OMI Validation Requirements Document

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List of Validation Requirements

General requirements

VR-1 Multiple independent measurement techniques shall be used, at a large number of representative locations and under a number of atmospheric and geometric conditions.

VR-2 New instrumentation shall be considered as a means for intercomparison rather than for validation.

VR-3 Validation shall continue throughout the OMI lifetime.

VR-4 Validation workshops shall be held regularly throughout the OMI lifetime.

VR-5 Experience gained during the validation of GOME, SCIAMACHY, UARS, and TOMS instruments, shall be exploited.

VR-6 Validation is envisaged to consist of three phases, namely the commissioning phase, the core phase, and the long-term validation phase.

VR-7 Correlative measurements should be made under the circumstances in which OMI measures.

VR-8 Correlative measurements should preferably be coincident with an OMI overpass.

VR-9 For some level 2 products (especially aerosols, clouds, UV products) large variations are expected within the OMI pixels. The effect of this inhomogeneity on the comparison between correlative and OMI measurements, which have different spatial resolutions, shall be investigated.

VR-10 Data measured within existing networks of instruments shall be exploited because these data are well-validated and often very stable over time.

VR-11 Additional correlative measurements shall be performed in areas of critical importance for atmospheric studies performed with OMI data, such as:

- Mid-latitude continental industrial areas (air pollution, tropospheric ozone, NO_2 and aerosols)
- Tropical continental areas (studies of NO_2 and ozone from biomass burning and studies of aerosols)
- High latitude regions (vortex) (polar stratospheric ozone loss, ozone loss-event warning)
- Tropical marine regions (tropical stratosphere, loss of ozone in the tropical remote troposphere).

If routine measurements are not available, this requirement should be met by campaign efforts [McPeters et al., 2002]

VR-12 Since, especially for ozone, the stability of the OMI data products needs to be assessed, regular repetition of validation efforts with the same instrumentation is needed, starting in the commissioning phase. The AVE mission series, planned by NASA, addresses this topic.

VR-13 OMI products should be validated after every significant change. If possible, this should be done with existing correlative data.

VR-14 Radiance validation should be applied to EP TOMS, SBUV/2, GOME, SCIAMACHY and then to OMI, thus insuring continuity of long term ozone trends measured among these instruments.

VR-15 Comparison of OMI radiances with those measured by other satellite instruments operating in the OMI wavelength range (e.g., GOME and SCIAMACHY) may not provide independent validation, but will allow for many cross comparison opportunities and likely reveal systematic biases between measurements.

VR-16 The data sources for validation are ground-based, balloon, airborne and satellite measurements.

VR-17 Measurements from satellite instruments are useful for OMI validation, provided that they have been independently validated and provide data that are coincident with those measured by OMI.

VR-18 Tools such as coincidence predictors are needed to facilitate accurate timing of correlative measurements.

VR-19 It is important to create, or to have access to, data-assimilation facilities for validation and interpretation.

VR-20 A software tool shall be available to predict which part of the swath is over a certain location at a certain time**.**

VR-21 A database containing correlative data, or links to these data, acquired during the commissioning and core phases of Aura, including campaigns within these phases, is necessary for efficient validation and shall be created by NASA.

VR-22 This database shall be easily accessible, through registered access.

VR-23 For contingency and for coverage of annual variations, the database must be capable to hold data collected during the commissioning and core phase.

VR-24 A common format for correlative data, or a tool to convert data into the common format, is required.

VR-25 Software tools shall be developed that have the capability to read and visualize the products in the database as well as the OMI level 1 and level 2 data.

VR-26 The provision of auxiliary data (atmospheric parameters etc.) not measured by OMI but needed for validation studies is required.

VR-27 The solar spectra measured by OMI should be intercompared with spectra measured by other satellite instruments and with published spectra.

VR-28 When level 2 data of multiple satellites are spliced for trend detection, each of the satellite instruments should be well-validated, preferably against the same ground based instruments.

VR-29 If satellite observations used for trend detection overlap in time, they shall be intercompared. Absolute values as well as trends derived from each of the satellite observations records shall be intercompared.

VR-30 By regularly validating the OMI level 2 data products against measurements by instruments that use different techniques (and different types of auxiliary data) spurious trends, due to trends in auxiliary data, can be traced.

VR-31 Spatial and spectral zoom, VFD, and NRT products require separate validation.

Specific commissioning validation phase requirements

VR-32 The first validation phase is the commissioning phase. It starts after instrument functional tests have been completed, and lasts about six months.

VR-33 It is essential to validate the irradiance and radiance products of OMI at an early stage, since all higher level products depend on the accuracy of these products.

VR-34 Selected level 2 OMI products will undergo preliminary validation during the commissioning phase.

VR-35 Per OMI product, only a limited number of satellite instruments (with global coverage) and ground based instruments shall be used as correlative instruments during the commissioning phase.

VR-36 At least three months of the commissioning phase shall be used to perform OMI measurements directly useful for validation of the operational products.

VR-37 The major part of the OMI measurements during the commissioning phase validation shall be performed in the global mode.

VR-38 Special attention shall be paid to good communication between the people who are performing validation, have developed algorithms, and are concerned with OMI in-flight calibration and functional testing, respectively. Important findings of these groups should be communicated as quickly as possible. Regular meetings, approximately monthly, are advisable

VR-39 All data retrieved from OMI measurements, including the functional test data, should be easily and quickly available for the participants in the commissioning phase validation, and must be organized well before launch.

Specific core validation phase requirements

VR-40 The second validation phase is the core phase, which overlaps with the commissioning phase and lasts until three years after launch.

VR-41 In the core validation phase, all OMI data products shall be validated thoroughly.

VR-42 An AO (Announcement of Opportunity) shall be organized in order to optimize European contributions to OMI validation.

VR-43 Data from existing ground-based and satelliteborne instruments as well as from dedicated campaigns shall be needed.

VR-44 Campaigns shall be incorporated within the EOS-Aura framework whenever possible.

VR-45 Participation in scientific validation projects, e.g., the NASA-NRA for Aura-validation, shall be encouraged.

VR-46 Existing campaigns, outside the scope of EOS-Aura validation, shall also be exploited.

VR-47 Campaigns are an essential part of the core phase. They shall provide data at locations where representative existing measurements are sparse.

VR-48 Campaigns dedicated to OMI validation should not be planned to start earlier than 1 year after launch.

VR-49 During the core validation phase, at least one year of measurements is needed to cover the different seasons**.**

VR-50 If data are reprocessed, they shall be validated again, using the already available correlative data.

VR-51 For core phase validation, correlative instruments must have an accuracy that is comparable to or better than the OMI product accuracy.

Specific long-term validation phase requirements

VR-52 The long-term validation phase starts after the core phase and lasts during the complete lifetime of the instrument.

VR-53 All available OMI data, including those measured in the first two years of operations, are subject to the long-term validation analyses.

VR-54 The long-term validation phase goals are detection of long-term changes in the accuracies of the products, e.g., due to instrument degradation, the validation of newly developed or advanced OMI data products, and the assessment of the suitability of OMI measurements for trend detection.

VR-55 The long-term validation goals necessitate a regular, optimized repetition of the essential elements of the core validation phase.

VR-56 The use of data from ground based networks is critical for long-term validation.

Specific validation rehearsal requirements

VR-57 A validation rehearsal is required to test validation procedures, and to get all participants in the OMI validation acquainted with working with OMI and correlative data sets, and the database.

VR-58 A limited set of synthetic OMI data should be available, to allow testing of validation tools.

VR-59 The rehearsal shall take place approximately 3 months before launch.

VR-60 All groups that intend to participate in the OMI validation shall submit at least one file of (synthetic or measured) data to the NASA validation database during the rehearsal stage, in the same format that is used during the later validation campaigns.

VR-61 Each PI planning to download in-situ or assimilation model data shall access and search the NASA database at least once and shall retrieve at least one data set delivered to the database by another investigator.

VR-62 Each validation PI shall install, run and test the software tool that is capable of reading all Aura products

VR-63 Each validation PI shall install, run and test the coincidence prediction software.

VR-64 Reports about the validation rehearsal shall be delivered by the validation PI's.

1 Introduction

1.1 OMI Validation

The EOS validation program defines validation as the process of assessing by independent means the uncertainties of the data products derived from OMI measurements, thus establishing validity and accuracy of the OMI data products. It is essential to validate all products of OMI, to assure their quality for scientific use. This includes validation of Level 1B products (radiance, solar irradiance).

Quality assessment, which is defined as checking the validity of the output products by internal consistency checks, is described in a separate document, and will not be discussed here in detail. Quality assessment can be an aid to the objective of validation.

This document describes the validation requirements for the Ozone Monitoring Instrument (OMI) aboard EOS-Aura. The baseline for the OMI validation is also described in the EOS Aura Science Data Validation Plan [Froidevaux and Douglass., 2001]. That document also contains preliminary descriptions of the campaigns envisaged within the EOS-Aura framework, funded by NASA (directly or through NRA's), on which the OMI validation partly depends. Data needs for OMI that are not (completely) met in the Aura Validation Document have been emphasized in the White Paper for OMI Validation [McPeters et al., 2002]. They are also discussed in the current document.

1.2 Document structure

This introduction is followed by Chapter 2, in which the OMI data products and their required accuracies (from the Science Requirements Document [Levelt et al., 2000] and Algorithm Theoretical Basis Documents (ATBD) Volumes II, III, and IV [Bhartia,2002; Stammes, 2002; Chance, 2002]) are presented. The validation strategy for OMI is outlined in Chapter 3. In this chapter, also the means for validation, i.e., correlative data, tools for validation, and databases, are described. Part of the strategy is to formulate three separate validation phases, namely the Commissioning Phase (described in Chapter 4), the Core Phase (described in Chapter 5), and the Long-Term Phase (described in Chapter 6). The Validation Rehearsal, which is to be carried out before launch to test procedures, tools and the data flow before the actual validation starts, thus before launch, is described separately, in Chapter 7. A number of annexes lists details about correlative instruments. Annexes A, B, C, describe the locations of groundbased measurement sites, the groundbased instruments themselves, and European aircraft potentially available for validation, respectively. These annexes were taken from the SCIAMACHY Detailed Validation Plan [2002]. Annex 4 provides a list of satellite instrumentation for correlative measurements (also from the SCIAMACHY Detailed Validation Plan, with small changes. Finally, Annex E is a list of acronyms used.

The detailed and specific Validation Requirements, which follow from this document, are listed at the beginning of this document.

2 OMI on EOS-Aura

2.1 The Aura mission

The Aura spacecraft will describe a sun-synchronous polar orbit, crossing the equator at 13:38 local time. The mission has a design lifetime of five years in orbit. There are four instruments on Aura, namely the Microwave Limb Sounder (MLS) and the High Resolution Dynamics Limb Sounder (HIRDLS), both limb sounding instruments, the Ozone Monitoring Instrument (OMI), a nadir sounder, and the Tropospheric Emission Spectrometer (TES), which has both limb and nadir sounding modes and can also point to targets of opportunity such as pollution sources and volcanic eruptions.

When the high vertical and horizontal resolution measurements from Aura are combined they may provide unprecedented insights into the chemical and dynamical processes in the stratosphere and upper troposphere. The

Aura instruments balance new capabilities with proven technological heritage, covering wavelengths in the ultraviolet, visible, throughout the infrared, and sub-millimeter and microwave ranges.

The mission is designed to collect data to answer the key questions of ozone depletion and recovery, the global change in air quality, and the changing climate. Key constituents (all important radical, reservoir, and source gases including first time ever global surveys of OH) in the ozone destroying catalytic NOx, ClOx and HOx cycles will be measured using HIRDLS, MLS and OMI. Monitoring of global ozone trends, with TOMS precision, will be continued using OMI. Furthermore, it appears to be feasible to retrieve tropospheric columns of O_3 and NO_2.

One of the objectives of the OMI mission requires a continuation of the TOMS data record. It is therefore necessary that ozone columns are also retrieved using the TOMS algorithm [McPeters et al, 1996].

Air quality assessments on urban-to-continental scales will have unprecedented coverage because of the mapping capabilities of OMI and the target gases measured by TES. These two instruments will measure most of the precursors to tropospheric ozone.

2.2 OMI

OMI, the Ozone Monitoring Instrument, is one of the four instruments on EOS-Aura. Details about the instrument and its scientific objectives can be found in the Science Requirements Document for OMI-EOS [Levelt et al., 2000]. Here, only the four science questions will be given:

- Is the ozone layer recovering as expected?
- What are the sources of aerosols and trace gases that affect global air quality and how are they transported?
- What are the roles of tropospheric ozone and aerosols in climate change?
- What are the causes of surface UV-B change?

An overview of the level 1 and 2 products that will be provided by OMI, along with their required accuracies, is provided below. The requirements have been derived from the OMI mission objectives as described in Chapter 2 of the Science Requirements Document.

The products which shall be available directly after launch are:

- Earth radiance and solar irradiance
- Ozone column density (using DOAS and TOMS algorithms)
- NO_2 column density processed with simple airmass factors (representative for unpolluted regions)

OMI products which will be available later are:

- Near Real Time (NRT) and Very Fast Delivery (VFD) ozone column densities
- Aerosol optical thickness and aerosol single scattering albedo (UV-VIS)
- Cloud pressure and cloud fraction
- Surface UV-B flux and VFD Surface UV-B flux
- Ozone profile
- NO_2 column density processed with airmass factors representative for all regions
- Tropospheric ozone (partial) column
- SO_2 column
- BrO column
- HCHO column
- OClO slant column
- VFD ozone profile
- Surface reflectance

- Improved aerosol optical thickness and aerosol single scattering albedo (UV-VIS)

An overall description of the data product availability and timeline will be given in another document (*OMI products, their production sites and timeline*, Levelt et al., in progress)

2.3 OMI level 2 data products

In this section, an overview of the accuracies of the OMI level 2 data products is given, based on the information presented elsewhere [OMI Data Product Accuracies*]*. More information about the products and a rationale for the accuracies given here is presented in the Science Requirements Document for OMI-EOS [Levelt et al., 2000] and the ATBD [Bhartia,2002; Stammes, 2002; Chance, 2002]. Ground pixel size and absolute and relative accuracies are listed in Table 1.

Table 1 Overview of the scientific requirements for the OMI data products.

Data product	**Accuracy of observations Absolute: Relative**	**Ground pixel size at nadir (km ´ km)**	**Remarks**
Irradiance [2)]	2 %	N/A	
Radiance	3% : 1 %	13 x 24	
Ozone column	3% : 1.5%	13 x 24	
Tropospheric ozone column	25% : 10%	52 x 48	
Ozone profile	10% : 10%	13 x 48	Vertical range 0-50 km
Aerosol optical thickness	30% (0.1) : 10% (0.05) [1)]	13 x 24	Requirement at 400 nm
Aerosol single scattering albedo	0.1 : 0.05	13 x 24	
NO_2 column	$2.10^{14}cm^{-2} : 2.10^{14}cm^{-2}$	26 x 48	Background
	30% : 20%		Polluted
Cloud pressure	100 hPa : 30 hPa	13 x 24	Two methods
Cloud fraction	≤ 0.1	13 x 24	Two methods
Surface UV-B flux	10% : 10%	13 x 24	
SO_2 column	$3.10^{16}cm^{-2}$ (50%) :$2.10^{16}cm^{-2}$ (20%)[1)]	13 x 24	non- volcanic
	30% : 20%		volcanic
BrO column	25% / 25%	13 x 24	
OClO slant column	15% / 10%	26 x 48	Polar vortex
HCHO column	35% / 25%	13 x 24	Pollution
Surface irradiance	5% (0.01)	13 x 24	
Near Real Time Products			
Ozone column	5 % (10 DU) [1)]	13 x 24	
Intermediate Level 1B product		13 x 24	Not validated, not an official product.
Very Fast Delivery Products			
Ozone column	≤ 5 % (10 DU) [1)]	13 x 24	Over Northern Europe
Surface UV-B flux	10 % : 10 %	13 x 24	Over Northern Europe
Surface irradiance	≤ 10-20 % (wavelength dependent)	13 × 24	Over Northern Europe Accuracy is wavelength dependent

Accuracies: Absolute accuracy is given at the horizontal and vertial resolution indicated in the third column and represents the root sum of the square of all errors, including forward model, inverse model, and instrument errors. Relative accuracy represents the repeatability of the retrieval.

Each product has a global coverage of one day, except for the Very Fast Delivery (VFD) products. Product delivery requirements are "within 3 hours after observation" for Near Real Time (NRT) products, and "within 30 minutes after data receipt" for the VFD products, for other products less than two days after observation. The accuracy is defined in the introduction of section 3.2.

"Column" denotes vertical column density.

1 DU (Dobson Unit) º 2.687 10^{16} molecules cm^{-2}.

Numbers from OMI Science Review presentation by P. Levelt, April 2003 unless otherwise noted.

Note 1) When multiple values are given, the largest of given percentage and absolute number applies.

Note 2) The requirement for solar irradiance follows from Chapter 4 of the Science Requirements Document for OMI-EOS. Irradiance is not a separate data product.

2.3.1 Ozone column density

OMI will continue the ozone measurements by the various TOMS instruments. Besides high accuracy of the measurements, good stability is required. Validation of the ozone column density will assess both of these aspects. The relatively high spatial resolution of OMI will yield useful data on spatial variation in ozone fields.

