# Ozone Monitoring Instrument Detailed Validation Handbook

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Preface

In this document we describe the detailed validation plans for the EOS-Aura OMI satellite data products, being: level 1b Earth radiance and Solar irradiance; level 2 total columns of ozone, nitrogen dioxide, formaldehyde, bromine oxide, chlorine dioxide and volcanic sulphur dioxide; aerosol optical depth and single scattering albedo; cloud fraction and cloud pressure; tropospheric columns of ozone and nitrogen dioxide; and ozone profiles. The OMI Validation Office at the Royal Netherlands Meteorological Institute (KNMI), manpowered by the editors of this document, coordinates the validation of all OMI products.

For each of the OMI products a member of the international OMI science team has been assigned to act as product coordinator. OMI product coordinators combine insight in the OMI data product retrieval algorithm with an insight in its scientific applications. OMI product coordinators judge the quality and strive to reach consistency of the various validation efforts performed by individual scientists in the OMI team, scientists working under the NASA Research Announcement for EOS-Aura validation of June 14, 2004 and scientists working under the joint ESA NIVR KNMI Announcement of Opportunity for OMI validation of June 24, 2004. The product coordinators provide feedback to the validation scientists and report their validation overview to the OMI Validation Office. The product coordinators are contributing the chapter devoted to the detailed validation plan of their assigned product to this document.

The validation of each of the OMI products is performed along similar lines. The first step is to visually inspect the measured and/or retrieved data, by plotting the data in different manners and judging the quality of the data in terms of magnitude and sign, noise and continuity. Such quick-look inspection is also known as “Science Q/A”, and is strictly speaking not part of validation. However, as it is essential to perform Science Q/A before or during the early validation, we do include it in this document. Subsequently, the measured and/or retrieved data are compared with the measured and/or retrieved data originating from other instruments, including those aboard EOS-Aura. This second step encompasses by far the largest effort as many correlative data sources are available, e.g., atmospheric data originating from ground-based sites, satellite measurements, airborne campaigns and models or assimilation codes. We assume that retrieval algorithms have been verified during algorithm development, and will not repeat that unless algorithm or other changes require this.

We refer the interested reader to the following important reference documents. The “OMI Validation Requirements Document” [RS-OMIE-KNMI-345, 2003] by E. J. Brinksma, F. Boersma, and P. F. Levelt, provides more detailed information on the requirements for correlative data and data comparisons to be suitable for OMI validation. The “OMI Policy for Standard Data Product Processing, Release, and Publication”, [PR-OMIE-KNMI-690, 2005] by P. F. Levelt (editor), provides the framework of the OMI project as well as the organizational structure concerning the decision tree within the OMI project.

Mark Kroon
Ellen Brinksma

July 2005, De Bilt, the Netherlands
1 Project description

The Ozone Monitoring Instrument (OMI) has been launched on the NASA EOS-Aura mission on the 15th of July 2004. The Royal Netherlands Meteorological Institute (KNMI) coordinates and plans the validation of all OMI data products. In this document, we describe in detail the validation plans for all OMI products.

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 [1]. Validation encompasses comparisons of OMI data with independent measurements taken under various conditions, covering all seasons, and representative for the entire globe. It is essential to validate all products of OMI, to assure their quality for scientific use. This includes validation of level 1b products being Earth radiance and Solar irradiance. Retrieved OMI data will be verified by performing quick-look consistency checks prior to validation. We include a description of this verification process in this document for the appropriate products. Following launch and instrument startup, OMI data will be validated within the framework of the commissioning and core validation phase. A timeline for validation and definitions of the commissioning and core validation phases are given in Chapter 3 of this document and in the OMI Validation Requirements Document [2]. Subsequently, OMI product accuracies will be established by thorough comparisons with independent correlative data, model data and assimilated data.

For our validation purposes an abundance of independent ground-based and air-borne measurements is available. An appropriate selection from this data needs to be made based on validation requirements. Ideally, independent data should be spatially and temporally collocated with OMI overpasses. In general, a time difference of a few hours up to a day is sufficient for comparisons of total ozone columns, depending on location and season and expected horizontal gradients. For other products, like aerosols, the horizontal gradients may be much larger and the collocation criteria should therefore be more stringent. For photoactive species with high diurnal variability, like nitrogen dioxide, validation with collocated data at exactly the OMI overpass time is necessary - if these measurements are not available, regional air quality model predictions are needed, e.g., the Chimere model currently operational at KNMI. The collocation and measurement time criteria can be met either by selecting from existing measurements that are routinely performed on at least a daily basis, or by requesting the instrument teams to adjust the ground instrument operation dates and times to better coincide with an EOS-Aura/OMI overpass, either for campaigns or routinely throughout the OMI lifetime. Setting up campaigns in which additional instrumentation is used at those locations and times where data scarcity exists to increase the amount of collocated ground-based and balloon/aircraft data is highly desired.

OMI will continue the global ozone record as measured by the various TOMS instruments since 1978. Besides high accuracy of the measurements, good stability is required. Validation of the total ozone column will assess both of these aspects. The relatively high spatial resolution of OMI will yield useful data on spatial variation in ozone fields. The stability of the ozone column measurements is important, because only accurate and stable data enable trend studies. Although the OMI data alone will not be able to show trends by 2006, preliminary investigations of time series of the difference between OMI data and correlative instrument data should be started by mid 2006, to reveal biases introduced by, e.g., seasonal effects, solar zenith angle, etc. This applies to all validation work packages that encompass comparisons with ground-based data.

This document is structured as follows. In chapter 2 we introduce OMI on EOS-Aura. Chapter 3 describes the main validation plan and presents the validation time line. In chapter 4 the validation coordination is described and in chapter 5 we describe the necessary validation tools. The following chapters 6 to 16 describe in detail the validation of a specific OMI product. These chapters are set up alike; starting with visual inspection of the data, the validation activities incorporate ground-based and satellite correlative data for comparisons with OMI data, cross comparisons with EOS-Aura data and finally ingestion into assimilation models. Chapter 17 contains the reference list. Additional information of satellite and ground-based sources for correlative data and address lists of the OMI science teams can be found in the Annexes.
2 OMI aboard EOS-Aura

2.1 The EOS-Aura mission

Earth Observing System (EOS) EOS-Aura is a NASA mission to study the Earth’s ozone layer, air quality and climate. This mission is designed exclusively to conduct research on the composition, chemistry and dynamics of the Earth’s upper and lower atmosphere employing multiple instruments on a single satellite. EOS-Aura was launched on the 15th of July 2004 from Vandenberg AFB for a design lifetime of five years. Measurements of atmospheric parameters in the troposphere, stratosphere, and mesosphere are being made by the High Resolution Dynamic Limb Sounder (HIRDLS), the Microwave Limb Sounder (MLS), the Ozone Monitoring Instrument (OMI), and the Tropospheric Emission Sounder (TES). Combining the high vertical and horizontal resolution measurements from EOS-Aura provides unprecedented insights into the chemical and dynamical processes in the stratosphere and upper troposphere. The EOS-Aura instruments balance new capabilities with proven technological heritage, covering wavelengths in the ultraviolet, visible, throughout the infrared, and sub-millimeter and microwave ranges. More information on EOS-Aura can be found on the following website: http://aura.gsfc.nasa.gov/.

EOS-Aura is performing a sun-synchronous ascending polar orbit at an altitude of 705 km at an inclination of 98 degrees with a local equator crossing time around 13:45 hrs. A polar orbit provides a perspective to collect high vertical resolution data of atmospheric constituents and temperature throughout the stratosphere on a daily basis. OMI is a nadir sounder. MLS and HIRDLS are limb-sounding instruments. TES has both limb sounding and nadir sounding modes and can also point to targets of opportunity such as pollution sources and volcanic eruptions. MLS is on the front of the spacecraft while OMI, HIRDLS and TES are mounted on the nadir side. These locations were chosen such that the instruments will sample the same air mass within 15 minutes.

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. An important objective of the OMI mission is to continue the TOMS total ozone data record. It is therefore necessary that ozone columns are also retrieved using the TOMS algorithm [3]. Furthermore, it appears to be feasible to retrieve tropospheric columns of ozone and NO2. 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 The Ozone Monitoring Instrument

The Ozone Monitoring Instrument is the Dutch-Finnish contribution to EOS-Aura. OMI is a nadir viewing, wide swath, ultraviolet-visible (UV/VIS) imaging spectrometer that will provide daily global measurements of the solar radiation backscattered by the Earth’s atmosphere and surface, and measurements of the Sun’s irradiance. OMI takes heritage from European atmospheric research instruments such as GOME and SCIAMACHY, which were first to perform high-resolution UV/VIS hyperspectral Earth radiance imaging. The measurements performed by OMI of total ozone columns and ozone profiles, aerosols, clouds, surface UV-B irradiance, and total columns of the trace gases NO2, SO2, HCHO, BrO, and OCIO fit well into EOS-Aura’s mission goals to study the Earth’s atmosphere. Combining OMI data with the other EOS-Aura instruments will allow derivation of tropospheric gases important for air quality and climate. More information on OMI aboard EOS-Aura can be found on the following website: http://www.knmi.nl/omi.

The American predecessor of OMI is NASA’s TOMS instrument. TOMS has a fairly small nadir ground-pixel size (38x38 km²) in combination with a daily global coverage. OMI combines the advantages of GOME, SCIAMACHY and TOMS, measuring the complete spectrum in the UV/VIS wavelength range with a very high spatial resolution nadir (13x24 km²) and achieves daily global coverage of all products. This is possible by using a two-dimensional detector, as has been used in the GOMOS and MERIS satellite instruments. The nadir-pointing telescope of OMI with a field of view of 114° captures a 2600 km wide swath, perpendicular to the flight direction of the satellite. The small pixel size enables OMI to look “in between” the clouds, giving better reach into the troposphere than any other UV/VIS backscatter instrument flown to date. Technical details about the OMI instrument and its scientific objectives can be found in the Science Requirements Document for OMI-EOS [4], the recent IEEE transactions on Geoscience and Remote Sensing, Special issue on the EOS Aura Mission [5,6] and references therein.
Overall responsibility for the OMI mission lies with the Netherlands Agency for Aerospace Programs (NIVR). The OMI principal investigator (PI) is Dr. Pieternel F. Levelt, residing at KNMI. She leads an international science team consisting of Dutch, American and Finnish core teams and international associates, which is developing retrieval algorithms, overseeing the instrument manufacturing and calibration, overseeing and conducting validation and using OMI data for scientific purposes. The Dutch team will lead instrument operations. Ground processing of OMI data will be shared between NASA Goddard Space Flight Center (GSFC) and KNMI. OMI data will be made available by the EOSDIS Goddard DAAC System.

2.3 The OMI science questions

Here we state the four OMI science questions that are highly synergetic with the EOS-Aura science questions:

Is the ozone layer recovering as expected?
OMI will measure total column ozone on a global basis, continuing the long term TOMS ozone data record and serving as a bridge to the NPOESS ozone monitoring instruments that (OMPS) will be flown by the US late this decade.

What are the sources of aerosols and trace gases that affect global air quality and how are they transferred?
OMI, in conjunction with other EOS-Aura instruments (particularly HIRDLS and TES), will provide global mapping of several key tropospheric constituents including aerosols and some EPA (Environmental Protection Agency) criteria pollutants and other radicals. These include tropospheric ozone, NO2, SO2, BrO, and HCHO in the planetary boundary layer.

What are the roles of tropospheric ozone and aerosols in climate change?
Aerosols increase the sunlight backscattered to space, and ozone is a greenhouse gas through its infrared absorption at 9.6 microns. The importance of aerosols to climate change is well known, and OMI will contribute by measuring both absorbing and non-absorbing aerosol.

What are the causes of surface UV-B change?
The atmospheric constituents that most affect the ultraviolet flux reaching the surface are total column ozone, clouds, and aerosols. OMI is designed to measure the first two of these with very high long-term accuracy. But aerosols, particularly aerosols that absorb in the UV (smoke, dust, black carbon, and exotic nitrated and aromatic aerosols found in urban smog) are important for deriving the amount of UVB radiation penetrating to the Earth's surface. OMI data, combined with data from ground-based instruments (AERONET and UV shadowband radiometers), and other satellite instruments on the A-train (MODIS and CALIPSO) should provide great improvement in our knowledge of the UV absorbing properties of aerosols, resulting in improved estimates of the surface UVB flux.

2.4 OMI level 2 data products

In this section, an overview of the OMI level 2 data products and their accuracies is given. More information about the products and a rationale for the accuracies given here is presented in the IEEE transactions on Geoscience and Remote Sensing, Special issue on the EOS Aura Mission [5,6]. The data product availability and timeline is presented in section 2.5. Ground pixel size and absolute and relative accuracies are listed below in Table 1.

Total ozone column
OMI will continue the total ozone column measurements by the various TOMS instruments and by GOME and SCIAMACHY. Besides high accuracy of the measurements, good stability is required. Validation of the total ozone columns will assess both of these aspects. The relatively high spatial resolution of OMI will yield useful data on spatial variation in ozone fields. Total ozone columns will be derived using the TOMS-algorithm and the DOAS-algorithm. Results of these two methods, applied on the same OMI data, should be compared carefully to give an indication of possible systematic effects.

Tropospheric ozone column
Tropospheric ozone columns will be derived by subtraction of the integrated MLS stratospheric ozone profiles from the OMI total ozone columns. The relatively high spatial resolution of OMI will yield useful data on spatial variation in tropospheric ozone fields, especially under polluted conditions. This data product is not a standard OMI data product!

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.

**Total NO2 column**
NO2 plays an important role in ozone chemistry. High amounts usually indicate tropospheric pollution, but lightning produced NO2 may also play a role. Total NO2 columns under background conditions are typically 10^{15} cm^{-2}, while in polluted areas GOME has reported total columns up to several times 10^{16} cm^{-2}. A tropospheric NO2 product will likely also be produced.

**Total SO2 column**
SO2 will be observed under volcanic conditions, and in strongly polluted regions (industrial outflow plumes). Volcanic eruptions will result in total columns of 2 DU up to 700 DU. SO2 originating from industrial pollution can be up to a few DU. Note that 1 DU (Dobson Unit) = 2.687 \times 10^{16} molecules cm^{-2}.

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</tr>
<tr>
<td>Ozone column</td>
<td>3% : 1.5%</td>
<td>13 x 24</td>
<td>Two methods</td>
</tr>
<tr>
<td>Tropospheric ozone column</td>
<td>25% : 10%</td>
<td>52 x 48</td>
<td></td>
</tr>
<tr>
<td>Ozone profile</td>
<td>10% : 10%</td>
<td>13 x 48</td>
<td>Vertical range 0-50 km</td>
</tr>
<tr>
<td>Aerosol optical thickness</td>
<td>30% (0.1) : 10% (0.05)</td>
<td>13 x 24</td>
<td>Requirement at 400 nm</td>
</tr>
<tr>
<td>Aerosol single scattering albedo</td>
<td>0.1 : 0.05</td>
<td>13 x 24</td>
<td></td>
</tr>
<tr>
<td>NO2 column</td>
<td>2.10^{16} cm^{-2} : 2.10^{16} cm^{-2}</td>
<td>26 x 48</td>
<td>Background</td>
</tr>
<tr>
<td>Cloud pressure</td>
<td>100 hPa : 30 hPa</td>
<td>13 x 24</td>
<td>Two methods</td>
</tr>
<tr>
<td>Cloud fraction</td>
<td>≤ 0.1</td>
<td>13 x 24</td>
<td>Two methods</td>
</tr>
<tr>
<td>Surface UV-B flux</td>
<td>10% : 10%</td>
<td>13 x 24</td>
<td></td>
</tr>
<tr>
<td>SO2 column</td>
<td>3.10^{16} cm^{-2} (50%) : 2.10^{16} cm^{-2} (20%)</td>
<td>13 x 24</td>
<td>Non- volcanic</td>
</tr>
<tr>
<td>BrO column</td>
<td>25% / 25%</td>
<td>13 x 24</td>
<td></td>
</tr>
<tr>
<td>OCIO slant column</td>
<td>15% / 10%</td>
<td>26 x 48</td>
<td>Polar vortex</td>
</tr>
<tr>
<td>HCHO column</td>
<td>35% / 25%</td>
<td>13 x 24</td>
<td>Pollution</td>
</tr>
<tr>
<td>Surface irradiance</td>
<td>5% (0.01)</td>
<td>13 x 24</td>
<td></td>
</tr>
<tr>
<td>Near Real Time Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone column</td>
<td>5 % (10 DU)</td>
<td>13 x 24</td>
<td>Not validated, not an official product.</td>
</tr>
<tr>
<td>Intermediate level 1b product</td>
<td></td>
<td>13 x 24</td>
<td></td>
</tr>
<tr>
<td>Very Fast Delivery Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone column</td>
<td>≤ 5 % (10 DU)</td>
<td>13 x 24</td>
<td>Over Northern Europe</td>
</tr>
<tr>
<td>Surface UV-B flux</td>
<td>10% : 10%</td>
<td>13 x 24</td>
<td>Over Northern Europe</td>
</tr>
<tr>
<td>Surface irradiance</td>
<td>≤ 10-20 % (accuracy is wavelength dependent)</td>
<td>13 x 24</td>
<td>Over Northern Europe.</td>
</tr>
</tbody>
</table>

Table 1: Overview of the scientific requirements for the OMI data products. Absolute accuracy is given at the horizontal and vertical 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. “Total column” denotes vertical total column. Numbers from OMI Science Review presentation by P. Levelt, April 2003 unless otherwise noted. 1 DU (Dobson Unit) = 2.687 \times 10^{16} molecules cm^{-2}. 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. Irradiance is not a separate data product. Note 3: NGPS stands for Nadir Ground Pixel Size in km x km.
Total BrO, HCHO, and OClO columns
Total columns of BrO are typically between $3 \times 10^{13} \text{ cm}^{-2}$ and $6 \times 10^{13} \text{ cm}^{-2}$ with little variation, except for tropospheric blooming events in polar springtime, where total columns larger than $10^{14} \text{ cm}^{-2}$ are observed.

Total HCHO columns range between $1 \times 10^{15}$ and $3 \times 10^{16} \text{ cm}^{-2}$ under polluted circumstances. 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 columns will be retrieved. This is likely only possible under ozone hole conditions where the solar zenith angle is usually very high, typically higher than 80°. The OClO slant columns range between $2 \times 10^{13} \text{ cm}^{-2}$ and $4 \times 10^{14} \text{ cm}^{-2}$ for solar zenith angles higher than 80°.

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, and validation should therefore take place in cloud-free pixels only.

Surface ultraviolet irradiance
Surface ultraviolet (UV) radiances from OMI are calculated using total ozone column measurements from OMI, surface albedo database, 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. The surface albedo database needs to be revised based on OMI data.

Clouds
The OMI cloud information consists of two main parameters: effective cloud fraction and cloud top 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 km²). Cloud information is crucial for the retrieval of other level 2 products. It should be noted that cloud top pressure and effective cloud fraction are dependent on assumptions made in the cloud retrieval algorithms.

