Operational Surface UV Product and Validation Service of Ozone and Atmospheric Chemistry Monitoring SAF

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Abstract
Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M SAF) will produce operationally a set of near real time and offline products based on measurements by instruments on the three consecutive MetOp satellites. The operational production is expected to begin in 2007 and to continue over a 15-years period. The Finnish Meteorological Institute (FMI) provides an offline surface UV product and its validation service. In this paper, we describe the UV product, its production chain, the validation service and show initial validation results for pre-operational products based on TOMS, OMI and NOAA AVHRR data.

INTRODUCTION
The main advantage of the satellite UV estimates over the ground-based measurements is their global spatial coverage. The O3M SAF offline surface UV product (fig. 1) is derived from measurements of the operational polar orbiting MetOp and NOAA satellites. The product contains the most important quantities of the Sun’s radiation that can be harmful to life and materials on the Earth. These quantities include daily doses and maximum dose rates of integrated UV-B and UV-A radiation together with values obtained by different biological weighting functions, solar noon UV index and quality control flags. The product is calculated in a 0.5 degree regular grid and stored in a HDF5 file. The user requirement for the product accuracy is 20%.

Figure 1. An example of the O3M SAF offline UV product derived from OMI data. A global map of erythemal daily UV dose [kJ/m²] for 7 October 2005, showing enhanced levels of UV radiation at the tip of South America due to the ozone hole.
The surface UV product is derived from GOME-2 near real time total column ozone product (NTO) and AVHRR reflectances, therefore combining data from two different instruments onboard the MetOp satellites. Sampling of the diurnal cloud cycle is improved by using additional AVHRR data from the NOAA satellites, available through the data exchange between EUMETSAT and NOAA. The processing data flow is depicted in figure 2.

![Diagram of processing data flow](image)

**Figure 2.** Overall processing data flow. The near real time total column ozone product (NTO) is produced by the German Aerospace Center (DLR). It is sent to the EumetCast uplink station at Usingen, Germany, where it is broadcasted via telecommunication satellites (Hot Bird). The product is received at FMI, together with AVHRR level 1b products both from MetOp and NOAA satellites. The MetOp AVHRR data are received at local area coverage (LAC) resolution while the NOAA data is received at global area coverage (GAC) resolution. After the processing, the product is stored in the FMI Archive, from where it can be accessed directly or via the Unified Meteorological Archive and Retrieval Facility (UMARF) at EUMETSAT.

The total column ozone product is used for two different purposes. It accounts for the reduction of the surface UV flux by the ozone absorption in the Hartley-Huggins band and for the reduction of the AVHRR channel 1 reflectance by the ozone absorption in the Chappuis band (fig. 3). The channel 1 reflectance is inverted to effective cloud optical depth in order to estimate the reduction of the surface UV flux by the cloud Mie scattering.

![GOME/ERS-2 earthshine spectrum](image)

**Figure 3.** GOME/ERS-2 earthshine spectrum (solid line) together with AVHRR/MetOp channel 1 spectral response function (dotted line) illustrate the use of the input NRT total column ozone product. It accounts both for the Hartley-Huggins band (up to ca. 350 nm) absorption in the surface UV flux calculation (280 – 400 nm) and the Chappuis band absorption (ca. 450 - 750 nm) in inverting the AVHRR channel 1 reflectance to effective cloud optical depth.
Accounting for the effects of clouds, i.e. the cloud correction, is one of the key problems in estimating the daily UV dose from satellite measurements, since cloud data are needed globally with sufficient temporal and spatial resolution to evaluate the diurnal integral:

\[
dd = \int_{t=\text{sunrise}}^{\text{sunset}} \int_{\lambda=280}^{400} W(\lambda) E^{\text{clear}}(\lambda, \theta, p, A, \Omega) CCF(\lambda, \theta, p, A, \tau)d\lambda dt
\]

where \(dd\) is the daily UV dose for the biological weighting function \(W\), and \(E\) is the spectral irradiance on the horizontal surface. The spectral irradiance is calculated for different atmospheric scenarios over the UV region (280-400 nm) with the radiative transfer code VLIDORT [Spurr, 2006] as a function of wavelength \(\lambda\), solar zenith angle \(\theta\), surface pressure \(p\), surface albedo \(A\) and total column ozone \(\Omega\). It is stored in two look-up tables, one containing the clear-sky (i.e. no clouds) irradiance \(E^{\text{clear}}\) and the other containing the cloud correction factor \(CCF\). The cloud correction factor for a cloud optical depth \(\tau\) is estimated as the ratio of the cloudy and clear-sky (\(\tau = 0\)) irradiances (eq. 2). It is nearly independent of the total column ozone \(\Omega\) (= constant \(C\) in eq. 2), and therefore, the look-up table for \(CCF\) is independent of ozone. This storage scheme is similar to the NASA TOMS processor [Krotkov, 2001].

