ATTENUATION OF SOLAR UV IRRADIANCES BY DIFFERENT TYPES OF CLOUD CONDITIONS: A POTENTIAL IMPROVEMENT FOR UV INDICES FORECAST.

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1. INTRODUCTION

The penetration of solar UV radiation through the atmosphere depends on various limitation factors as: solar zenith angle (SZA), ozone overhead column and atmospheric absorbers and scatters, mainly clouds and aerosols. In particular, clouds are responsible for a great deal of the observed irradiance variability. The interpretation of observed UV-B time series, and e.g. the detection of possible trends due to human activity, requires the correct understanding of the effects of these different 'factor of influence' and a detailed study of their evolution with time.

A global presentation of these different effects has already be done during the 5th Conference on Atmospheric Chemistry at Long Beach in 2003, [*Gillotay et al. 2003*]. This paper will focus more specifically on cloud impact on the Solar UV penetration through the Earth atmosphere by analysing the radiation transfer for various cloud conditions and cloud types.

Spectral UV measurements in Uccle (Brussels) Belgium are available since April 1989 by combining the IASB measurements and data from KMI/IRM.

Total ozone is measured at Uccle by the Royal Meteorological Institute (KMI/IRM) using a Dobson and a Brewer spectroradiometer, [*De Muer and De Backer*, 1992]. Ozone, temperature and relative humidity profiles are obtained by balloon soundings, also provided by KMI/IRM. Since 2000, clouds are directly monitored at the station site by two different instruments: the Total Sky Imager (TSI, from YES) providing clouds cover fraction by analysis of visible CCD camera pictures, and the CIR-7 (Atmos-Fr /IASB-BIRA – Be) measuring temperature of 181 points of the sky dome (IR : 9-14 µm) providing cloud cover fraction and ceiling altitude. Moreover, cloud fraction and type as well as the ground meteorological parameters (pressure, temperature, horizontal visibility…) are monitored routinely by KMI/IRM and IASB/BIRA.

The major results are presented and discussed in terms of effect of Clouds cover, Cloud type on the penetration of the UV irradiance

An improved 'parametric cloud model' for the prediction of the UV indices is also presented and discussed.

2. EXPERIMENTAL

2.1 Ground based monitoring station

The IASB/BIRA automated station is located at Uccle, a residential area in the Brussels suburbs (lat.: 50°47'54''N, long: 4°21'29''E, Alt.: 105m asl).

It is operational since mid-march 1993 [*Gillotay*, 1996]. The core instruments of the main station are two double mono-chromator (modified HD10, Jobin-Yvon). It includes also three filter radiometers (SPUV-10, UVMFR-7 from Yankee Environmental System, (YES), GUV 511C from Biospherical Instruments) and four pyranometers (YES), two in the UV-B range (UVB-1), one in the UV-A (UVA-1) and the last covering the wavelength range from the UV-A up to the near IR (TSP-700).

One spectro-radiometer, with its optical axis pointing the zenith direction, is fitted with a Lambertian Teflon diffuser with a 2 π sr field of view, measures the total solar irradiance (diffuse + direct), and a nearly perfect cosine response. The other is mounted on a sun tracker (INTRA, Brusag) and measures the direct solar spectrum with a field of view of 4-sun diameter (2°).

One scan, in perfect simultaneity is performed with each spectro-radiometer every 15 minutes for SZA smaller than 100°.

The 10-channels filter radiometer (SPUV-10, YES) measure the direct solar irradiance from 300 nm to 1040 nm. It is mounted on a sun tracking system. This radiometer is designed to provide direct solar irradiance measurements from which the ozone total column and the atmospheric turbidity (the optical depth of aerosols in clear sky conditions) can be deduced.

GUV 511C and UVMFR-7 are respectively 5 and 7 channels 2 π sr filter radiometers. The UVMFR-7 equipped with a shadowing band is designed to perform direct and diffuse quasi-simultaneous measurements of the solar irradiance, from which complementary information on ozone and aerosols can be deduced.

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The pyranometers cover the full range of the solar spectra scanned by the monochromators. It permits a direct measurement of integrated doses with a much higher time sampling (1 mean integrated measurement every minute). One of the UV-B meters is shadowed in order to measure the diffuse component of the solar irradiance.

A schematic view of the IASB station is shown on figure 1.

