SURFACE UV MODELLING AND VALIDATION USING GOME DATA

A. Menkhaus, M. Weber, C. Haite, J. P. Burrows

Institute of Environmental Physics,
University of Bremen FB1,
P.O. Box 330 440,
28334 Bremen, Germany.
(e-mail: anja.menkhaus@iup.physik.uni-bremen.de; mark.weber@iup.physik.uni-bremen.de;
christine.haite@iup.physik.uni-bremen.de; john.burrows@iup.physik.uni-bremen.de)
Uwe Feister
Deutscher Wetterdienst,
P. O. Box 60 05 52,
14405 Potsdam, Germany.
(e-mail: ufeister@dwd.d400.de)

ABSTRACT

Three different satellite based methods for the calculation of the UV radiation from GOME spectral data at the earth surface are presented. The main difference between the three methods is the way cloud information is derived from GOME data and how it is implemented in the algorithms. The first idea in how to handle the clouds is based on an empirical cloud correction factor which is derived from reflectivity measurements at 380nm. The second method calculates the UV surface spectra by taking a weighted sum of clear sky and overcast spectrum where the weight f is the partial cloudiness in percent, computed from the GOME data in two alternative ways. All radiative transfer calculations are done by a multiple scattering pseudospherical radiative transfer model (RTM) including aerosols and clouds as layers.

For the validation of the three models data from ground based Brewer spectroradiometers operated by the German Weather Service (DWD) are used. The spatial and temporal coincidence between the satellite overpass and the ground based measurement deeply affects the quality of the UV field estimation. The presence of broken clouds and the short time scale cloud variability within the field of view of the satellite are the major factors giving rise to significant discrepancies. Provided that the atmospheric conditions are mostly unperturbed, the overall agreement is good. A higher resolution cloud detection algorithm is a very promising tool to deal with more disturbed situations.

1. INTRODUCTION

Due to the depletion of stratospheric ozone an enhancement of the biologically harmful UVB radiation reaching the earth surface is expected (Ref. 21). Other effects such as possible increases in aerosol loading and variations in the cloud coverage have also to be taken into account to study longterm trends in UV surface radiation. One disadvantage of ground based UV measurements is that they mainly look at local effects. A satellite based method in deriving UVB radiation, however, is able to produce global maps of UV fluxes and analyse global UV trends with respect to cloud, aerosol and ozone variability.

The first approach to derive UV radiances from satellite measurements was based on data from the NIMBUS 7 solar backscattered ultraviolet (SBUV) instrument (Ref. 8). It uses atmospheric radiation budgets and the law of energy conservation to compute the biologically active UV radiation. A second method calculates the surface UV radiation over Antartica with the help of NOAA/AVHRR cloud information and NIMBUS 7/TOMS total ozone data (Ref. 17, 16). Another algorithm was developed by NASA/GSFC to determine UVB fluxes from the NIMBUS 7/TOMS instrument using total ozone and reflectivity measurements for cloud correction (Ref. 3, 12, 13). In this paper GOME data are used to derive surface UVB radiation. GOME provides in addition to total ozone auxiliary information about the atmosphere, for example fractional cloud cover and UV/VIS reflectivity. It is, therefore, possible to derive the UV index from a single satellite instrument.

2. GOME INSTRUMENT

The Global Ozone Monitoring Experiment (GOME) is a new passive remote sensing instrument launched by ESA aboard the second European Research satellite (ERS-2) in late April 1995 (Ref. 5, 1, and references therein).

The primary objective of GOME is the derivation of vertical columns of relevant atmospheric trace gases, such as O_3, NO_2, BrO, OClO, SO_2, H_2CO, from the backscattered radiance and direct solar irradiance measurements (Ref. 1, 18, 10, 22, 4). GOME comprises entrance optics, a spectrometer, as well as electronic and thermal subsystems. The spectrometer is basically a double monochromator, where the light is separated into four spectral channels. Each of the latter contains a holographic grating and a Reticon Si diode array detector with 1024 pixels. In this manner the entire spectrum from 240 to 790 nm is observed simultaneously and the spectral resolution varies between 0.2 and 0.4 nm depending on the spectral channels (Ref. 1). Part of the light which reaches the predisperser prism is branched out and recorded with three broadband polarization monitoring devices (PMD), which approximately cover the spectral range of the GOME spectral channels 2 (300-400nm), 3 (400-600nm), and 4 (600-800nm), respectively. The PMDs measure the amount of light at an instrument defined polarization angle. GOME is a nadir viewing instrument and the measurement sequence consists of three across-track scans lasting 1.5 sec each. Each forward scan covers a surface area of 40 km along-track × 320 km across-track. The readout time of the PMDs is 93.75 msec, such that each spectral scan of 1.5 sec includes 16 PMD measurements. Besides measuring the fractional polarisation of the backsattered radiances, the PMD measurements can be used to obtain additional information on cloud distribution and surface reflectivity variation at a higher spatial resolution (40×20 km^2) than is possible from the spectral channels alone.