Ozone column densities will be derived using the TOMS-algorithm and the DOAS-fitting method. Results of these two methods, applied on the same OMI data, should be compared carefully to give an indication of possible systematic effects. Very fast delivery (VFD) and Near-real-time (NRT) ozone products will become available at a later stage, and are likely of lesser accuracy than the DOAS and TOMS-method ozone columns. All ozone products based on OMI data should be intercompared.

2.3.2 Tropospheric ozone column density

Tropospheric ozone columns will be derived by subtraction of the integrated HIRDLS stratospheric profiles from the OMI column densities. A possible improvement after launch is to use data assimilation to combine HIRDLS temperature and O3 profiles with OMI O3 profiles.

The relatively high spatial resolution of OMI will yield useful data on spatial variation in tropospheric ozone fields, especially under polluted conditions.

2.3.3 Ozone profile

Inherent to the ozone profile retrieval method, accuracy and resolution are interdependent. With the accuracies listed in the table, resolutions of about ~10 km troposphere, ~5 km stratosphere are expected. Besides the accuracy, also the stability of the ozone profile measurements is important, for enabling trend studies (in which OMI data will be joined with other satellite data). Although the ozone profiles have a moderate vertical resolution, the relatively high spatial resolution contributes to making the ozone profiles delivered by OMI unique.

In the validation of the ozone profiles, consideration should be given to the limited vertical resolution of the OMI profiles with respect to the higher-resolution correlative data. Using the OMI ozone profile resolution and averaging kernels, correlative data should first be brought to a vertical resolution (and correlation) comparable to that of the OMI profiles. Assimilation of the ozone profiles may be used as a tool to fully incorporate the OMI vertical resolutions.

2.3.4 NO_2 column densities

NO_2 plays an important role in ozone chemistry. High amounts usually indicate tropospheric pollution, but lightning produced NO_2 may also play a role. NO_2 column densities under background conditions are typically 10^{15} cm^{-2}, while in polluted areas GOME has reported number densities up to 10^{16} cm^{-2}.

To be able to detect NO_2 under background conditions with the accuracy described in Table 1, averaging to 26 x 48 km pixels is required. For further details, see Boersma et al. [2002].

A tropospheric NO_2 product will likely also be produced.

2.3.5 SO_2 column densities

SO_2 will be observed under volcanic conditions, and in strongly polluted regions (industrial outflow plumes). Volcanic eruptions will result in column densities of 2 DU up to 700 DU [Bluth et al., 1997]. SO_2 originating from industrial pollution can be up to a few DU [Eisinger and Burrows, 1999]. In order to discern fluctuations of industrial SO_2, the accuracy for the vertical column must be better than 0.4 DU and the ground pixel size must be smaller than 40 x 40 km. The tropospheric background column density of SO_2 is expected to be between 0.2 and 0.6 DU, close to the detection limit of OMI.

2.3.6 BrO, HCHO, and OClO column densities

Vertical column densities of BrO are typically between 3 and 6×10^{13} cm^{-2} with little variation, expect for tropospheric blooming events in polar springtime, where column densities larger than 10^{14} cm^{-2} are observed [Chance, 1998].

HCHO has a vertical column density between 10^{15} and 3×10^{16} cm^{-2} under polluted circumstances [Chance et al., 2000; Thomas et al., 1998; Perner et al., 1997]. The accuracy has to be 10^{15} cm^{-2} under these conditions (Levelt et al., 2000). A major issue in HCHO retrievals, and hence also in their validation, is the application of an appropriate airmass factor, as the airmass factor depends strongly on the tropospheric distribution of HCHO, which is very ill-determined.

OClO slant column densities will be retrieved. This is likely only possible under ozone hole conditions. Under these conditions the solar zenith angle is usually very high, typically higher than 80°. The OClO slant column densities are between 2×10^{13} and 4×10^{14} cm^{-2} for solar zenith angles higher than 80° [Wagner et al, 1999].

2.3.7 Aerosol optical thickness and aerosol single scattering albedo

The aerosol optical thickness is the extinction by aerosols integrated over a vertical path from the surface to the top-of-the-atmosphere. It is a measure for the total aerosol load. The aerosol single scattering albedo is the relative contribution of scattering to the aerosol optical thickness and is used as a measure for the absorption by aerosols.

Retrieval of aerosol properties is only possible for cloud-free areas, validation should therefore take place in cloud-free pixels only. The pixel size for OMI aerosol retrieval is 13 x 24 km. Due to strong spatial variations, correlative measurements should be taken at various locations within one pixel. Because of the difficulties of aerosol retrieval over land, aerosol information over the continents might be less accurate, although still valuable.

2.3.8 Surface ultraviolet irradiance

Surface ultraviolet (UV) radiance from OMI is calculated using ozone column measurements from OMI, surface albedo, and geometry to estimate the clear-sky surface UV irradiance, consecutively this is converted into actual surface UV irradiance using a cloud/aerosol transmittance factor derived from OMI data. Surface ultraviolet radiances will be produced for four ultraviolet wavelengths (305, 310, 324, 380 nm). An erythemally weighted irradiance will also likely be produced.

To study geographical distribution of the OMI UV irradiance, validation should combine long-term comparisons at many locations around the globe with special campaigns, where various ground UV instruments are distributed within the OMI footprint. The goal of such measurements is to address the effect of subpixel variations due to clouds and local conditions.

2.3.9 Clouds

The OMI cloud information consists of two main parameters: cloud fraction and cloud pressure. Cloud information shall be retrieved on at least the same scale as the smallest ground pixel of any of the OMI data products (13 x 24 km).

Two cloud algorithms will be implemented:

- The Raman method, which has been previously applied
- The O_2-O_2 absorption method

Both methods yield cloud fraction and cloud pressure. For more details, see Volume IV of the OMI ATBD [Stammes, 2002].

Cloud information is crucial for the retrieval of other level 2 products. Level 2 product validation shall take place under clouded as well as cloud-free conditions. Correlation of cloud and other level 2 products can provide information on the accuracy of the cloud products.

It should be noted that cloud pressure and cloud fraction are dependent on assumptions made in the cloud retrieval algorithms. The product names should therefore be interpreted as “effective” cloud fraction and pressure.

3 Data Validation Objective and Strategy

3.1 Introduction

Product validation is preceded by quality assessment (QA), which takes place in two steps: in the first step, SIPS staff performs routine checks on the data following guidelines provided by algorithm scientists, in the second step, algorithm and calibration scientists perform internal checks and investigate trending. QA procedures and responsibilities will be described elsewhere (OMI Quality Assessment Document, in progress).

The next step is validation, which encompasses comparisons with data from correlative data sources, either from routine or campaign measurements. Validation is an iterative process: validation results are used to trace systematic errors in the instrument and its operational algorithms and thus (through feedback to the algorithm developers and calibration scientists) to improve the level 1 and level 2 products. By updating the operational software, these products will then be validated again, until the specified accuracy requirements are met.

3.2 Validation strategy

The validation strategy is to rely on correlative measurements based on validated techniques. Multiple independent measurement techniques shall be used, at a large number of representative locations and under a number of atmospheric and geometric conditions. (**VR-1**). A large part of the validation will be based on existing measurements, and it is important to emphasize that the OMI validation depends heavily on, e.g., regular sounding stations (pressure, temperature, wind speed and ozone, including at tropical locations), and permanent observatories (in situ sampling, remote sensing instruments, i.e. lidar and spectrometers in the microwave, infrared, visible and UV).

New instrumentation shall be considered as a means for intercomparison rather than for validation (**VR-2**). This implies that simultaneous observations performed from EOS-Aura can initially not be used for validation, but only for intercomparison purposes. These intercomparisons are very useful, because of the large data sets and their near-collocation.

Validation shall continue throughout the OMI lifetime (**VR-3**).

The validation objective will be achieved by:

- The collection of suitable validation data, e.g., measurements from ground-based, airborne, balloon borne and satellite platforms.
- The development of a validation database and a data assimilation facility for validation. The database should have common formats for all types of data. Database development and maintenance is considered to be a NASA responsibility for EOS-Aura.
- The development of appropriate tools: coincidence predictor, software for data assimilation, cataloguing, database tools.
- The provision of auxiliary data (atmospheric parameters etc.) not measured by OMI but needed for validation studies.
- The analysis of OMI and correlative data sets.
- The assessment of the uncertainties of OMI data products.
- The iterative validation and reprocessing, converging to high quality data products.

Validation workshops shall be held regularly throughout the OMI lifetime (**VR-4**).

Experience gained during the validation of GOME, SCIAMACHY, UARS, and TOMS instruments, shall be exploited (**VR-5**).

Correlative measurements should be made under the circumstances in which OMI measures (**VR-7**). They should preferably be coincident with an OMI overpass (**VR-8**). For some level 2 products (especially aerosols, clouds, UV products) large variations are expected within the OMI pixels. The effect of this inhomogeneity on the comparison between correlative and OMI measurements, which have different spatial resolutions, shall be investigated (**VR-9**).

Data measured within existing networks of instruments shall be exploited, since these data are well-validated and often very stable over time (**VR-10**). Measurements from satellite instruments are useful for OMI validation, provided that they have been independently validated (**VR-17**), since these measurements can have global coverage.

3.3 Validation phases

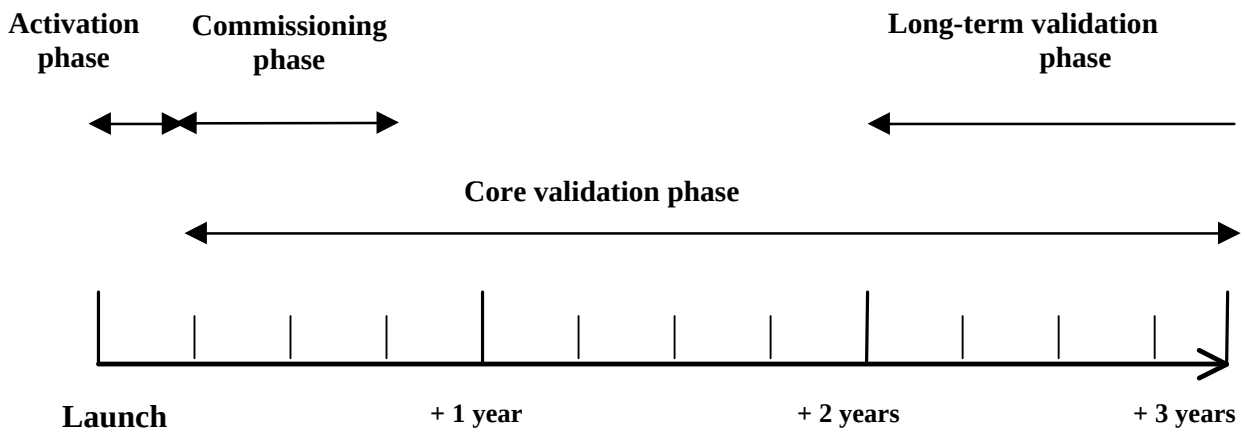

Figure 3.1. Timeline for OMI validation

Validation is envisaged to consist of three phases, namely the commissioning phase, the core phase, and the long-term validation phase (**VR-6**), as outlined in Figure 3.1. Each validation phase has a distinct goal. Within the three validation phases, priorities for the validation order (in time) of the various products will be established. This is described in the OMI Validation Handbook [Brinksma et al., 2003].

The first validation phase is the commissioning phase (see Chapter 4), which aims to provide a quick-look first validation of the level 1 and selected level 2 products. It starts after instrument functional tests have been completed, and lasts about six months (**VR-32**). During commissioning phase validation, absolute irradiance and absolute radiance, clouds, ozone columns, and some other level 2 products shall undergo preliminary validation (**VR-34**). The requirements for this preliminary validation are less stringent than those for the core phase validation. Per OMI product, only a limited number of satellite instruments (with global coverage) and ground based instruments shall be used as correlative instruments (**VR-35**). The preliminary validation may be limited to subsets of the available data, e.g., to cloud-free pixels, unpolluted scenes, or moderate geometries. Note that for OMI instrument operations and Level 1B calibration, an Instrument Commissioning Phase is defined, which takes place in the first three months of operation (here “Activation Phase”, in line with Aura nomenclature), this phase should not be confused with the Validation Commissioning Phase.

The second validation phase is the core phase (see Chapter 5), which ensures a thorough validation of all data products in order to provide an error assessment for the first official data release of validated OMI products.

The core phase overlaps with the commissioning phase and lasts until three years after launch (for all Aura instruments) (**VR-40**). In the core validation phase, all OMI data products shall be validated thoroughly (**VR-41**); the accuracies of the products as described in SRD and ATBD shall be assessed. Spatial and spectral zoom, VFD, and NRT products require separate validation (**VR-31**).

An AO (Announcement of Opportunity) shall be organized in order to optimize European contributions to OMI validation (**VR-42**).

Data from existing groundbased and satelliteborne instruments as well as from dedicated campaigns shall be needed (**VR-43**). Campaigns shall be incorporated within the EOS-Aura framework (**VR-44**) whenever possible, and participation in scientific validation projects, e.g., the NASA-NRA for Aura-validation, shall be encouraged (**VR-45**). Existing campaigns, outside the scope of EOS-Aura validation, shall also be exploited (**VR-46**). Funding for additional campaigns shall be sought from external sources, e.g., from the EU and Dutch national funds.
During dedicated validation campaigns, aircraft and/or balloon measurements (at specific sites and seasons) involving combinations or `clusters' of large multi-instrument payloads will be employed. Intensive validation campaigns will take place during the core phase. Possibly, a limited number of small campaigns will be performed during the commissioning phase.

The third phase is the long-term phase (see Chapter 6), which starts two years after launch and lasts for the complete lifetime of the instrument (**VR-52**). All available OMI data, including those measured in the first two years of operations, are subject to the long-term validation analyses (**VR-53**).

The main goals for this phase are detection of long-term changes in the accuracies of the products, e.g., due to instrument degradation; the validation of newly developed or advanced OMI data products; and the assessment of the suitability of OMI measurements for trend detection (**VR-54**). This necessitates a regular, optimized repetition of the essential elements of the core validation phase (**VR-55**). Included in the long-term validation phase are detection of instrumental degradation and its influence on the level 1 and level 2 data products. The use of data from ground based networks is critical for long-term validation (**VR-56**). In the long-term validation phase, ground based measurements and repetitive campaigns (e.g., the AVE series of missions, which aims to measure multiple times per year to aid Aura validation) are needed. For the ground based measurements, an effort to have regular overpass validation shall be made (e.g., at NDSC sites).

3.4 Level 1B verification

It is essential to validate all products of OMI. This includes validation or verification of the Level 1B products radiance and solar irradiance. In validation, by definition independent means are used to assess the uncertainties of the OMI data, while in verification an assessment of Level 1B data uncertainties is made using OMI data only. Strong links exist between calibration, verification and validation of Level 1B data. An extensive in-flight calibration program is planned for OMI (Dobber, 2003). The calibration, verification and validation efforts together shall enable monitoring of instrumental trends starting in the commissioning phase and extending throughout the lifetime of OMI.

The stability of long-term observations of OMI data products has high priority, particularly for ozone column densities, since the ozone measurement series will be combined with data from other satellites for trend detection. OMI will continue the long-term observations of TOMS and GOME ozone column densities, and of SBUV ozone profiles. Column and profile ozone trend detection precision must be on the order of 1% and 5% per decade, respectively. A good way to assure this is to validate or verify Level 1B products, in addition to Level 2 product validation, because it is expected that instrument deterioration induces trends in the Level 1B data, which could not be diagnosed directly if validation efforts were limited to level 2 validation.

According to our previous definition, validation takes place with correlative instruments. Here, we will show that OMI itself can be used to provide correlative measurements (sections 3.4.1 and 3.4.2). This will be called

verification rather than validation. Whether this should be part of the validation program, is under discussion at the time of writing.

3.4.1 Radiances compared with radiative transfer model spectra and groundbased level 2 data

For cloud-free sites, if ozone profile, aerosol information and surface albedo are known, radiative transfer models can be used to calculate the expected OMI nadir radiances. These are consecutively compared with the measured spectra.

Techniques developed to establish the in-flight calibration of TOMS instruments through internal consistency checks can be considered as verification of L1B data (they are also known as "soft calibration" techniques). These techniques will be most useful during the core and long term validation phases for establishing the stability of the L1B radiances. But comparisons with results from previous instruments (of minimum ocean reflectivity for example) can also establish absolute levels.

In general these techniques are based on the results from an initial processing in which internal inconsistencies allow us to trace calibration errors. One such technique, *pair justification*, is based on the principle that ozone measured at different wavelengths or under different viewing conditions must be consistent. The *spectral discrimination technique* is a generalization of pair justification, that can be used at non-ozone sensitive wavelengths. It depends on calculating residuals - the difference between radiances that are measured and those calculated using an assumed ozone amount and scene characteristics. In *scene stabilization*, absolute changes in spectrometer sensitivity can be observed by studying signals measured at the nadir over highly reflecting surfaces that can be expected to be stable from year to year - over the Antarctic and Greenland ice sheets for instance.

3.4.2 Verification using only OMI measurements

Possibilities of verification using only OMI data are:

- Compare Level 1B radiances measured during different orbits, i.e. at different swath angles, at the same geolocation. An issue is the time delay between observations and the possibly changed atmospheric or surface conditions. The approach only works for high latitudes, where there is significant overlap between orbits.
- Long-term validation/calibration using well-defined ground scenes, in order to monitor the long-term degradation of the primary telescope mirror. The scenes have yet to be selected. Details will be described within the calibration program. A link with the previous item (validation using different orbits) must be established.