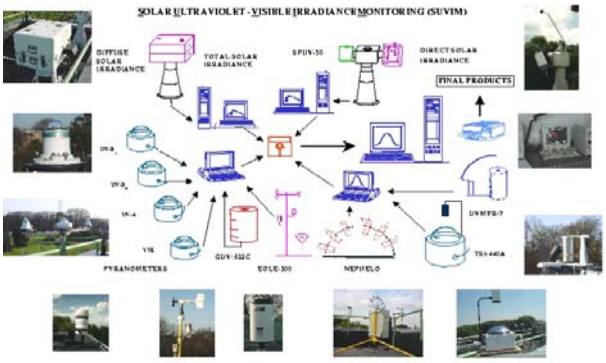

Figure 1. *Schematic view of the IASB UV station*

2.2 Calibration and quality control of the data

Periodical absolute calibration is performed in a dark room using five different NIST-FEL 1000 W standard lamps. Furthermore, stability is periodically checked by means of a **T**ransportable **L**amp **S**ystem (TLS) developed specifically in our laboratory. It consists of five 200 W quartz-halogen lamps and a Mercury low-pressure source, mounted on a carrousel inside a movable container. In the field, the different lamps are successively placed and automatically aligned with the entrance optics of the instruments. With both 'standards' the uncertainties can be estimated to be less than ±5% on all the wavelength range. This estimation was confirmed during the previous European Inter-comparison Campaign. [*Gardiner et al.*, 1993]. Moreover, the coherency of the data set is verified by comparing the filter radiometer and broadband measurements with the corresponding convoluted spectral measurements.

2.3. Time series of measurements

Erythemal doses at noon in Uccle are evaluated from both sets of spectral UV-Visible measurements, by weighting each spectrum by the CIE action spectrum. [McKinlay and Diffey, 1987]. The KMI/IRM data set is corrected to take into account the lack of spectral measurements between 325 and 400 nm. The comparison of the two data sets gives a good agreement (within 5%) for most of the cases over the overlap period (1993-2001). Nevertheless, in some occasions, the discrepancy can reach 20-25%. This is probably due to 1) the unperfected synchronism between the measurements and 2) the correction of the Brewer measurements which does not take into account the modification of the cloud cover during one scan duration.

Figure 2 illustrates the available time series and shows their seasonal variation. The peak values are achieved in June, corresponding to the smallest SZA of the year and relatively low ozone columns.

The scatter within the seasonal fluctuation can be ascribed to changes in cloud coverage.

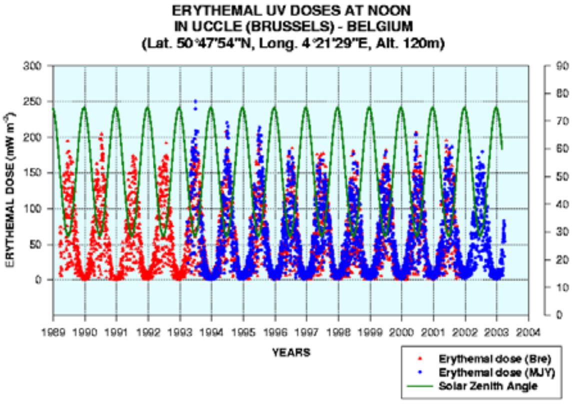

Figure 2. *Time series of the erythemal doses at Uccle.*

3. EFFECT OF CLOUDS

3.1 Complete overcast with low altitude clouds

In order to investigate the role of clouds as a function of wavelength, average spectra for well-defined conditions (complete overcast, similar zenith angles) have been derived from the observations, and compared with a corresponding clear sky spectrum. The average cloud transmission ratios for SZA=30 ° are displayed, as an exmeple, on figure 3, for major types of low altitude cloud conditions observed in Belgium, and compared to a modelled transmission ratio.

A 1-km low cloud with an optical depth 50 has been assumed. Despite the large variability of the cloud impact, a consistent picture is found. The attenuation is lowest in the UV-A, and highest in the ozone absorption bands (UV-B) because of the increased multiple scattering and tropospheric ozone absorption caused by cloud.

The attenuation increases into a lesser extent in the visible range, reflecting the lesser importance of Rayleigh diffusion at higher wavelengths.