3. GOME UV MODELS

One of the most important and challenging needs in computing the UV radiation reaching the ground from satellite data is the knowledge of the atmosphere's composition. The actual and local amount of the main absorbers in the UV region like oxygen and ozone is measured by the GOME instrument. However, the correlation between stratospheric ozone depletion and an enhancement of ultraviolet radiation reaching the earth's surface can be only studied if other impacts to the incoming solar light are considered. Particularly clouds have a dramatic screening effect on the UV flux. The probability that a GOME pixel (40 x 320 km^2) is contaminated with clouds is estimated to be more than 99.8% (Ref. 2). Thus, the necessity of correcting UV calculations for clouds is obvious and one main aspect in this work. In Figure 1 the two extreme cases of clear and complete overcast sky and its impact on the UV index are shown in the time series of GOME derived UV indices in Bremen (53°N, 9°E). Under partial cloud cover the derived UV index lies between the two extreme values shown in the bottom of Figure 1, if the fractional cloud cover information from GOME is used (see section 3.2). In early March an ozone mini-hole with total ozone as low as 210 DU passed through Bremen causing an increase of UV exposure by a factor of almost two, which is, however, still less than half of that reached in the summer.

3.1. Reflectivity Models

The following method was first applied for TOMS satellite data (Ref. 3). An empirical correction factor determined from the top of atmosphere reflectivity at 380 nm is used:

$$F = F_{clr}[1 - (R - 0.05)/0.90]\,, \qquad (1)$$

with F being the actual surface flux and F_{clr} the clear sky surface flux. The reflectivity R is obtained by averaging the GOME sunnormalised radiances from 380 to 381 nm. F_{clr} is calculated with a radiative transfer model GOMETRAN (Ref. 19), which includes the total ozone column information obtained from GOME. The RTM calculation includes full multiple scattering, pseudospherical geometry, and an aerosol parametrization scheme. The aerosol optical thickness is taken from the global aerosol data set (Ref. 11). For reflectivities $R > 0.5$ the ground albedo, described by the off-set 0.05 in the above formula, can be neglected and the surface flux can be expressed as follows:

$$F = F_{clr}(1 - R) \qquad (2)$$

(Ref. 3).

