O3M SAF

Ozone and Atmospheric Chemistry Monitoring

ALGORITHM THEORETICAL BASIS DOCUMENT

NRT UV (NUV/CLEAR, NUV/CLOUD) PRODUCTS

Version 3.3

Prepared by: Helge Jønch-Sørensen Danish Meteorological Institute

DOCUMENT STATUS SHEET

Issue	Date	Modified Items / Reason for Change
1.0	02.05.2004	Initial revision.
1.3	21.11.2004	Updated sections 1 and 4. NUV version number added to section
1.4	30.08.2011	Updated sections 1 and 3 Including now the NUV/CLOUD algorithm
1.5	12.03.2012	Section 1 expanded description of NUV/CLOUD algorithm. Section 2 corrected.
1.6	25.04.2012	Section 1: New Fig.1 and new table showing the accuracies of the various methods. Five references added. 07.05.2012 This table added
1.7	27.05.2013	Metop-B ORR Paragraph on the use of Metop-A and -B ATO added in Section 3. Minor corrections in text.

1. Near Real Time UV index algorithm (Version 3.3)

Clear sky UV index:
The NUV produces clear-sky UV-fields, i.e. the UV-index (*WMO, 1994*) . The radiative transfer model employed is the widely used UVSPEC (*Kylling, 1995*) which is based on the discrete ordinate method DISORT (*Stamnes, 1989*) and has been thoroughly tested for stability. The calculations are performed with total ozone as the only dynamic input parameter whereas climatological parameters are used for all other atmospheric input data as well as surface albedo.

In order to meet the near real time requirement the NUV processor is based on look-up tables of UV (CIE) index. In the look-up tables pre-calculated UV index values have been tabulated for wide ranges of solar zenith angles, total ozone, albedo and five different ozone profiles.

The range in ozone in the look-up tables are from 0 DU to 600 DU in steps of 20 DU, for SZA the range is from 0 to 95° in steps of 5°, and for three surface albedo values: 0, 0.5 and 1.0.

Five look-up tables have been produced for model atmospheres representative of conditions at different geographical latitudes and seasons. UV-indices are then determined from the tables by interpolating subsequently in ozone value, SZA and albedo. Finally corrections for sun-earth distance, aerosol, and altitude are applied:

$$UV\text{-}index = UV_{int} K_{sun\_earth} K_{AOD} K_{altitude} \quad (1)$$

Where:

UV_{int}: UV-index from interpolation in the look-up tables.

K_{sun_earth}: The correction factor for actual sun-earth distance.

$K_{sun\_earth} = a_0 + a_1\cos(\theta) + a_2\sin(\theta) + a_3\cos(2\theta) + a_4\sin(2\theta)$,

$\theta = 2\pi(d - 1)/N$; where d is the day of year and N is the number of days in the year. a_0=1.00011, a_1=0.034221, a_3=0.000719, a_4=0.000077

K_{AOD}: The correction factor for aerosols. The effect of aerosols is parameterized by $K_{AOD} = e^{-kAOD}$. AOD is the aerosol optical depth and k is a constant in principle depending on the aerosol type (urban, rural, maritime etc.). We have set k to 0.5 independent of local conditions.

$K_{altitude}$: The correction factor for altitude is $k_{altitude}$ =1+0.05 x altitude [km].

The NRTUV processor includes the following parameters in the calculations:

- Current total ozone (Assimilated GOME-2 total ozone, ATO).
- Astronomical parameters (solar zenith angle and sun-earth distance)
- Ozone profile, climatology from AFGL (*Anderson, 1987*).
- Albedo, climatology (*Tanskanen, 2004*)
- Aerosols, climatology from the Global Aerosol Data Set (GADS). A summer and a winter data set are available (*Köpke, 1997*).
- Topography (*ETOPO5 and GTOPO30*).

The processor has the option to use the ECMWF assimilated ozone forecast or an ozone climatology derived from TOMS total ozone in case no new GOME-2 ozone data is available at the usual time of processing, this is described in more detail in section 3.

