is undertaken. No regression is done if the standard deviation of the data set exceeds 30%, or if the time series comprises less than 20 co-located pairs of profiles. The slope of this regression is considered to be significantly different from zero if zero is not in the 95% confidence interval (slope ± 2*error) of the calculated slope. The error on the calculated slope is obtained using standard statistics, to which the effect of noise autocorrelation is added.

This temporal analysis has been performed for each satellite at each selected ozonesonde or lidar station. Graphs representing the drifts as a function of the latitude, for different altitude levels, are shown in Figures 45-49. Significant drifts are plotted in red, while non-significant drifts are plotted in black. The error bars represent the 95% confidence intervals for the drift estimate.

A sufficiently long time series of data and a sufficient number of coincident pairs of profiles is required; to detect drifts at the few percent per year level. For this reason, the analysis is inconclusive for ACE-FTS and POAM-II/III. For these instruments, drifts are indeed detected, but they are not significant and/or not consistent from station to station (see e.g. Figure 45 and Figure 46 for ACE-FTS and POAM-III respectively). This analysis might improve for ACE-FTS as the time series get longer.

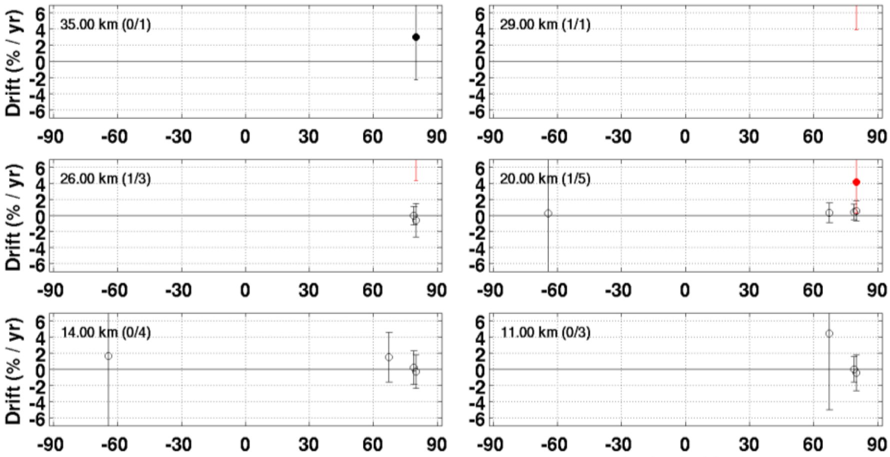

Figure 45: Slope of the multi-year linear trend fitted to time series of the relative differences between ACE-FTS v3.0 and ozonesonde (open circle) or lidar (closed circle) ozone measurements at each station, plotted as a function of latitude and at different altitude levels. Red markers represent trends with statistical significance (95% confidence level). Trends with no significance are shown in black.

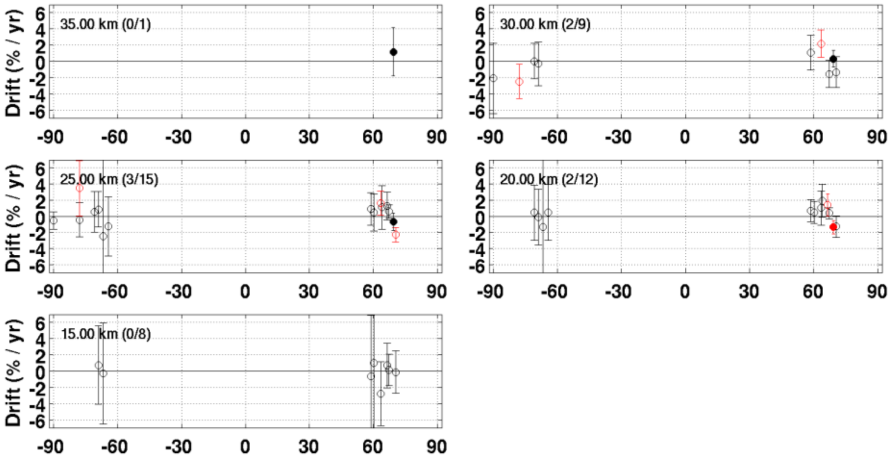

Figure 46: Same as Figure 45 for POAM-III v4 at different altitude levels.

The analysis revealed significant drifts for GOMOS and SCIAMACHY, even if the results are not fully consistent from station to station. The GOMOS data (Figure 47) show negative drifts of 1 to 2% per year at Northern mid-latitudes, from 20 to 30 km altitude. The SCIAMACHY data (Figure 49) present positive drifts of 0.5 to 1% per year at 26 km altitude, and maybe at 23 km as well. For the moment it is not clear whether MIPAS ozone profiles drift with respect to correlative measurements (Figure 48). In Section IV.2.7 we have reported evidence for the time-dependence of the MIPAS vertical averaging kernels which are used to smoothen the correlative profile to the satellite resolution. This has an important impact on the drift analysis, so no conclusive results can be given until this issue is understood.

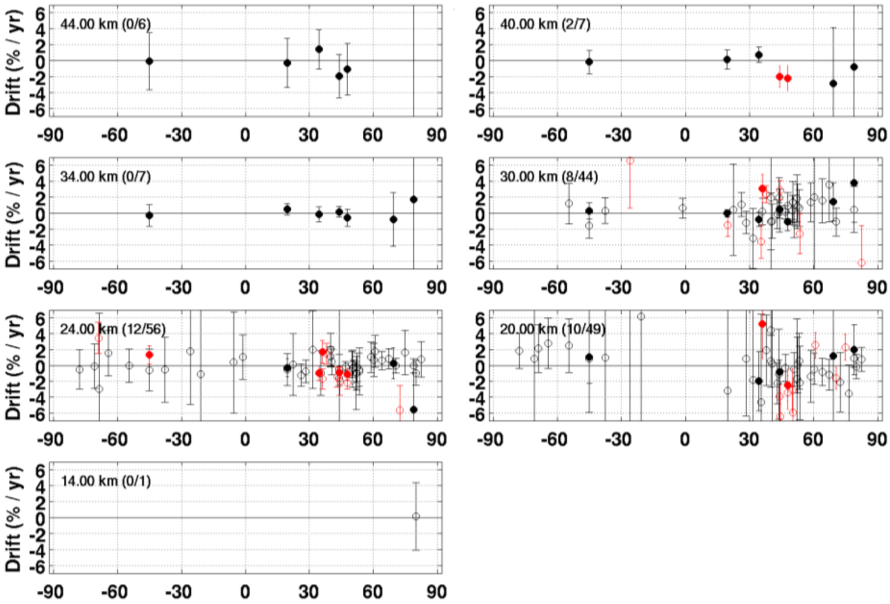

Figure 47: Same as Figure 45 for GOMOS IPF 5.00 / GOPR 6.0cf at different altitude levels.

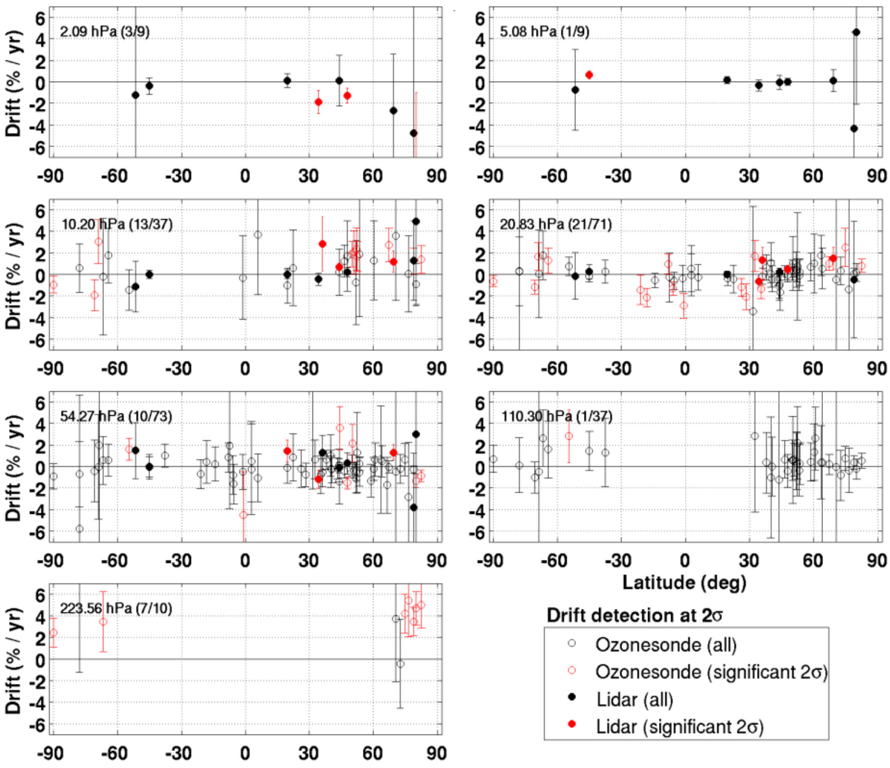

Figure 48: Same as Figure 45 for MIPAS IPF 5.05 at different pressure levels. The correlative profiles were not smoothened with MIPAS vertical averaging kernel, but using a layer-average.

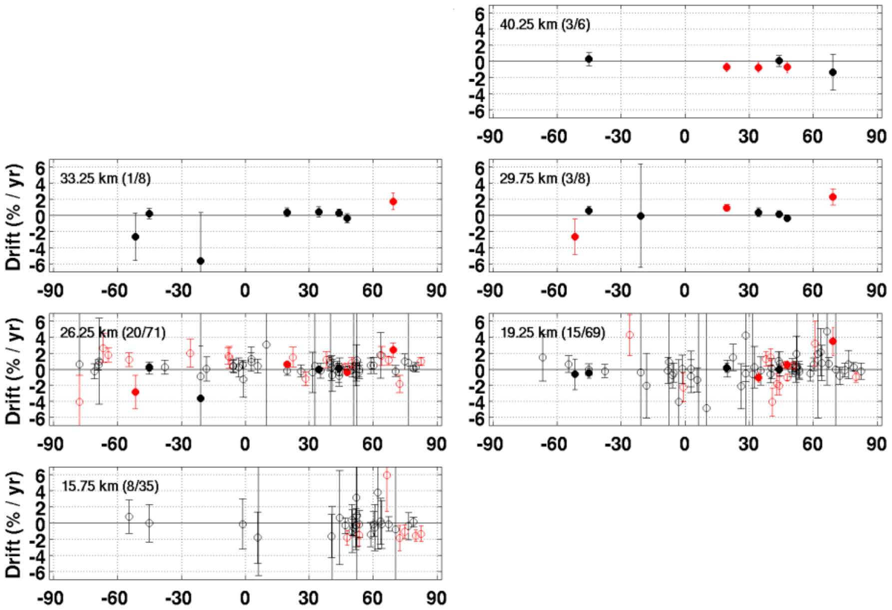

Figure 49: Same as Figure 45 for SCIAMACHY SGP 3.01 at different altitude levels.

Besides drifts, seasonal features were observed as well in the comparison data, for MIPAS (cfr. Section IV.2.7) and SCIAMACHY (cfr. [Lambert et al., 2009] and [Hubert et al., 2010]). The linear model in our drift analysis does not yet include this effect. However, ignoring a seasonal term should not alter the estimated value of the drift, but rather make the drift error estimation too conservative. Our choice hence limits the statistical power to detect drifts, but does not increase the number of false detections. We intend to quantify the impact of the seasonal cycle on the drift estimation in the future.

IV.5.4.3.2 Meridian and vertical structures

While the agreement between satellite and ground-based data varies with altitude and latitude, it does not vary significantly between stations close in latitude and it shows long-term stability for most satellites. These findings allow us to derive multi-year and zonal statistics, which we use hereafter to study meridian and vertical features of the consistency between the various satellites. Figures 50-53 show, as a function of latitude and altitude, the median relative difference between satellite and correlative ground-based data, averaged into 5°-wide latitude bins.

In general, the mean agreement between satellite and ground-based data in the stratosphere is 7% or better, with a standard deviation of about 10%. In the upper troposphere lower stratosphere (UTLS) data quality generally decreases (see following section), with the bias and/or spread of the comparisons increasing to 20-30%. In the following paragraphs we discuss the features that differ from the general one.

For GOMOS (Figure 50) a mean negative bias of roughly 5% is observed at high northern latitudes. The GOMOS Quality Working Group (QWG) is investigating possible links between this bias and the contamination of GOMOS spectra by auroral light.

The comparisons for MIPAS (Figure 51) are in line with the general features. The bias in the Tropics varies from station to station. This station-to-station variability becomes much smaller when smoothing the correlative profiles with MIPAS vertical averaging kernel. However, the latter might be time-dependent, see Section IV.2.7.

The SCIAMACHY comparison data (Figure 52) bear a negative bias of about 10% at all altitudes. The stability of this bias with altitude indicates that the altitude pointing correction implemented in SGP 3.01 is working properly. This negative bias disappeared with the newer version SGP 5.01 of the processor, see Section IV.3.10.

The ACE-FTS data (Figure 53) do not show any feature different from those of the satellite datasets described before. The orbital inclination of ACE is such that the amount of collocations with ground-based data at tropical sites is very small. Consequently, only polar and mid-latitude regions offer sufficient statistical power.

Our analysis using the ground-based networks as standard transfer confirms a 5% bias between POAM-II and POAM-III datasets, even though both agree with ground-based data within about 7% like the other instruments.

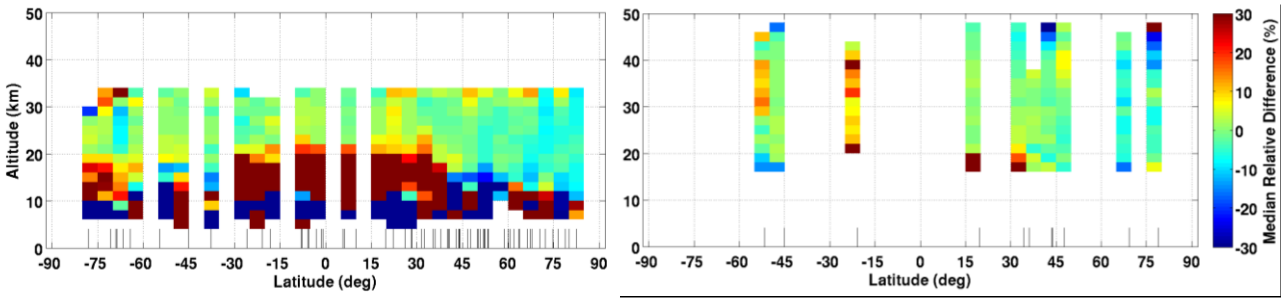

Figure 50: Median relative differences between GOMOS IPF 5.00 / GOPR 6.0cf and ozonesonde (left) or lidar (right) ozone profile data, as a function of altitude and latitude.

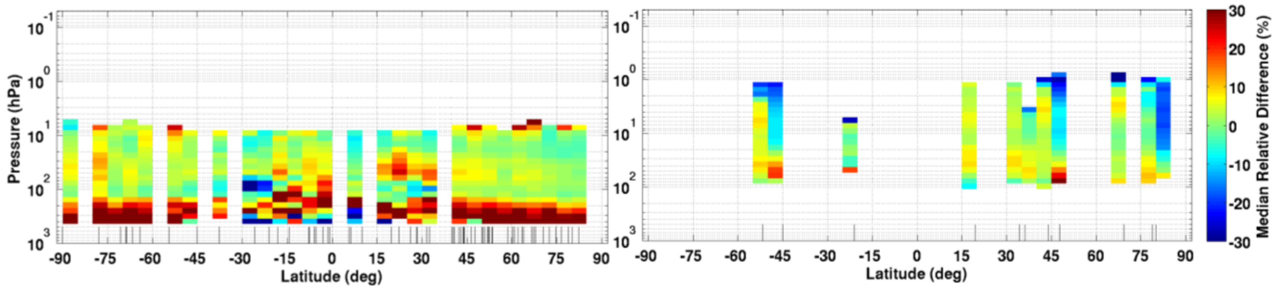

Figure 51: Same as Figure 50, for MIPAS IPF 5.05 data. The vertical scale is in pressure. The correlative profiles were not smoothened with MIPAS vertical averaging kernel, but using a layer-average.

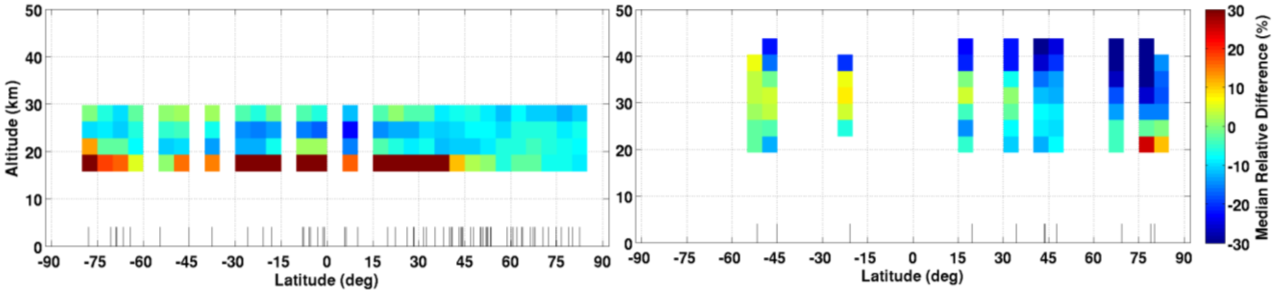

Figure 52: Same as Figure 50, for SCIAMACHY SGP 3.01 data.

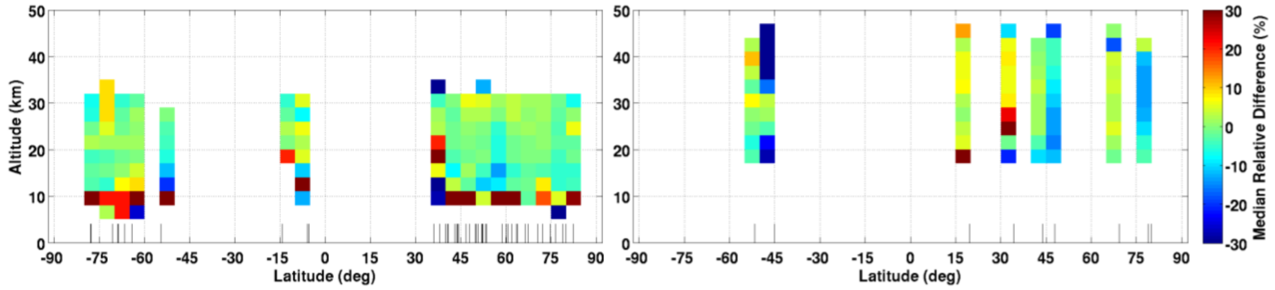

Figure 53: Same as Figure 50, for ACE-FTS v3.0 data.

IV.5.4.3.3 Lowest altitude with statistical quality

Below an altitude threshold varying usually between 10 and 20 km, the quality of individual limb profiles can differ significantly from the quality estimates derived statistically from comparisons with correlative data. Above this threshold altitude the ozone profiles agree statistically with ground-based network data. This threshold altitude depends on the measurement and retrieval techniques and their associated sensitivity to clouds and aerosols. The effective sensitivity of a limb data set to clouds and aerosols can be low, especially if corrected for in the retrieval. If not, it can be the source of additional noise and errors; see e.g. Sonkaew et al. [2009] who estimate that for the most frequently occurring clouds an error of 6% is introduced in SCIAMACHY and OSIRIS limb ozone data above 15 km. In the case of GOMOS, scintillation effects contribute to lower this threshold altitude. In several other cases the data set is less affected by clouds as cloudy scenes are detected and filtered out using a cloud mask.

Using the meridian and vertical analysis results reported in the above sections, we estimate here the respective threshold altitude of six limb ozone profile data sets by two different means. The upper panel of Figure 54 shows the altitude below which the median relative difference exceeds 20%, while the lower panel shows the altitude below which the half 68% inter-percentile exceeds 30%. These two criteria give comparable results. The threshold altitude is found to vary primarily as a function of latitude, likely following the meridian variation of the tropopause height, from 8 km in the Arctic to 18 km at the Equator. This correlation is to be linked with the known correlation between stratospheric aerosol loading and tropopause height as observed by Hofmann et al. [1975]. As anticipated the threshold altitude varies also with the viewing technique and its radiation source: it is the lowest for infrared sounding (10 to 15 km) and the highest for UV-visible scattering and star occultation (15 to 20 km). In the star occultation case, atmospheric scintillation, which increases as the atmosphere becomes denser, adds to the radiative transfer perturbations caused by aerosols and clouds.

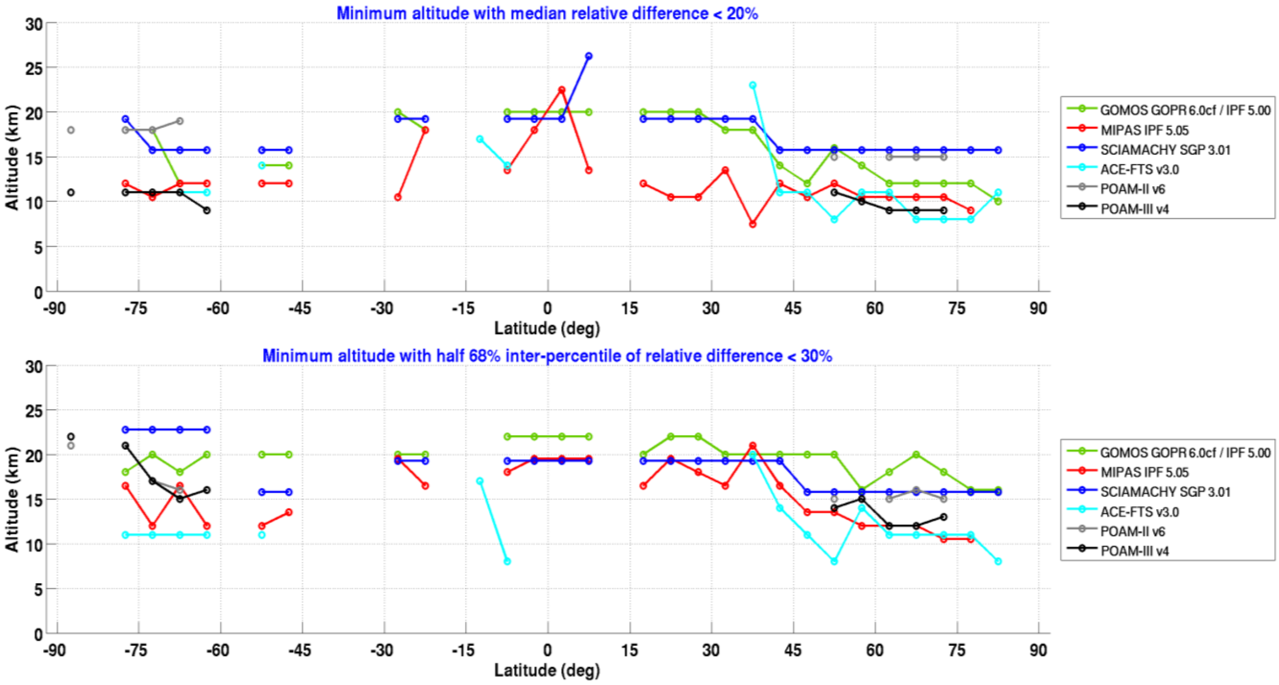

Figure 54: Threshold altitude of satellite measurements, below which median relative differences exceed systematically 20% (top) and below which half 68% inter-percentiles exceed systematically 30% (bottom).

IV.5.4.4 Conclusion

In the stratosphere, the analysis concludes to a mutual consistency of the studied ozone profile data records, to within 7% ± 10%. In the lower stratosphere the data quality degrades. However, a few exceptions and peculiarities have been detected and reported.

- GOMOS IPF 5.00 / GOPR 6.0cf ozone profiles have a negative bias of 5% in the Arctic.
- MIPAS IPF 5.05 ozone profiles follow the general tendency. After smoothing the correlative data with the MIPAS vertical averaging kernels, a bias remains between the FR and OR part of the mission.
- Over the entire altitude range, SCIAMACHY SGP 3.01 underestimates ozone densities by 10%.
- Although both agree with ground-based data with a mean difference within ±7%, we confirm a 5% bias between POAM-II and POAM-III ozone data.

For most of the data sets, the observed agreement seems to remain stable along the satellite measurement period. However, due to the short time series of the available data and/or the low temporal sampling rate, the current non-detection of drifts does not guarantee the temporal stability of the data set. Exceptions to the absence of drifts are GOMOS and SCIAMACHY. GOMOS bears a negative drift of 1 to 2% per year from 20 to 30 km altitude at Northern mid-latitudes. SCIAMACHY, in addition to a seasonal behaviour, shows positive drifts of 0.5 to 1% per year at 26 km altitude (and maybe at 23 km as well) at all latitudes. However, for both GOMOS and SCIAMACHY, the analysis is not fully consistent from station to station and would greatly benefit from the extension of the time series. For MIPAS the drift picture is not conclusive since the vertical averaging kernel, used to smoothen the correlative profiles, seems to be time-dependent. This has a large impact on the drift results. The use of the Envisat datasets for the establishment of long-term ozone profile time series is limited by the presence of drifts.

Below 10-20 km, the ozone profile data quality of any limb sounding instrument degrades rapidly, and should not be used in the establishment of long-term ozone profile records. This study shows that the threshold altitude (defined here as the lowermost altitude below which the median difference with ground-based data exceeds 20% or the half 68% inter-percentile exceeds 30%) varies with the latitude and the measurement technique. Lowest altitudes (10 km at the poles and 15 km at the tropics) are reached by infrared sounders like ACE-FTS and MIPAS, while scintillation limits this altitude to 18-20 km for the GOMOS star occultation instrument and scattering limits this altitude to 15-20 km for the SCIAMACHY UV-visible instrument.

