OMI Very Fast Delivery and the Sodankylä Satellite Data Centre

Gilbert W. Leppelmeier, *Member, IEEE*, Osmo Aulamo, Seppo Hassinen, Anssi Mälkki, Tarja Riihisaari, Riku Tajakka, Johanna Tamminen, and Aapo Tanskanen

***Abstract*—The Ozone Monitoring Instrument (OMI) operates onboard the National Aeronautics and Space Administration's Earth Observing System Aura satellite, which was launched in July 2004. Like its sister spacecraft Terra and Aqua, Aura's capabilities include direct broadcast (DB), i.e., the ability to broadcast data at the same time as they are being measured and stored in the spacecraft's memory for later transmission to Earth. The Finnish Meteorological Institute's Satellite Data Centre at Sodankylä in Finnish Lapland is exploiting this capability to receive OMI data while Aura is in sight of the receiver, which enables nearly immediate production of OMI data products for a region that includes a large part of Europe, stretching from the North Pole to the Italian Alps. The current OMI Very Fast Delivery (VFD) products include maps of surface UV-B, ozone columns, and cloud coverage.**

***Index Terms*—Atmospheric measurements, direct broadcast (DB), monitoring, ozone, satellite, UV-B.**

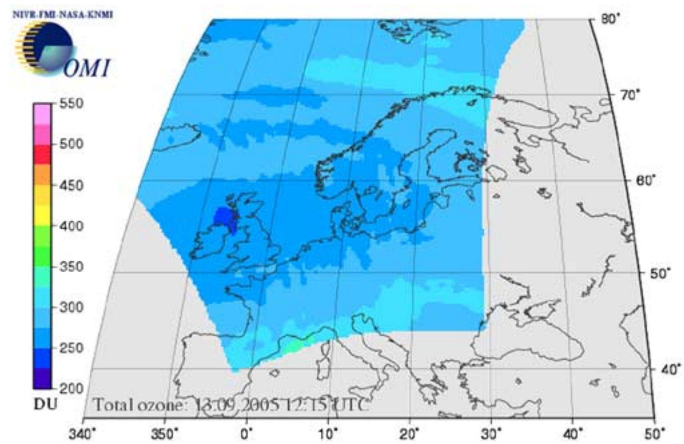

Fig. 1. Total vertical column ozone map.

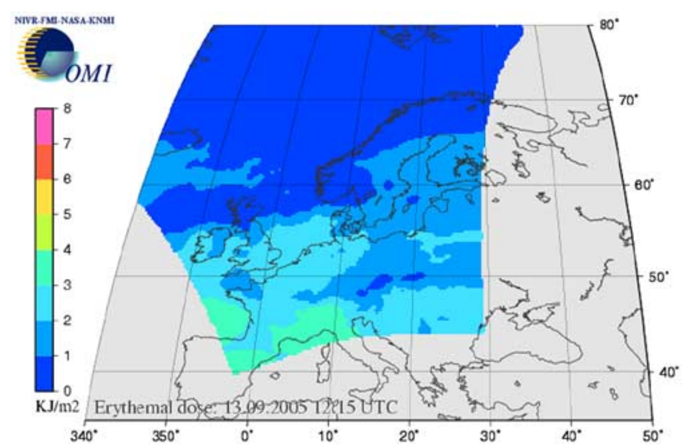

Fig. 2. Erythemal UV dose map.

I. Introduction

The Ozone Monitoring Instrument (OMI) is a wide-swath, nadir-viewing, ultraviolet-visible (UV-VIS) imaging spectrometer onboard the National Aeronautics and Space Administration's Earth Observing System (EOS) Aura mission [1]. Its spectral range of 250–500 nm enables it to record sunlight scattered from the Earth's surface, from which one can derive information about the Earth's atmosphere, such as the content of ozone, NO_2, SO_2, HCHO, aerosols, cloud heights and fractions, and surface UV radiation. The broad swath (2600 km) ensures daily coverage of the entire globe and the small ground pixel size (13 × 24 km) presents detailed spatial distribution not available from earlier missions (for details, see [2])

The very fast delivery (VFD) concept is straightforward: receive data as they are being taken, process immediately at a local site, and make the results available for users through the Internet. As the EOS Aura satellite flies over the Sodankylä receiving station the data are directly transmitted and processed immediately. The direct broadcast (DB) data include OMI measurements over Northern Europe, typically from Northern Italy to the North Pole (see Figs. 1–4). The local time of the measurement is around noon. The retrieved local atmospheric products are available from the Internet (http://omivfd.fmi.fi) within half an hour from the overpass.