The use of climatologies for the surface albedo and aerosol optical depth have been investigated. The change from the original surface albedo climatology (Herman, 1997) to the new (Tanskanen, 2004) led to small improvements for several locations. As regards the aerosol optical depth climatology no other global climatology has been found. For a few locations with measurements of both UV-index and aerosol optical depth the NUV was recalculated with the actual AOD as input. The results were ambiguous and it was clear that the AOB may vary very much on a time scale of hours. Generally the adopted AOD climatology represent values near the lower envelope of the measured AOD for the stations and will thus contribute to an overestimation of the estimated clear sky UV-index. The main use of a Near Real Time UV-index is expected to be in human healthcare providing individuals information on where and when to take protective actions against UV radiation and in this situation an overestimation is to be preferred to the opposite.

Cloud cover corrected UV index:

In order to correct the UV index to the expected local cloud conditions the ECMWF total cloud cover forecast is applied. The fractional cloud cover is retrieved from the ECMWF Deterministic Atmospheric Model, the Total cloud cover (TCC) product. This forecast is available in 3-hour intervals on global scale on a 0.25x0.25 degree grid. The cloud cover fraction is interpolated in time (to local noon) and location to match the NUV/Clear grid. At each grid point the NUV/Clear is multiplied with a scale factor depending on the cloud cover fraction (ccf). For ccf below 0.2 then fractor is 1 (no correction) for ccf between 0.2 and 0.7 the factor is 0.6 and for ccf above 0.7 the factor is 0.3.

The very simple approach is based on several years of empirical studies of the local UV index forecast for Copenhagen. The approach has been assessed again for this study now using the NUV clear sky UV index. In figure 1 the UVobs / UVclear (2007-2009) is shown against the observed cloud cover. As expected there is a large variation of UVobs / Uvclear for each value of the cloud cover, especially for cloud cover above 0.2. This variation is expected because of cloud information not included in the cloud cover fraction, i.e. different cloud types, actual distribution on the sky. Furthermore the cloud cover observation is not always performed at the same time that the UVclear is valid, at maximum solar elevation, and the visual inspection of either images or direct sky may be subject to “human bias”.

The above mentioned simple algorithm is also shown in Fig. 1 together with the median value in each cloud cover bin.