3.4.3 Radiance comparison with other satellite instruments

Radiances can be compared with those measured by other satellite instruments operating in the OMI wavelength range (e.g., SCIAMACHY, and GOME-1 or GOME-2). These comparisons will not be conclusive, since non-coincidence and inhomogeneity will be a significant problem and the various satellite instruments may be subject to similar systematic effects. Also, instrument details (like the ground pixel size and detector characteristics) will hamper interpretation of the intercomparison results. However, these quick-look comparisons will be useful because they will allow for many cross comparison opportunities and may reveal systematic errors in the OMI Level 1 products. (**VR-15**). A similar approach was employed in the early GOME validation program [Koelemeijer et al., 1998].

3.4.4 Radiance comparison with groundbased instrumentation

The work described in this subsection is experimental at the time of writing. For cloud-free sites, if ozone profile and surface albedo are known, cross calibration and validation of OMI radiances can be accomplished over a broad range of wavelengths in the ultraviolet by comparing OMI nadir radiances with zenith sky radiances measured from the ground. The ground measurements are performed by a well-calibrated spectrometer/radiometer observing over a similar wavelength range [Hilsenrath and Ahmad, 2002]. In addition an accurate radiative transfer code that accounts for polarization, multiple scattering, rotational Raman

scattering, and aerosols is needed to predict the downward and upward radiances. The technique should be applied to EP-TOMS, SBUV/2, GOME, SCIAMACHY, and then to OMI thus insuring continuity of long term ozone trends measured among these instruments (**VR-14**). The ground based instrument calibration and corrections to sky radiances due to aerosols and clouds must be precise over the long term to insure that the calibration stability can be tracked with the precision stated above.

3.4.5 Solar irradiance validation

The solar irradiance (solar spectral intensity irradiated onto the atmosphere) measured by OMI should be intercompared with solar spectra measured by other satellite instruments and with published spectra (**VR-27**), since inaccuracies in the solar spectra might cause errors in other OMI products. This validation takes place in the early validation commissioning phase, and may be repeated when new correlative instruments become available (e.g., GOME-2). A good understanding of the absolute solar irradiance as measured by OMI is important for understanding the in-flight calibration status of the instrument in general.

3.5 Level 2 validation

The data sources for validation are ground-based, balloon, airborne and satellite measurements **(VR-16**). The airborne measurements can be divided into those from regular airplanes operating below 13 km, e.g. DLR FALCON, CESSNA, DC-8, and WB-57, and from stratospheric airplanes operating above 18 km, e.g. GEOPHYSIKA, ER-2. Measurements from satellite instruments (e.g. SCIAMACHY, EP-TOMS, GOME-2, NOAA-SBUV/2, ATSR-2, SAGE III) are useful for OMI validation, provided that they have been independently validated and provide data that are coincident with those measured by OMI (cf. **VR-17**). EOS-Aura measurements that have not been validated (e.g., measurements performed shortly after launch) will be useful for intercomparison purposes (cf.**VR-2**).

During the core validation phase, at least one year of measurements is needed to cover the different seasons **(VR-49**).

Additional correlative measurements shall be performed in areas of critical importance for atmospheric studies performed with OMI data, such as:

1. Mid-latitude continental industrial areas (air pollution, tropospheric ozone, NO_2 and aerosols)
2. Tropical continental areas (studies of NO_2 and ozone from biomass burning and studies of aerosols)
3. High latitude regions (vortex) (polar stratospheric ozone loss, ozone loss-event warning)
4. Tropical marine regions (tropical stratosphere, loss of ozone in the tropical remote troposphere).

(VR-11)

If routine measurements are not available, **VR-11** should be met by campaign efforts. Campaigns shall be incorporated within the EOS-Aura framework whenever possible (cf. **VR-44**), but also other campaign possibilities should be exploited (cf. **VR-46**). A description of instrument needs for OMI validation is given elsewhere [McPeters et al., 2002]. An interesting instrument for validation is the OMI simulator, which could be adapted to be flown on an airplane.

Since, especially for ozone, the stability of the OMI data products needs to be assessed, regular repetition of validation efforts with the same instrumentation is needed, starting in the commissioning phase. The AVE mission series, planned by NASA, addresses this topic (**VR-12**). Updated, enhanced or new OMI data products, also shall be validated. OMI products should be validated after every significant change. If possible, this is done using existing correlative data (**VR-13**).

A table of potential correlative data sources for the various OMI data products is presented in Table 3.1. In the EOS-Aura Science Data Validation Plan [*Froidevaux and Douglass, eds.*, 2001] an overview of satellite instruments operational during the EOS-Aura lifetime is provided.

Assimilated data are discussed in section 3.6.1

Ground-based stations are pivotal for the validation program. Of particular importance are data collected by networks where data continuity is secured and the data is reliable and well validated. The following list gives an overview of existing networks and data centers which can be used for validation:

- Dobson/Brewer global network, for ozone column data.
- WOUDC (World Ozone and Ultraviolet Data Center), for sonde ozone profiles and other data.
- NDSC. This worldwide network of about a dozen primary sites and many more complementary stations will form the backbone of ozone observations (column densities and profiles from mid or high troposphere through the stratosphere). Other data (NO_2 twilight column densities, UV/VIS measurements, aerosol instrumentation) are also often available from NDSC sites.
- DOAS/SAOZ/UV-visible networks, in which the EU has supported campaigns to validate and standardize this observation method for stratospheric species.
- SHADOZ – sonde network that provides additional ozone sonde soundings in the tropics and Southern Hemisphere.
- Aeronet, providing measurements on aerosol characteristics, worldwide.
- Earlinet (European Aerosol Research Lidar Network)
- TOR-2 (Tropospheric Ozone Research) European network.
- ARM (Atmospheric Radiation Mission), an American network measuring radiation, cloud and aerosol properties.
- Local networks, also important for tropospheric measurements.

All these networks have their own policy with respect to data distribution and use by external scientists and/or research groups. Networks are often part of international programs like IGAC or WMO/WCRP (GCOS, GAW, SPARC).

A brief discussion is presented below for the comparison and validation activities for each of the OMI Level 2 products, with guidelines for reference data sets. These sections are adapted from those in the EOS Aura Science Data Validation Plan [Froidevaux and Douglass, 2001].

3.5.1 Ozone profiles

Ozone profiles are measured by various satellite instruments, and by ground-based and small balloon instruments throughout the world. NDSC stations provide well-validated ozone profile measurements with good absolute accuracy (within 5-10%) from sondes, stratospheric lidars, some microwave sensors. For the altitude region below 30 km, sonde measurements are available for 20°-80° N (e.g. from WOUDC), with more limited data available for other latitudes. Continuation of the SHADOZ program would ensure availability of profiles for the tropics. To achieve global coverage, measurements by Aura will be compared with measurements from various satellite sensors. Examples of satellites measuring ozone profiles are SCIAMACHY, GOMOS, MIPAS (all on board Envisat), NOAA-SBUV/2, SAGE-III, but there are many more.
Aircraft-based ozone lidar profiles (above and below the aircraft) should enable investigation of spatial variation within an OMI pixel as well as from pixel-to-pixel.

<u>Reference data sets:</u>
1 SCIAMACHY ozone profiles. Other satellite data sets are listed in Table 2; expected periods of operation for the satellites are given in Annex D.
2 Sondes, lidar, microwave
3 Airborne profiling instrumentation during campaigns

<u>Long-term validation</u>: SAGE and ENVISAT data, combined with ground-based profile data for the stratosphere (e.g., from ozonesondes, lidars, microwave instruments), will provide comparisons towards long-term validation of stratospheric O3.

Ozone profiles will be validated by comparison to satellite instruments with global coverage (SCIAMACHY, NOAA-SBUV/2) and to one set of data from a ground based network (NDSC sonde data for the troposphere and lower stratosphere, NDSC lidar data for higher troposphere and stratosphere).

3.5.2 Total and tropospheric ozone column densities

Measurements of the ozone column densities take place worldwide within the Brewer-Dobson network. Measurements are taken almost daily. Also, various satellite instruments measure ozone column density data. However, it is expected that additional correlative tropospheric O3 column data are needed during biomass burning events, when O3 concentrations are high and variable, and in the tropics in general (in addition to the SHADOZ program). Sonde measurements can provide these data. Sondes in non-tropical (industrial) polluted areas would also be useful.
For the validation of tropospheric ozone, ozonesondes are the best data source at several sites, including the tropical regions. Comparisons are planned with other tropospheric products derived from TOMS and SCIAMACHY data; these products do not have the precision of sonde-derived columns, especially outside the tropics, but they provide a more global picture.
Campaigns are envisaged for regions where tropical ozone has high variability, e.g., polluted or biomass-burning areas. Airborne lidar measurements (with lidars pointing upward as well as downward) will yield profiles throughout the troposphere and stratosphere, typically at about 100 locations per flight. These can be used to assess spatial variations in the tropospheric ozone fields.

Reference data sets:
1 Existing Brewer-Dobson network for column density validations.
2 Ozonesondes for tropospheric partial column validations, especially in polluted areas.
3 Existing satellite instruments for column density validations (GOME, Envisat instruments, SAGE, etc.)
4 During campaigns: airborne lidars used for profile comparisons should be incorporated in the OMI O3 column density validations

Long-term validation: There is a significant amount of high quality data from ground-based networks for O3 column densities for long-term validation; TOMS and SCIAMACHY data can also be used. For the stratospheric column densities, validated profiles would be used (see above notes). Tropospheric products will rely heavily on ozonesondes for long-term validation.

3.5.3 Aerosols

Two aerosol products will be derived from OMI spectra: aerosol optical thickness (AOT) and single scattering albedo (SSA). OMI will retrieve aerosol parameters for cloud-free pixels only. Besides validation by direct comparisons to correlative measurements of AOT and SSA, in situ measurements of aerosol properties are needed, to validate the assumptions that have to be made in deriving aerosol quantities. Also, for deriving aerosol properties, good cloud masks and good ground albedo information is needed, and therefore validation of these products is desired.

Aerosol optical thickness (AOT):
For the visual wavelengths, Aeronet will provide data for validating the AOT. However, the current Cimel instruments within Aeronet should be extended, or new instrumentation should be placed, to also measure the ultraviolet part of the spectral AOT (see also McPeters et al., 2002). Other important validation sources include ground-based lidar systems and space-based lidars like CALIPSO and GLAS. AOT measurements by satellite instruments will be used for intercomparison purposes only.
Reference data sets:
1 Aeronet ground-based sunphotometer measurements.
2 Ground-based lidar measurements
3 Space-based lidar measurements from CALIPSO and possibly GLAS
4 Validated AOT measurements taken by satellite instruments: SCIAMACHY, MODIS, TOMS, POLDER (on ADEOS-II and Parasol), MISR.
Long-term validation:

Comparisons with the Aeronet data will be most useful for long-term validation purposes.

Aerosol Single Scattering Albedo (SSA):
We will primarily rely on Aeronet for the aerosol SSA data taken by ground-based sun photometers, although it is not certain that the measurements by Aeronet will give single scattering albedos that are accurate enough to be useful for validation of the OMI single scattering albedo.

Reference data sets:
Aeronet ground-based sun photometer measurements.
Long-term validation:
Comparisons with the Aeronet data will be most useful for long-term validation purposes.

Aerosol properties measurements for validation:
To validate assumptions made in the OMI AOT and SSA algorithms, the following measurements are needed:

- aerosol size distribution measurements
- measurements of the chemical composition of the particles
- aerosol absorption measurements
- aerosol scattering measurements

Most of these measurements are only made during campaigns, however, some stations perform them more regularly.

3.5.4 NO_2 column densities

Several satellite platforms provide global measurements of NO_2 column densities. Their sensitivity for the lowest part of the atmosphere, however, is limited. Ground-based UV/VIS spectrometers (DOAS and SAOZ, data contained in NDSC database) and FTIR measurements also provide column densities, at various sites with reasonable global coverage. However, they do not cover polluted areas well (see below).

An important issue is the contribution of tropospheric NO_2 to the column densities. Due to the limited amount of measurements worldwide, NO_2 profile climatologies poorly characterize the actual profile shape in areas with severe pollution. Many ground-based instruments within NDSC are located at a high elevation, or in relatively clean areas, where little tropospheric NO_2 is expected. Since OMI wants to measure tropospheric and total column densities of NO_2 under various circumstances, including biomass burning and industrial pollution, additional measurements of tropospheric NO_2 under polluted conditions are needed. This calls for campaigns in industrial or biomass burning regions (using airborne or balloon measurements), employing, e.g., UV/VIS DOAS type instruments. An additional possibility is to use correlative lidar measurements, from a ground-based mobile NO_2 lidar operated by RIVM in the Netherlands (52°N), where moderate to high NO_2 concentrations in the lower troposphere can be expected. Funding was granted for a project in which these measurements will take place [Levelt et al., 2002].

Another important issue for the NO_2 validation is its diurnal variability. NO_2 is destroyed rapidly in the presence of sunlight, and thus concentrations during OMI overpasses will differ from those measured by ground-based techniques which measure most accurately at sunrise and sunset. Measurements coincident with OMI overpasses are preferred, if these can have sufficient accuracy. Existing techniques can be applied for small solar zenith angles but give less accurate results than at sunrise/sunset.

Since tropospheric NO_2 is highly variable in the horizontal direction, networks in which the NO2 concentrations at the ground are measured are useful when used in conjunction with models predicting the height of the boundary layer. Under the assumption that NO_2 is distributed homogeneously through the boundary layer, and that the free troposphere contains little NO_2, the tropospheric NO_2 loading can be determined with about 50-100% uncertainty. Knowledge of the horizontal distribution of NO_2 in the boundary layer is important for the validation itself but also for checks of the assumptions made (i.e., the airmass factor depends strongly on the amount of boundary layer NO_2).
Reference data sets:
(1) SCIAMACHY, GOME

(2) ground-based UV/VIS and FTIR, preferably NDSC extended with instruments in polluted areas. NDSC stations in Japan are at low elevation and in polluted areas. Feasibility of using daytime FTIR spectra for NO_2 column retrievals should be investigated.
(3) additional campaign-based UV/VIS and FTIR (DC8 airborne measurements of NO_2, or balloon-based UV/VIS spectrometers)
(4) ground-based lidar (The Netherlands)
(5) ground level measurements combined with boundary layer height predictions from meteorological data
Long-term validation:
Same data sets as above, with addition of NIWA long-term measurements (45°S, 170°E, clean troposphere) [Liley et al., 2000].

3.5.5 Effective Cloud Fraction

Most of the Level 2 OMI data products depend on the quality of the (internal) effective cloud fraction product. Validation of the effective cloud fraction is therefore important. It takes place directly, by comparing cloud properties with correlative measurements from other instruments, and indirectly, i.e., interlinked with the validation of other products.

An example of direct validation is to compare the OMI effective cloud fraction with that of another instrument, e.g., MODIS. An example of indirect validation is to incorporate MODIS cloud products into an OMI level2 product and compare the results with conventional level 2 products (that use OMI cloud fractions). In this way, the sensitivity of the retrieved OMI level 2 products for cloud fraction is tested.

Among primary sources for intercomparison are MODIS, CALIPSO and CloudSat cloud fractions. Their horizontal resolution needs to be taken into account. The WMO Network may provide valuable information since it produces cloud fractions that have been measured with a different, independent technique. Other validation sources include the SCIAMACHY and ATSR-2 visible radiances cloud cover product.
Reference data sets:
1 Validated CALIPSO, CloudSat and MODIS cloud fractions
2 WMO Network
3 Validated effective cloud fractions from SCIAMACHY and ATSR-2 visible radiances cloud cover product (if available)
Long-term validation:
Comparisons with CALIPSO, CloudSat, MODIS, and GOME II would be most useful for long-term validation.

3.5.6 Cloud Pressure

Most of the Level 2 OMI data products depend on the quality of the cloud pressure, especially those products that have a strong tropospheric component (e.g., NO_2, BrO). Validation of this data product is difficult, since the retrieved cloud pressure depends on the (correlative instrument) spectral region, on cloud albedo and optical thickness, and the spatial resolution of the correlative instrument. On the other hand, comparisons between different instruments can indicate under which circumstances the cloud pressure derived from OMI can be interpreted to have a physical meaning.

The strategy to validate cloud pressure must rely on comparisons with cloud top pressures derived from similar spectral regions as used for OMI. The most important satellite instrument employing a different technique (lidar altimetry) while staying near the OMI spectral region (at 532 nm) is CALIPSO. Other satellite instruments that may be useful for intercomparison include AVHRR and SCIAMACHY, and in a later stage possibly GOME II.

Internal validation will take place between the cloud pressures derived from OMI measurements by the two different methods used: O_2-O_2 absorption and rotational Raman scattering.
Reference data sets:
1 Cloud top pressure from MODIS, AVHRR, and SCIAMACHY.
2 Validated cloud top pressure from CALIPSO
Long-term validation:
Comparisons with CALIPSO as well as with CloudSat would be useful for long-term validation.

3.5.7 SO_2 column densities

Under background conditions (i.e., non volcanic conditions), SO_2 amounts are expected to be less than 0.5 DU over much of the world (Chin et al., 2000). In polluted regions of the northern hemisphere the model results are less than 2 DU. Local amounts near sources are higher but must be averaged over the OMI footprint. OMI SO_2 detection limits will depend on details of the wavelength dependence of the S/N ratio but may be better than 2 DU. The present uncertainty in standard Brewer SO_2 background amounts is 1 - 2 DU for direct sun data with a well calibrated instrument. SO_2 may be detected in the vicinity of sources. Validation of background SO_2 measurements will require special efforts with double monochromator instruments, such as SSBUV or double Brewers.

