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MONITORING SURFACE UV-B IRRADIANCE FROM SPACE USING GOME; COMPARISONS WITH GROUND-BASED MEASUREMENTS

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ABSTRACT

Since UV exposure increase may have several harmful effects on human health or ecosystems and given that the ozone depletion has not yet reached its maximum, the necessity for monitoring the surface UV radiation is of great importance. Satellite measurements are the only way to achieve a global view of the radiative fields.

We present some preliminary results of global UV fields estimation at the Earth's surface computed using data from the Global Ozone Monitoring Experiment (GOME) instrument. A first simple model is used to test the best strategy for implementing the cloud modeling. It relies heavily on the cloud coverage estimation from GOME. We have compared this scheme with a more accurate model derived from the algorithm developed for the Total Ozone Mapping Spectrometer (TOMS) instrument by NASA/GSFC. First comparisons of the daily CIE weighted irradiance showed deviations between satellite estimates and measurements as large as a factor of 2.5. Possible explanations are discussed. A first comparison between the two different satellite models is also presented. © 2001 COSPAR. Published by Elsevier Science Ltd. All rights reserved.

INTRODUCTION

It is now established that an increase in surface UV radiation results from stratospheric ozone depletion. Since UV exposure increase may have several harmful effects on human health and ecosystems, and given that ozone depletion has not yet reached its maximum, monitoring UV radiation at the Earth's surface is of great importance.

The monitoring of UV radiation at the Earth's surface essentially relies on ground-based observations. Remote sensing is, however, the only way to achieve a global view of the radiative fields. The European Global Ozone Monitoring Experiment (GOME) instrument on board of the ERS-2 satellite measures the radiation backscattered by the atmosphere and reflected by the ground. Its performances make it a potentially good instrument for providing valuable information for UV monitoring from space.

The NASA Goddard Space Flight Center (GSFC) has provided since 1996 UV erythral exposure maps derived from the 15-year (1978-1993) data set of the Total Ozone Mapping Spectrometer (TOMS) on board of NIMBUS 7 satellite (Eck *et al*, 1995). The estimation of surface UV-B from GOME data can certainly benefit from the TOMS experience. Moreover, the GOME instrument provides additional information about the state of the atmosphere observed by the spectrometer. In particular, it gives useful information about the cloud coverage of the observed scene.

THE GOME INSTRUMENT

The Global Ozone Monitoring Experiment (GOME) was launched on-board the ERS-2 spacecraft in April 1995. This instrument is a nadir-viewing spectrometer that observes solar radiation backscattered by the Earth's atmosphere and scattered from its surface. The primary objectives of this instrument are to measure the atmosphere's content of ozone, nitrogen dioxide, as well as other trace gases using a technique known as Differential Optical Absorption Spectroscopy (DOAS). Knowledge of the solar incident radiation is also required to establish the amount of absorption. The reader is

referred to reports from ESA, 1993 and ESA, 1995 for details about the GOME instrument. To summarize, the GOME instrument is a 4-channel diode array spectrometer. Each channel detector is a 1024 pixels diode array, and the full wavelength range spans 240 nm to 790 nm. The instrument resolution varies from 0.15 nm to 0.3 nm depending on the channel. GOME was launched in a sun synchronous near polar orbit with a descending node at 10:30am local time and an altitude of about 795 km. Each forward scan covers a surface area of 40 km along track \times 320 km across-track. Global coverage is achieved after 42 orbits or approximately 3 days while global surface coverage at latitude higher than 60 degrees is provided each day.

An extensive validation program was conducted during the first six months of the instrument's operation. The goal of this program was to assess the performance of both the instrument and data processing with respect to well known references. This validation program included both the level 1 data (solar irradiance and Earth's radiance) and level 2 data (ozone and nitrogen dioxide total column). Reports on the validation campaign can be found in ESA, 1996 and ESA, 1997.

UV-B ESTIMATION AND CLOUD MODELING

In addition to the usual atmospheric absorbers in the UV like oxygen and ozone, clouds have a dramatic screening effect on the incoming extraterrestrial fluxes from the Sun. Incoming flux is scattered by cloud droplets and the intensity reaching the ground is considerably reduced (Krotkov *et al.*, 1998).