2.5 OMI product release plan
Below the OMI product release plan as of May 2006 is presented, following a description of each of the releases. The release schedule of tropospheric O₃ product assumes that the HIRDLS or MLS O₃ profiles will be available 3 months in advance in a comparable release form. The release dates are based on the assumption that the instrument performance on-orbit is nominal, and that sufficient funding is available, on both the US and the Netherlands side for the in-flight calibration program.

**Beta release:** Early release product that enables users to gain familiarity with data formats and parameters. Algorithm changes are occurring frequently. Products have easily recognized deficiencies. Internal release to algorithm developers OMI Science Team only.

**Provisional release:** Algorithm changes are infrequent. Product images look reasonable when compared to other space-borne instruments or comparable data in limited situations. Scientific use should be performed with caution and with careful reference to QA statements provided with each product. Availability to validation PI’s responding to AO and NRA, algorithm developers and OMI Science Team Members only.

**Validated stage 1:** Accuracy is estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts. Deficiencies have been documented and QA fields are filled in. First public release.

**Validated stage 2:** Accuracy is assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts. Results have been presented at scientific conferences and workshops, and updated algorithms have been published.
Validated stage 3: Accuracy is assessed and the uncertainties in the product are well established via independent measurements in a systematic and statistically robust way representing global conditions. The results are published in peer-reviewed scientific literature.

<table>
<thead>
<tr>
<th>Product</th>
<th>Beta release</th>
<th>Provisional release</th>
<th>Validated stage 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MISSION CRITICAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1B</td>
<td>September 2004 (L+2)</td>
<td>June 2006 (L+23)</td>
<td>November 2006 (L+28)</td>
</tr>
<tr>
<td>Ozone total column (TOMS)</td>
<td>October 2004 (L+3)</td>
<td>January 2005 (L+6)</td>
<td>Released</td>
</tr>
<tr>
<td>NO₂ total column</td>
<td>October 2004 (L+3)</td>
<td>July 2005 (L+12)</td>
<td>May 2006 (L+22)</td>
</tr>
<tr>
<td>Tropospheric O₃ column</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Tropospheric NO₂ column</td>
<td>October 2004 (L+3)</td>
<td>July 2005 (L+12)</td>
<td>May 2006 (L+22)</td>
</tr>
<tr>
<td><strong>MISSION ESSENTIAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud Height (O₂-O₂)</td>
<td>October 2004 (L+3)</td>
<td>June 2005 (L+11)</td>
<td>May 2006 (L+22)</td>
</tr>
<tr>
<td>Cloud Height (Raman)</td>
<td>October 2004 (L+3)</td>
<td>June 2005 (L+11)</td>
<td>Released</td>
</tr>
</tbody>
</table>

Table 2: Most recent update (May 2006) of the OMI product release dates. Release dates are given in exacts months and in (months after launch). Validated products are released in 3 stages. Stage 2 (3) release occurs 12 (24) months after stage 1 (2). Release definitions are adapted from MODIS (following this link to their website): [http://modis-atmos.gsfc.nasa.gov/products_calendar.html](http://modis-atmos.gsfc.nasa.gov/products_calendar.html)
3 Main Validation Plan

3.1 Validation Phases

Validation is envisaged to consist of three phases, namely the commissioning phase, the core phase, and the long-term validation phase. A schematic overview of the validation phases is presented in Figure 1.

The commissioning phase aims to provide a quick-look first validation of the level 1 and selected level 2 products. It starts after the OMI instrument functional tests have been completed and lasts about six months. During the commissioning phase, absolute irradiance and absolute radiance, cloud cover and cloud pressure, total ozone columns and total NO2 columns will undergo preliminary validation. 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 and ground-based/airborne instruments shall be used as correlative instruments. The preliminary validation will be limited to subsets of the available data, e.g., to cloud-free pixels, unpolluted scenes, and moderate geometries.

The core phase 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. 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 each level 1 and level 2 data product shall be validated rigorously: the accuracies of the products as described in the IEEE transactions on Geoscience and Remote Sensing, Special issue on the EOS Aura Mission [5,6] will be assessed. Spatial and spectral zoom, VFD, and NRT products require separate validation. Where possible, multiple correlative measurement techniques should be used, to enhance the results and to avoid ambiguities due to possible instrumental effects in the correlative data. During the core validation phase, at least one year of measurements is needed to cover the different seasons. If data are reprocessed, they shall be validated again, using the already available correlative data. Intensive measurement campaigns are an essential part of the core phase. They shall provide data at locations and under conditions where representative existing measurements are sparse. This includes locations at which retrieval weaknesses yield results with limited accuracies and locations where specific conditions exist (e.g., areas with high industrial pollution). A limited number of field campaigns, such as INTEX and AVE, will be performed during the commissioning phase. We refer the interested reader to document PL-OMIE-KNMI-535 [12] on details of the AVE validation campaigns.

Figure 1: Schematic depiction of the OMI validation timeline. Here L denotes the launch date. LEO stands for launch and early operations phase. Note the importance of campaigns during an extended period of time for continuity of measurements and to cover event of opportunity.

The long-term phase starts two years after launch and lasts for the complete lifetime of the instrument. All available OMI data, including those measured in the first two years of operations, are subject to the long-term validation analyses. 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. This necessitates a regular, optimized repetition of the essential elements of the core validation phase. 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 and an effort to have regular overpass validation shall be made (e.g., at NDSC sites). In the long-term validation phase, repetitive campaigns are needed, e.g., the AVE series of missions which aims to measure multiple times per year to aid EOS-Aura validation.

### 3.2 Product coordinators

The validation of OMI level 1b and level 2 data will be an international effort, carried out by a number of international validation scientists. Each of them has submitted proposals to either the European AO for OMI validation, or the US NRA for EOS-Aura validation, or is part of the international OMI Science Team. To obtain thorough scientific insight in the quality of the OMI data products, **product coordinators** have been appointed. Product coordinators combine insight in the OMI data product retrieval algorithm with an insight in its scientific applications. Individual scientists performing the validation report to and iterate with the product coordinators, who in turn report to and iterate with the Validation Office, headed by the Validation Working Group Chair, at KNMI. Each of the OMI products will have a product coordinator assigned, as listed below in Table 3. The product coordinators are backed by their scientific support team. The support team serves as a sounding board and information backup for the products coordinators.

Tasks of the product coordinator are to:

- Assist the Validation Office in writing chapters of the Detailed Validation Handbook that describes in detail the activities needed for the specific product’s validation.
- Advise the Validation Office on validation needs not yet covered (correlative data, instruments, funding needs).
- Relay OMI-related information from the Validation Office to the validation scientists.
- Monitor the validation progress and combine results from the different validation scientists in order to assess the product quality under many atmospheric conditions, at many locations worldwide, validated against various different correlative instruments.
- Detect inconsistencies between independent validation results and initiate discussions to resolve these, for instance through postings on the OMI validation web site or at meetings.
- Obtain a common view on the product quality among the validation scientist involved.
- Post regular product validation status reports on the OMI validation web site.
- Present product validation results at OMI and EOS-Aura meetings and in written reports.

![Table 3: OMI product coordinators and scientific support team. We refer to the contact list in Annex 3.](image)
3.3 Aura Validation Data Center

The EOS-Aura Validation Data Center (AVDC) is a centralized, long-term, archive for validation data hosted by the Atmospheric Chemistry and Dynamics Branch at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. The AVDC mission is to support the Earth Observing System Aura validation and science activities, and the future “A-Train” Earth Science satellites validation activities. Please visit the AVDC website at http://avdc.gsfc.nasa.gov.

Data archived at the AVDC will originate from several special EOS-Aura validation campaigns; NASA aircraft and balloon deployments, established measurement networks for collection atmospheric data; the Network for Detection of Stratospheric Change (NDSC), the Southern Hemisphere Additional Ozone sondes (SHADOZ), and the World Meteorological Organization (WMO)’s Global Atmosphere Watch (GAW), among others.

The AVDC will also support the EOS-Aura mission by providing auxiliary meteorological data to enhance the science value of the validation data. In addition, orbit prediction tools will be available to locate and predict satellite overpasses, co-located data products, and provide satellite instrument field of view (FOV) data.

Data archived at the EOS-Aura Validation Data Center (AVDC) originates from several sources, including:

- NASA Research Announcement (NRA) funded EOS-Aura validation projects.
- Special EOS-Aura validation campaigns, including NASA EOS-Aura Validation Experiment (AVE) aircraft deployment and the NASA large-balloon missions.
- Established measurement networks for collection atmospheric data, such as from the Network for Detection of Stratospheric Change (NDSC), the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) program, etc.

In addition, the AVDC supports the EOS-Aura mission by providing:

- EOS-Aura instrument field of view (FOV) predictions.
- EOS-Aura co-located Level 2 data products (data subsetting).

OMI data will be distributed by the Aura Validation Data Center (AVDC). The AVDC will be subsetting OMI data for validation; the AVDC will be collocating OMI data over all ground stations that are likely to participate in validation. This saves OMI validation PI’s the effort of making match-ups and, because OMI data files are large, limits the data flux. In return you are required to submit your correlative data to the AVDC for Aura validation scientists to benefit from your findings. Appropriate acknowledgment of the data ownership is required. Please visit the AVDC website at http://avdc.gsfc.nasa.gov. Using the AVDC requires signing the AVDC data protocol [13].

For questions regarding Aura Validation Data Center (AVDC), access information, data protocol or technical issues, please contact:

Bojan R. Bojkov (AVDC Project Manager)
NASA Goddard Space Flight Center, Code 613.3
Greenbelt, MD 20771, USA
E-mail: bojan.bojkov #at# gsfc.nasa.gov
Phone: (+01) 301-614-6846
Fax: (+01) 301-614-5903

3.4 Aura Validation Campaigns

NASA is planning various large scientific campaigns throughout the Aura lifetime. Examples are INTEX and TC4. Although the performed measurements are not tuned to validation, they are at least partially of interest to Aura and OMI validation. NASA campaign leaders appreciate receiving Aura input on validation opportunities to optimize flights for scientific and validation purposes.

NASA is also organizing AVE, the Aura validation Experiment. AVE is a series of mini campaigns dedicated solely to Aura validation. AVE campaigns can be stand-alone activities or provide additional equipment to existing campaigns to complement the existing suite of measurements. AVE campaigns actively require the input from Aura validation representatives as the flight planning is performed at the deployment site only location a few days is advance. Details on validation campaigns and AVE activities and the benefits for OMI validation can be found in PL-OMIE-KNMI-535 [12] and references therein.
4 Validation Coordination

Validation Coordinator: Mark Kroon – KNMI

4.1 Introduction

KNMI, as the PI institute for OMI, coordinates validation of all OMI data products. In this chapter, the coordinating tasks are described which consist of; OMI validation working group coordination, writing of the validation handbook and detailed validation plans, OMI validation website maintenance and communication, acquiring of additional funding for validation, attending EOS-Aura validation working group and meetings, and activities for gathering correlative data. Here only general, high-level tasks are described; tasks that are specific for only one of the OMI products are described within the respective chapter.

Task 4.1 OMI Validation Working Group Coordination

Start / End: Throughout the lifetime of OMI
Summary: KNMI, as the PI institute for OMI, is responsible for the quality of the OMI data products. Validation is a tool to check and improve this. The overall coordination of OMI validation is a task for KNMI.

Task parts:
- Lead validation efforts for OMI science data
- Gain insight in quality of all OMI data products and report to the OMI PI.
- Management and coordination of the product coordinators. Product coordinators, appointed for each of the OMI data products, are the contacts between the validation working group chair (at KNMI) and the individual validation scientists. KNMI has the task to disseminate information to the product coordinators, and through them, organize the validation of all OMI products.
- Organization of OMI Validation Working Group meetings, after launch, to coordinate validation of OMI products, to compare results obtained by the various groups and to exchange results and ideas.

Associated names and subject:
Mark Kroon  KNMI - OMI validation working group lead (WPL)
Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist
Richard McPeters  GSFC – OMI validation contact in US science team
All OMI product coordinators (see Table 3)

Task 4.2 Writing of validation handbook and detailed validation plans

Start / End: Jan 2003 / L+1 year
Summary: The OMI validation handbook contains detailed validation plans per OMI product and serves as a guideline for validation planning and as a source of information for AO and NRA scientists.

Task parts:
- Writing the OMI validation handbook.
- Writing the OMI long-term validation plan.

Information sources:
SCIAMACHY validation requirements document
SCIAMACHY validation handbook
SCIAMACHY detailed validation plan

Associated names and subject:
Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist
Mark Kroon  KNMI - OMI validation working group lead (WPL)
Richard McPeters  GSFC - US OMI Validation team lead
Ankie Pitters  KNMI - SCIAMACHY validation coordinator
All OMI product coordinators (see Table 3)
Task 4.3  EOS-Aura validation working group and science team meetings

Start / End:  Throughout the lifetime of OMI
Summary:  OMI Validation is coordinated within the framework of EOS-Aura validation, especially with regards to validation campaigns such as AVE funded by NASA. Therefore, participation in the EOS-Aura Validation Working group is necessary and useful.

Task parts:
- Attend EOS-Aura meetings, attend EOS-Aura Validation Working Group Meetings, present validation results
- Obtain and provide information on EOS-Aura wide activities such as validation campaigns
- Obtain and provide feedback on EOS-Aura wide plans such as validation campaigns

Associated names and subject:
Ellen Brinksma   KNMI - OMI/SCIAMACHY validation scientist
Anne Douglass   GSFC - EOS-Aura validation coordinator
Lucien Froidevaux  JPL - EOS-Aura validation coordinator
Mark Kroon     KNMI - OMI validation working group lead (WPL)
Richard McPeters  GSFC - US OMI Validation team lead

Task 4.4  OMI validation working group and science team meetings

Start / End:  Throughout the lifetime of OMI
Summary:  The regular meetings of the international OMI science team and the OMI validation working group provide opportunities for presenting validation results and exchanging information on validation plans and campaigns in general.

Task parts:
- Attend OMI meetings, present validation status and outlook
- Organize and chair OMI validation working group meetings, present validation results
- Obtain and provide information on validation activities such as validation campaigns

Associated names and subject:
Ellen Brinksma   KNMI - OMI/SCIAMACHY validation scientist
Ernest Hilsenrath  GSFC - OMI Co-PI
Mark Kroon     KNMI - OMI validation working group lead (WPL)
Pietermel Levelt  KNMI - OMI-PI
Richard McPeters  GSFC - US OMI Validation team lead
Johanna Tamminen  FMI - OMI Co-PI

Task 4.5  NASA validation campaigns

Start / End:  Pre-AVE January 2004 / Throughout the Aura lifetime
Summary:  NASA is planning various large scientific campaigns throughout the Aura lifetime. Examples are INTEX and TC4. Although the performed measurements are not tuned to validation, they are at least partially of interest to Aura and OMI validation. NASA campaign leaders appreciate receiving Aura input on validation opportunities to optimize flights for scientific and validation purposes. NASA is also organizing AVE, the Aura Validation Experiment. AVE is a series of mini campaigns dedicated solely to Aura validation. AVE campaigns can be stand-alone activities or provide additional equipment to existing campaigns to complement the existing suite of measurements. AVE campaigns actively require the input from Aura validation representatives as the flight planning is performed at the deployment site only location a few days is advance. Details on validation campaigns and AVE activities and the benefits for OMI validation can be found in [12] and references therein.

Task parts:
- Formulate validation opportunities per validation campaign based on payload, meteorology and location
- Attend campaigns at the deployment site
- Actively participate in daily flight planning
- Optimize opportunities for OMI validation in synergy with other Aura wide interest
**Task 4.6  Website Maintenance and Communication**

**Start / End:** Throughout the lifetime of OMI  
**Summary:** For facilitating the communication within the OMI Validation Workgroup, a website will be created. KNMI-experience gained with the SCIAMACHY website (http://www.sciamachy-validation.org) will be used. The purpose of this website is to provide a platform for distribution of discussions on validation results, and to provide information to validation scientists (including AO and campaign participants). Open as well as password-restricted parts are in place. Note - creation of the website itself is described in the “Tools” chapter.

**Task parts:**
- Build the website (http://www.knmi.nl/omi/validation)  
- Promote use of the website for discussions on OMI validation results  
- Monitor platform for discussions and guide discussions  
- Present results

**Information source:** SCIAMACHY validation website (http://www.sciamachy-validation.org)

**Associated names and subject:**  
Ellen Brinksma  KNMI – OMI/SCIAMACHY validation scientist / website on validation coordinator  
Mirna van Hoek  KNMI - OMI website developer  
Rene Noordhoek  KNMI - OMI scientific secretary / OMI website coordinator  
Ankie Piters  KNMI - SCIAMACHY validation website coordinator

**Task 4.7  Acquire additional funding for validation**

**Start / End:** Throughout the lifetime of OMI  
**Summary:** From the experience gained with validation, problem areas may be identified that require extra work. When worked out in the form of proposals, it requires funding to be realized. This funding needs to be acquired from national (e.g. GO) and international science funding programs (e.g FP7).

**Task parts:**
- Identify validation problem areas  
- Write and submit proposals to (inter)national calls for proposals and funding programs

**Data sources:**  
Cordis website (www.cordis.lu and http://fp6.cordis.lu/fp6/home.cfm)  
Senter-EG/Liaison website (http://www.egl.nl) and contacts (Matthijs Soede, m.soede #at# egl.nl)

**Funding Sources**  
National GO program (NIVR, SRON) and European FP6 and FP7 Programs

**Associated names and subject:**  
Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist  
Joost Carpay  NIVR – Program Manager  
Mark Kroon  KNMI - OMI validation working group lead (WPL)  
Pieternel Levelt  KNMI - OMI Principal Investigator  
Ankie Piters  KNMI - SCIAMACHY validation coordinator
Task 4.8 Correlative data gathering activities

Start / End: Throughout the lifetime of OMI

Summary: Validation of EOS-Aura satellite data is performed largely on the basis of routine correlative data and dedicated campaign data. Contacts need to be established with the providers of such data in order to stay informed on recent developments, new instrumentation, recalibration of instruments, planned campaigns, changes to campaign plans. Furthermore, several members of each EOS-Aura instrument team have been appointed EOS-Aura liaison for a specific type of instrumentation. The task of the liaison is to stay informed on recent developments, new instrumentation, and recalibration of instruments. The liaison provides the principal investigator of the instruments involved with up-to-date information and procedures concerning the EOS-Aura Validation Data Center.

Task parts:
- Participate in database rehearsal, general database tasks and correlative data liaison tasks for EOS-Aura.
- Gather data through liaison task for EOS-Aura Correlative Database.
- Investigate availability of routine data and validation campaign data for OMI validation.
- Organize additional data gathering when/where necessary.

Data sources:
All possible sources, see annex.

Associated names and subject:
Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist
- NDSC liaison for ground-based UV/VIS instruments
Mark Kroon  KNMI - OMI validation working group lead (WPL)
5 Development of Validation Tools

5.1 Introduction

Validation tools are computer software programs that are written specifically for the purpose of inspection of the quality of satellite data and comparisons with correlative data from ground-based sites, airborne campaigns and other satellites. For visual inspection purposes such tools are capable of reading and plotting satellite data in various manners and analyzing the quality of the data in terms of magnitude and sign, noise and continuity. More advanced validation requires the tools to be capable of performing statistical comparisons with spatially and temporally collocated correlative data originating from all sources available.