The validation of SO_2 column densities in volcanic eruption clouds is problematic because the timing of eruptions is unpredictable and the trajectories of the clouds cannot be forecast accurately. In the past, chance passages of SO_2 clouds over Brewer instruments have provided validation for satellite observations. Brewer spectrophotometers, COSPEC (correlation spectrometers), and UV/VIS measurements from the ground are the primary validation sources for the SO2 vertical column densities. Use of these is not entirely satisfactory as the accuracies of these methods have yet to be reviewed accurately. In addition, the methods have not been intercompared, although COSPEC instrument intra-comparisons have been made. Other satellite instruments, such as TOMS, MODIS, ASTER, SCIAMACHY, SBUV/2, and GOME 2 provide global correlative observations. Integrated MLS vertical SO_2 profiles can be compared with column measurements for large volcanic clouds.

If there is a significant volcanic SO_2 input into the stratosphere, balloon data and SCIAMACHY data would provide a basis for validation. Column data from OMI and TOMS will be compared with the integrated profiles.

Reference data sets:
1 UV/VIS SO2 column densities from ground-based DOAS instruments.
2 Brewer network SO_2 column amounts in archived data sets
3 COSPEC special campaigns on active volcanoes
4 TOMS SO_2 and ash data record on eruptions
5 Validated SO_2 column densities from ASTER, MODIS, SCIAMACHY and GOME 2 (if available)
Long term validation: SO_2 emissions are episodic with extremely high variability due to volcanic eruptions.

3.5.8 BrO Column Density

Limited correlative data exist for the validation of BrO vertical column densities; comparisons to other data should be regarded as intercomparisons rather than validation, since one has to allow for differences in reference spectra and fitting procedures. We regard UV/VIS spectroscopic BrO column measurements from the ground as the primary validation source; the technique is similar, although not identical, to UV/VIS spectroscopic measurements from a satellite platform. Vertically integrated BrO profiles from SAOZ balloons carrying UV/VIS spectrometers will also be used. SCIAMACHY and GOME 2 BrO slant and vertical column measurements are valuable validation sources as well since they provide global coverage.
Groundbased correlative measurements must be made over high-latitude locations, where both vortex and outside-vortex conditions are expected.
Reference data sets:
1. UV/VIS BrO column densities from ground-based spectroscopic instruments.
2. Integrated BrO profiles from LPMA DOAS data or from SAOZ payloads.
3. Validated BrO column densities from SCIAMACHY (if available).
4. Validated BrO column densities from GOME 2 (if available).
Long term validation:
Comparisons with the UV/VIS from ground-based measurements and from SCIAMACHY would be most useful for long term validation.

3.5.9 OClO Slant Column Density

Limited correlative data is available for the validation of OClO slant columns. Comparisons to other data should be regarded as intercomparisons rather than validation, since one has to allow for differences in reference spectra and fitting procedures. We regard UV/VIS spectroscopic OClO column measurements from the ground as the primary validation source, since this technique, although similar, is not the exact same as UV/VIS spectroscopic measurements from a satellite platform. Vertically integrated OClO profiles from SAOZ balloons carrying UV/VIS spectrometers will also be used. However, SCIAMACHY and GOME 2 OClO slant and vertical column measurements are valuable validation sources as well since they provide global coverage.
Ground-based correlative measurements must be made over high-latitude locations, where both vortex and outside-vortex conditions are expected.
Reference data sets:
1. UV/VIS OClO column densities from ground-based spectroscopic instruments.
2. Integrated OClO profiles from the Laboratoire de Physique Moléculaire et Applications (LPMA) DOAS data or from SAOZ payloads.
3. Validated OClO column densities from SCIAMACHY (if available)
4. Validated OClO column densities from GOME II (if available)

Long term validation:
Comparisons with the UV/VIS from ground-based measurements and from SCIAMACHY would be most useful for long term validation.

3.5.10 HCHO Column Density

HCHO slant and vertical column densities are currently measured by GOME [Thomas et al., 1998; Chance et al., 2000; Palmer et al., 2001] and will be measured by SCIAMACHY. Ground- and aircraft-based measurement campaigns will be necessary for OMI validation, especially when concentration are expected to be high, i.e., for periods with strong tropospheric hydrocarbon emissions. A past example is the U.S. Southern Oxidants Study, measuring continental production of HCHO from isoprene [Lee et al., 1998]. Measurements are also necessary to confirm rates of production in the maritime free troposphere, such as those from the 1997 Subsonic Assessment (SASS) Ozone and Nitrogen Oxide Experiment (SONEX) [Singh et al., 2000]. Measurements over the southeastern U.S. in summertime, and over the midlatitude oceans (preferably in summertime for maximum production from oxidation of CH_4) would provide optimum data sets. Midlatitude maritime measurements could be combined with campaigns to study intercontinental pollution transport.
Reference data sets:
1. Validated HCHO column densities from SCIAMACHY
2. Validated HCHO column densities from GOME 2 (after 2005)
3. During campaigns, groundbased UV-VIS and aircraft-based data.

Long term validation:
Comparisons with column values from SCIAMACHY would be most useful for long term validation.

3.5.11 Surface UV Irradiance and Surface UVB

To validate the surface UV irradiance, a combination of existing instrumentation around the globe and special campaigns should be made. In these campaigns, various UV instruments should be distributed within the OMI footprint, to address the effect of sub-pixel variability due to clouds, aerosols, and other local conditions.

The following UV validation requirements should be met:
- Use long-term UV stations with high-level instrument QA/QC
- Ground-station locations should be carefully selected to avoid inhomogeneous local conditions (like surface albedo variations, relief, local pollution sources).
- UV measurements should be accompanied with spectrally resolved AOT and SSA measurements (at 305, 310, 324, 380, 415, 440, 500 nm)
- To address subpixel inhomogeneity, several measuring sites are needed within one OMI pixel.
- Special UV validation campaigns are propsed, at sites listed below.

Subpixel variations :

The scale of UV irradiance variation is related to variability in cloudiness, albedo, ozone and aerosols. The scale of cloudiness variability is on the order of a kilometer. Due to this, it is difficult to compare the spaceborne and ground-based UV data directly. The typical pixel sizes of global spaceborne UV datasets vary between 15 and 320 km. To be able to use ground-based UV data for satellite validation, various measurement sites are needed within a satellite pixel. In this way the validation may be carried out in a physically reasonable way. It is proposed that three validation areas be established for the OMI UV validation. Typically 6 additional simple radiometers/validation areas would be needed. Existing facilities and meteorological know-how will form the basis for the validation areas. The following areas are proposed:
A. SW Finland, 60 N
Existing spectral and broadband UV measuring programme since 1990
Advanced calibration facilities
Snowcover 2-5 months a year
Low aerosol content
High solar zenith angle conditions
B. Greece 30-40 N
Existing spectral and broadband UV measuring programme since 1990
Advanced calibration facilities
High aerosol content, occasionally influence of Saharan dust
High tropospheric ozone content
C. USA sites
Primary: Greenbelt, Md.
- existing spectral and broadband UV measuring programme
(BUV, Double Brewer since 2000)
- calibration site for aerosol Aeronet network (Cimel sun/sky measurements)
- Lidar for aerosol and cloud heights
- spectral UV (groundbased) zenith sky measurements by SSBUV instrument
- UV and VIS shadow-band radiometers from USDA network within 10km.
Secondary: ARM site in Oklahoma
- existing broadband VIS radiation and clouds measuring programme
- UV and VIS shadow-band radiometers from USDA network

Groundbased validation network:

Besides the pixel and aircraft validation activities also long-term UV stations with high-level instrument QA/QC practices are planned to be used in OMI UV validation. Such stations are located in e.g. Europe, USA, Canada, Antarctica and New Zealand. The data available from European UV Database (FMI), World Ozone and UV Datacentre (AES), NSF Network (Biospherical Inc.) and from individual scientists are planned to be used for long-term OMI UV validation besides the pixel validation areas.
Additional funding is needed for these validation activities. Partial funding may be applied from the European Commission research programmes.

The USDA UV-B Monitoring and Research Program located at Colorado State University has 28 permanent sites located throughout the USA (including Alaska and Hawaii) and 2 in Canada collocated with Canadian Brewers. High quality, annually calibrated and spectrally characterized 7 channel UV shadow-band radiometers measure total, diffuse and direct irradiances every 3 minutes. Nominal wavelengths are 300, 305, 311, 317, 332, and 368 nm (2 nm FWHM). The data is posted on the Web the next day (http://uvb.nrel.colostate.edu/UVB). Aerosol optical depths at 332 nm and 368 nm will also be available on request. To complement the shadowbands, the Network is operating at MD, OK, and CO double UV monochromators with excellent stray light rejection and wavelength repeatability. USDA proposes to share any Network data with OMI as part of the North American ground-based validation network. In addition the Network operates the sites within 150 km and could add several more broadband UV-B and UV-B sensors at additional sites within the spatial array and share the data with OMI.

Aircraft campaigns

To study the 3-dimensional distribution of UV irradiance field aircraft measurements are the optimal choice. For OMI validation it would be desirable to install up and down looking UV instruments and possibly also an actinic flux instrument onboard the aircraft that will be used for OMI trace gas validation. The aircraft measurements should be complemented by ground-based instruments in the flight area. The impacts of aerosols, cloudiness, albedo and ozone should be studied. This may be best achieved by carrying out 2-3 campaigns at different environments. Areas of interest are low latitudes with high aerosol loading (dust, biomass burning) and high latitudes with high albedo and strong ozone depletion. Variable cloudiness conditions would be desired for some flights. Potential coordination with the pixel validation activities would be an advantage. The results of the campaigns are expected to be of high scientific value.

Table 2. Potential Correlative Data Sources for OMI Level 2 Data

Geophysical Parameter	Altitude range (km)	Potential Correlative Data Sources	
		Campaign	**Routine**
O_3 Profile	0 to TH	A-in situ, A-lidar, B-in situ, sonde	Sonde, G-lidar, A-MOZAIC
	TH to 20	A-in situ, A-lidar, B-in situ, sonde	Sonde, G-lidar, GOME, SAGE, ODIN, MIPAS, SCIAMACHY, ILAS-II, ACE
	20 to 40	B-in situ, A-lidar, sonde	Sonde, G-lidar, G-MW, G-SAOZ, Umkehr, GOME, SCIAMACHY, GOMOS, MIPAS, SAGE, POAM III, ODIN, SBUV/2, SABER, ILAS-II, ACE
	> 40		G-lidar, G-MW, Umkehr, GOME, SCIAMACY, GOMOS, MIPAS, SAGE, ODIN, SABER, ILAS-II, ACE, SBUV/2
O_3 Column	Column	A-lidar	A-UV/VIS Brewer, Dobson, Umkehr, G-UV/VIS, sonde, G-lidar, TOMS, GOME, AIRS, SCIAMACHY, SBUV/2
	Trop. Column	A-lidar, A-UV/VIS	Profiling instruments (e.g., sonde, G-trop. Lidar), GOME, TOMS, SCIAMACHY
	Strat. Column	A-lidar, A-UV/VIS	Profiling instruments (e.g., sonde, G-strat. lidar, G-MW), SCIAMACHY, SBUV/2
Aerosol optical thickness and SSA		A-data, B-in situ	G-lidar, G-photometer (especially within Aeronet), SAGE, GOME, TOMS, POLDER, SCIAMACHY
NO_2	Column	A-UV/VIS, B-UV/VIS	G-VIS, GOME, SCIAMACHY
	Trop. Column	A-UV/VIS, B-UV/VIS, G-UV/VIS, G-lidar	G-VIS, GOME, SCIAMACHY, G-in situ (sampling at surface level) combined with meteorological models
SO_2 (volcanic)	Column	A-COSPEC, G-Brewer	G-UV/VIS, G-Brewer, COSPEC, SCIAMACHY, TOMS (Column), GOME
SO_2 (non-volcanic)	Column		Need for validation exists under polluted conditions – instrumentation as above.
BrO	Column	A or B-UV/VIS	G-UV/VIS, GOME, SCIAMACHY
OClO	Slant Column	A-UV/VIS, B-UV/VIS	G-UV/VIS, GOME, SCIAMACHY
HCHO	Column	G-UV/VIS, A-in situ	GOME, SCIAMACHY
Cloud Fraction		A-data, B-data	WMO Network, ARM, Weather satellites, ATSR-2, GOME, AIRS, MODIS, CloudSat, CALIPSO
Cloud Pressure		A-data, B-data	G-radar, ARM, Weather satellites, ATSR-2, GOME, ODIN, AIRS, MODIS, ENVISAT, ILAS-II, CloudSat, CALIPSO
UV Surface Irradiance		UV spectrometers	G-UV, TOMS

Data sources are classified into broad categories for "campaign" and "routine mode". The measurement techniques are distinguished by the following general types: A (Aircraft), B (Balloon), sonde (or small balloon), rocket, G (Ground-based), or by the satellite acronyms. Measurement techniques

(for A, B, or G types) are broadly defined by the following abbreviations: IR (infrared techniques, e.g. occultation, or emission), MW (microwave, or near-millimeter wavelengths), lidar, UV, VIS, in situ. "Data" may refer to both in situ *& remote sensing techniques. TH stands for tropopause height. Altitude range is meant to be approximate, with typical ranges of "TH-4 to TH" representing the upper troposphere, "TH to 20" representing the lower stratosphere, "20 to 40" representing the middle stratosphere, and "> 40" representing the upper stratosphere. In this table, SAGE refers to SAGE III (and SAGE II, if available), GOME refers to data from GOME and/or GOME 2, Polder refers to the Polder instruments on board ADEOS-II and Parasol.*

Note: This table is an excerpt from Table 5.3 in the EOS Aura Science Data Validation Plan.

3.6 Tools for validation

Tools such as coincidence predictors are needed to facilitate accurate timing of correlative measurements (**VR-18**). Other validation tools which shall be needed are software for data processing, cataloguing tools, data assimilation tools, trajectory codes, and auxiliary data.

3.6.1 Data-assimilation models

Data assimilation is an important tool for the validation of satellite measurements [Levelt et al., 1996a, 1996b]. Data-assimilation models were already used for, e.g., the validation of the ERS scatterometer on the ERS-1 [Stoffelen and Anderson, 1997] and ERS-2 satellites, the validation of the UARS instruments [Swinbank et al., 1993] and the validation of GOME [Piters et al., 1996a, 1996b]. They are planned to be used within the EU projects GOA and ASSET [GOA].

Exploiting data-assimilation models makes it possible to determine random and systematic errors in the measurements and perform on-line quality control of the instruments, so that extreme values become evident. Assimilating correlative measurements (ground based or satellite data) into a validated atmospheric model enables simultaneous, collocated comparison with assimilated OMI measurements. Therefore it is important to create, or to have access to, data-assimilation facilities for validation and interpretation (**VR-19**).

Data assimilation techniques have been used extensively in meteorology for several years, enabling the improvement of the quality of the weather forecast. In data assimilation, satellite observations of atmospheric species are fed into an atmospheric model and weighted with model-calculated ozone values in order to obtain the best available description of the atmosphere, and to make optimal use of the data. Incorporating data assimilation into the validation of OMI will lead to a good description of the atmosphere and enable analyses and forecasts which are consistent with all available real-time measurements and with all available dynamical information. By extending dynamical models with data assimilation it is possible to obtain maps of atmospheric species (level 4 products, which are global image product which consist of data measured at different times).

Advection and assimilation models, which retain the dynamical information on the atmospheric species, make it possible to use non-collocated ground-based and satellite measurements for validation. Moreover, data assimilation offers the possibility to identify ground stations which deliver controversial data by comparison with observations of a satellite instrument. Furthermore, models extended with data assimilation also produce statistical information on the quality of instruments and observations. Data assimilation models can also be used for comparison of satellite observations with predicted tracer values based on previous satellite observations. Differences between the tracer amounts directly observed by the satellite instrument and the model predicted tracer amounts give information on the self-consistency of the satellite instrument and the quality of the model.

3.6.2 Trajectory codes

For the interpretation of validation results, a trajectory code, that is able to show where air parcels originated from, is useful. Trajectory codes are available at KNMI.

3.6.3 Coincidence predictor

Although OMI has a wide swath which enables global coverage in a day, a software tool shall be available to predict which part of the swath is over a certain location at a certain time (**VR-20**). This information is needed in the field, to give PI's of correlative instruments the possibility to measure simultaneous with an OMI overpass. Since OMI data quality may depend on swath angle, that information should be included in the predictions.

3.7 Validation database

A database containing correlative data, or links to these data, acquired during the commissioning and core phases of Aura, including campaigns within these phases, is necessary for efficient validation and shall be created by NASA **(VR-21**). Only the members of the validation team should have access to this database until the official release of data. All PIs and co-PIs of accepted validation proposals (including those funded by NASA-NRA's) should be part of this validation team. Access to the database can be granted to other investigators by the OSAB.

3.7.1 Database introduction and requirements

For validation of OMI data products, independent observations are performed by a large number of *in situ*, remote sensing and satellite instruments for comparison with the geophysical OMI data products. An easily accessible database for these correlative validation data is required. The database is meant for measurements obtained during the validation phase and should have common agreed formats for all types of data. The goal of the validation database is to make these indexed data accessible for all scientists and engineers performing the validation and calibration. OMI data should also be available for validation to all co-coordinating (and participating) groups of the core validation. In order to facilitate the use of both OMI data products as well as validation data, software tools shall be developed that have the capability to read and visualize all basic Aura products.