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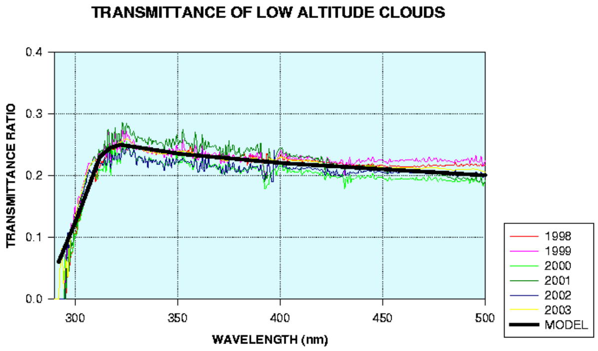

Figure 3. *Ratio of cloudy (8 Octas) to clear sky irradiance.*

3.2 Complete overcast with mid altitude clouds, cirrus and multiple layers.

Other conditions have also been examined in detail namely: mid-altitude clouds, cirrus and multiple layers. In all the cases a comparison between the experimental data and model show a very good agreement. The attenuation factors for the four 'mean conditions' are summarized in figure 4.

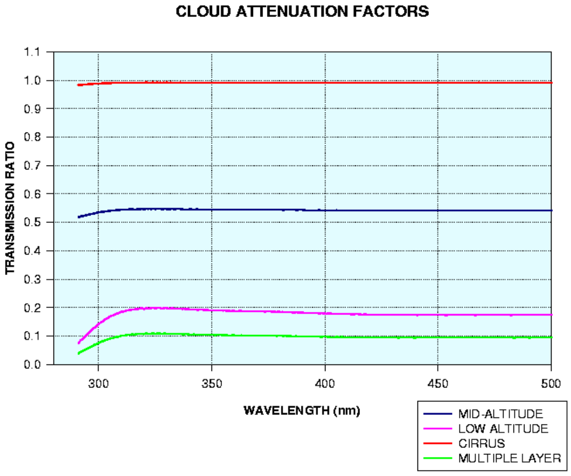

Figure 4. *Cloud transmission ratio corresponding to 4 observed cloud conditions.*

Finally, the average attenuation of sunlight by different type of clouds can be also directly estimate from the pyranometers data. As expected, the attenuation by cirrus clouds (high altitude) is found to be very small. In contrast, low clouds (mainly stratocumulus) reduce solar irradiance by about a factor 5 on average. A more detailed study on this topics can be find in [Gillotay et al, 2002]

This attenuation is found to increase monotonously with the solar zenith angle in the UV-A and UV-B ranges, but in lesser extend for the total integrated irradiances (300-3000 nm).

3.3 Broken Cloud conditions.

The broken clouds conditions being essentially extremely variable, it is practically impossible to find a 'mean condition' representing a significant number of observed cases. It is nevertheless possible, to model the Solar UV spectral irradiances in particular cases, especially if we have accurate 'pictures' of the sky, by means, for instance of the TSI or the CIR. [Gillotay et al, 2002]

4. IMPROVEMENT OF THE UV INDEX PREDICTIONS.

4.1 UV Index prediction procedure.

Predictions of the clear-sky UV Index are based on two methods: a prediction model for total ozone and a radiative transfer model, that calculates the UV-spectrum, based on a number of input parameters.

Prediction of total ozone is based on a regression model. Since the diurnal variation in total ozone is mainly due to weather systems (e.g. *[Reed, 1950]*), total ozone at day D+1 can be described by total ozone at day D and a set of meteorological parameters (see e.g. *[Burrows et al. 1994]*).

The predicted total ozone is then used as an input parameter for the radiation transfer model. The Tropospheric Ultraviolet and Visible (TUV) model [*Madronich, 1993*] is used. Other input parameters are solar zenith angle (SZA), aerosol optical depth and surface albedo. Next day's SZA at local noon can easily be calculated. For the aerosol optical depth, no local information is available; consequently, a typical value of 0.38 at 340 nm is introduced as input parameter in the model. This lack of accurate aerosol information may introduce an error of a few percent in the predicted UV Index. Finally, we can assume that the surface albedo is remaining constant throughout the summer season.

4.2. Experimental determination of UV Index

The experimental determinations of the UV index used for this comparison were mainly those produced by the IASB ground-based monitoring station located in Uccle (Brussels – BELGIUM, Lat. 50° 48' N, Long. 4°21'E, Alt. 120 m a.s.l). It is equipped with several types of instruments performing, since 1993, measurements in the UV (UV-B & UV-A) and visible ranges. Spectro-radiometers, broadband instruments and narrow band filter-radiometers are used simultaneously and complementarily to provide the most complete picture of the UV radiation field in the Brussels area. [*Gillotay, 1996*].

4.3 Comparison between predicted and measured UV index.

To illustrate the comparison of predicted and measured UV index at noon, the results of year 2004 will be examined in details. Results and conclusions, obtained for other years are the same and the general conclusion will be easily extendable to all the measurements and predictions available in the Brussels area.