This work uses ground-based networks as a transfer standard to investigate the consistency of ozone profile data records from (very) different satellite instruments. It assumes that ground-based networks and comparison methodologies are suitable for this purpose. This assumption calls for a few clarifications. A first remark is that the station-to-station homogeneity of network data sets is not perfect and that network inhomogeneity can sometimes exceed the internal homogeneity of satellite data sets. Station-to-station homogeneity depend on a variety of factors, like differences in instrument maintenance, operation, calibration, data retrieval, as well as the range of measured atmospheric states, which also varies from one station to another. Significant initiatives are carried out at international level to understand the sources of station-to-station/instrument-to-instrument discrepancy and improve network homogeneity, e.g. current efforts to establish and apply transfer functions for ozonesondes, and homogenisation of retrieval settings for UV-visible and FTIR spectrometers. In the mid-term improved ground-based data series might refine validations reported here. A second remark is that comparison methodologies used in this work are based on current best practices as published in the literature. That means that comparison issues related to differences in observation geometries, sampling and smoothing are addressed mainly in the vertical dimension, not in the horizontal dimension. A few demonstrations of the importance of horizontal aspects have been published in the context of the former TASTE project, e.g. in Cortesi et al. (MIPAS O_3 profile validation, ACP 2007) and Ridolfi et al. (MIPAS temperature profile validation, ACP 2007), where we had calculated the following metrological contributions to satellite/NDACC discrepancies: differences in vertical and horizontal smoothing, and differences in spatial sampling (systematic geographical mismatch). The evaluation of these comparison errors of metrological nature relies on an accurate description of both the measurement characteristics (including scanning geometry/sequence and orbit) and retrieval characteristics. In these studies based on MIPAS and NDACC (ozonesondes and lidars) data the random component of comparison results is shown to be explained satisfactorily by the RMS of the random errors of MIPAS and NDACC data plus the metrological errors as calculated in these papers. The interpretation of apparent biases revealed by the comparisons is less clear. Linked to the Multi-TASTE project, a full chapter in the ISSI Book on Atmospheric Water Vapour (Lambert et al., 2012), summarised in Section **V.3** of the present report, is dedicated to multi-dimensional smoothing and sampling issues for the comparison and merging of water vapour measurements. Test cases in this chapter conclude that the evaluation of apparent biases of metrological origin is needed, at least at stations in presence of quasi-permanent atmospheric gradients (e.g. dynamical barriers, high mountain ranges, Lee waves…) Accurate, quantitative consideration of network homogeneity issues and of multi-dimensional smoothing/sampling issues fall beyond the scope of the current project, as studies are still under development, but they are recommended for future projects, especially if validations have to demonstrate that satellite data meet stringent quality requirements raised by climate research studies. Considering network homogeneities and biases associated with multi-dimensional issues it can also be recommended to carry out statistical studies always with the greatest care. Common statements like “a large amount of comparison pairs will improve statistically the accuracy of comparison results by reducing the impact of natural variability” neglect the discrepancies of metrological origin and associated biases.

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V SUPPORT TO STRATEGY SPECIFICATIONS

V.1 GEO Quality Assurance framework for Earth Observation (QA4EO)

In 2006 the Working Group on Calibration and Validation (WGCV) of the Committee on Earth Observation Satellites (CEOS) was tasked by GEO to develop a data quality strategy for the Global Earth Observation System of Systems (GEOSS), beginning with space-based observations and investigating possible expansion to other observations and higher level products (GEO Task DA-06-02). In response, CEOS WGCV established the Quality Assessment framework for Earth Observation, QA4EO. Delivered to GEO after successful review by standardisation bodies and by the Global Space-based Inter-Calibration System (GSICS) and after endorsement by CEOS, QA4EO consists of ten key guidelines linked through an overarching document, the Guidelines Framework. A short QA4EO "user" guide has also been written. All documents can be found on the QA4EO web site (http://qa4eo.org). At the time of this report, GEO Task DA-06-02 activities continue through DA-09-01a and further extension is anticipated in 2012-2015.

The QA/QC experience available within NDACC and GAW in general and acquired by Multi-TASTE partners in particular has been instrumental in establishing and implementing QA4EO principles. Among others, IASB-BIRA has participated actively in different workshops and meetings, e.g., by representing the atmospheric composition community at the QA4EO governance meeting held in Ilhabela (Brazil) in May 2009 and the QA4EO Team meeting in Moscow (Russia) in May 2011, and by contributing, together with DLR, ESA and NASA, to the coordination of the Atmosphere and Climate Change session of the QA4EO workshop organised by the GEO Secretariat and hosted by RAL-Space (Harwell, UK) in October 2012.

Different activities of Multi-TASTE partners are directly relevant to the transposition of the high level QA4EO guidelines into practical implementations. Hereafter we describe shortly the most representative of these activities, addressing the development of best practices for the validation of satellite data, the development of harmonised metadata, and the development of initiatives for the traceability of validation processes and results.

Expertise gained by the team in terms of validation methods, sustainability of the validation process over a satellite lifetime and beyond, contribution to several steps of the life cycle of a data product (incl. delta validation of successive algorithm upgrades), end-to-end validation of a data production chain composed of separate modules, long-term validation needs and challenges, and multi-mission aspects with a view to establishing consolidated data records, have contributed significantly to the writing of the latest version of the PROMOTE C5 Service Validation Protocol (Lambert, November 2009), a planning and framework document established for ESA and the PROMOTE atmospheric service community, and applied during the course of the project by all PROMOTE services. This document serves now as an endorsed basis for the Validation Protocols of two successors of PROMOTE, namely, MACC (Lambert, 2010) and PASODOBLE (Lambert, 2011). Those two EU FP7 projects aim at building the GMES Atmospheric Service (GAS). Similarly, the expertise available with Multi-TASTE has been transposed directly into the Product Validation Plans of the ESA Climate Change Initiative (CCI) projects dealing with ozone (Lambert et al., 2011) and with greenhouse gases (Notholt et al., 2011).

Generic Environment for Cal/Val Analysis (GECA), an ESA-funded project under the lead of the prime contractor Logica, aims at establishing a harmonised environment suitable for the first-step validation of Earth Observation sensors performing atmospheric composition measurements, and also of SAR, land and ocean observations. GECA developments rely on intensive exchanges within a dedicated team of satellite validation experts, in which Multi-TASTE scientists play a leading role. In addition to the coordination of the team of validation experts from all thematic domains, they contribute expertise on atmospheric validation methods, viewing procedures, metadata formats, data policy, traceability, and archiving of validation results, and access to peer data centres. In 2011 Multi-TASTE partners involved in ozone profile/column and NO_2 column validations contributed to the verification of a GECA prototype.

In parallel to GECA, the new GEOMS standard (Generic Earth Observation Metadata Standard) has been developed. This format is an optimised and homogenised version of AVDC/NDACC and NILU's HDF formats. The definition of the new standard was finalized in March 2011 by the GEOMS team (Retscher et al.), quickly followed by its implementation for all ground-based measurement techniques used within Multi-TASTE. The current EVDC at NILU still uses the previous metadata format HDF 4.1.3, in which all correlative measurements collected within Multi-TASTE were delivered. But the NDACC, EVDC/NILU and AVDC databases will be/are being converted to the GEOMS standard. Translation tools are expected to be provided in order to support data providers and users during the transition.

To ensure traceability of validation results produced within the project, Multi-TASTE partners proposed in 2009 a set of guidelines for validation metadata, to accompany validation graphs and files. Since, these metadata guidelines have been circulated among ESA and NDACC partners, several suggestions have been implemented, and an improved version is proposed in annex.

V.2 Development of INSPIRE Implementing Rules on Metadata and Data Specifications

Published in the Official Journal on the 25th of April 2007, the INSPIRE Directive entered into force on the 15th of May 2007. To ensure that the spatial data infrastructures of the Member States are compatible and usable in a Community and transboundary context, the Directive requires that common Implementing Rules (IR) are adopted in a number of specific areas: Metadata, Data Specifications, Network Services, Data and Service Sharing, and Monitoring and Reporting. These IRs are adopted as Commission Decisions or Regulations, and are binding in their entirety. They apply to all geospatial data produced by a public institution in the European Union, thus certainly Earth Observation data acquired by ESA and TPM satellites evaluated in Multi-TASTE.

At the time of this report, most of IRs have been negotiated and adopted legally for spatial data themes of Annexes I and II of the Directive, that is:

- Annexe I: Coordinate reference systems, Geographical grid systems, Geographical names, Administrative units, and five other themes.
- Annexe II: Elevation, Land cover, Orthoimagery, and Geology.

The development of IRs for spatial data themes of Annexe III, which has the more direct application to atmospheric composition data, progressed significantly in 2011 and will end in 2012. Among relevant themes of Annexe III: 13. Atmospheric conditions, 7. Environmental monitoring facilities, 1. Statistical units, 5. Human health and safety, 12. Natural risk zones, and 14. Meteorological geographic features.

IASB-BIRA had been involved in past reviews of IRs now adopted for Annexe I and II. For Annexe III, this past experience and preliminary discussions with JRC have shown the interest to interact actively in the areas of Metadata and of Data Specifications, e.g., to adopt an appropriate definition of data quality which, in the general text of the Directive and in drafts of the IRs, is limited to the concepts of lineage and resolution, and also to include in a balanced way the third and fourth dimensions of data sets, limited to the horizontal dimensions. Registered officially as an INSPIRE Legally Mandated Organisation (LMO, contact point J.-C. Lambert), IASB-BIRA initiated in 2010 contacts with the INSPIRE Office at JRC to take part to Annexe III developments relevant to atmospheric satellite data and validation results. IASB-BIRA also started the coordination of an INSPIRE Spatial Data Interest Community (SDIC, contact point Anne De Rudder) carrying the voice of NDACC, of QA/validation projects using NDACC data like ESA's Multi-TASTE and and EUMETSAT O3M-SAF, and of EC FP6/FP7 projects building up the GMES Atmospheric Service (GAS) like MACC (core atmospheric services, Coordinator A. Simmons, ECMWF), PASODOBLE (downstream air quality services, Coordinator T. Herbertseder, DLR), and GEOmon (ground-based monitoring in support to the GAS, Coordinator for Activity 4 on stratosphere: Martine De Mazière, IASB-BIRA).

The last step of the Directive implementation process is the publication, before the 15th of May 2012, of Implementing Rules on data specifications related to data themes listed in Annexes II & III to the Directive. SDIC and LMO were invited in Spring 2011 to provide some feedback on the second version of these specifications (one document per data theme, except for Atmospheric conditions and Meteorological features, which are now merged into a single specification), through two evaluation mechanisms: consultation and testing. The two exercises closed on the 21st of October 2011, with due participation of IASB-BIRA both as LMO and as SDIC Coordinator, thus representing among others Multi-TASTE and NDACC. Some concerns were raised again on this occasion regarding the suitability of the current INSPIRE framework to atmospheric data in general, concerns which were forwarded also to the EC Project Officer for MACC and PASODOBLE, Dr. Stijn Vermoote, and conveyed to the GEO Secretariat and QA4EO stakeholders during the GEO QA4EO Workshop of October 2011. To summarise, the main issues remain related to the notion of quality and the handling of EO data dimensionality adopted in INSPIRE IRs.

By scientific standards (see [1], [4]), the quality of Earth Observation data depends on the provision of an estimator of its closeness to truth – or to some most plausible state such as a statistical average. This uncertainty estimator is part of the "quality indicator" (QI) which is crucial to allow potential users to assess the reliability of the data and its fitness for their purposes. In the context of atmospheric data products and services a valid quality indicator should couple this data uncertainty estimator with assessments of the completeness of metadata – without which a data set might be useless or used improperly – and assessments of compliance with respect to service specifications, standard data formats etc. Unfortunately, by forcing ISO standard 19115[3] to apply to environmental data, INSPIRE tries to fit a narrow suit to a wide body and bypasses the essential question of data quality. In the very particular case of geographic information, the data is the location itself, and so the precision of the geolocation is indeed identical to the quality indicator. But this ceases to be true for the vast majority of Earth Observation data, and certainly atmospheric composition data, for which geolocation is only part of the coordinate. Precision of the coordinate of course contributes to the data accuracy but it is only one element of it and by far not the most essential quality element for users of Multi-TASTE results. On the other hand, spatial resolution (understood in INSPIRE as isotropic horizontal resolution), which is currently defined in the INSPIRE Metadata Implementing Rules as one of the two aspects of quality (the other one being lineage), is not a quality indicator. Some quantity may be known with a very low resolution – e.g. zonal averages of ozone data and their evolution with time –, yet be of very high quality because perfectly suited to its purpose and assuming reliable values. Inversely, a dataset may be provided at an extraordinary fine resolution, yet be useless or even dangerous because including doubtful values. Another concern is that other resolutions than the horizontal one (vertical and temporal) are an important piece of EO metadata which should be mandatory where relevant, but they are currently not included as such in the INSPIRE Metadata IR.

In all generality, data relative to part or total of the Earth system are expressed in four-dimensional frames of reference, or coordinate systems: three spatial dimensions and one time dimension. By default, the objects considered by the INSPIRE Metadata IR are flat, eternal and motionless – which actually conforms to the INSPIRE current restriction to 2-D information. They are characterised by their geographic extent. Vertical and temporal extents may be provided but only as occasional attributes. It is rather surprising that a regulation which aims to tackle the realm of Earth data forgets about their basic four-dimensional nature. If only for offering support to monitoring[4], INSPIRE should remember the central role of time. As for the vertical dimension, it is inherent in the study of the ocean, soil and atmosphere and the phenomena that they host, for which relevant time scales range from seconds to centuries.

Finally, as underlined at the end of the previous section, resolution (understood as 4-dimensional), or an alternative description of the discrete domain of definition, should be a mandatory piece of metadata when relevant (but should not be provided as an indicator of quality).

[3] ISO 19115 Geographic information – Metadata.
[4] See INSPIRE Directive, § (11), p. 2.

V.3 Strategy for the validation of water vapour data products

Water vapour being a key trace gas and an important ECV with high uncertainty both in the troposphere and the stratosphere, existing collaborations have been enhanced and coordinated in the framework of the EC COST Action ES0604: Atmospheric Water Vapour in the Climate System (WaVaCS), and the ISSI working group on Atmospheric Water Vapour, built on the heritage of the NDACC H_2O WG. The website of the ISSI WG http://www.iapmw.unibe.ch/research/projects/issi/workshop3/report.html presents useful information, including an extensive database of publications on atmospheric water vapour, its measurement and validation results, which is accessible also via http://www.watervapour.org. Several partners of the Multi-TASTE consortium joined those groups and participated to the ISSI WG meetings in February and November 2008 and July 2009. In 2010 they completed their contribution to the writing of the ISSI book entitled *Ground based remote sensing and in situ methods for monitoring atmospheric water vapour*, and latest reviews by external experts were completed in 2011. The ISSI Book has now been published by Springer in the ISSI Scientific Report Series. Coordinated by N. Kämpfer from the University of Bern, this book consists of a science overview, a first part on in situ sensors (thin film capacitive sensors, chilled mirror hygrometers, and Ly-a fluorescent sensors), a second part on remote sensing sensors (microwave radiometry, Fourier transform infrared spectrometry, and lidar), a third part on networks and global monitoring (role of networks for global monitoring, overview of satellite sensors, multi-dimensional perspective on the comparison and merging of complementary water vapour observations, and survey of cross-validation), and several appendices including useful fact sheets on all measurement method.

In the context of Envisat and TPM validation, information reported in the ISSI Book gives confidence that microwave radiometer data are the most appropriate source of validation data for stratospheric profiles retrieved from GOMOS, MIPAS, SCIAMACHY and ACE-FTS measurements, although at lower vertical resolution. In the UTLS, small-weight balloon-borne cryogenic frost point hygrometers (CFH) and FLASH Ly-a fluorescent sensors offer the best accuracy. The quality of UTLS humidity profile data measured by regular PTU sondes flown regularly on-board meteorological balloons depends on the manufacturer and the serial number. Knowing that most of the H_2O total column is in the troposphere, the validation of water vapour column data as retrieved from SCIAMACHY and similar sensors can rely on the accuracy of FTIR and microwave column measurements and of columns derived from profile measurements by lidar (profile up to about 8 km a.s.l.) and by CFH sondes and FLASH Ly-a fluorescent sensors (from the ground up to about 20 km a.s.l.). GPS data are of suitable quality as well but they were out of scope of ISSI WG activities.

V.4 Note on the validation of infrared trace gases from GOSAT and TROPOMI

In the time frame of the TASTE and Multi-TASTE projects, the European NDACC FTIR community contributing to the EU projects UFTIR and HYMN, has made a considerable effort to harmonize the network data for CH_4 and N_2O. A similar effort has been made for water vapour and reported in the ISSI book on atmospheric water vapour. Retrieval and delivery of provisional CO_2 column data to the Envisat Cal/Val database has also started, although on an experimental basis (see Annexe II).

Two points are worth mentioning as to the validation of near-infrared greenhouse gas (GHG) products from sounders like GOSAT-TANSO (operating since 2009) and Sentinel-5 Precursor TROPOMI (launch in 2014).

1. The efforts made in Europe for the harmonization of the ground-based network FTIR data for CH_4 and N2O, are being extended to the whole NDACC FTIR community. This will enable us to include all stations from the network in a global validation effort.
2. At present, NDACC FTIRs retrieve CH_4 and N_2O vertical profiles and columns from spectra in the mid-infrared (MIR, 700 - 4000 cm^{-1} or 2.5 – 14 μm). SCIAMACHY CH_4 and NO_2 column data are retrieved in the near-infrared (NIR, 1 – 2.4 μm or 10000 – 4200 cm^{-1}). Therefore it cannot be excluded that validations of satellite NIR data using ground-based MIR data are affected by biases of spectroscopic origin. Many of the NDACC FTIR teams are however expanding their measurement capabilities to the NIR, in an effort to join TCCON (http://www.tccon.caltech.edu/) and to participate in the validation of satellite NIR GHG data products. This means that MIR and NIR data products can be intercalibrated at certain ground-based stations where both types of measurement are carried out (quasi-)simultaneously. This requires however an additional effort. The community is

searching for the resources to make this intercalibration for a better consistency between the NIR and MIR CH_4 and N_2O data products and to enable the use of all types of measurements at all stations for satellite validation purposes.

V.5 Multi-dimensional perspective on smoothing and sampling issues in data validation and merging

Differences in smoothing and sampling of the atmospheric structures and their temporal variability remain an important source of uncertainty in data comparison and data merging. The problem can even amplify in multi-mission applications, as tasked in current CCI projects and SPARC initiatives. In TASTE we had demonstrated the value added to the validation of MIPAS ozone and temperature profiles by considering comparison errors due to differences in horizontal smoothing and sampling (Cortesi et al., 2007; Ridolfi et al., 2007). Getting on with this necessary research in metrology of satellite validation, activities carried out in the framework of the ISSI WG have given to Multi-TASTE partners the opportunity to acquire better understanding of smoothing and sampling characteristics of current H_2O measurement. In return, building on the TASTE experience, the comparison and merging of water vapour data have been used as test cases for qualitative and quantitative studies of smoothing and sampling issues. In particular, Multi-TASTE partners have led Chapter 9 of the aforementioned ISSI Book, entitled “Comparing and merging water vapour observations: A multi-dimensional perspective on smoothing and sampling issues” (Lambert et al., 2012). This chapter intends to increase awareness to important data comparison and merging issues that should not be neglected for a species exhibiting so rapid changes and so intense gradients. Positioned at the interface between retrieval specialists and data users interested in atmospheric water vapour measurements, the concepts described and illustrated in this chapter are quite general and applicable to other species than water vapour.

Atmospheric water vapour is an interesting test case at it exhibits significantly high variability in both space and time in the troposphere and a sharp vertical gradient at the hygropause. Tropospheric variability as well as the hygropause can alter considerably the comparison of data obtained by instruments offering different sensitivity to the vertical profile and to horizontal gradients. A short difference in time and a small horizontal distance between the actual measurement points to be compared is sufficient to generate large discrepancies exceeding often the sum of the error bars of the individual measurements.

Figure *55* illustrates how sampling and smoothing differences between MIPAS and balloon sonde measurements (top), can add bias and noise in data comparisons (bottom). As a direct outcome of Multi-TASTE involvement in the ISSI WG activities, it is planned explicitly to give quantitative attention to these aspects in validation tasks of the Ozone_cci project, wherein climate research users have expressed stringent data quality requirements necessitating data characterisation and validation methods of improved accuracy. The Multi-TASTE experience is also to be transposed in the development of validation facilities for GOME-2 and IASI trace gases data planned in the upcoming CDOP-2 project of the EUMETSAT O_3M-SAF.

Multi-dimensional aspects of smoothing and sampling issues have also been reported to the data assimilation community, among others at the 8th SPARC Data Assimilation workshop of June 2011 in Brussels (Jackson and Polavarapu, 2012). Current chemical data assimilation systems ingest atmospheric observations via an observation operator usually based on simple spatial interpolation. The underlying assumption is that the atmospheric information contributed by the observation comes from the column over the ground footprint (for nadir sounders) or from the tangent point (for limb/occultation sounders), with negligible spread around this footprint or tangent point. But in recent years we have developed, with support from the EC FP6 GEOmon and ProDEx SECPEA projects, multi-dimensional observation operators for NDACC instruments (Lambert et al., 2011) and for four major families of satellite sounders: nadir and limb UV-visible scattering (Vandenbussche et al., 2009b, 2010a), limb infrared emission (von Clarmann et al., 2009), and solar occultation (Vandenbussche et al., 2010b). They better represent the spatial characteristics of the retrieved information. The latter can spread anisotropically over several hundreds of kilometers around its barycenter, which can be distant from the footprint or the tangent point by up to hundreds of kilometers in extreme cases. We have reported to the SPARC DA community several test cases – mainly from Multi-TASTE results – where different observation operators yield significantly different trace gas concentrations or columns, hence different data comparison results. Potential effects on tracer-tracer correlations and long-term reanalyses have also been discussed. Our development of improved observation operators and their Multi-TASTE demonstrations are extended currently to tropospheric observations by MAX-DOAS and FTIR instruments, in the EC FP7 NORS project, aiming at developing and demonstrating NDACC-based operational support to the GMES Atmospheric Service (GAS).

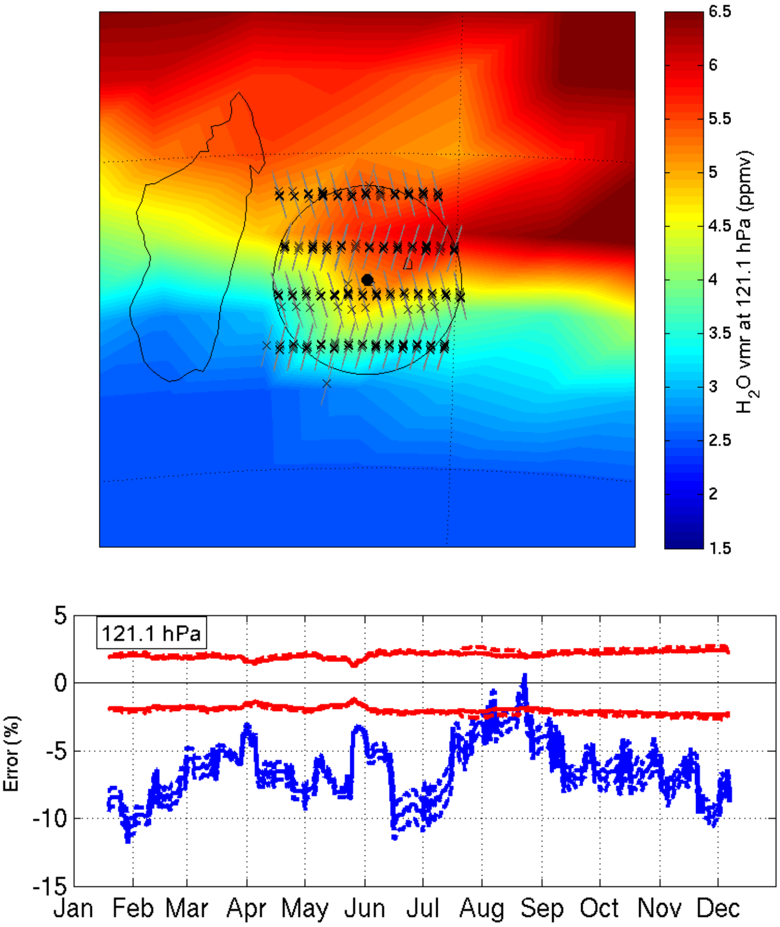

Figure 55: Top : Sampling by MIPAS of the stratospheric H2O field at the 121 hPa level, in a radius of 500 km around the NDACC station of La Réunion (Indian Ocean, 21°S, 55°E), achieved after one month of measurements in January 2003. The large island on the left is Madagascar. Crosses and tilted lines represent, respectively, the horizontal projection of tangent points at 121 hPa and of the corresponding 95% spread of the retrieved information (horizontal averaging kernels according to von Clarmann et al., 2009). Grey lines rising to the left and to the right represent late evening and early morning overpasses, respectively. The H2O field was generated by the BASCOE assimilation system and provided by Q. Errera and the BASCOE team at BIRA-IASB. Bottom: Annual variation (over 2003) of the corresponding contributions to the comparison error between MIPAS and balloon-based sondes (either CFH, Lyman-□ or PTU) due to horizontal smoothing differences and spatial mismatch (adapted from Lambert et al., 2012). Dashed lines represent the random component which adds to the systematic errors represented as solid lines. In red, the uncertainty due to the fact that MIPAS captures information spread over several hundred kilometres more or less around its tangent point, while an in situ sounding record H2O at a resolution of the order of one hundred metres. In blue, the systematic bias due to the fact that MIPAS tangent points are programmed along the orbit on fixed positions distant by 500 kilometres, with the consequence that the distance in latitude between MIPAS and the station cannot go under a minimum value. The latter ranges from zero for stations located exactly on MIPAS latitude circles, through about 50 km at Reunion Island, to 250 km for stations just half way between two latitude circles of MIPAS measurements. In the absence of large and permanent gradients, the sampling difference generates in the comparisons some noise that can be reduced statistically by comparing numerous pairs of data. But In cases of large, permanent gradients, like in this figure for a station at the border of the inter-tropical convergence zone, this distance generates a bias between the two systems, which cannot be eliminated by performing comparisons on a large amount of data, and which might well be attributed erroneously to one of the two measurement systems if the sampling difference is ignored.

V.6 New challenges for NDACC in view of planned satellite missions

The independent calibration and validation of satellite experiments is a major goal of NDACC, and Multi-TASTE relies significantly on the availability and quality of data provided by this network of high quality remote sounding stations. Since its official inception in 1991, NDACC has contributed to the geophysical validation of not far from sixty atmospheric composition missions. Beyond validation activities, NDACC supports satellite missions also with expertise in remote sensing, in calibration, in retrieval algorithms, and in atmospheric composition and processes at regional scale. Moreover, NDACC instruments complement satellite capabilities with continuous observations of species and at altitudes, precisions and resolutions not reachable from space. In return, satellite data records extend NDACC data to the global domain and to higher altitudes, and they provide data quality feedback to the stations, e.g., in terms of network homogeneity.

Dedicated initially to the monitoring of changes in the stratosphere with an emphasis on the evolution of the ozone layer, NDACC priorities and measurement capabilities have broadened considerably to encompass the overall atmospheric composition, including tropospheric chemistry and air quality, and links between climate change and atmospheric composition change. Priorities and capabilities of satellite missions have broadened in parallel. To foster further developments of NDACC capabilities meeting future satellite needs in the next decade, we have collected information on planned and potential missions through the channels offered by the NDACC Satellite WG, the CEOS Working Group on Calibration and Validation (WGCV) and the CEOS Atmospheric Composition Constellation (ACC). Via the NDACC Working Groups we have also collected information on current operational capabilities of NDACC and on planned developments of NDACC instrumentation and measurement sites. From the confrontation of those informations we have identified new challenges for NDACC, summarised in Table 2. They were reported at two NDACC Steering Committee meetings (in 2010 and 2011), to the whole NDACC community during the NDACC Symposium 2011 on Reunion Island, at the CEOS WGCV Plenary of May 2011 in Moscow, and at the 8th Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer (8ORM) organised by UNEP and hosted by WMO in Geneva in May 2011.