The effective cloud optical depth is estimated from the AVHRR channel 1 (centered at ca. 630 nm, fig. 3) reflectance. The reflectance is calculated with the VLIDORT radiative transfer code for model atmospheres, and stored in a look-up table as a function of solar and satellite zenith angles, relative azimuth angle, surface pressure, surface albedo, total column ozone and cloud optical depth. The effective cloud optical depth is then obtained by interpolating between the calculated values. As a first approximation, all clouds are modelled as a homogeneous layer with a droplet size distribution and droplet effective radius from Bréon et al. [Bréon, 2000]. The Chappuis absorption of ozone (fig. 3) is accounted for by using the near real time total column ozone product in calculating the modelled channel 1 reflectance.

The AVHRR instrument is onboard both MetOp and NOAA satellites. As MetOp will be on a morning orbit and NOAA maintaining the afternoon orbit, at least two samples of the diurnal cycle can be obtained globally (fig 4.). More overpasses will be available at high latitudes where the instrument swaths overlap for consecutive orbits. This sampling scheme provides a sufficient compromise between the global coverage and sampling of the diurnal cycle. Moreover, the processing data flow can be kept simple as both the MetOp and NOAA AVHRR data will be available through EumetCast.

Figure 4. The diurnal cycle of UV dose rate (clear-sky case shown for clarity) together with the sampling achieved by MetOp and NOAA AVHRR measurements. The sampling of the diurnal cycle is improved at high latitudes where the instrument swaths overlap for consecutive orbits.
VALIDATION SERVICE

The surface UV product is validated by an operational validation service. This service, also located at FMI, performs two different validation activities. Firstly, online quality checks are made within the first 30 days of product processing to detect possible degradation of the product quality. These quality checks are performed with preliminary ground-based reference data, and the results are shown on a web page. Secondly, the UV product is fully validated against quality-checked ground-based measurements. These results are provided as half-yearly validation reports. The currently selected validation sites are listed in Table 1. More sites will be added to the list as they become available in order to obtain better global coverage.

<table>
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<tr>
<th>Site name</th>
<th>Country</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude / m</th>
<th>Data provider</th>
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</table>

Table 1. Ground-based measurement sites used for surface UV product validation.

RESULTS FOR PROTOTYPE PRODUCTS

Test products of daily CIE weighted [McKinlay and Diffey, 1987] dose were compared with ground-based Brewer spectrophotometer measurements at Northern Finland, Sodankylä (67.37N, 26.63E). The Brewer measurements are described in detail by Lakkala et al. [Lakkala, 2003]. AVHRR level 1b GAC data covering Sodankylä were extracted for the period from February 2001 to September 2003 from the NOAA Satellite Active Archive. Data from two operational satellites of the KLM mission were used during this period. NOAA-K and NOAA-L data were used until 24 August 2002, thereafter data from NOAA-L and NOAA-M were used. All AVHRR data was calibrated using the corresponding operational calibration coefficients. EP TOMS version 8 total ozone products were used for the whole period.

Figure 5 shows the satellite estimates of daily CIE dose against the corresponding Brewer spectrophotometer measurements in Sodankylä from 23 February 2001 to 1 September 2003. For this period, 489 matching measurements were obtained, covering all cloud conditions from clear-sky to overcast both in the summer and during the snow-covered winter period. The agreement of satellite estimates to the Brewer measurements is good with a correlation coefficient of 0.98. The mean error is -2.1 indicating no significant bias between the two data sets. The rms of the relative difference is 19.3 %, indicating that the user requirement for 20 % accuracy can be achieved with this method. However, the error is strongly dependent on the weather and surface conditions for a given day, for example the amount of clouds and snow, and the time of the year (solar zenith angle). Figure 6 shows the relative difference between satellite estimates and Brewer measurements of the daily CIE dose against the Brewer measurement. As expected, the relative error increases with decreasing dose. Very large errors up to 80 % are observed for doses smaller than ca. 0.7 kJ/m².
Small UV doses are difficult to estimate from satellite measurements for a number of reasons. Firstly, the sensitivity of the visible reflectance to cloud optical depth decreases with increasing cloud optical depth. Secondly, the sensitivity also decreases with increasing solar zenith angle, therefore increasing the error in the winter time when the Sun is low. Thirdly, the sensitivity also decreases with increasing surface albedo. This again increases the error in the winter when the ground is snow covered. Finally, the surface albedo varies with snow cover and its determination is error-prone. The future developments of this method will aim at reducing the error for small doses by switching to channel 2 data to improve the sensitivity for bright surfaces [Han, 1999; Xiong, 2002] and by applying time-window methods [Tanskanen, 2003] to increase the accuracy of the surface albedo determination.

Figure 7 shows a comparison of a prototype product derived from OMI data with the corresponding ground-based Brewer spectrophotometer measurements in Sodankylä from 15 February to 30 September 2005, and in Jokioinen from 24 January to 1 September 2005. 130 coincident measurements were obtained for Sodankylä and 192 for Jokioinen. The agreement of the satellite estimates to the Brewer measurements is good with a correlation coefficient of 0.97 for both sites. The rms error of the relative difference is 19.3 % for Sodankylä and 23.4 % for Jokioinen, again suggesting that the user requirement for 20 % accuracy can be achieved with this method.
Figure 7. A prototype offline UV (OUV) product derived from OMI data against ground-based Brewer spectrophotometer measurements in Sodankylä from 15 February to 30 September 2005 (x, blue), and in Jokioinen from 24 January to 1 September 2005 (cross, red).

REFERENCES