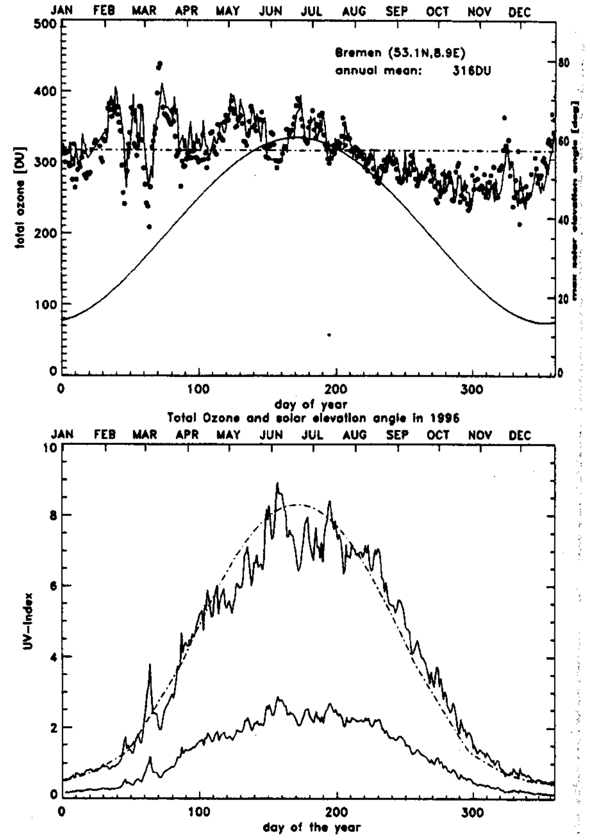

Figure 1: 1996 time series of daily total ozone measured by GOME (solid line) and ground based ozone data from an UV zenith sky spectrometer in Bremen, Germany (53°N, 9°E, solid points). All GOME data recorded within a distance of 500km from Bremen were averaged. The horizontal line corresponds to the GOME annual mean of 316DU. Also shown are the annual variation of the maximum solar elevation angle above horizon each day. Bottom: Using the daily GOME total ozone and the daily maximum solar zenith angle a time series of the UV index under clear-sky condition (top curve) and overcast condition (bottom curve) are shown in the bottom. A reference UV index time series calculated from the annual total ozone mean is shown as a smooth line. An uniform altostratus cloud with vertical extent from 1.5 to 2 km and optical depth of 20 has been assumed, which reduces the UV index by a factor of about 3.2 from that under clear sky condition.

3.2. Cloud Cover Models

The second and third model use the GOME observation of fractional cloud cover which is derived in two different ways. In the radiative transfer model GOMETRAN clouds can be parametrized in two ways: as a bidirectional reflecting surface or as a scattering layer with radiation penetrating the clouds. In both methods the cloud is assumed to be extended homogeneously over the entire GOME ground pixel. Since the most common scenario is a sky with partial cloud cover, the radiative transfer calculation ist done twice, once for clear sky situation (F_{clr}) and then for a completely overcast scene (F_{cloud}). These two results are combined to a weighted average, where the weight is determined by the fractional cover f:

$$F = (1 - f) * F_{clr} + f * F_{cloud}. \tag{3}$$

There are two independent methods to derive the cloud fraction f from GOME: the ICFA (Initial Cloud Fitting Algorithm) method and the PMD (Polarization Measurement Device) algorithm.

3.2.1. The Initial Cloud Fitting Algorithm (ICFA)

The Initial Cloud Fitting Algorithm (ICFA) was first proposed by Kuze and Chance in 1994 and has been extended to be part of the operational GOME level 1 to level 2 processing (Ref. 20). The major aim of ICFA is to obtain a cloud correction to the retrieved trace gas columns (Ref. 1).

The algorithm is based on the following idea: The missing O_2 absorption below the cloud top measured in the oxygen A band at 760 nm gives an estimate of the fractional cloud cover. By least squares fitting, the cloud fraction is searched which minimizes the difference between measured and precomputed transmittances, exploiting the moderately high spectral resolution of GOME (Ref. 1).

The calculated UV spectra are finally multiplied with the CIE function resulting in the erythemally weighted spectrum. Integration over the UV wavelength region and multiplying by 40 leads to an UV index between 0 and 16.

3.2.2. The PMD algorithm

An alternative way to obtain a more accurate and detailed measure of the cloudiness is to enhance the spatial resolution. The three broadband Polarization Measurement Devices (PMDs) of the GOME instrument, which are used to determine the polarization state of the incoming radiances, are read out 16 times faster than the diode arrays, yielding an improved spatial resolution of 40 x 20 km^2.

The three reflectivity signals from the PMDs, approximately covering the red, green and blue part of the visible GOME spectrum, are tested against user-defined thresholds (Ref. 14). Pixels showing a reflectivity lower than a predefined minimum are identified as cloud free and pixels, whose PMD signals exceed a certain maximum threshold are declared complete overcast. For partially cloudy scenes, i.e. the signal P lies between P_{min} and P_{max}, the fractional coverage f is computed as follows:

$$f = \frac{|P_i - P_{i,min}|}{P_{i,max} - P_{i,min}}, \tag{4}$$

where the index i denotes the number of the device (i=1,2,3).

Due to the different spectral reflection properties of different earth surface types the actual test varies with the surface type detected. The surface dependence of the *ratios* of certain pairs of the signals is also exploited. Furthermore a permanent update of the thresholds is performed, thus providing an optimum basis for cloud classification, derived directly from the instrument's signal.