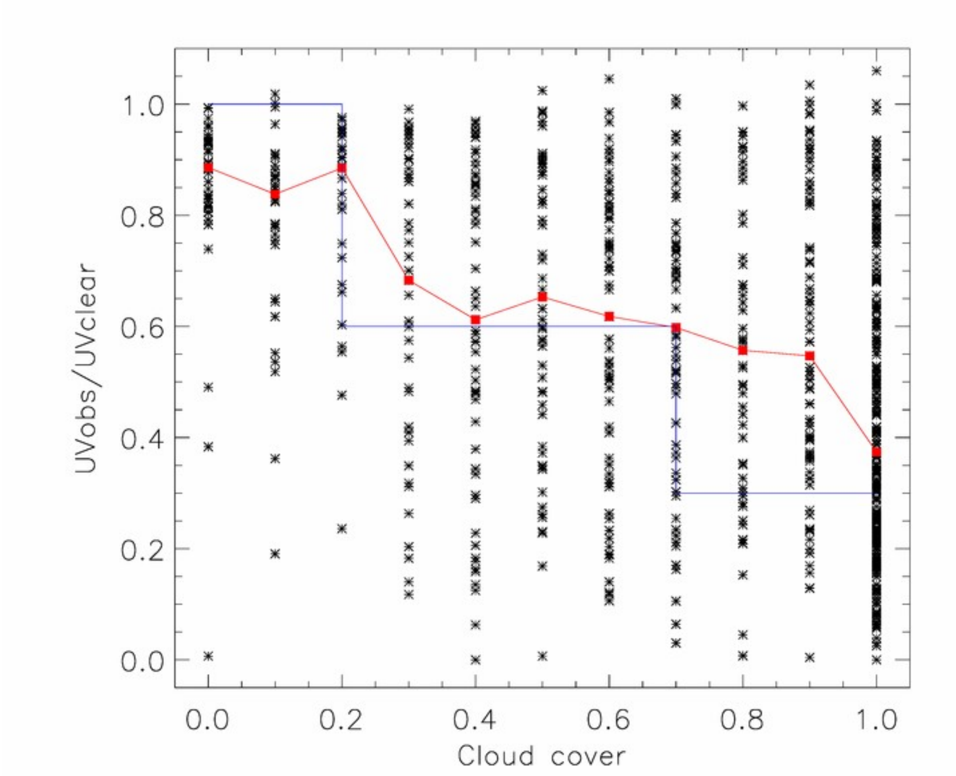

Figure 1. The cloud cover correction factor shown against the cloud cover fraction . Connected red squares are the median value in each bin. The blue line is the simple approached.

Several other approaches have been tested, involving functional dependencies in whole or in part of the cloud cover fraction range. Common to all is the request that at a cloud cover fraction of 0.0 the correction factor is 1, thus no effect of clouds. At total overcast the correction factor was fixed to 0.3 based on the Fig. 1 and results from different locations (*Estupinan et al 1996, Bais et al 1993, Josefson 1986, Ilyas 1987, Cutchis 1980)* .

The different approaches are illustrated in Fig. 2 below.

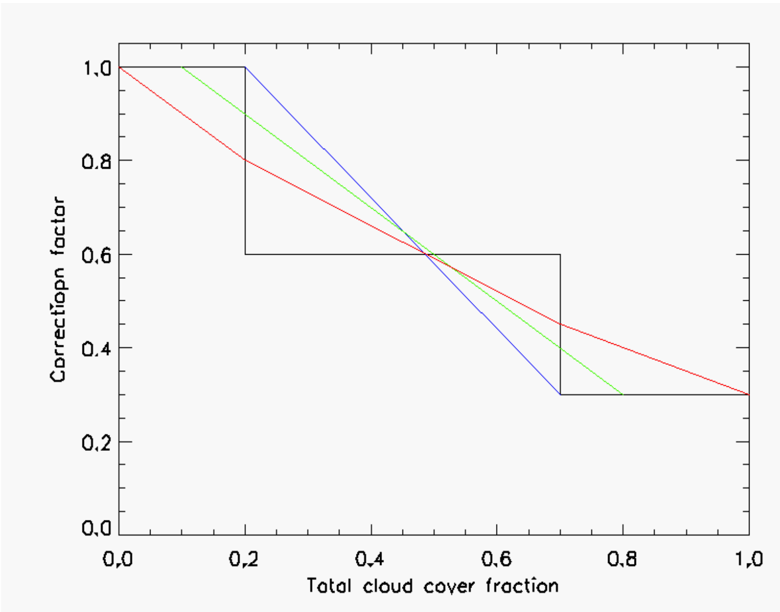

Figure 2. The simple, step function (black) with a linear relation all through the ccf interval (red) and combinations of the two former with varying starting and ending points.

To evaluate the quality of the various methods the mean absolute difference was calculated as < | Xcalc – X | / X> where Xcalc is the Uvobs/UVclear value derived from the method in question and X is the measured UVobs/UVclear. In the table below this number is given for each approach.

Method	Mean absolute difference
Step	20.2 %
Linear from (0,1) to (1,0.3)	20.6 %
Linear from (0.2,1) to (0.7,0.3)	22.7 %
Linear from (0.1,1) to (0.8,0.3)	20.7%

All above methods were also tested with the minimum correction factor (0.3 in the above shown) being 0.2 and 0.4, resulting in mean absolute differences from 20.9% to 23.5%.