The requirements for the database are

- Easy access (registered) (**VR-22**).
- For contingency and for coverage of annual variations, the database must be capable of holding data collected during the commissioning and core phase (**VR-23**).
- A common format for correlative data, or a tool to convert data into the common format, is required (**VR-24**). Putting correlative data into HDF format is considered.
- Software tools shall be developed that have the capability to read and visualize the products in the database as well as the OMI level 1 and level 2 data (**VR-25**).
- The provision of auxiliary data (atmospheric parameters etc.) not measured by OMI but needed for validation studies is required (**VR-26**).

3.7.2 Campaign and network validation data

The validation database shall contain all correlative data collected during validation campaigns. The accessibility of network validation data shall be established by links from the OMI web page on the World Wide Web, and by links from the OMI validation database through EOSDIS. All scientists and engineers involved in performing validation and calibration shall have access to network data being used during OMI validation phases.
Within the Aura project, liaisons have been appointed that are responsible for bringing routine data, from one specific technique or set of instruments per liaison, into the database. They are also responsible for getting the data into a joint format, either by converting data before storing them, or by offering conversion software to the database users.

4 Commissioning Phase Validation

4.1 Objective and operational requirements

The commissioning phase validation objective is the preliminary validation of a number of level 1 and level 2 data products. Quick-look comparisons will be made, which provide first checks on the general functionality of OMI and its operational algorithms. Commissioning phase validation shall take place between three and nine months after launch, in accordance with the Aura commissioning phase duration. Quality Assessment of the data will be described elsewhere (OMI Quality Assessment Document, in progress)

At least three months during the commissioning phase shall be used to perform OMI measurements directly useful for validation of the operational products (**VR-36**). The major part of the OMI measurements during the commissioning phase validation shall be performed in the global mode (**VR-37**). According to current planning, a limited number of measurements in the spectral zoom mode will be taken during the launch and early operations phase (LEO phase) of OMI, while once monthly an orbit of measurements in the spatial zoom mode will be performed during the first year of operations (this includes the validation commissioning phase). Since various aspects of the data taken in the spectral and spatial zoom modes differ from those in the global mode, separate validation is needed. (cf. **VR-31**) The same goes for validation of VFD and NRT products. Validation of data taken in the spectral and spatial zoom modes will be described in the OMI Validation Handbook [Brinksma et al., 2003].

Special attention shall be paid to good communication between the people who are performing validation, have developed algorithms, and perform OMI in-flight calibration and functional testing, respectively. Important findings of these groups should be communicated as quickly as possible. Regular meetings, approximately monthly, are advisable (**VR-38**).

All data retrieved from OMI measurements, including the functional test data, should be easily and quickly available for the participants in the commissioning phase validation, and must be organized well before launch (**VR-39**, cf. **VR-21**).

4.2 Timeline for commissioning phase validation

It is essential to validate the irradiance and radiance products of OMI at an early stage, since all higher level products depend on the accuracy of these products (**VR-33**). In addition to this, selected level 2 OMI products will undergo preliminary validation during the commissioning phase (**VR-34**), after various QA tasks have been performed. The priority with which products will be validated during the commissioning phase is given in the following list.

- First priority: Validation of ozone column densities, and Level 1 products, viz. Earth radiance spectrum, solar irradiance spectrum, reflectance.
- Second priority: Validation of cloud products and column densities of NO_2 (note – NO_2 validation focuses on unpolluted cases during the commissioning phase).

Note that validation of these products may overlap in time.

In general, easier cases will be selected first, e.g., for ozone and NO_2 products, cloud-free cases will be evaluated before the more complicated partly clouded situations. Also, modest viewing geometries (pixels in the middle of the OMI swath) will be selected first, as pixels there are small, and thus better comparable to that of ground based instruments. Also, the retrieval for these pixels should be more accurate. For NO_2, the focus during the commissioning phase is on unpolluted areas, where stratospheric NO_2 dominates the column density.

During the commissioning phase, use of existing networks of ground based data, and of existing validated satellite data will be made. When (preliminary) data are released, they must be accompanied by a detailed description of the knowledge on the systematic and random errors.

4.3 Commissioning phase validation of Level 1B Normalized Radiances

The general validation plans for Level 1B validation were described in section 3.4. Summarizing, the various methods for validating Level 1B radiances are:

1. Radiances compared with radiative transfer model spectra and groundbased level 2 data (section 3.4.1)
2. Validations using only OMI measurements (section 3.4.2)
3. Radiance comparison with other satellite instruments (section 3.4.3)
4. Radiance comparison with groundbased instrumentation (section 3.4.4)

The timeline and priorities for the commissioning phase validation of level 1B validation will be described in the OMI Validation Handbook (Brinksma et al., in progress).

The solar irradiance is validated by first comparing with published spectra, and then comparing with solar irradiances measured by other satellite instruments.

4.4 Commissioning phase validation of selected Level 2 products

The commissioning phase validation will start with the mission critical products; ozone columns and NO_2 columns (the latter focusing on unpolluted cases). Timelines and priorities will be described in more details in the OMI Validation Handbook.

4.4.1 Ozone column densities

Commissioning phase validation of level 2 products will start with validation of ozone columns. These will be intercompared with results from satellites with global coverage (SCIAMACHY, EP-TOMS, and SBUV/2), and with data from a ground based network (Brewer - Dobson Network). Ozone profiles, if available at launch, will also be validated in the commissioning phase, by comparison with ground based networks (sondes and lidar, e.g., from NDSC and SHADOZ).

The ozone column densities derived from the same OMI Level 1B data using the DOAS and TOMS methods, respectively, should be intercompared.

4.4.2 Cloud pressure and fraction

The main purpose of retrieving cloud properties with OMI is to enable accurate retrieval of all other OMI level 2 products. Cloud pressure and cloud fraction will be validated in an early stage.

The OMI cloud product is derived by application of two independent algorithms, denoted as "O_2-O_2" and "Raman" (see sections 3.5.5 and 3.5.6). Validation of cloud properties is difficult, since the derived cloud properties are effective properties that depend on the size and location of the scene viewed. This should be taken into account when comparisons between OMI and correlative instruments are made.

During the commissioning phase

- cloud pressures derived from O_2-O_2 band absorption and Raman scattering algorithms (applied to the same OMI level 1 data) shall be compared.
- Each of these two cloud pressures shall be compared to cloud pressures derived from another UV- or VIS satellite instrument (e.g., from the FRESCO method applied to Sciamachy data, or MODIS data).

- OMI cloud fractions will be compared to cloud fractions from another satellite instrument which has a much smaller pixel size (e.g., MODIS on EOS-Aqua)

4.4.2.1 Use of OMI level 2 data for cloud validation

By validating level 2 products under partly cloudy conditions, information about the accuracy of the cloud products can be obtained. Correlations between cloud parameters and the level 2 data in which those cloud parameters have been used, can point to errors in the cloud data, or in the cloud correction algorithm. It is assumed that the level 2 products were well-validated under cloud-free conditions.

Cloud parameters are available from the two different methods, O_2-O_2 and Raman. By validating two sets of the same level 2 data, that only differ because they have been processed with O_2-O_2 and with Raman cloud parameters, respectively, the difference between the two cloud retrieving methods can be investigated. This will be done during the commissioning phase (or early in the core validation phase).

4.4.3 NO_2 column densities

NO_2 column densities will be validated under unpolluted conditions during the commissioning phase (when their values are dominated by the stratospheric contribution). Correlative data to be used are SCIAMACHY column data, and stratospheric profile data if available, and column data measured by the SAOZ or DOAS instruments (available from, e.g., the NDSC database).

5 Core Validation

5.1 Objectives

Core validation for the instruments aboard the EOS-Aura satellite takes place from L+3 months through L+36 months. During the core validation phase, OMI data products and correlative data will be collected and analyzed, in order to assess the accuracies of the level 1 and level 2 data products. Campaigns are an essential part of the core phase. They shall provide data at locations where representative existing measurements are sparse (**VR-47**). This may include locations at which retrieval weaknesses yield results with limited accuracies and locations where specific conditions exist (e.g., areas with industrial pollution). Campaigns dedicated to OMI validation should not be planned to start earlier than 1 year after launch (**VR-48**).

Each Level 1 and 2 data product shall be validated rigorously during the core validation period. The validation yields information about the accuracy of OMI data products. Where possible, multiple correlative measurement techniques should be used, to enhance the results, and avoid ambiguities due to possible instrumental effects in the correlative data (cf. **VR-1**). During the core validation phase, at least one year of measurements is needed to cover the different seasons (**VR-49**). If data are reprocessed, they shall be validated again, using the already available correlative data (**VR-50**).

The current plan is success-oriented, should problems be encountered during the core validation phase, an adjustment of the plan is necessary.

5.2 OMI Level 1B data products

Achieving good stability of long term observations of OMI data products has high priority. Hence, the Level 1B validation efforts from the commissioning phase shall be continued and expanded during the core validation phase. For details, see section 3.4 and the OMI In-flight Calibration Plan (Dobber, 2003). Even though the largest Level 1B validation efforts take place during the commissioning phase, the validation and long-term calibration and monitoring efforts will continue throughout the complete duration of the mission.

5.3 OMI Level 2 data products

During the core phase, thorough validation of all OMI data products is performed. The core phase starts at the same time as the commissioning phase, which was described in Chapter 4, and then extends further to provide validation of all OMI data products, under all representative conditions. The validation objectives will be met through the validation strategy and the product validation approaches that were described in Chapter 3,

Correlative instruments used in the core phase must have an accuracy that is comparable to or better than the expected OMI product accuracies (**VR-51**). The latter were listed in the table in Chapter 2. Overviews of the instrumentation available for level 2 validation were presented in the EOS-Aura Validation Plan and will also be discussed in the OMI Validation Handbook (Brinksma et al., 2003).

Campaigns are necessary to add correlative data under those circumstances in which regular instrumentation does not provide measurements, e.g., in biomass burning or industrial areas. Especially for ozone, NO_2, and aerosols under polluted conditions, campaign efforts are needed.

For a detailed description, per OMI product, of the correlative instruments used, the time and location of correlative measurements, the reader is referred to the OMI Validation Handbook.

6 Long-Term Validation

6.1 Objectives

The long-term validation phase starts after the core phase and lasts during the complete lifetime of the instrument (cf. **VR-52**). The objectives of the long-term validation phase are:

- To update regularly the validation of OMI data products after new OMI ground processor versions are issued, and to validate new or advanced OMI data products.
- To provide additional input to the in-flight calibration by identifying trends in data products that may point to instrument degradation (or other changes) over time.
- To identify the influence of trends in auxiliary data on trends in OMI level 2 data.
- To provide input to OMI algorithm improvement or development.

6.2 Regular validation updates

The main elements of the core validation shall be repeated regularly (cf. **VR-55)**, to enable validation of updated, enhanced or new OMI data products. After every significant change, products should be validated (cf. **VR-13**). When changes in the calibration, or other changes that influence the level 1 data are made, validation of all updated level 2 products will be necessary (cf. **VR-54**).

When level 1 or 2 data are changed due to changes in the algorithms, validation can be based on older correlative measurement data and reprocessed (older) OMI data, and thus no additional correlative measurements need to be planned. For instrument changes (e.g., large changes in the calibration settings), however, renewed correlative measurement efforts are needed, coincident with OMI measurements taken using the new configuration.

The long-term validation strategy calls for the regular comparison at critical times and locations of the data products of OMI with the data from ground based and aircraft/balloon borne measurements. The use of data from ground based networks, including NDSC (Network for the Detection of Stratospheric Change), Dobson, Brewer networks and tropospheric measurement sites (SHADOZ, Southern Hemisphere Additional Ozonesondes) is critical for long-term validation (**VR-56**). Where and when possible, satellite data from other instruments flying at the same time should be used. This includes other instruments on EOS-Aura. A balanced approach is required, where optimal use of available data is made, in combination with additional specific measurements where and when necessary.

6.3 Validation of detected trends in geophysical parameters

An important scientific objective of OMI is to determine trends in geophysical parameters (trace gas distributions, atmospheric constituents, pressure and temperature fields). To enable this, a long-term validation effort that checks the long-term stability of the results is essential.

For trend detection, long data series are necessary. One single satellite instrument can in general not provide this, and therefore records of observations by various satellites are spliced. Each of the satellite instruments should be well-validated, preferably against the same ground based instruments (that must thus overlap in time with both satellite instruments) (**VR-28**). If the satellite observation records overlap in time, they shall also be intercompared. Absolute values as well as trends derived from each of the satellite observations records shall be intercompared (**VR-29**).

As described previously, care should be taken that instrumental trends are properly monitored, through the in-flight calibration and through Level 1B validation. Deterioration of optical components in OMI over time is anticipated, and this should be accurately monitored to prevent inducing spurious trends in the level 2 products.

Another aspect of long-term validation is that auxiliary data may be subject to trends themselves. An example could be the influence of using a fixed rather than an actual temperature profile in the retrievals, while significant temperature trends occur. By regularly validating the OMI level 2 data products against measurements by instruments that use different techniques, and different types of auxiliary data, spurious trends, due to trends in auxiliary data, can be traced (**VR-30**).

6.4 Detection of trends in Level 1B data

As was described in section 3.4.2, long-term validation/calibration using well-defined ground scenes, will be applied to monitor the long-term degradation of the primary telescope mirror. Also, the soft calibration techniques discussed in section 3.4.1 will be important tools for monitoring the long-term stability of the Level 1B products. Candidate scenes are desert areas, or salt lakes, since their surface albedo is stable and well-known, and atmospheric conditions are stable. Details are described in the OMI In-flight Calibration Plan. A link with validation using different orbits must be established.

7 Rehearsal

7.1 Goals

A validation rehearsal is required to test validation procedures, and to get all participants in the OMI validation acquainted with working with OMI and correlative data sets, and with the database (**VR-57**). The purpose of this validation rehearsal is to test database access, availability of cataloguing and reading tools, and other procedures before launch, in order to speed up procedures during the after-launch commissioning phase. A limited set of synthetic OMI data should be available, to allow testing of validation tools (**VR-58**). Note that neither the correlative nor the Aura data files need to contain realistic data, fill values with the proper data format suffice.

The rehearsal shall take place approximately 3 months before launch (**VR-59**). During the rehearsal, data base access and validation tools are tested. All participating correlative instrument groups shall submit at least one file of (synthetic or measured) data to the database. This file shall be in the same format that is used during the later validation campaigns (**VR-60**). Each validation PI planning to download in situ or assimilation model data shall access and search the NASA database at least once and shall retrieve at least one data set delivered to the database by another investigator (**VR-61**). Each validation PI shall install, run and test the software tool that is capable of reading all Aura products (**VR-62**), and install, run and test the coincidence prediction software (**VR-63**). Reports about the validation rehearsal shall be delivered by the validation PI's (**VR-64**). These reports shall include recommendations for improvement to the validation procedures. Also, PI's can give their thoughts on validation methods, i.e. the use of scatter plots, time series, difference plots, in the test report.

The OMI rehearsal may be part of a more general Aura rehearsal campaign. The rehearsal period will emphasize data transfer procedures, including the use of the NASA data storage facility. In addition, the rehearsal shall provide the opportunity to test various software tools involved in the validation procedures.

In detail, the rehearsal goals are:

1. **Testing of communication channels**

Validation PI's shall sign up and login at the NASA validation database at least one time during the validation rehearsal. Each PI planning to submit in situ or assimilation model data shall access the database once to deposit a properly formatted in situ data set to the database. Each PI planning to download in situ or assimilation model data shall access and search the NASA database at least once and shall retrieve at least one data set from another investigator.

2. **Testing of validation handling software**

Each validation PI shall install, run and test the software tool that is capable of reading all Aura products. PI's shall also install, run and test the coincidence prediction software. They can do so by generating overpass schemes from the software, compare to their own observation plans and NASA schedules.

3. **Testing of reporting procedures and generating a test report**

Each PI shall fill in a report on the validation rehearsal. Each PI is also asked to provide recommendations for improvement to the validation procedures. It is required that PI's give their thoughts on validation methods, i.e. the use of scatter plots, time series, difference plots, in the test report.

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Annex A Locations of Ground Based Validation Measurements

This annex provides an overview of existing groundbased measurement sites, that potentially can serve as correlative data stations for OMI validation. This list was taken from the SCIAMACHY Detailed Validation Plan [2002]. Note that it serves as background information only, this list is not complete – and also, not all sites listed here will necessarily take part in OMI validation.