Sodankylä (67.48° N, 26.53° E) can be classified as an Arctic site, often lying beneath the middle or the edge of the stratospheric polar vortex and in the zone of polar stratospheric ozone depletion. The Finnish Meteorological Institute's Arctic The Finnish Meteorological Institute's Arctic Research Centre (FMI-ARC) started a program of regular ozone soundings in Sodankylä in late 1980s. Regularly scheduled for Wednesdays at UTC noontime, these sondes happily coincide with the Aura overpass. In addition, each year some 30-odd sondes are launched as part of international campaigns.

Manuscript received April 30, 2005; revised September 19, 2005.

G. W. Leppelmeier, retired, is with G&S Associates, Oy, Espoo 02360, Finland (e-mail: gwl@gands.pp.fi).

O. Aulamo, S. Hassinen, A. Mälkki, T. Riihisaari, R. Tajakka, J. Tamminen, and A. Tanskanen are with the Finnish Meteorological Institute, 00101 Helsinki, Finland (e-mail: aapo.tanskanen@fmi.fi).

Digital Object Identifier 10.1109/TGRS.2005.863718

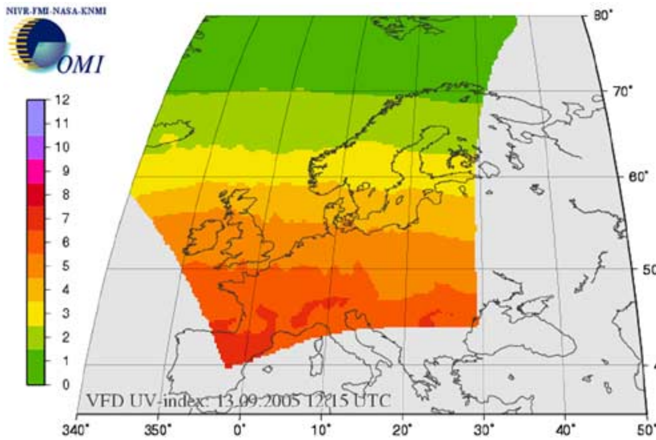

Fig. 3. VFD UV-index map.

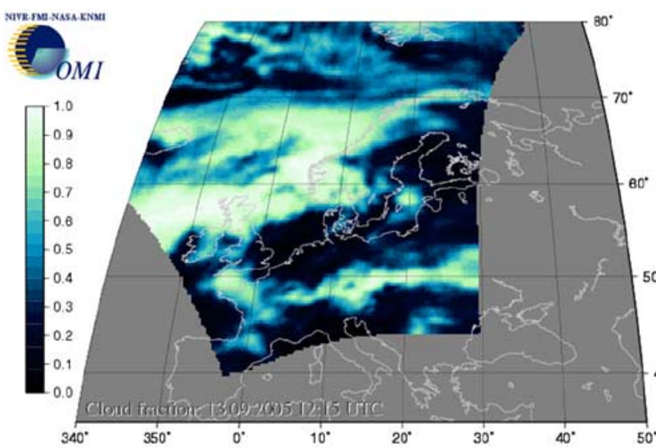

Fig. 4. Cloud fraction map.

II. VFD Products

The VFD products are directed primarily to the general public. Therefore, selection of the products to be processed from the DB data is based on the general interest in them. Although the main scientific interest still rests with the global products that are produced "offline" (i.e., batch-processed and available in 3–7 days), quick analysis and reaction are made possible by the VFD "online" processing, which occurs immediately as the data are received. The broad audience is naturally most interested on the current UV-radiation described by the clear-sky UV irradiance and the erythemally weighted daily UV dose. The other VFD products, also assumed to have wider general interest, are total ozone distribution and cloud fraction.