Clear sky conditions

Figure 5 illustrates the comparison between predicted and measured values for clear sky conditions during the period April 01, 2004 – September 30, 2004. It can be immediately seen that the results are in very close agreement (less than ± 10 % peak to peak). The maximum of discrepancies (around + or – 10%) can be explained by unexpected ozone conditions observed on day 04/160 (June 9, 2004) and day 04/235 (August 23, 2004) with respectively a significant increase and decrease of the ozone total column.

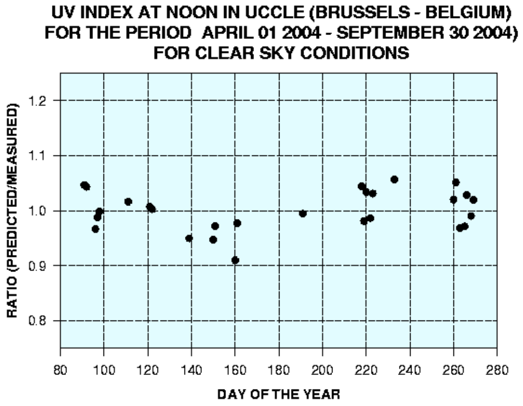

Figure 5. *Comparison of predicted and measures UV index for clear sky conditions*

Cloudy sky conditions

Predictions for cloudy sky conditions are much difficult because of the relatively low precision of the meteorological models in terms of prediction of the cloud coverage and the nature of the different cloud layers. Usually, the UV index corresponding to cloudy sky conditions is simply the predicted UV index for clear sky divided by a factor 2, Figure 6 demonstrates that such a simple hypothesis is totally insufficient to predict properly the UV exposure during clear sky conditions.

New Treatment

We have introduced a new treatment of the cloudy days taking into account the amount of octa provided by the meteorological forecast and a mean optical density for the attenuation of solar irradiance by the most commonly clouds observed in Belgium. UV index being determined as the integration of the UV effective dose on periods of a few hours, the atmospheric conditions, especially the cloud effect, can be described by means of a mean picture where the direct, diffuse and “attenuated diffuse” components of the solar irradiance, statistically weighted are involved. The ‘mean cloud’ properties are defined as Optical density 50, 1-km thickness and 1 km as altitude of the base of the cloud. Four types of cloudy conditions were defined: Hazy sun, 1/3 cloudy (2-3 octa), 2/3 cloudy (4-6 octa) and 3/3 cloudy (7-8 octa). A linear combination of the direct, diffuse and diffuse attenuated by clouds components of the solar irradiance is then used to calculate the UV index in cloudy sky conditions. The coefficients for the linear combination are given in Table 1.

	Sunny Typ0	Hazy Type1	1/3 cloud Type 2	2/3 cl. Type 3	Cloudy Type 4
Direct	100%	80 %	55 %	30 %	0 %
Diffuse	100%	80%	55 %	30 %	0 %
Diff OD50	0 %	20%	55 %	70 %	100 %

Table1 *Coefficients for the calculation of UV index in cloudy conditions.*

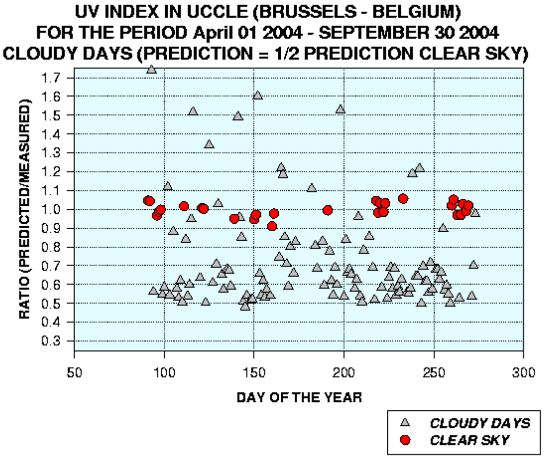

Figure 6. *Comparison of predicted and measured UV index for cloudy sky conditions with classical treatment : cloudy = clear sky /2*

Figure 7 shows the comparison of predicted and measured UV index for cloudy days taking into account the treatment defined above. For types 1-3, the observed discrepancies between predicted and measured UV index are less than ± 20% peak to peak, which is an important improvement compared to the previous method illustrated by Figure 3. In the case of totally cloudy days (type 4), the results are not as encouraging. Some of the predicted values were to high and other are to low. It is clear that the exact nature, thickness and altitude of the base of the clouds are not provided by meteorological forecast and only mean characteristics are used in our estimation. Consequently, particular conditions (far away from the mean properties) cannot be correctly described by this approach.