Station	Lat.	Lon.	ID	Instruments	Networks
Alert	82.5	-62.2			
Eureka	80.05	-86.42	eu	FTIR, Lidar Nd:YAG, lidar Raman	NDSC(p)
Ny-Alesund	78.91	11.88	na	DOAS, Dobson, MWR, FTS, FTIR, GUV, O3S, SAOZ, Lidar, radiosondes	NDSC(p), SAOZ
Longyearbyen	78.12	15.40	ly	DOAS	
Barentsburg	78.10	13.20	bb	M-124	
Thule	76.52	-68.76	th	Dobson, O3S, SAOZ	NDSC(p), SAOZ
Scoresbysund	70.48	-21.96	sc	SAOZ	NDSC(c), SAOZ
Tromsö	69.65	18.95	tr	Brewer, Dobson, GUV	
Andoya	69.28	16.18	an	DOAS, lidar, Brewer	NDSC(c)
Murmansk	68.97	33.05	mu	M-124, UV-vis and IR spectrometer	
Kiruna	67.88	21.01	ki	DOAS, FTIR, MWR, backscatter lidar	NDSC(c), NIWA
Sodankylä	67.37	26.67	sk	O3S, SAOZ	NDSC(c), SAOZ
SondreStromfjord	67.00	50.62	ss	Brewer	NDSC(p)
Zhigansk	66.72	123.40	zg	SAOZ	NDSC(c)
Salekhard	66.7	66.7	sa	O3S, SAOZ	SAOZ
Petchora	65.12	57.10	pe	M-124	
Arhangelsk	64.58	40.50	ag	M-124	
Vindeln	64.24	19.77		Dobson/Brewer	
Reykjavik	64.1	-21.5		Brewer	
Orlandet	63.42	9.24	or	O3S	
Yakutsk	62.02	129.63	ya	Brewer, O3S	
Jokioinen	60.8	23.5		O3S	
Harestua	60.22	10.75	ha	DOAS, FTIR	NDSC(c)
Gardermoen	60.1	11.04		O3S	
Lerwick	60.1	-1.1		Dobson, Brewer, O3S	
Saint Petersburg	59.970	30.30	sp	M-124, UV-vis and IR spectrometer	
Oslo	59.93	10.75	os	Brewer, Dobson, GUV	
Norrkoping	58.58	16.15		Brewer	
Ekaterinburg	56.80	60.63	eb	M-124	
Tomsk	56.5	85.0	to	UV-vis and IR spectrometer	NDSC(c)
Moscow	55.75	37.57	mo	M-124, O3S	
Zvenigorod	55.42	36.47	zv	UV-vis and IR spectrometer	NDSC(c)
Obninsk	55.2	36.2	ob	UV-vis and IR spectrometer	
Bremen	53.11	8.86	br	DOAS, MWR, FTS, radiosonde	
Aberystwyth	52.42	-4.07	ab	lidar, O3S, SAOZ	NDSC(c), SAOZ
Legionowo	52.2	20.6		O3S, radiosonde	
Lindenberg	52.2	14.1		O3S, radiosonde, Brewer	
Debilt	52.10	5.18	db	Brewer, O3S	NDSC(c)
Bilthoven	52.1	5.12		Tropospheric lidar	
Cahirciveen (Valentia obs.)	51.6	-10.1		O3S, Brewer, radiosonde	
Uccle	50.80	4.35	uc	Brewer, Dobson, O3S, radiosonde	NDSC(c)

Hradec Kralove	50.2	15.8		Dobson, Brewer	
Camborne	50.1	-5.2		Dobson, Brewer	
Praha	50.0	14.5		O3S	
Oberpfaffenhofen	48	12		FTIR	
Hohenpeissenberg	47.80	11.02	ho	Brewer, Dobson, lidar, O3S	NDSC(c)
Zugspitze	47.42	10.98	zu	FTIR	NDSC(p)
Bern	46.95	7.45	be	MWR, GPS, sun photometer	NDSC(p)
Arosa	46.77	9.76	ar	Brewer, Dobson	NDSC(c)
Jungfraujoch	46.55	7.98	ju	FTIR, lidar, MWR, SAOZ, sun photometer	NDSC(p), SAOZ
Payerne	46.49	6.57	pa	O3S, radiosonde	NDSC(c)
Bordeaux	45.83	-0.53	bo	Dobson, MWR	NDSC(p)
Ispra	45.5	8.4		Brewer, sun photometer	
Bucharest	44.3	26.1		Brewer/Dobson	
Haute Provence	43.94	5.71	oh	DOAS, Dobson, lidar, O3S, SAOZ	NDSC(p), SAOZ
Toronto	43.8	-79		Nd:YAG and Raman Lidar	
Kislovodsk	43.73	42.66	kv	UV-vis and IR spectrometer	NDSC(c)
Perugia	43.1	12.2		GPS receiver	
Issyk-Kul	42.63	76.98	ik	UV-vis and IR spectrometer	NDSC(c)
L'Aquila	42.2	13.2		Lidar, sodar, O3S, MWR, wind profiler, GPS	
Roma	41	12		MWR, vaisala ceilometer, lidar RAMAN	
Thessaloniki	40.4	22.6		Brewer	
Greenbelt	39.1	-76.49		Brewer	
Athens	37.6	23.4		Dobson, O3S, radiosonde	
Table Mountain	34.4	-117.7		Ozon lidar	
Kitt Peak	31.9	-111.6	kp	FTIR	NDSC(c)
Izana	28.29	-16.49	iz	FTIR, DOAS, Brewer	NDSC(c)
Mauna Loa (and Hilo)	19.54	-155.58	ml	FTIR, DOAS, Dobson, Brewer, lidar, O3S	NDSC(p), NIWA
Merida	8	-71	me	DOAS, FTS, lidar, MWR	
Paramaribo	5.81	-55.21	pr	Brewer, O3S	NDSC(c)
Maldives	3	73		DOAS, MWR	
Nairobi	-1.27	36.80	nr	Dobson, DOAS	
Saint Denis	-20.85	55.47	re	DOAS, FTIR, lidar, O3S, SAOZ	NDSC(c), SAOZ
Reunion	-21.5	55.3		OZON lidar, FTIR, DOAS	NDSC(c)
Bauru	-22.35	-49.03	ba	SAOZ	NDSC(c), SAOZ
Wollongong	-34.4	150.9	wo	FTIR	NDSC(c)
Broadmeadows	-37.4	144.5		O3S	
Lauder	-45.05	169.68	la	DOAS, Dobson, FTIR, lidar, MWR, O3S	NDSC(p), NIWA
Kerguelen	-49.36	70.26	ke	SAOZ	NDSC(c), SAOZ
Punta Arenas	-53.20	-70.90	pu	GUV	
Macquarie	-54.5	159.0	ma	DOAS	NDSC(c), NIWA
Marambio	64.28	-56.72	mm	DOAS, Dobson, O3S	NDSC(c)
Vernadsky/Faraday	-65.22	-64.32	fa	Dobson	NDSC(c)
Dumont d'Urville	-66.7	140.01	dd	lidar, O3S, SAOZ	NDSC(p), SAOZ
Rothera	-67.57	-68.13	ro	SAOZ	NDSC(c), SAOZ
Neumayer	-70.65	-8.25	ne	DOAS,O3S	NDSC(c)
Halley	-75.58	-26.77	hb	DOAS, Dobson	NDSC(c)
Arrival Heights	-77.83	166.6	ah	DOAS,FTIR	NDSC(p), NIWA
Belgrano	-77.87	-34.62		Brewer	

O3S: Ozonesondes
SAOZ: Système d'Analyse par Observations Zénithales; network of SAOZ spectrometers
DOAS: Differential Optical Absorption Spectrometry
FTIR: Fourier Transform Infrared Spectrometer
MWR: Millimetre Wave Radiometer
FTS: Fourier Transform Spectroscopy
NDSC: Network for the Detection of Stratospheric Change. (p) = primary site, (c) = complementary site
NIWA: NIWA (National Institute of Water and Atmospheric research) network of UV-visible spectrometers
GUV: Global Ultraviolet filter radiometer
M-124 = Russian filter UV radiometer

Annex B Description of Groundbased Instruments and Networks

Various ground-based remote-sensing techniques provide complementary high-quality measurements of column amount and of vertical distribution of stratospheric ozone and other trace constituents at low, middle and high latitudes, as well as information on aerosol content.

The **Dobson** spectrophotometer measures the ozone column amount with an accuracy of 2-3% for Sun elevation higher than 15°. It is a two-beam instrument based upon the differential absorption method in the ultraviolet Huggins band where ozone exhibits strong absorption features. The measurement principle relies on the ratio of the direct sunlight intensities at two standard wavelengths. The most widely used combination, recommended as the international standard, is the couple of pairs of wavelengths referred to as the AD double pair (305.5-325.4; 317.6-339.8 nm). Since 1958, Dobson spectrophotometers have been deployed in a worldwide network.

The **Brewer** grating spectrophotometer is similar in its principle to the Dobson, but it has an improved design and is fully automated. The determination of the ozone column abundance is obtained from a combination of five wavelengths in the spectral region between 306 and 320 nm. Since the 1980's, Brewer instruments are operated in network as well. Most Brewers are single monochromators, but a small number are double monochromators.

Differential Optical Absorption Spectroscopy (DOAS) applied to UV-visible zenith-sky observations performed at twilight allows the measurement of column amounts of various trace constituents such as ozone, NO_2, O_4, H_2O, OClO or BrO, and of vertical distributions of NO_2. The DOAS retrieval technique consists in studying narrow absorption features after removal of the broadband signal where scattering processes interfere. Based on this technique, several **SAOZ** (Systeme d' Analyse par Observation Zenithale) and other **UV-visible DOAS spectrometers** have performed network operations since the late 1980's and have monitored column amounts of ozone and NO_2 from the Arctic to Antarctica, with an accuracy of about 3-5% for ozone and 10% for NO_2. Ground-based UV-visible DOAS spectrometry with the off-axis viewing geometry permits the separation of tropospheric and stratospheric contributions to the vertical column of species such as ozone, NO_2, BrO, HCHO and SO_2.UV-visible DOAS spectrometers are also operated in solar occultation mode during stratospheric balloon flights, providing vertical distributions of ozone, NO_2, BrO and OClO in the upper troposphere and in the stratosphere up to about 35 km.

Fourier transform infrared spectrometers (FTIR) are used to derive from high spectral resolution measurements of the solar spectrum the column amounts of a large number of atmospheric trace constituents that offer absorption features in the infrared range, including ozone, nitrogen compounds, HCl, HF, CO, CH_4, CFCs, etc. Typical relative uncertainties are currently around 5% for ozone, HCl, HF and HNO_3, 10% for NO and NO_2, and 25% for $ClONO_2$. It is also possible to retrieve height-resolved information on the abundance of molecules such as ozone, N_2O, CO, and CH_4.

Ozonesondes measure the O_3 concentration through the amount of electrons generated in an electro-chemical reaction of O_3 in a KI solution (ECC sonde). The sonde is attached to a balloon, which reaches its maximum altitude at about 30-40 km. At this altitude the balloon bursts and the sonde falls down. Attached to the ozone sonde is a **radio sonde**, measuring pressure, temperature, and humidity. The vertical resolution of the profile is prescribed by the combination of the upward velocity (approximately 5 m/s) of the sonde and the time interval between the measurements (10 seconds), and is of the order of 100 m. The precision of the ozone concentrations is approximately 2%, and the accuracy is 5%. About 30 operational ozone sonde stations exist worldwide, the largest concentration of stations being in the northern mid-latitudes.

The **Differential Absorption Lidar (DIAL)** technique provides accurate vertical distributions of ozone. A stratospheric lidar yields an accuracy within 3% over the whole 15-45 km altitude range and a precision varying typically from 0.5% to 10% corresponding to the related vertical resolution, which varies from 0.5 to 8 km with increasing altitude. These observations require essentially clear sky conditions and are acquired mainly during nighttimes.

Aerosol lidar measurements provide vertical distribution of scattering ratio and particle backscatter at one or several given wavelengths (355, 532 and 1064 nm are typical). Aerosol profiles are obtained from about the tropopause up to 30-35 km with an altitude resolution of 15-75m and with a precision of 2% for the scattering

ratio profile and a precision from 8 to 16% (volcanic/background) for the vertically integrated particle backscatter. An aerosol model is used to retrieve aerosol extinction, mass, and surface data from backscatter profiles. The depolarising effect of aerosols can be recorded by a polarising beamsplitter, and depolarisation measurements are used to distinguish between particles of different shapes and phase states. Soundings with **backscatter sondes** add in-situ information about particle concentration profiles.

Rayleigh lidars allow the observation of the atmospheric temperature from the Rayleigh backscattered signal in the upper troposphere, the stratosphere and the mesosphere, while **Doppler lidars** observe atmospheric winds.

Microwave radiometry, which is based on the study of collision broadened emission lines of atmospheric constituents with high resolution in frequency, allows the inference of altitude profiles of atmospheric trace gases in the range of 20 to 70 km, and is well suited to investigate their short term variations in the stratosphere and in the mesosphere. Observations are insensitive to weather conditions and aerosol load. Ozone radiometers working at 142 or 110 GHz yield an accuracy of 10-15% with an altitude resolution of approximately 8-12 km. The frequencies of 278 and 204 GHz are routinely used to measure vertical distributions of ClO. Microwave radiometers using newest technology of superconducting diodes allow measurements at different frequencies for the observation of other minor constituents such as H_2O, HO_2, HNO_3, SO_2, or N_2O.

The **Network for the Detection of Stratospheric Change (NDSC)** is based upon the complementarity of the aforementioned ground-based techniques (Lambert *et al.*, 1999). Dedicated to the observation and understanding of stratospheric changes and their impact on climate, this network of high-quality remote-sounding research stations consists of about seventy sites distributed in five primary stations (Arctic, Alpine, Hawaii, New Zealand, Antarctic), fully equipped with almost all the observation techniques, and a number of complementary stations, equipped with a limited number of instruments only but validated in the same way as the primary stations. The NDSC is a major contributor of the Global Ozone Observing System (GO_3OS) of the World Meteorological Organisation (WMO) within the framework of its Global Atmosphere Watch (GAW). Complementary to the NDSC, seventeen SAOZ and other NDSC-qualified UV-visible DOAS spectrometers constitute the so-called **SAOZ/UV-visible DOAS network** that monitor ozone and NO_2 column amounts at a variety of sites in the world, from the Arctic to the Antarctic. The instruments operated at the NDSC and UV-visible DOAS stations regularly participate to algorithm exercises and to blind instrument intercomparison campaigns in order to control their quality, to assess their accuracy, to examine their consistency with other types of instruments, and to certify them for use in the NDSC.

Sunphotometers measure the direct sunlight in ca. 6 narrow spectral bands between 360 and 1000 nm. By using the Langley method the optical thickness of the atmosphere can be determined. After subtraction of the Rayleigh optical thickness and the ozone optical thickness, the aerosol optical thickness is obtained.

Aeronet (AErosol RObotic NETwork) is an optical ground based aerosol monitoring network and data archive consisting of sunphotometers. This network provides globally distributed near real time observations of aerosol spectral optical depths, aerosol size distributions, and precipitable water in diverse aerosol regimes.

CMDL network: The CMDL co-operative sampling network is an ongoing collaboration between government agencies and universities around the world. Samples of air are collected on a weekly basis at about 70 locations and the shipped to Boulder for analysis of CO_2, CO, CH_4, H_2, and most recently N_2O and SF_6. Most sites are located in the marine boundary layer, while a few are situated on mountaintops or in areas of regional scale pollution.

Annex C Validation Aircraft

Aircraft are excellent platforms to validate space experiments, because an aircraft can operate virtually everywhere on the globe under most weather conditions and in all seasons. Furthermore campaigns can be planned to very closely match in time and space the observing characteristics of a space sensor.

Aircraft available in the US have been documented elsewhere (Anderson et al., 2002; Froidevaux and Douglass, 2001).

The following European research aircraft have previously been used successfully in satellite sensor validation campaigns and/or atmospheric research campaigns:

FALCON Germany.
Operated by DLR, Oberpfaffenhofen in Germany, this aircraft (operating below 13 km) will perform two main flight campaigns, both covering the geographic area from the equator up to high northern latitudes. One of these campaigns will take place in early spring, the other in autumn, thereby covering two distinct atmospheric situations. For the campaigns, the Falcon will be equipped with three remote sensing instruments: The Airborne Submillimetre wave Radiometer (ASUR), operated by IUP Bremen, the Ozone Lidar Experiment (OLEX) operated by DLR and the Airborne MultiAxis Differential Optical Absorption Spectrometer (AMAXDOAS) developed and operated by the IUP Bremen and IUP Heidelberg. Each of the proposed instruments have their own set of measurement parameters, ASUR: stratospheric profiles of O_3, H_2O, N_2O, ClO and BrO, OLEX: stratospheric profiles of O_3, stratospheric aerosol extinction, aerosol/molecular backscatter ratios and particle depolarisation, AMAXDOAS: stratospheric and tropospheric columns of O_3, NO_2, BrO and OClO.

M-55 GEOPHYSIKA, High-altitude Aircraft, Russia/Italy.
The activities of the Russian aircraft M-55 are coordinated in Western Europe by L. Stefanutti (CNR-IROE, Florence) and by his deputy R. McKenzie (European Ozone Research Coordinating Unit, Cambridge). This aircraft flies at a cruising altitude of up to 21 km and cruising speed of 720 km/h. The endurance is 6.5 hours (i.e. track of 4000 km). The measurements will be made during three deployments, which cover the middle and high latitudes.
The aircraft will be equipped with the following remote sensing instrumentation: MIPAS-STR, SAFIRE-A, MAL, GASCOD-A and the in-situ instruments: HAGAR, FISH, FLASH, ECOC, FOZAN, SIOUX and HALOX. This instrumentation covers most of the level-2 chemical products from Sciamachy.
The MIPAS-STR is a version of MIPAS, which has been adapted to STRatospheric flights on aircraft. It was originally designed for the German aircraft STRATOS-B. Its characteristics correspond to the space-borne MIPAS instrument.
SAFIRE-A is a Fourier Transform Spectrometer for the observation of the atmospheric emission spectrum in the far Infrared spectral region. The project involves Italian, British, French and US groups. The instrument is capable of measuring the vertical distribution from tropopause to flight altitude and the vertical column above flight height of the minor stratospheric constituents that display features in the far infrared region, namely O_2, O_3, H_2O, H_2O_2, OH, HO_2, HDO, HCl, HOCl, ClO, N_2O, HNO_3, NO_2, HBr, HF, CO and HCN.
FOZAN (Fast Ozone Analyser) operates on the chemiluminescent reaction between the ozone and the airflow and the solid-state sensor.
ECOC (Electro-Chemical Ozone Cell) is an ozonometer.
FLASH (Fluorescent Airborne Stratospheric Hygrometer) and ACH (Aircraft Condensation Hygrometer) are both used for water vapour measurements.
GASCOD (Gas Absorption Spectrometer Correlating Optical Differences) operates in the ultraviolet and visible spectral regions and enables several trace gases (O_3, NO_2, BrO, OClO) to be measured simultaneously.