UV-B Estimation using GSFC Algorithm

Since the release of the first UV erythral doses from TOMS measurements in 1996, the original TOMS algorithm has been considerably revised and several improvements have been implemented. The main improvement deals with the estimation of the putative cloudiness of the scene. The Lambertian equivalent (effective) reflectivity at 380 nm is now replaced by a Correction Factor (CF) derived from the measured radiance at 360 nm (Krotkov *et al.*, 1998).

We have tested a preliminary release of the updated GSFC algorithm using GOME data. Figure 1a displays the UV erythral irradiance (CIE action spectrum (McKinlay and Diffey, 1987)) at local noon from GOME data processed through a preliminary version of GSFC algorithm. The GOME inputs are the N values at 6 different channels (ratio of radiance/irradiance) for CF computation, total ozone, satellite solar zenith angle and location. This model estimates a putative cloud optical thickness directly using the long wavelength radiances measurements. A correction factor is then computed to correct the clear sky flux for clouds. In the version used in this paper, aerosol load is not taken into account. A test set of 30 orbits from July 10 to July 13, 1996, has been used.

UV-B Estimation using GOME ICFA

GOME provides an estimation of the cloud coverage of the observed pixel using the Initial Cloud Fitting Algorithm (ICFA). Cloud top pressure and pixel cloud coverage are estimated by comparing computed and measured radiances around the oxygen A-band (761 nm) and are a standard level 2 product.

To test the possible use of ICFA cloud coverage for UV-B estimation, we have built a very simple model based on a 2-stream pseudo-spherical radiative transfer model (Kylling *et al.*, 1995) making use of the ozone measurements from GOME as well as the cloud coverage and cloud top pressure from ICFA. When a cloudy scene is detected, the final surface flux is a linear combination of the clear sky estimated flux and fully cloudy scene flux. However, since ICFA does not give any information concerning the cloud optical or physical thickness, some crude assumptions still have to be made. The cloudy scene is defined such that a water cloud layer of optical thickness 25 (at 550 nm) and physical depth of 1 km is inserted at the prescribed altitude. The fluxes are then computed using the above mentioned model.

Figure 1b shows the UV erythral irradiance at local noon using the same set of input data as Figure 1a and computed using the described algorithm. This sample global map makes use of ICFA values from 1997 (from the GOME Data Processor (GDP) 1.0) which unfortunately was known to be problematic and overestimates the cloud fraction. This has been corrected in the next version of ICFA (GDP 2.0) since January 1998. The agreement between CF and ICFA