4. VALIDATION OF THE UV MODELS

For the validation of the UVB models ground based measurements by Brewer spectroradiometers operated by the German Weather Service (DWD) in Potsdam, Hohenpeissenberg and Lindenberg were collected. The Brewer instruments in Lindenberg and Hohenpeissenberg are single monochromators while in Potsdam measurements are made with a single and, in addition, with a double monochromator. Spectra from Hohenpeissenberg and Potsdam are corrected for the cosine error (Ref. 7) while the correction is not applied to measurements from Lindenberg leading to an error of up to a maximum of 10% to 15%. At days with partial cloudiness it is difficult to compare model values with measurements since clouds have a large effect on the UV spectra. Even short time differences between the GOME overpass and the ground based measurement can lead to large deviations in the UV index because the satellite and the ground measurement might see different sky conditions. One ground based spectral measurement takes about eight minutes and quick cloud passages can lead to inconsistent surface measurements. It should be mentioned that GOME cloud detection with PMDs has a maximum spatial resolution of 40 x 20 km^2 and GOME sees therefore spatially averaged cloudiness, whereas only *local* cloud information is important for the ground based measurements.

Figure 2 shows the UV indices for all coincidences between GOME overpasses and DWD measurements in the months April to September in 1996 and 1997. Spatial coincidence was fulfilled if the PMD subpixel (40 x 20 km^2) contained the DWD station. The time differences between the two measurements had to be less than 30 minutes. The best correlation between the GOME and the DWD UV index is found with the PMD model. Both the ICFA and the Reflectivity Model tend to underestimate the UV index. The ICFA cloud fraction calculated with the GOME Data Processor (GDP) Version 2.0 (1996-1997) is known to be overestimated (see Figure 3) which may explain the underestimation of the UV index by the Bremen ICFA model. Better agreement shall be obtained for the new version 2.3 (1998-present).

The Hohenpeissenberg measurement station lies at a sea level of 970m. Our assumption for the aerosol optical thickness of 0.2 may be too high leading to GOME UV indices too small for this station. The scattering of the points in Figure 2 can be mainly explained by the influence of broken clouds.

In Figure 4 only those points where the averaged cloud fraction over the 16 PMD-subpixels (16 sequential PMD measurements occur during one high spectral resolution scan) is lower than 10% are plotted and the time gap between the measurements is smaller than 5 minutes. Under such restricted circumstances there is an excellent correlation between our model and the DWD data. In the bottom of Figure 4 we can see that the best correlation is found for the data from Potsdam. For Lindenberg the deviations seem to be larger because the spectra are not corrected for the cosine error. The GOME UV indices for Hohenpeissenberg seem to be a bit too low perhaps due to a too heavy aerosol loading assumed as mentioned already above.

The difficulties in modelling the UV index under broken cloud condition are shown in Figure 5. Greatest deviations should occur in the region where the averaged cloud fraction lies between 0.3 to 0.7 which can be seen in the upper plot of the picture. As the cloud fraction approaches 1 one would expect small deviations between model and measurement as for clear-sky conditions. This is not the case in general because of unknown parameters for the complete description of the clouds (cloud optical thickness, cloud type and height), which have to be estimated.

In the bottom of Figure 5 we can see that with increasing variability of the cloud fraction from PMD pixel to PMD pixel within the agreement between model and measurement becomes worse because of the fluctuating cloud conditions.

5. CONCLUSIONS

We have shown that GOME specific products can be used efficiently for the estimation of global surface UV irradiance. However the most problematic issue is the time lag between satellite observation and ground measurement. If broken clouds are shielding the field of view at the time of overpass, accurate UV index is difficult to estimate. To solve this problem, the use of higher resolution PMD measurements seems to be the most promising methodology for detecting and taking this situation into account. This validation is limited both in time and space. Together with improvements in the models, a more comprehensive intercomparison is needed that would include the effects of ground albedo and aerosol attenuation.

