VALIDATION RESULTS FROM THE JOINT ESA KNMI NIVR CALIBRATION AND VALIDATION ANNOUNCEMENT OF OPPORTUNITY FOR THE OZONE MONITORING INSTRUMENT

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ABSTRACT
In this paper we report on the progress achieved within the framework of the joint ESA KNMI NIVR Calibration and Validation Announcement of Opportunity for the Ozone Monitoring Instrument aboard the NASA EOS Aura satellite. This OMI AO effort has rendered a wealth of validation results and scientific insights. Herein this contribution only a selection of the validation results is presented.

OZONE MONITORING INSTRUMENT
The Dutch-Finnish Ozone Monitoring Instrument (OMI) [1,2] aboard the NASA EOS-Aura satellite [3] is a compact nadir viewing, wide swath, ultraviolet-visible push-broom type imaging spectrometer that provides daily global coverage with high spatial and spectral resolution. EOS-Aura was launched on the 14th of July 2004 in a sun-synchronous polar orbit at 705 km altitude with an ascending node equator-crossing time roughly at 13:45. During the daytime portion of each orbit, the OMI instruments measures the Earth radiance and, once per day, the Solar irradiance near the northern hemisphere terminator. The ratio of Earth radiance and Solar irradiance is the Earth reflectance from which many atmospheric data products are retrieved using advanced algorithms; trace gas concentrations of O₃, NO₂, SO₂, HCHO, BrO OCIO, cloud height and effective cloud fraction, aerosol optical depth and single scattering albedo, and surface UV irradiance levels are produced. Please visit the OMI home page at http://www.knmi.nl/omi for more information on OMI validation, scientific results and elaborate accounts of the OMI AO achievements.

FOCUS OF THE OMI AO
The philosophy of the OMI Announcement of Opportunity is to invite atmospheric scientists worldwide - with a focus on Europe - to work with the OMI team on the validation of OMI data products. The main advantage of joining the OMI AO is early data access for validation and scientific studies. In return, the OMI AO PI's are required to upload their correlative data to the Aura Validation Data Center (AVDC) at http://avdc.gsfc.nasa.gov, for the benefit of the validation of the other Aura instruments. Please visit the OMI AO section on http://eopi.esa.int/esa/esa for more information on the OMI AO call for proposals.

CHRONOLOGY
The joint ESA KNMI NIVR OMI AO call for proposals was published on 24th June 2004 in sync with the United States National Research Announcement (NRA) on EOS Aura validation. At the closing day on 24th September 2004, 21 proposals had been received originating from scientists all over Europe. Following an international review of submitted proposals, all OMI-AO proposals were accepted by March 2005 and work could commence. To date, 19 proposals have been active.

OZONE VALIDATION
Validation of the OMI-DOAS and OMI-TOMS total ozone data products benefits greatly from the AO activities. For example, under proposal 2925 of Dr. Dimitris Balis, elaborate comparisons are made against the WMO ground based network of Dobson and Brewer instruments. Based on the period between August 2004 and September 2006 the average percent difference between OMI-DOAS and Brewer total ozone column observations is 0.98% ± 0.52%. The corresponding percent difference between OMI-TOMS and Brewer total ozone column observations is 0.11% ± 0.19% for the average of the latitude bands. These results are however valid only for the northern hemisphere comparisons and mainly for the latitudes 30°N-60°N. The average difference between OMI-
DOAS and Dobson total ozone column observations, which have a better latitudinal coverage, is 1.57% ± 2.11%, showing better agreement over the 30°S-40°S belt. The average difference between OMI-TOMS and Dobson total ozone column observations is 0.85% ± 1.47%, with higher values found for the tropical stations. These high values over the tropics can also be related to quality issues of the ground-based measurements and therefore these stations have been excluded from the study of McPeters et al [4]. OMI-DOAS comparisons with Brewer observations indicate a trend with solar zenith angle, as shown in Figure 1; at large SZA OMI-DOAS overestimates ozone by 3 to 5%. For SZA values greater than 85°, OMI-DOAS underestimates total ozone by -10%. The OMI-TOMS comparisons against Dobson or Brewer data do not show any significant SZA dependence.

Figure 1: Dependence on solar zenith angle (SZA) of satellite and ground-based total ozone differences for OMI-DOAS (upper) and OMI-TOMS (lower) versus Brewer data. In OMI-DOAS collection 3 data the displayed SZA dependence will be corrected. (Images by courtesy of D. Balis, LAP, Proposal 2925).

More information can be found on the website http://lap.physics.auth.gr/ozonemaps. A paper has been submitted to JGR describing the activities of proposal 2925 in detail [5]. Based on these findings the OMI-DOAS retrieval algorithm has been improved. At the time of writing the OMI data record is being reprocessed into collection 3 where these shortcomings will have been solved.

