EUMETSAT
AC SAF
ATMOSPHERIC COMPOSITION MONITORING

ALGORITHM THEORETICAL BASIS DOCUMENT

Global 1-day UV Index Forecast

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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.
1.8	13.06.2013	Typo in Sect. 3 corrected, closing ORR RID
1.9	19.06.2019	Metop-C ORR Sect. 1 Some typos. Last paragraph (page 8, regarding new cloud cover correction algorithm) dates have been updated. Sect. 2 Typos Sect.. 3 1st paragraph changed to include Metop-C. Last paragraph changed to include NUV/CLOUD Sect. 4 Dates for validation updated
1.10	12.10.2019	Table: "Internal product ID's for project control" added
1.11	31.03.2020	Changed according to RR
1.12	31.01.2022	NUV/CLOUD, 3 layer, 1h algorithm for review (RR)
1.13	07.02.2025	Changed according to PCR-ORR

Internal product ID's for project control

MxG-NUV	O3M-410.1

Applicable documents

AC SAF Validation Report NUV, SAF/AC/DMI/V&V/RP/001, Issue 6.3, 07.02.2025

Introduction to EUMETSAT Satellite Application Facility on Atmospheric Composition monitoring (AC SAF)

Background

The monitoring of atmospheric chemistry is essential due to several human caused changes in the atmosphere, like global warming, loss of stratospheric ozone, increasing UV radiation, and pollution. Furthermore, the monitoring is used to react to the threats caused by the natural hazards as well as follow the effects of the international protocols.

Therefore, monitoring the chemical composition and radiation of the atmosphere is a very important duty for EUMETSAT and the target is to provide information for policy makers, scientists and general public.

Objectives

The main objectives of the AC SAF is to process, archive, validate and disseminate atmospheric composition products (O_3, NO_2, SO_2, BrO, HCHO, H_2O, OClO, CO, NH3), aerosol products and surface ultraviolet radiation products utilising the satellites of EUMETSAT. The majority of the AC SAF products are based on data from the GOME-2 and IASI instruments onboard Metop satellites.

Another important task besides the near real-time (NRT) and offline data dissemination is the provision of long-term, high-quality atmospheric composition products resulting from reprocessing activities.

Product categories, timeliness and dissemination

NRT products are available in less than three hours after measurement. These products are disseminated via EUMETCast, WMO GTS or internet.

- Near real-time trace gas columns (total and tropospheric O_3 and NO_2, total SO_2, total HCHO, CO) and high-resolution ozone profiles
- Near real-time absorbing aerosol indexes from main science channels and polarization measurement detectors
- Global UV indexes, clear-sky and cloud-corrected

Offline products are available within two weeks after measurement and disseminated via dedicated web services at EUMETSAT and AC SAF.

- Offline trace gas columns (total and tropospheric O_3 and NO_2, total SO_2, total BrO, total HCHO, total H_2O) and high-resolution ozone profiles
- Offline absorbing aerosol indexes from main science channels and polarization measurement detectors
- Offline surface UV, daily doses and daily maximum values with several weighting functions

Data records are available after reprocessing activities from the EUMETSAT Data Centre and/or the AC SAF archives.

- Data records generated in reprocessing
- Lambertian-equivalent reflectivity
- Total OClO

Users can access the AC SAF offline products and data records (free of charge) by registering at the AC SAF web site.

More information about the AC SAF project, products and services: https://acsaf.org/

AC SAF Helpdesk: helpdesk@acsaf.org

Twitter: https://twitter.com/Atmospheric_SAF

1. Global UV index (NUV) algorithm (Version 3.5)

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.

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

(Spencer, 1971)

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.). This is a widely used approximation of the extinction law for UV index calculations. A value of k= 0.5 is used independent of local conditions.

$K_{altitude}$: The correction factor for altitude is $k_{altitude}$ =1+0.05 x altitude [km]. Different studies find the increase of UV-index to be from 2 % to 12 % pr 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 has 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 AOD 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 Global 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.