The overall average deviation between forecast and measured UV index does not improve using more complex relations between ccf and correction factor. The reason is that the total cloud cover is a crude parameter in describing the influence of a cloud cover on the UV radiation. A high altitude cover of thin clouds are generally reducing the UV index much less than a low altitude cloud cover which often consists of thicker clouds. However, until more robust cloud cover parameters are available as forecast and have been assessed, the simple approach is maintained, since it reproduce the measured UV index at a satisfactory accuracy.

An algorithm involving a relation between the three layer cloud cover forecast (low, medium and high cloud cover, ECMWF parameters LCC, MCC and HCC) is being assessed in 2013. The preliminary results show an improved accuracy for Copenhagen, when validated against ground based measurements from other locations this procedure may be applied from end of 2013.

2. ACCURACY ESTIMATES

In order to estimate the accuracy of the final calculated UV-index it is necessary to have an estimate of the accuracies of all involved parameters. The accuracy of the UV-index is calculated by propagation of the uncertainties through the calculation. The variance of the UV index calculated in (1) is derived as:

$$\sigma^2_{UV} = (f_{uvi}\,\sigma_{uvi})^2 + (f_{sun\_earth}\,\sigma_{sun\_earth})^2 + (f_{AOD}\,\sigma_{AOD})^2 + (f_{alt}\,\sigma_{alt})^2 \qquad (2)$$

where σ_{sun_earth}, σ_{AOD} and σ_{alt} are the estimated accuracies of the three parameters and treated as constants.

σ_{uvi} is the accuracy of the interpolated UVI , the approach is to estimate the error (standard deviation) of the UV-index derived from the interpolation in the look-up table assuming the interpolation in the three parameters (ozone, SZA and albedo) to be independent and summing the variances. The accuracy of the three interpolations are calculated as the product of the accuracy of the parameter and the slope of the relation between the parameter and the UV-index. Thus for any entry in the look-up table, given by (ozone, SZA, albedo) slopes (α_{ozone}, α_{SZA},α_{albedo}) at this position are calculated and:

$$\sigma^2_{uvi} = (\alpha_{ozone}\,\sigma_{ozone})^2 + (\alpha_{SZA}\,\sigma_{SZA})^2 + (\alpha_{albedo}\,\sigma_{albedo})^2$$

Returning to (2) f_x is the partial derivative of UV with respect to x ($\delta(UV)/\delta_x$) thus:

$$f_{uvi} = K_{sun\_eart} K_{AOD} K_{alt}$$

$$f_{sun\_eartb} = UV_i\, K_{AOD} K_{alt}(-a_1\sin(\theta)+a_{2\cos}(\theta)-2a_3\sin(2\theta)+2a_4\cos(2\theta))2\pi/365$$

$$f_{AOD} = UV_i\, K_{altB} K_{sun\_earth}(-0.5e^{-0.5AOD})$$

$$f_{alt} = UV_i\, K_{AOD} K_{sun\_earth} 0.05/1000$$

The accuracy of the input total ozone is either taken from the error field delivered along with the ATO or by using an assumed accuracy of 10 DU. This quantity can be changed in the NUV configuration file. The error on the day-angle (Θ) depends on the day of year and is set to zero, $\sigma_{altitude}$ is assumed to be 100m, σ_{SZA} is set to $(1/60)^o$. The accuracy of the AOD is not well known. As shown in the first validation report, the actual optical depth of a given site may be highly variable and the difference from the climatology value large. We assume a σ_{AOD} of 0.1. We apply monthly average climatologies for the albedo correction and the typical r.m.s. of the difference between albedo values for two subsequent months is 0.03, with large regional differences. The actual albedo on a given day may be much larger than the value from the climatology, especially in areas with possibility for snow cover. The effect of changed albedo depends highly on the SZA, with dramatic effect for small SZA and much smaller effect for larger SZA. In the following we assume an accuracy of 0.05.