One great advantage of GOME is that the satellite actually measures backscattered UVB radiation. Because GOME measures a broad spectral range (240nm - 790nm) it is possible to perform direct aerosol retrieval (Ref. *Guzzi et al.* 1998) using the decreasing behaviour of the part of the spectrum, where trace gas absorption does not play such a important role. Furthermore, we plan to implement a cloud retrieval code which consists of a combination of the absorption of the O_2 A band and the PMD algorithm to simultaneously derive the cloud fraction, cloud top height and perhaps cloud type (Ref. 9). Further improvements are expected from the use of O_3 profiles retrieved from GOME (Ref. 1) in place of the total column. In the model calculations we currently use the 1D radiative transfer code GOMETRAN++ (Ref. 15, 19). The next step beyond is to test our computations with a 3D radiative transfer model in order to improve the GOME UV index under inhomogenous cloud condition (Ref. 6). The combination of UV surface flux, cloud and possibly aerosol properties may provide important contribution to the further understanding of longterm trends of surface UV in conjunction with stratospheric ozone depletion and variability in meteorological conditions.

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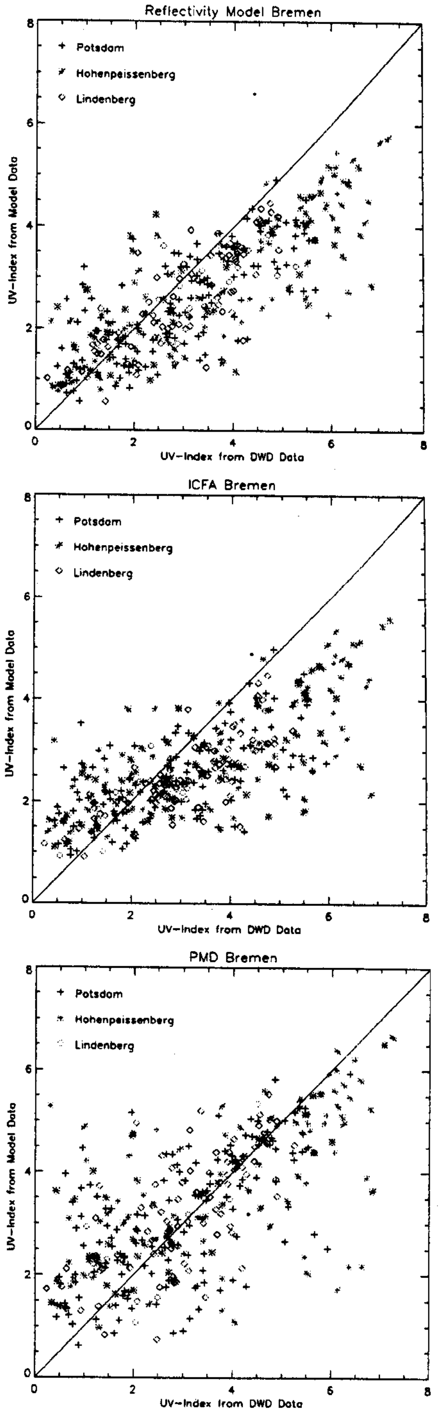

Figure 2: Scatter plot for the GOME UV index from the three models versus ground based DWD data (April to September 1996 and 1997). Top: Reflectivity model, ICFA model (middle); bottom: PMD model.