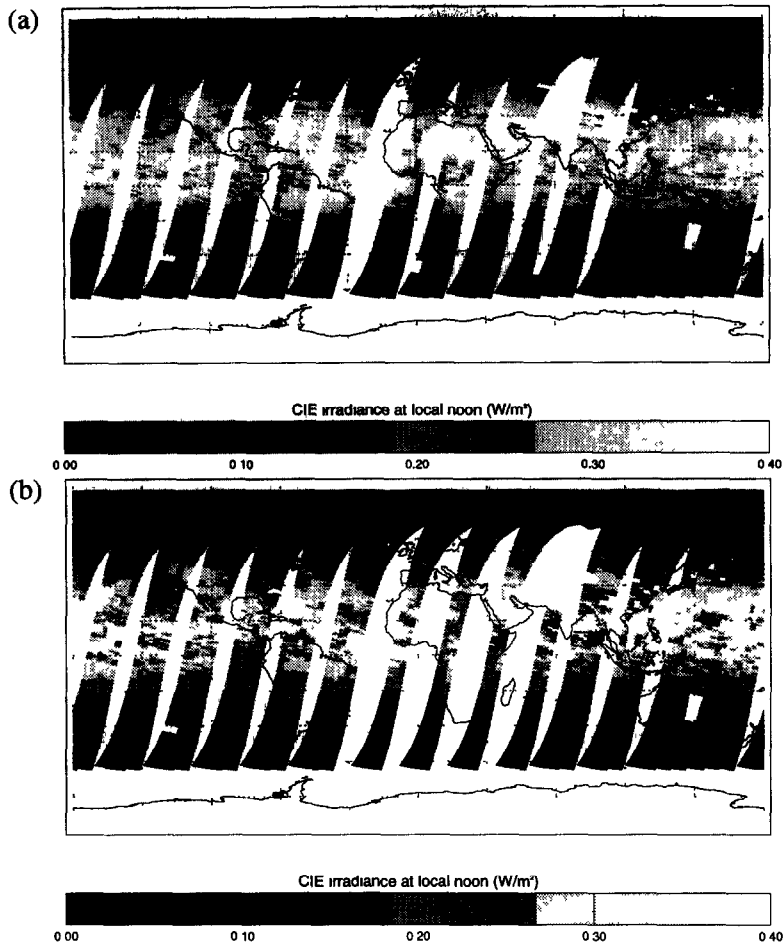


Fig 1 Sample global CIE irradiance computed at local noon using the GSFC-CF algorithm (a) and ICFA algorithm (b)

model is good for clear sky pixels. However, cloudy pixels, whose UV dose rate calculation make use of the ICFA estimation, exhibited in general values lower than the CF algorithm due to the above mentioned ICFA overestimation. This discrepancy is particularly noticeable when the surface albedo is high like the Sahara region. Figure 1a and b give just a succinct visual insight to the products and their problems. A more in-depth comparison between CF and ICFA will be present later in this paper using data from both 1997 and 1998.

A new research product can help enhance considerably the spatial resolution. Indeed, information similar to ICFA about the cloud field can also be obtained from the 16 Polarization Measurement Devices (PMD) measurements for each pixel. Such a product has already been developed at the German Aerospace Center (DLR) (Loyola and Ruppert, 1998). It has the advantage to give a higher resolution of the cloud coverage, each PMD sub-pixels being 1/16 the size of a regular pixel. This approach has been successfully tested. The enhanced spatial resolution is depicted in Figures 2 for a single orbit in 1996 using (corrupted) ICFA and PMD cloud estimation.

COMPARISONS WITH GROUND BASED MEASUREMENTS

A preliminary comparison with ground-based UV measurements made at Uccle (Belgium, 50N, 4E) has been performed for both ICFA-based and CF based daily integrated CIE doses. Two months in 1997 have been selected: August and September. Figure 3 displays the absolute values of both satellite based integrated daily doses estimation and the measurements performed at Uccle. Only satellite pixels whose distance between the pixel center and Uccle is shorter than 400 kilometers are selected. This means that, for some days, two pixels originating from two successive orbits may fulfill the requirements for the same day, giving two different estimations of the fluxes. During the two



Fig 2 The enhanced spatial resolution from PMD is shown here. One single orbit from August 1996 is used to compute UV fluxes, on the left using ICFA cloud screening and using PMD cloud screening on the right

months, 47 satellite measurements met these requirements. It is also important to note that there is only one GOME overpass around noon from which the atmospheric constituents are derived as well as the cloudiness of the field of view. This information is then assumed to be constant throughout the day for daily integrated dose computation using both the CF and ICFA model. On the other hand, ground based measurements are performed locally with a high frequency of 15 minutes. Any changes in atmospheric condition during the day will be taken into account in dose calculation.