In brief, three series of low-orbit polar missions are taking over the long-term, global monitoring of the ozone column and of the ozone profile (at low vertical resolution), initiated with the TOMS/SBUV and GOME/SCIAMACHY/OMI series started in 1978 and 1995, respectively: three GOME-2 on-board EUMETSAT EPS MetOp (MetOp-A launched on 19 October 2006, MetOp-B and MetOp-C to be launched in 2012 and 2017, respectively); three TOU/SBUS on-board NSMC/CMA FengYun-3 (FY-3A launched on 27 May 2008, FY-3B on 5 November 2010); and OMPS on-board NOAA NPP/JPSS (launched on 28 October 2011). Similar instrumentation is expected to continue operation in the post-EPS timeframe with the ESA/EUMETSAT GMES Sentinel 5 (launch around 2020) and NASA's GACM (project for 2025), with Sentinel 5 Precursor (TROPOMI) to be launched in 2014 by ESA as a gap-filler mission. A geostationary constellation of air quality/climate monitoring satellites are envisaged from 2018 with ESA/EUMETSAT GMES Sentinel 4, Korean GMES and Japanese GMAP-Asia missions, and after 2020 with NASA's GEO-CAPE, as well as pseudo-geostationary capabilities from Molniya orbits for the Arctic (CSA PHEMOS concept studies). These latter will offer high spatial resolution access to short-term variations of the atmosphere, including lower the troposphere, but with geographical coverage limited to the geostationary field-of-view – Sentinel 4 being further focused on Europe and surroundings. Global monitoring of greenhouse gases (including CO_2 and CH_4) by SCIAMACHY (2002-2012) and GOSAT (since 2009) will continue with NASA OCO-2 after 2014. Profiling capabilities of trace gases at high vertical resolution from the upper troposphere up to the mesosphere have already reduced considerably after the loss of ERBS SAGE-II, UARS HALOE, UARS MLS, and Meteor-3M SAGE-III in 2005, Aura HIRDLS in 2009, JEM SMILES in 2010, and Envisat in April 2012. They will further reduce after the current era of Odin (since 2001), SCISAT ACE (since 2003) and EOS Aura (since 2004). At the time being, there are several concept studies and projects, e.g., to operate ACE-FTS on future platforms, and to develop the ALTIUS limb instrument for the lightweight PROBA platform. PREMIER, an infrared and microwave limb instrument, is a candidate for ESA's Earth Explorer 7 (around 2016). However, there is no firm programme guaranteeing appropriate continuation of solar occultation and limb profilers after OMPS on NPP (launched in 2011) and SAGE-III on ISS (launch scheduled in 2014).

In support to satellite observations and their validation, current ground-based capabilities should be maintained, and even extended to cover a wider scope of atmospheric states and regions of interest. Additional deployments of facilities in the tropics and the Southern Hemisphere are encouraged. But in recent years the regular decrease in the number of stations reporting data to NDACC (instrumentation used by Multi-TASTE) and WOUDC (Dobsons, Brewers and ozonesondes) has become a concern; there are signs that this reduction of facilities will continue. More and more stringent user requirements call for further efforts to intercalibrate instruments, to address quality issues in particular in the tropics, to improve the station-to-station homogeneity of networks, and to consolidate long-term data records, especially in view of data assessments addressing the interactions between atmospheric composition changes and climate change. To guarantee interoperability of the systems, traceability of the data quality, and fitness for purpose of the data, enhanced cooperation between space agencies, within ground-based networks, and between ground-based networks, satellite teams, and generic data users, is highly desirable in the fields of instrument calibration, level-1-to-2 retrieval algorithm development, geophysical validation, data access and data policy, methods for data integration and merging (including comparisons with models and with data assimilation results), communication, training, and education. Traceability and consistency of quality-assurance methods and of quality information from end–to-end, that is, from the acquisition of binary data by the instrument to the delivery of four-dimensional atmospheric fields by modelling and assimilation systems, is of particular concern. Multi-mission/multi-sensor/multi-agency projects and strategies like the GEO Quality Assurance framework for Earth Observation (QA4EO), the Global Space-based Inter-Calibration System (GSICS), SPARC and WMO assessments, NASA’s GOZCARDS and ESA’s Climate Change Initiative, and topical intercomparison campaigns aiming at understanding and reducing discrepancies between different types of observations (like ESA funded CINDI), are warmly encouraged. These new steps in the integrated exploitation of satellite and ground-based data may require the development of dedicated methods and tools, addressing issues like multi-dimensional representativeness, and should be supported by adequate research.

Table 2: Summary of new challenges for NDACC instrumentation and activities in the light of future satellite missions.

FUTURE OF SATELLITES	CHALLENGES FOR NDACC
Gap analysis for satellite mission planning: only a few satellites in 2014–2019, before the advent of the Sentinels	Ensure continuity of NDACC monitoring and of sustainability of expertise over this period to fill in potential gaps in satellite missions
Improvement of existing satellite instrumentation: improved version of ACE-FTS and of SAGE-III, progress in remote sensing in the UVVIS and MW spectral ranges…	Broaden NDACC list of species; characterise and improve NDACC measurement characteristics (range, sensitivity, resolution…) accordingly
Geostationary (incl. Molniya) missions: unprecedented temporal frequency of observation (and subsequent high bit rate) and higher horizontal resolution	Develop/enhance diurnal sampling capabilities; better characterise horizontal and vertical resolution/sensitivity of NDACC measurements
New instrument concepts	New products and characteristics, e.g., enhanced tropospheric measurement capabilities
Better exploitation of existing data: consolidation, multi-mission...	Address aspects of sustainability, long term stability, network homogeneity, traceability…
Operational and service aspects; emphases on users	Improve and document operational aspects (QA/QC, fast delivery…); analyse URDs and enhance visibility of compliance; document errors and information content characterisation…

FUTURE OF SATELLITES	CHALLENGES FOR NDACC
More integration via CEOS, GEOSS, GMES, ECDRs…	Formulate and document best practices; develop dedicated methods and tools; interact with CCI, SPARC, CEOS…; develop a specific activity line for the GEOSS

V.7 The Great SCIAMACHY Validation Assessment

In the previous Section **V.6**, Multi-TASTE partners have analysed general requirements of satellite validation in the next decade and identified new needs for further developments of NDACC instrumentation, network extension, operations and methods. These new challenges and opportunities have been handed to the NDACC Steering Committee and Working Groups, and to also the UNEP/WMO Ozone Research Managers. Similarly, the SCIAMACHY Validation and Interpretation Group (SCIAVALIG) has undertaken in 2011 The Great SCIAMACHY Validation Assessment (TGSVA). This initiative aims at identifying where improvements need to be made to the SCIAMACHY data record and subsequently to its validation, now spanning almost a decade. More specifically, the expected outcome of this assessment is:

- Identification of validation gaps
- Setting up new and dedicated measurements with standard equipment
- Providing recommendations for funding, development and deployment of new, dedicated equipment
- Defining or joining future campaigns aimed at achieving SCIAMACHY goals.

For this purpose, an assessment questionnaire established by SCIAVALIG Co-chairs and reviewed by ESA was sent to calibration experts, algorithm developers, validation scientists and end-users of SCIAMACHY, to approach this challenge from various perspectives. A large number of responses were received, including several contributions from Multi-TASTE scientists for the UV-visible and infrared level-2 data products. A report with recommendations was issued by SCIAVALIG in November 2011[5]. This report compile the responses received, complemented by the comments and suggestions received at the recent SCIAMACHY Science Advisory Group (SSAG no. 43, October 5/6 2011) meeting, where this overview was first presented.

The response from the SCIAMACHY community indicates where needs exist and thus where to focus attention. The TGSVA assessment clearly indicates that imperative validation needs exist for UVVIS data products like BrO, OClO and HCHO, largely because of the lack of correlative data. Here dedicated campaigns are suggested to capture challenging conditions such as bromine explosions. Imperative validation needs also exist for the infrared data products, such as CO, CO_2, CH_4, H_2O, and HDO. Here the strengthening of the funding position of ground-based stations affiliated with NDACC and TCCON is suggested to warrant data quality and continuity. It is also suggested to support NDACC and TCCON for feasible strategic expansions of these networks by quality-proven existing systems and promising new systems, to cover key source regions on the globe at least within the remaining operational time frame of Envisat. For other data products, more in-depth algorithm and validation studies are suggested, less costly but equally important, not necessarily to be performed within the operational time frame of Envisat but to be developed in prevision of upcoming missions such as the Sentinels.

In the TGSVA report SCIAVALIG has taken the liberty to assess these responses in terms of priority, feasibility and costs. Hence the report provides a ranked single-table overview of proposed actions plus their detailed descriptions. The final decision on what course of actions should follow is in the hands of ESA, the national funding agencies, SADDU and SSAG.

[5] Feedback on The Great SCIAMACHY Validation Assessment, by M. Kroon, A. Richter, and J.-C. Lambert on behalf of SCIAVALIG, 45 pp., November 2011.

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VI VALORISATION

VI.1 Correlative Database

Thanks to interagency agreements and/or joint AO/Cat-1 proposals involving most of consortium partners, the Envisat Cal/Val database is also valuable and used for the validation of ESA's Third Party missions such as SCISAT-1 ACE-FTS and MAESTRO, and for the validation of EOS-Aura OMI (joint ESA/NIVR/KNMI AO for OMI) and EUMETSAT GOME-2 and IASI (joint ESA/EUMETSAT RAO for EPS/MetOp). Correlative measurements stored at NILU in the Cal/Val database are also used in support to new processor developments carried out in the framework of ESA projects like QWGs, CCI and GDP5/GODFIT. In the reporting period the data were used namely for sensitivity studies and for the delta-validation of the direct fitting algorithm GODFIT implemented in 2010/2011 in the operational GOME Data Processor version 5 (GDP 5/GODFIT project). The data were also used for the assessment of suitability of ozone profile data generated by the neural network NNORSY run at ZSW on GOME spectra (suitability of NNORSY-GOME ozone profile data for GODFIT retrievals, in support of the GDP 5 project) and for the quality assessment of ozone profile data generated by the neural network NNORSY run at ZSW on SCIAMACHY level-1 data (CHEOPS-SCIA project).

VI.2 Technical/Project Meetings

Results obtained by members of the consortium, independently or in a concerted way, as well as issues related to the project, were reported, exchanged and discussed by email and during teleconferences and meetings on many occasions. They are listed in Annexe 2.

VI.3 Validation Workshops, Scientific Conferences, and Symposia

When and where appropriate, Envisat and TPM validation results were presented during scientific workshops and major symposia. A complete list of events dedicated explicitly to satellite validation or with dedicated validation sessions, of which several were organised by Multi-TASTE project team members, can be found in Annexe 2.

VI.4 Publications and Reports

Members of the Multi-TASTE consortium contributed to a list of peer-reviewed papers, conference proceedings and technical reports (see Sections VII.1 and VII.3, Annexe 1).

Validation results produced by Multi-TASTE partners are an important input to the validation of several of former ESA's GSE PROMOTE services related to ozone, greenhouse gases and aerosols, and air quality (see http://www.gse-promote.org). Several results were integrated in the PROMOTE Service Validation Report (document C6, version 3 published in October and November 2009), available via the validation section of the PROMOTE web site.

VI.5 Quality Assurance in support to the GMES Atmospheric Service

The final meeting of ESA's GSE PROMOTE took place in October 2009. Since, three EC FP7 projects have taken over many of PROMOTE services for further consolidation and operationalisation in the context of the future GMES Atmospheric Service: MACC, building up the GMES Atmospheric Core Service, started in summer 2009, which will be followed by MACC-II in 2012; PASODOBLE, consolidating GMES Atmospheric Downstream Services for Air Quality, started in May 2010; and EVOSS, building up a European volcanic observatory from space, started in April 2010. These projects assume that the satellite data they use as input are validated under the responsibility of the space agencies operating the respective atmospheric composition satellites. Multi-TASTE activities contribute to ESA's obligation to carry out appropriate data quality assurance.

VI.6 Dissemination of Expertise

The expertise gained by Multi-TASTE partners contributed to the success of the validation of the Canadian SCISAT-1 ACE-FTS and ACE-MAESTRO, ACE being a Third Party Mission of ESA. Expertise is also being disseminated in the framework of GOSAT validation AO projects.

The experience gained by Multi-TASTE in the "routine" validation of satellite data by a consortium has provided an interesting feedback to the EC FP6 IP GEOmon project (http://www.geomon.eu), ended in June 2011. As another precursor of the future GMES Atmosphere Service, GEOmon aimed at integrating ground- and air-based atmospheric monitoring systems over Europe and improving their link with satellite data. In this framework, several Multi-TASTE partners had worked together and with other institutions to further improve satellite validation methods and establish validation standards. Experience gained by Multi-TASTE members with fast delivery issues was a valuable input to GEOmon Data Management Committee discussions and activities, and to EC WG establishing guidelines for the implementation of the future GAS. Building on the achievements of GEOmon, the NDACC-based part of GEOmon is now further extended in the EC FP7 project NORS, with the aim to demonstrate and establish operational activities cut to the needs of the GAS. Again, the Multi-TASTE experience with long-term and routine validation, as well as its expertise in validation methods and tools, provide valuable input to this new project, and the consortium contributes a member to the NORS Steering Committee.

As a contribution to the 10-year implementation plan of the GEOSS, the CEOS WG on Calibration and Validation (WGCV, see http://wgcv.ceos.org) has been tasked by the Group on Earth Observation (GEO) to develop an EO data quality strategy, beginning with space-based observations and evaluating possible extension to other systems. In this context, the TASTE/Multi-TASTE experience is useful for the establishment of validation standards and of best practices in acquisition, collection and management of validation data. In particular, Multi-TASTE contributed significantly to the COSPAR/CEOS Joint Session on the 'Development of reference practices for the calibration and validation of atmospheric composition remote sensing'. A few Multi-TASTE results also illustrate the regular ACSG reports presented during the CEOS WGCV plenaries.

Scientific experts defining the scientific requirements, working on the metadata standards, and describing the Cal/Val manipulation operations for ESA's Generic Environment for Cal/Val Analysis (GECA), another contribution to CEOS activities, also benefit from the TASTE/Multi-TASTE experience. After successful contribution to the User Requirement Document (URD), in the reporting period Multi-TASTE scientists provided GECA with recommendations for Cal/Val test sites, co-location criteria, metadata, and test case studies. In summer 2011 they also tested the GECA prototype and provided feedback to ESA, Logica and S&T.

ESA's Climate Change Initiative activities started in September 2010. The expertise developed by Multi-TASTE in multi-mission validation is instrumental in establishing for the Ozone_cci project three of its major deliverables, namely, Data Access Requirement Document (DARD), Product Validation Plan (PVP), and Data Base for Task 2. Later in the course of the Ozone_cci project, the practical know-how acquired by Multi-TASTE will support different validation tasks, like the MIPAS and GOME nadir Round-Robin exercises aiming at the selection of the most appropriate retrieval algorithm for ECV production, and the production of validation assessments.

VII ANNEXE 1: ARTICLES AND PRESENTATIONS

VII.1 Peer-reviewed articles

Angelbratt, J., J. Mellqvist, T. Blumenstock, T. Borsdorff, S. Brohede, P. Duchatelet, F. Forster, F. Hase, E. Mahieu, D. Murtagh, A.K. Petersen, M. Schneider, R. Sussmann, and J. Urban, A new method to detect long-term trends of methane (CH4) and nitrous oxide (N2O) total columns measured within the NDACC ground-based high resolution solar FTIR network, Atmos. Chem. Phys., 11, 6167-6183, doi:10.5194/acp-11-6167-2011, 2011.

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VII.5 Oral presentations

De Clercq, C., Implémentation du système global pour la mesure de la composition atmosphérique: concepts et méthodes pour une analyse intégrée des données satellitales, PhD thesis defended at Liège University, July 7, 2009.

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VII.6 Posters

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Dils, B., M. De Mazière, C. Vigouroux, F. Forster, R. Sussmann, T. Borsdorff, P. Bousquet, T. Blumenstock, M. Buchwitz, S. Dalsoren, P. Demoulin, P. Duchatelet, C. Frankenberg, J. Hannigan, F. Hase, I. Isaksen, N. Jones, J. Klyft, I. Kramer, E. Mahieu, J. Mellqvist, L. Neef, J. Notholt, K. Petersen, I. Pison, O. Schneising, A. Strandberg, K. Strong, S. Szopa, J. Taylor, P. van Velthoven, M. van Weele, S. Wood and M. Coffey, A Comparison of methane data products from Chemistry Transport Models, SCIAMACHY, and a quasi-global network of FTIR stations, poster presentation at the ESA Atmospheric Science Conference, Barcelona, Sept. 7-11, 2009.

Dils, B., M. De Mazière, C. Vigouroux, F. Forster, R.Sussmann, T.Borsdorff, P. Bousquet, T. Blumenstock, M. Buchwitz, S. Dalsoren, P.Demoulin, P. Duchatelet, C.Frankenberg, J. Hannigan, F. Hase, I.Isaksen, N. Jones, J.Klyft, I. Kramer, E. Mahieu, J. Mellqvist, L. Neef, J.Notholt, K. Petersen, I. Pison, O. Schneising, A.Strandberg, K. Strong,S. Szopa, J. Taylor, P. van Velthoven, M. van Weele, S. Wood, A comparison of Methane data products from Chemistry Transport Models, SCIAMACHY and a quasi-global network of FTIR stations, poster presentation at the NDACC-IRWG annual meeting, Murramarang, Australia, June 2-4, 2010.

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Duchatelet, P., E. Mahieu, R. Sussmann, F. Forster, T. Borsdorff, P.F. Bernath, C.D. Boone, K.A. Walker, M. De Mazière, and C. Vigouroux, Determination of isotopic fractionation δ_{13}C of methane from ground-based FTIR observations performed at the Jungfraujoch, poster presented at the "EGU 2009 General Assembly", 19 – 24 April 2009, Vienna, Austria, 2009.

Duchatelet, P., P. Demoulin, F. Hase, E. Mahieu, P.F. Bernath, C.D. Boone, and K.A. Walker, Updating hydrogen fluoride (HF) FTIR time series above the Jungfraujoch: comparison of two retrieval algorithms and impact of line shape models, poster presentation (EGU2010-1354) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Godin-Beekmann, S., A. Pazmiño, A. Griesfeller, F. Goutail and G. Ancellet, Evaluation of ozone variability from multiple measurements at northern mid-latitude station , QOS, Tromsoe, Norway, July 2008.

Goutail, F., A. Pazmino, J. P. Pommereau, SAOZ UV-Vis reanalysis, Helsinki, IGACO-WMO meeting, June 2009.

Goutail, F., D. Ionov,, A. Pazmino, J.-P. Pommereau, F. Hendrick, M. van Roozendael, M. Pastel, A. Griesfeller, Validation of satellite total ozone and NO_2 data with ground-based SAOZ network, Envisat Atmospheric Science Conference, Barcelona, Sept. 2009.

Goutail ,F., A. Pazmiño, J. P. Pommereau, M. Pastel, D. Ionov, F. Hendrick, M. Van Roozendael, E. Kyrö, P. Eriksen, V. Dorokhov, G. Held, Validation of nadir viewing satellite total ozone and NO_2 column with ground-based SAOZ network, GEOmon annual meeting, London, UK, Jan. 2010.

Goutail, F., A. Pazmino, A. Griesfeller, D. Ionov, K. Clemer, M. Van Roozendael, Monitoring pollution using a SAOZ zenith sky spectrometer, GEOmon annual meeting, London, UK, Jan. 2010.

Goutail, F., A. Pazmino, A. Griessfeller, D. Ionov, K. Clemer, M. Van Roozendael, Tropospheric columns using SAOZ zenith sky spectrometer, poster presentation (EGU2010-5177) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Griesfeller A., S. Godin-Beekmann, F. Goutail, D. Ionov, A. Pazmiño, I. Petropavlovskikh, J.-P. Pommereau, Long-term time series of ozone at Observatoire de Haute-Provence (OHP), 44°N, 6°E, European Geophysical Union, Vienna, 2009.

Griesfeller, A., F. Goutail, F. Hendrick, D. Ionov, M. Pastel, A. Pazmiño, J.-P. Pommereau, M. Van Roozendael, Homogenization of UV-Vis reprocessing for ozone, Geomon annual meeting, Geneva, Jan 2009.

Hay, T.; Kreher, K.; Johnston, P.V.; Bodeker, G.; Schofield, R.; Thomas, A.; McDonald, A.; Martinez-Aviles, M.; Profiling of MAX-DOAS BrO measurements from Antarctica and NO_2 measurements from CINDI, poster presentation (EGU2010-8141) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Hubert, D., Vandenbussche, S. and Lambert, J.-C., Long-term stability and multi-mission consistency of nine satellite ozone profilers, poster presentation at the SPARC/IO3C/WMO-IGACO Workshop on Past Changes in the Vertical Distribution of Ozone, OMM, Genève, Switzerland, January 25-27, 2011.

Hubert, D., Vandenbussche, S., Granville, J. Pieroux, D. and Lambert, J.-C., Towards a consolidated climatic data record of the ozone profile: global assessment of long-term drifts for nine satellite sounders, poster presentation at the GEOmon Final General Assembly, Brussels, Belgium, February 2-4, 2011.

Javed U., et al., Measurements of NO2 using MAX-DOAS observations of sun-illuminated targets, DPG Spring meeting, Hamburg, Germany, March 2009.

Koukouli., M., J.-C. Lambert, D. Balis, D. Loyola, W. Zimmer, M. Van Roozendael, C. Lerot, and J. Granville, Validation of different configurations of the GODFIT/GDP5 algorithm using groundbased total ozone data, ESA Atmospheric Science Conference 2009, Barcelona, Spain, 7-11 September 2009.

Lejeune, B., E. Mahieu, C. Servais, P. Duchatelet, and P. Demoulin, Optimized approach to retrieve information on the tropospheric and stratospheric carbonyl sulfide (OCS) vertical distributions above Jungfraujoch from high-resolution FTIR solar spectra, poster presentation (EGU2010-3513) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Mahieu, E., P. Duchatelet, C.P. Rinsland, Q. Li, C.D. Boone, K.A. Walker, P.F. Bernath, M. De Mazière, B. Dils, and the GIRPAS Team, Time series of ^{12}CO and ^{13}CO at northern mid-latitudes: Determination of Partial Column and $\delta^{13}C$ seasonal and interannual variations, poster presented at the "EGU 2009 General Assembly", 19 – 24 April 2009, Vienna, Austria, 2009.

Oetjen, H., et al., OClO measured from Satellite and Ground and Comparison with Modelling Studies, SPARC workshop on "The Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion", Cambridge, Great Britain, June 2008.

Pastel, M., F. Goutail, J. P. Pommereau, A. Pazmiño and Gerhard Held; Trend analysis of tropical stratospheric O3 and NO2 columns , QOS, Tromsoe, Norway, July 2008.

Pazmino, A., F. Goutail, J. P. Pommereau, M. Pastel, D. Ionov, F. Hendrick, M. Van Roozendael, R. Evans, V. Dorokhov, E. Kyro, P. Heikkinen, P. Eriksen, G. Held, Homogenization of UV-Visible NDACC spectrometers reprocessing for ozone and NO2, poster presentation (EGU2010-5044) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Kivi, R., E. Kyrö, H. Vömel, F. Immler, N. Kämpfer, C. Straub, V. Yushkov, S. Khaykin, T. Christensen, and F. G. Wienhold, Polar stratospheric cloud, water vapor and ozone observations at Sodankylä, poster presentation (EGU2010-13701) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Kyrö, E., J. Pulliainen, P. Heikkinen, P. Ahonen, R. Kivi, J. Hatakka (2010), Early results on the validation of GOSAT/TANSO GHG observations at the Sodankylä-Pallas satellite pixel (67N, 27E), poster presentation (EGU2010-9252) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Lacour, J.-L., H. Herbin, D. Hurtmans, L. Clarisse, P.-F. Coheur, S. Fally, C. Hermans, M. De Mazière, Measurements of water isotopologues from IASI and ground-based FTIR at a subtropical site in the southern hemisphere, poster presentation at the Second IASI international conference (25-29 January 2010, Sévrier, France), 2010.

Parrondo M. C., M. Yela, M. Gil, H. Ochoa, Ozone variability over Antarctic Continent, poster presentation (EGU2010-10158) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Parrondo, M.C., M. Yela, M. Gil, and H. Ochoa, Analysis of ozonesonde measurements at Belgrano Station, SCAR XXXI meeting, Buenos Aires, July 30 – August 11, 2010.

Petersen, K., T. Blumenstock, B. Dils, F. Hase , C. Hermans, M. De Mazière, J. Notholt, M. Schneider, T. Warneke, Ground-based FTIR observations at the tropical and subtropical NDACC stations Paramaribo, Tenerife Is. and Ile de La Reunion, poster presentation at SCOUT-O_3 final meeting, Schliersee, Germany, June 15-17, 2009.

Pinardi, G., Y. Huan, K. Clémer, J.-C. Lambert, C. Fayt, F. Hendrick, C. Hermans, M. Van Roozendael, On the use of the MAXDOAS technique for the validation of tropospheric NO2 column measurements from satellites, 2011 NDACC Symposium, Saint Paul, Reunion Island, France, November 7-10, 2011.

Revell, L., G. Bodeker, D. Smale, O. Morgenstern, P. Huck, G. Brailsford, S. Nichol, S. Wood, and B. Williamson, How will future greenhouse gas emissions affect the Antarctic ozone hole?, poster presentation, Antarctica New Zealand Annual Antarctic Conference, Christchurch, 5-7 July, 2010.

Rozanov, A., B.-M. Sinnhuber, H. Bovensmann, M. Gil, P. V. Johnston, K.Kreher, J. Orphal, O. Puentedura, M. Van Roozendael, and J. P. Burrows, Seven years of stratospheric BrO observations from SCIAMACHY, 5th Limb Conference and workshop, 16-19 November, Helsinki, 2009.

Schönhardt, A. et al., The influence of scattering and absorption processes in sea water on atmospheric radiation - results from ship-borne DOAS measurements, DPG Spring meeting, Hamburg, Germany, March 2009.

Sussmann, R., F. Foster, T. Borsdorff, M. De Mazière, B. Dils, C. Vigouroux, T. Blumenstock, M. Buchwitz, J.P. Burrows, P. Demoulin, P. Duchatelet, C. Frankenberg, J. Hannigan, F. Hase, N. Jones, J. Klyft, I. Kramer, E. Mahieu, J. Mellqvist, J. Notholt, K. Petersen, O. Schneising, A. Strandberg, K. Strong, J. Taylor and S. Wood, Satellite validation of column-averaged methane on global scale: groundbased data from 15 FTIR stations versus last generation ENVISAT/SCIAMACHY retrievals, poster presented at the "IGAC 10th International Conference", 7 – 12 September, 2008, Annecy, France, 2008.

Vandenbussche, S., C. De Clercq, J. Granville, and J.-C. Lambert, NDACC-based detection of long-term drifts in nine satellite ozone data records, GEOmon Third General Assembly, London, UK, 18-20 January 2010.

Vandenbussche, S., Pieroux, D. and Lambert, J.-C., Observation operators for satellite validation and data assimilation: What they are and when they make the difference, poster presentation at the GEOmon Final General Assembly, Brussels, Belgium, February 2-4, 2011.