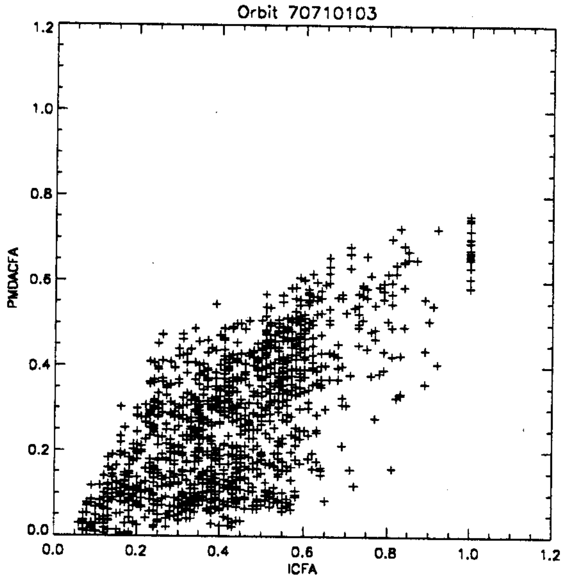
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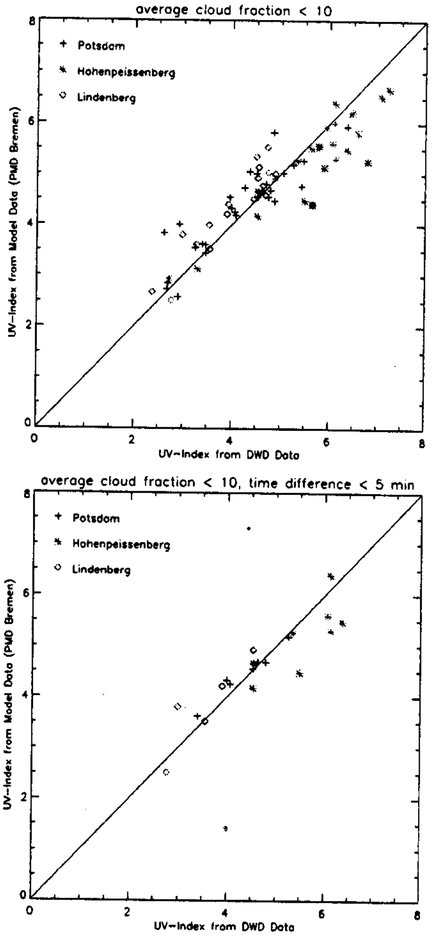
Figure 3: Operational ICFA product versus a cloud fraction derived from averaging over the 16 PMD cloud fractions. ICFA overestimates the fractional cloud cover with respect to the PMD algorithm.


average cloud fraction < 10

average cloud fraction < 10, time difference < 5 min

Figure 4: These plots demonstrate the difficulties to calculate the UV Index in the presence of clouds. Top: Scatter plot using GOME UV index under nearly clear-sky conditions (fractional cloud cover less than 0.1). Bottom: in addition time gap between GOME overpass and ground based measurement is limited to 5 minutes. By restricting the time gap and limiting the maximum averaged cloud fraction, the agreement is much better (bottom).

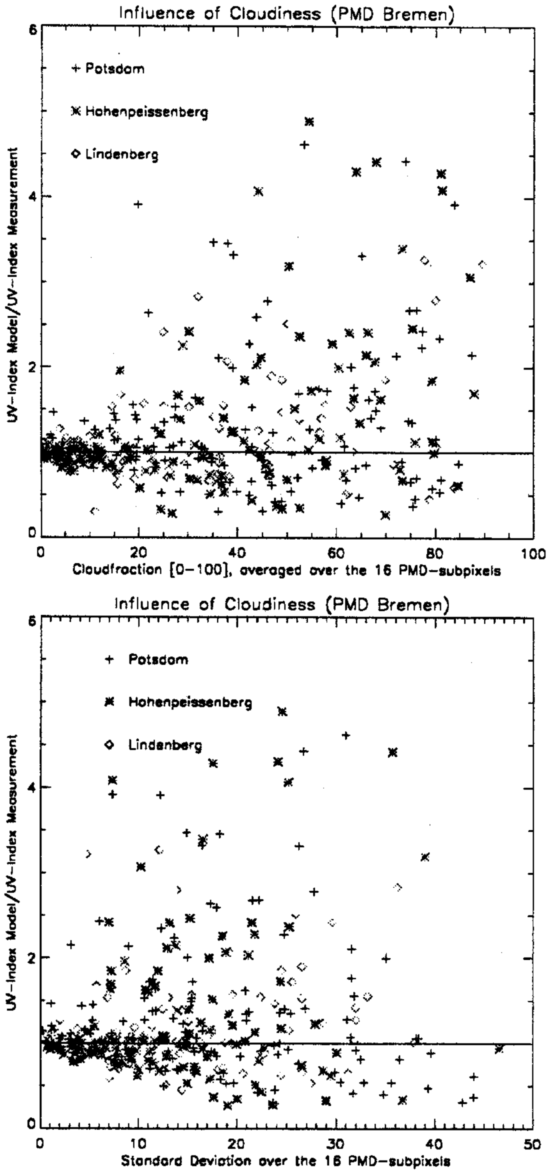


Figure 5: The influence of the cloudiness on the difference between GOME derived and ground based data: The standard deviaton of the 16 PMD cloud fractions is a measure of the broken clouds.