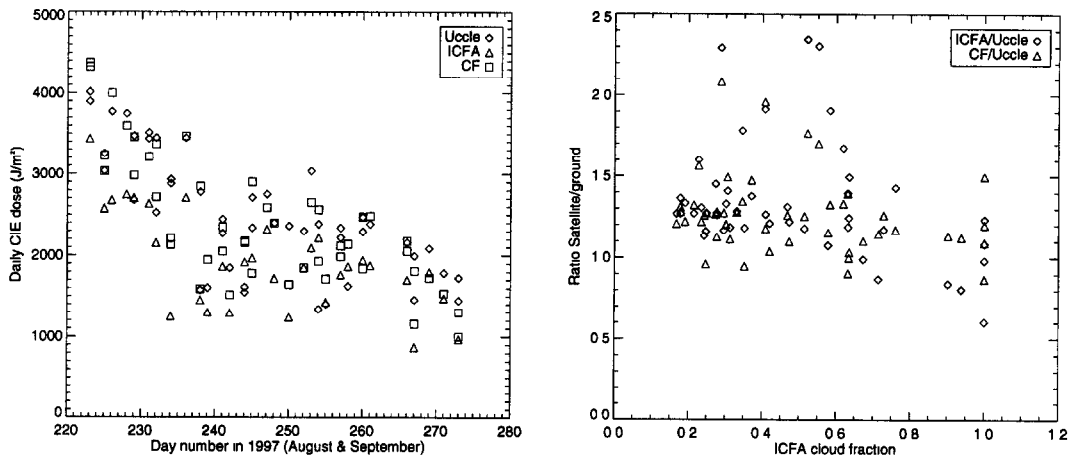


Fig 3 Comparison of ICFA-based and CF-based daily integrated CIE dose with respect to ground based measurements made at Uccle (Belgium). The left panel gives the absolute values of the three measurements. The right panel displays the ratios of satellite estimations versus ICFA estimated cloud fraction.

Large deviations of a factor two can be noticed for several days. Although it was hoped that the selected period in summer would be relatively cloud free, it turns out not to be the case. As noted earlier, both satellite estimations make the crude assumption that the cloud cover remains constant throughout the day. High temporal variability of the cloudiness of the sky affects significantly the integrated daily dose (Zerefos *et al*, 1997). Because of the high frequency of ground-based measurements (≈ 15 min), the cloudiness variability is taken into account in ground based measurements and large discrepancies can be expected. This is illustrated in the following two examples (Figure 4). The first one depicts a relatively steady daily cloud cover while the second corresponds to a highly fluctuating cloudiness.

The ratios of satellite measurements versus ground measurements is close to one in the first case while the satellite estimation is more than twice as high as the ground based measurements

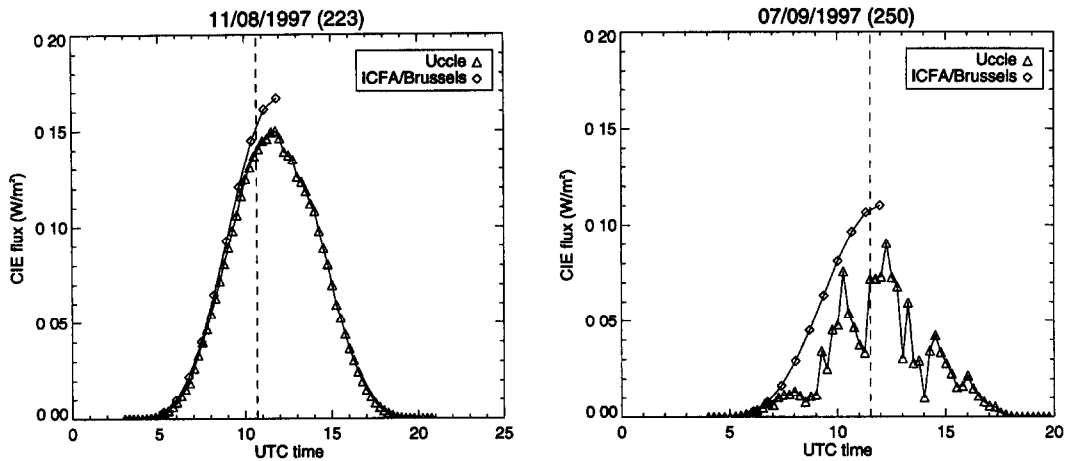


Fig 4 Two particulars days from the measurements in 1997 The satellite estimation is very close to the ground measurements in the first case (0.89 for ICFA/Uccle and 1.2 for CF/Uccle) while a high cloud variability considerably hampers the satellite estimation in the second case (1.9 and 1.3 for ICFA and CF respectively) In both cases the estimated ICFA cloud coverage was 0.5 The dashed vertical line indicates the time of the day of the satellite overpass