NITROGEN DIOXIDE VALIDATION

The OMI NO2 data product is being thoroughly analyzed under the OMI-AO banner. For example, under proposal 2926 of Prof. Dr. Yury Timofeyev, OMI NO2 column data was compared to ground-based DOAS UV-visible twilight observations at Issyk-Kul (Kyrgyzstan, 43°N/77°E) and St. Petersburg (Russia, 60°N/30°E) in 2004-2006. Overall, daytime satellite measurements (around noon) are found to be consistent with sunrise ground-based data. The agreement is improved after correcting for the NO2 photochemical change between sunrise and the satellite overpass. For this purpose, the NO2 diurnal cycle has been simulated with a box photochemical model derived from the SLIMCAT 3D chemical-transport model. Adjusted to the time of sunrise, OMI NO2 data agree with UV-VIS ground-based data within +3.5% ± 13.8% (+0.1 ± 0.3 1015 mol/cm2) over the remote station at Issyk-Kul, and within -7.0% ± 38.4% (-0.2 ± 1.4 1015 mol/cm2) over polluted area of St. Petersburg.

Figure 2: Comparison of ground-based total NO2 column measurements performed at St. Petersburg with operational ERS-2 GOME, scientific ENVISAT SCIAMACHY and Aura OMI data in 2004-2006.

Figure 3: Diurnal cycle of NO2 vertical column simulated with SLIMCAT 3D chemical-transport model. Note the strong differences in the diurnal cycle between May and November. (Images by courtesy of Dmitry Ionov, SPB, proposal 2926).
CLOUD VALIDATION

OMI clouds are comprehensively validated and scientifically studied under proposal 2940 of Dr. Piet Stammes. The OMI O$_2$–O$_2$ cloud product is compared to the MODIS cloud product from the Aqua platform. Because of the small difference in overpass time (about 20 minutes) and good spatial overlap of the ground track, both instruments provide an excellent opportunity for satellite cross validation. The MODIS level 2 cloud product was mapped onto the OMI level 2 grid for a direct comparison. The two main parameters retrieved by the OMI O$_2$–O$_2$ cloud product are an effective cloud fraction and a cloud pressure. The effective cloud fraction is a measure for the reflectance of UV/VIS radiation, and should not be compared to the MODIS (geometric) cloud fraction directly. Instead we use the MODIS cloud optical thickness and a radiative transfer model to obtain the MODIS cloud reflectance and compare against that. Figure 4 shows a scatter density plot of both effective cloud fractions; these cloud fractions show a correlation of 0.92 and an average difference of 0.01. Because of fundamental differences between the MODIS thermal infrared measurements and the OMI O$_2$–O$_2$ cloud pressure, derived from visible radiation, the cloud pressures of the two instruments are expected to behave differently. Figure 5 shows a comparison over land of the OMI O$_2$–O$_2$ cloud pressure with the cloud pressure derived from POLDER O$_2$ A-band measurements. Here the measurements are performed at comparable wavelengths, and the cloud pressures are expected to behave in a similar fashion. Two papers [6,7] have been submitted to JGR describing the activities of proposal 2940 in detail.

AEROSOLS

Aerosols are extensively studied as part of proposal 2941 by Dr. Pieternel Levelt. In order to check the accuracy of the OMI multi-wavelength algorithm, the aerosol optical depth retrieved was compared with collocated Sun photometer data that are available from the AERONET website (http://aeronet.gsfc.nasa.gov/), level 1.5, version 2. The OMI derived aerosol optical depth at 442 nm was compared to the AERONET aerosol optical depth at 440 nm. The sites used for the validation were selected throughout Europe for their representiveness for different types of surfaces and aerosols. OMI derived aerosol optical depth were averaged over an area of 50 km radius to provide a mean value for the ground site. Figure 6 shows the comparison between the OMI and AERONET retrieved aerosol optical depths, for the Cabauw site. In general the agreement is within the standard deviation of the OMI area average, for both small and large aerosol optical depth values and for all considered sites, except for El–Arenosillo and Cabo–da–Roca. For every single ground site the OMI results trace the AERONET data. It appears that averaging the aerosol optical depth values over 50 km around a site may not be representative for highly polluted area such as Ispra and Paris where there are significant gradients in the spatial distribution of the aerosol optical depth. However, spatial averaging is necessary to reduce pixel to pixel variability and provide a statistical significant result. In the comparisons for Cabauw as shown in Figure 6 there are some outliers where the retrieved values are much higher than the AERONET aerosol optical depth. Apparently, the cloud screening in these cases was not strict enough.
DANDELIONS FIELD CAMPAIGN
During the DANDELIONS field campaigns conducted in May-June 2005 and September 2006 as part of proposal 2941 by Dr. Pieterernel Levelt, an extensive dataset of ground based, balloon and satellite data on NO2, aerosols, and ozone was obtained. The data are available through the AVDC website for use in other validation efforts. From the field data it was shown that different ground based MAX-DOAS instruments, operating simultaneously during the campaign, provide very similar results, reaching correlations of 0.91 and linear regression slopes of 0.99. Furthermore, it was shown that good agreement was obtained between tropospheric NO2 from OMI and the ground based MAX-DOAS systems, reaching correlations of 0.6, and between total NO2 from OMI and direct-sun DOAS, reaching correlations of 0.68. During DANDELIONS it was also shown that ground based observations of the aerosol optical thickness (AOT) compare well among three ground based instruments and are shown to correspond well with AOT values observed by OMI, reaching correlations of 0.95. A paper has been submitted to JGR describing the campaigns efforts and its results in detail [8]. Part of the work is also submitted to JGR for publication in [9].