As an example of the error-budget we use the following input:

Total ozone = 350 DU, SZA = 30°, albedo = 0.1, AOD= 0.2, altitude= 500m, day number = 1

In the appropriate look-up table the UVI is 7.1 and the slopes (α_{ozone}, α_{SZA},α_{albedo}) are found to be: (-0.03, -0.19, 3.18) this implies that $\sigma^2_{uvi} = (-0.3)^2 + (-0.003)^2 + (0.159)^2$, and σ_{uvi} = 0.34. Thus the significant contributions to the error on the interpolated UVI are the ozone and albedo accuracies. Using the input parameters we find:

$$K_{sun\_earth} = 1.03,\ K_{AOD} = 0.91,\ K_{altitude} = 1.025$$

$$f_{uvi} = 0.96 \text{ , } f_{sun\_earth} = 0.08, f_{AOD} = -3.30, f_{altitude} = 0.32$$

Inserting into (2) yields:

$$\sigma^2_{UV} = (0.33)^2 + (0)^2 + (-0.33)^2 + (0.03)^2 \text{ and}$$

$$\sigma_{UV} = 0.47$$

As demonstrated by this example the main contributions to the formal error of the final calculated clear sky UV-index are the accuracies of the total ozone, the surface albedo and the aerosol optical depth. The effect of this will be investigated further in the validation using ground based UV measurements from locations with a large variarity of AOD and albedo.

The σ_{UV} are calculated at each grid point as described above and in the output product the average formal accuracy of each of the available regional maps are presented in the information file.

3. QUALITY CONTROL

The NUV product is designed to be produced on the basis of the daily ATO file delivered by KNMI. As a backup we also obtain the ECMWF assimilated total ozone every night. During the period of parallel operation of the Metop-A and Metop-B satellites the ATO from the GOME instruments on both satellites will be processed, but only NUV products from one instrument sendt to users. Untill NUV Metop-B products are declared operational the NUV-A will be the 1st priority. As long as both ATO products are available and of the required quality a comparison between NUV-A and -B will be presented on the NUV webpage.

In case the ATO data is not available at the time of processing (02 UTC) or the ATO data failed to pass the criteria described below the ECMWF data will be the next choice of input data. The same requirements of timeliness and quality as for the ATO data are applied to the ECMWF data. If this data set also fails the ozone climatology (TOMS) stored on the processing computer will be used as input to the NUV processor. For all parts of the output product it is clearly stated what kind of input data has been used, and in case the climatology has been chosen, it is stated in the information file that this may implicate a degradation of the accuracy of the UV-index.

After the data has been received on time but before the calculations begin the a number of tests are performed on the input data file. The date, the longitude and latitude grid are tested to be as expected and the data is tested for containing a full global grid. If any of these tests are failed the processor will not use this data but go to the next priority (ATO-ECMWF-climatology). Then the input ozone field is checked for out of limit data (>600 DU and <40 DU) and NaN data. The number of grid points with any of these erroneous data is listed in the operator log file and if the number is above a threshold of 1% of the total number, the processor choose not to use this data set as input but next priority. The threshold level is controlled in the NUV configuration file. The same type of control is applied to the cloud cover fraction file.

After final calculation of the global NUV/Clear field, the current field is compared with the similar fields for the last 7 days and the field for the same day the year before. Points with large deviations are flagged in an operator output file for inspection.

On line quality monitoring is available on the NUV web page. Here the daily zonal mean for five latitude zones are shown compared to the previous two years. Furthermore, the most recent available ground based UV measurements are shown together with the calculated NUV/Clear. At present the results from three instruments operated by DMI are available with a delay of 1-2 days. The NUV/Cloud product will be included in the on line quality monitoring.

4. VALIDATION

The UV index is validated against ground based measurements and the results presented in validation reports. In the most recent report (Issue 4/2012) the NUV/CLEAR and NUV/CLOUD has been compared with ground based measurements from Copenhagen and the five sites in the NOAA SURFRAD network covering the year 2011. When more measurements from other locations are available the validation will be repeated, this is expected to be in late 2013.

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