The VFD products, erythemal UV daily dose distribution, the clear sky UV-index, the total ozone column distribution and the cloud fraction will be available from the Internet in the form of geographical distribution maps. While it is not planned to distribute gridded data—at least not at the beginning—UV values at selected locations in Finland will be given.

A. Surface UV Irradiance

Exposure to UV radiation is known to cause health problems for humans; examples include eye problems, skin cancer, and immunosuppression. Today, people want to be aware when the UV radiation is so high that protection against UV radiation is needed. The UV products from the VFD processing will give this information daily based on measurements instead of predictions. Examples of total ozone column, clear-sky UV irradiance, and erythemally weighted daily dose are shown in Figs. 1–3.

The UV algorithm used in the VFD processing is identical with the one used in the OMI offline processing for global surface UV products [5], [6]. However, the difference between the two processing systems is that in VFD processing the ozone column that is used as the input to the UV algorithm is obtained using the DOAS algorithm [3], whereas the global processing uses the ozone column obtained with the Total Ozone Mapping Spectrometer (TOMS) ozone column algorithm [7]. The UV algorithm inherits from the TOMS UV algorithms [4] and has been further optimized for OMI. The accuracy of the UV products depends on atmospheric and other geolocation-specific conditions and varies between 7% to 30%. [6].

B. Ozone and Clouds

In the VFD processing the total ozone column is computed using the differential optical absorption spectroscoy (DOAS) algorithm [3], which inherits from the DOAS algorithms used successfully for SCIAMACHY and Global Ozone Monitoring Experiment. (GOME) ozone retrievals.

The retrieval of several cloud products is important not only to end users, but also because these parameters are essential for the ozone and other trace gas retrieval since the clouds have a strong impact on the measured signal. An example of the cloud fraction that is produced in the VFD processing is shown in Fig. 4.

C. Validation

The VFD products are normally in the form of pictures (i.e., maps) and are publicly available on the Internet (http://omivfd.fmi.fi). Validation of the VFD products included the following steps.

Step 1) Validation of total ozone relying on the validated OMI global total ozone products (OMTO3 and OMIDO3). Simple verification of these datasets will be performed.

Step 2) Similarly, the cloud fraction product will be compared with the offline OMI global product.

Step 3) The validation of the UV-index will be done by using two Brewer Instruments located at Sodankylä and Jokioinen in Finland. In addition, comparison will be made with the offline global product.

III. Sodankylä Satellite Centre

The OMI VFD processing is implemented as an element of the Satellite Data Centre at the FMI-ARC in Sodankylä, Finnish Lapland (67.48° N, 26.53° E). This facility was initiated as the Finnish FIN-CoPAC (Processing and Archiving Centre) for the European Space Agency's ENVISAT mission, its task being to produce Level 2 products from the Global Ozone Monitoring by Occultation of Stars (GOMOS) instrument. Once the GOMOS processing became operational, processing of data from the Swedish Odin satellite was started, and now the facility will also host the data archive for EUMETSAT's Ozone Monitoring Satellite Application Facility (O3M-SAF).

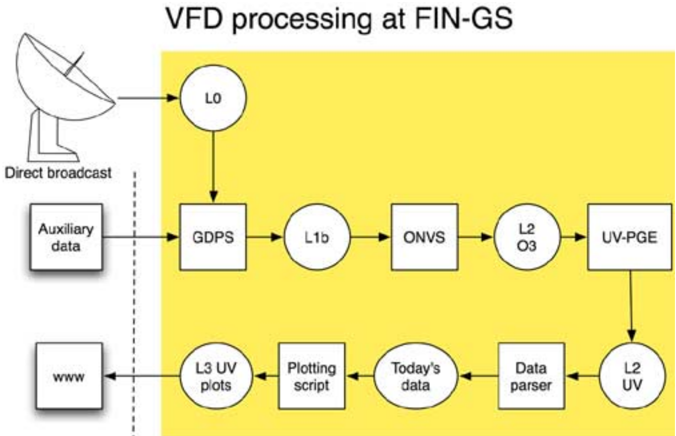

Fig. 5. VFD processing flowchart.