Task 5.1 Quick-look tools for OMI data inspection

Start / End: OMI commissioning phase
Summary: Validation tools are mainly written in RSI-IDL. Quick-look tools provide easy plotting of global data fields, zoom in on regional data sets, cross-cuts in the longitude and latitude directions, time series of OMI data. The tools are capable of reading the HDF-EOS format OMI data, i.e., level 1b (HDF-4) as well as all level 2 data (HDF-5). Additional data fields and quality parameters, such as flags, cloud information, geolocation information, etc. are also read. Note that level 1b data contains spectra for each OMI pixel.

Task parts:
- Develop and debug validation tools, preferably starting from existing software.
- Write documentation/manual for these tools.
- Iterate with calibration, validation and Q/A groups.

Data sources:
- Existing OMI and SCIAMACHY software.
- IDL example routines.

Associated names and subject:
Ronald van der A  KNMI - developed SALSA SCIAMACHY validation tool
Ellen Brinksma  KNMI - developed SCIAMACHY-ground-based validation tool.
Ruurd Dirksen  KNMI - developed tool for reading and analyzing OMI level 1B calibration data
Pepijn Veefkind  KNMI - OMI algorithm working group lead (WPL)
Robert Voors  KNMI - developed tool for reading and analyzing OMI level 1B calibration data

Task 5.2 Advanced tools for OMI geolocation verification

Start / End: OMI commissioning phase
Summary: OMI R(ed) G(reen) B(lue) images are distilled from the level 1B OMI VIS channel by narrow band integration of the Earth radiance intensity around 470 nm, 410 nm and 350 nm and assigning histogram equalized red, green and blue color values, respectively. Plotting these RGB values on the globe reveals the location of geophysical Earth surface details such coastlines and deserts as observed by OMI. Comparison with the high resolution contour map as provided by IDL, based on the 1993 CIA world map, reveals the quality of the geolocation values assigned to OMI pixels by the SIPS processor based on EOS-Aura NOSE data.

Task parts:
- Develop tool for ingesting OMI RGB data, global plotting of OMI RGB data, zoom-in to appropriate level to reveal geophysical details, shifting world map with respect to OMI data.
- Write documentation/manual for these tools.

Data sources:
- Existing OMI and SCIAMACHY software.
- IDL example routines.
Associated names and subject:
Ruud Dirksen         KNMI – OMI RGB data processing
Mark Kroon           KNMI - OMI validation working group lead (WPL) / OMI geolocation verification

Task 5.3  Advancing BEAT towards OMI and EOS-Aura
Start / End:     Throughout the lifetime of OMI
Summary:         The Basic ENVISAT Atmospheric Toolbox, also known as BEAT, was developed by the Dutch company Science and Technology. This work was funded by ESA. BEAT overcomes all issues related to data file formats of the SCIAMACHY, GOMOS and MIPAS instruments aboard ENVISAT and enables users to ingest this data with a single line of code. Adapting BEAT to ingest OMI data holds the promise of enabling efficient comparisons between OMI and appropriate ENVISAT data. Because OMI data is stored in the Aura wide standardized HDF-EOS format, adapting BEAT to ingest Aura data is just one step further. ESA has funded the work on adapting BEAT to ingest OMI data which commenced mid 2004 and is currently ongoing.

Task parts:
- Provide information and specifications on OMI and Aura data products to BEAT developers
- Test new releases of BEAT with OMI data and correlative data

Data sources:  BEAT website (http://www.science-and-technology.nl/beat/)

Associated names and subject:
Ellen Brinksma      KNMI - OMI/SCIAMACHY validation scientist
Mark Kroon           KNMI - OMI validation working group lead (WPL)
Sander Niemeijer     Science and Technology, Delft, The Netherlands, BEAT developer
Pepijn Veefkind      KNMI - OMI algorithm working group lead (WPL)

Task 5.4  Creation and Maintenance of a Website for OMI Validation
Start / End:     OMI commissioning phase
Summary:         The purposes of the website were described in Task 4.3.

Task parts:
- Create a website dedicated to OMI validation as part of the OMI website at KNMI
- Post information on OMI validation, OMI validation AO, product release plan and OMI data access
- Maintain the OMI validation website, along the guidelines provided by the OMI validation coordinator.

Information sources:
SCIAMACHY validation website as an example

Associated names and subject:
Ellen Brinksma      KNMI - OMI/SCIAMACHY validation scientist / Validation website coordinator
Mirna van Hoek      KNMI - OMI website developer
Rene Noordhoek      KNMI - OMI scientific secretary / website coordinator
Ankie Piters        KNMI - SCIAMACHY validation coordinator / SCIAMACHY validation website
6 Level 1b validation

Product Coordinator: Mark Kroon - KNMI

6.1 Introduction

As a result of the poor on-ground calibration of OMI, an extensive in-flight calibration program is currently running at KNMI and NASA GSFC [14]. In this program the behavior of the OMI instrument in flight is continuously monitored and the operational settings are optimized on an almost daily basis. The in-flight calibration program monitors detector performance in terms of dark current maps, bad and dead pixel maps, transient pixel behavior as results of cosmic rays, detector non-linearity, detector sensitivity and much more. Thus far the in-flight calibration program has delivered astounding improvements in monitoring, understanding and improving the OMI instrument performance.

Direct validation of the level 1b radiance and irradiance product of OMI is difficult and may not be essential for the production of stable OMI satellite data products. However, validation of radiance and irradiance is invaluable for understanding the instrument and its degradation in space. Part of this validation is performed under the in-flight calibration program. Remaining tasks are described in this chapter.

6.2 Relevant OMI Announcement of Opportunity proposals

2910 - Cross validation of ENVISAT and Aura/OMI data products and scientific analysis across platforms. PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2915 - Validation of the OMI surface UV irradiance products and Finnish contribution to validation of the OMI ozone profile products. PI: Dr. Aapo Tanskanen, Finnish Meteorological Institute, Finland

2927 - Calibration and validation of OMI measurements using a numerical weather prediction assimilation system. PI: Dr. Stefano Migliorini, Data Assimilation Research Center, University of Reading, United Kingdom

2945 - Validation of OMI products over Europe with ground-based UV instruments. PI: Prof. Dr. Philipp Weihs, Universität für Bodenkultur, Department für Wasser - Atmosphäre - Umwelt, Austria

Task 6.1 Geolocation Verification

Start / End: Provisional Release L1 data / Throughout OMI lifetime

Summary: The geolocation of OMI pixels in terms of latitude and longitude is calculated from the EOS-Aura nominal orbit (NOSE) data by the SIPS processor. To verify the assigned positions one needs to compare the geolocation of geophysical features that OMI can observe with their true geolocation. While orbiting the Earth, OMI will observe geophysical features such as deserts, coast lines, smaller and larger islands. These features and their transitions are encountered by the OMI pixels under various geometries and will be recorded in the reflectivity spectra. Their occurrence is indicative of the true position of the OMI nadir viewing position and the OMI swath. The difference with the assigned OMI nadir viewing position and the true geolocation is indicative of the geometrical alignment of OMI aboard EOS-Aura (see 0 for description of tools).

Task parts:
- Obtain assigned geolocation of observed geophysical transitions from level 1B data plots.
- Compare assigned positions with validated database of true positions.
- Calculate mismatch between assigned OMI pixels positions and true global positions.

Data sources:
- OMI level 1b Earth reflectance data
- Digital elevation map of the World
- CIA 1993 World map as installed with RSI IDL

Associated names and subject:
- Ruud Dirksen, KNMI - OMI calibrations scientist
- Marcel Dobber, KNMI - OMI calibrations scientist
Task 6.2  Reflectance validation using a radiative transfer model

Start / End:  Provisional Release L1 / Provisional Release L1 +3 months

Summary:  The OMI reflectance, the ratio of the Earth radiance and the solar irradiance, will be compared to the result of reflectance simulations. Input for these simulations, performed with a radiative transfer model, are ozone profiles (from a correlative satellite instrument) or ozone column (sufficient for $\lambda > 320$ nm), surface albedo, aerosol data and OMI/Modis cloud information (because cloud-free scenes need to be selected). For cloud-free sites the radiative transfer models can be used to calculate the expected OMI nadir reflectance if ozone profile, aerosol information and surface albedo are known. These are compared with the measured spectra.

Task parts:
- Gather correlative ozone column and profile data, cloud and aerosol data, gather surface albedos (climatology).
- Select OMI reflectance from cloud-free, well-known, stable scenes.
- Run radiative transfer model for OMI viewing and solar geometries.

Tips:
- Define pre-flight a set of stable Earth scene calibration targets which can also be used for spectra validation.
- Define / retrieve a set of orbits which are used to test the L0-L1 processor upgrades which can also be used to monitor the impact of the processor upgrade.

Data sources:
- OMI level 1b radiance data and irradiance data
- OMI level 2 data (O3, No2, aerosols, clouds)
- SCIAMACHY level 2 data
- Radiative Transfer Model (Stammes, De Haan)

Associated names and subject:
- Johan de Haan  KNMI - RTM developer / user
- Piet Stammes  KNMI - RTM developer / user
- Remco Braak  KNMI – RTM developer / user

Task 6.3  Radiance and reflectance comparison with other satellite radiances

Start / End:  Provisional Release L1 / Provisional Release L1 + 3 months

Summary:  Radiances and reflectances can be verified by comparison 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 1b products. A similar approach was employed in the early GOME validation program. For more advanced and detailed validation purposed, the spatially and temporally collocated measurements by Aqua-MODIS are suitable only. Long term level 1b validation needed for establishing system degrading trends can be performed with measurements over stable Earth scenes.

Task parts:
- Compare OMI level 1B radiances and reflectances with data measured by independent and validated satellites such as SCIAMACHY, TOMS and GOME instruments, and with other A-train instruments (Aqua-MODIS).
- Check ratio’s, differences, peaks, and correlation between OMI and other satellite spectra.
- Report verification results in meetings and written report.

Data sources:
- OMI level 1b data
- SCIAMACHY, TOMS, Aqua-MODIS, level 1b data
Task 6.4  Radiance comparison using ground-based data

Start / End:  From Provisional Release onwards
Summary:  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 [15]. 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. 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.

Task parts:
- This is a US task. Coordinate comparison of the outcome of this task with other radiance validation results.

Associated names and subject:
Ernest Hilsenrath  NASA-GSFC
Nick Krotkov  NASA-GSFC
7 Ozone column work package

Product Coordinator(s): Ellen Brinksma - KNMI (OMI DOAS)
Richard McPeters - GSFC (OMI TOMS)

7.1 Introduction

A major priority of OMI is to continue the global ozone record as measured by the various TOMS instruments since 1978. Besides high accuracy of the measurements, good stability over time is required for the scientific purposes of these data. Validation of the total ozone column will assess both of these aspects. The relatively high spatial resolution of OMI will yield useful data on spatial variation in ozone fields.

Total ozone columns will be derived using the TOMS-algorithm and the DOAS-fitting method. Hereinafter, the products will be called OMI-TOMS and OMI-DOAS. Ozone columns measured by OMI have an accuracy of 2% / 4 DU [4]. 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 OMI-TOMS and OMI-DOAS. All ozone products based on OMI data will be intercompared.

SCIAMACHY, EP-TOMS, and NOAA-16 SBUV/2 data are assumed to be readily available during the OMI commissioning and core validation phases. Ample expertise with these correlative data is present at KNMI (SCIAMACHY) and in the US (TOMS and SBUV/2). The accuracies of the SCIAMACHY and TOMS ozone columns are 1.6% and 1.0 - 1.5% respectively.

Validation has to take place under a range of representative conditions. For total ozone columns, specifically, the following conditions are distinguished

Driven by ozone conditions
- Mid-latitude unpolluted
- Mid-latitude polluted
- Arctic and Antarctic low column ozone (ozone hole)
- Arctic and Antarctic high column ozone
- Tropical unpolluted (low ozone columns, relatively stable over time)
- Tropical polluted, biomass burning areas (high tropospheric ozone content)

Driven by measurement conditions
- Various cloud conditions, ranging from cloud free through fully clouded. This includes studies of cloud fraction, cloud albedo, cloud height, ghost columns.
- Areas of strong spatial constituent gradients (e.g., Antarctic vortex edge area exhibits large stratospheric ozone gradient, biomass burning conditions show large tropospheric gradients)
- Range of solar zenith angles, including low sun (polar winter)
- Range of viewing geometries, i.e. compare pixels within a given OMI swath

7.2 Ozone validation priorities and timeline

Prior to launch:
- Algorithm verification on synthetic data (derived from GOME spectra) is performed (WP 7.1.1 - 0)

Starting at L+3 (start of commissioning phase), in parallel:
- Q/A and Science Q/A (includes comparisons with simple ozone climatology)

Starting at L+6:
- Comparisons with routine Dobson and Brewer data (0)
- Qualitative, quick-look comparisons between SCIAMACHY and OMI data (WP 7.4.1)
- Comparisons between OMI-TOMS and OMI-DOAS results.
Starting at L+12:

- Quantitative comparisons between OMI and other satellites (SCIAMACHY, TOMS, SBUV/2) (WP 7.4.1)
- Comparison with integrated ground-based profile data under those conditions where ground-based columns are not reliable (0)

7.3 Relevant OMI Announcement of Opportunity proposals

- 2870 - Remote sensing observations over Bremen/Germany, an industrial semi polluted area
  PI: Prof. Justus Notholt, Institut für Umwelt Physik, University of Bremen, Germany

- 2907 - OMI validation by ground based remote sensing: ozone columns and atmospheric profiles
  PI: Dr. Angelina Shavrina, Main Astronomical Observatory of National Academy of Sciences of Ukraine, Ukraine

- 2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
  PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

- 2925 - Validation of OMI total ozone using ground-based Brewer observations
  PI: Dr. Dimitris Balis, Aristotle University of Thessaloniki - Laboratory of Atmospheric Physics, Greece

- 2926 - Validation of OMI ozone and NO₂ vertical column data with ground-based spectroscopic measurements in Russia and NIS
  PI: Prof. Dr. Yury Timofeyev, Research Institute of Physics, St. Petersburg State University, Russian Federation

- 2927 - Calibration and validation of OMI measurements using a numerical weather prediction assimilation system.
  PI: Dr. Stefano Migliorini, Data Assimilation Research Center, University of Reading, United Kingdom

- 2931 - Validation of Aura OMI trace gas products.
  PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

- 2943 - Comparison of scientific total ozone retrieval results from OMI, GOME, and SCIAMACHY using the weighting function DOAS approach and validation of OMI operational data products.
  PI: Dr. Mark Weber, , Institut für Umwelt Physik, University of Bremen, Germany

- 2945 - Validation of OMI products over Europe with ground-based UV instruments.
  PI: Prof. Dr. Philipp Weihs, Universität für Bodenkultur, Department für Wasser - Atmosphäre - Umwelt, Austria

Task 7.1 Algorithm verification

WP 7.1.1 Apply algorithm on synthetic data

Start/End: Ready before launch

Summary: Apply the OMI algorithm on synthetic data, e.g., data created from GOME observations with the “GOME to OMI tool” developed by P. Veefkind (KNMI). Check all intermediate results (slant column densities SCD), air mass factors (AMF)) for consistency with algorithm description. Check error propagation. Compare ozone columns from different fitting windows. Check fitting errors, RMS info and flags. Compare with ozone columns derived with a similar algorithm applied on the same OMI data. We assume that this WP is completed as part of the algorithm/software development.

Associated names and subject:
Pepijn Veefkind KNMI - OMI algorithm working group lead (WPL)

WP 7.1.2 Synthetic OMI ozone result comparisons

Start / End: before launch / end of LEO (L+3)

Summary: The DOAS and TOMS-method OMI ozone columns are derived from the same synthetic level 1b OMI data, using different algorithms. The NRT and VFD ozone columns are derived from different level 1B data, but still apply to the same ground pixels. Comparisons between these four different results are useful for revealing algorithm systematic effects, including effects of the differently selected wavelength regions. We assume that this WP is completed as part of the algorithm/software development.

Associated names and subject:
Pepijn Veefkind KNMI - OMI algorithm working group lead (WPL)
WP 7.1.3 Synthetic EOS-Aura ozone result comparisons
Start / End: before launch / end of LEO (L+3)
Summary: All four EOS-Aura instruments measure ozone. Synthetic spectra in the various wavelength regions have been generated and were input to the ozone algorithms. Results were compared. We assume that this WP is completed as part of the algorithm/software development.

Associated names and subject:
Nathaniel Livesey MLS Science Team, coordinator of comparison effort
Robert Voors OMI Contributor to comparison effort

Task 7.2 Q/A and first Science Q/A
Start / End: end of LEO (L+3) / throughout OMI lifetime
Summary: Check for non-physical values and spikes in physical quantities (such as ozone column) and lookup table entries (AMF, albedo). Plot values on a globe, check for unexpected features. Check all data fields (data and geolocation). Check for discontinuities/jumps in ozone column values along orbit, between orbits, and day-to-day. Check magnitude and sign of total columns. Correlate ozone columns with cloud information, to check for systematic effects induced by clouds or errors in the cloud retrieval.

Task parts:
• Apply tools, perform analysis of values (see summary above)
• Report verification results in meetings and written report.
• Delta validation - repeat if data updates are available

Associated names and subject:
Pepijn Veefkind KNMI - OMI algorithm working group lead (WPL)

Task 7.3 OMI-TOMS and OMI-DOAS comparisons
Start / End: Provisional release total ozone columns / throughout OMI life time
Summary: OMI-TOMS and OMI-DOAS are derived from the same level 1b data, using different algorithms. In this work package these results are compared as a function of zenith angle, azimuth angle, longitude, latitude, albedo etc. If differences are found, these need to be handled first prior to comparisons with correlative data.

Task parts:
• Use tools from Task 5.1 to Task 5.3, and 0 to perform comparisons, checking the various flags.
• Iterate results with OMI-TOMS validators

Associated names and subject:
Pepijn Veefkind KNMI - OMI algorithm working group lead (WPL)
Rich McPeters NASA - GSFC TOMS PI, US OMI Validation team lead
Gordon Labow NASA-GSFC OMI-TOMS validation scientist
Ellen Brinksma KNMI OMI-DOAS validation scientist

Task 7.4 Comparison with routine ground-based data
Start / End: Provisional release total ozone columns / throughout OMI lifetime
Summary: OMI ozone column data will be compared to routine ground-based data (Brewer instruments, Dobson instruments). There is an extensive network of Brewer/Dobson data, and these instruments have good precision. Under conditions where Dobson-Brewer instruments are not reliable, other sources will be used, including integrated profile measurements.