COMPARING ICFA TO CF

The ICFA algorithm assumes a cloud layer of constant optical depth and variable spatial extension while the CF algorithm assumes a uniform cloud layer of variable optical depth whose value is estimated from the backscattered radiance. Integrated CIE doses computed from both algorithms have been compared for a set of approximately 72000 pixels in 1997 and 1998. This test set includes measurements from August and September 1997 as well as measurements made in January 1998. Figure 5 displays the relative differences of $CF - ICFA$ CIE doses normalized to the mean $(CF + ICFA)/2$. Zonal mean over 5° latitude bands are depicted. We did isolate the measurement from 1997 and 1998 in this plot. The striking feature here is the large deviations that show up at high latitude. The 1997 data exhibit a characteristic deviation around $20^\circ N$ corresponding to pixels over Sahara where the ICFA cloud fraction is systematically overestimated and the dose underestimated. Several possible sources of errors can be pinpointed, all affecting the ICFA algorithm. As already mentioned, data from 1997 rely on a previous unreliable version of the ICFA algorithm. Secondly, at high solar zenith angle, the 2-stream algorithm is not as accurate as the CF algorithm which uses a more sophisticated spherical model (Krotkov *et al.*, 1998). This may explain partly the discrepancies at high latitude but further investigations are still required. Let us note that only 5% of all the pixels are considered "cloud free" by both ICFA and CF. Overall, for mid latitude, both algorithms are in relatively good agreement. The standard deviation, displayed on the right of Figure 5, shows a scatter limited to $\pm 20\%$ between -50 and $+50^\circ$ latitude.

CONCLUSION

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 for real time daily UV dose computation. If broken clouds are shielding the field of view at the time of overpass, accurate UV dose 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.

Both algorithms agree fairly well at least for this limited pixel sample and given the relative simplicity of the ICFA model. However, the scatter is still wide. Let us note that the sample considered here is restricted to orbits over Europe and Africa and does not include highly variable ground albedo (snow, ice).

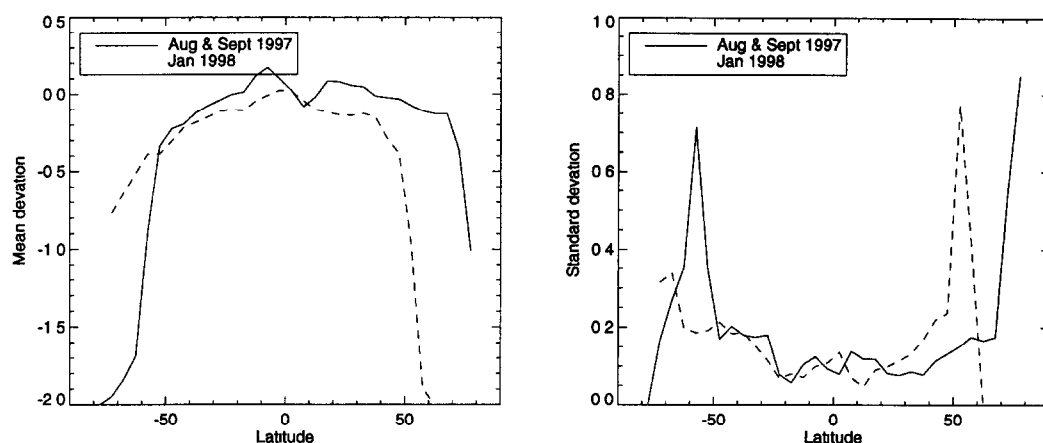


Fig 5 Relative deviation between CF-based and ICFA-based CIE irradiance measurements ($(CF - ICFA) / \langle CIE \rangle$) The left panel shows the latitude dependency of the ratio's and systematic negative deviation at high latitude Values are averaged over 5° latitude bands The left panel displays the standard deviation of the ratio's

Other methodologies are using additional satellite cloud informations for this purpose by using instruments with a very high spatial resolution (Meerkotter *et al*, 1997) This approach uses high resolution cloud optical depth estimation from NOAA/AVHRR with a resolution of 1 km However, this approaches require the ingestion of a huge amount of data They are best suited for regional or local mapping

This validation is still very 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

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