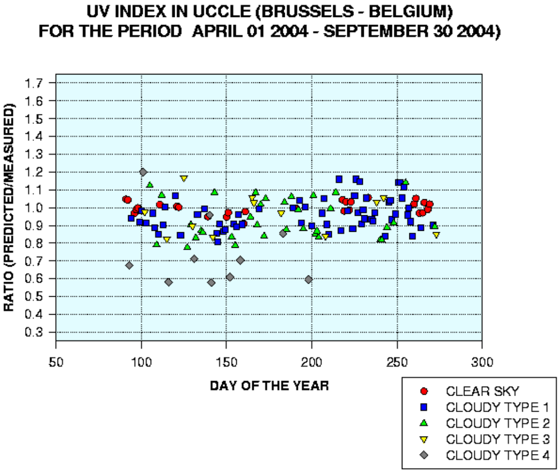

Figure 7. *Comparison of predicted and measured UV index for cloudy sky conditions with classical treatment: cloudy = clear sky /2*

The statistical analysis of the discrepancies between predicted and measured UV index, summarized in Table 2, leads to the following results:

Clouds	Type 0	Types 0-4	Types 0-3
Deviation			
10 %	100 %	70 %	75 %
15 %	100 %	85%	88 %

Table 2 *Statistical comparison between predicted and measured UV index values (in % of cases for given deviation).*

1) Taking into account all the meteorological conditions (clear sky and cloudy sky type 1-4), 70 % of the predicted values deviates less than 10 % from the observed values and in 85 % of the cases the deviation is lower or equal to 15 %.
2) If we exclude the cloudy conditions described by type 4, 75 % of the predictions are within ±10 % compared to the measurements and 88% are within ±15%.

5. CONCLUSIONS

We have shown in the first part of this study that the influence of totally cloudy sky conditions on Solar UV radiation transfer can be reasonably describe, for our mid-latitude regions, by 3-4 attenuation factors that take into account the effect of troposheric ozone.

We have also shown that predicted values of the UV index in clear sky conditions is a reliable information that can be transmitted to public in order to improve the prevention of the risks linked to UV exposure on human health. The introduction of the new treatment of the cloudy sky conditions improve significantly the accuracy of the predicted UV index values and permit to offer a better information on UV exposure during days for which the hazard are limited but not negligible.

REFERENCES

De Muer, D., and H. De Backer, 1992, Revision of 20 years of Dobson total ozone data at Uccle (Belgium): Fictitious Dobson total ozone trends induced by sulfur dioxide trends, *J. Geophys. Res.*, *97*, 5921-5937.

Gardiner B.G., Webb A.R., Bais A. F., Blumthaler M., Dirmhirn I., Forster P., Gillotay D., Henriksen K., Huber M., Kirsch P.J., Simon P.C., Svenoe T., Weihs P. and Zerefos C.S., 1993, European Intercomparison of ultraviolet spectroradiometers, *Environ. Technol.*, *14*, 25-43.

Gillotay D., 1996, UV monitoring in Belgium: Past, present and future. in Measurements and Trends of Terrestrial UVB Radiation in Europe, (Ed. B. L. Diffey), pp. 41-53.

Gillotay D., T. Besnard and I. Labaye, 2002, Impact of cloud spatial distribution on solar UV radiation transfer., in proceedings of 11th conference on Cloud Physics, Ogden, UT, USA, 3-7 June.

Neckel, H., and D. Labs, 1984, The Solar Radiation Between 3300 and 12500 A, *Solar Physics*, *90*, 205-258.

McKinlay, A.F; and B.L. Diffey 1987, A reference action spectrum for Ultraviolet induced erythema in human shin. CIE J. **6** p; 17-22

Stamnes, K., S. C. Tsay, W. J. Wiscombe, and K. Jayaweera, 1988, Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media, *Appl. Opt.*, *27*, 2502-2509.

Van Hoosier, M., J.D. Bartoe, G. Brueckner, and D. Prinz, 1988, Absolute solar spectral irradiance 120 nm - 400 nm (Results from the Solar Ultraviolet Spectral Irradiance Monitor - SUSIM- Experiment on board Spacelab 2), *Astro. Lett. and Communications*, *27*, 163-168.

World Climate Programme (WCP), 1986, A preliminary cloudless standard atmosphere for radiation computation, *WMO Report WMO/TD-No. 24*, World Meteorological Organisation.