Abstract
The Surface UV product of EUMETSAT’s Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M SAF) is described. Initial products derived from Metop-A and NOAA-18 data are compared with ground-based UV measurements at Jokioinen and Sodankylä, Finland.

INTRODUCTION
The ozone layer in the stratosphere protects life on Earth from the harmful effects of ultraviolet (UV) radiation from the Sun. Despite reductions in the use of ozone-depleting chemicals, ozone loss will continue to pose a threat to the environment for the foreseeable future.

The Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M SAF) derives geophysical quantities, including ozone, trace gases and aerosols, from the measurements of the GOME-2 instrument onboard the Metop satellite. These quantities, together with estimates of cloud optical depth and surface reflectance, allow derivation of surface UV dose rates and daily doses. The products derived from the satellite data give a global view of the surface UV levels, and therefore complement the direct ground-based measurements. However, the diurnal variability of the dose rate is large because it is strongly modulated by the cloud cover. This is a problem for global products, because at least one morning and one afternoon measurement of cloud optical depth are need for reasonable accuracy in the daily UV dose [Martin et al., 2000, Meerkötter et al., 1997], while one polar-orbiting satellite can only give one daily measurement globally.

In the O3M SAF UV product, the required two samples of diurnal cloud cover are obtained by exploiting the synergy between the Metop and NOAA satellites in the Initial Joint Polar-Orbiting Operational Satellite System (IJPS). The AVHRR/3 instruments onboard the morning orbit Metop and the afternoon orbit NOAA satellites give at least two measurements of daily cloud cover globally, and even more at high latitudes where the swaths of consecutive orbits overlap. These measurements of cloud optical depth, together with total column ozone, aerosol and surface reflectance data, are used as input to VLIDORT radiative transfer model. The resulting product contains estimates of daily maximum dose rates and daily integrated doses, weighted with different biological weighting functions, in a 0.5° × 0.5° grid. An example of the daily erythemal dose product is shown in figure 1.

Figure 1. An example product field. Erythematic (CIE) daily dose [kJ/m²] on 20 June 2007. The global coverage is limited by the swath of GOME-2 instrument, leaving stripes at low latitudes. The polar night and large solar zenith angles limit the coverage at the winter pole.
ALGORITHM

In order to calculate the daily (integrated) dose, \( dd_w \), for a biological weighting function \( W \) from:

\[
dd_w = \int_{t=sunrise}^{t=sunset} dsr_W(t) \, dt
\]  

the dose rate, \( dsr_W \), is calculated for selected times of day (\( t_d \), currently every half an hour) from:

\[
ds_W(t_d) = \int_{\lambda=290}^{\lambda=400} W(\lambda) E(\lambda, \theta(t_d), p, A, \Omega(t_d), \tau_{CL}(t_d), \tau_{AER}) \, d\lambda
\]

where \( E \) is the spectral irradiance, \( \lambda \) is the wavelength, \( \theta \) is the solar zenith angle, \( p \) is the surface pressure, \( A \) is the surface albedo, \( \Omega \) is the total column ozone, \( \tau_{CL} \) and \( \tau_{AER} \) are the cloud and aerosol optical depths, respectively. The spectral irradiance is calculated with the radiative transfer model VLIDORT [Spurr, 2006] when all the input parameters have been determined. The solar zenith angle is readily calculated for a given time of the day (\( t_d \)), the surface pressure is taken from the ECWMF analysis, the surface albedo is taken from climatology [Tanskanen, 2004] and the aerosol optical depth at UV wavelengths is estimated from the Angstrom law. The total ozone and the cloud optical depth at \( t_d \) are obtained as explained below.

The total ozone is obtained from the GOME-2 total column ozone product which produced by the German Aerospace Center (DLR), also in the framework of the O3M SAF. The ozone data are used for two different purposes. Firstly, it accounts for the reduction of the surface UV flux by the ozone absorption in the Hartley-Huggins band, and secondly, for the reduction of the AVHRR channel 1 reflectance by the ozone absorption in the Chappuis band (fig. 2).