The total assimilated total ozone (ATO) field valid for LT 12 globally is input to the processor, thus the first calculated UV index is the clear sky UV index at LT 12 at all grid points. In order to meet the request for a 1h resolution product a pre calculated field of normalized UV indices are applied. This field is constructed by calculating the UV index for all grid points for all 24 hours and for all days of the year assuming a constant total ozone column of 300 DU. The fields are normalize and the daily 24 hours field is produced by scaling to the newly calculated noon UV index.

Cloud cover corrected UV index:

In order to correct the UV index to the expected local cloud conditions the fractional cloud cover for low-, medium- and high clouds are retrieved from the ECMWF Deterministic Atmospheric Model. The low altitude is defined as pressure levels above 0.8 times the surface pressure, medium level is from 0.45 to 0.8 times the surface pressure and high clouds are situated at pressure levels below 0.45 times the surface pressure. For a standard atmosphere these three levels corresponds to approximately 0-2 km, 2-6 km and above 6 km.

The ECMWF cloud cover fractions (CCF) are received from the 00z and 12z runs with a 3h time resolution on a 0.25x0.25 degree global grid. The CCFs transferred to a 1h grid applying linear interpolation between the 3h grid points. Thus we have CCFs for each cloud level for each hour (UT) of the current date. The time (in UT) of minimum solar zenith angle (local solar noon) is calculated for each grid point and the the final CCF grid referring to local time is constructed.

The damping if the clear sky UV index caused be cloud cover is calculated as:

$$UV_{cloud} = UV_{clear} \cdot (1 - (A_0 \cdot CCF_{low} + A_1 \cdot CCF_{med} + A_2 \cdot CCF_{high}))$$

$$\text{where } A_0 = 0.391 \text{ , } A_1 = 0.416 \text{ and } A_2 = 0.019$$

This relation was chosen for the simplicity

A 1st version was derived from observed noon UV indices from Copenhagen (YES and Brewer instrument) for the years 2011-2014 and from 2011 data from two measuring stations operated by the National Science Foundation (NSF), Summit (Greenland) and Barrow (Alaska) equipped with SUV spectroradiometers. The best fit to the parameters A_0, A_1 and A_2 was derived from the UV_{obs} /UV_{clear} relation for all days with reliable data.

In 2017 the algorithm was assessed again using Brewer instrument data from six stations operated by NOAA-EPA Brewer Spetrophotometer UV and Ozone Network (NEUBrew). Bondville (Illinois), Boulder (Colorado), Fort Peck (Montana), Houston (Texas) and Raleigh (North Carolina). Also included was the (YES) UV measurements from Copenhagen 2015-2017.

Multiple regression tests involving the total data set and subsamples defines by CCF values, location (altitude, costal/rural) solar zenith angle, were performed and the most stable solution to the relation was $A_0 = 0.391$, $A_1 = 0.416$ and $A_2 = 0.019$, the formal error for the three values are 0.041, 0.047and 0.041 respectively.

It was found that the observed noon UV index was reproduced by the UV_{cloud} product with a difference and standard deviation of -1.2 and 1.9 respectively, the mean absolute relative difference being 24.3%.

As an additional test the global UV_{cloud} field for 2017 was compared with the corresponding AC SAF off line UV product (OUV). The global comparison showed a mean agreement with the OUV of 18% with a standard deviation of 26%. More on this comparison can be found in the validation report.

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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 $(1/60)^0$. 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 $\sigma_{uvi} = 0.34$. Thus the significant contributions to the error on the interpolated UVI are the ozone and albedo accuracies. Using the input parameters we find:

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

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

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 variation 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-B, and -C satellites the ATO from the GOME instruments on all satellites will be processed. The operational product will be either one of the three calculated NUV or a combination of two or more, this will be flagged in the products. As long as all ATO products are available, and meeting the required quality, a comparison between NUV- B and –C 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 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 for both NUV/CLEAR and NUV/CLOUD. 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 two instruments operated by DMI are available with a delay of 1-2 days.

4. VALIDATION

The UV index is validated against ground based measurements and the results presented in validation reports. In the most recent report (30/01/2025) the NUV/CLEAR and NUV/CLOUD has been compared with ground based measurements from Copenhagen and the 6 sites in Argentina from the SAVER-Net network for the years 2016-2019.

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