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Measurements and modeling of biologically active UV solar radiation: towards balancing between risks and benefits

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OVERVIEW OF THE UV ACTIVITIES IN BELGIUM SINCE THE END OF THE EIGHTIES

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Abstract An overview of the UV activities in Belgium is presented including the balloon borne, Space borne and ground based measurements (at 5 stations) of the global and direct Solar irradiance. Main results in terms of biologically active UV are discussed in relationship with the main factors of influence as Ozone, Clouds and Aerosols. Positive UV effective doses trend (+0.6 % /Year) is discussed in correlation with the ozone negative trend (-0.2 % /year) and more favorable meteorological conditions. Finally, some information are on the future activities namely, the UV indices predictions in real conditions.

1. Introduction

Since more than thirty years, the Belgian Institute for Space Aeronomy (BISA) is interested in the interaction between Solar radiations and the atmosphere with as main goal, a better understanding and modeling of the atmospheric physics and chemistry.

2. Balloon borne od Space borne activities.

During the seventies, a series of stratospheric balloon-borne campaigns where performed to measure the “extraterrestrial” solar spectrum and its variations in the UV range as a function of the main solar cycle. (Simon et al., 1981). The error on the estimation of the residual absorption due to the remaining atmosphere (above 40 km) was a major obstacle to very high precision spectra. Nevertheless stratospheric balloon flights provide a relatively cheap tool to access quasi-extraterrestrial solar irradiances and concentration profile of minor constituents (measured during the ascending or descending phase of the flight).

At the end of the seventies, BISA designed, in collaboration with the Service d’Aéronomie, CNRS (France) and the observatories of Heidelberg and Hannover (Germany) an instrument called SOLSPEC (Solar Spectrum) for the first international space mission SPACELAB 1. It consisted in three double spectro-radiometers (UV, Visible and IR) mounted on a single scanning mechanism, equipped with internal calibration lamps for absolute intensity scale and wavelength scale verifications. The successive versions of this instrument took part to four short (~10 days) space flights (Spacelab 1 in 1983, Atlas 1, 2 and 3 during the 1992-1994 period) and a mission of eighteen months onboard of Eureca 1 in 1993-1994. A third generation of SOLSPEC is presently, since February 2007, on the ISS as major part of the SOLAR payload.

More detailed information will be founded in Thuillier et al., 1992; 1996; 1997; 1998; 1999; 2009. Figure 1 illustrates the solar spectrum measured by SOLSPEC during the Atlas 1 and ISS missions.

3. Ground based activities

At the end of the eighties, satellite measurements confirmed the depletion of stratospheric ozone, which educe the efficiency of this natural UVB filter.

In order to verify the potential increase of UVB at the ground level, to study the penetration mechanisms in the atmosphere and to establish a reliable UVB climatology, the BISA Solar Radiation Group has developed, in the framework of European programmes, ground based UVB monitoring stations.

The penetration of solar UV radiation through the atmosphere depends on the solar zenithal angle (SZA), the ozone overhead column and other at-

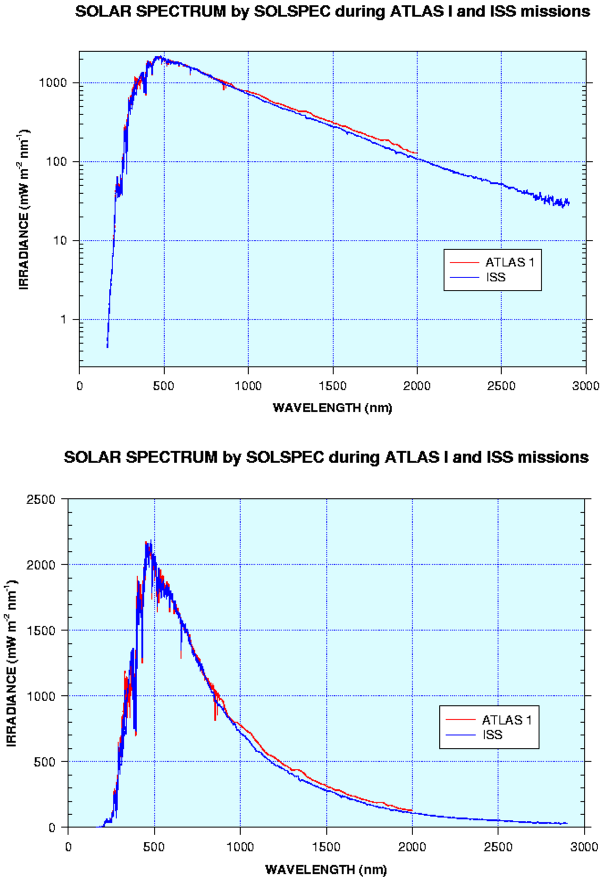


Fig. 1. Extra-terrestrial Solar Spectrum measured by SOLSPEC during the Atlas 1 and ISS missions.