Task parts:
• Gather correlative data from various databases or correlative database.
• Perform comparisons based on spatial and temporal collocation criteria. Decide on coincidence/colation criteria, write correlative data selection routine, write software for comparing ground-based and OMI data
• Interpret results, looking for systematic effects in both OMI and ground-based data (e.g., solar zenith angle dependence, seasonal effects, ozone column dependence, etc.)
Data sources:
- Brewer, Dobson, FTIR, LIDAR, Microwave, MOSAIC, Umkehr, UV/VIS, NDSC, WOUDC, NILU
- Column validation performed mainly with WOUDC and NDSC Brewer and Dobson network with global coverage. Measurements only over land, often in clean environments.

Associated names and subject:
- Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist / WMO Brewer data
- Marc Allaart   KNMI - GOME SCIAMACHY validation
- Ge Verver     KNMI - Paramaribo validation site
- Ankie Piters  KNMI - SCIAMACHY ozone validation
- Jean Christopher Lambert KNMI - SCIAMACHY ozone column product coordinator, OMI AO PI.

Task 7.5  Comparison with validated satellite data

Summary: OMI ozone column data will be compared to column data from other satellites. A first comparison is made using quick-look tools, plotting global maps of both OMI and other satellite ozone columns. More quantitative comparisons will select the nearest collocation with every OMI pixel from the correlative satellite data. Attention must be given to presumed information; do OMI and other instruments measure on the same airmass, use the same temperature climatology, etc.

WP 7.4.1  Comparisons with SCIAMACHY
Start / End:  Provisional release OMI total ozone columns / throughout OMI and SCIAMACHY life time

Task parts:
- Modify/Develop software tools for quick-look comparisons (from start of the commissioning phase)
- Modify/Develop software tools for thorough, quantitative comparisons (later in the commissioning phase)

Data resources:
- SCIAMACHY and OMI (DOAS and TOMS) total ozone columns
- IDL software developed for SCIAMACHY data validation
- BEAT able to ingest SCIAMACHY data, recently adapted to ingest OMI data

Associated names and subject:
- Ellen Brinksma  KNMI - OMI/SCIAMACHY validation scientist
- Marc Allaart   KNMI - SCIAMACHY ozone validation
- Ankie Piters  KNMI - SCIAMACHY validation

WP 7.4.2  Comparisons with EP-TOMS
Start / End:  Provisional release total ozone columns / throughout EP-TOMS useful life time

Task parts:  Coordination/supervision if necessary

Data resources:
- EP-TOMS ozone columns
- IDL software developed for SCIAMACHY data validation

Associated names and subject:
- Rich McPeters  NASA - GSFC TOMS PI, US OMI Validation team lead

WP 7.4.3  Comparisons with other satellites
Start / End:  Provisional release total ozone columns / throughout OMI and SCIAMACHY life time

Task parts:  Coordination/supervision if necessary

Data resources:  Satellite instruments:
Ozone columns are measured by the following satellites: AIRS, SCIAMACHY, SBUV-2
Task 7.6  Comparison with campaign data
Start / End:  Pre-AVE January 2004 / throughout the Aura lifetime
Summary:  NASA is planning various large campaigns within the framework of validation. Ozone measurements are an integral part of these campaigns. Ozone total columns and ozone tropospheric columns are to be measured and are suitable for validation of OMI data. Simultaneous recording of cloud properties and aerosol loads are a must. Interesting measurements are to be performed in pristine, urban, industrial or biomass burning regions with accompanying high and low aerosols loading.

Task parts:
- Formulate validation opportunities per validation campaign based on payload, meteorology and location
- Attend campaigns at the deployment site and actively participate in daily flight planning for OMI goals
- Assess usefulness of campaign data serving as input for following campaign opportunity

Data sources  Campaigns: AVE, Polar-AVE, INTEX-East, INTEX-West, TC4, SOLVE

Associated names and subject:
David Fahey  NOAA - AVE project scientists
Lucien Froidevaux  JPL - EOS-Aura validation lead
Paul Newman  GSFC - AVE project scientists
Rich McPeters  GSFC - OMI US validation lead
Mark Schoeberl  GSFC - Aura project scientist / AVE project scientists

Task 7.7  Correlation between OMI and TES
Start / End:  Provisional release total ozone column and TES ozone data / throughout Aura-OMI-TES lifetime
Summary:  OMI is the only instrument aboard EOS-Aura that directly measures total ozone columns; TES will deliver ozone columns by integrating their nadir measurements. HIRDLS and MLS deliver ozone profiles from the upper troposphere through the stratosphere, which may be integrated to yield (incomplete) columns.

Task parts:
- Intercompare OMI/TES data
- Iterate with TES scientists about results

Data sources:  TES ozone column data

Associated names and subject:
J. Logan  Harvard - TES ozone validation
M. Kroon  KNMI – OMI validation lead – total ozone coordinator

Task 7.8  Comparison with integrated ground-based profile data
Start / End:  After results of OMI-Brewer/Dobson have been interpreted / ?
Summary:  For a limited number of locations (mostly NDSC primary sites), namely where stratospheric ozone lidar or microwave, and ozone sondes measure, OMI ozone columns can be compared to integrated ground-based profile data. These measurements have high accuracy (few %) compared to the groundbased ozone column (Dobson/Brewer) instruments; in fact they are the most accurate ozone column measurements available. These comparisons will be done to complement those between OMI and Brewer - Dobson.

Task parts:
- Gather correlative data from various databases or correlative database. Develop data reading tools for ground-based data (or adapt existing programs if available). Develop tool to splice sonde and other data, decide on splicing altitude (note - this decision can be based on sonde and other profiling instrument comparisons, or on trial and error), write routine to integrate profiles and convert to Dobson Units.
- Use software and expertise gained in ozone profile validation WP and in WP2.5 to compare spliced integrated profiles with OMI data.
• Interpret results, looking for systematic effects in OMI data (e.g., solar zenith angle dependence, seasonal effects, ozone column dependence, etc.). Verify (from literature validation exercises) that the specific sondes and other profilers used were independently validated with good results.

Data sources: Sonde, and lidar or microwave data are available from NDSC (NASA-Ames format, reading software supplied).

Associated names and subject:
Daan Swart (RIVM), Greg Bodeker (NIWA) lidar/sonde data Lauder, NZ
Other NDSC investigators similar profile data.

Task 7.9  Comparison with campaign sonde data
Start / End: Provisional release total ozone column / throughout the Aura lifetime
Summary: There is a lack of correlative total ozone column and tropospheric ozone column data in tropical regions. The SHADOZ program allows for balloon launches from various tropical sites, including Paramaribo station. One hundred additional balloon launches are funded through KNMI, which may be performed tropical (Paramaribo) or industrial sites (The Netherlands). They will also be used to add ozone profile (and, if integrated, column) data to large campaigns. It is important to validate OMI results under tropical conditions or other conditions in which large tropospheric content is expected, since tropospheric ozone influences the airmass factors assumed (errors up to 5% [7-10]), and the OMI sensitivity in the troposphere may be limited.

Task parts:
• Investigate where additional balloon launches are most useful, coordinate additional sonde program
• Use software and expertise gained in WP2.6 to integrate balloon profiles, use climatology to extend sonde profile through the stratosphere (above the sonde burst height).
• Investigate horizontal pixel-to-pixel OMI ozone column variability (may be significant in areas with high tropospheric ozone amounts). Decide on criteria for collocation/time difference and evaluate OMI pixel size vs. balloon measurement.

Data sources:
• Campaigns such as AVE, Dandelions, INTEX-E, INTEX-W, POLAR, TC4, CAMEX
• Correlative data is sparse over sea and aircraft/balloon campaigns can fill in the gaps.
• SHADOZ program
• Paramaribo station
• Launches from De Bilt

Associated names and subject:
Gé Verver (KNMI) Paramaribo station
Marc Allaart(KNMI) Sonde coordinator De Bilt / Paramaribo

Task 7.10  Tropospheric Ozone Column
Start / End: Provisional release ozone profile / throughout the Aura lifetime
Summary: For the validation of tropospheric ozone, ozonesondes are the only routine data source at a range of sites. Locations of special interest are the tropics, during biomass burning events, when ozone concentrations are high and variable, and polluted areas in general (e.g., industrial areas). Comparisons are planned with tropospheric products derived from SCIAMACHY data; these products do not have the precision of sonde-derived columns 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.

Task parts:

Data resources:
• Sonde data (SHADOZ, regular ozone soundings, campaigns)
• Tropospheric ozone (e.g., using assimilation) from SCIAMACHY (www.temis.nl)
• Campaigns: AVE, INTEX-E, INTEX-W, POLAR, TC4
Task 7.11  Comparison with assimilated data

Start / End:  Provisional release total ozone column data / throughout the Aura lifetime
Summary:  Assimilated data can be used for OMI ozone column validation in two ways; Firstly, assimilation of GOME and SCIAMACHY data improves the number of collocations and may be used to better compare OMI data with satellite or ground-based data taken at a different time. The difference in observation pixel size or vertical extent is resolved by using assimilation. Secondly, assimilation can be used on OMI data itself, to view the difference of observed minus forecasted data, known as OmF, where the forecast is generated by an assimilation run on older data. Tropospheric ozone columns can be derived by subtraction of the integrated assimilated stratospheric profiles from the OMI column densities.

Task parts:
- Adapt the existing assimilation code for GOME and SCIAMACHY data to handle OMI data.
- Write software routines that compare assimilated GOME and SCIAMACHY data and OMI observations.
- Write software routines that compare assimilated OMI data with OMI observations

Data resources:
- GOME data / assimilated GOME data
- SCIAMACHY data / assimilated SCIAMACHY data
- OMI data (level 2)
- Assimilated OMI data

Associated names and subject:
Henk Eskes  KNMI - data assimilation code / GOME data level 2
OMI-team  KNMI - OMI data level 2
8  Ozone profile work package

Product Coordinator: Ellen Brinksma - KNMI

8.1  Introduction

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 (e.g., from WOUDC), with limited data available south of 20 N. Continuation of the SHADOZ program would ensure availability of profiles for the tropics and Southern hemisphere. To achieve global coverage, measurements by EOS-Aura will be compared with measurements from various satellite sensors. Examples of satellites measuring ozone profiles are SCIAMACHY (if still available also GOMOS, MIPAS) on Envisat, NOAA-SBUV/2, SAGE-II and III.

Inherent to nadir ozone profile retrievals, 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 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 and the profile errors. 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.

8.2  Relevant OMI Announcement of Opportunity proposals

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2915 - Validation of the OMI surface UV irradiance products and Finnish contribution to validation of the OMI ozone profile products
PI: Dr. Aapo Tanskanen, Finnish Meteorological Institute, Finland

2930 - Use of neural networks algorithms for the retrieval of ozone and other trace gases profiles from OMI measurements
PI: Dr. Fabio Del Frate, Tor Vergata University, Italy

2931 - Validation of Aura OMI trace gas products.
PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

2932 - Validation of the ozone profile from the Ozone Monitoring Instrument onboard of the NASA EOS-Aura Satellite using the Umkehr observations by the Dobson spectrophotometers.
PI: Prof. Dr. Janusz Wojciech Krzycin, Institute of Geophysics, Polish Academy of Sciences, Poland

2942 - Validation of OMI Ozone Profiles and Aerosol Optical Thickness using ground based measurements
PI: Dr. Rene Lemoine, Royal Meteorological Institute of Belgium, Belgium

2944 - Balloon-borne ozone-soundings at L'Aquila (Italy) for a local validation of OMI measurements of ozone vertical profiles
PI: Dr. Vincenzo Rizi, Dipartimento di Fisica - Universita Degli Studi, Italy

Task 8.1  Algorithm verification

Start/End:  Ready before launch
Summary:  Apply the OMI ozone profile retrieval algorithm on synthetic data, e.g., data created from GOME and SCIAMACHY observations with the “GOME to OMI tool” developed by P. Veefkind (KNMI). Check all intermediate results for consistency with algorithm description. Compare ozone profiles from different fitting windows. Check error propagation. Check fitting errors, RMS info and flags. We are assuming that this WP is completed as part of the algorithm/software development.
Task parts:
- Develop data sorting / plotting / quick-look tools (for OMI profiles)
- Apply tools to selected synthetic OMI profiles and real OMI profiles
- Report results in meetings and written report.

Data resources: Synthetic OMI level 1 data

Associated names and subject:
Pepijn Veefkind  KNMI - OMI algorithm working group lead (WPL)
Johan de Haan, Robert Voors  KNMI - algorithm developers

Task 8.2  Value verification
Start / End:  Beta release OMI ozone profiles / Provisional release
Summary:  Check for non-physical values and spikes in physical quantities. Plot values on a globe, check for unexpected features. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in ozone profile values along orbit, between orbits, and day-to-day.

Task parts:  Apply tools for quick-looks
Give feedback to algorithm developers about product quality (meeting, report).

Associated names and subject:
Pepijn Veefkind  KNMI - OMI algorithm working group lead (WPL)
Johan de Haan  KNMI - OMI algorithm developer

Task 8.3  Validation with routine ozone profile data
Start / End:  Provisional release OMI ozone profiles
Summary:  OMI ozone profile data will be compared to routine ground-based data. These instruments have a lower number of coincidences with OMI overpasses, but much better precision and stability than satellite data.

Task parts:
- Gather correlative data from various databases or correlative database
- Develop data reading tools for ground-based data (or adapt existing programs if available)
- Communicate with ground-based data providers on protocols, data quality, availability etc.
- Decide on coincidence/collocation criteria (trade off between good coincidence/collocation and good statistics), write correlative data selection routine, write software for comparing ground-based and OMI data
- Interpret results, looking for systematic effects in both OMI and ground-based data (e.g., solar zenith angle dependence, seasonal effects, ozone column dependence, etc.)

Data sources:
- Data networks: NILU, WOUDC, SHADOZ
- Campaigns: AVE, INTEX, CAMEX. Network funded balloons are launched mainly over land in clean environments hence campaigns must be directed to polluted regions.
- MOSAIC yields profile information during take off and landing and from then on yields cruise altitude information. Selected flights over oceans may contribute, particularly to UT and TTL region.

Associated names and subject:
Douglas Kinisson  NCAR - HIRDLS validation - EOS-Aura Liaison for MOSAIC
Ellen Brinksma  KNMI – OMI ozone profile validation expert
Task 8.4  Comparison with validated satellite data
Start / End: Provisional release OMI ozone profiles / ?
Summary: OMI ozone profile data will be compared to profile data from other satellites. A first comparison is made using quick-look tools. To make more quantitative comparisons, software shall be written to select the nearest collocation with every OMI pixel from the correlative satellite data. SCIAMACHY data is assumed to be readily available during the OMI commissioning and core validation phases. Expertise with this correlative data is also readily available at KNMI.

Task parts: Perform comparisons and report the results.

Data resources:
Ozone profiles are measured by SCIAMACHY (limb mode), SAGE-II, SAGE-III, SBUV-2, MIPAS, ODIN, SABER, ACE, POAM.
Note: Beat-L2, which includes the collocation tool, is unable to handle OMI and SCIAMACHY profiles.

Associated names and subject:
Ankie Piters / Dorien Lolkema: SCIAMACHY ozone profiles

Task 8.5  Correlation within EOS-Aura
Start / End: Provisional release OMI ozone profiles / ?
Summary: Other instruments on EOS-Aura measure ozone profiles. Especially MLS ozone profiles from the mid-troposphere through the stratosphere and above will be considered for intercomparison with OMI profiles.

Task parts: Gather regridded (level 3) data from other instruments
Perform correlations with other data.

Data sources: MLS / TES / HIRDLS ozone profile data

Associated names and subject:
Mark Kroon  KNMI – OMI validation lead
Douglas Kinisson  NCAR - HIRDLS validation - EOS-Aura Liaison for MOSAIC
Nathaniel Livesey  JPL - MLS algorithm developer
Gloria Manney  JPL - MLS algorithm developer / validation scientist
9 Nitrogen dioxide work package

Product Coordinator: Ellen Brinksma - KNMI

9.1 Introduction

Several satellite platforms provide global measurements of total NO2 columns. An important issue is the contribution of tropospheric NO2 to the total columns. The sensitivity of most satellites 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 provide total column observations, however, they do not cover polluted areas well (see below).

Due to the limited amount of measurements worldwide, NO2 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 NO2 is expected. With OMI we intend to measure tropospheric and total columns of NO2 under various circumstances, including biomass burning and industrial pollution. Hence additional measurements of tropospheric NO2 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 NO2 lidar operated by RIVM in the Netherlands (52°N), where moderate to high NO2 concentrations in the lower troposphere can be expected. Funding was granted for a two-year (2004-2006) project in which these measurements will take place [16].

Another important issue for the NO2 validation is its diurnal variability. NO2 is destroyed rapidly in the presence of sunlight, and thus concentrations during OMI overpasses will differ from those measured by ground-based techniques that 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 NO2 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 NO2 is distributed homogeneously through the boundary layer, and that the free troposphere contains little NO2, the tropospheric NO2 loading can be determined with roughly 50-100% uncertainty. Knowledge of the horizontal distribution of NO2 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 NO2).

NO2 plays an important role in ozone chemistry. High amounts usually indicate tropospheric pollution, but lightning produced NO2 may also play a role. Total NO2 columns under background conditions are typically $10^{15} \text{ cm}^{-2}$, while in polluted areas GOME has reported number densities up to $10^{16} \text{ cm}^{-2}$.

Total NO2 columns will be validated under unpolluted conditions (columns dominated by stratospheric contribution) during the commissioning phase. Correlative data to be used are SCIAMACHY column and stratospheric profile data, and column data measured by the SAOZ or DOAS instruments (available from, e.g., the NDSC database).

9.2 Relevant OMI Announcement of Opportunity proposals

2870 - Remote sensing observations over Bremen/Germany, an industrial semi polluted area
PI: Prof. Justus Notholt, Institut für Umwelt Physik, University of Bremen, Germany

2898 - Determination of HCHO column abundances from FTIR solar observations at the Jungfraujoch, Switzerland.
PI: Dr. Philippe Demoulin, Institute of Astrophysics and Geophysics - University of Liege, Belgium

2907 - OMI validation by ground based remote sensing: ozone columns and atmospheric profiles
PI: Dr. Angelina Shavrina, Main Astronomical Observatory of National Academy of Sciences of Ukraine, Ukraine

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2919 - Year-round ground based spectrometric measurements of column NO2 at Zvenigorod, Moscow region, under various atmospheric circumstances and comparison of these measurements with the actual OMI satellite instrument observation.
PI: Dr. Aleksandr N. Gruzdev, A.M. Obukhov Institute of Atmospheric Physics, Russian Federation
2921 - Using OMI measurements to extend the GOME/SCIAMACHY tropospheric NO2 record
PI: Dr. Andreas Richter, Institut für Umwelt Physik, University of Bremen, Germany

2926 - Validation of OMI ozone and NO2 vertical column data with ground-based spectroscopic measurements in Russia and NIS.
PI: Prof. Dr. Yury Timofeyev, Research Institute of Physics, St. Petersburg State University, Russian Federation

2929 - Validation of tropospheric NO2 measurements from OMI in urban and suburban sites in the UK
PI: Dr. Paul Monks, University of Leicester, Department of Chemistry, University of Leicester, United Kingdom

2931 - Validation of Aura OMI trace gas products
PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

2938 - Validation of OMI OCIO and NO2 observations using SCIAMACHY data. Investigation of the stratospheric polar chemistry and chlorine trends.
PI: Dr. Thomas Wagner, Institut für Umwelt Physik, University of Heidelberg, Germany

2941 - Validation of SCIAMACHY and OMI NO2 and aerosol data using Dutch ground based measurements
PI: Dr. Pieteren F. Levelt, KNMI, De Bilt, The Netherlands

2945 - Validation of OMI products over Europe with ground-based UV instruments
PI: Prof. Dr. Philipp Weihs, Universität für Bodenkultur, Department für Wasser - Atmosphäre - Umwelt, Austria

Task 9.1 Algorithm verification
Start/End: Ready before launch
Allocated time: We assuming that this WP is completed as part of the algorithm/software development.
Summary: Apply the OMI algorithm on synthetic data, e.g., data created from other observations with the “Other to OMI tool” to be developed by P. Veefkind (KNMI). Check all intermediate results (slant column densities (SCD) and air mass factors (AMF) for columns) for consistency with algorithm description. Check error propagation. Compare NO2 columns from different fitting windows. Check fitting errors, RMS info and flags.