Vanhaelewyn, G., P. Duchatelet, C. Vigouroux, B. Dils, N. Kumps, C. Hermans, P. Demoulin, E. Mahieu. R. Sussmann, and M. De Mazière, Comparison of the error budgets associated with ground-based FTIR measurements of atmospheric CH4 profiles at Ile de la Réunion and Jungfraujoch, poster presentation (EGU2010-15537) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Vigouroux, C., F. Hendrick, T. Stavrakou, B. Dils, I. De Smedt, C. Hermans, A. Merlaud, F. Scolas, C. Senten, G. Vanhaelewyn, S. Fally, M. Carleer, J.-M. Metzger, J.-F. Müller, M. Van Roozendael, and M. De Mazière, Ground-based FTIR and MAXDOAS observations of HCHO at Reunion Island and comparions with SCIAMACHY and the CTM IMAGES, poster presentation at the ESA Atmospheric Science Conference, Barcelona, Sept. 7-11, 2009.

Vigouroux, C., Martine De Mazière, Bart Dils, Jean-François Müller, Cindy Senten, Trissevgeni Stavrakou, Gauthier Vanhaelewyn, Sophie Fally, Valentin Duflot, Jean-Luc Baray and the Instrumental Support Team, Time-series of biomass burning products from ground-based FTIR measurements at Reunion Island (21°S, 55°E) and comparisons with the CTM IMAGES, poster presentation (EGU2010-4751) at the EGU General Assembly 2010, Vienna, May 2-7, 2010.

Vigouroux, C., Martine De Mazière, Bart Dils, Jean-François Müller, Cindy Senten, Trissevgeni Stavrakou, Gauthier Vanhaelewyn, Sophie Fally, Valentin Duflot, Jean-Luc Baray and the Instrumental Support Team, Time-series of biomass burning products from ground-based FTIR measurements at Reunion Island (21°S, 55°E) and comparisons with the CTM IMAGES, poster presentation at the NDACC-IRWG annual meeting, Murramarang, Australia, June 2-4, 2010.

VIII ANNEXE 2: PARTICIPATION TO MEETINGS

- NDACC Steering Committee meeting 2008, Kangerlussuaq, Greenland, September 25-30, 2008. Pre-project discussions between Multi-TASTE partners.
- The Multi-TASTE Project Kick-off meeting took place at BIRA-IASB on October 7th, 2008.
- ESA GSE PROMOTE Annual Meeting 2008, Brussels, Belgium, October 8-9, 2008. Contribution of TASTE/Multi-TASTE expertise to PROMOTE validation protocol.
- ESA GECA project teleconference, October 17, 2008. Multi-TASTE contributions: scientific expertise in satellite validation.
- 4th EUMETSAT O3M-SAF CDOP Project Team Meeting, MétéoFrance, Toulouse, France, October 22-23, 2008.
- GOMOS Quality Working Group meeting #18, ACRI-ST, France, October 27-28, 2008: oral presentation by T. Fehr (ESA) on behalf of BIRA-IASB.
- GECA teleconference, November 14, 2008. Multi-TASTE contributions: scientific expertise in satellite validation.
- Jungfraujoch Atmospheric Workshop, Bern, Switzerland, November 24-26, 2008. Invited oral presentation of satellite validations using NDACC observations at the Jungfraujoch.
- GEOmon Annual Assembly, WMO, Geneva, Switzerland, January 26-28, 2009.
- GIGAS Workshop towards Harmonisation of Spatial Data Infrastructure (SDI) intitiatives, Brussels, Belgium, January 28-29, 2009. Representation of interests and expertise of the atmospheric composition/satellite validation community.
- GODFIT/GDP 5 progress meeting, DLR, Oberpfaffenhofen, Germany, February 19, 2009.
- Multi-TASTE teleconferences on March 9, 2009. Attended by C. De Clercq, J.-C. Lambert, S. Vandenbussche, T. Fehr, and E. Kwiatkowska.
- 5th EUMETSAT O3M-SAF Project Team Meeting, FMI, Helsinki, Finland, March 25, 2009.
- DPG (Deutsche Physikalische Gesellschaft) Spring meeting, Hamburg, Germany, March 27, 2009.
- GEMS Final Assembly, Jülich FZ, Germany, March 30-April 3, 2009. Illustration of long-term validations and multi-mission validations from Multi-TASTE.
- HYMN modellers/FTIR meeting, Bremen, Germany, April 6-8, 2009.
- European Geosciences Union General Assembly, Vienna, Austria, 19-24 April, 2009.
- Global Atmosphere Watch (GAW) 2009 Workshop, Geneva, Switzerland, 7 May 2009.
- GECA progress meeting, IASB-BIRA, Brussels, Belgium, May 12, 2009.
- ACE Science Team Meeting, University of Waterloo, Ontario, Canada, May 11-13, 2009.
- Second EUMETSAT EPS/MetOp RAO Workshop, Barcelona, Spain, May 20-22, 2009.
- Quality Assurance for Earth Observation (QA4EO) governance meeting, Ilhabela, São Paulo, Brazil, May 25, 2009.
- 30th Plenary of the CEOS WGCV, Ilhabela, São Paulo, Brazil, May 26-29, 2009.
- GODFIT/GDP 5 validation meeting, and Combined User and Algorithm Forum of the O3M-SAF, Halkidiki, University of Thessaloniki, Greece, June 4-5, 2009.
- Multi-TASTE teleconference on June, 11, 2009. Attended by C. De Clercq, J.-C. Lambert, S. Vandenbussche, T. Fehr, and E. Kwiatkowska.
- IGACO-O3 Workshop on the comparison of DOAS/SAOZ total ozone measurements with satellite measurements, FMI, Helsinki, Finland, June 29-30, 2009.
- Fifth international symposium on non-CO2 Greenhouse Gases (NCGG-5), Wageningen, The Netherlands, June 30-July 3, 2009.

- 3rd meeting of the ISSI WG on atmospheric water vapour, Bern, Switzerland, July 13-16, 2009. Attended by delegates from BIRA-IASB, FMI, IMK/FZK, and ULg.
- EOS Aura Science Team Meeting, Leiden, The Netherlands, 14-17 September 2009.
- ESA Atmospheric Science Conference, Barcelona, Spain, September 7-11, 2009. Attended by nearly all Multi-TASTE partners.
- 15th WMO/IAEA Meeting of Experts on Carbon Dioxide, Other Greenhouse Gases, and Related Tracer, Jena, Germany, 7-10 September, 2009.
- 8th International Carbon Dioxide Conference, Jena, Germany, 13-19 September, 2009.
- EUMETSAT Meteorological Satellite Conference, Bath, UK, September 21-24, 2009.
- NDACC Steering Committee meeting 2009 at WMO HQ, Geneva, September 29-October 1, 2009. Attended by E. Kwiatkowska (ESA), J.-C. Lambert (Multi-TASTE Coordinator), by delegates from BIRA-IASB, IFE/IUP, INTA, NIWA, ULg, and by the Japanese delegate H. Nakane (NIES).
- GEOmon Activity 4 (Stratosphere) Workshop, Paris, France, October 5-6, 2009. Session on coordinated validation of stratospheric satellites animated by IASB-BIRA. Attended by J.-C. Lambert and by delegates from BIRA-IASB, BAS-NERC, CNRS/LATMOS, IFE/IUP, IMK/FZK, INTA, and ULg.
- IMECC mid-term review meeting, Gembloux, Belgium, 6 October 2009.
- GOMOS Quality Working Group Meeting #21, ESRIN, Frascati, Italy, October 6, 2009.
- Multi-TASTE/GOSAT teleconference on October 10, 2009, between E. Kwiatkowska, J.-C. Lambert, and T. Fehr. Prepared via email exchanges with Y. Sasano and T. Yokota (NIES).
- HYMN Workshop and Final Meeting, RMI, Brussels, Belgium, October 12-14, 2009. Attended by delegates from BIRA-IASB, FZK/IMK, IFE/IUP, and ULg.
- 6th EUMETSAT O3M-SAF Project Team Meeting, Copenhagen, Denmark, October 27-28, 2009.
- GSE PROMOTE Final Meeting, ESRIN, Frascati, Italy, October 29-30, 2009.
- 5th International Atmospheric Limb Conference, FMI, Helsinki, Finland, November 16-19, 2009. Attended by delegates from BIRA-IASB, CNRS/LATMOS, FMI-ARC, and IFE/IUP, with oral presentations.
- MACC General Assembly hosted by ECMWF, Reading, UK, January 11-15, 2010.
- GEOmon General Assembly, London, UK, January 18-20, 2010. Session dedicated to satellite validation animated by IASB-BIRA. Attended by delegates from BIRA-IASB, CNRS/LATMOS, FMI, FZK/IMK, IFE/IUP, INTA, and ULg.
- SCIAMACHY Science Advisory Group hosted by Netherlands Space Office (NSO), Den Haag, Netherlands, February 4, 2010. Planning of SCIAMACHY data reprocessing (new products and improved products) and subsequent validation activities, attended by BIRA-IASB and IFE/IUP.
- ProDEx SECPEA Annual Meeting hosted at BIRA-IASB, February 23, 2010.
- QA4EO Team Meeting (March 1, 2010) + CEOS WGCV-31 Plenary (March 2-5, 2010) hosted by National Institute of Standards and Technology (NIST), Potomac, MD, USA.
- EGU General Assembly, Vienna, Austria, May 2-7, 2010.
- MIPAS Quality Working Group meeting #23, KIT, Karlsruhe, Germany, June 16-18, 2010.
- SCIAMACHY Quality Working Group meeting, ESA-ESRIN, Frascati, Italy, June 21-23, 2010.
- ESA Living Planet Symposium, Bergen, Norway, June 28-July 2, 2010. Special session on atmospheric Cal/Val. Attended by delegates from BIRA-IASB, CNRS/LATMOS, FZK/IMK, and IFE/IUP.
- 38th COSPAR Scientific Assembly, Bremen, Germany, July 18-24, 2010. Organisation by IASB-BIRA of the COSPAR/CEOS Joint Session on the 'Development of reference practices for the calibration and validation of atmospheric composition remote sensing' (in A11 Atmospheric

Chemistry and Physics). Attended by delegates from BIRA-IASB, CNRS/LATMOS, FZK/IMK, IFE/IUP, and NIWA.

- SCIAMACHY Quick Look Validation meeting, IASB-BIRA, Brussels, Belgium, September 6-7, 2010. Validation workshop dedicated to SCIAMACHY processor upgrades, organised by IASB-BIRA, IUP/Bremen and KNMI, hosted by IASB-BIRA.
- Ozone_cci Project Team Meeting, hosted by BIRA-IASB, Brussels, Belgium, September 7-8, 2010.
- GOME GDP5 Final Meeting, ESRIN, Frascati, Italy, September 14, 2010.
- EUMETSAT Meteorological Satellite Conference 2010, Cordoba, Spain, September 20-24, 2010.
- EOS Aura Science Team Meeting, Boulder, Colorado, USA, September 27-29, 2010.
- NDACC Steering Committee meeting 2010, Queenstown, New Zealand, October 5-8, 2010. Attended by delegates from BIRA-IASB, CNRS/LATMOS, FZK/IMK, IFE/IUP, and NIWA.
- SCIAMACHY Science Advisory Group, Brussels, Belgium, November 17, 2010. Attended by J.-C. Lambert, who presented the Activity report of SCIAVALIG and reported on the SCIAMACHY Processors Upgrade Quick Look Validation meeting held at IASB-BIRA on September 6-7, 2010.
- INSPIRE Annexe III Atmospheric Thematic Domains Ad Hoc meeting, European Commission, Brussels, Belgium, November 24, 2010.
- SPARC/IO3C/WMO-IGACO Workshop on Past Changes in the Vertical Distribution of Ozone, WMO, Geneva, Switzerland, January 25-27, 2011. Attended by delegates form BIRA-IASB, CNRS/LATMOS, FMI-ARC, and IMK/FZK.
- GEOmon Final General Assembly, Brussels, Belgium, February 2-4, 2011. Attended by delegates from BIRA-IASB, CNRS/LATMOS, FMI, FZK/IMK, IFE/IUP, INTA, and ULg.
- SCIAMACHY Algorithm Development and Data Usage (SADDU) Working Group Meeting, IUP, Bremen, Germany, March 1-2, 2011.
- Consultation meeting on Atmospheric Composition Thematic Domains, GMES Atmospheric Service and INSPIRE, JRC, Ispra, Italy, March 17, 2011.
- MIPAS Quality Working Group meeting #25, IFAC, Firenze, Italy, March 21-23, 2011.
- EGU General Assembly, Vienna, Austria, April 3-8, 2011.
- 8th UNEP Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer, WMO, Geneva, Switzerland, May 2-4, 2011.
- 33rd CEOS WGCV Plenary + QA4EO Workshop preparatory meeting, Moscow, Russian Federation, May 16-20, 2011.
- Seventh International Workshop on Greenhouse Gas Measurements from Space, University of Edinburgh, Scotland, UK, May 16-18, 2011. Attended by infrared teams.
- GECA QR1, Leatherhead, UK, May 26-27, 2011.
- Sino-German Workshop on Remote Sensing of Atmospheric Pollutants in Chinese Megacities, Hefei, China, May 31 - June 3, 2011.
- 8th Stratospheric Processes And their Role in Climate (SPARC) Data Assimilation (SPARC-DA7) Workshop, BELSPO, Brussels, Belgium, June 20-22, 2011.
- 7th Meeting of the CEOS Atmospheric Composition Constellation (ACC-7), Columbia, Washington Area, USA, June 21-22, 2011.
- INSPIRE Conference 2011, Edinburgh, UK, June 29-30, 2011.
- CINDI Workshop and 5th International DOAS Workshop, Mainz, Germany, July 12-15, 2011.
- 5th International DOAS Workshop, Mainz, Germany, July 13-15, 2011. Attended by UV-visible teams.
- VIII Symposium on Polar Studies, Palma de Mallorca, Spain, September 7-9, 2011.
- 4th Ozone_cci Progress Meeting, Karslruhe, Germany, September 20-21, 2011.

- GEO QA4EO Workshop, hosted by RAL Space, Harwell-Oxford, UK, October 18-20, 2011. Use of Multi-TASTE results in an oral presentation by IASB-BIRA to illustrate specifics of atmospheric composition remote sensing and associated data quality issues.
- NDACC Symposium 2012, Saint Paul, Ile de la Réunion, November 7-10, 2011, followed by NDACC Steering Committee meeting 2011 on November 11. Attended by all Multi-TASTE partners.

IX ANNEXE 3: CORRELATIVE DATABASE STATUS

This Annexe presents an overview of the correlative measurements delivered from 2006 to 2011 to the Envisat Cal/Val Data Centre operated at NILU on behalf of ESA (accessible via http://nadir.nilu.no/calval). It starts with individual station reports (Section XI.1), and it gets on with an overview of data uploads to the Cal/Val centre in the form of monthly data distribution tables (Section IX.2).

To get a consistent overview despite the wide variety of ground-based measurement capabilities, numbers reported in the upload tables correspond to the number of days for which there is at least one measurement suitable for Envisat and TPM validation. It should be noted that the actual amount of individual measurements stored on Cal/Val may vary with:

- The type of ground-based instrument: e.g. the feasibility of direct sun observations by Brewers, Dobsons and FTIRs depend on weather conditions, while scattered-light UVVIS observations are feasible virtually in all weather;
- The latitude: standard techniques requiring sunlight do not provide measurements during polar night; zenith-sky spectrometers measuring during twilight can not measure in the heart of the polar night and of the polar day where there is by definition no twilight.
- The actual presence of the molecule: OClO is a product of one of the channels of the coupling between ClO and BrO; therefore the presence of this molecule is highly dependent on the level of chlorine activation by heterogeneous reactions on polar stratospheric clouds (PSCs);
- The data type and file format adopted by the Data Submitter: some stations store data in monthly files, others in daily files, and others by individual measurement; some Brewer or microwave data files report one measurement every 30 min (reaching sometimes several thousands a month) while others provide only daily averages (thus a maximum of 31 values a month);
- The type of data processing: SAOZ/UVVIS data at remote stations processed in real-time by the built-in software and transmitted to CNRS via the ARGOS satellite data collection system include only one average value for each twilight, while reprocessing at the central laboratory of all the recorded spectra yields one value for every individual measurement.

IX.1 Station Reports

IX.1.1 BIRA-IASB, Brussels, Belgium

At the Harestua station in Norway, UV and VIS DOAS spectrometers operated by BIRA-IASB worked nominally until August 2011, thus a couple of months before the end of the project. The instruments stopped while waiting for the delivery of nitrogen bottles needed to flush the detectors (delivery planned originally in June 2011); frequent data logging problems and less frequent power cuts are also reported, although without dramatic consequence on data delivery. Vertical column measurements of ozone, NO_2 and BrO, and slant column measurements of OClO have been analysed, re-formatted and uploaded to the Envisat Cal/Val Data Centre without delay. They have been used for the validation of SCIAMACHY nadir column data. Additionally, low-resolution vertical profiles of NO_2 and BrO have also been retrieved from the spectra, which have been useful for the validation of SCIAMACHY and MIPAS profile data products.

At the Jungfraujoch station in Switzerland, the SAOZ VIS spectrometer operated by BIRA-IASB worked fine, except a few breaks due to a failing electronic board inside the box: in August-October 2009, September-November 2010, and from June 2011 onwards. Vertical column measurements of ozone and NO_2 have been analysed, re-formatted and uploaded to the Envisat Cal/Val Data Centre without delay.

At Reunion Island, FTIR measurements with a Bruker 120M had been organized since 2002 on a campaign basis, with two major periods for Envisat validation: from August to October 2004 and from May to end of

October 2007. In May 2009, the instrument was installed inside a building of the University at Saint Denis, for a quasi-permanent operation. It has been making solar absorption measurements since the end of May 2009, except from March 8th to April 21st 2010 due to a serious instrument failure. These measurements are based on the standard NDACC-IRWG settings in the mid-infrared range.

Also on Reunion Island, an instrument with improved capabilities, the Bruker 125HR spectrometer, was installed at Saint-Denis in September 2011. This instrument measures in the near-infrared spectral range recommended for TCCON, for the observation of greenhouse gases. A period of parallel measurements with regular NDACC measurements in the middle infrared spectral range has taken place at the end of 2011, to enable the intercomparison of NDACC and TCCON data, focusing on CH_4 but also looking into the other species. When the new NDACC building at the mountain site (Maïdo observatory) will be operational (2012) one of the two instruments will be relocated to that site.

The FTIR data for Saint-Denis have been made available in HDF AVDC/NDACC format via the NDACC database for CH_4 (2004 and 2007), CO (2004 and 2007), N_2O (2004 and 2007) and HCl (2004, 2007 and 2009); via the OPAR (Observatoire de Physique de l'Atmosphère de la Réunion) website; and via the local database at BIRA-IASB for HNO_3 (2007). The data could not be uploaded to the Envisat Cal/Val database due to the unfortunate incompatibility of the AVDC/NDACC and NILU's HDF formats. The data analysis had delays, among others because of the departure of one member of the group and the maternity leave of another member. We have been submitting every 3 months data for HCl and HF profile data to the GEOmon database and the NDACC database, in the AVDC-NDACC HDF format. We also submitted the HNO_3 data for 2007, 2009 and 2010 in the same format. Now NDACC has moved to GEOMS and we have to adapt our formatting routines before we can continue data submission. We have not submitted anything to the NILU Cal/Val database because the formats are not compatible. We worked a lot on retrieval strategies and derivation of time series for CH_4, HCN and organic biomass burning products (methanol, formic acid, C_2H_6, C_2H_2, ...) and comparisons with the IMAGES CTM of the troposphere. The papers by Paulot et al. (2010) and Stavrakou et al. (2011), include satellite validation.

IX.1.2 CNRS/LATMOS, Guyancourt, France

During the first year of Multi-TASTE, the CNRS team has performed all measurements indicated in WP3100-a. The real time SAOZ columns (O_3 and NO_2) have been converted to monthly HDF files and the data transferred every month on the Cal/Val database until September 2011.

The CNRS team has started a systematic comparison of ozone and NO_2 long term time series with various satellites, including TOMS on Nimbus 7, Meteor-3 and Earth Probe, ERS-2 GOME, Envisat SCIAMACHY, OMI-TOMS, OMI-DOAS, and MetOp-A GOME-2. As during the previous winters since 2005, a mobile SAOZ has been installed at Eureka/Canada for the winters 2010 and 2011 ACE validation campaign. The comparison has been presented during various workshop and congress. The results are now published in ACP. Since January 2005, a SAOZ has been installed on the roof of the University Paris VI, inside Paris, France. The data have been used during the GEOmon/CINDI campaign and the MEGAPOLI project.

In 2008, 42 ozonesondes were launched from Dumont d'Urville, and 52 from OHP. In 2009, 30 ozonesondes have been launched at Dumont d'Urville, and 52 from Observatoire de Haute-Provence. In 2010, 42 Ozonesondes have been launched at Dumont d'Urville, 52 from Observatoire de Haute-Provence. The type of PTU unit to which ozonesondes are coupled has changed from Vaisala to Modem sondes for both stations, respectively since 2007 and 2008. As the format is not the same, the conversion software was rewritten and the data are now directly archived in NASA Ames format. Another program was developed to convert NASA/Ames files into HDF files, suitable for the NDACC and Envisat Cal/Val databases. The ozonesonde data at OHP (until September 2010) and Dumont d'Urville (until July 2010) are on the NDACC and Cal/Val database. The data from mid-2010 until now will be processed as soon as they have been submitted to NDACC.

IX.1.3 FMI-ARC, Sodankylä, Finland

All ground-based instruments operated by FMI have worked nominally according to WP 3100-b. Brewer observations have been continuous (sun elevation permitting, with a natural break due to low sun elevation in winter). Brewers in Finland were calibrated during summer 2009. FMI participates in a new Brewer network project funded by ESA. In this framework, the Brewer Intercomparison Campaign (CEOS Intercal Nordic campaign) took place in Sodankylä in spring 2011. Scientific topics included investigation of differences between Dobson and Brewer spectrophotometers especially under high solar zenith angle conditions, stray light issues in single monochromator Brewers, algorithm differences and ozone cross section effects.

Ozonesoudes were launched on a regular basis in Sodankylä (Arctic Finland) and Marambio (Antarctic Peninsula) and during winter/spring campaigns in Jokioinen in Finland. The largest number of ozonesondes was flown in March, which contributed to the Arctic ozone loss studies. All data have been analysed, re-formatted and uploaded to the Envisat Cal/Val database without delay. A large number of additional ozonesondes was flown in January-March 2010 during the LAPBIAT Atmospheric Sounding Campaign in Sodankylä. These additional sondes were also made available for Cal/Val purposes. Preliminary comparisons between ground-based and satellite data have been carried.

In late December 2008, a new FTIR instrument, based on Bruker IFS 125 HR with A547N Solar Tracker, was installed in Sodankylä. The new FTIR system has been operated on regular basis in Sodankylä and measures several atmospheric gases, including CO_2, O_3, CO, and CH_4. These data not foreseen in the original Multi-TASTE proposal could maybe be used in a later stage. Our FTIR has participated in GOSAT CO_2 validation activities since May 2009 [Wunch et al., 2011].

Data from the reference water vapour hygrometer was used in the validation of SCIAMACHY limb profile retrievals of water vapour in the upper troposphere and the lower stratosphere [Rozanov et al., 2010].

IX.1.4 IFE/IUP, Bremen, Germany

FTIR and Microwave measurements at Ny-Ålesund (Spitsbergen) and Bremen (Germany)

The Multi-TASTE funding was essential to continue with the FTIR and microwave observations planned in WP 3100-d. Microwave and FTIR data at Ny-Ålesund (Spitsbergen), are based on measurement days. For the microwave data a full measurement day consists of 24 microwave spectra. For the FTIR-data typically 5-10 spectra consisting of about 5-10 micro-windows are used. Ozone profiles have been measured continuously throughout the year with the microwave instrument since 2008, except for short maintenance breaks during summertime, and also in July 2010 when there was a major failure of an essential part (LO oscillator). The replacement is planned by October 2011. At Bremen, the analysis failed for data from May 2008. Currently the reason for the failure is still being investigated.

The FTIR instruments at Bremen (Germany) and Ny-Ålesund (Spitsbergen) are operational, all relevant gases are measured and retrieved. However, the submission of data has been delayed because of HDF format issues, solved in the course of the project with the help of Aasmund Vik (NILU).

Validation activities were carried out on SCIAMACHY data products retrieved with scientific processors IMAP v4.9 and WFM-DOAS version 1.0: H_2O, CO_2, CH_4; GOSAT TANSO-FTS L2 products v.0140: CO_2 and CH_4; and MIPAS CO profile data retrieved with the IMK/IAA processor. The Total Carbon Column Observations Network (TCCON) begins to become more and more important. Together with Paul Wennberg (founder of TCCON, Caltech, U.S.A.) and David Griffith (University of Wollongong/Australia), IFE applied that the TCCON observations are accepted within the Global Atmosphere Watch (GAW) of WMO.

UVVIS DOAS measurements at Ny-Ålesund (Spitsbergen), Bremen (Germany), Mérida (Venezuela), Iraklion (Crete) and Nairobi (Kenya)

Ground-based MAX-DOAS measurements (as planned in WP 3100-d) were performed by IUP Bremen at the stations in Ny-Ålesund, Bremen, Nairobi and Heraklion (here for a few days only). The Merida station has provided measurements only until March 2008 for technical and logistical reasons (see below). Table 3 gives an overview of the data acquisition at the different stations.

Table 3: Overview on the data acquisition at the IUP Bremen stations. Red colour indicates no measurements, green colour data already submitted to the Cal/Val data base, orange data that have been taken and analyzed but are not yet on the database, blue are available from the GEOMON ftp server.

Station	Lat.	Instrument	Species	C/P	Institute
Ny-Ålesund	79°N	MAX-DOAS MAX-DOAS	O_3, NO_2, BrO,OClO (NO_2, BrO)	C TC	IFE / AWI
Bremen	53°N	MAX-DOAS MAX-DOAS	O_3, NO_2, BrO, (OClO) NO_2, HCHO	C Trop. C	IFE
Heraklion	35°N	MAX-DOAS MAX-DOAS	O_3, NO_2, BrO NO_2, HCHO	C Trop. C	IFE
Mérida	8°N	MAX-DOAS MAX-DOAS	O_3, NO_2, BrO (HCHO, NO_2)	C Trop. C	IFE
Nairobi	1°S	MAX-DOAS MAX-DOAS	O_3, NO_2, BrO NO_2, HCHO	C Trop. C	IFE

The stratospheric column measurement data have been uploaded to the Cal/Val Database in the agreed HDF format. Tropospheric columns and profiles of NO_2 and HCHO have been derived for the measurements in Bremen, Nairobi and Heraklion, but due to formatting issues are not yet on the Cal/Val database (see next paragraph). But again they are available using the link to public ftp server as part from the GEOmon project.