mospheric absorbers and scatters such as 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 ‘factors of influence’ and a detailed study of their evolution with time. The instrumentation is described in the next section. The Royal Meteorological Institute (KMI/IRM) using a Dobson and a Brewer spectroradiometer, (De Muer and De Backer, 1992), measures total ozone at Uccle. Ozone, temperature and relative humidity profiles are obtained by balloon soundings, also provided by KMI/IRM. The cloud fraction and type as well as the ground meteorological parameters (pressure, temperature, horizontal visibility, pluviometry,…) are monitored routinely at the station sites. Since 2000, clouds are directly monitored by two different instruments: the Total Sky Imager (TSI, from YES) providing clouds cover fraction by analysis of visible CCD camera pictures, and the CIR13 and CIR4 (Atmos-Fr /IASB-BIRA – Be) measuring by thermal infrared radiometry the temperature of the sky dome (IR – 8-14 µm) providing cloud cover fraction and ceiling altitude.

UV measurements in Uccle (Brussels) Belgium are available since April 1989 by combining the BISA measurements and data from KMI/IRM. The major results are presented and discussed in terms of correlation between the UV-B irradiance and the main atmospheric parameters like Ozone, Clouds cover, Aerosols, … Potential trends are also presented and discussed.

4. Experimental

4.1. Ground based monitoring stations

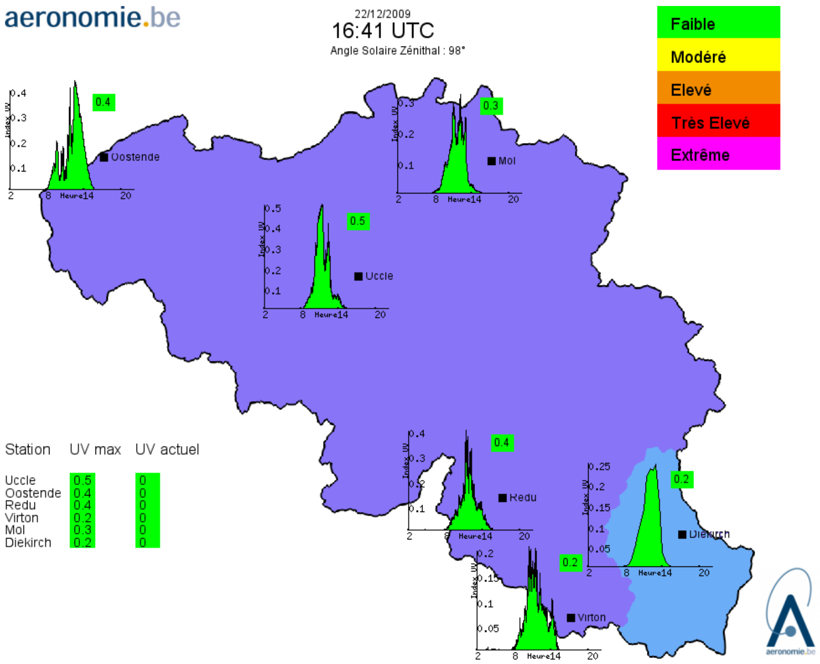
The BISA automated stations are located at Uccle, a residential area in the Brussels suburbs (lat.: 50°48’N, long: 4°21’E, Alt.: 105m), at Redu-Transinnes, in an agricultural area (lat.: 50°00’N, long: 5°09 ‘E, Alt.: 450m), at Ostende, close to the North Sea, (lat.: 51°14’N, long: 2°56‘E, Alt.: 0m), at Virton in a small city area, (lat.: 49°34’N, long: 5°32 ‘E, Alt.: 250m) and at Mol, in a forest environment (lat.: 51°13’N, long: 5°05 ‘E, Alt.: 75m)

They are respectively operational since mid-March 1993 (Uccle), mid-June 2004 (Redu), April 2006 (Ostende), December 2007 (Virton) and December 2008 (Mol). The location of the 5 stations are mapped on in figure 2.

Uccle is the main station equipped with a large variety of equipment:

The core instruments of the main station are two double monochromator (modified HD10, Jobin-Yvon and Bentham DTM300). It includes also four filter radiometers (SPUV-10, UVMFR-7 and MFR7 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). In addition to these radiometric captors, 2 types for instrument to measure clouds (TSI and CIR) are also deployed as well as a meteorological station (RM Young) to measure the basic environmental parameters.