The effective cloud optical depth is estimated from the AVHRR channel 1 (centered at ca. 630 nm, fig. 2) 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 the measurement geometry (solar zenith, satellite zenith and 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. Currently, all clouds are modelled as a homogeneous layer with a droplet size distribution and droplet effective radius equal to C1-cloud model [Deirmendjian, 1969]. The total ozone and cloud optical depth data are interpolated step-wise to the dose rate calculation times.
PROCESSING

The UV product is processed at FMI as a part of the distributed O3M SAF processing network. The near-real-time total column ozone product (NTO) is produced by the German Aerospace Center (DLR). Data are transmitted between the institutes via EUMETCast (fig. 3). The AVHRR data from Metop and NOAA satellites are also taken from EUMETCast. The product is still in development status. When operational, the product will be archived in the FMI archive in Sodankylä and can be ordered via the EUMETSAT UMARF facility.

INITIAL RESULTS

Metop-A AVHRR level 1b and the total ozone products covering the period from 1 June to 31 August 2007 were downloaded from EUMETCast. For these initial results, the NOAA-18 AVHRR data were not yet available via EUMETCast, and were therefore downloaded from the NOAA CLASS archive. The ground based data are SL-501 broadband measurements from Sodankylä (67.37N, 26.63E) and Jokioinen (60.81N, 23.50E). Figure 4 shows the measured and satellite-derived erythemal dose rate on days with different cloud cover.

On the fairly clear day of 2 June, the modelled and the measured dose rates match well. As expected, more deviations are seen for the cloudy days because the spatial and temporal sensitivity of the two methods are different. The broadband ground-based values are measured every 10 minutes on a very confined area, therefore reacting to every single cloud passing over the measurement site. The satellite data, on the other hand, are measured less frequently and are averaged over the 0.5°×0.5° grid cell. Despite these differences in the data sets, the overall shape of the diurnal cycle is captured, and the corresponding daily integrated doses (table 1) are below the user requirement of 20 % for this product.
Figure 4. Erythemal (CIE) dose rate in Sodankylä on days with increasing cloud cover: 2 June (top left), 3 June (top right), 6 June (bottom left) and 20 June 2007 (bottom right).

<table>
<thead>
<tr>
<th>Day</th>
<th>ground-based</th>
<th>satellite</th>
<th>satellite-ground</th>
<th>100*(satellite-ground)/ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 June</td>
<td>2.995</td>
<td>3.031</td>
<td>0.036</td>
<td>1.20</td>
</tr>
<tr>
<td>3 June</td>
<td>2.856</td>
<td>3.042</td>
<td>0.186</td>
<td>6.51</td>
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<tr>
<td>6 June</td>
<td>2.061</td>
<td>2.081</td>
<td>0.020</td>
<td>1.47</td>
</tr>
<tr>
<td>20 June</td>
<td>1.361</td>
<td>1.536</td>
<td>0.175</td>
<td>12.86</td>
</tr>
</tbody>
</table>

Table 1. Erythemal (CIE) daily doses [kJ/m^2] for the selected days of figure 4.

Figure 5 shows the time series of the satellite estimates and ground-based measurements for the summer period. The gaps in the satellite data are either due to missing input data or are flagged out as unreliable cases. The quality flagging scheme fails to detect some spurious cases, but clearly the satellite estimates capture the modulation of the daily dose by the cloud cover. Slight overestimation of the daily dose is however observed.

Figure 6 shows a scatter plot of the same data as in figure 5. The combined data of Sodankylä and Jokioinen give the following statistics: linear regression line y = 0.969x + 0.318, mean error = 0.257 kJ/m^2 and RMS of the relative differences = 22%. The mean error quantifies the overestimation that was observed in figure 5, while the RMS percent indicates that the user requirement of 20% can be achieved with this method.
Figure 5. Satellite estimates of erythemal (CIE) daily dose [kJ/m²] (red) and ground-based measurements (green) in Sodankylä (left) and in Jokioinen (right) from 1 June to 31 August 2007.

Figure 6. Scatter plot of the Sodankylä data (green) and Jokioinen data (red). The linear regression line is given by $y = 0.969 \times x + 0.318$, the Pearson correlation coefficient is 0.966.

SUMMARY AND OUTLOOK

We have shown that the combination of Metop and NOAA data can give sufficient sampling of the diurnal cloud cover for estimation of the surface UV daily doses. Future work includes global validation, refinements to the cloud and aerosol modelling, and improvement of the quality flagging algorithm.

REFERENCES