MOZAIC, European program, coordinated by CNRS – France
The MOZAIC program was designed especially to collect O_3 and H_2O in-situ data, using automatic equipment installed aboard five long-range Airbus A340 aircraft flying regularly all over the world. MOZAIC started in

August 1994 and is still running. Presently, the program is in its third phase (up to March 2003) and a fourth phase is expected for at least 3 more years (thus providing measurements up to at least the end of 2006). Since September 2001 there have been additional in-situ measurements of CO and NOy. 90 % of the data are recorded at cruise altitude, between 9 and 12 km, corresponding to the upper troposphere – lower stratosphere (UTLS) region. These commercial aircraft do not fly higher than 41000 feet (or 196 hPa). The other 10 % of measurements are performed during take off and landing phases at the vicinity of about 60 airports (Europe, USA, Caribbean, Northern South America and Brazil, equatorial and south Africa, middle East, India and South East Asia, North West of China and Japan). Thus the MOZAIC aircraft are the only ones sampling the lower atmosphere so regularly (for mid-northern latitudes at least) and so densely (between 9 and 12 km altitude) and for regions not sampled by ozone sondes (northern tropics for example). Details concerning the coverage of the MOZAIC data and the frequency of measurements over each airport can be found on the program web site http://www.aero.obs-mip.fr/mozaic.

In the frame of the Sciamachy validation MOZAIC is of particular interest because it provides regular (high quality and precision) measurements in the UTLS region and soundings over regions never sampled before such as the northern tropics for example. The horizontal flights at the vicinity of the tropopause will help in assessing the ozone distribution in both the upper troposphere and lower stratosphere. The MOZAIC database also contains potential vorticity analyses, thus giving the position of the aircraft relatively to the tropopause. One problem for assessing tropospheric or stratospheric ozone (columns or profiles) will be to well define and to well localise the tropopause. In that sense MOZAIC provides the most appropriate data set. Moreover, this data set at 9-12 km altitude will definitely help in validating the satellite measurements obtained in the limb-scanning mode.

Annex D Satellite Instruments

Table G.1 and Table G. 2 give an overview of the products that can be retrieved from current and future satellite missions in respectively the troposphere and stratosphere. This is followed by more detailed information per instrument (EOS reference Handbook 1995, 1995 CEOS yearbook).

Table G.1 **Satellite instruments and their products retrieved in the troposphere. p=profile, c=column, ut=upper troposphere, x indicates that some information concerning this product is measured, phys. par. = physical parameters (p, T, clouds etc. see text for details), * = not all species of this group are measured.**

{PRIVATE} Instrument	Phys. par.	Aerosol	O_3	NOx*	ClOx*	SO_2	HCHO	BrO
AATSR	x	x						
AIRS	x							
ASTER	x							
ATSR-2	x	x						
AVHRR/3	x							
EOSP	x	x						
GOME	x		p,c	c	c	c	c	c
GOME-2	x	x	p,c	c	c	c	c	c
HIRDLS	ut	ut	ut	ut				
MASTER	ut		ut		ut			ut
MERIS	x	x						
MIPAS	x	x	ut	ut	ut			
MISR	x	x						
MLS			ut			ut		
MODIS-N	x	x						
MOPITT								
MVIRI	x							
MWR								
OMI			c	c				
POLDER	x	x						
SBUV-2			c					
SCIAMACHY	c	c	c	c	c	c	c	c
SEVIRI	x		c					
TES			p	p				
TOMS			c					
TOVS	p		c					

Table G. 2 **Satellite instruments and their products retrieved in the stratosphere. p=profile, c=column, x indicates that some information concerning this product is measured, phys. par. = physical parameters (p, T, clouds etc. see text for details), * = not all species of this group are measured**

{PRIVATE} Instrument	Phys. par.	aerosol	O_3	NOx*	ClOx*	SO_2	HCHO	BrO
ATSR-2	x	x						
AVHRR/3	x							
EOSP	x	x						
GOME	x		p,c	c	c	c	c	c
GOME-2	x		p,c	c	c	c	c	c
GOMOS	p	p	p	p	p			p
HALOE	p	p	p	p				
HIRDLS	p	p	p	p				
ILAS II	x	p	p	p				
MASTER	p		p		p			p
MIPAS	p	p	p	p	p			
MLS			p	p	p	p		
MOPITT								
OSIRIS	p	p	p	p				
OMI	x		c	c				
SAGE II	P	p	P	p				
SAGE III	p	p	p	p	p			
SBUV-2			c					
SCIAMACHY	p,c	p,c	p,c	p,c	c	c	c	c
SMR	p		p	p	p			
TOMS			c					
TOVS	p		c					

AATSR

Mission: ENVISAT
Time frame: 2002-2007.
Viewing geometry: Two-angle.
Spectral Range: 7 channels in the visible and IR (555, 659, 865, 1600, 3700, 10850 and 12000 nm).
Application/Products: a.o. cloud cover and cloud top height, sea and land surface temperature.
Altitude Range: n.a.
Spatial Resolution: 1 km x 1 km.
Swath width: 500 km.
Accuracy: Sea surface temperature: < 0.5K over 0.5 ° x 0.5 ° (lat/long) area with 80 % cloud cover. Land surface temperature: 0.1K relative.

ACE

Mission: SCISAT
Time frame: 2002-2004
Viewing geometry: Direct Sun
Spectral Range: 4 bands: 5.5 - 13 µm and 2 - 5.5 µm (FTS part); 0.525 and 1.02 (VNI part)
Application/Products: Ozone profiles, aerosols, other molecules.
Altitude Range: n.a.
Spatial Resolution:

Swath width:	500 km.
Accuracy:	Sea surface temperature: < 0.5K over 0.5 ° x 0.5 ° (lat/long) area with 80 % cloud cover. Land surface temperature: 0.1K relative.

AIRS

Mission:	EOS-Aqua (PM).
Time frame:	2002-2007.
Viewing geometry:	Nadir.
Spectral Range:	Visible-SWIR: 0.4-1.7 µm. TIR: 3.4-15.4 µm.
Application/Products:	Temperature/humidity sounding.
Altitude Range:	Surface to 100 hPa.
Spatial Resolution:	Vertical: 1-2 km, horizontal: 13.5 km at nadir.
Swath width:	1650 km.
Accuracy:	Temperature retrieval: 1K.

ATSR-2

Mission:	ERS-2.
Time frame:	1995-now.
Viewing geometry:	Nadir, along-track scanning.
Spectral Range:	4 SWIR-TIR channels: 1.6, 3.7, 11.0 and 12 µm. 4 Visible/Reflected channels: 0.65, 0.85, 1.27 and 1.6 µm. Microwave channels: 23.8 and 36.5 GHz with a bandwidth of 400 MHz.
Application/Products:	Sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content.
Altitude Range:	n.a.
Spatial Resolution:	IR ocean channels: 1 km x 1 km. Microwave near nadir viewing 20 km instantaneous field of view.
Swath width:	500 km.
Accuracy:	Sea surface temperature to < 0.5K over 0.5 ° x 0.5 ° (lat/long) area with 80% cloud cover. Land surface temperature: 0.1K.

AVHRR/3

Mission:	NOAA 16, 17, N & N'.
Time frame:	1998-2009.
Viewing geometry:	Nadir, cross-track scanning.
Spectral Range:	Five spectral channels (1: 0.58-0.68 µm, 2: 0.75-1.1 µm, 3: 3.55-3.93 µm, 4 and 5: 10.5-12.5 µm).
Application/Products:	Applications for channel 1 include daytime cloud and surface mapping. Applications for channels 3 (3.55 to 3.93 micrometers), 4 and 5 (10.5 to 12.5 micrometers) include sea surface temperature monitoring and day/night-time cloud mapping, snow and ice extent, ice or snow melt inception, and temperatures of radiating surfaces.
Altitude Range:	n.a.
Spatial Resolution:	1.1 km (compressed global area coverage (GAC) data recorded at 4 km resolution).
Swath width:	3000 km (approximate), 55.4 ° scan off nadir.
Accuracy:	

EOSP

Mission:	EOS-AM 2.
Time frame:	2004-2007.
Viewing geometry:	Nadir & limb.
Spectral Range:	Visible and near-infrared (0.41 to 2.25 µm) (12 channels).

Application/Products: Global maps of cloud and aerosol properties from retrievals of 12-channel radiance and polarisation measurements. Specific products are:

- Cloud-top pressure, with 30 m vertical resolution and 40 km horizontal resolution.
- Cloud particle phase at cloud top, with 100 km horizontal resolution.
- Cloud particle size at cloud top, with 100 km horizontal resolution.
- Cloud optical thickness, with 40 km horizontal resolution.
- Aerosol optical thickness at an altitude range of 0 to 35 km, with 40-km horizontal resolution.
- Atmospheric correction radiances covering the spectral region from 0.41 to 2.25 µm, with 40 km horizontal resolution.

Altitude Range: see products.
Spatial Resolution: 10 x 10 km at nadir, see products.
Swath width: Limb to limb scan (± 65 deg).
Accuracy: 5 % radiance. 0.2 % polarisation.

GOME

Mission: ERS-2.
Time frame: 1995-now.
Viewing geometry: Nadir.
Spectral Range: 240-790 nm with a resolution of 0.2 to 0.4 nm.
Application/Products:

- Solar irradiance: Once a day GOME measures the solar irradiance spectrum.
- Earth radiance: An Earth radiance spectrum is obtained for every ground pixel.
- Earth polarisation: Is measured in 3 bands.
- Ozone column.
- Ozone profile: Ozone profiles are not yet derived operationally, but probably will be in the near future.
- NO_2 column.
- BrO column: only scientific data processing.
- HCHO column: only scientific data processing.
- OClO column: only scientific data processing.

Altitude Range: 0 - 60 km (for O_3 profiles).
Spatial Resolution: 40 x 320 km (nominal). Global coverage in 3 days. Vertical: for height 0 to 12 km: 6km and for height 14-60 km: 4 km.
Swath width: 960 km.
Accuracy: The GOME total ozone column has a precision better than 2 % and an accuracy depending on solar zenith angle (better than 5 % for solar zenith angles less than 80 deg.). The accuracy of the NO_2 column for regions with relatively low tropospheric NO_2 is estimated to be about 10 %.

GOME-2

Mission: METOP-1.
Time frame: 2005-2010.
Viewing geometry: Nadir.
Spectral Range: 240-790 nm.
Application/Products: Basically the list of observable species/parameters for GOME-2 will be the same as for GOME-1.
Altitude Range: 0 - 60 km (for O_3 profiles).
Spatial Resolution: (At 960 km swath) Horizontal: 40 x 40 km to 320 x 320 km. Vertical: for height 0 to 12 km: 6km and for height 14-60 km: 4 km.
Swath width: to 1920 km.
Accuracy: Ozone columns: < 1%. Ozone profiles 0-12 km: <10 %, 14-60 km: <5 %. Precision <1 %.

GOMOS

Mission:	ENVISAT.
Time frame:	2002-2007.
Viewing geometry:	Stellar occultation.
Spectral Range:	UV-Visible: 0.25-0.675 µm, NIR: 0.756-0.773 µm, 0.926-0.952 µm.
Application/Products:	Stratospheric profiles of ozone, NO_2, NO_3, H_2O, temperature profiles and aerosols plus some other trace species.
Altitude Range:	15 - 40 km (for O_3 15 - 90 km). Note: 15 km to be replaced by 20 km for daytime occultation.
Spatial Resolution:	Vertical 1.7 km.
Swath width:	n.a.
Accuracy:	Self-calibrating. The quality of GOMOS data is best at night, at day it depends on solar angles, and it varies a lot between different targeted stars.

HIRDLS

Mission:	EOS-Aura.
Time frame:	2004-2010.
Viewing geometry:	Limb.
Spectral Range:	TIR 6-18 µm in 21 channels.
Application/Products:	HIRDLS is designed to sound the upper troposphere, stratosphere and mesosphere to determine global distribution of temperature and concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $ClOlNO_2$, aerosols and the locations of polar stratospheric clouds and cloud tops.
Altitude Range:	5-80 km.
Spatial Resolution:	4 ° x 4 ° (400 x 400 km) and 1 km vertical resolution; Programmable to other modes and resolution.
Swath width:	6 profiles across 2000-3000 km.
Accuracy:	5-10 % mixing ratio absolute accuracy.

ILAS II

Mission:	ADEOS II.
Time frame:	2002-2005.
Viewing geometry:	Limb, solar occultation.
Spectral Range:	Infrared region (2-13 µm) and the near visible region (753 to 784 nm).
Application/Products:	O_3, HNO_3, CH_4, N_2O, H_2O, CFC_{11}, CFC_{12}, $ClONO_2$, NO_2, aerosols, pressure and temperature.
Altitude Range:	10-60 km.
Spatial Resolution:	Horizontal: IR 13 x 2 km, visible: 2 x 2 km. Vertical resolution: 1km.
Swath width:	
Accuracy:	5 % (1% for ozone).

MASTER

Mission:	future ESA missions.
Time frame:	2003-2013.
Viewing geometry:	Limb.
Spectral Range:	Microwave: 199-207, 296-306, 318-326, 342-348 GHz.
Application/Products:	Upper troposphere/lower stratosphere profiles of O_3, H_2O, CO, HNO_3, SO_2, N_2O, ClOx, pressure and temperature.
Altitude Range:	Higher troposphere, lower stratosphere.
Spatial Resolution:	3 km.
Swath width:	1 - 1.5 K.
Accuracy:	

MERIS

Mission:	ENVISAT
Time frame:	2002-2007.
Viewing geometry:	Nadir.
Spectral Range:	Visible and near-infrared range, 390 - 1040 nm in 15 bands.
Application/Products:	Measurement of the solar reflected radiation from the Earth's surface and from clouds through the atmosphere. The data will be used for the generation of large-scale maps, a.o. for clouds, aerosol and water vapour.
Altitude Range:	n.a.
Spatial Resolution:	Full resolution: 0.25 km x 0.25 km. Reduced resolution: 1 km x 1 km.
Swath width:	1150 km (global coverage in 3 days).
Accuracy:	Solar Reflectance absolute < 2 %.

MIPAS

Mission:	ENVISAT.
Time frame:	2002-2007.
Viewing geometry:	Limb.
Spectral Range:	4.15 µm - 14.6 µm.
Application/Products:	By operational data processing (on-line and off-line) distributions of the following parameters will be produced: p, T, O_3, H_2O, CH_4, N_2O and HNO_3 (later others could be added). Scientific data processing in Karlsruhe will lead to trace gas profiles of the following species (planned): NO, NO_2, N_2O_5, HNO_4, $ClONO_2$, CFC-11, CFC-12, CFC-22, CO and others.
Altitude Range:	5 - 80 km (NO_2 20 - 40 km, aerosol 5- 30 km).
Spatial Resolution:	Vertical resolution: 3km, horizontal resolution: 30km.
Swath width:	
Accuracy:	Radiometric precision 1-3 %.

MISR

Mission:	EOS-Terra
Time frame:	2004-2009.
Viewing geometry:	Nine viewing angles. Nadir, forward and afterward of nadir.
Spectral Range:	Four spectral bands centred at 443, 555, 670 and 865 nm.
Application/Products:	Two standard Level 2 science products: The top of Atmosphere/Cloud product and the Aerosol/Surface Product.
Altitude Range:	n.a.
Spatial Resolution:	Spatial sampling: 275, 550 or 1100 m.
Swath width:	360 km.
Accuracy:	Level 1 products absolute 3-6 % relative 1-2 %, Level 2 products parameter dependent. 0.03 hemispherical albedo, 10 % aerosol opacity.

MLS

Mission:	EOS-Aura.
Time frame:	2004-2010.
Viewing geometry:	Limb.
Spectral Range:	Microwave. Spectral bands: 200, 300, 600 GHz and 2.5 THz.
Application/Products:	Lower stratospheric temperature and concentrations of O_3, ClO, HCl, HNO_3, H_2O, N_2O, OH and upper tropospheric concentrations of H_2O and O_3. Furthermore MLS measures SO_2, and other gases mentioned above, in volcanic plumes.
Altitude Range:	0-80 km.
Spatial Resolution:	3 x 300 km horizontal x 1.2 km vertical.
Swath width:	
Accuracy:	Level 1 B radiance < 3 %.

MODIS

Mission: EOS-Terra + EOS-Aqua
Time frame: 1999-2007.
Viewing geometry: Cross-track scanning.
Spectral Range: 36 spectral bands; 21 within 0.4 to 3.0 µm and 15 within 3 to 14.5 µm.
Application/Products: MODIS provides specific global data products, which a.o. include the following:

- Surface temperature.
- Cloud cover.
- Cloud properties characterised by cloud droplet phase, optical thickness, droplet size, cloud top pressure and emissivity.
- Aerosol properties defined as optical thickness, particle size and mass transport.
- Cirrus cloud cover.