SURFACE UV
The surface UV estimates derived from OMI measurements (OMUVB) have been widely validated with ground-based UV measurements. For example within the AO proposal 2915 of Dr. Aapo Tanskanen, the daily erythemal doses derived from OMI have been compared with those calculated from 18 ground-based UV spectrometers. In Figure 7 is shown the comparison of the OMI-derived and ground-based daily doses in Jokioinen, southern Finland. A paper has been submitted to JGR describing the activities of proposal 2915 in detail [10]. There Tanskanen et al. report that for flat, snow free regions with modest loadings of absorbing aerosols or trace gases the OMI-derived daily erythemal doses are 0-10% overestimated and that about 70% of the OMI-derived doses are within ±20% from the ground reference. For sites significantly affected by absorbing aerosols or trace gases they found large biases up to 50%. Additionally, at some high-latitude sites the satellite-derived doses can be occasionally up to 50% too small because of too small climatological surface albedo. Similar results have been reported by other OMI AO PI's.

OTHER OMI DATA PRODUCTS
In general, correlative data sources for the remaining OMI operational data products are sparse. Fortunately, the OMI-AO hosts several PI's operating ground based instruments dedicated to measuring exactly these species, e.g., SO2, HCHO. Here it is reported that, e.g., observations on formaldehyde columns and retrievals of ozone profiles are readily available for comparisons. At the time of writing all OMI operational data products have been provisionally released and a large number are already publicly available, i.e., all OMI data products are available for validation. We are therefore looking forward to receiving results on the validation of aerosols, formaldehyde, bromine oxide, chlorine dioxide, and sulphur dioxide.

AO BENEFITS
The main benefit of joining the OMI AO was early OMI data access for validation and scientific studies.
In return, OMI Validation benefits greatly from all the AO activities. Scattered over European laboratories and institutes there are 21 professional groups active in validating their OMI data products of interest. Their validation results are delivered to the OMI validation office in the form of half yearly reports. Their correlative data are delivered to the Aura Validation Data Center for the benefit of validating EOS-Aura data products. Their results contribute greatly to the work performed by the international OMI validation team and by NRA scientists working on EOS-Aura validation. The OMI validation effort has been expanded significantly with the availability of correlative observations from various measurement systems [Mini MAX-DOAS (KNMI, BIRA, IUP), MFDOAS (Leicester), MAX-DOAS (Bremen, Heidelberg, Brussels), NO$_2$ Lidar (RIVM)]; from ground based networks [BREDOM MAX-DOAS (IUP-Bremen, IUP-Heidelberg), AERONET, FTIR, SAOZ, Surface-UV, Brewer, Dobson, Umkehr, Sondes]; and from satellite instruments [SCIAMACHY, PARASOL, MODIS]. Most importantly, OMI validation benefits mostly from the many scientists nowadays actively and enthusiastically involved with the validation of OMI data products.

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REFERENCES


WEBLINKS
OMI AO website at KNMI
http://www.knmi.nl/omi/research/validation/ao/

OMI AO documents at KNMI (ask for username and password from kroon@knmi.nl)
http://www.knmi.nl/omi/research/validation/ao/documents.html

OMI AO website at ESA
http://eopi.esa.int/esa/

Aura Validation Data Center
http://aura.gsfc.nasa.gov

Aura Public Data
http://disc.gsfc.nasa.gov/Aura/data_products.shtml

OMI Public Data
http://disc.gsfc.nasa.gov/Aura/OMI/

!! WHEN USING OMI DATA PLEASE READ THE OMI README FILES CAREFULLY!!

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