As part of the European project GEOMON we agreed on a common HDF data format for future uploads of enhanced MAX-DOAS data products (e.g. trace gas profiles, tropospheric columns). To avoid double work in the future we defined our HDF-files according to the current NASA-AVDC (and NDACC) standard. NILU currently does not support this standard with their ESA-CDB (which includes the Envisat Cal/Val database) system. So, as long as NILU is not supporting this version, we decided to put the data to the GEOMON ftp-server.

At Ny-Ålesund the entire ozone and NO_2 time series since 2003 was reanalysed following the new settings recommended for NDACC and - even more important - using one single Fraunhofer spectrum as background for each year. This led to a much more consistent data set (see e.g. Figure 56). Stratospheric BrO and OClO columns were analysed and are available via ftp://ftp.nilu.no/pub/GEOmon/activity4_StratosphericOzone as part of the EU project GEOMON. The new developed telescope is running without any serious problems. Thus on 239 of 245 days measurements were possible! In April 2011 another measurement sequence has been added to the regular schedule. By pointing the telescope to different targets (mountains surrounding Ny-Ålesund) a more accurate retrieval of tropospheric trace gases was possible. First results will become available quite soon and then uploaded to the data base.

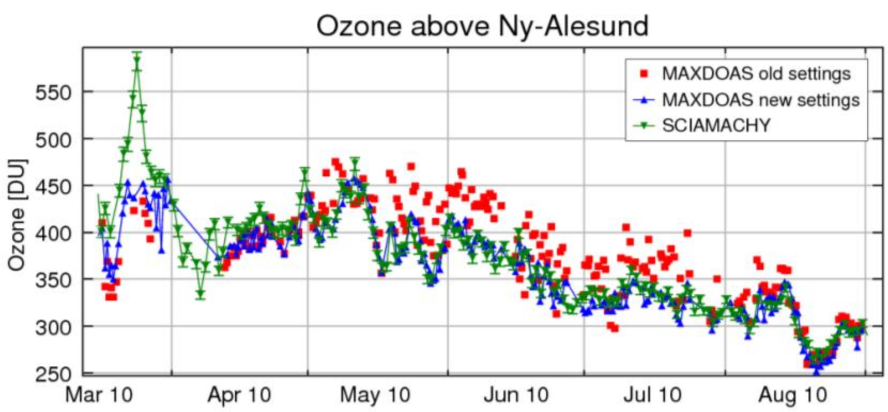

Figure 56: Comparison of MAX-DOAS ozone data at Ny-Ålesund with SCIAMACHY time series in 2010. With the new data set (available for all years since 2003) a much better agreement with satellite overpass data is obtained.

The instrument in Bremen worked nominally. In addition, the Bremen campaign instrument participated in two campaigns, the Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring Instruments (CINDI) in the Netherlands and the TRANSBROM campaign between Japan and Australia [Krüger and Quack, 2012]. The quality of the BrO column in Bremen is affected by strong tropospheric NO_2 pollution which has a spectral interference with the BrO retrieval.

The Mérida station has provided measurements of total columns of NO_2 and ozone which have been uploaded (until March 2008) to the Envisat Cal/Val data base. The instrument has been removed in June 2010 from its location as access via the cable car was no longer deemed to be safe and will therefore not be possible for at least two years until the cable car has been refurbished. The instrument has been brought back to Bremen for testing and upgrading and will be located to another measurement site as soon as an appropriate arrangement could be made. For fall 2011 this instrument will be installed for one month in the Malaysian part of Borneo. This will be carried out as part of the EU project SHIVA.

In Heraklion (Iraklion), frequent interruptions of power supply and internet connections led to substantial data gaps, in particular in 2010. In addition the visible channel was most probably damaged during a thunderstorm event in August 2009 and both channels were seriously damaged during a thunderstorm event in October 2010. In the meantime the whole system was sent back to Bremen for reparation. Since the local support is no longer secured in Heraklion the system will be moved to Athens in the beginning of 2012, where maintenance and access will be simpler. The MAX-DOAS will be established on the roof of the hosting Institute at Penteli hill, an ideal location providing open and wide horizon over Athens at an altitude of 480 m a.s.l., which is well within the boundary layer for most period of the year, thus being suitable for pollution scanning and therefore also a good location for satellite validation in urban environments. The existing data from the instrument could not yet be uploaded to the Cal/Val database as there is not yet an entry for this measurement location. We have contacted the responsible at NILU to solve this problem as soon as possible.

In 2009 and 2010 the instrument in Nairobi, which was repaired in December 2008, was offline for most of the time (about 50 measurement days in 2009 and 2010) as result of lack of local support and problems with stability of electrical power supply. Another problem was the quite often very slow internet connection to Kenya which prevents simple checks of the data acquisition software. The instrument has been maintained in February 2011, after regular crashes of the instrument due to electronic malfunctions. Since then the instrument works stable with the exception of some data gaps due to power breaks at the site. In 2010-2011 we were able to perform measurements on 178 days (from 365). All data have been uploaded to the Cal/Val database. It is still being investigated whether the instrument can be relocated to another location in Nairobi or elsewhere in Africa, the latter solution is preferred.

As part of the European FP6 project GEOmon we agreed on a common HDF data format for future uploads of enhanced MAXDOAS data products (e.g. trace gas profiles, tropospheric columns). To avoid double work in the future we defined our HDF-files according to the current NASA-AVDC (and NDACC) standard. For further details of this format see report by BIRA-IASB. First data sets for tropospheric NO_2 have been uploaded in the new data format to GEOMON databases. Upload to Cal/Val should follow within the next four weeks.

ENVISAT validation activities include the comparison of operational and scientific retrievals of O_3, NO_2, SO_2, OClO, H_2O columns from measurements of the SCIAMACHY instrument; the validation of SCIAMACHY OClO retrievals with ground-based MAX-DOAS observations in Ny-Ålesund, Summit, and Bremen [Oetjen et al., 2011]; the validation of SCIAMACHY tropospheric NO_2-columns using the ground-based MAX-DOAS measurements collected during the DANDELIONS and CINDI campaigns [see publication by Roscoe et al. and Piters et al.] and the validation of SCIAMACHY O_3, NO_2, HCHO, IO and BrO retrievals using the ship-borne MAX-DOAS measurements taken during the TRANSBROM cruise [see publication by Peters et al. 2012]. Contributions to the delta validation of the SCIAMACHY processor upgrade SGP 5.01 include the detailed verification of nearly all SCIAMACHY products using scientific retrievals developed by the IUP Bremen and the submission of ground-based observations for the pole-to-pole validation of O_3 and NO_2 columns

Further activities: Development of a new airborne UVVIS DOAS instrument

In order to provide a link between ground-based and satellite observations a new airborne imaging DOAS instrument has been developed at the University of Bremen. The instrument has been tested on several flights onboard the Polar 5 in June 2011 and first results are very promising (see Figure 57).

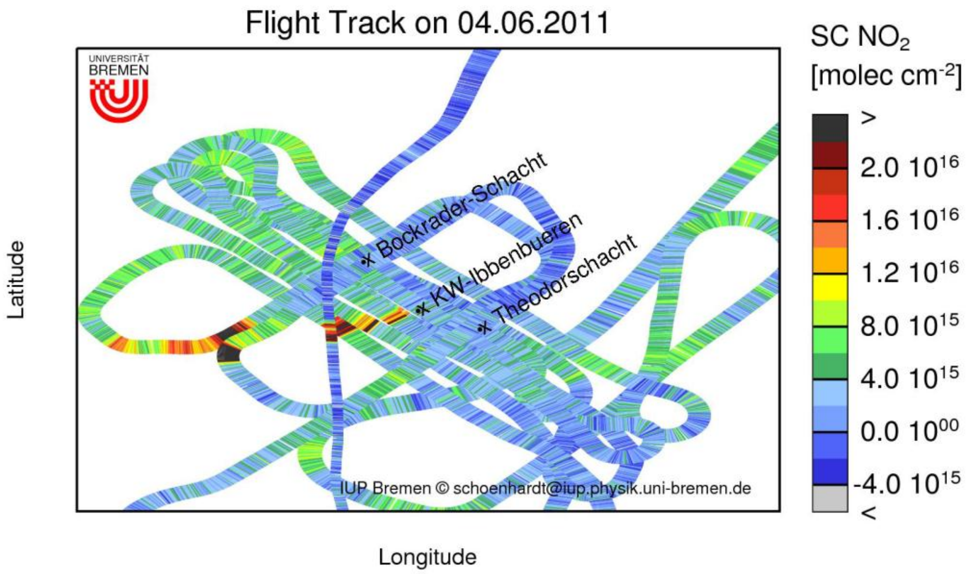

Figure 57: NO_2 amounts along the flight track retrieved from the flight on 04.06.2011. Downwind from the black coal power plant Ibbenbüren (Northern Germany), strong enhancement of NO2 is visible. Enhanced NO2 is on the order of 10^{16} molec/cm². The width of the flight track depends on flight altitude, narrower lines correspond to lower flight altitude.

IX.1.5 IMK/KIT, Karlsruhe, Germany

Measurements at Kiruna (Sweden) and Izaña (Tenerife Island) have been performed as planned in WP 3100-e. Kiruna measurements have been performed on 54 days of observation in 2008, 42 days of observation in 2009, and 67 days of observation in 2010. Izaña measurements have been performed on 89 days of observation in 2008, 101 days of observation in 2009, and 87 days of observation in 2010. The Kiruna instrument had a failure of the scanner motor in June 2008 and May 2009. Although the scanner motor was replaced by a new one as soon as possible some days of observation have been missed. The Kiruna instrument had a failure of the reference laser in January 2010, the Tenerife instrument in February 2010. Both lasers were replaced by new ones as soon as possible.

The Izaña O_3 measurements have been validated by intensively comparing with Brewer [Schneider et al., 2008a] and sonde data [Schneider et al., 2008b]. Data of all FTIR species listed in WP 3100 (O_3, N_2O, CO, CH_4, NO_2, HNO_3) are uploaded to the Cal/Val as well as to the NDACC data base. The new data analysis harmonisation approach as well as format harmonization (HDF format) within NDACC has been applied for the entire data set from the beginning of the measurement up to the end of 2010 for Tenerife and April 2011 for Kiruna.

Data from both sites have been used to validate SCIAMACHY's CO data on a long term basis [De Laat et al., 2010]. Izaña ozone data have been used to compare with IASI satellite data [Viatte et al., 2011]. Kiruna data have been used to compare with HDO/H2O data from SCIAMACHY [Frankenberg et al., 2009]. MIPAS and ACE validation papers have been published in 2009 [Payan et al., 2009; Dupuy et al., 2009].

IX.1.6 INTA, Torrejón de Ardoz (Madrid), Spain

For UV-Visible measurements at Izaña, measurements of NO_2 and O_3 are going on as planned in WP 3100-f. Quality controlled data have been submitted in HDF format at Cal/Val database until until July 2011. We detected degradation in the instrument from middle 2006. Data were corrected in 2009 and a new version has been uploaded to the database. On February 2010 the instrument has been replaced by a new one, after a few months working together for inter-comparison purposes. The new instrument (RASAS-II) participated in the CINDI campaign in June-July 2009. During August 2010-July 2011, the instrument has had few problems of diverse origin leading to some data gaps. Two main data gaps have been caused by wind storms, pulling down the light entrance and breaking the optical fibre. Periods were November 29 to December 15, 2010 and February 16 to March 12, 2011. A laboratory temperature instability from January 10 and February 15, 2011, led to an increase in data errors during these days. Some other short data gaps have been due to problems with the instrument software and have been already solved. Measurements of BrO are on-going although after severe failure and repairing of detector in 2007 degradation in the signal-to-noise ratio has been detected. On March 2011 the BrO instrument was replaced by a new one.

At Marambio, measurements of NO_2 are going on as planned. Quality controlled data have been submitted in HDF format at Cal/Val database until May 2011. Measurements have been interrupted from 16th to 31st of July 2009, due to a problem in the instrument. In February 2010, the instrument was changed to a new housing. The sealed insulator used in the new container caused some problems with water filtrations and ice inside the instrument until beginning of March, when it was carefully sealed by a new insulator. Due to this change of emplacement of the instrument, as well as its repairs and cleanliness, it has been necessary to change reference to the analysis of the data in two occasions. On May 25, 2011, a decalibration of the instrument took place. Evaluation of the data from then on is in progress.

At Belgrano, measurements of NO_2 are going on as planned. Quality controlled data have been submitted in HDF format at Cal/Val database until until April 2011. Measurements from August will be analyzed after the Antarctic spring, then a new reference spectrum will be chosen for the DOAS retrieval.

At Ushuaia, measurements of NO_2 are going on as planned. Quality controlled data have been submitted in HDF format at Cal/Val database until July 2011.

Ozonesoundes have been launched at Belgrano, Keflavik and Ushuaia as planned. Quality controlled data have been submitted in HDF format at Cal/Val database until July 2011.

IX.1.7 NIWA, Lauder, New Zealand

Despite a few exceptions described here after, the overall status of the NIWA measurements is very good for the time period up to July 2011; the instruments are state-of-the-art and the data quality is carefully monitored. WP 3100-g has performed almost nominally. However, we lost the NIWA FTIR scientist (Dr. Stephen Wood) in May 2011 and are in the process of rearranging our responsibilities and reassessing our priorities. Any financial support we can get e.g. via Multi-TASTE funding and related satellite validation projects provides valuable support of our observations and allows us to continue our measurement programme at a very high standard. This year, we have not experienced any serious problems with instrumentation, logistics or manpower - apart from the redundancy of our FTIR scientist in late May.

Total UV-visible DOAS column data have been submitted up to the end of August 2011 for the following stations: Lauder, Macquarie Island and Arrival Heights. Data have been submitted also for Mauna Loa and Kiruna, but instruments stopped operation in the reporting period. At Macquarie Island, due to a change-over in instrumentation, an additional quality assessment was required for the Macquarie Island data but has now been completed and the data is of good quality. At Mauna Loa, measurements were processed routinely until 29 February 2008 (the data has also been submitted to the database until then) when the instrument failed and was found to be un-repairable. A new array detector spectrometer to measure both NO_2 and BrO (330 – 450 nm region measurements) simultaneously was installed on 28 April 2009 and has been operating since. The instrument is performing well and the data was investigated and found to be of good quality. Data processing and data submission to the Cal/Val database was postponed due to funding shortfalls. The UV-visible measurements made at Kiruna, Sweden, stopped in March 2010 due to instrument failure. This DOAS instrument has been working fine until the end of February 2010 and data have been submitted. The measurements stopped early March 2010 because of computer failure. Additionally, the spectrometer had already previously shown some signs of fatigue and we are currently negotiating the replacement or withdrawal of the instrument.

For FTIR measurements in Lauder (New Zealand) and in Arrival Heights (Antarctica), data have been submitted to the Cal/Val database and the data sets are up to date, since 2003. For both stations there has been a brief period (2-3 months) of instrument failure. Columns of O_3, N_2O, CH_4, HNO_3, CO and HCl in New Zealand and in Antarctica, have been submitted to the Cal/Val database as planned and the data sets are all up to date, July 2011 inclusive. Partial stratospheric and tropospheric columns are submitted for CH_4 and NO_2. The profile data and format will be prepared according to the recommendations and guidelines within the FTIR working group and submitted as soon as these discussions have been completed.

The ozonesonde data for Lauder has been updated until the end of August 2011. There are still approximately 20 flights made on water vapour sondes during the last year that will be processed and submitted shortly; due to the tight funding situation the development of the necessary software has taken longer than expected. Additionally, software is currently being developed to add a solar radiation correction for the air temperature data on the RS92 sondes.

The Lauder and Arrival Heights Dobson data have also been updated until the end of July 2011 and there have been no issues. The Lauder Dobson experienced a couple of problems in 2009 which have not been impacting on the data quality though (any affected data has been excluded). The Lauder Dobson was switched off for a week during August 2009 for repairs. An intercomparison using a reference Dobson instrument, and an upgrade of the Lauder Dobson, is planned for January 2012 in collaboration with NOAA, USA and the Bureau of Meteorology, Australia.

As part of our contribution to Multi-TASTE, we have further developed our capability to retrieve profile information from MAX-DOAS measurements. This retrieval technique includes a forward model (full spherical Monte Carlo radiative transfer model called NIMO (NIWA Monte Carlo)) describing the relation between DSCDs and the to-be-retrieved trace gas concentration profile and an optimal estimation routine allowing us to choose the most likely possible set of profiles consistent with the measured DSCDs. The retrieval has been tested using MAX-DOAS measurements of NO_2 from the CINDI campaign in Cabauw and the retrieved profiles for the lower troposphere and boundary layer are comparable to the profiles retrieved by other participating groups. The retrieval has also been performed on measurements of BrO from Antarctica and enhanced boundary layer BrO concentrations were retrieved on days when BrO was observed in the DSCDs. Two publications will be submitted shortly to ensure that the retrieval technique can be referenced with a peer-reviewed publication before the results are submitted to the Cal/Val database.

Section III.3 below describes the work carried out by NIWA on “Techniques for analysing ground-based UV-visible long-term BrO and NO_2 observations for satellite validation and trend analysis”, presented at the COSPAR 2010 Scientific Assembly.

IX.1.8 ULg, Liège, Belgium

The FTIR instruments at the Jungfraujoch have been working nominally during the reporting period. Month-to-month fluctuations in the number of measurements essentially result from weather conditions. The remote control of the Bruker instrument is fully operational since October 2008. Regarding manpower, P. Duchatelet who was in charge of validation investigations and of the retrievals of CH4 and N2O has left the team (30-Jun-2011) after completing his PhD thesis. We are actually looking for a suitable candidate to replace him. Submission to Envisat Cal/Val have been somewhat delayed in the beginning of the project. This is because the HDF template adopted jointly by the NDACC and AVDC data hosting facilities is still not accepted by the Envisat Cal/Val data base. With the help of Aasmund Fahre Vik (NILU), ULg has been able to find a transitory solution which required the renaming of some of the variables. Massive archiving of daily HDF files has started as soon as this solution has been implemented at NADIR (mid-September 2009). Data archiving has progressed nominally, the temporary HDF FTIR template is satisfactory. However, harmonization with the NDACC template is eagerly awaited. Up to now, all archives files have been submitted to NADIR using the NILU template. We did not yet switch to the new harmonized GEOMS HDF format thus far but will be ready to do so in the next months. These files either contain profile measurements of HNO_3, CO, CH_4 or N_2O, retrieved from all Jungfraujoch high resolution FTIR solar observations available (after QA/QC checks). It is worth mentioning that the new CH_4 and N_2O archives include data retrieved using the EC FP6 HYMN harmonized approaches. Since summer 2009, CO FTIR profile data from the Jungfraujoch have been included in a validation study of five years of SCIAMACHY measurements (IMLM) [de Laat et al., 2010]. Also, CH_4 data products have been included in comparisons with model and SCIAMACHY products [Dils et al, 2010]. In collaboration with University of Waterloo and University of Toronto, we are performing HCFC-22 retrievals to validate ACE version 3 level 2 products for that species. Several sites of the northern mid- to high-latitudes are contributing to this effort.

IX.2 Overview of Data Uploads to Cal/Val Centre

IX.2.1 Monthly Data Distribution for O_3 Column Data

2006

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	8	18	31	30	31	23	31	31	30	22	4	0	259
Jokioinen	FMI	61N	23E	14	23	27	30	30	28	28	30	30	30	16	5	291
De Bilt	KNMI	52N	5E	31	28	31	30	31	30	31	31	30	31	30	31	365
Uccle	RMI	51N	4E	30	28	31	30	31	30	31	31	29	31	30	31	363
Hohenpeißenberg	DWD	48N	11E	24	21	25	24	29	30	31	30	27	30	25	27	323
Arosa	MCH	47N	10E	25	28	26	28	26	27	27	25	25	26	27	23	313
Paramaribo	KNMI	6N	55W	31	26	15	30	31	29	25	31	24	29	27	28	326

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	14	12	19	11	16	17	20	13	18	21	14	17	192
Arosa	MCH	47N	10E	25	23	16	21	21	27	25	22	26	26	24	24	280
Lauder	NIWA	45S	170E	0	0	0	0	0	0	0	0	0	21	20	15	56
Vernadsky	BAS/KTSU	65S	65W	31	28	31	20	0	0	0	31	30	12	0	0	183
Halley	BAS	76S	27W	31	27	31	15	0	0	0	6	29	31	30	7	207
Arrival Heights	NIWA	78S	167E	0	0	0	0	0	0	0	0	0	2	15	13	30

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	0	1	0	0	0	0	0	11
Kiruna	FZK/IMK	68N	20E	0	9	13	7	10	12	6	13	6	7	5	0	88
Bremen	IUP/IFE	53N	9E	2	2	3	3	6	5	6	3	9	3	0	1	43
Izaña	FZK	28N	16W	4	5	14	7	9	17	14	14	13	11	11	10	129
Lauder	NIWA	45S	170E	8	11	4	9	11	8	5	11	7	11	6	3	94
Arrival Heights	NIWA	78S	167E	9	4	3	2	0	0	0	0	2	4	5	0	29

M124	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Murmansk	MGO	69N	33E	0	0	0	29	27	29	31	29	25	0	0	0	170
Pechora	MGO	65N	57E	11	27	30	30	31	28	28	31	30	25	0	0	271
Arkhangel'sk	MGO	65N	41E	0	0	0	0	0	0	0	0	29	25	0	0	54
Yakutsk	MGO	62N	130E	9	14	22	29	30	30	30	27	28	26	10	0	255
St Petersburg	MGO	60N	30E	0	27	30	30	30	28	30	31	30	28	26	0	290
Magadan	MGO	60N	151E	24	22	26	26	23	24	28	23	27	26	16	25	290
Vitim	MGO	59N	113E	15	19	21	22	27	24	26	28	28	26	19	0	255
Krasnoyarsk	MGO	56N	93E	0	0	0	0	0	0	0	0	29	23	19	17	88
Omsk	MGO	55N	73E	28	26	30	29	31	30	28	30	30	30	26	28	346
Samara	MGO	53N	50E	21	18	28	28	30	30	30	28	30	28	24	18	313
Nikolaevsk	MGO	53N	141E	15	19	17	18	27	0	0	28	25	20	20	27	216
Irkutsk	MGO	52N	104E	28	25	31	30	30	27	28	30	30	29	24	30	342
Voronezh	MGO	52N	39E	28	24	26	30	31	29	31	30	28	28	0	0	285
Vladivostok	MGO	43N	132E	30	25	29	28	28	0	0	0	29	31	30	30	260

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	10	31	30	31	25	31	31	28	24	0	0	241
Thule	DMI	77N	69W	0	18	31	30	5	0	0	21	30	31	0	0	166
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	31	30	31	31	30	31	23	0	310
Sodankylä	CNRS/FMI	67N	27E	31	28	30	30	31	26	30	31	30	31	30	31	359
Zhigansk	CNRS/CAO	67N	123E	26	11	30	26	29	28	29	31	30	31	30	27	328
Salekhard	CNRS/CAO	66N	67E	22	28	31	30	31	30	31	31	30	31	28	28	351
Harestua	BIRA.IASB	60N	11E	10	23	31	30	31	30	28	31	30	31	25	31	331
Bremen	IUP/IFE	53N	9E	29	12	24	28	30	23	18	24	0	22	30	29	269
Jungfraujoch	BIRA.IASB	47N	8E	29	24	4	0	6	12	18	0	2	30	29	30	184
OHP	CNRS	44N	6E	31	28	31	30	31	30	31	31	30	31	30	31	365
Izaña	INTA	28N	16W	31	28	31	30	31	28	28	29	30	31	30	31	358
Mérida	IUP/IFE	8N	71W	27	23	25	26	18	24	20	28	0	26	17	31	265
St Denis	CNRS	21S	55E	31	28	30	30	31	30	31	28	30	31	29	31	360
Bauru	CNRS/UNESP	22S	49W	14	28	31	30	31	30	31	31	30	31	29	27	343
Kerguelen	CNRS	49S	70E	31	28	31	30	31	30	31	31	30	31	30	31	365
Dumont d'Urville	CNRS	67S	140E	31	28	31	30	31	30	30	31	30	31	29	31	363
Rothera	BAS	68S	68W	31	28	31	29	31	30	30	27	30	31	30	31	359

2007

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	2	16	30	30	29	30	31	31	30	23	6	5	263
Jokioinen	FMI	61N	23E	14	22	28	30	29	30	31	31	29	28	29	8	309
De Bilt	KNMI	52N	5E	30	28	31	19	31	25	28	31	30	29	28	22	332
Uccle	RMI	51N	4E	31	26	30	0	0	0	0	0	0	0	0	0	87
Hohenpeißenberg	DWD	48N	11E	19	24	29	29	29	28	29	27	25	24	20	21	304
Arosa	MCH	47N	10E	22	26	26	30	26	28	30	25	27	29	24	27	320
Paramaribo	KNMI	6N	55W	31	27	31	30	31	29	27	30	28	30	28	31	353

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	9	13	17	17	15	19	19	15	11	16	13	10	174
Arosa	MCH	47N	10E	22	19	25	28	20	25	27	21	14	26	17	25	269
Lauder	NIWA	45S	170E	19	18	20	16	20	15	16	20	20	20	24	16	224
Vernadsky	BAS/KTSU	65S	65W	31	28	31	30	0	0	0	31	30	31	30	31	273
Halley	BAS	76S	27W	31	28	31	3	0	0	0	4	30	31	30	30	218
Arrival Heights	NIWA	78S	167E	10	5	7	0	0	0	0	0	6	13	6	7	54

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	1	0	7	6	4	3	4	0	0	0	25
Kiruna	FZK/IMK	68N	20E	4	9	16	11	7	0	1	11	9	11	3	0	82
Bremen	IUP/IFE	53N	9E	1	1	7	6	4	2	4	2	2	1	3	1	34
Izaña	FZK	28N	16W	10	14	5	12	12	10	16	20	10	8	3	10	130
Lauder	NIWA	45S	170E	5	4	8	4	8	7	8	10	10	8	7	7	86
Arrival Heights	NIWA	78S	167E	4	3	7	2	0	0	0	0	6	10	1	8	41

M124	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Murmansk	MGO	69N	33E	0	0	30	28	28	26	27	31	28	25	0	0	223
Igarka	MGO	67N	87E	0	0	0	0	0	0	0	0	0	0	11	0	11
Pechora	MGO	65N	57E	0	27	31	28	0	0	0	0	0	0	20	0	106
Markovo	MGO	65N	170E	0	0	0	0	0	0	0	0	0	0	17	0	17
Arkhangel'sk	MGO	65N	41E	0	0	27	25	0	0	0	0	27	26	20	0	125
Tura	MGO	64N	100E	0	0	0	0	0	0	0	0	0	0	19	0	19
Yakutsk	MGO	62N	130E	0	0	26	29	30	30	30	30	26	20	10	5	236
Hanty-Mansijsk	MGO	61N	69E	0	0	0	0	0	0	0	0	0	0	0	27	27
St Petersburg	MGO	60N	30E	0	27	27	30	30	27	31	31	29	27	24	26	309
Magadan	MGO	60N	151E	24	20	22	25	22	24	27	30	28	24	27	26	299
Vitim	MGO	59N	113E	0	0	0	0	28	29	30	31	26	17	13	12	186
Ekaterinburg	MGO	57N	61E	0	0	0	0	0	0	0	0	0	0	26	27	53
Krasnoyarsk	MGO	56N	93E	0	0	0	0	0	0	0	0	0	0	17	17	34
Omsk	MGO	55N	73E	31	27	31	30	25	30	31	31	29	31	25	24	345
Samara	MGO	53N	50E	0	22	27	28	0	0	0	0	0	0	0	22	99
Nikolaevsk	MGO	53N	141E	0	0	0	0	23	22	20	23	28	23	21	23	183
Petropavlovsk	MGO	53N	159E	0	0	0	0	0	0	0	27	30	30	0	0	87
Irkutsk	MGO	52N	104E	27	28	31	30	31	28	29	31	29	29	25	28	346
Voronezh	MGO	52N	39E	27	19	28	28	31	30	31	31	28	30	24	20	327
Karaganda	MGO	50N	73E	24	20	28	0	30	29	30	31	30	28	23	26	299
Yuzhno-Sahalinsk	MGO	47N	143E	27	19	24	27	30	29	30	27	26	30	27	24	320
Vladivostok	MGO	43N	132E	29	27	27	26	0	0	0	0	0	0	0	29	138