The latest addition to the facility was the installation of an X-band receiving station in March 2003, capable of receiving DB from passing satellites. Sodankylä is very nicely situated in Northern Europe, and real-time data from nadir-viewing instruments on polar-orbiting satellites typically cover regions of interest to many environmental monitoring applications. When the possibility of receiving OMI data from EOS-Aura became apparent, FMI decided to build a dedicated station for this purpose with its own investment funds. An additional bonus that was noticed quite early was that the data from the two other EOS satellites (Terra and Aura) could be received with similar hardware, and both those satellites are carrying the Moderate Resolution Imaging Spectrometer instrument, whose data are used in Finland for environmental applications at FMI, as well as at other institutes.

IV. VFD System Description

As mentioned above, the VFD concept is straightforward: receive data, process it immediately at a local site, and make the data available for users through the Internet (see Fig. 5). The implementation of this concept at FMI SDC consists of the following:

- 2.4-m dish antenna, mounted on the roof of the dedicated building (see Fig. 6);
- necessary receiver hardware and backend processing/control computers in the same building;
- fast optical fiber connection to the main ARC building, where the processing facility is located;
- Linux-based processing system, consisting of separate computing nodes for processing, control, and distribution/archive;
- fiber-optic based Internet connection (100 Mb/s) to the world.

The processing is controlled by dedicated control software developed during the OMI development phase. This software controls the starting of processing modules and data flow among them according to predefined process control files. The system is analogous to those used in the OMI SIPS and Envisat FIN-CoPAC, and in the SDC case has a user interface that is quite similar to the GOMOS interface, in order to minimize operator confusion. The processing chain also includes the steps to place the products to the local data archive, and generate plots of the data and put them on the World Wide Web server as needed. Some of the technical details of the processing system are given in Table I.

Fig. 6. VFD receiving station in Sodankylä, Finland.

As can be seen from Table I, the production of VFD regional products can be performed with quite modest hardware. The receiving system with the 2.4-m antenna can successfully support X-band telemetry up to 25 Mb/s, in the case of EOS Aqua/Aura and Terra down to elevation angles of 0° but for FMI's internal usage orbits with elevation less than 5° are not recorded. In practice this means coverage to northern Italy, with east–west extension depending on the instrument in question. For OMI the east–west extension is 2600 km (for one pass). The processing power is sufficient for processing near-real-time data: even with a large bitrate, the total amount of data for a single pass of at most 11 min is such that, for example, for OMI, the processing is typically completed within 15 min of the end of contact to the satellite. Currently the OMI products are not archived in the strict sense of the word. Images of the last couple of days are available until they are replaced by the new ones. The format used is portable network graphics (png).

In general, the only difference between the online VFD processing and the offline processing of global products is that the auxiliary data used for producing global products

TABLE I
RECEIVING STATION CHARACTERISTICS

Antenna and receiver

Antenna diameter	2,4m
Focal distance	898mm
Weight	364kg
Axis velocity	10,5 degrees/second tracking (Az and cross) 5,2 degrees/second targeting (Az) 3,5 / 1,75 degrees/second (El)
Number of axes	Three (Azimuth, cross-level, elevation)
Gain	43.6dB at 8.2 GHz
Elevation travel limits	0-180 degrees
Feed /downconverter	X-band LHC/RHC. Remotely switchable polarization with continuously tunable downconverter (720 MHz output)
LNA Noise Temperature	≤45° K (0.7dB)
G/T	>dB/K at 8.2 GHz, as measured through the radome at 5° elevation clear sky
Demodulator/Bit Synchronizer	Capable of demodulating USQPSK /SQPSK
Decoder	Viterbi

Acquisition environment

Operating system	Red Hat Linux 7.2 with SeaSpace customized TeraScan
Hard Drive capacity	120 GB
Main memory	1 GB RAM
Processor	Pentium4 2.0GHz

Processing environment

Operating system	Red Hat Linux 7.2 with SeaSpace customized TeraScan
Hard drive capacity	120 GB
Main memory	1 GB RAM
Processor	2 x 2.4 GHz Intel XEON

may include some updates that occur after reception of data, but before processing. The resulting differences are hardly visible.