Associated names and subject:
F. Boersma  KNMI - NO2 algorithm developer
Pepijn Veefkind  KNMI - OMI algorithm working group lead (WPL)
E. Brinksma  KNMI - NO2 algorithm developer
J. Gleason et al.  GSFC - NO2 algorithm developer

Task 9.2 Value verification
Start / End: Provisional release total NO2 column / ?
Summary: Check for non-physical values and spikes in physical quantities. Plot values on a globe, check for unexpected features. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in NO2 column values along orbit, between orbits, and day-to-day.

Associated names and subject:
F. Boersma  KNMI - NO2 algorithm developer
Pepijn Veefkind  KNMI - OMI algorithm working group lead (WPL)
E. Brinksma  KNMI - NO2 algorithm developer
J. Gleason et al.  GSFC - NO2 algorithm developer

Task 9.3 Comparison with validated satellite data
Start / End: Provisional release total NO2 column / ?
Summary: OMI NO2 column data will be compared to data from other satellites. A first comparison is made using quick-look tools. To make more quantitative comparisons, software shall be written to select the nearest collocation with every OMI pixel from the correlative satellite data. SCIAMACHY data is assumed to be readily available during the OMI commissioning and core validation phases. Expertise with this correlative data is also readily available at KNMI SCIAMACHY.
Task parts:
- Gather satellite NO2 column data (SCIAMACHY nadir mode, maybe GOME)
- Create quick-look comparisons of OMI and correlative satellite data
- Create collocated data comparisons
- Report outcome to OMI validation office.

Data sources:
- NO2 columns are measured by the following satellites: SCIAMACHY (nadir mode), GOME

Associated names and subject:
Pepijn Veefkind   KNMI - OMI algorithm working group lead (WPL)
E. Brinksma   KNMI - NO2 algorithm developer

Task 9.4  Comparison with routine ground-based data
Start / End:  Provisional release total NO2 column / ?
Summary:  OMI NO2 column data will be compared to routine ground-based NO2 column data. These instruments have a lower number of coincidences with OMI overpasses, but better precision than satellite data.

Task parts:
- Get correlative data from AVDC, provide feedback on completeness of AVDC NO2 data
- Develop validation tools for comparison with OMI data
- Interpret results, taking into account time difference (photo-active species), and sensitivity for tropospheric NO2 (in polluted areas).
- Decide on coincidence/collocation criteria (trade off between good coincidence/collocation and good statistics), write correlative data selection routine, write software for comparing ground-based and OMI data

Data sources:
- AVDC SAOZ and DOAS data
- NO2 column measurement sites (Brewer MK-III and MK-IV instruments)
- Data from AVE campaigns

Associated names and subject:
Eric Buscela   GSFC - Brewer instrument NO2
Marc Allaart   KNMI - WOUDC data / NILU data / Brewer instrument NO2

Task 9.5  Comparison with campaign ground-based and airborne data
Start / End:  Provisional release total NO2 column / ?
Summary:  OMI NO2 column data will be compared to campaign ground-based NO2 column data.

Task parts:
- Gather correlative data from various campaign databases.
- Develop data reading tools for ground-based data (or adapt existing programs if available)
- Communicate with ground-based data providers on protocols, data quality, availability etc.
- Write proposals to get funding for operation of dedicated instruments.

Data sources:
- RIVM Lidar is a very useful instrument for Dutch NO2 validation. MAX-DOAS instruments of the University of Bremen, BIRA, and the University of Heidelberg operate routinely or on location during campaigns. A MaxDOAS instrument is also routinely operated in Paramaribo. When successful, more instruments may be required to gain flexibility and worldwide deployment.
- NO2 column measurement sites (Brewer MK 4 instruments)
- Data from AVE campaigns
- RIVM Lidar is a very useful instrument for Dutch NO2 validation. MAX-DOAS instruments of the University of Bremen, BIRA, and the University of Heidelberg operate routinely or on location during campaigns. A
MaxDOAS instrument is also routinely operated in Paramaribo. When successful, more instruments may be required to gain flexibility and worldwide deployment.

Associated names and subject:
Ellen Brinksma KNMI - DANDELIONS / RSVP-Cesar projects
Mark Kroon KNMI) AVE campaigns

10 Aerosols Work Packages

Product Coordinator: Omar Torres - NASA GSFC

10.1 Introduction

Two aerosol products will be derived from OMI spectra: aerosol optical thickness (AOT) and single scattering albedo (SSA). Moreover, these two aerosol products will each be derived by two different algorithms, developed by Pepijn Veefkind at KNMI and Omar Torres at GSFC, respectively. OMI will retrieve aerosol parameters for cloud-free pixels only. Besides validation of these products 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):
Current Cimel sun-photometers at most AERONET sites measure AOT at four wavelengths within the spectral range of OMI observations (340, 380, 440 and 500 nm). These measurements will be used to validate OMI aerosol retrievals at near UV and visible wavelengths in most parts of the world. Sun-photometer sites that belong to the French component of AERONET (i.e., PHOTONS) measure AOT at only one wavelength (440 nm) within the OMI spectrum. Most of the PHOTONS sites are located in France, Spain, and Northern Africa. For the validation of OMI aerosol retrievals over the large area of influence of Saharan desert aerosols it is recommended that more sun-photometers with near UV measuring capabilities be installed.(see also McPeters et al., 2002). Other important validation sources include ground-based lidar systems (EARLINET, MPLNET) and space-based lidars like CALIPSO and GLAS. AOT measurements by satellite instruments will be used for intercomparison purposes only.

Aerosol Single Scattering Albedo (SSA):
As with the AOT, the primary source of data for validation of the OMI SSA product will be AERONET measurements. AERONET derives column aerosol SSA from measurements of sky radiances at 440, 670, 870, and 1020 nm. With the current AERONET instrumentation, only the 440 nm SSA value can be used in OMI validation. The sun-photometer sky radiance measurements should be extended to the AERONET near UV channels (340 and 380 nm), so that a direct comparison with the OMI near UV SSA values can be done.
In-situ observations of aerosol SSA can also be obtained by simultaneously measuring the aerosol scattering and absorption coefficients. Scattering coefficient of aerosols are obtained using integrating nephelometer measurements. Currently available nephelometers operate at wavelengths 450 nm and longer. Aerosol absorption coefficient can be measured using commercially available Particle Soot/Absorption Photometers (PSAP). For use in OMI validation of aerosol SSA, both, the nephelometer and the PSAP, should be modified for operation at near UV wavelengths.

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 13x24 km². 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.

10.2 Relevant OMI Announcement of Opportunity proposals

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2941 - Validation of SCIAMACHY and OMI NO₂ and aerosol data using Dutch ground based measurements
PI: Dr. Pieternel F. Levelt, KNMI, De Bilt, The Netherlands

2942 - Validation of OMI Ozone Profiles and Aerosol Optical Thickness using ground based measurements
PI: Dr. Rene Lemoine, Royal Meteorological Institute of Belgium, Belgium

2945 - Validation of OMI products over Europe with ground-based UV instruments
PI: Prof. Dr. Philipp Weihs, Universität für Bodenkultur, Department für Wasser - Atmosphäre - Umwelt, Austria

**Task 10.1 Algorithm verification**

Start/End: Ready before launch
Allocated time: We assuming that this WP is completed as part of the algorithm/software development.
Summary: Apply the OMI algorithm on synthetic data, e.g., data created from other observations with the “Other to OMI tool” to be developed by P. Veefkind (KNMI). Check all intermediate results for consistency with algorithm description. Check error propagation. Check RMS info and flags.

**GSFC Tasks:**

**Associated names and subject:**

**Task 10.2 Value verification**

Start / End: ? / ?
Summary: Check for non-physical values and spikes in retrieved products. Map the global distribution of aerosol optical depth and single scattering albedo, to check for the presence of suspicious anomalies. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in aerosol optical depth and single scattering albedo values along orbit, between orbits, and day-to-day.

**Task parts:**

**Data sources:** Please indicate your data sources for correlative data clearly

**Associated names and subject:**

Omar Torres GSFC
Gerrit de Leeuw TNO
Pepijn Veefkind KNMI - OMI algorithm working group lead (WPL)

**Task 10.3 Comparison with validated satellite data**

Start / End: ? / ?
Summary: OMI column aerosol optical depth will be compared to aerosol optical depth values retrieved from observations by other space-borne instruments such as MODIS (on Aqua and Terra) and TOMS (Earth Probe) and Parasol. Assumptions on aerosol vertical distribution can be checked against observations from CALIPSO, Cloudsat, and GLAS active sensors.

**GSFC Tasks:**

**Data sources:**

- OMI will measure single scattering albedo (SSA) and aerosol optical depth (AOD) only: Assumptions are made on the above-mentioned physical properties. These assumptions must be validated by other means.
- Several aerosol properties are measured in the troposphere by the following satellite instruments: AATSR, ATSR-2, EOSP, GOME-2, HIRDLS, MERIS, MIPAS, MODIS, POLDER, SCIAMACHY.
- Several aerosol properties are measured in the stratosphere by the following satellite instruments:ATSR-2, EOSP, GOMOS, HIRDLS, ILIAS-II, MIPAS, OSIRIS, SAGE-III, SCIAMACHY.

**Associated names and subject:**

Lorraine Remer MODIS data
Omar Torres GSFC - EP-TOMS aerosol data
Chip Trepte CALIPSO data
Task 10.4  Comparison with routine ground-based data

Summary:

GSFC Tasks:
- Write an extraction tool for retrieving Aeronet data during OMI overpasses (using Aeronet web archive)
- Perform routine comparisons between Aeronet and OMI data.

Data sources:
- Aerosol Robotic Network (AERONET)
- Micropulse Lidar Network (MPLNET)
- European Aerosol Research Lidar Network (EARLINET)

Associated names and subject:
Brent Holben  Aeronet Project
Ellsworth Welton  MPLNET Project
Albert Ansmann  EARLINET

< add section 10.5 Comparison with Aircraft-based Measurements (CPL) >
11 Clouds Work Packages
Product Coordinator: Johan de Haan - KNMI

11.1 Introduction
Remote sensing by nadir pointing spectrometers preceding OMI, i.e. GOME and SCIAMACHY, use the O2 A band to obtain information on cloud properties. As OMI does not measure in the wavelength range of the O2 A band alternatives had to be found. It was decided to explore two algorithms to obtain information on the cloud pressure and cloud cover, one based on absorption by the O2-O2 collision complex near 477 nm wavelength, and the other based on rotational Raman scattering which gives rise to filling in of solar Fraunhofer lines.

The main purpose of the cloud retrieval algorithms is to support the retrieval of trace gases like ozone and NO2. That is, these algorithms should provide enough information on clouds such that retrieval algorithms for ozone and NO2 can adequately correct for partially cloud-covered pixels. Often, two cloud properties are used for this purpose, namely an effective cloud fraction and the cloud pressure. Corrections are then made by assuming that the detector sees nothing of the trace gas that is hidden by the cloud. The effective cloud fraction is a radiometric equivalent cloud fraction, corresponding with the cloud fraction of an optically thick cloud having a reflectance of 0.8. Further, the cloud pressure represents, for practical purposes, the midlevel of the cloud or cloud system considered. More research is needed to specify these quantities in more detail.

Absorption by O2-O2 is proportional to the square of the number density of oxygen. By measuring the depth of the absorption feature by O2-O2, the number of oxygen molecules above the cloud (and to some extend inside the cloud) is determined, which is then translated to a pressure level of the cloud. The retrieved pressure is often near the middle of the cloud, but may lie below the cloud for optically thin high clouds. Due to the quadratic dependence on the oxygen number density, a retrieval method based on this collision complex will be sensitive to low clouds and relatively insensitive to high clouds. Although absorption by O2-O2 is weak, sensitivity tests show that fairly accurate cloud pressures can be derived if the DOAS method is used. Applying the DOAS method to GOME data yielded initial tests of the algorithm and showed that reasonable values of the cloud pressure were obtained. Moreover, the results of the O2-O2 algorithm compared well with results of the FRESCO algorithm that employs absorption the O2 A band. A more thorough comparison of the two algorithms, partly based on sensitivity analysis, is needed to better understand the differences obtained with the two algorithms.

When light is once scattered by air molecules, nearly 4% of the scattered light is due to rotational Raman scattering. Rotational Raman scattering causes wavelength shifts up to about 2 nm, which tends to destroy spectral fine structures present in the incident light. Spectral features with a resolution of 2 nm or less are effectively removed from the spectrum. The result is that solar Fraunhofer lines are filled in. As the Raman scattering is due to the molecules, measurement of these Fraunhofer line-filling amounts to measuring the amount of air molecules above (and partly inside) the cloud. Roughly half of the filling in is due to N2 and the other half is due to O2. If multiple scattering is important, the amount of filling in tends to increase. Nearly 8% of the light that has been scattered twice by molecules has at least once been Raman scattered. However, by using radiative transfer calculations, one can estimate the cloud pressure from the observed amount of Fraunhofer line-filling. A complicating factor is that there might be other mechanisms that cause inelastic scattering, resulting in an additional filling in of Fraunhofer lines. Raman scattering in clear ocean water is such a mechanism and will introduce a bias in the retrieved cloud pressure. Moreover, the amount of Raman scattering in ocean water is modulated with the phytoplankton concentration in the ocean. Hence, one first has to estimate the phytoplankton concentration, e.g. from cloud-free pixels, and then use this data when performing an ocean Raman correction. Over land no significant inelastic scattering is expected that interferes with the derivation of the cloud pressure.

Before validation starts, results of the two cloud algorithms should be intercompared. The differences in retrieved cloud fraction and effective cloud pressure should be charted and, if possible, interpreted. This may help users to select the cloud data that suits best their purposes. An initial comparison shows that for high clouds the O2-O2 algorithm tends to give higher cloud pressures than the Raman algorithm, in particular for thick clouds in the tropics.
11.1.1 Effective Cloud Fraction

Most of the level 2 OMI data products depend on the quality of the effective cloud fraction product. Validation of the effective cloud fraction obtained with both algorithms 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. Note that for direct validation one has to account for the radiometric nature of the effective cloud fraction, i.e. the actual cloud cover has to be weighted with the reflectivity of the cloud.

An example of direct validation is to compare the OMI effective cloud fraction with that of another instrument, e.g., MODIS (Joint products: see http://modis-atmos.gsfc.nasa.gov and click on JOINT at the top of the page). An example of indirect validation is to investigate whether retrieved total ozone columns are correlated with retrieved cloud fractions. If no significant correlation is found, clouds apparently do not disturb the retrieved spatial variation in the total ozone column, which is exactly what we want. If a correlation remains, it does not necessarily mean that the cloud properties are incorrect, because a correlation can also be due to an incorrect amount of trace gas under the cloud pressure level (the ghost column). In that case the climatology used to calculate the ghost column has to be improved.

Among primary sources for inter-comparison are MODIS, CALIPSO, and CloudSat cloud fractions. Their horizontal resolution and the optical thickness of the clouds considered needs to be taken into account. The optical thickness is important in view of the radiance weighting that is required. The WMO ground-based network may provide valuable information since it produces cloud fractions that have been measured with a different, independent technique. Here again attention should be given to the optical thickness of the clouds in view of the radiance weighting. In addition, METEOSAT data might be useful to trace the movement of clouds, which may help to ensure that different instruments look at the same cloud formation.

Possible sources of bias in the retrieved cloud fraction are inaccuracies in the surface albedo database used in the retrieval algorithm and the radiometric calibration of OMI. If the radiometric calibration of OMI is inaccurate, perhaps due to degradation, this will directly introduce a bias in the retrieved cloud fraction. If parts of Germany are snow covered in March, which is uncommon, the surface albedo database will not be representative for the snow covered parts of Germany, and the retrieved cloud fraction will be incorrect. A daily update of the surface albedo database using information on snow and ice would be required to eliminate such a bias. In the O₂-O₂ retrieval algorithm it is forseen that the surface albedo is adjusted based on NISE (Near real time Ice and Snow Extend) snow/ice data, but the accuracy of this adjustment is not yet known.

Reference data sets:
1 Validated MODIS, CALIPSO, and CloudSat cloud fractions
2 WMO Network
3 METEOSAT

Long-term validation:
Comparisons with CALIPSO, CloudSat, MODIS, SCIAMACHY and GOME II would be most useful for long-term validation.

11.1.2 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., NO₂, BrO). Validation of this data product is difficult, since the retrieved cloud pressure depends, amongst others, on the vertical structure of the cloud system considered (e.g., one or two cloud layers) and the presence of snow/ice on the surface. Further, measurements at infrared wavelengths are more sensitive to thin high clouds than measurements at UV/VIS wavelengths, and IR measurements tend to produce a pressure level closer to the top of the cloud system than UV/VIS measurements. 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 clear physical meaning.

The strategy to validate cloud pressure must rely on comparisons with cloud 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. However, CALIPSO is scheduled for launch in the summer of 2005 (launched April 28, 2006, ed) and it may take time before validated data products become available. Therefore, we choose MODIS on Aqua as a primary instrument for comparisons. In addition, METEOSAT (second
generation) might be used to trace movements of clouds and to give information on cloud properties, as every 15 minutes data becomes available.

**Reference data sets:**
1. Cloud top pressure from MODIS, METEOSAT (second generation)
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. Results obtained with the O$_2$ A band algorithm for GOME II and SCIAMACHY might also be used to detect trends in the average cloud pressure (the time difference between overpasses of OMI the one hand and GOME II and SCIAMACHY on the other hand is large and these latter two instruments should not be used for core validation, but they can be used for long-term validation).

The validation can be divided into a number of tasks. Detailed timelines cannot be given, as certainly the cloud fraction depends a lot on the quality of the level 1b product. The purpose of the tasks listed here is to give an impression of the work that needs to be done and an estimate of the time involved. Much depends on the scientists that will actually perform the validation.