The two spectro-radiometers (HD10 modified and Bentham), with their optical axis pointing the zenith direction, are fitted with a Lambertian Teflon diffuser (2 p sr field of view) measures the total solar irradiance (diffuse + direct), with a nearly perfect cosine response. One scan, in perfect simultaneity is performed with each spectro-radiometer every 15 minutes for SZA smaller than 100°.



Station	UV max	UV actuel
Uccle	0.5	0
Oostende	0.4	0
Redu	0.4	0
Virton	0.2	0
Mol	0.3	0
Diekirch	0.2	0

Fig. 2. Map localizing the 6 stations of the Belgium-Luxemburg network.

The 10-channels filter radiometer (SPUV-10, YES) measures 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 2511, MFR7 and UVMFR-7 are respectively 6, 7 and 7 channels 2 p sr filter radiometers. The MFR-7 and UVMFR-7 equipped with a shadowing band are designed to perform direct and diffuse quasi-simultaneous measurements of the solar irradiance, from which complementary information on ozone and aerosols can be deduced. 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.

Finally, KMI/IRM perform UV-B measurements with a Brewer (Mk II) single mono-chromator from 280 to 325 nm, initially at noon (from April 1989 to December 1990) and on an hourly base (January 1991 – today). A schematic view of the IASB station is shown in figure 3.

The four other stations are equipped with GUV 2511, 6 channels filter radiometers, a set of three pyranometers (UVB, UVA and TSP), a meteo station, and a CIR to measure cloud cover and ceiling.

4.2. Calibration and quality control of the data

Periodical absolute calibration is performed in a dark room using five different NIST-FEL 1000W standard lamps. Furthermore, stability is periodically checked by means of a Transportable Lamp System (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% over 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.

4.3. Time series of measurements

Erythemal doses at noon at the 5 stations are evaluated from both sets of broadband and narrowband measurements in addition to the spectral UV-Visible measurements weighted 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 different

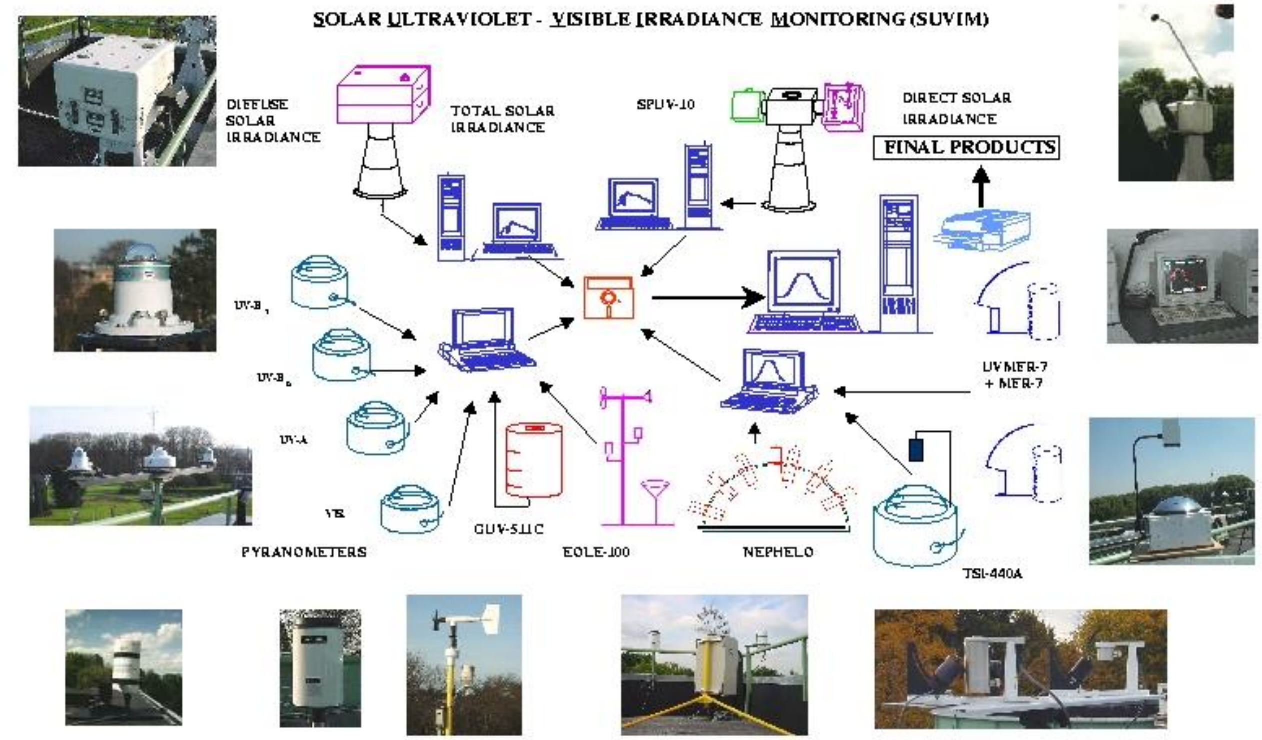


Fig. 3. Schematic view of the Uccle UV station.