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	28	30	31	0	28	30	28	22	0	0	197
Thule	DMI	77N	69W	0	19	29	29	1	0	0	23	24	31	0	0	156
Scoresbysund	CNRS/DMI	70N	22W	13	28	31	30	31	27	26	20	30	28	23	0	287
Sodankylä	CNRS/FMI	67N	27E	31	26	31	30	31	30	31	31	30	31	30	31	363
Zhigansk	CNRS/CAO	67N	123E	30	26	30	29	25	25	29	30	29	21	29	26	329
Salekhard	CNRS/CAO	66N	67E	26	26	31	30	31	30	26	31	30	31	30	26	348
Harestua	BIRA.IASB	60N	11E	30	28	31	30	31	30	30	31	30	31	30	28	360
Bremen	IUP/IFE	53N	9E	31	27	28	29	30	30	29	31	27	29	29	31	351
Jungfraujoch	BIRA.IASB	47N	8E	26	4	28	28	15	7	0	0	0	0	0	0	108
OHP	CNRS	44N	6E	21	27	31	30	31	28	30	31	30	31	30	24	344
Izaña	INTA	28N	16W	31	28	31	29	31	26	30	31	29	31	30	31	358
Mérida	IUP/IFE	8N	71W	14	13	6	13	7	27	18	28	25	22	21	25	219
St Denis	CNRS	21S	55E	31	27	31	24	31	27	24	31	29	30	30	30	345
Bauru	CNRS/UNESP	22S	49W	29	27	31	30	31	30	31	30	30	30	27	20	346
Kerguelen	CNRS	49S	70E	31	28	31	30	31	30	31	31	30	30	29	31	363
Dumont d'Urville	CNRS	67S	140E	31	27	31	30	31	30	31	31	30	31	30	31	364
Rothera	BAS	68S	68W	27	16	31	30	31	29	31	31	30	31	30	31	348
Dome Concorde	CNRS	75S	123E	0	0	31	29	25	0	10	0	0	0	0	0	95

2008

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	5	20	31	30	31	22	31	31	29	26	8	0	264
Jokioinen	FMI	61N	23E	9	23	30	30	30	28	31	31	30	30	30	6	308
De Bilt	KNMI	52N	5E	29	23	28	27	31	30	31	31	0	0	0	0	230
Hohenpeißenberg	DWD	48N	11E	26	27	27	25	24	27	28	28	25	23	27	16	303
Arosa	MCH	47N	10E	27	28	28	23	28	26	28	31	28	28	25	20	320
Paramaribo	KNMI	6N	55W	31	29	31	30	31	28	31	31	30	31	30	29	362

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	18	18	7	10	16	12	18	18	17	12	15	12	173
Arosa	MCH	47N	10E	25	28	21	17	24	24	27	26	24	26	23	19	284
Lauder	NIWA	45S	170E	21	19	18	19	16	17	18	21	20	26	21	19	235
Vernadsky	BAS/KTSU	65S	65W	31	29	31	2	0	0	0	31	30	31	30	31	246
Halley	BAS	76S	27W	27	25	23	9	0	0	0	3	29	29	25	27	197
Arrival Heights	NIWA	78S	167E	6	5	1	0	0	0	0	0	6	12	15	20	65

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	6	0	0	2	4	3	0	0	0	18
Kiruna	FZK/IMK	68N	20E	2	5	9	9	1	1	9	2	7	3	6	0	54
Bremen	IUP/IFE	53N	9E	1	4	0	1	0	0	2	0	0	0	1	0	9
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73
Lauder	NIWA	45S	170E	9	5	6	10	7	8	7	6	6	8	8	5	85
Arrival Heights	NIWA	78S	167E	7	4	1	1	0	0	0	0	5	0	0	5	23

M124	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Tiksi	MGO	72N	129E	0	10	0	0	0	0	0	0	0	0	0	0	10
Murmansk	MGO	69N	33E	0	21	27	0	0	0	0	0	0	0	0	0	48
Olenek	MGO	68N	112E	0	23	29	0	0	0	0	0	0	0	0	0	52
Pechora	MGO	65N	57E	8	24	30	0	0	0	0	0	0	0	0	0	62
Markovo	MGO	65N	170E	6	27	0	0	0	0	0	0	0	0	0	0	33
Arkhangel'sk	MGO	65N	41E	6	18	25	0	0	0	0	0	0	0	0	0	49
Tura	MGO	64N	100E	10	23	0	0	0	0	0	0	0	0	0	0	33
Yakutsk	MGO	62N	130E	6	9	25	0	0	0	0	0	0	0	0	0	40
Hanty-Mansijsk	MGO	61N	69E	22	22	0	0	0	0	0	0	0	0	0	0	44
St Petersburg	MGO	60N	30E	28	24	30	0	0	0	0	0	0	0	0	0	82
Magadan	MGO	60N	151E	25	20	29	0	0	0	0	0	0	0	0	0	74
Vitim	MGO	59N	113E	16	16	0	0	0	0	0	0	0	0	0	0	32
Ekaterinburg	MGO	57N	61E	27	26	28	0	0	0	0	0	0	0	0	0	81
Krasnoyarsk	MGO	56N	93E	19	18	24	0	0	0	0	0	0	0	0	0	61
Omsk	MGO	55N	73E	26	28	31	0	0	0	0	0	0	0	0	0	85
Samara	MGO	53N	50E	21	19	23	0	0	0	0	0	0	0	0	0	63
Nikolaevsk	MGO	53N	141E	24	20	19	0	0	0	0	0	0	0	0	0	63
Petropavlovsk	MGO	53N	159E	27	25	25	0	0	0	0	0	0	0	0	0	77
Irkutsk	MGO	52N	104E	27	28	30	0	0	0	0	0	0	0	0	0	85
Voronezh	MGO	52N	39E	26	28	29	0	0	0	0	0	0	0	0	0	83
Karaganda	MGO	50N	73E	27	23	28	0	0	0	0	0	0	0	0	0	78
Yuzhno-Sahalinsk	MGO	47N	143E	26	25	30	0	0	0	0	0	0	0	0	0	81
Vladivostok	MGO	43N	132E	31	28	0	0	0	0	0	0	0	0	0	0	59

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	11	31	30	23	17	24	8	29	21	0	0	194
Scoresbysund	CNRS/DMI	70N	22W	13	29	0	0	0	0	27	28	29	28	23	0	177
Sodankylä	CNRS/FMI	67N	27E	31	29	31	0	0	0	24	31	30	31	30	30	267
Zhigansk	CNRS/CAO	67N	123E	25	21	29	0	0	0	10	6	30	28	25	20	194
Salekhard	CNRS/CAO	66N	67E	24	28	29	0	0	0	31	31	30	31	30	0	234
Harestua	BIRA.IASB	60N	11E	31	26	31	30	23	30	29	29	23	26	30	20	328
Bremen	IUP/IFE	53N	9E	25	17	31	28	26	29	31	31	17	27	24	31	317
Jungfraujoch	BIRA.IASB	47N	8E	0	0	0	0	0	0	0	0	0	26	27	29	82
OHP	CNRS	44N	6E	28	29	30	0	0	0	31	30	29	31	30	30	268
Izaña	INTA	28N	16W	31	29	31	30	31	30	31	31	30	31	30	31	366
Mérida	IUP/IFE	8N	71W	29	22	14	0	0	0	0	0	0	0	0	0	65
St Denis	CNRS	21S	55E	30	29	31	0	0	0	31	28	30	30	28	30	267
Bauru	CNRS/UNESP	22S	49W	28	23	24	0	0	0	28	30	25	27	25	30	240
Kerguelen	CNRS	49S	70E	0	28	29	0	0	0	31	30	29	27	29	30	233
Rio Gallegos	CNRS	52S	69W	0	0	0	29	30	23	31	31	29	29	27	20	249
Dumont d'Urville	CNRS	67S	140E	31	29	30	30	31	26	31	31	0	0	0	0	239
Rothera	BAS	68S	68W	31	26	30	30	31	29	31	29	30	31	26	31	355
Dome Concorde	CNRS	75S	123E	0	0	28	27	23	0	13	31	30	31	30	30	243

2009

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	1	19	30	30	31	29	31	30	28	24	0	0	253
Jokioinen	FMI	61N	23E	14	23	31	30	30	26	30	31	30	30	29	9	313
Hohenpeißenberg	DWD	48N	11E	19	17	23	28	29	28	0	0	28	30	23	16	241
Arosa	MCH	47N	10E	27	19	28	27	30	25	28	29	30	30	23	23	319
El Arenosillo	AEMET	37N	7W	0	0	0	0	0	0	0	0	8	0	0	0	8
Izaña	AEMET	28N	16W	0	0	0	0	0	0	0	0	0	0	13	10	23
Paramaribo	KNMI	6N	55W	6	18	16	22	31	30	28	26	30	31	29	30	297

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	10	13	14	17	15	13	0	0	18	17	12	7	136
Arosa	MCH	47N	10E	24	16	25	24	29	23	24	25	26	25	20	19	280
El Arenosillo	DWD	37N	7W	0	0	0	0	0	0	0	0	5	0	0	0	5
Irene	DWD	26S	28E	0	0	0	0	0	0	0	0	0	2	0	0	2
Lauder	NIWA	45S	170E	23	18	19	18	15	18	18	14	25	25	26	17	236
Vernadsky	BAS/KTSU	65S	65W	31	28	31	30	0	0	9	31	30	31	30	31	282
Halley	BAS	76S	27W	31	27	25	13	0	0	0	3	29	29	27	31	215
Arrival Heights	NIWA	78S	167E	14	9	5	0	0	0	0	0	11	15	15	0	69

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	5	6	7	2	0	0	0	0	31
Kiruna	FZK/IMK	68N	20E	0	10	8	1	1	2	1	4	6	4	1	0	38
Bremen	IUP/IFE	53N	9E	0	0	0	1	5	4	1	3	3	0	0	0	17
Izaña	FZK	28N	16W	9	4	9	16	12	12	1	14	5	8	1	3	94
Lauder	NIWA	45S	170E	4	4	2	4	7	10	4	9	8	9	9	4	74
Arrival Heights	NIWA	78S	167E	11	5	7	1	0	0	0	0	6	10	12	7	59

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	26	29	31	8	22	31	30	22	0	0	199
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	30	22	24	31	29	31	23	0	293
Sodankylä	CNRS/FMI	67N	27E	31	28	31	30	31	30	30	30	30	31	30	29	361
Zhigansk	CNRS/CAO	67N	123E	16	26	11	29	29	29	30	31	28	30	21	20	300
Salekhard	CNRS/CAO	66N	67E	29	25	31	30	30	27	22	5	8	31	30	29	297
Harestua	BIRA.IASB	60N	11E	25	27	29	29	29	20	16	15	24	22	21	30	287
Bremen	IUP/IFE	53N	9E	30	28	30	25	22	29	31	31	28	31	30	31	346
Jungfraujoch	BIRA.IASB	47N	8E	31	28	31	30	29	26	15	4	0	0	18	24	236
OHP	CNRS	44N	6E	31	28	31	29	31	8	31	31	30	31	20	21	322
Izaña	INTA	28N	16W	31	28	25	27	27	30	31	31	27	27	28	30	342
St Denis	CNRS	21S	55E	31	28	31	30	29	30	31	31	30	31	25	29	356
Bauru	CNRS/UNESP	22S	49W	31	24	31	30	31	30	31	28	16	2	6	7	267
Kerguelen	CNRS	49S	70E	30	28	31	29	12	29	29	29	30	30	30	28	335
Rio Gallegos	CNRS	52S	69W	27	24	21	27	12	21	28	30	23	23	16	25	277
Dumont d'Urville	CNRS	67S	140E	27	27	30	28	31	27	27	28	30	28	29	26	338
Rothera	BAS	68S	68W	31	26	27	29	31	30	31	31	27	31	30	31	355
Dome Concorde	CNRS	75S	123E	31	28	30	30	13	0	4	30	27	31	30	27	281

2010

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	1	16	30	30	21	30	28	30	30	23	8	3	250
Jokioinen	FMI	61N	23E	19	23	28	30	31	29	30	29	29	31	3	1	283
Hohenpeißenberg	DWD	48N	11E	18	19	27	28	22	17	29	27	27	18	18	15	265
Arosa	AEMET	47N	10E	0	0	0	0	0	0	5	0	0	0	0	0	5
Arosa	MCH	47N	10E	26	26	29	25	23	25	28	29	23	25	21	20	300
Izaña	AEMET	28N	16W	0	0	0	0	0	0	0	0	10	8	0	0	18
Paramaribo	KNMI	6N	55W	30	28	31	21	29	29	30	31	24	26	26	31	336

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	11	12	17	20	9	13	19	13	16	11	9	9	159
Arosa	MCH	47N	10E	25	21	26	23	18	20	25	22	21	22	19	12	254
Izaña	DWD	28N	16W	0	0	0	0	0	0	0	0	7	5	0	0	12
Lauder	NIWA	45S	170E	22	22	23	20	17	11	18	20	22	18	20	15	228
Vernadsky	BAS/KTSU	65S	65W	7	0	0	0	0	0	9	31	30	31	30	31	169
Halley	BAS	76S	27W	31	25	24	9	0	0	0	4	30	28	28	30	209
Arrival Heights	NIWA	78S	167E	0	3	6	0	0	0	0	0	4	10	15	10	48

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	0	0	0	0	0	5	1	0	0	0	6
Kiruna	FZK/IMK	68N	20E	0	4	12	8	5	3	1	4	5	8	2	0	52
Bremen	IUP/IFE	53N	9E	1	1	5	10	2	6	5	0	0	0	0	0	30
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	4	70
Lauder	NIWA	45S	170E	5	6	4	7	7	5	4	4	8	7	5	5	67
Arrival Heights	NIWA	78S	167E	6	7	4	3	0	0	0	0	2	5	1	6	34

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	25	19	28	23	26	30	0	0	0	0	151
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	31	30	28	27	30	28	23	0	300
Sodankylä	CNRS/FMI	67N	27E	29	23	22	30	31	30	30	27	30	31	30	31	344
Zhigansk	CNRS/CAO	67N	123E	24	19	26	24	31	28	17	22	27	27	22	19	286
Salekhard	CNRS/CAO	66N	67E	31	28	31	30	31	5	10	31	30	31	30	30	318
Harestua	BIRA.IASB	60N	11E	31	27	31	29	23	16	29	10	23	30	7	19	275
Bremen	IUP/IFE	53N	9E	31	28	31	30	22	28	22	30	24	30	22	22	320
Jungfraujoch	BIRA.IASB	47N	8E	30	24	24	24	29	8	16	4	0	0	0	18	177
OHP	CNRS	44N	6E	31	28	31	30	31	30	31	31	28	30	30	31	362
Izaña	INTA	28N	16W	31	25	25	17	20	23	24	22	23	26	25	11	272
St Denis	CNRS	21S	55E	31	28	31	27	31	30	28	31	30	31	30	31	359
Bauru	CNRS/UNESP	22S	49W	31	27	30	28	31	30	30	31	30	30	30	29	357
Kerguelen	CNRS	49S	70E	31	27	31	30	31	30	31	31	30	31	29	31	363
Rio Gallegos	CNRS	52S	69W	18	18	30	30	29	26	28	26	23	22	25	22	297
Dumont d'Urville	CNRS	67S	140E	23	24	31	30	30	30	29	31	30	31	30	31	350
Rothera	BAS	68S	68W	31	27	31	30	31	30	31	31	29	31	30	31	363
Dome Concorde	CNRS	75S	123E	31	27	31	28	0	0	3	24	30	31	30	24	259

2011

Brewer	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	AEMET	67N	27E	0	0	13	0	0	0	0						13
Sodankylä	FMI	67N	27E	0	20	28	29	30	30	30	31					219
Jokioinen	FMI	61N	23E	11	24	8	20	31	30	30	30					205
Hohenpeißenberg	DWD	48N	11E	21	0	0	0	0	0	0						21
Arosa	MCH	47N	10E	28	25	29	29	29	26	0						166
El Arenosillo	AEMET	37N	7W	0	0	0	0	0	0	10						10

Dobson	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Hohenpeißenberg	DWD	48N	11E	7	0	0	0	0	0	0						7
Arosa	MCH	47N	10E	20	18	25	26	24	16	0						129
Lauder	NIWA	45S	170E	12	19	22	18	13	21	20	16					141
Vernadsky	BAS/KTSU	65S	65W	31	28	31	30	19	0	8	31					186
Halley	BAS	76S	27W	31	28	27	13	0	0	0						105
Arrival Heights	NIWA	78S	167E	5	4	4	0	0	0	0						13

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	4	7	2	1	3					21
Kiruna	FZK/IMK	68N	20E	0	15	14	8	0	0	0						37
Lauder	NIWA	45S	170E	7	3	7	7	7	7	6						44
Arrival Heights	NIWA	78S	167E	2	4	3	1	0	0	0						10

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Scoresbysund	CNRS/DMI	70N	22W	13	28	30	30	31	30	31	31					224
Sodankylä	CNRS/FMI	67N	27E	31	28	31	30	25	29	27	31					232
Zhigansk	CNRS/CAO	67N	123E	21	15	27	28	22	24	24	31					192
Salekhard	CNRS/CAO	66N	67E	31	25	28	30	30	30	31	19					224
Harestua	BIRA.IASB	60N	11E	20	24	30	28	27	15	22						166
Bremen	IUP/IFE	53N	9E	22	28	30	29	31	30	31	31					232
Jungfraujoch	BIRA.IASB	47N	8E	31	27	31	30	28	7	0						154
OHP	CNRS	44N	6E	31	27	31	30	31	30	31	31					242
Izaña	INTA	28N	16W	30	13	4	21	28	28	31	14					169
Nairobi	IUP/IFE	1S	37E	0	11	28	23	31	29	29	28					179
St Denis	CNRS	21S	55E	31	9	23	30	31	30	24	31					209
Bauru	CNRS/UNESP	22S	49W	29	27	31	30	31	30	31	30					239
Kerguelen	CNRS	49S	70E	29	27	31	30	30	30	30	31					238
Rio Gallegos	CNRS	52S	69W	27	26	29	26	30	28	31	27					224
Dumont d'Urville	CNRS	67S	140E	31	27	31	30	30	30	30	31					240
Rothera	BAS	68S	68W	31	28	31	29	31	24	31	31					244
Dome Concorde	CNRS	75S	123E	27	22	31	29	25	0	2	31					167

IX.2.2 Monthly Data Distribution for O_3 Profile Data

Note that ozonesonde data files also include pressure and temperature profile data measured by the PTU sensor of the radiosonde to which the electrochemical ozonesonde is attached.

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	9	13	7	10	12	6	13	6	7	5	0	88
Izaña	FZK	28N	16W	4	5	14	7	9	17	14	14	13	11	11	10	129

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	0	0	0	0	0	0	0	0	0	26	26
Kiruna	FZK/IMK	68N	20E	31	28	30	0	20	12	0	0	20	30	30	31	232
Bremen	IUP/IFE	53N	9E	0	0	0	0	0	0	0	0	0	0	0	17	17
Payerne	UBERN	47N	7E	30	28	31	30	24	30	25	29	30	31	30	29	347
Mérida	FZK/IMK	8N	71W	0	4	0	22	1	18	13	26	26	19	21	3	153

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	AWI	79N	12E	9	8	10	5	5	4	4	4	4	3	4	6	66
Thule	DMI	77N	69W	1	1	1	0	0	0	0	0	0	0	0	3	6
Scoresbysund	DMI	70N	22W	4	3	4	3	4	5	4	3	4	4	3	0	41
Sodankylä	FMI	67N	27E	3	4	13	13	4	4	4	5	4	4	5	4	67
Keflavik	INTA	64N	23W	3	4	0	0	0	0	0	0	0	0	0	0	7
Legionowo	IMWM	52N	21E	6	4	5	5	8	6	7	6	4	1	0	0	52
De Bilt	KNMI	52N	5E	4	3	4	4	4	4	4	5	6	3	5	4	50
Uccle	RMI	51N	4E	12	12	14	11	12	11	11	12	13	13	11	9	141
Hohenpeißenberg	DWD	48N	11E	10	12	13	11	10	7	9	9	8	8	12	11	120
Payerne	MCH	47N	7E	15	12	14	10	12	12	12	14	12	12	13	12	150
OHP	CNRS	44N	6E	3	4	4	4	4	5	2	2	2	2	5	2	39
Paramaribo	KNMI	6N	55W	4	4	5	4	3	3	3	3	4	3	4	3	43
Lauder	NIWA	45S	170E	3	4	4	2	4	6	7	5	4	5	3	4	51
Marambio	FMI	64S	57W	2	2	3	2	2	6	7	6	4	8	9	5	56
Dumont d'Urville	CNRS	67S	140E	1	1	0	1	1	1	2	2	3	3	3	3	21
Belgrano	INTA	78S	38W	3	1	3	2	4	2	2	5	5	5	4	3	39

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	4	9	16	11	7	0	1	11	9	11	3	0	82
Izaña	FZK	28N	16W	10	14	5	12	12	10	16	20	10	8	3	10	130

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	26	22	25	17	0	0	0	0	0	0	0	15	105
Kiruna	FZK/IMK	68N	20E	28	26	1	0	0	0	0	0	0	11	25	31	122
Payerne	UBERN	47N	7E	29	28	29	25	28	29	31	27	27	30	25	30	338
Mérida	FZK/IMK	8N	71W	0	6	0	0	0	0	23	6	9	29	22	27	122

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Thule	DMI	77N	69W	3	4	5	4	0	0	0	0	0	0	0	0	16
Scoresbysund	DMI	70N	22W	4	3	3	4	3	5	3	5	4	4	3	1	42
Sodankylä	FMI	67N	27E	10	28	9	5	5	4	4	5	3	5	4	4	86
Salekhard	CAO	66N	67E	6	6	6	0	0	0	0	0	0	0	0	0	18
Keflavik	INTA	64N	23W	6	7	5	0	0	0	0	0	0	0	0	0	18
Jokioinen	FMI	61N	23E	7	6	1	0	0	0	0	0	0	0	0	0	14
De Bilt	KNMI	52N	5E	6	5	4	4	4	4	4	5	4	4	5	4	53
Uccle	RMI	51N	4E	12	11	13	11	11	8	0	2	4	6	6	1	85
Hohenpeißenberg	DWD	48N	11E	13	11	11	10	9	7	9	9	8	10	11	10	118
Payerne	MCH	47N	7E	14	11	13	11	13	12	14	14	12	13	14	11	152
OHP	CNRS	44N	6E	5	2	6	4	3	4	1	4	3	5	3	4	44
Paramaribo	KNMI	6N	55W	4	4	2	2	3	2	1	3	2	3	2	4	32
Lauder	NIWA	45S	170E	3	8	4	7	7	2	6	4	4	5	6	5	61
Marambio	FMI	64S	57W	3	2	1	1	3	5	7	15	8	10	7	5	67
Dumont d'Urville	CNRS	67S	140E	1	1	1	1	2	2	5	7	5	8	3	2	38
Belgrano	INTA	78S	38W	2	3	1	2	2	3	9	10	9	5	3	1	50

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	2	5	9	9	1	1	9	2	7	3	6	0	54
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	27	21	7	3	0	0	0	0	0	20	19	26	123
Kiruna	FZK/IMK	68N	20E	25	26	29	15	0	0	0	0	0	0	0	0	95
Payerne	UBERN	47N	7E	29	24	22	23	30	30	30	21	20	23	23	23	298
Mérida	FZK/IMK	8N	71W	27	23	27	0	0	0	0	0	0	0	0	0	77

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	4	5	5	5	4	4	5	4	4	4	4	3	51
Keflavik	INTA	64N	23W	5	7	4	0	0	0	0	0	0	0	0	3	19
Jokioinen	FMI	61N	23E	2	7	1	0	0	0	0	0	0	0	0	0	10
De Bilt	KNMI	52N	5E	5	6	4	5	4	4	5	6	4	5	4	5	57
Hohenpeißenberg	DWD	48N	11E	13	12	11	13	7	8	9	8	9	7	11	12	120
Payerne	MCH	47N	7E	14	13	11	13	12	12	14	14	14	14	12	13	156
OHP	CNRS	44N	6E	4	3	4	4	4	4	5	4	3	4	3	3	45
Paramaribo	KNMI	6N	55W	3	0	2	3	0	0	0	0	0	0	0	0	8
Lauder	NIWA	45S	170E	6	4	4	5	5	6	7	4	5	6	5	6	63
Ushuaia	INTA	55S	68W	0	0	0	4	2	2	3	2	4	6	5	1	29
Marambio	FMI	64S	57W	2	2	2	2	2	3	7	9	8	9	9	10	65
Dumont d'Urville	CNRS	67S	140E	2	3	2	3	3	3	3	2	4	6	4	3	38
Belgrano	INTA	78S	38W	2	2	2	3	1	2	3	4	6	7	4	4	40

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	10	8	1	1	2	1	4	6	4	1	0	38
Izaña	FZK	28N	16W	9	4	9	16	12	12	1	14	5	8	1	3	94

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	10	23	19	29	14	6	0	1	1	0	2	0	105
Payerne	UBERN	47N	7E	20	17	11	0	0	0	0	1	0	0	0	0	49

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	4	3	4	4	2	4	5	4	4	3	4	5	46
Keflavik	INTA	64N	23W	5	4	4	0	0	0	0	0	0	0	0	0	13
Jokioinen	FMI	61N	23E	1	0	0	0	0	0	0	0	0	0	0	0	1
De Bilt	KNMI	52N	5E	4	2	4	7	4	2	4	4	3	5	3	5	47
Hohenpeißenberg	DWD	48N	11E	13	12	12	12	8	9	9	9	8	8	12	12	124
Payerne	MCH	47N	7E	12	12	12	11	13	13	13	14	14	12	13	11	150
OHP	CNRS	44N	6E	2	4	5	5	4	4	4	4	5	4	4	5	50
Lauder	NIWA	45S	170E	6	6	5	4	6	6	5	2	3	1	2	3	49
Ushuaia	INTA	55S	68W	2	2	2	3	2	1	1	1	6	4	4	1	29
Marambio	FMI	64S	57W	2	2	2	4	2	2	1	1	1	0	3	8	28
Dumont d'Urville	CNRS	67S	140E	2	2	2	2	3	2	1	3	4	4	4	4	33
Belgrano	INTA	78S	38W	4	2	2	3	3	3	3	4	5	5	5	2	41