V. SUMMARY AND FUTURE PROSPECTS

Originally the small DB receiving station at Sodankylä was intended as a demonstration of what could be done with direct broadcast data, and as a pathfinder for a larger facility that would be capable of full data dumps from polar orbiting Earth observation missions. It has succeeded eminently on both counts. The response of FMI's atmospheric research groups to preliminary OMI VFD results, and of other research groups in Finland to similar direct broadcast data from Aqua and Terra has been very encouraging. We expect that as more groups become aware of the capability to capture DB data from polar satellites, the demand for such observations will grow.

In addition, the experience and ease with which the development of the small receiving station has been accomplished will support the effort to develop a more capable ground station at Sodankylä

ACKNOWLEDGMENT

The authors wish to thank Space Systems Finland for the excellent control software, KNMI for providing the ozone column algorithm used in the UV-B processing, and NASA for the TOMS UV algorithm and for support in its further development.

REFERENCES

[1] P. F. Levelt, E. Hilsenrath, G. W. Leppelmeier, G. H. J. van den Oord, P. K. Bhartia, J. Tamminen, J. F. de Haan, and J. P. Veefkind, "Science objectives of the Ozone Monitoring Instrument," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 5, pp. 1199–1208, May 2006.

[2] P. F. Levelt, G. H. J. van den Oord, M. R. Dobber, A. Mälkki, H. Visser, J. de Vries, P. Stammes, J. Lundell, and H. Saari, "The Ozone Monitoring Instrument," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 5, pp. 1093–1101, May 2006.

[3] J. P. Veefkind, J. F. de Haan, E. J. Brinksma, M. Kroon, and P. F. Levelt, "Total ozone from the Ozone Monitoring Instrument (OMI) using the DOAS technique," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 5, pp. 1239–1244, May 2006.

[4] N. A. Krotkov, P. K. Bhartia, J. R. Herman, Z. Ahmad, and V. Fioletov, "Satellite estimation of spectral surface UV irradiance 2: Effect of horizontally homogenous clouds and snow," *J. Geophys. Res.*, vol. 106, pp. 11 743–11 759, 2001.

[5] N. A. Krotkov, J. Herman, P. K. Bhartia, C. Seftor, A. Arola, J. Kaurola, P. Taalas, and A. Vasilkov, "OMI surface UV irradiance algorithm," NASA Goddard Space Flight Center, Greenbelt, MA, OMI Algorithm Theoretical Basis Document III, 2002. [Online]. Available: http://www.knmi.nl/omi/documents/data/OMI_ATBD_Volume_2_V2.pdf.

[6] A. Tanskanen, A. N. Krotkov, J. R. Herman, and A. Arola, "Surface ultraviolet irradiance from OMI," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 5, pp. 1267–1271, May 2006.

[7] P. K. Bhartia and C. W. Wellemeyer, "TOMS-V8 total O_3 algorithm," NASA Goddard Space Flight Center, Greenbelt, MD, OMI Algorithm Theoretical Basis Document Vol II. [Online]. Available: http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd.

Gilbert W. Leppelmeier (M'72) has been involved in space research missions for 19 years, first at the Technical Research Centre of Finland and then at the Finnish Meteorological Institute. He was Co-Principal Investigator for the Ozone Monitoring Instrument onboard Aura from the start of the mission through 2004. Other space missions include Envisat, Odin, SOHO, Spectrum-Roentgen-Gamma, Cassini/Huygens, as well as a number of studies of atmospheric missions to Mars and Earth. Earlier research includes solid-state physics, nonlinear optics, laser fusion energy, and magnetic fusion energy. Since retirement from FMI in 2000 his continued activity in space and atmospheric sciences has been under the aegis of G&S Associates, Oy, Espoo, Finland.