spectral 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. Comparison of erythemal doses obtained from integrated measurements and spectral measurements gives the same agreement of around 5 %. Figure 4 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, see for example Gillotay,(1996) and Gillotay et al., (2001) and variations of aerosols type and optical depth.

5. Factors of influence

The two most important factors limiting the penetration and explaining the day-to-day variations of the UV-B radiation to the Earth's surface are the ozone and the cloud coverage ans aerosols. These three 'factors of influence' will be detailed in the next sections.

5.1. Ozone

Figure 5 illustrates the anti-correlation between ozone total column and UV-B integrated irradiance corrected for the effect of cloud cover. The applied correction is relatively simple: it consists in the ratio UV-B/UV-A that takes into account, as a first approximation, the effect of clouds as a neutral filter, combined with a corrective factor to describe the non-neutral effect of clouds in the shorter wavelengths of the spectrum.

A discrete ordinates radiative model (Stamnes et al., 1988) has been used to simulate the experimental data and to verify the anti-correlation function between ozone and UV-B.

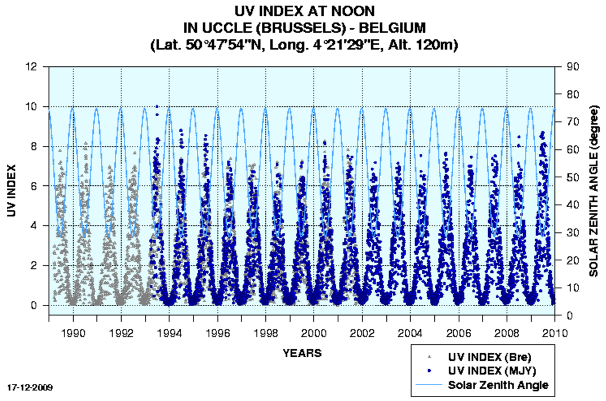


Fig. 4. Time series of the erythemal doses at Uccle.

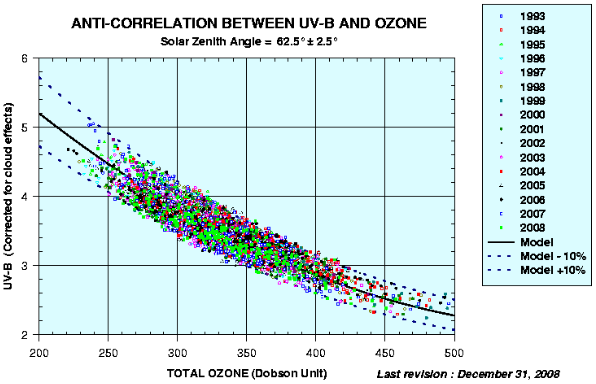


Fig. 5. Anti-correlation between ozone and UV-B.

The extraterrestrial flux is a combination of the SUSIM spectrum below 350 nm (Van Hoosier et al., 1984) and the Neckel and Labs spectrum (Neckel and Labs, 1984) up to 600 nm. The wavelength dependence of the aerosol optical properties follows the parameterization of WCP (WCP, 1986) for typical continental mixtures. This choice is motivated by air pollution lower in Uccle than in typical urban centers. The weak dependence of cloud extinction and asymmetry factor is parameterized following the procedure developed by Slingo (1989).

A good agreement (better than 5%) between experimental data and the simulation has been established for SZA between 30° and 70° in clear sky condition. The discrepancies between modeled and experimental data increase generally with the SZA and might exceed 10% at high SZA in the visible range. Figure 5 shows clearly that (i) the anti-correlation factor observed experimentally is well reproduced by modeling and (ii) practically all the experimental conditions are included within a ± 10% limit vs the predicted values. This 10 % variation can easily be explained by considering the error in the ozone measurements (2-5%), the unsophisticated correction of the cloud layer effects (5 %) and error licked to aerosols type and optical depth (2-5%).

5.2. 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 in figure 6, and compared to a modeled transmission ratio. A 1-km low cloud with an optical depth equal to 5.0 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.