It may be useful to define beforehand a number of so-called cloud validation orbits, which need not be entire orbits but can be partial orbits. For these orbits optimal information from ground stations should be available, e.g. Cabauw, ARM sites with lidar/radar equipment. Satellite observations of cloud properties of these orbits from MODIS, CALIPSO, etc. should also be collected. Reprocessing of data after changes in the algorithm can initially be limited to these validation orbits. That should give sufficient information to judge whether the algorithm has actually improved.

### 11.2 Relevant OMI Announcement of Opportunity proposals

**2910** - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms  
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

**2940** - Cloud validation for OMI (OMI-Clouds)  
PI: Dr. Pieter Stammes, KNMI, De Bilt, The Netherlands

**Task 11.1 Algorithm verification**

Start/End: Ready before launch  
Allocated time: We assuming that this WP is completed as part of the algorithm/software development.

**Remark:** Depending on the outcome of the other tasks, renewed algorithm verification and/or algorithm improvement might be needed. Further, the OMI cloud algorithms are sensitive to radiometric calibration errors, and validation of the cloud product is only useful after we have a reasonably accurate level 1b product.

**Associated names and subject:**  
J.F. de Haan and J. Joiner

**Task 11.2 Value verification**

Start / End: June 1, 2005 / Sept. 1, 2005  
Allocated time: 3 Months  
Summary: Statistical analysis of the cloud product as a function of various parameters, such as solar zenith angle, viewing zenith angle, geographical area (cloud type), and comparison between the O$_2$-O$_2$ cloud product and the Raman cloud product. Here GOME data will be used, transformed to resemble OMI data, so-called GOMI data.

**Task parts:** Perform statistical analysis and, in collaboration with GSFC, compare the two OMI cloud products.

**Data sources:** OMI O$_2$-O$_2$ and Raman cloud products.

**Associated names and subject:**  
J.P Vreekkind, M. Sneep, J. Joiner, A. Vassilkov
**Task 11.3  Comparison with validated satellite data**

Start / End: Sept. 1, 2005 / June 1, 2006  
Allocated time: 9 months  
Summary: Comparison the OMI O\textsubscript{2}-O\textsubscript{2} cloud product, including the small pixel variance, with Aqua-MODIS cloud data. Optionally: comparisons with other satellite data and comparison of the OMI Raman cloud product with MODIS data, depending on the available resources.

**Task parts:**  
- Perform the comparison of the OMI O\textsubscript{2}-O\textsubscript{2} cloud product with MODIS data.  
- If possible and useful, compare with other satellite data such as CALIPSO and Cloudsat.

**GSFC Tasks:**  
- Similar as above, but for the Raman cloud algorithm.

**Data sources:**  
- OMI O\textsubscript{2}-O\textsubscript{2} cloud product  
- Aqua MODIS Joint atmospheric product MODIS http://modis-atmos.gsfc.nasa.gov and click on JOINT

**Associated names and subject:**  
P. Stammes, M. Sneep, J. Joiner

**Task 11.4  Comparison with routine ground-based data**

Start / End: June 1, 2006 / March 1, 2007  
Allocated time: 9 months  
Summary: Detailed validation by comparison with ground-based radar/lidar measurements in Cabauw. Initially for the O\textsubscript{2}-O\textsubscript{2} cloud algorithm. If feasible, also for the Raman cloud algorithm. If resources become available, comparisons with other radar/lidar ground stations will be done.

**Task parts:** Perform the detailed comparison for the O\textsubscript{2}-O\textsubscript{2} algorithm.

**GSFC Tasks:**  
- Similar as above, but for the Raman cloud algorithm.

**Data sources:** Ground-based lidar and radar measurements performed at Cabauw will be used for validation of cloud geometry (cloud fraction, cloud top, cloud base and cloud vertical structure). These measurements are performed operationally in the framework of the CESAR project. More information about these measurements, see the website: http://www.cesar-observatory.nl and also the recent BBC2 cloud campaign website http://www.knmi.nl/samenw/bbc2.

**Associated names and subject:**  
P. Stammes, M. Sneep, H. Klein Baltink, J. Joiner
12 Surface UVB Work Packages

Product Coordinator: Apoo Tanskanen - FMI

12.1 Introduction

The OMI measurements are used to estimate the ultraviolet (UV) radiation reaching the Earth’s surface. Noontime surface UV irradiance estimate is produced for four wavelengths (305, 310, 324, 380 nm). Additionally, the erythemal dose rate and the erythemal daily dose are estimated. Estimation is based on use of a radiative transfer model whose input parameters are derived from the OMI measurements. The surface UV algorithm inherits from the TOMS UV algorithm developed by NASA/GSFC. This model is one-dimensional and 3D effects of clouds or terrain inhomogeneity cannot be take into account. It estimates the clear-sky surface irradiance which is adjusted to actual surface irradiance by a transmittance factor that aims at accounting for attenuation of UV radiation by clouds and aerosols. The clear-sky estimate requires as an input total column ozone data derived earlier either with the DOAS or the TOMS algorithm. The cloud and aerosol effects are derived from the measured backscatter radiances and the reference irradiances. It should be noted that estimation of the cloud/aerosol effects is based on a single observation of the atmospheric conditions above the ground pixel that covers a relatively large area. Thus, the accuracy of the surface UV estimate depends on the atmospheric conditions. Secondly, the accuracy of the various surface UV products differ: the low wavelength irradiances are more sensitive to modeling errors. Using a radiative transfer model it has been estimated that in a clear sky, snow and aerosol free case the accuracy of the surface UV irradiance can be as good as 6.5% at 380 nm, while it is of the order of 10% at 305 nm. However, snow cover or episodic aerosol plume can result in product accuracy of some 20 or 30%.

Coexistent surface UV products from other satellite instruments (EP-TOMS, GOME, SCIAMACHY) are used to obtain the first impression of the OMI surface UV data quality. However, the primary reference data for validation of the OMI surface UV product are the spectral ground-based measurements of the surface irradiance. Validation is planned to rely mostly on the existing UV monitoring sites with high-level instrument QA/QC. The validation sites shall represent various latitudes, climatic conditions, land cover types and altitudes. Validation sites with inhomogeneous local conditions (such as surface albedo variations, relief, local pollution sources) should be avoided or at least these presumable sources of error should be documented. Some validation sites provide concurrent measurements of aerosol optical depth and single scattering albedo that can be used to validate surface UV algorithm to account for aerosols. Furthermore, there are plans to address subpixel inhomogeneity with several UV instruments within a OMI pixel and to study the 3-dimensional distribution of UV irradiance with aircraft measurements.

12.2 Relevant OMI Announcement of Opportunity proposals

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms  
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2915 - Validation of the OMI surface UV irradiance products and Finnish contribution to validation of the OMI ozone profile products. PI: Dr. Aapo Tanskanen, Finnish Meteorological Institute, Finland

2940 - Cloud validation for OMI (OMI-Clouds)  
PI: Dr. Pieter Stammes, KNMI, De Bilt, The Netherlands

2945 - Validation of OMI products over Europe with ground-based UV instruments  
PI: Prof. Dr. Philipp Weihs, Universität für Bodenkultur, Department für Wasser - Atmosphäre - Umwelt, Austria

Task 12.1 Algorithm verification

Start / End: Ready before launch  
Summary: Apply the UV algorithm on synthetic data, check that results and quality flags are consistent with the algorithm description. Apply the UV algorithm on Nimbus-7 and Earth Probe TOMS data and compare the results with the NASA/GSFC TOMS products. Verify that the fast look-up-table method for estimation of the clear-sky surface UV produces similar results as a true radiative transfer code. Compare the cloud correction factor defined using the plane parallel cloud models with the simple correction factor.

Associated names and subject:
A. Tanskanen (FMI)  TOMS UV FMI algorithm
Task 12.2 Value verification
Start / End: L+9 / L+12
Allocated time: 3 months
Summary: Check for non-physical product values. Check for unexpected features on global distribution plots. Check all data, geolocation and quality fields.

Task parts:
- Check product values
- Generate distribution plots and check them visually

Associated names and subject:
N. N. (FMI) OMUVB Value verification

Task 12.3 Comparison with validated satellite data
Start / End: L+12 / L+18
Allocated time: 6 months
Summary: OMUVB product is compared with the EP/TOMS UV product. Optionally OMUVB product is compared with some other surface UV irradiance satellite data.

Task parts:
- Develop software tools for comparison of various satellite data sets
- Compare the products, make statistical analysis, report results

Data sources: EP/TOMS UV product

Associated names and subject:
A. Tanskanen OMUVB product
Rich McPeters NASA - GSFC TOMS PI, US OMI Validation team lead

Task 12.4 Comparison with routine ground-based data
Start / End: L+18 / L+30
Allocated time: 12 months
Summary: OMI surface UV products are be compared with routine ground-based UV irradiance measurement data. Comparison requires generation of the overpass data for the reference sites as well as further processing of the ground-based measurement data, so that the comparison can be made. The validation sites shall represent various latitudes, climatic conditions, land cover types and altitudes. The number of the reference data sites will depend on the data availability.

Task parts:
- Communicate with providers of the ground-based data on data protocols, quality, availability, etc
- Generate overpass data for the selected validation sites
- Decide on coincidence/collocation criteria, write software for comparison
- Interpret results. Look for systematic bias in OMI data

Data sources:
- European UV database (EUVDB)
- World Ozone and Ultraviolet Radiation Data Centre (WUDC)
- The National Science Foundation (NSF) Ultraviolet (UV) Monitoring Network

Associated names and subject:
A. Tanskanen OMUVB product
J. Kaurola (FMI) EUVDB data
V. Fioletov (Meteorological Service of Canada) WUDC data
G. Bernhard (Biospherical) NSF/UV data
Task 12.5 OMI Subpixel variation study

Start / End: L+18 / L+30
Allocated time: 12 months
Summary: The existing ground-based surface UV and aerosol measurement instrumentation and dispersed inexpensive instruments are used to gain an improved understanding of the spatial variation of the surface UV irradiance within the OMI footprint

Data sources:
- AERONET/CIMEL and UV-MFRSR instruments of the USD UV network
- Dispersed observing sites around the reference sites

Associated names and subject:
D. Brooks (Drexel University)
N. Krotkov (GEST/UMBC)

Reference Information

Stations and measurements: Finland:
Jokioinen (60° 49' N, 23° 30' E)
  spectral UV, 286.5-365 nm, 2 π sr
  8-minute measurements every 30 minutes
  erythemal UV (zenith?, spectral interval)
  ca. 305-310 nm
  continuous measurement (1-hour averaging for usable results)
  total ozone vertical column
  aerosol optical thickness (direction? wavelengths?)
  sun-tracking 367.6, 411.4, 500.5, and 861.6 nm

Sodankylä:
  spectral UV (zenith?, spectral range?), 290-325 nm, 2 π sr
  8-minute measurements every 30 minutes
  erythemal UV: same as Jokioinen
  total ozone vertical column
  ozone profile (daily balloon launch at 1000 GMT)
  aerosol optical thickness: same as Jokioinen

Stations and measurements: Antarctic network:
Ushuaia (54°48’ S, 68°19’ W, i.e. Argentina)
  NILU-UV radiometers:
  302, 312, 320 340, and 380 nm
  ca. 10 nm bandwidth (FWHM)

Marambio (64°14’ S, 56°37’ W)
  NILU-UV radiometers:
  302, 312, 320 340, and 380 nm
  ca. 10 nm bandwidth (FWHM)

Belgrano (77°52’ S, 34°37’ W)
  NILU-UV radiometers:
  302, 312, 320 340, and 380 nm
  ca. 10 nm bandwidth (FWHM)
13 Bromine Oxide Work Packages

Product Coordinator: Kelly Chance – Harvard-Smithsonian Center for Astrophysics

13.1 Introduction

Introduction to the physics and chemistry of BrO
Vertical column densities of BrO are typically between $3 \times 10^{13}$ cm$^{-2}$ and $6 \times 10^{13}$ cm$^{-2}$ with little variation, except for tropospheric blooming events in polar springtime, where column densities larger than $10^{14}$ cm$^{-2}$ are observed [Chance, 1998]. BrO was first measured from space by GOME, in the region 344 nm - 360 nm. While it was anticipated that BrO could be measured globally [Chance et al., 1991], it was also thought that BrO would be of interest primarily as a stratospheric gas. However, lower tropospheric ozone destruction in the Arctic polar sunrise has been coupled with bromine chemistry associated with the ice pack [Barrie et al., 1988]. ER-2 observations show the presence of enhanced BrO in the free troposphere during the Arctic polar sunrise [McElroy et al., 1999], and GOME measurements have now confirmed and further quantified enhancements in BrO in both Arctic and Antarctic spring [Wagner and Platt, 1998]. The OMI measurements of BrO will make such observations at higher spatial resolution that, coupled with cloud determination, will permit the location and persistence of enhanced polar tropospheric BrO to be studied in sympathy with tropospheric O$_3$ in order to quantify the effects on tropospheric O$_3$.

Specifics of the derivation of BrO
OMI Earth radiances are directly fitted using a nonlinear least-squares technique, as developed for GOME and SCIAMACHY. Careful attention is given to including interfering species in the fits, choice of reference spectra, correction for the Ring effect, and correction for spectral undersampling. Final wavelength calibration is made dynamically, during the fitting process. Vertical column abundances are determined using air mass factors calculated with the LIDORT radiative transfer model [Spurr et al., 2001], assuming a typical stratospheric BrO distribution.

Order of magnitude and accuracy of BrO
Fitting accuracies are $5-10 \times 10^{12}$ cm$^{-2}$. Inversion to obtain the vertical column is a minor error source except when boundary layer BrO over the polar ice packs in springtime is present. In those cases, the air mass must be corrected assuming knowledge of the distribution in the boundary layer. Such correction is not currently made operationally.

Ways and means to validation of BrO
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 potentially valuable validation sources as well since they provide global coverage. The GOME capability to measure BrO has been well demonstrated, and progress is being made toward its retrieval from SCIAMACHY. (Lower signal-to-noise ratios in SCIAMACHY as compared to GOME, and instrumental artifacts, make the retrievals more challenging.) Ground-based measurements are readily made in the ultraviolet, with the advantage that they can better qualify boundary layer BrO over the polar ice packs in springtime. The distribution of BrO does not have high spatial variability except for polar spring component. Ground-based correlative measurements must be made over high-latitude locations, where both vortex and outside-vortex conditions are expected. Aircraft measurements of the tropospheric profile in the polar spring would be very valuable.

Breakdown of validation into logical subsequent tasks
1. Compare OMI with GOME and SCIAMACHY global data
2. Compare OMI with ground based measurements at normal and polar spring-enhanced sites, carefully considering available cloud products in the latter case
3. Compare OMI with available aircraft and balloon measurements
4. Reconsider air mass factor formulation in light of ground-based and aircraft measurements

Special conditions for validation of BrO
Comparisons must include coincidence in time as well as geolocation, or account for it in chemistry and radiative transport modeling.
13.2 Relevant OMI Announcement of Opportunity proposals

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2931 - Validation of Aura OMI trace gas products
PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

Task 13.1 Algorithm verification
Start / End: L-1/L+3
Allocated time: 4 years
Summary: This is an ongoing process, which began well before flight, and should continue through the mission, since knowledge gained both by learning the characteristics of the instrument in flight and by validation measurements must be integrated into improved versions of the algorithm.

Task parts:
1. Choice of reference spectra
2. Implementation of slit function model and correction for spectral undersampling
3. Comparison of air mass factor assumptions with correlative measurements

Associated names and subject:
T. Kurosu SAO - BrO algorithm developer
K. Chance SAO - OMI U.S. Science Team

Task 13.2 Value verification
Start / End: Provision release of data products/L+3
Summary: Check for non-physical values and spikes in physical quantities. Plot values globally, check for unexpected features. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in BrO column values along orbit, between orbits, and day-to-day.

Associated names and subject:
T. Kurosu SAO - BrO algorithm developer
K. Chance SAO - OMI U.S. Science Team

Task 13.3 Comparison with routine ground-based data and balloon measurements
Start / End: Provision release of data products/L+3
Summary: Comparisons will be made with ground-based data provided by investigators selected in the European and U.S. announcements.

Task parts:
1. Compare OMI with ground-based measurements at normal and polar spring-enhanced sites, carefully considering available cloud products in the latter case
2. Compare with available aircraft and balloon measurements
3. Reconsider air mass factor formulation in light of ground-based and aircraft measurements

Data sources (assumed selected for OMI validation):
1. UV/VIS BrO column densities from ground-based spectroscopic instruments
2. Integrated BrO profiles from LPMA DOAS data or from SAOZ payloads
3. BrO vertical column densities from GOME, GOME-2, and SCIAMACHY, as available

Associated names and subject:
T. Kurosu SAO - BrO algorithm developer
K. Chance SAO - OMI U.S. Science Team
J.-C. Lambert IASB – ground-based measurements
Task 13.4  Comparison with validated satellite data

Start / End:  Provision release of data products/L+3
Summary:  OMI measurements are compared to GOME climatology, to SCIAMACHY measurements, and (if available) to GOME-2 measurements.

Task parts:
1. Compare OMI with satellite measurements at normal and polar spring-enhanced sites, carefully considering available cloud products in the latter case
2. Apply lessons learned for correction of spatial artifacts in OMI data products

Data sources: Data come from SAO measurements and other investigators selected in the calls for proposals.

Associated names and subject:
T. Kurosu  SAO - BrO algorithm developer
K. Chance  SAO - OMI U.S. Science Team
E. Hilsenrath  NASA - satellite measurements
J.-C. Lambert  IASB - satellite measurements

References for this Chapter

[Chance, 1998]

[Chance et al., 1991]

[Barrie et al., 1988]

[McElroy et al., 1999]

[Wagner and Platt, 1998]

[Spurr et al., 2001]
14 Chlorine dioxide Work Packages

Product Coordinator: Kelly Chance – Harvard-Smithsonian Center for Astrophysics

14.1 Introduction

The physics and chemistry of OClO
Chlorine dioxide (OClO) slant column densities are 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°. OClO was first measured from space by GOME. The OClO slant column densities are between $2 \times 10^{13}$ cm$^{-2}$ and $4 \times 10^{14}$ cm$^{-2}$ for solar zenith angles higher than 80° [Wagner et al., 1999].

Specifics of the derivation of OClO
OMI Earth radiances are directly fitted using a nonlinear least-squares technique, as developed for GOME and SCIAMACHY. Careful attention is given to including interfering species in the fits, choice of reference spectra, correction for the Ring effect, and correction for spectral undersampling. Final wavelength calibration is made dynamically, during the fitting process.

Order of magnitude and accuracy of OClO
The OClO slant column densities are between $2 \times 10^{13}$ cm$^{-2}$ and $4 \times 10^{14}$ cm$^{-2}$ for solar zenith angles higher than 80° [Wagner et al., 1999]. Final slant column accuracies are expected to be $\sim 5 \times 10^{12}$ cm$^{-2}$.

Ways and means to validation of OClO
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.