Altitude Range: n.a.
Spatial Resolution: Surface temperature 1 km, cloud cover 250 m by day 1 km by night.
Swath width: 2300 km at 110° (±55°;).
Accuracy: Surface temperature 0.2 K for ocean and 1 K for land.

MOPITT

Mission: EOS-Terra.
Time frame: 1999-2004.
Viewing geometry: Nadir.
Spectral Range: 4.6 and 2.3 µm band for CO, 2.2 µm band for CH_4.
Application/Products: Total column amount of CO and CH_4 and CO profiles.
Altitude Range: 0-15 km.
Spatial Resolution: Horizontal 22 km, vertical resolution for CO profiles 3km.
Swath width: 612 km, swath length 88 km
Accuracy: CH_4 columns1 %, CO columns 10 %, CO profiles 10 %.

MVIRI

Mission: Meteosat.
Time frame: 1997-2002.
Viewing geometry: Nadir.
Spectral Range: Visible-NIR: 0.5 to 0.9 µm, TIR: 5.7 to 7.1 µm (water vapour), 10.5 to 12.5 µm.
Application/Products: a.o. cloud cover and cloud top height.
Altitude Range: n.a.
Spatial Resolution: Visible: 2.5 km, water vapour: 5 km, (after processing) TIR: 5 km.
Swath width: Full Earth disc.
Accuracy:

MWR

Mission: ENVISAT.
Time frame: 2002-2007.
Viewing geometry: Near nadir viewing.
Spectral Range: Microwave. The frequencies are 23.8 and 36.5 GHz, with a 400 MHz bandwidth.
Application/Products: The altimeter path delay due to atmospheric humidity, the vertically integrated water vapour content, and the integrated cloud liquid water content (but not used quantitatively).
Altitude Range: n.a.
Spatial Resolution: 20 km.
Swath width: 20 km.
Accuracy: *(Estimated)* On the brightness temperatures 3K absolute accuracy, but about 0.5K radiometric sensitivity. The water vapour is obtained with less than 0.3 g/cm^2 uncertainty. The estimated accuracy on the liquid water content is 0.05 km/m^2.

OMI

Mission:	EOS-Aura
Time frame:	2004-2010
Viewing geometry:	Nadir
Spectral Range:	270-500 nm
Application/Products:	Columns of: O_3, NO_2, SO_2, BrO, OClO, HCHO. O_3 profiles, aerosols, clouds, surface UV-B flux
Altitude Range:	O_3 profiles: 0-50 km
Spatial Resolution:	Nominal at nadir for most products: 13 x 24 km^2
Swath width:	2600 km
Accuracy:	See section 2.3 of this document

OCO

Mission:	OCO (A-train)
Time frame:	2007-
Viewing geometry:	Nadir, also “glint” and “target” modes.
Spectral Range:	Three bands: 760 nm (O_2-A band), 1580 nm, 2060 nm.
Application/Products:	CO_2, cloud top pressure, fluxes
Altitude Range:	
Spatial Resolution:	
Swath width:	
Accuracy:	

OSIRIS

Mission:	Odin
Time frame:	2001-2003.
Viewing geometry:	Limb.
Spectral Range:	Imaging spectrograph: 280-800 nm, near-infrared (NIR) telescopes: operating at 1.27 micrometers; each of the continuous bands being 10 nanometers in bandwidth.
Application/Products:	Aerosols, p, T, O_3, O_2, O_4, NO, NO_2 and possibly ClO.
Altitude Range:	20 - 70 km , 70 - 120 km for NO.
Spatial Resolution:	Vertical resolution: 1-2 km possible.
Swath width:	
Accuracy:	Ozone: 15 %.

POLDER

Mission:	ADEOS II (also on PARASOL)
Time frame:	2002-2005.
Viewing geometry:	Nadir.
Spectral Range:	The measuring wavelengths are 443, 670 and 865 nm.
Application/Products:	Polarization of the sunlight, yielding cloud/aerosol information.
Altitude Range:	n.a.
Spatial Resolution:	6 x 6 km.
Swath width:	2400 km (across track) x 1800 km (along track).
Accuracy:	Expected accuracy of 2-3 %.

SAGE II

Mission:	ERBS
Time frame:	1984 – present
Viewing geometry:	Solar and lunar occultation.
Spectral Range:	7 between 385 and 1020 nm.
Application/Products:	• Ozone profiles, from the mid-troposphere to 85 km. • NO_2 profiles, from the tropopause to 45 km. • H_2O profiles, from the planetary boundary layer to 50 km. • Troposferic aerosol.

SAGE III

Mission: METEOR-3M N1
Time frame: 2001-2004
Viewing geometry: Solar and lunar occultation.
Spectral Range: Nine spectral regions between 290-1550 nm.
Application/Products:
- Ozone profiles, from the mid-troposphere to 85 km.
- NO_2 profiles, from the tropopause to 45 km.
- H_2O profiles, from the planetary boundary layer to 50 km.
- NO_3 profiles (stratosphere) from lunar occultation measurements.
- OClO profiles (stratosphere) from lunar occultation measurements.
- Aerosols and clouds, from the troposphere into the stratosphere and where appropriate, the mesosphere.
- Temperature/pressure profiles.

Altitude Range: See products.
Spatial Resolution: 1-2 km in the vertical.
Swath width:
Accuracy:

SBUV/2

Mission: NOAA 9, 11, 14, 16, 17, N & N'.
Time frame: 1996-2009.
Viewing geometry: Nadir, no scan mirror.
Spectral Range: Small bands in the wavelength region 100-400 nm.
Application/Products: Spectral Earth radiance, solar irradiance measurements and trace gases including ozone distribution.
Altitude Range: 25-55 km.
Spatial Resolution: 170 km. Vertical resolution O_3 profile: 8-15 km.
Swath width: Nadir pointing.
Accuracy: Total ozone concentration: absolute accuracy of 1 %.

SEVIRI

Mission: MSG1, MSG2 and MSG3 (EUMETSAT).
Time frame: 2002-2014.
Viewing geometry: Nadir.
Spectral Range: Visible: 0.56-0.71 µm, 0.5-0.9 µm (broadband). NIR: 0.71-0.95 µm. SWIR: 1.44-1.79 µm. TIR: 3.4-4.2 µm, 8.3-9.1 µm, 9.8-11.8 µm, 11.0-13.0 µm, 5.35-7.15 µm, 6.85-7.85 µm, 9.46-9.94 µm, 13.04-13.76 µm.
Application/Products: a.o. cloud cover, cloud top height and total ozone.
Altitude Range:
Spatial Resolution: 1 km for one broadband visible channel, 3 km for all other channels.
Swath width: Full Earth disc.
Accuracy:

SIM

Mission: SORCE.
Time frame: 2002-2005.
Viewing geometry: Sun pointing
Spectral Range: 250 – 2000 nm
Application/Products: Spectral irradiance.
Altitude Range: n.a.
Spatial Resolution: n.a.
Swath width: Full solar disc.
Accuracy: 0.1 %

SMR

Mission:	Odin.
Time frame:	2001-2003.
Viewing geometry:	Limb.
Spectral Range:	Frequencies: 118.25-119.25 GHz, 486.1-503.9 GHz, 541.0-580.4 GHz. Bandwidth: 100 MHz to 1 GHz.
Application/Products:	p, T, O_3, CO, NO_2, N_2O, NO, O_2, ClO and H_2O.
Altitude Range:	20-80 km.
Spatial Resolution:	11-12 km.
Swath width:	
Accuracy:	

SOLSTICE II

Mission:	SORCE.
Time frame:	2002-2005.
Viewing geometry:	Sun pointing.
Spectral Range:	5-440 nm (solar UV irradiance from 30 to 440 nm, the solar UV irradiance from 115 to 320 nm at much higher resolution, and extreme UV irradiance between 5 and 20 nm).
Application/Products:	Solar ultraviolet irradiance.
Altitude Range:	n.a.
Spatial Resolution:	n.a.
Swath width:	Full solar disc.
Accuracy:	Absolute: 3-5 %. Relative: 1 %.

TES

Mission:	EOS-Aura.
Time frame:	2004-2010.
Viewing geometry:	Limb and nadir.
Spectral Range:	2.3 to 15.4 μm at a spectral resolution of 0.025 cm^{-1}.
Application/Products:	Vertical concentration profiles of O_3, CO, CH_4, H_2O, NO, NO_2, CFCs and nitric acid from the surface to the lower stratosphere.
Altitude Range:	Limb: 0-32 km.
Spatial Resolution:	Vertical (limb): 2.3 km. Horizontal (nadir): 50x5 km (global) or 5x0.5 km (local). The horizontal resolution of the data products is 53 x 169 km.
Swath width:	
Accuracy:	

TOMS

Mission:	Earth Probe
Time frame:	1996-present
Viewing geometry:	Nadir.
Spectral Range:	6 narrow spectral bands centred at the following wavelengths: 308.6, 312.5, 317.5, 322.3, 331.2, 360.0 nm.
Application/Products:	Total column amounts of ozone, reflectance, aerosol index
Altitude Range:	n.a.
Spatial Resolution:	38 x 38 km.
Swath width:	3100 km.
Accuracy:	Ozone: 1-2 %, the precision of the TOMS albedo measurement is better than 0.8 % at all wavelengths.

TOVS

Mission:	NOAA series 16,17, N and N'.
Time frame:	1998-2009.
Viewing geometry:	Nadir.
Spectral Range:	19 bands in the following wavelength regions: 690 nm, 3760-4570 nm, 6720-14950 nm and MW a.o. the 5.5-mm oxygen band.
Application/Products:	Water vapour content, temperature profiles and O_3 total columns.
Altitude Range:	Temperature profiles: 0 - 65 km.
Spatial Resolution:	20 x 20 km.
Swath width:	2800 km.
Accuracy:	Ozone total columns: 5-7 %.

Annex E List of Acronyms

A	Aircraft measurements
AATSR	Advanced Along Track Scanning Radiometer
ACE	Atmospheric Chemistry Explorer (on SCISAT)
ACH	Aircraft Condensation Hygrometer (in-situ instrument for water vapour measurements)
ADEOS	ADvanced Earth Observing System
Aeronet	AErosol RObotic NETwork
AES	Atmospheric Environmental Service (of Environment Canada)
AIRS	Atmospheric Infrared Sounder (on Aqua)
AMAXDOAS	Airborne MultiAxis Differential Optical Absorption Spectrometer
AO	Announcement of Opportunity
AOT	Aerosol Optical Thickness
Aqua	name of a satellite (not an acronym)
ARM	Atmospheric Radiation Mission
ASSET	Assimilation of Envisat Data (EU Project)
ASTER	Advance Spaceborne Thermal Emission and Reflectance Radiometer
ASUR	Airborne Submillimetre wave Radiometer
Aura	name of a satellite (not an acronym)
AYBD	Algorithm Theoretical Basis Document
ATSR	Along Track Scanning Radiometer
AVE	Aura Validation Experiment
AVHRR	Advanced Very High Resolution Radiometer
B	Balloon, sonde (or small balloon), rocket measurements
CALIPSO	Cloud-Aerosol Lidar And Infrared Pathfinder Spaceborne Observations
CEOS	Committee for Earth Observation Satellites
Cimel	Aerosol instrument manufacturer
CMDL	(NOAA) Climate Monitoring & Diagnostics Laboratory
CNR-IROE	Consiglio Nazionale Ricerche - Istituto Ricerca Onde Elettromagnetiche (Florence, Italy)
CNRS	Centre National pour la Recherche Scientifique
COSPEC	Correlation Spectrometer
DAAC	Distributed Active Archive Center
DIAL	Differential Absorption Lidar
DLR	Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Centre
DOAS	Differential Optical Absorption Spectroscopy
DU	Dobson Unit
Earlinet	European Aerosol Research Lidar Network
ECC	Electrochemical Concentration Cell
ECMWF	European Centre for Medium-range Weather Prediction
ECOC	Electro-Chemical Ozone Cell (an ozonometer)
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EP (TOMS)	Earth Probe (TOMS)
ERBS	Earth Radiation Budget Satellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

FLASH	Fluorescent Airborne Stratospheric Hygrometer (in-situ instrument for water vapor measurements)
FMI	Finnish Meteorological Institute
FOZAN	Fast Ozone Analyser (in situ instrument)
FRESCO	Fast Retrieval Scheme for Cloud Observables
FTIR	Fourier Transform Infra-red Radiometer
FTS	Fourier Transform Spectroscopy (or Spectrometer)
FWHM	Full Width at Half Maximum
GASCOD	Gas Absorption Spectrometer Correlating Optical Differences
G	Ground-based measurements
GAC	Global Area Coverage
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GLAS	Geoscience Laser Altimeter System
GOA	GOME Assimilated and Validated Ozone and NO2 Fields for Scientific Users and for Model Validation
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
(NASA/)GTE	(NASA/)
GUV	Global Ultraviolet filter radiometer
HAGAR	High Altitude Gas Analyser
HALOE	Halogen Occultation Experiment
HALOX	Halogen Oxide Monitor
HIRDLS	High Resolution Dynamics Limb Sounder
IGAC	International Global Atmospheric Chemistry
ILAS	Improved Limb Atmospheric Spectrometer
INTEX	Intercontinental Chemical Transport Experiment
IUP	Institut für Umweltphysik (Heidelberg)
JPL	Jet Propulsion Laboratory
IR	Infrared
KNMI	Koninklijk Nederlands Meteorologisch Instituut Royal Netherlands Meteorological Institute
L	(Time of) Launch
LEO	Launch and Earl Operations
Lidar	Light detection and ranging
LPMA	Laboratoire de Physique Moléculaire et Applications
LTE	Local Thermodynamic Equilibrium
MASTER	Millimeter Wave Acquisitions for Stratosphere/Troposphere Exchange Research
MD, OK, and CO	double UV monochromators
MERIS	Medium-Resolution Imaging Spectrometer
METEOR	Polar Meteorological satellite series of Russia
METOP	Meteorological Operational (satellites)
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MIPAS-STR	A version of MIPAS adapted to STRatospheric flights on aircraft.
MISR	Multi-angle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MODIS	Moderate-resolution Imaging Spectroradiometer (on EOS-Terra)
MOPITT	Measurements Of Pollution In The Troposphere
MOZAIC	Measurement of OZone and wAter vapour by Airbus In-Service airCraft
MVIRI	Meteosat Visible and Infrared Imager
MW	Microwave or near millimetre (wavelengths)
MWR	Millimetre Wave Radiometer
N/A	Not Applicable

NASA	National Aeronautics and Space Administration
NDSC	Network for the Detection of Stratospheric Change
NIR	Near Infrared
NIVR	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart Netherlands Agency for Aerospace Programs
NIWA	National Institute for Water and Atmospheric research (New Zealand)
NRA	(NASA-) National Research Announcement
NOAA	National Oceanic and Atmospheric Administration
NRT	Near-Real time (see footnote of Table 1)
NSF	(US) National Science Foundation
OCO	Orbiting Carbon Observatory
Odin	Swedish satellite (not an acronym)
OLEX	Ozone Lidar Experiment
OM (data)	Operational Meteorological (data)
OMI	Ozone Monitoring Instrument
OSAB	OMI Science Advisory Board
OSIRIS	Optical Spectrograph and InfraRed Imaging System (on Odin satellite)
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a lidar
PI	Principal Investigator
POLDER	POLarization and Directionality of the Earth's Reflectances (on ADEOS-2)
POAM	Polar Ozone and Aerosol Measurement
QA	Quality Assessment
QC	Quality Control
RIVM	Rijksinstituut voor Volksgezondheid en Milieu Netherlands Institute for Public Health and the Environment
S/N	Signal to Noise
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
SAFIRE-A	a Fourier Transform Spectrometer for the observation of the atmospheric emission spectrum in the far Infrared spectral region
SAGE	Stratospheric Aerosol and Gas Experiment
SAOZ	Système d'Analyse par Observations Zénithales; network of SAOZ spectrometers
SBUV	Solar Backscatter Ultraviolet Instrument
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SHADOZ	Southern Hemisphere Additional Ozone Sondes
SIM	Spectral Irradiance Monitor
SIOUX	instrument aboard Geophysika
SIPS	Science Investigator Processing System
SMR	mm/sub-mm radiometer (on Odin satellite)
SOLSPEC	Solar Spectrum Instrumen
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SORCE	Solar Radiation and Climate Experiment
SPARC	Stratospheric Processes and their Role in Climate
SRD	Science Requirements Document for OMI-EOS
SSA	(Aerosol) Single Scattering Albedo
SSBUV	Space Shuttleborne Solar Backscatter Ultraviolet Instrument
SWIR	Shortwave Infrared
SZA	Solar Zenith Angle
Terra	name of a satellite (not an acronym)
TES	Tropospheric Emission Spectrometer (on Aura)
TH	Tropopause Height
TIR	Total Infrared
TOA	Top Of Atmosphere
TOMS	Total Ozone Mapping Spectrometer

TOR	Tropospheric Ozone Research
TOVS	Tiros Ozone Vertical Sounder
UARS	Upper Atmosphere Research Satellite
USDA	United States Department of Agriculture
UTLS	Upper Troposphere and Lower Stratosphere
UV	Ultraviolet , or UV channel of OMI
VFD	Very Fast Delivery (see footnote of Table 1)
VIS	Visual (channel of OMI)
VNI	Visible/Near-Infrared
VR	Validation Requirement
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WOUDC	World Ozone and Ultraviolet Data Center