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	4	12	8	5	3	1	4	5	8	2	0	52
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	4	70

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	13	28	31	28	4	0	0	6	10	21	28	28	197
Payerne	MCH	47N	7E	0	0	0	1	0	16	23	26	4	7	0	0	77

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	5	5	5	4	4	4	4	3	5	4	4	3	50
Keflavik	INTA	64N	23W	4	5	4	0	0	0	0	0	0	0	0	0	13
Jokioinen	FMI	61N	23E	1	2	0	0	0	0	0	0	0	0	0	0	3
De Bilt	KNMI	52N	5E	4	3	2	8	5	3	4	4	5	4	4	5	51
Hohenpeißenberg	DWD	48N	11E	12	12	14	18	9	8	8	9	9	9	11	12	131
Payerne	MCH	47N	7E	13	11	14	12	12	14	13	12	13	12	12	13	151
OHP	CNRS	44N	6E	3	4	5	2	2	4	4	4	2	0	0	0	30

Lauder	NIWA	45S	170E	2	3	6	6	3	2	2	6	2	3	2	2	39
Ushuaia	INTA	55S	68W	2	1	2	1	2	2	2	2	5	3	2	1	25
Marambio	FMI	64S	57W	6	2	1	2	1	7	8	8	9	3	5	9	61
Dumont d'Urville	CNRS	67S	140E	2	1	2	1	2	1	2	0	0	0	0	0	11
Belgrano	INTA	78S	38W	2	1	3	2	2	2	3	3	5	5	5	4	37

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	14	8	0	0	0						37

Microwave	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	31	17	15	19	18	2	0						102
Payerne	MCH	47N	7E	29	26	30	30	29	0	0						144

Ozonesonde	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Sodankylä	FMI	67N	27E	4	5	16	6	4	4	3	3					47
Keflavik	INTA	64N	23W	3	6	7	0	0	0	0						16
Jokioinen	FMI	61N	23E	0	0	6	2	0	0	0						8
Hohenpeißenberg	DWD	48N	11E	13	12	13	12	9	9	8	10					89
Payerne	MCH	47N	7E	12	8	11	12	13	12	10	15					101
Lauder	NIWA	45S	170E	2	4	3	4	5	3	3	2					26
Ushuaia	INTA	55S	68W	2	2	2	2	3	1	2						14
Marambio	FMI	64S	57W	2	2	1	2	2	9	8	5					34
Belgrano	INTA	78S	38W	2	3	2	2	2	3	3						17

IX.2.3 Monthly Data Distribution for NO_2 Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	0	1	0	0	0	0	0	11
Kiruna	FZK/IMK	68N	20E	0	8	14	7	8	10	7	13	6	6	4	0	83
Bremen	IUP/IFE	53N	9E	2	2	3	5	6	6	7	3	9	4	1	1	49
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	9	25	30	28	19	31	31	28	26	0	0	227
Thule	DMI	77N	69W	0	18	31	30	5	0	0	21	30	31	0	0	166
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	31	30	31	31	30	31	23	0	310
Kiruna	NIWA	68N	20E	23	26	31	30	31	1	22	18	20	31	30	3	266
Sodankylä	CNRS/FMI	67N	27E	31	28	30	30	31	26	30	31	30	31	30	31	359
Zhigansk	CNRS/CAO	67N	123E	26	11	30	26	29	28	29	31	30	31	30	27	328
Salekhard	CNRS/CAO	66N	67E	22	28	31	30	31	30	31	31	30	31	28	28	351
Harestua	BIRA.IASB	60N	11E	12	23	31	30	31	30	28	31	30	31	25	31	333
St Petersburg	SPBSU	60N	30E	31	28	31	30	31	30	31	30	30	31	30	30	363
Bremen	IUP/IFE	53N	9E	29	12	29	30	31	29	23	22	0	24	29	30	288
Jungfraujoch	BIRA.IASB	47N	8E	31	28	21	2	16	24	18	0	3	31	30	30	234
OHP	CNRS	44N	6E	31	28	31	30	31	30	31	31	30	31	30	31	365
Issyk Kul	KSNU	43N	77E	31	26	29	30	31	30	31	31	29	31	30	31	360
Izaña	INTA	28N	16W	31	28	31	30	31	28	28	29	30	31	30	31	358
Mauna Loa	NIWA	20N	156W	31	28	31	30	30	30	31	31	29	26	28	31	356
Mérida	IUP/IFE	8N	71W	27	23	25	25	17	23	18	27	0	26	17	31	259
St Denis	CNRS	21S	55E	31	28	30	30	31	30	31	28	30	31	29	31	360
Bauru	CNRS/UNESP	22S	49W	23	28	31	30	31	30	31	31	30	31	29	27	352
Lauder	NIWA	45S	170E	31	28	31	30	24	30	31	31	30	31	30	21	348
Kerguelen	CNRS	49S	70E	31	28	31	30	31	30	31	31	30	31	30	31	365
Macquarie	NIWA	54S	159E	31	27	31	28	30	30	31	31	30	31	30	31	361
Marambio	INTA	64S	57W	30	28	31	30	30	29	31	31	30	31	30	31	362
Dumont d'Urville	CNRS	67S	140E	31	28	31	30	31	30	30	31	30	31	29	31	363
Rothera	BAS	68S	68W	31	28	31	29	31	28	25	27	30	31	30	31	352
Belgrano	INTA	78S	38W	0	14	29	22	0	0	0	0	18	31	0	0	114
Arrival Heights	NIWA	78S	167E	0	12	31	22	0	0	0	11	30	25	0	0	131

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	1	0	7	6	4	3	4	0	0	0	25
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
Bremen	IUP/IFE	53N	9E	2	1	7	9	2	0	0	0	0	0	0	0	21
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	15	30	31	0	27	31	28	22	0	0	184
Thule	DMI	77N	69W	0	19	29	29	1	0	0	23	24	31	0	0	156
Scoresbysund	CNRS/DMI	70N	22W	13	28	31	30	31	27	26	20	30	28	23	0	287
Kiruna	NIWA	68N	20E	23	16	30	30	31	1	21	31	6	23	30	3	245
Sodankylä	CNRS/FMI	67N	27E	31	26	31	30	31	30	31	31	30	31	30	31	363
Zhigansk	CNRS/CAO	67N	123E	30	26	30	29	25	25	29	30	29	21	29	26	329
Salekhard	CNRS/CAO	66N	67E	26	26	31	30	31	30	26	31	30	31	30	26	348
Harestua	BIRA.IASB	60N	11E	29	28	30	30	31	30	30	31	30	31	30	27	357
St Petersburg	SPBSU	60N	30E	31	28	29	27	31	30	29	31	27	30	26	31	350
Bremen	IUP/IFE	53N	9E	30	27	31	30	26	28	11	8	30	31	29	29	310
Paris	CNRS	49N	2E	31	28	31	30	29	30	31	31	30	31	30	31	363
Jungfraujoch	BIRA.IASB	47N	8E	28	5	31	30	15	10	0	0	0	0	0	0	119
OHP	CNRS	44N	6E	21	27	31	30	31	28	30	31	30	31	30	24	344
Issyk Kul	KSNU	43N	77E	30	28	30	27	31	29	30	30	30	31	30	31	357
Izaña	INTA	28N	16W	31	28	31	29	31	26	30	31	29	31	30	31	358
Mauna Loa	NIWA	20N	156W	30	24	27	30	30	29	31	31	28	28	30	31	349
Mérida	IUP/IFE	8N	71W	15	14	6	13	9	23	19	29	26	26	19	25	224
St Denis	CNRS	21S	55E	31	27	31	24	31	27	24	31	29	30	30	30	345
Bauru	CNRS/UNESP	22S	49W	30	28	31	30	31	30	31	31	30	30	28	25	355
Lauder	NIWA	45S	170E	29	28	31	30	31	30	29	31	30	31	28	31	359
Kerguelen	CNRS	49S	70E	31	28	31	30	31	30	31	31	30	30	29	31	363
Macquarie	NIWA	54S	159E	31	28	30	29	31	30	31	31	30	31	30	31	363
Ushuaia	INTA	55S	68W	31	25	28	30	28	30	30	17	28	27	9	29	312
Marambio	INTA	64S	57W	31	27	31	30	31	30	31	31	30	30	30	31	363
Dumont d'Urville	CNRS	67S	140E	31	27	31	30	31	30	31	31	30	31	30	31	364
Rothera	BAS	68S	68W	27	16	31	30	31	29	29	30	30	31	30	31	345
Dome Concorde	CNRS	75S	123E	0	0	31	29	25	0	10	0	0	0	0	0	95
Belgrano	INTA	78S	38W	0	16	31	22	0	0	0	14	29	30	0	0	142
Arrival Heights	NIWA	78S	167E	0	12	31	22	0	0	0	10	30	25	0	0	130

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	6	0	0	2	4	3	0	0	0	18
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	4	5	0	50
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	2	5	71

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	5	31	29	0	24	30	9	29	17	0	0	174
Scoresbysund	CNRS/DMI	70N	22W	13	29	0	0	0	0	27	28	29	28	23	0	177
Kiruna	NIWA	68N	20E	23	29	28	30	31	0	22	31	30	30	30	2	286
Sodankylä	CNRS/FMI	67N	27E	31	29	31	0	0	0	24	31	30	31	30	30	267
Zhigansk	CNRS/CAO	67N	123E	25	21	29	0	0	0	10	6	30	28	25	20	194
Salekhard	CNRS/CAO	66N	67E	24	28	29	0	0	0	31	31	30	31	30	0	234
Harestua	BIRA.IASB	60N	11E	29	26	31	30	23	30	29	29	23	26	30	19	325
St Petersburg	SPBSU	60N	30E	30	27	31	0	0	0	0	0	0	0	0	0	88
Bremen	IUP/IFE	53N	9E	28	11	30	27	26	30	31	31	30	29	23	30	326
Paris	CNRS	49N	2E	12	12	12	12	12	12	12	12	12	12	12	12	144
Jungfraujoch	BIRA.IASB	47N	8E	0	0	0	0	0	0	0	0	0	26	30	30	86
OHP	CNRS	44N	6E	28	29	30	0	0	0	31	30	29	31	30	30	268
Issyk Kul	KSNU	43N	77E	30	29	29	0	0	0	0	0	0	0	0	0	88
Izaña	INTA	28N	16W	31	29	31	30	31	30	31	31	30	31	30	31	366
Mauna Loa	NIWA	20N	156W	31	24	0	0	0	0	0	0	0	0	0	0	55
Mérida	IUP/IFE	8N	71W	31	22	16	0	0	0	0	0	0	0	0	0	69
St Denis	CNRS	21S	55E	30	29	31	0	0	0	31	28	30	30	28	30	267
Bauru	CNRS/UNESP	22S	49W	28	23	25	27	31	30	28	30	25	29	27	31	334
Lauder	NIWA	45S	170E	30	29	29	30	31	30	31	31	30	31	23	31	356
Kerguelen	CNRS	49S	70E	0	28	29	0	0	0	31	30	29	27	29	30	233
Rio Gallegos	CNRS	52S	69W	0	0	0	29	30	23	31	31	29	29	27	20	249
Macquarie	NIWA	54S	159E	31	29	31	30	31	30	31	28	27	31	30	24	353

Ushuaia	INTA	55S	68W	22	29	31	30	28	30	30	30	23	30	28	31	342
Marambio	INTA	64S	57W	31	29	30	30	31	30	31	31	30	31	30	30	364
Dumont d'Urville	CNRS	67S	140E	31	29	30	30	31	26	31	31	0	0	0	0	239
Rothera	BAS	68S	68W	31	26	30	30	31	29	31	29	30	31	26	31	355
Dome Concorde	CNRS	75S	123E	0	0	28	27	23	0	13	31	30	31	30	30	243
Belgrano	INTA	78S	38W	0	16	30	19	0	0	0	15	29	30	0	0	139
Arrival Heights	NIWA	78S	167E	0	13	31	22	0	0	0	11	30	24	0	0	131

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	5	6	7	1	0	0	0	0	30
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	4	1	3	7	5	1	0	39
Izaña	FZK	28N	16W	9	4	8	15	12	8	1	13	5	8	1	4	88

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	23	29	31	4	26	31	30	22	0	0	196
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	30	22	24	31	29	31	23	0	293
Kiruna	NIWA	68N	20E	23	28	31	30	31	0	22	31	30	31	30	3	290
Sodankylä	CNRS/FMI	67N	27E	31	28	31	30	31	30	30	31	30	31	30	30	363
Zhigansk	CNRS/CAO	67N	123E	16	26	11	29	29	29	30	31	28	30	21	20	300
Salekhard	CNRS/CAO	66N	67E	29	25	31	30	30	27	22	5	8	31	30	29	297
Harestua	BIRA.IASB	60N	11E	25	27	29	29	29	20	16	15	24	22	19	30	285
Bremen	IUP/IFE	53N	9E	31	15	31	28	9	11	31	31	30	31	30	31	309
Paris	CNRS	49N	2E	4	4	4	5	10	12	11	11	10	10	10	10	101
Jungfraujoch	BIRA.IASB	47N	8E	31	28	31	30	31	30	18	14	8	0	20	25	266
OHP	CNRS	44N	6E	31	28	31	29	31	8	31	31	30	31	20	21	322
Izaña	INTA	28N	16W	31	28	25	27	27	30	31	31	27	27	28	30	342
St Denis	CNRS	21S	55E	31	28	31	30	29	30	31	31	30	31	25	29	356
Bauru	CNRS/UNESP	22S	49W	31	28	31	30	31	30	31	31	30	23	10	21	327
Lauder	NIWA	45S	170E	31	28	31	27	31	30	31	31	30	31	30	30	361
Kerguelen	CNRS	49S	70E	30	28	31	29	12	29	29	29	30	30	30	28	335
Rio Gallegos	CNRS	52S	69W	27	24	21	27	12	21	28	30	23	23	16	25	277
Macquarie	NIWA	54S	159E	30	28	31	30	31	30	31	31	30	30	8	17	327
Ushuaia	INTA	55S	68W	27	28	26	30	31	30	28	26	30	30	30	30	346
Marambio	INTA	64S	57W	30	28	31	30	29	28	15	31	30	30	29	30	341
Dumont d'Urville	CNRS	67S	140E	27	27	30	28	31	27	27	28	30	28	29	26	338
Rothera	BAS	68S	68W	31	26	27	29	31	30	31	31	27	31	30	31	355
Dome Concorde	CNRS	75S	123E	31	28	30	30	13	0	4	30	27	31	30	27	281
Belgrano	INTA	78S	38W	0	16	31	22	0	0	0	15	28	30	0	0	142
Arrival Heights	NIWA	78S	167E	0	12	31	21	0	0	0	11	30	24	0	0	129

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	22	20	28	23	26	30	0	0	0	0	149
Scoresbysund	CNRS/DMI	70N	22W	14	28	31	30	31	30	28	27	30	28	23	0	300
Kiruna	NIWA	68N	20E	23	28	0	0	0	0	0	0	0	0	0	0	51
Sodankylä	CNRS/FMI	67N	27E	29	23	25	30	31	30	30	30	30	31	30	31	350
Zhigansk	CNRS/CAO	67N	123E	24	19	26	24	31	28	17	22	27	27	22	19	286
Salekhard	CNRS/CAO	66N	67E	31	28	31	30	31	5	10	31	30	31	30	30	318
Harestua	BIRA.IASB	60N	11E	31	27	31	29	23	16	29	10	23	28	7	19	273
Bremen	IUP/IFE	53N	9E	26	27	31	30	22	28	27	30	25	30	22	19	317
Paris	CNRS	49N	2E	12	12	12	12	31	12	12	12	12	12	12	12	163
Jungfraujoch	BIRA.IASB	47N	8E	30	24	24	27	31	10	19	0	0	0	0	17	182
OHP	CNRS	44N	6E	31	28	31	30	31	30	31	31	28	30	30	31	362
Izaña	INTA	28N	16W	31	25	25	17	20	23	24	22	23	26	25	11	272
St Denis	CNRS	21S	55E	31	28	31	27	31	30	28	31	30	31	30	31	359
Bauru	CNRS/UNESP	22S	49W	31	28	30	28	31	30	30	31	30	31	30	31	361
Lauder	NIWA	45S	170E	31	28	31	30	31	30	31	31	27	31	30	27	358
Kerguelen	CNRS	49S	70E	31	27	31	30	31	30	31	31	30	31	29	31	363
Rio Gallegos	CNRS	52S	69W	18	18	30	30	29	26	28	26	23	22	25	22	297
Macquarie	NIWA	54S	159E	31	28	31	30	30	30	29	31	30	30	30	31	361
Ushuaia	INTA	55S	68W	30	24	30	29	31	28	31	31	28	31	30	31	354

Marambio	INTA	64S	57W	31	23	31	30	25	30	31	31	30	31	30	31	354
Dumont d'Urville	CNRS	67S	140E	23	24	31	30	30	30	29	31	30	31	30	31	350
Rothera	BAS	68S	68W	31	27	31	30	31	30	31	31	29	31	30	31	363
Dome Concorde	CNRS	75S	123E	31	27	31	28	0	0	3	24	30	31	30	24	259
Belgrano	INTA	78S	38W	0	17	31	25	0	0	0	10	28	24	0	0	135
Arrival Heights	NIWA	78S	167E	0	12	31	22	0	0	0	11	30	25	0	0	131

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Scoresbysund	CNRS/DMI	70N	22W	13	28	30	30	31	30	31	31					224
Sodankylä	CNRS/FMI	67N	27E	31	28	31	30	25	29	27	31					232
Zhigansk	CNRS/CAO	67N	123E	21	15	27	28	22	24	24	31					192
Salekhard	CNRS/CAO	66N	67E	31	25	28	30	30	30	31	19					224
Harestua	BIRA.IASB	60N	11E	19	24	30	28	27	15	22						165
Bremen	IUP/IFE	53N	9E	24	28	30	30	30	25	31	30					228
Jungfraujoch	BIRA.IASB	47N	8E	31	27	31	30	29	8	0						156
OHP	CNRS	44N	6E	31	27	31	30	31	30	31	31					242
Izaña	INTA	28N	16W	30	13	4	21	28	28	31	14					169
Nairobi	IUP/IFE	1S	37E	0	11	28	23	30	29	29	27					177
St Denis	CNRS	21S	55E	31	9	23	30	31	30	24	31					209
Bauru	CNRS/UNESP	22S	49W	29	27	31	30	31	30	31	30					239
Lauder	NIWA	45S	170E	31	27	31	30	29	30	31	31					240
Kerguelen	CNRS	49S	70E	29	27	31	30	30	30	30	31					238
Rio Gallegos	CNRS	52S	69W	27	26	29	26	30	28	31	27					224
Macquarie	NIWA	54S	159E	31	28	31	30	30	30	31	31					242
Ushuaia	INTA	55S	68W	31	28	31	30	30	30	29						209
Marambio	INTA	64S	57W	31	20	31	30	20	0	0						132
Dumont d'Urville	CNRS	67S	140E	31	27	31	30	30	30	30	31					240
Rothera	BAS	68S	68W	31	28	31	29	31	24	31	31					244
Dome Concorde	CNRS	75S	123E	27	22	31	29	25	0	2	31					167
Belgrano	INTA	78S	38W	0	17	31	23	0	0	0						71
Arrival Heights	NIWA	78S	167E	0	12	31	22	0	0	0	10					75

IX.2.4 Monthly Data Distribution for NO_2 Profile Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	0	0	0	0	0	0	0	6	6	4	0	16
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	4	5	0	50
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	2	5	71

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	4	1	3	7	5	1	0	39
Izaña	FZK	28N	16W	9	4	8	15	12	8	1	13	5	8	1	4	88

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40

IX.2.5 Monthly Data Distribution for BrO Column Data

2006

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	20	24	31	30	31	30	30	31	30	31	29	31	348

2007

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	31	28	31	30	31	30	30	31	25	21	2	0	290

2008

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	1	10	29	30	27	30	31	30	25	25	24	28	290

2009

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	20	27	29	29	28	21	28	25	24	19	22	31	303

2010

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	28	26	31	30	23	10	28	10	23	30	7	24	270

2011

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	24	20	25	27	29	18	13						156

IX.2.6 Monthly Data Distribution for OClO Column Data

2006

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	17	24	31	30	0	0	0	0	0	0	28	31	161

2007

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	27	28	31	30	0	0	0	0	0	0	1	0	117

2008

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	0	0	28	28	0	0	0	0	0	0	24	25	105

2009

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	19	27	29	29	0	0	0	0	0	0	22	30	156

2010

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	17	23	31	29	0	0	0	0	0	0	7	23	130

2011

UV-Vis DOAS	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Harestua	BIRA.IASB	60N	11E	20	20	25	27	0	0	0						92

IX.2.7 Monthly Data Distribution for CO Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	3	2	0	0	0	0	0	15
Kiruna	FZK/IMK	68N	20E	0	8	13	5	6	9	4	11	4	5	4	0	69
St Petersburg	SPBSU	60N	30E	6	10	14	4	2	11	10	4	9	0	0	0	70
Zvenigorod	SPBSU	56N	37E	4	9	13	10	10	13	10	8	2	0	1	0	80
Bremen	IUP/IFE	53N	9E	2	2	3	3	6	5	7	3	9	5	1	1	47
Jungfraujoch	ULg-GIRPAS	47N	8E	7	9	1	8	5	10	18	4	6	6	7	6	87
Izaña	FZK	28N	16W	4	5	13	7	8	17	14	13	12	9	11	10	123
Lauder	NIWA	45S	170E	6	11	4	9	11	8	4	11	7	10	5	4	90
Arrival Heights	NIWA	78S	167E	10	3	3	2	0	0	0	0	2	7	6	0	33

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	0	8	6	5	4	4	0	0	0	29
Kiruna	FZK/IMK	68N	20E	0	6	14	7	7	3	4	7	6	4	2	0	60
St Petersburg	SPBSU	60N	30E	4	11	6	11	10	14	8	7	7	2	1	2	83
Zvenigorod	SPBSU	56N	37E	1	10	8	8	11	12	8	16	13	3	0	0	90
Bremen	IUP/IFE	53N	9E	2	1	7	9	2	2	2	4	1	2	3	1	36
Jungfraujoch	ULg-GIRPAS	47N	8E	3	0	9	13	8	0	12	7	18	8	10	6	94
Izaña	FZK	28N	16W	10	14	5	12	12	10	16	16	10	8	3	9	125
Lauder	NIWA	45S	170E	4	4	9	4	9	7	8	10	10	8	7	3	83
Arrival Heights	NIWA	78S	167E	4	3	4	2	0	0	0	0	6	10	1	8	38

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	3	3	4	5	4	0	0	0	30
Kiruna	FZK/IMK	68N	20E	1	3	8	6	1	1	9	1	6	2	6	0	44
St Petersburg	SPBSU	60N	30E	5	3	3	0	0	0	0	0	0	0	0	0	11
Bremen	IUP/IFE	53N	9E	1	4	2	7	6	2	2	0	1	0	1	1	27
Jungfraujoch	ULg-GIRPAS	47N	8E	11	13	0	3	8	14	12	3	15	8	3	6	96
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73
Lauder	NIWA	45S	170E	8	5	5	9	7	7	7	5	5	6	3	2	69
Arrival Heights	NIWA	78S	167E	7	4	1	1	0	0	0	0	5	0	0	5	23

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	9	6	6	8	3	4	0	0	0	40
Kiruna	FZK/IMK	68N	20E	0	5	7	0	0	2	1	3	6	3	0	0	27
Bremen	IUP/IFE	53N	9E	0	0	1	2	6	4	1	5	5	0	0	0	24
Jungfraujoch	ULg-GIRPAS	47N	8E	12	6	5	8	10	9	12	21	10	13	4	6	116
Izaña	FZK	28N	16W	9	4	8	16	12	7	1	13	5	7	1	3	86
Lauder	NIWA	45S	170E	0	2	2	4	6	9	3	9	8	9	5	1	58
Arrival Heights	NIWA	78S	167E	12	3	4	1	0	0	0	0	7	12	12	7	58

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	9	3	2	3	5	2	0	0	0	27
Kiruna	FZK/IMK	68N	20E	0	2	9	7	5	4	2	4	8	8	2	0	51
Bremen	IUP/IFE	53N	9E	1	2	6	9	2	7	5	0	0	0	0	0	32
Jungfraujoch	ULg-GIRPAS	47N	8E	9	3	7	12	6	14	15	10	11	9	5	0	101
Izaña	FZK	28N	16W	0	0	4	4	7	15	10	11	4	6	4	5	70
Lauder	NIWA	45S	170E	3	3	3	7	7	5	4	4	8	7	4	3	58
Arrival Heights	NIWA	78S	167E	6	7	4	3	0	0	0	0	4	5	1	6	36

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	4	7	2	1	3					21
Kiruna	FZK/IMK	68N	20E	0	11	15	8	0	0	0						34
Bremen	IUP/IFE	53N	9E	2	4	6	9	5	1	0	1					28
Jungfraujoch	ULg-GIRPAS	47N	8E	11	8	13	10	9	0	0						51
Lauder	NIWA	45S	170E	5	2	4	6	7	7	6						37
Arrival Heights	NIWA	78S	167E	2	3	3	1	0	0	0						9

IX.2.8 Monthly Data Distribution for CO Profile Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	8	13	5	6	9	4	11	4	5	4	0	69
Jungfraujoch	ULg-GIRPAS	47N	8E	7	9	1	8	5	10	18	4	6	6	7	6	87
Izaña	FZK	28N	16W	4	5	13	7	8	17	14	13	12	9	11	10	123

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	6	14	7	7	3	4	7	6	4	2	0	60
Jungfraujoch	ULg-GIRPAS	47N	8E	3	0	9	13	8	0	12	7	18	8	10	6	94
Izaña	FZK	28N	16W	10	14	5	12	12	10	16	16	10	8	3	9	125

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	1	3	8	6	1	1	9	1	6	2	6	0	44
Jungfraujoch	ULg-GIRPAS	47N	8E	11	13	0	3	8	14	12	3	15	8	3	6	96
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	5	7	0	0	2	1	3	6	3	0	0	27
Jungfraujoch	ULg-GIRPAS	47N	8E	12	6	5	8	10	9	12	21	10	13	4	6	116
Izaña	FZK	28N	16W	9	4	8	16	12	7	1	13	5	7	1	3	86

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	2	9	7	5	4	2	4	8	8	2	0	51
Jungfraujoch	ULg-GIRPAS	47N	8E	9	3	7	12	6	14	15	10	11	9	5	0	101
Izaña	FZK	28N	16W	0	0	4	4	7	15	10	11	4	6	4	5	70

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	11	15	8	0	0	0						34
Jungfraujoch	ULg-GIRPAS	47N	8E	11	8	13	10	9	0	0						51

IX.2.9 Monthly Data Distribution for CO_2 Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	3	2	0	0	0	0	0	15