Osmo Aulamo received the M.Sc. degree in physics from the University of Helsinki, Espoo, Finland, in 1986.

He is currently Head of Satellite Operations at the Arctic Research Centre, Finnish Meteorological Institute (FMI), Helsinki. He began working at the Geophysics Department of FMI in 1984. In the beginning of 1998, he moved to Sodankylä to build the GOMOS ozone data processing center for the European Space Agency's ENVISAT mission. In the OMI program, he heads the OMI Direct Broadcast Ground Station in Sodankylä.

Seppo Hassinen received the M.Sc. and Phil.Lic. degrees from the University of Helsinki, Espoo, Finland, in 1995 and 1997, respectively.

He started working at the Finnish Meteorological Institute (FMI), Helsinki, in 1998. He has worked with GOMOS and OSIRIS instruments and has also been involved in the development of an assimilation system for data from these instruments. He is currently Product Manager for OMI-VFD products at FMI.

Anssi Mälkki received the Ph.D. degree in space physics from the University of Helsinki, Helsinki, Finland, in 1993.

He currently works as Research Manager at the Space Research Unit, Finnish Meteorological Institute, Helsinki. He worked at the Space Science Department of the European Space Agency, Noordwijk, The Netherlands, from 1994 to 1996. In the OMI Program, he has worked as Project Manager and Program Manager for the Finnish contribution. He is currently the coordinator of WMO-sponsored IGACO-O3 secretariat at FMI.

Tarja Riihisaari received the Licentiate of Physics degree from Turku University, Turku, Finland, in 2002.

She is currently with the Earth Observation Unit of the Finnish Meteorological Institute, Helsinki, and has been the Manager of EUMETSAT's Satellite Applications Facility for Ozone Monitoring since 2001. Previously, she worked for 11 years in several positions in the electronics industry and in research. Previous positions include work as a Supplier Quality Manager at Nokia Mobile Phones, as Senior Research Scientist at the Technical Research Centre of Finland (VTT), and as Project Manager in the National Technology Agency's (TEKES) ETX program project "Integrated passives for RF applications." Research activities include inductor integration to BiCMOS processes and satellite systems ground segment development.

Riku Tajakka received the B.Sc. degree in space and aviation technique from Rovaniemi Polytechnic, Rovaniemi, Finland, in 2003.

He is currently Technical Manager of the Satellite Receiving Centre at the Arctic Research Centre, Finnish Meteorological Institute, Helsinki. In 2001, he began working in the Finnish–Swedish satellite cooperation program at the Swedish Space Corporation. In the spring of 2002, he moved to Sodankylä to build the OMI Direct Broadcast Ground Station.

Johanna Tamminen received the M.Sc. degree in mathematics, the Phil. Lic. degree in applied mathematics, and the Ph.D. degree in applied mathematics from the University of Helsinki, Helsinki, Finland, in 1993, 1999, and 2004, respectively.

She has been with the Finnish Meteorological Institute, Helsinki, since 1991, and has experience in data retrieval algorithms and statistical inverse problems. She has participated the European Space Agency's Global Ozone Monitoring by Occultation of Stars (GOMOS) satellite instrument project and was a member of the European Space Agency's (ESA) GOMOS Expert Support Laboratory during the instrument development and is currently a Member of ESA's GOMOS Quality Working Group. She is Co-Investigator of the SPICAM instrument onboard ESA's Mars Express satellite, and since the beginning of 2005 she has been Co-Principle Investigator of the Ozone Monitoring Instrument onboard NASA's EOS Aura satellite.

Aapo Tanskanen received the M.Sc. and Lic.Tech. degrees from Helsinki University of Technology, Espoo, Finland, in 1997 and 2002, respectively, both in nuclear engineering.

From 1996 to 2002, he was with the Technical Research Centre of Finland as a Reactor Physicist. He joined the Finnish Meteorological Institute (FMI), Helsinki, in 2002 and has worked mainly on application of satellite data on estimation of the surface UV irradiance. He is currently the Head of the UV Radiation Research Group at FMI. He is a member of the OMI Science Team.