It has also been proposed to validate OMI OClO slant column using profile measurements from SCIAMACHY in limb scattering mode through the use of a forward radiative transfer model, which can simulate the upwelling radiances observed by OMI (e.g., LIDORT [Spurr et al., 2001]). The validation will compare slant columns of OClO observed by OMI with OClO slant columns forward-modeled by LIDORT using the vertical profiles of OClO from SCIAMACHY during coincidences with OMI. The SCIAMACHY OClO profiles will be scaled to OMI local time using the Canty et al., [2004] model (constrained by SCIAMACHY BrO and MLS ClO) before obtaining model OClO slant columns. This approach assumes that the bulk of the OClO is in the stratosphere (a valid assumption based on zenith-sky observations [Sanders et al., 1989]) and thus can be retrieved from SCIAMACHY limb scattering observations. SCIAMACHY measures OClO profiles with 8 pptv (about 25%) precision at the number density peak (around 20 km) in the chemically perturbed vortex. SCIAMACHY OClO profile shapes and peak heights will be used to extend OMI observations by calculating air mass factors for the conversion to vertical column densities of OMI OClO, resulting in a high-resolution indicator of chlorine activation for Aura that is independent of viewing geometry. These vertical columns can then be compared with SCIAMACHY vertical columns.

Breakdown of validation into logical subsequent tasks
1. Compare OMI with GOME/SCIAMACHY global data
2. Compare OMI with ground based measurements at normal and polar spring-enhanced sites
3. Compare OMI with OClO derived from SCIAMACHY limb radiance measurements of OClO and BrO, MLS ClO, and modeling

Special conditions for validation of OClO
Comparisons must include coincidence in time as well as geolocation, or account for it in chemistry and radiative transport modeling. A typical temporal coincidence criterion is within 4 hours, with diurnal scaling applied.
14.2 Relevant OMI Announcement of Opportunity proposals

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2931 - Validation of Aura OMI trace gas products
PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

2938 - Validation of OMI OClO and NO\textsubscript{2} observations using SCIAMACHY data. Investigation of the stratospheric polar chemistry and chlorine trends.
PI: Dr. Thomas Wagner, Institut für Umwelt Physik, University of Heidelberg, Germany

Task 14.1 Algorithm verification
Start / End: L-1/L+3
Allocated time: 4 years
Summary: This is an ongoing process, which began well before flight, and should continue through the mission, since knowledge gained both by learning the characteristics of the instrument in flight and by validation measurements must be integrated into improved versions of the algorithm.

Task parts:
1. Choice of reference spectra
2. Implementation of slit function model and correction for spectral undersampling

Associated names and subject:
T. Kurosu SAO - OClO algorithm developer
K. Chance SAO - OMI U.S. Science Team

Task 14.2 Value verification
Start / End: Provision release of data products/L+3
Summary: Check for non-physical values and spikes in physical quantities. Plot values globally, check for unexpected features. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in OClO column values along orbit, between orbits, and day-to-day.

Task 14.3 Comparison with routine ground-based data
Start / End: Provision release of data products/L+3
Summary: Comparisons will be made with ground-based data provided by investigators selected in the European and U.S. announcements.

Task parts:
1. Compare OMI with ground-based measurements at normal and polar spring-enhanced sites
2. Compare with available aircraft and balloon measurements

Data sources (assumed selected for OMI validation):
1. UV/VIS OClO column densities from ground-based spectroscopic instruments
2. Integrated OClO profiles from LPMA DOAS data or from SAOZ payloads
3. OClO slant column densities from GOME, GOME-2, and SCIAMACHY, as available
4. Derived OClO from SCIAMACHY limb and MLS measurements

Associated names and subject:
T. Kurosu SAO - OClO algorithm developer
K. Chance SAO - OMI U.S. Science Team
J.-C. Lambert IASB - satellite and ground-based measurements
Task 14.4 Comparison with validated satellite data

Start / End: Provision release of data products/L+3

Summary: OMI measurements are compared to GOME climatology, to SCIAMACHY measurements, to GOME-2 measurements (if available), and to derived OClO from SCIAMACHY limb and MLS emission measurements

Task parts:
1. Compare OMI with satellite measurements under polar vortex conditions
2. Apply lessons learned for correction of spatial artifacts in OMI data products.

Data sources: Data come from SAO measurements and other investigators selected in the calls for proposals.

Associated names and subject:
T. Kurosu SAO - OClO algorithm developer
K. Chance SAO - OMI U.S. Science Team
E. Hilsenrath NASA - satellite measurements
J.-C. Lambert IASB - satellite and ground-based measurements
T. Wagner U. Heidelberg - SCIAMACHY measurements

References for this Chapter

[Wagner et al., 1999] - KNMI supplied

[Spurr et al., 2001]  

[Canty et al., 2005]  

[Sanders et al., 1989]  
15 Formaldehyde Work Packages

Product Coordinator: Kelly Chance – Harvard-Smithsonian Center for Astrophysics

15.1 Introduction

Introduction to the physics and chemistry of HCHO

Formaldehyde (HCHO) is a principal intermediate in the oxidation of hydrocarbons in the troposphere, providing an important indicator of biogenic activity and of biomass burning. HCHO was proposed for measurement from space by the GOME and SCIAMACHY instruments [Chance et al., 1991]. 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 when instrument calibration difficulties have been overcome. Ground- and aircraft-based measurement campaigns will be necessary for OMI validation, especially when concentrations 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 summer, and over the mid-latitude oceans, preferably in summertime for maximum production from oxidation of CH₄, would provide optimum data sets. Mid-latitude maritime measurements could be combined with campaigns to study intercontinental pollution transfer.

Specifics of the derivation of HCHO

OMI radiances are directly fitted using a nonlinear least-squares technique, as developed for GOME and SCIAMACHY. Careful attention is given to including interfering species in the fits, choice of reference spectra, correction for the Ring effect, and correction for spectral undersampling. Final wavelength calibration is made dynamically, during the fitting process. Vertical column abundances are determined using air mass factors calculated with the LIDORT radiative transfer model [Spurr et al., 2001], assuming vertical distributions derived from the GEOSCHEM global 3-D model of tropospheric chemistry and transport [Bey et al., 2001].

Order of magnitude and accuracy of HCHO

HCHO has a vertical column density between 1×10¹⁵ cm⁻² and 3×10¹⁶ cm⁻² under polluted circumstances [Chance et al., 2000; Thomas et al., 1998; Perner et al., 1997]. The current OMI fitting uncertainties are ~1×10¹⁶ cm⁻².

Ways and means to validation of HCHO

Comparisons to other satellite 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 measurements from the ground and aircraft measurements as the primary validation sources. GOME HCHO determinations are currently problematic, due to instrument aging, although this may be overcome with improved re-calibration. GOME-2 measurements may be available by late 2006. SCIAMACHY measurements are currently problematic because of low signal-to-noise and instrument artifacts. The latter may improve with updated spectral calibration.

Breakdown of validation into logical subsequent tasks

1. Compare OMI with GOME/SCIAMACHY global data
2. Compare OMI with ground based measurements, carefully considering available cloud products
3. Compare OMI with available aircraft measurements, carefully considering available cloud products
4. Reconsider air mass factor formulation in light of ground-based and aircraft measurements

Special conditions for validation of HCHO

A major issue in HCHO retrievals, and hence also in their validation, is the application of an appropriate air mass factor, as the air mass factor depends strongly on the tropospheric distribution of HCHO, which is usually not well-determined, and requires the use of chemistry and transport modeling.

15.2 Relevant OMI Announcement of Opportunity proposals

2870 - Remote sensing observations over Bremen/Germany, an industrial semi polluted area
PI: Prof. Justus Notholt, Institut für Umweltpsik, University of Bremen, Germany
2898 - Determination of HCHO column abundances from FTIR solar observations at the Jungfraujoch, Switzerland.
Pi: Dr. Philippe Demoulin, Institute of Astrophysics and Geophysics - University of Liège, Belgium

2907 - OMI validation by ground based remote sensing: ozone columns and atmospheric profiles
Pi: Dr. Angelina Shavrina, Main Astronomical Observatory of National Academy of Sciences of Ukraine, Ukraine

2910 - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms
Pi: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

2931 - Validation of Aura OMI trace gas products
Pi: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

Task 15.1 Algorithm verification
Start / End: L-1/L+3
Allocated time: 4 years
Summary: This is an ongoing process, which began well before flight, and should continue through the mission, since knowledge gained both by learning the characteristics of the instrument in flight and by validation measurements must be integrated into improved versions of the algorithm.

Task parts:
1. Choice of reference spectra
2. Implementation of slit function model and correction for spectral undersampling
3. Comparison of air mass factor assumptions with correlative measurements

Associated names and subject:
T. Kurosu SAO - HCHO algorithm developer
K. Chance SAO - OMI U.S. Science Team

Task 15.2 Value verification
Start / End: Provision release of data products/L+3
Summary: Check for non-physical values and spikes in physical quantities. Plot values globally, check for unexpected features. Check all data and geolocation fields (including flags, errors, intermediate results, Q/A parameters, etc). Check for discontinuities/jumps in HCHO column values along orbit, between orbits, and day-to-day.

Associated names and subject:
T. Kurosu SAO - HCHO algorithm developer
K. Chance SAO - OMI U.S. Science Team

Task 15.3 Comparison with routine ground-based and aircraft data
Start / End: Provision release of data products/L+3
Summary: Comparisons will be made with ground-based data provided by investigators selected in the European and U.S. announcements.

Task parts:
1. Compare OMI with ground-based measurements at normal and enhanced emission sites, carefully considering available cloud products
2. Compare with available aircraft and balloon measurements at normal and enhanced emission sites, carefully considering available cloud products
3. Reconsider air mass factor formulation in light of ground-based and aircraft measurements

Data sources (assumed selected for OMI validation):
1. UV/VIS HCHO column densities from ground-based spectroscopic instruments
2. HCHO column densities from aircraft
3. HCHO vertical column densities from GOME, GOME-2, and SCIAMACHY, as available
Task 15.4  Comparison with validated satellite data

Start / End: Provision release of data products/L+3

Summary: OMI measurements are compared to GOME climatology, to SCIAMACHY measurements, and (if available) to GOME-2 measurements.

Task parts:
1. Compare OMI with satellite measurements at background and enhanced emission sites, carefully considering available cloud products
2. Apply lessons learned for correction of spatial artifacts in OMI data products.

Data sources: Data come from SAO measurements and other investigators selected in the calls for proposals.

References for this Chapter


[Lee et al., 1998] - Reference needed!

[Singh et al., 2000] - Reference needed!


[Perner et al., 1997] - Reference needed!
16 Sulphur Dioxide Work Packages

Product Coordinator: Arlin Krueger - NASA GSFC

16.1 Introduction

The physics and chemistry of SO2

Sulphur dioxide (SO2) is a short-lived atmospheric constituent that is produced primarily by volcanoes and burning of fossil fuels. Volcanic emissions can originate from explosive eruptions, effusive eruptions or by passive outgassing of near surface magma in active volcanoes. Fossil fuel burning takes place at the surface where SO2 is released in the boundary layer or, with tall smokestacks, into the lowest troposphere. SO2 is soon converted to sulfate by reaction with OH in air or by reaction with H2O2 in aqueous solutions. The mean lifetime varies from a day or two near the surface to more than a month in the stratosphere. Thus, air pollution clouds remain in the boundary layer or low troposphere near the source. Passive volcanic emissions tend to stay at the altitude of the vent while volcanic eruption clouds typically rise to the troposphere or lower stratosphere where they can drift globally.

Specifics of the retrieval of SO2

SO2 has strong absorption bands that overlap with the UV Huggins and Hartley bands of ozone. Thus, it is necessary to simultaneously solve for both gases as well as for the scattering properties of the atmosphere. A maximum likelihood algorithm incorporates the measured radiances and solar irradiance, average expected abundances and variances, and the signal-to-noise ratio of the data to match observations to lookup tables of radiances for the expected range of ozone and SO2 amounts. The solution depends on the vertical distribution of SO2. As most air pollution sources release the SO2 into the boundary layer or low troposphere, we assume a constant mixing ratio distribution in the boundary layer. The height of the boundary layer is specified either from external data or from climatology. As the retrieval dependence on altitude becomes small in the stratosphere, we assume that eruption clouds are at 15 km. Passive emissions frequently take place from tops of volcanoes that release the SO2 into the free troposphere. We initially assume this occurs near 5 km.

Order of magnitude and accuracy of the product

Fresh volcanic clouds typically contain column amounts of SO2 of 50 to 800 DU. As the clouds age they are sheared and chemically converted so that the peak amounts fall to less than 10 DU and ultimately to zero. Ash in the volcanic cloud can produce as much as 30% overestimations if not accounted for in the lookup tables. Passive emissions typically have less than 50 DU SO2 and often are free of ash so that no error occurs due to aerosol scattering.

The amount of SO2 in the boundary layer is typically very small (less than 2 DU except very near to a source). In non-polluted regions, including most of the southern hemisphere, the amount is near zero. In polluted regions the sulfate haze from older SO2 constitutes a source of error in the retrievals if not accounted for in the atmospheric model used in the look up tables.

Retrieval errors come from noise in the radiance measurements, wavelength matching errors in the radiance to irradiance ratio, errors in Raman scattering corrections, errors in aerosol optical depths, and from errors in the atmospheric models and in physical data. Based on simulations, we expect that the standard deviation of the retrieved SO2 will be about 0.5 DU.

Means and ways to validate SO2

SO2 column amounts are measured routinely by Brewer spectrophotometer stations and by COSPEC or mini-spectrometer instruments positioned near volcanoes. As SO2 is transient in the atmosphere validation must take place close to the source or opportunistically during passage of a drifting volcanic cloud over a fixed observing station. In 25 years of TOMS volcanic cloud observations, only three cases were found of volcanic clouds drifting over Brewer stations. Thus, validation of volcanic cloud data by fixed stations is questionable. However, comparison with data from other, dissimilar instruments on satellites is possible. Retrievals of SO2 at 7.3 and 8.6 microns have been made from MODIS, AIRS, ASTER, microwave limb sounders, and TOVS and in the UV from TOMS, GOME and SCIAMACHY. These instruments will be valuable for lending credibility to OMI retrievals.

Air pollution SO2 is measured primarily by in situ methods on the ground or on light aircraft. The aircraft are used to measure the vertical profile of SO2, which then can be integrated to get a total column amount for comparison with satellite data. In addition, a few double Brewer spectrophotometers with precision of about 1 DU are available for
comparisons. GOME and SCIAMACHY data have the precision to make valid comparisons with OMI although the FOV is quite different. The IR instruments are incapable of measuring low altitude SO₂ due to lack of thermal contrast with the ground and due to interference by water vapor.

**Breakdown of validation into logical subsequent tasks**

1. Confirm that near zero SO₂ is obtained in all background areas.
2. Compare SO₂ at active volcanic sources that are monitored with mini spectrometers.
3. Compare OMI with GOME/SCIAMACHY global data.
4. Compare polluted region SO₂ with Brewer data at Washington & Toronto.
6. Compare OMI volcanic cloud data with other satellite data.
7. Compare OMI volcanic cloud data with chance overpass of Brewer network stations.

**Special conditions for validation of SO₂**
The validation of total SO₂ columns 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 SO₂ 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 SO₂ profiles can be compared with column measurements for large volcanic clouds. If there is a significant volcanic SO₂ 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.

### 16.2 Relevant OMI Announcement of Opportunity proposals

**2907** - OMI validation by ground based remote sensing: ozone columns and atmospheric profiles  
PI: Dr. Angelina Shavrina, Main Astronomical Observatory of National Academy of Sciences of Ukraine, Ukraine

**2910** - Cross Validation of Envisat and Aura/OMI Data Products and Scientific Analysis Across Platforms  
PI: Dr. Ernest Hilsenrath, NASA Goddard Space Flight Center, United States of America

**2931** - Validation of Aura OMI trace gas products  
PI: Dr. Jean-Christopher Lambert, Belgian Institute for Space Aeronomy, Belgium

### Task 16.1 Algorithm verification

- **Start / End:** L - 1 year / ?
- **Allocated time:**
- **Summary:** Algorithm verified by use of simulated radiances and data from GOME. Simulated data are used to establish optimum fitting window, optimum a priori variances, and error sensitivities. GOME data permits verification with real data, validation of albedo calculation, estimation of retrieval noise propagation in background areas with near zero SO₂, and testing of flags.

- **Associated names and subject:**
  - A. Krueger: algorithm performance and optimization
  - N. Krotkov: maximum likelihood algorithms
  - O. Dubovik: Retrieval theory
  - S. Datta: research and operational code development
  - S. Carn: operational code testing

### Task 16.2 Value verification

- **Start / End:** First availability of wavelength registered radiance/irradiance data from OMI/ end of OMI mission
- **Allocated time:**
- **Summary:** The most demanding test of the algorithm is in background areas where zero SO₂ should be found for all observing conditions. The background areas are extensive, covering essentially all of the southern hemisphere and the northern hemisphere oceanic areas during all seasons. If the retrievals find less
than the noise level in the data then one is confident that the radiance to irradiance ratio is correct, and
the algorithm and atmospheric models used in the tables are complete. Within polluted regions the
SO\textsubscript{2} column density is expected to be less than 2 DU except when a strong source is within a pixel.
Volcanic passive emissions contain moderate amounts of SO\textsubscript{2} (< 50 DU) that will be found only
downwind of active volcanoes. Explosive eruptions produce large amounts of SO\textsubscript{2} (> 100 DU) that
are carried with the winds at UT/LS levels. Air pollution SO\textsubscript{2} will be verified by comparison with
Brewer spectrophotometer data and aircraft-borne in-situ SO\textsubscript{2} profile data. Passive volcanic emission
SO\textsubscript{2} will be validated by comparison with fluxes measured with COSPEC and mini-spectrometers
located at volcano observatories. The variety of environments into which passive volcanic SO\textsubscript{2} is
emitted will require testing of the algorithm under different atmospheric conditions (e.g., tropical and
extratropical). Eruption cloud SO\textsubscript{2} validations will depend on chance passage of volcanic clouds over
Brewer stations.

Data sources:
Brewer spectrophotometer stations, Airborne SO\textsubscript{2} profiles, DOAS spectrometer stations, COSPEC/mini-spectrometer,
Volcano Observatories.
Potential targets: Soufriere Hills, Montserrat and Kiluaea, Hawaii (tropical, ~1 km, oceanic); Nyiragongo, D.R. Congo
(tropical, 4-6 km, land), Popocatepetl, Mexico/Tungurahua, Ecuador/Lascar, Chile (>5 km), Etna, Italy (high latitude)

Associated names and subject:
A. Krueger validation planning
S. Schaefer COSPEC validations
S. Carn mini spectrometer data from volcanic sources
R. Dickerson validation of air pollution sources and background levels

Task 16.3 Comparison with routine ground-based data
Start / End: L + 1yr / ?
Allocated time:
Summary: Primary source of ground-based SO\textsubscript{2} column data is from double Brewer spectrophotometers and
single Brewers using a special spectral sampling mode. These stations take data routinely. The GSFC
SSBUV data are available to compare radiances with OMI.