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	0	8	6	5	4	4	0	0	0	29

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	3	3	4	5	4	0	0	0	30

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	9	6	6	8	1	0	0	0	0	34

IX.2.10 Monthly Data Distribution for CH_4 Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	3	2	0	0	0	0	0	15
Kiruna	FZK/IMK	68N	20E	0	8	14	7	8	10	7	13	6	6	4	0	83
St Petersburg	SPBSU	60N	30E	4	7	12	6	3	12	15	8	13	1	0	0	81
Zvenigorod	SPBSU	56N	37E	3	8	9	2	1	6	4	4	1	0	0	0	38
Bremen	IUP/IFE	53N	9E	2	2	3	5	6	6	7	3	9	4	1	1	49
Jungfraujoch	ULg-GIRPAS	47N	8E	11	10	1	7	6	10	18	4	6	6	8	6	93
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126
Lauder	NIWA	45S	170E	6	8	4	7	8	1	2	10	7	10	5	3	71
Arrival Heights	NIWA	78S	167E	4	0	1	1	0	0	0	0	2	5	5	0	18

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	0	8	6	5	4	4	0	0	0	29
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
St Petersburg	SPBSU	60N	30E	5	13	8	8	12	16	6	9	7	2	0	2	88
Zvenigorod	SPBSU	56N	37E	1	8	7	5	11	5	4	12	11	2	0	0	66
Bremen	IUP/IFE	53N	9E	2	1	7	9	2	2	2	4	1	2	3	1	36
Jungfraujoch	ULg-GIRPAS	47N	8E	2	0	9	14	8	0	14	7	20	11	11	7	103
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126
Lauder	NIWA	45S	170E	5	4	9	3	2	4	7	10	10	10	9	9	82
Arrival Heights	NIWA	78S	167E	3	3	7	2	0	0	0	0	7	9	1	4	36

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	3	3	4	5	4	0	0	0	30
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	3	5	0	49
St Petersburg	SPBSU	60N	30E	5	3	3	0	0	0	0	0	0	0	0	0	11
Bremen	IUP/IFE	53N	9E	1	4	2	7	6	2	2	0	1	2	1	1	29
Jungfraujoch	ULg-GIRPAS	47N	8E	12	14	0	3	7	15	12	2	14	9	3	8	99
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	3	5	72
Lauder	NIWA	45S	170E	12	8	9	10	6	6	7	3	6	7	8	5	87
Arrival Heights	NIWA	78S	167E	7	2	1	1	0	0	0	0	5	0	0	1	17

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	9	6	6	8	2	0	0	0	0	35
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	2	1	3	5	4	1	0	34
Bremen	IUP/IFE	53N	9E	0	0	1	2	8	4	3	5	5	0	0	0	28
Jungfraujoch	ULg-GIRPAS	47N	8E	12	7	5	10	13	11	13	9	11	14	4	8	117
Izaña	FZK	28N	16W	9	4	8	16	12	11	1	13	5	8	1	4	92
Lauder	NIWA	45S	170E	3	1	3	4	4	3	3	8	7	7	9	3	55
Arrival Heights	NIWA	78S	167E	10	5	8	1	0	0	0	0	5	11	8	5	53

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	0	0	2	1	1	5	3	0	0	0	12
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Bremen	IUP/IFE	53N	9E	1	2	6	9	2	7	5	0	0	0	0	0	32
Jungfraujoch	ULg-GIRPAS	47N	8E	10	8	8	12	7	14	17	12	14	9	7	2	120
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71
Lauder	NIWA	45S	170E	5	7	5	6	5	4	4	4	7	8	6	4	65
Arrival Heights	NIWA	78S	167E	7	7	4	3	0	0	0	0	5	4	2	2	34

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	4	7	2	1	3					21
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40
Bremen	IUP/IFE	53N	9E	3	4	6	9	5	1	0	1					29
Jungfraujoch	ULg-GIRPAS	47N	8E	14	10	14	10	11	0	0						59
Lauder	NIWA	45S	170E	8	3	9	6	7	8	5						46
Arrival Heights	NIWA	78S	167E	2	2	3	0	0	0	0						7

IX.2.11 Monthly Data Distribution for CH_4 Profile Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	0	0	0	0	0	0	0	6	6	4	0	16
Jungfraujoch	ULg-GIRPAS	47N	8E	11	10	1	7	6	10	18	4	6	6	8	6	93
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126
Lauder	NIWA	45S	170E	6	8	4	7	8	1	2	10	7	10	5	3	71
Arrival Heights	NIWA	78S	167E	4	0	1	1	0	0	0	0	2	5	5	0	18

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
Jungfraujoch	ULg-GIRPAS	47N	8E	2	0	9	14	8	0	14	7	20	11	11	7	103
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126
Lauder	NIWA	45S	170E	5	4	9	3	2	4	7	10	10	10	9	9	82
Arrival Heights	NIWA	78S	167E	3	3	7	2	0	0	0	0	7	9	1	4	36

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	3	5	0	49
Jungfraujoch	ULg-GIRPAS	47N	8E	12	14	0	3	7	15	12	2	14	9	3	8	99
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	3	5	72
Lauder	NIWA	45S	170E	12	8	9	10	6	6	7	3	6	7	8	5	87
Arrival Heights	NIWA	78S	167E	7	2	1	1	0	0	0	0	5	0	0	1	17

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	2	1	3	5	4	1	0	34
Jungfraujoch	ULg-GIRPAS	47N	8E	12	7	5	10	13	11	13	9	11	14	4	8	117
Izaña	FZK	28N	16W	9	4	8	16	12	11	1	13	5	8	1	4	92
Lauder	NIWA	45S	170E	3	1	3	4	4	3	3	8	7	7	9	3	55
Arrival Heights	NIWA	78S	167E	10	5	8	1	0	0	0	0	5	11	8	5	53

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Jungfraujoch	ULg-GIRPAS	47N	8E	10	8	8	12	7	14	17	12	14	9	7	2	120
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71
Lauder	NIWA	45S	170E	5	7	5	6	5	4	4	4	7	8	6	4	65
Arrival Heights	NIWA	78S	167E	7	7	4	3	0	0	0	0	5	4	2	2	34

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40
Jungfraujoch	ULg-GIRPAS	47N	8E	14	10	14	10	11	0	0						59
Lauder	NIWA	45S	170E	8	3	9	6	7	8	5						46
Arrival Heights	NIWA	78S	167E	2	2	3	0	0	0	0						7

IX.2.12 Monthly Data Distribution for HCl Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Bremen	IUP/IFE	53N	9E	2	2	3	5	6	6	7	3	9	4	1	1	49
Lauder	NIWA	45S	170E	7	14	4	7	10	8	3	10	7	10	7	4	91
Arrival Heights	NIWA	78S	167E	9	3	4	2	0	0	0	0	2	7	6	0	33

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Bremen	IUP/IFE	53N	9E	2	1	7	9	2	0	0	0	0	0	0	0	21
Lauder	NIWA	45S	170E	5	4	10	4	6	6	8	10	10	10	8	10	91
Arrival Heights	NIWA	78S	167E	4	2	7	2	0	0	0	0	7	8	1	6	37

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Lauder	NIWA	45S	170E	10	8	9	9	7	6	7	4	6	8	9	4	87
Arrival Heights	NIWA	78S	167E	6	4	2	1	0	0	0	0	5	0	0	5	23

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Lauder	NIWA	45S	170E	4	3	2	4	5	8	3	8	7	7	9	3	63
Arrival Heights	NIWA	78S	167E	12	5	9	0	0	0	0	0	6	10	8	8	58

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Lauder	NIWA	45S	170E	5	7	5	5	4	4	3	4	7	8	6	4	62
Arrival Heights	NIWA	78S	167E	6	7	4	3	0	0	0	0	5	5	3	6	39

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Lauder	NIWA	45S	170E	8	3	9	6	7	8	5						46
Arrival Heights	NIWA	78S	167E	2	0	0	0	0	0	0						2

IX.2.13 Monthly Data Distribution for HNO_3 Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	0	1	0	0	0	0	0	11
Kiruna	FZK/IMK	68N	20E	0	9	13	7	10	12	6	13	6	7	5	0	88
Bremen	IUP/IFE	53N	9E	2	2	3	3	6	5	6	3	9	3	0	1	43
Jungfraujoch	ULg-GIRPAS	47N	8E	11	10	1	8	5	10	17	4	6	6	8	8	94
Izaña	FZK	28N	16W	4	5	14	7	9	17	14	14	13	11	11	10	129
Lauder	NIWA	45S	170E	5	8	4	9	10	9	8	10	5	11	7	5	91
Arrival Heights	NIWA	78S	167E	9	3	3	0	0	0	0	0	0	7	6	0	28

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	1	0	7	5	3	2	3	0	0	0	21
Kiruna	FZK/IMK	68N	20E	4	9	16	11	7	0	1	11	9	11	3	0	82
Bremen	IUP/IFE	53N	9E	1	1	7	6	4	2	4	2	2	1	3	1	34
Jungfraujoch	ULg-GIRPAS	47N	8E	3	0	9	13	8	0	14	7	20	11	10	7	102
Izaña	FZK	28N	16W	10	14	5	12	12	10	16	20	10	8	3	10	130
Lauder	NIWA	45S	170E	4	5	7	4	7	10	10	11	9	8	6	7	88
Arrival Heights	NIWA	78S	167E	5	3	9	2	0	0	0	0	4	10	1	9	43

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	6	0	0	2	2	2	0	0	0	15
Kiruna	FZK/IMK	68N	20E	2	5	9	9	1	1	9	2	7	4	6	0	55
Bremen	IUP/IFE	53N	9E	1	4	0	1	0	0	2	0	0	0	1	0	9
Jungfraujoch	ULg-GIRPAS	47N	8E	12	14	0	3	8	15	12	3	15	9	4	8	103
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73
Lauder	NIWA	45S	170E	9	5	5	10	7	9	8	7	5	5	5	4	79
Arrival Heights	NIWA	78S	167E	6	4	5	1	0	0	0	0	3	0	0	8	27

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	7	5	6	6	2	3	0	0	0	32
Kiruna	FZK/IMK	68N	20E	0	10	8	1	1	2	1	4	6	4	1	0	38
Bremen	IUP/IFE	53N	9E	0	0	0	1	5	4	1	3	3	0	0	0	17
Jungfraujoch	ULg-GIRPAS	47N	8E	13	6	9	10	10	9	13	22	11	14	4	6	127
Izaña	FZK	28N	16W	9	4	9	16	12	12	1	14	5	8	1	3	94
Lauder	NIWA	45S	170E	3	2	3	5	6	11	4	9	10	6	6	2	67
Arrival Heights	NIWA	78S	167E	11	5	11	2	0	0	0	0	4	13	12	8	66

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	9	3	2	2	5	1	0	0	0	25
Kiruna	FZK/IMK	68N	20E	0	4	12	8	5	3	1	4	5	8	2	0	52
Bremen	IUP/IFE	53N	9E	1	1	5	10	2	6	5	0	0	0	0	0	30
Jungfraujoch	ULg-GIRPAS	47N	8E	8	7	7	12	6	14	16	12	6	3	6	1	98
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	4	70
Lauder	NIWA	45S	170E	6	4	3	6	6	3	4	4	5	6	3	4	54
Arrival Heights	NIWA	78S	167E	7	7	4	3	0	0	0	0	2	7	1	8	39

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	4	7	2	1	3					21
Kiruna	FZK/IMK	68N	20E	0	15	14	8	0	0	0						37
Jungfraujoch	ULg-GIRPAS	47N	8E	13	9	14	10	11	0	0						57
Lauder	NIWA	45S	170E	6	0	7	7	8	8	6						42
Arrival Heights	NIWA	78S	167E	2	5	0	0	0	0	0						7

IX.2.14 Monthly Data Distribution for HNO_3 Profile Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Jungfraujoch	ULg-GIRPAS	47N	8E	11	10	1	8	5	10	17	4	6	6	8	8	94

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Jungfraujoch	ULg-GIRPAS	47N	8E	3	0	9	13	8	0	14	7	20	11	10	7	102

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	2	5	9	9	1	1	9	2	7	4	6	0	55
Jungfraujoch	ULg-GIRPAS	47N	8E	12	14	0	3	8	15	12	3	15	9	4	8	103
Izaña	FZK	28N	16W	6	3	10	6	5	7	11	5	8	4	3	5	73

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	10	8	1	1	2	1	4	6	4	1	0	38
Jungfraujoch	ULg-GIRPAS	47N	8E	13	6	9	10	10	9	13	22	11	14	4	6	127
Izaña	FZK	28N	16W	9	4	9	16	12	12	1	14	5	8	1	3	94

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	4	12	8	5	3	1	4	5	8	2	0	52
Jungfraujoch	ULg-GIRPAS	47N	8E	8	7	7	12	6	14	16	12	6	3	6	1	98
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	4	70

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	14	8	0	0	0						37
Jungfraujoch	ULg-GIRPAS	47N	8E	13	9	14	10	11	0	0						57

IX.2.15 Monthly Data Distribution for N_2O Column Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	2	3	5	0	1	0	0	0	0	0	11
Kiruna	FZK/IMK	68N	20E	0	8	14	7	8	10	7	13	6	6	4	0	83
Bremen	IUP/IFE	53N	9E	2	2	3	5	6	6	7	3	9	5	1	1	50
Jungfraujoch	ULg-GIRPAS	47N	8E	9	9	1	7	6	10	15	4	6	6	7	6	86
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126
Lauder	NIWA	45S	170E	6	12	4	7	8	0	2	9	7	10	5	3	73
Arrival Heights	NIWA	78S	167E	4	1	1	1	0	0	0	0	1	2	2	0	12

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	1	0	7	6	4	3	4	0	0	0	25
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
Bremen	IUP/IFE	53N	9E	2	1	7	9	2	2	2	4	1	2	3	1	36
Jungfraujoch	ULg-GIRPAS	47N	8E	2	0	9	13	8	0	14	7	19	11	11	6	100
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126
Lauder	NIWA	45S	170E	5	4	7	3	2	2	2	6	9	9	9	9	67
Arrival Heights	NIWA	78S	167E	5	3	7	2	0	0	0	0	1	7	1	4	30

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	6	0	0	2	4	3	0	0	0	18
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	4	5	0	50
Bremen	IUP/IFE	53N	9E	1	4	2	7	6	2	2	0	1	2	1	1	29
Jungfraujoch	ULg-GIRPAS	47N	8E	12	13	0	3	7	15	12	2	14	8	4	8	98
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	3	5	72
Lauder	NIWA	45S	170E	11	8	7	9	1	2	3	3	6	7	7	2	66
Arrival Heights	NIWA	78S	167E	7	2	1	1	0	0	0	0	4	0	0	4	19

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	3	8	5	6	7	3	4	0	0	0	36
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	2	1	3	5	4	1	0	34
Bremen	IUP/IFE	53N	9E	0	0	1	2	8	4	3	5	5	0	0	0	28
Jungfraujoch	ULg-GIRPAS	47N	8E	12	6	10	10	11	10	13	9	9	14	4	8	116
Izaña	FZK	28N	16W	9	4	8	16	12	12	1	13	5	8	1	4	93
Lauder	NIWA	45S	170E	3	1	0	2	0	0	0	8	7	7	9	3	40
Arrival Heights	NIWA	78S	167E	12	5	8	0	0	0	0	0	1	5	5	8	44

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	9	4	2	4	5	3	0	0	0	31
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Bremen	IUP/IFE	53N	9E	1	2	6	9	2	7	5	0	0	0	0	0	32
Jungfraujoch	ULg-GIRPAS	47N	8E	8	8	7	12	7	14	17	12	13	8	5	2	113
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71
Lauder	NIWA	45S	170E	5	7	5	6	5	4	4	4	7	8	6	4	65
Arrival Heights	NIWA	78S	167E	7	7	4	2	0	0	0	0	0	2	3	3	28

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Ny-Ålesund	IUP/IFE	79N	12E	0	0	4	4	7	2	1	3					21
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40
Bremen	IUP/IFE	53N	9E	3	4	6	9	5	1	0	1					29
Jungfraujoch	ULg-GIRPAS	47N	8E	13	10	13	10	11	0	0						57
Lauder	NIWA	45S	170E	8	3	9	6	7	7	5						45
Arrival Heights	NIWA	78S	167E	2	3	3	0	0	0	0						8

IX.2.16 Monthly Data Distribution for N_2O Profile Data

2006

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	0	0	0	0	0	0	0	6	6	4	0	16
Jungfraujoch	ULg-GIRPAS	47N	8E	9	9	1	7	6	10	15	4	6	6	7	6	86
Izaña	FZK	28N	16W	4	5	14	7	8	17	14	13	13	10	11	10	126
Lauder	NIWA	45S	170E	6	12	4	7	8	0	2	9	7	10	5	3	73
Arrival Heights	NIWA	78S	167E	4	1	1	1	0	0	0	0	1	2	2	0	12

2007

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	3	7	15	11	9	4	6	9	8	9	3	0	84
Jungfraujoch	ULg-GIRPAS	47N	8E	2	0	9	13	8	0	14	7	19	11	11	6	100
Izaña	FZK	28N	16W	10	13	5	12	12	10	16	18	10	8	3	9	126
Lauder	NIWA	45S	170E	5	4	7	3	2	2	2	6	9	9	9	9	67
Arrival Heights	NIWA	78S	167E	5	3	7	2	0	0	0	0	1	7	1	4	30

2008

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	1	4	9	7	1	1	9	2	7	4	5	0	50
Jungfraujoch	ULg-GIRPAS	47N	8E	12	13	0	3	7	15	12	2	14	8	4	8	98
Izaña	FZK	28N	16W	6	3	9	6	5	7	11	5	8	4	3	5	72
Lauder	NIWA	45S	170E	11	8	7	9	1	2	3	3	6	7	7	2	66
Arrival Heights	NIWA	78S	167E	7	2	1	1	0	0	0	0	4	0	0	4	19

2009

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	10	7	1	0	2	1	3	5	4	1	0	34
Jungfraujoch	ULg-GIRPAS	47N	8E	12	6	10	10	11	10	13	9	9	14	4	8	116
Izaña	FZK	28N	16W	9	4	8	16	12	12	1	13	5	8	1	4	93
Lauder	NIWA	45S	170E	3	1	0	2	0	0	0	8	7	7	9	3	40
Arrival Heights	NIWA	78S	167E	12	5	8	0	0	0	0	0	1	5	5	8	44

2010

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	3	12	8	6	5	2	5	8	8	4	0	61
Jungfraujoch	ULg-GIRPAS	47N	8E	8	8	7	12	7	14	17	12	13	8	5	2	113
Izaña	FZK	28N	16W	0	0	4	4	7	15	11	11	4	6	4	5	71
Lauder	NIWA	45S	170E	5	7	5	6	5	4	4	4	7	8	6	4	65
Arrival Heights	NIWA	78S	167E	7	7	4	2	0	0	0	0	0	2	3	3	28

2011

FTIR	Inst.	Lat	Long	J	F	M	A	M	J	J	A	S	O	N	D	#
Kiruna	FZK/IMK	68N	20E	0	15	16	9	0	0	0						40
Jungfraujoch	ULg-GIRPAS	47N	8E	13	10	13	10	11	0	0						57
Lauder	NIWA	45S	170E	8	3	9	6	7	7	5						45
Arrival Heights	NIWA	78S	167E	2	3	3	0	0	0	0						8

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X ANNEXE 4: GUIDELINES FOR VALIDATION METADATA

To ensure traceability of the validation process – a QA4EO requirement – we have proposed and used the following guidelines for validation metadata, that is, brief but unambiguous documentation of the validation process leading to a comparison graph or data file. They are illustrated with an example text that could accompany any validation graph (attached to the graph as a readme.file.text) and any comparison data file (e.g. included in the file as a header or simply attached externally to the file). Now that GEOMS is available and operational, it might be interesting to extend it with a format for validation results.

X.1 General information

The header should provide a short, high level description of the content of the related file or graph.

```
# ENVISAT SCIAMACHY VALIDATION STATISTICS
# VALIDATED DATA: LIMB OZONE VERTICAL PROFILE SGP5.01
# CORRELATIVE DATA: MCH OZONESONDE AT PAYERNE, SWITZERLAND
# VALIDATION ANALYSIS BY IASB-BIRA, BELGIUM
# LAST UPDATE: 15-Sept-2011 15:20:27
#
# This file contains ground-based validation results of Envisat SCIAMACHY limb ozone
# profile data retrieved with version 5.01 of the off-line processor SGP. The
# validation process is documented hereafter in the header. Monthly statistics of the
# percent relative difference between satellite and correlative observations are reported
# as a function of the vertical coordinate.
```

or

```
# This file accompanies graphs providing visualisation of ground-based validation
# results of Envisat SCIAMACHY limb ozone profile data retrieved with version 5.01
#  of the off-line processor SGP. The validation process is documented hereafter.
# The associated graph presents monthly statistics of the relative difference between satellite
# and correlative observations, plotted as a function of altitude and time.
```

X.2 Traceability of satellite data

The metadata on satellite data should be a short description of the satellite data used to obtain the validation results. Without proper information on the producer/provider of the satellite data and the data processing version, validation results are not traceable and can not be trusted.

```
# SATELLITE OBSERVATIONS
# Data processing/archiving: D-PAC
# Data processor/version: SGP 5.01 Off-Line
# Data file name (optional; not relevant when a large number of data files are analysed)
# Retrieved parameter: ozone number density (molec.cm-3)
# Vertical coordinate: altitude (km)
```

X.3 Traceability of correlative data

The metadata on correlative data should be a short, unambiguous description of the correlative measurements used to obtain the validation results. Accurate information on the data calibration/processing version and the data archiving centre is particularly crucial.

```
# CORRELATIVE OBSERVATIONS
# Station: Payerne / Switzerland / 46.82N / 6.95E / 491m a.s.l.
# Instrument: ECC ozonesonde
# Resp. institute: MCH
# Data archiving: Envisat Cal/Val
# Data processor/version: WMO/GAW Standard Operation Procedure
# Measured parameter: ozone partial pressure (mPa)
# Vertical coordinate: pressure (hPa)/altitude (km)
```

X.4 Traceability of correlative analysis process

The metadata on correlative analysis should be a short, unambiguous description of the comparison manipulations undertaken to obtain the validation results. From this information one should be able to check if the validation process complies with agreed standards and best practices. The step-by-step description of the data manipulations should also allow proper interpretation of the comparison results and further investigation of the satellite and correlative data quality.

CORRELATIVE ANALYSIS
Cal/Val system (if any): Multi-TASTE
Data filtering: none
(note: could be a filter on the error given in the data file, on the GOMOS star magnitude etc.)
Conversion of units: none (e.g., from VMR to number density)
Time span: 2002-2009
Temporal co-location: max. 12h difference
(or e.g. use of a photochemical model to account for diurnal cycle effects)
Vertical co-location: see vertical smoothing
(another possibility could be e.g. a cross-correlation of the profiles to reduce altitude pointing uncertainties)
Horizontal co-location: DOVP, max. 300km distance
Temporal smoothing: none
(e.g., correlative data averaged over a time window around the satellite overpass)
Vertical smoothing: ozonesonde data box-averaged at satellite resolution
(other possibilities: e.g., smoothed using the averaging kernels and a priori of the satellite retrieval)
Horizontal smoothing: none
Relative difference calculated as (SATELLITE - GROUND)/GROUND
Statistics: monthly mean/standard deviation and median/inter-percentile of the relative difference

X.5 Format description of the validation results

The validation results contained in the related file or visualised in the related graph should be clearly described.

CONTENT OF THIS DATA FILE or INFORMATION DISPLAYED ON THIS GRAPH
Altitude (km, in column)
Month (in row)
Amount of comparison events by month and by altitude
Relative difference: median (%)
Relative difference: inter-percentile interval at 68% level (%)

X.6 Credit (and responsibilities)

The metadata file should identify by whom the validation were produced and reported. Information on who to contact might be useful.

CREDIT
Analysis carried out at the Belgian Institute for Space Aeronomy (IASB-BIRA)
Validation scientist(s): D. Hubert
Data processing scientist(s): J. Granville
Contact: xxx@aeronomie.be

XI ANNEXE 5: ACRONYMS AND ABBREVIATIONS

BIRA-IASB	Belgian Institute for Space Aeronomy
CCI	Climate Change Initiative
CEOS	Committee on Earth Observation Satellites
CINDI	Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring Instruments
CNRS	Centre National de la Recherche Scientifique
CSA	Canadian Space Agency
DOAS	Differential Optical Absorption Spectroscopy
DSCD	differential slant column density
EC	European Commission
ECV	Essential Climate Variable
Envisat	ESA's Environmental Satellite
ERS-2	ESA's Remote Sensing Satellite
EVDC	Envisat Validation Data Centre
FMI-ARC	Finnish Meteorological Institute - Arctic Research Centre
FP	Framework Programme
FTIR	Fourier Transform Infrared spectrometer
GAS	GMES Atmospheric Service
GAW	WMO's Global Atmosphere Watch
GCOS	Global Climate Observing System
GECA	Generic Environment for Cal/Val Analysis
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GMES	Global Monitoring of Environment and Security
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOSAT	Greenhouse Gases Observing Satellite
GSICS	Global Space-based Inter-Calibration System
HRTP	High Resolution Temperature Profile (GOMOS)
IFE	Institute of Environmental Physics
IMK/FZK	Institute for Meteorology and Climate Research/Forschungszentrum Karlsruhe
INSPIRE	EC Directive "Infrastructure for Spatial Information in the European Community"
INTA	Instituto Nacional de Técnica Aeroespacial
IP	Integrated Project
IPF	Instrument Processing Facility
IR	Infra Red (spectrometry) / Implementing Rule (INSPIRE)
JAXA	Japan Aerospace Exploration Agency
JRC	EC Joint Research Centre
LATMOS	Laboratoire Atmosphères, Milieux, Observations Spatiales
MACC	Monitoring Atmospheric Composition and Climate (EC FP7 IP)
MIPAS	Fourier transform spectrometer for the detection of limb emission spectra in the middle and upper atmosphere
NDACC	Network for the Detection of Atmospheric Composition Change
NDSC	Network for the Detection of Stratospheric Change
NIES	National Institute for Environmental Studies
NIR	Near InfraRed
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NORS	Network Of Remote Sensing
NR	Nominal Resolution (MIPAS)
PASODOBLE	Promote Air quality Services integrating Observations – Development Of Basic Localised Information for Europe
PROMOTE	PROtocol MOniToring for the GMES Service Element: Atmosphere
PTU	pressure/temperature/humidity sonde
QA	Quality Assurance

QA4EO	Quality Assurance framework for Earth Observation
QWG	Quality Working Group
RR	Reduced Resolution (MIPAS)
SCD	Slant Column Density
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY
SHADOZ	Southern Hemisphere Additional Ozonesondes
TANSO	Thermal ANd short wave infra-red Sensor for Observing greenhouse gases
TGSVA	The Great SCIAMACHY Validation Assessment
ULg	Université de Liège
WaVaCS	Atmospheric Water Vapour in the Climate System (COST Action ES0604)
WGCV	CEOS Working Group on Calibration and Validation
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Center

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