Data sources:
Brewer spectrophotometers

Associated names and subject:
Brewer spectrophotometers Toronto - J Kerr or TBD
GSFC - R. McPeters, Alex Cede
SSBUV - E. Hilsenrath

Task 16.4 Validation with validated satellite data
Start / End: upon release of OMI data / end of OMI mission
Allocated time:
Summary: OMI SO\textsubscript{2} retrievals can be compared with EP TOMS, GOME 2, SCIAMACHY, MODIS, AIRS,
TOVS, and VIIRS retrievals. Only TOMS has been validated and that is only for volcanic clouds.
Only GOME and SCIAMACHY are capable of measuring air pollution and passive volcanic
emissions.

Data sources and associated names:
GOME/SCIAMACHY J Burrows/ U Bremen
EP TOMS A. Krueger/UMBC
MODIS W. Rose/ MTU
AIRS S. Carn/UMBC
TOVS F. Prata/CSIRO
VIIRS TBD
17 References


Although most documents can be retrieved from dedicated websites, all documents are available from the editors of this document upon request. Please send an email to mark.kroon #at# knmi.nl or ellen.brinksma #at# knmi.nl, specifying the desired documentation.
18 Annex 1: Correlative satellite instruments

18.1 Satellites and measured products

The approved atmospheric chemistry satellite missions expected to be operational during (part of) the EOS-Aura lifetime are listed in the table below, along with the instruments, relevant for EOS-Aura validation, that they carry.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Satellite</th>
<th>TIME FRAME</th>
<th>O3</th>
<th>A</th>
<th>NOx</th>
<th>ClO</th>
<th>N2O</th>
<th>SO2</th>
<th>HCHO</th>
<th>BrO</th>
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<td>ut</td>
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<tr>
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<td>ERS-2</td>
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<td></td>
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<td>EOS-AM2</td>
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<td></td>
<td>x</td>
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<td></td>
<td></td>
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<tr>
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<td>ERS-2</td>
<td>1995-now</td>
<td>p,c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
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<td>METOP-1</td>
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<td>p,c</td>
<td>x</td>
<td>c</td>
<td>c</td>
<td>c</td>
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<td>ut</td>
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<td>ut</td>
<td>ut</td>
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<tr>
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<td>ut</td>
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<td>1998-now</td>
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<tr>
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<td>2002-now</td>
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<td>c</td>
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<td>SBUV-2</td>
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<td>1996-2009</td>
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</table>

Table 4.5.1: 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.
Table 4.5.2: 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.

18.2 Additional details on Satellites and measured products

AATSR
Mission: ENVISAT
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: 500 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.

AIRS
Mission: EOS-Aqua (PM).
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
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 / bandwidth 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'.
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
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 altitude range 0 to 35 km, 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-2
Mission: METOP-1.
Viewing geometry: Nadir.
Spectral Range: 240-790 nm.
Application/Products: List of observable species/parameters for GOME-2 will be the same as for GOME-1.
Altitude Range: 0 - 60 km (for O3 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: 1920 km.
Accuracy: Ozone columns: < 1%.
Ozone profiles 0-12 km: <10 %, 14-60 km: <5 %. Precision <1 %.

GOMOS
Mission: ENVISAT.
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, NO₂, NO₃, H₂O, temperature profiles and aerosols plus some other trace species.
Altitude Range: 15 - 40 km (for O₃ 15 - 90 km). 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.
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 O₃, H₂O, CH₄, N₂O, NO₂, HNO₃, N₂O₅, CFC₁₁, CFC₁₂, ClONO₂, 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.

MASTER
Mission: future ESA missions.
Viewing geometry: Limb.
Application/Products: Upper troposphere/lower stratosphere profiles of O₃, H₂O, CO, HNO₃, SO₂, N₂O, ClOx, pressure and temperature.
Altitude Range: Higher troposphere, lower stratosphere.
Spatial Resolution: 3 km.
Swath width: 1 - 1.5 K.
Accuracy: 

MERIS
Mission: ENVISAT.
Viewing geometry: Nadir.
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.
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, O₃, H₂O, CH₄, N₂O and HNO₃ (later others could be
added). Scientific data processing in Karlsruhe will lead to trace gas profiles of the following species (planned): NO, NO₂, N₂O₅, HNO₃, ClONO₂, CFC-11, CFC-12, CFC-22, CO and others.

Altitude Range: 5 - 80 km (NO₂ 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
Spectral Range: Four spectral bands centred at 443, 555, 670 and 865 nm.
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.
Viewing geometry: Limb.
Spectral Range: Microwave. Spectral bands: 200, 300, 600 GHz and 2.5 THz.
Application/Products: Lower stratospheric temperature and concentrations of O₃, ClO, HCl, HNO₃, H₂O, N₂O, OH and upper tropospheric concentrations of H₂O and O₂. Furthermore MLS measures SO₂, 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
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 / Cirrus cloud cover
- Cloud properties characterized by cloud droplet phase, optical thickness, droplet size, cloud top pressure and emissivity
- Aerosol properties defined as optical thickness, particle size and mass transfer
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.
Viewing geometry: Nadir.
Spectral Range: 4.6 and 2.3 μm band for CO, 2.2 μm band for CH₄.
Application/Products: Total column amount of CO and CH₄ 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$_4$ columns 1%, CO columns 10%, CO profiles 10%.

**MVIRI**
Mission: Meteosat.
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.

**MWR**
Mission: ENVISAT.
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$^2$.

**OCO**
Mission: OCO (A-train)
Time frame: 2009-?
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

**OSIRIS**
Mission: Odin
Time frame: 2001-?.
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 %.

**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$_2$O profiles, from the planetary boundary layer to 50 km.
- Tropospheric aerosol.
Spatial Resolution: 1-2 km in the vertical.
Swath width: n/a
Accuracy: ozone profiles v.6: 5% (tropopause - 30 km), biased 50% low in troposphere

SAGE III
Mission: METEOR-3M N1
Time frame: 2001-present
Viewing geometry: Solar and lunar occultation.
Application/Products:
- Ozone profiles, from the mid-troposphere to 85 km.
- NO₂ profiles, from the tropopause to 45 km.
- H₂O profiles, from the planetary boundary layer to 50 km.
- NO₃ profiles (stratosphere) from lunar occultation measurements.
- OCIO 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: n/a
Accuracy: ozone profiles v3.0: 1-2 % NH, 3 % SH
bias of +2% with respect to SAGE II (15-40 km)

SBUV/2
Mission: NOAA 16, 17, N & N'.
Viewing geometry: Nadir, no scan mirror.
Application/Products: Spectral Earth radiance, solar irradiance measurements and trace gases including ozone distribution.
Altitude Range: 20-55 km; total column.
Spatial Resolution: 170 km. Vertical resolution O₃ profile: 8-15 km.
Swath width: Nadir pointing, 170 km.
Accuracy: Total ozone concentration: absolute accuracy of 1 %; profile accuracy ~5%.

SCIAMACHY
Mission: ENVISAT.
Viewing geometry: Near nadir and limb viewing.
Spectral Range: UV 240-314 nm, 0.24 nm / UV 309-405 nm, 0.26 nm / VIS 394-620 nm, 0.44 nm / VIS 604-805 nm, 0.48 nm / VIS 785-1050 nm, 0.54 nm / IR 1000-1750 nm, 1.48 nm / IR 1940-2040 nm, 0.22 nm / IR 2265-2380 nm, 0.26 nm / IR 2540-2600 nm, 0.22 nm / IR 2920-3030 nm, 0.22 nm / IR 3065-3160 nm, 0.22 nm.
Application/Products: Spectral Earth radiance, solar irradiance measurements and trace gases including ozone distributions and aerosols.
Altitude Range: 10 - 100 km
Spatial Resolution: 16x32 km nadir / Vertical resolution 3 km
Swath width: 1000 km nadir / 1000 km limb
Accuracy: Total ozone concentration: 1.6 % (TOSOMI and ESA products)
Ozone profile: IFE version 1.61 bias -3 to 6 % (under development)
DLR/official ESA ozone profiles v2.4 and 2.5: do not use

SEVIRI
Mission: MSG1, MSG2 and MSG3 (EUMETSAT).
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: Full Earth disc.
Spatial Resolution: 1 km for one broadband visible channel, 3 km for all other channels.
Swath width: Full Earth disc.
Accuracy:

SIM
Mission: SORCE.
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 %

SOLSTICE II
Mission: SORCE.
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.
Viewing geometry: Limb and nadir.
Spectral Range: 2.3 to 15.4 \(\mu\)m at a spectral resolution of 0.025 cm\(^{-1}\).
Application/Products: Vertical concentration profiles of O\(_3\), CO, CH\(_4\), H\(_2\)O, 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.
19  Annex 2: Ground-based Instruments and Networks

19.1  Ground-based Instruments

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.

**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 15-75 m 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.

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.

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.

**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, NO₂, O₃, H₂O, OClO or BrO, and of vertical distributions of NO₂. 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 NO₂ from the Arctic to Antarctica, with an accuracy of about 3-5% for ozone and 10% for NO₂. 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, NO₂, BrO, HCHO and SO₂. UV-visible DOAS spectrometers are also operated in solar occultation mode during stratospheric balloon flights, providing vertical distributions of ozone, NO₂, BrO and OCIO in the upper troposphere and in the stratosphere up to about 35 km.

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 nighttime.

**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, CH₄, CFCs, etc. Typical relative uncertainties are currently around 5% for ozone, HCl, HF and HNO₃, 10% for NO and NO₂, and 25% for ClONO₂. It is also possible to retrieve height-resolved information on the abundance of molecules such as ozone, N₂O, CO, and CH₄.

**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 H2O, HO2, HNO3, SO2, or N2O.

**Ozonesondes** measure the O3 concentration through the amount of electrons generated in an electro-chemical reaction of O3 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.

**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.

**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.

### 19.2 Correlative data networks

**Aeronet (AErosol ROBotic NETwork):** Optical ground-based aerosol monitoring network and data archive consisting of sunphotometers for the derivation of aerosol parameters. This network provides globally distributed near real time observations of aerosol spectral optical depths, aerosol size distributions, and precipitable water in diverse aerosol regimes.


**ARM (Atmospheric Radiation Measurement) Program:** Initiated by the U.S. Department of Energy in 1989, with 3 highly instrumented facilities (Climate and Radiation Test Beds, or CART) to measure the radiative energy flux profile of the clear and cloudy atmosphere.

**Sites:** 3 main sites (Southern Great Plains site in Oklahoma, Alaska site, Tropical Western Pacific site). Instruments and products: Combined data from microwave, infrared, lidar, and sonde instruments for near-continuous profiles of T and H2O in the troposphere; some aerosol information from Raman lidar.

**Reference:** [http://www.arm.gov/](http://www.arm.gov/)

**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 CO2, CO, CH4, H2, and most recently N2O and SF6. Most sites are located in the marine boundary layer, while a few are situated on mountaintops or in areas of regional scale pollution.

**COSE (Compilation of atmospheric Observations in support of Satellite measurements over Europe):** European database of many different species, including ozone profiles, ClO, BrO. Supported by the European Union (until date to be determined).


**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 (GOS) of the World Meteorological Organisation (WMO) within the framework of its Global Atmosphere Watch (GAW).

**Sites:** There are 5 primary stations with a number of sites: Arctic station (Eureka, Canada; Ny Alesund, Norway, Thule, Greenland; Sondre Stromfjord, Greenland); “Alpine” station (Garmisch, Germany; Zugspitze, Germany; Bern, Switzerland; Jungfraujoch, Switzerland; Observatoire de Bordeaux, France; Plateau de Bure, France; Observatoire de
Haute Provence, France); Hawaii station (Mauna Kea, U.S.A; Mauna Loa, U.S.A., Hilo, U.S.A.); New Zealand station (Lauder), Antarctic station (Dumont d’Urville, McMurdo, Arrival Heights, Scott Base, South Pole). There are also about 40 complementary sites/stations (only a few in the tropics). A few instruments (ozone/temperature lidar, aerosol/temperature lidar, microwave, FTIR) can be moved for campaign purposes.

**Instruments and products:** ozonesondes (O₃ profiles), Dobson instruments (O₃ columns), lidars (T, O₃, and aerosol profiles), microwave instruments (O₃, ClO, H₂O, N₂O profiles), Fourier transform infrared spectrometers (many different column measurements, including O₃, CH₄, N₂O, HNO₃, CO, NO, NO₂, CINO₂, HCl, HF, CH₃O, and some profile information), UV/VIS instruments (column NO₂, O₃, OClO, BrO), aerosol sondes (aerosol backscatter profiles), and spectral UV instruments (spectral distribution of UV irradiance at the ground).

Reference: [http://www.ndsc.ws](http://www.ndsc.ws)

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 NO₂ 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.

**WOUDC (World Ozone and UV Data Center - WODC and WUDC) and SHADOZ:**

**WODC and SHADOZ:**

The Toronto World Ozone Data Center (WODC) (under WMO and operated by the Meteorological Service of Canada) contains extensive archives of ozone profile and ozone column data. Sondes for ozone (and T, usually) are launched from 50 to 100 sites around the world, about once a week (some less often, some more often). The altitude range is typically from the ground to about 30 km. A recent program called SHADOZ (Southern Hemisphere Additional Ozonesondes) has provided measurements from 10 locations in the southern tropics and subtropics during the period 1998-2005.


**WUDC: (World Ultraviolet Data Center)**

Contains, as above, extensive archives on ultraviolet data.


Ground stations measuring NO₂ with Brewer MK 4 instruments:

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</table>

WMO region:
Antarctica, I (Africa), II (Asia), III (S.America), IV (N.America), V (SW.Pacific), VI (Europe)
20  Annex 3: OMI Contact List

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Proposal 2925: Validation of OMI total ozone using ground-based Brewer observations.

Dr. P. (Philippe) Demoulin, Institut d' Astrophysique et de Géophysique / Institute of Astrophysics and Geophysics, University of Liege, Allée du 6 Août, 17, Sart Tilman, Bât. B5c, 4000 Liége, BELGIQUE / BELGIUM, Phone: +32 4 366 9785, Fax: +32 4 366 9747, Email: demoulin #at# astro.ulg.ac.be.
Proposal 2988: Determination of H2CO column abundances from FTIR solar observations at the Jungfraujoch, Switzerland.

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Proposal 2930: Use of neural networks algorithms for the retrieval of ozone and other trace gases profiles from OMI measurements.

Dr. A.N. (Aleksandr) Gruzdev, A.M. Obukhov Institute of Atmospheric Physics (IAP), Russian Academy of Sciences, Pyzhevsky per., 3, Moscow 119017, RUSSIA, Phone: +7 095 951-6453, Email: a.n.gruzdev #at# mail.ru.
Proposal 2919: Proposal 2919: Year-round ground-based spectrometric measurements of column NO2 at Zvenigorod, Moscow region, under various atmospheric circumstances and comparison of these measurements with the actual OMI satellite instrument observations.

Dr. E. (Ernest) Hilsenrath, NASA Goddard Space Flight Center, Code 916, Greenbelt, MD 20771, UNITED STATES OF AMERICA, Phone: 01-301-614-6033, Fax: 01-301-614-5903, Email: ernest.hilsenrath #at# nasa.gov.

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Proposal 2932 Validation of the ozone profile from the Ozone Monitoring Instrument onboard of the NASA EOS-Aura Satellite using the Umkehr observations by the Dobson spectrophotometers.

Dr. J.C. (Jean) Lambert, Belgisch Instituut Voor Ruimte-Aeronomie (BIRA), Pole Espace / BIRA-IASB, Avenue Circulaire 3, B-1180 Bruxelles, BELGIUM, Phone: +32-(0)-2-373 04 68 (direct) / +32-(0)-2-373 04 04 (switchboard), Fax: +32-(0)-2-374 84 23, Email: j-c.lambert #at# aeronomie.be / michelv #at# aeronomie.be.
Proposal 2931: Validation of EOS-Aura OMI trace gas products.

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Proposal 2942: Validation of OMI Ozone Profiles and Aerosol Optical Thickness using ground-based measurements.

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Proposal 2941: Validation of SCIAMACHY and OMI NO2 and aerosol data using Dutch ground-based measurements.

Dr. S. (Stefano) Migliorini, NERC Data Assimilation Research Centre, University of Reading, PO Box 243, Earley Gate, Reading RG6 6BB, United Kingdom, Phone: +44 118 378 7843, Fax: +44 118 378 5576, Email: stefano #at# met.reading.ac.uk. Proposal 2927: Calibration and validation of OMI measurements using a numerical weather prediction assimilation system.

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Proposal 2929: Validation of tropospheric NO2 measurements from OMI in urban and suburban sites in the UK.

Prof. Dr. J. (Justus) Notholt, Institute of Environmental Physics / Institut für Umweltpsychik (IUP), University of Bremen / Universität Bremen, Otto-Hahn-Allee 1, 28359 Bremen, DEUTSCHLAND (GERMANY), Phone: +49 421 218 9572, Fax: +49 421 218 5145, Email: notholt #at# uni-bremen.de / jnotholt #at# iup.physik.uni-bremen.de.
Proposal: Remote sensing observations over Bremen/Germany, an industrial semi polluted area.
Proposal 2921: Using OMI measurements to extend the GOME/SCIAMACHY tropospheric NO2 record

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Proposal 2944: Balloon-borne ozone-soundings at L’Aquila (Italy) for a local validation of OMI measurements of ozone vertical profiles.

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Proposal 2907: OMI validation by ground-based remote sensing: ozone columns and atmospheric profiles.

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Proposal 2940: Cloud validation for OMI (OMI-Clouds).

Proposal 2938: Validation of OMI surface UV irradiance products, and Finnish contribution to validation of the OMI ozone profile products.

Dr. A. (Aapo) Tanskanen, Ozone and UV Radiation Research, Finnish Meteorological Institute (FMI), P.O.Box 503, FIN-00101, Helsinki, FINLAND, Phone: +358 9 1929 4156, Fax: +358 9 1929 3146, Email: aapo.tanskanen #at# fmi.fi.
Proposal 2915: Validation of the OMI surface UV irradiance products, and Finnish contribution to validation of the OMI ozone profile products.

Proposal 2926: Validation of OMI ozone and NO2 vertical column data with ground-based spectroscopic measurements in Russia and NIS.

Dr. T. (Thomas) Wagner, Institut für Umweltphysik / Institute of Environmental Physics (IUP), University of Heidelberg, Im Neuenheimer Feld 229, D-69120 Heidelberg, Phone: +49 (0) 6221 54 - 6314, Fax: +49 (0) 6221 54 - 6405 , Email: Thomas.Wagner #at# iup.uni-heidelberg.de.
Proposal 2938: Validation of OMI OC1O and NO2 observations using SCIAMACHY data. Investigation of the stratospheric polar chemistry and chlorine trends.

Dr. M. (Mark) Weber, Institut für Umweltphysik / Institute of Environmental Physics (IUP), University of Heidelberg, FB1, Im Neuenheimer Feld 229, D-69120 Heidelberg, GERMANY, Phone: +49 2361.999 466, Fax: +49 4554.999 466, Email: weber #at# uni-bremen.de.
Proposal 2943: Comparison of scientific total ozone retrieval results from OMI, GOME, and SCIAMACHY using the weighting function DOAS approach and validation of OMI operational data products.

Proposal 2945: Validation of OMI products over Europe with ground-based UV instruments.