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 topic are given 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 not for the total integrated irradiances (300-3000 nm). These last results have to be examined in the more detailed future modeling studies.

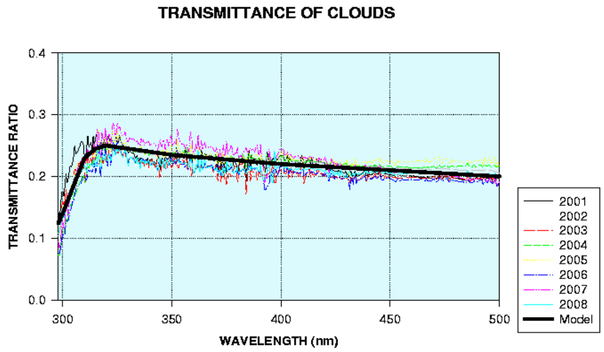


Fig. 6. Ratio of fully cloudy (8 Octas) to clear sky irradiance.

5.3. Aerosols

Aerosols have also a significant role in the attenuation of the UV flux at the Earth surface.

In Belgium, in general, and more particularly in Brussels, we observe usually a mixture of continental and maritime aerosols, with optical depth (at 500 nm) ranging from 0.05 to 0.3 as shown by the "Cimel" measurements performed at the Institute (Herman C., 2010), available on aeronet. In some specific cases we observe (i) continental aerosols during stable eastern wind conditions, (ii) maritime aerosols during stable western wind conditions and (iii) urban aerosols during high urban pollution episodes, usually accompanied by high tropospheric ozone concentrations.

Table 1 summarized the aerosols effect on the penetration of biologically active UV radiations (UV index). As we could expect, effect of aerosols is more pronounced for high solar zenith angle; due to the longer optical path in the atmosphere. It is also evident from Table 1 that "Urban" aerosols type has a most lager impact than the other types, probably due to the presence of small particles and specific absorber like ozone and peroxides.

Table 1. Effect of Aerosols on the UV index for various aerosols types and optical depths at two Solar Zenith Angle conditions.

SZA & Ozone	25°	306 DU			70°	306 DU		
Optical depth	0	0.1	0.2	0.3	0	0.1	0.2	0.3
Maritime	8.50	8.25	8.07	7.91	0.79	0.70	0.67	0.66
Relative	*1.00*	*0.97*	*0.95*	*0.93*	*1.00*	*0.89*	*0.85*	*0.83*
Continental	8.50	8.16	7.87	7.62	0.79	0.69	0.65	0.63
Relative	*1.00*	*0.96*	*0.92*	*0.90*	*1.00*	*0.87*	*0.82*	*0.80*
Mixture	8.50	8.20	8.00	7.77	0.79	0.70	0.66	0.64
Relative	*1.00*	*0.97*	*0.94*	*0.91*	*1.00*	*0.88*	*0.84*	*0.81*
Urban	8.50	7.75	7.08	6.47	0.79	0.64	0.57	0.52
Relative	*1.00*	*0.91*	*0.83*	*0.76*	*1.00*	*0.81*	*0.72*	*0.66*

6. Trends

The bring to light of potential trends of UV-B radiation at the Earth's surface due to human activity is of high interest for the public health medical community as well as for all the scientists interested in the effects of UV-B on biology and material sciences.

The aim of this section is just to illustrate what can be deduced from a 14-years period of UV-B monitoring. Figure 7 illustrates the high variability of UV-B effective doses on a monthly base mainly due to the variability of meteorological conditions.

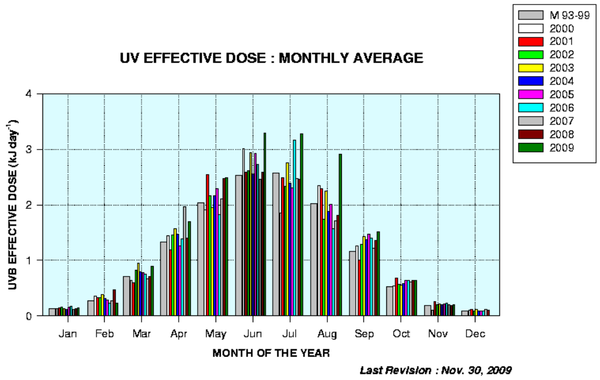


Fig. 7. UV-B effective monthly averaged doses in Uccle (Brussels) Belgium.

Figures 8 and 9 give an idea of the potential trends of UV-B and ozone in Brussels. UV-B trends show an increase of 0.6 % per year that looks coherent with the ozone trends of 0.2 %.

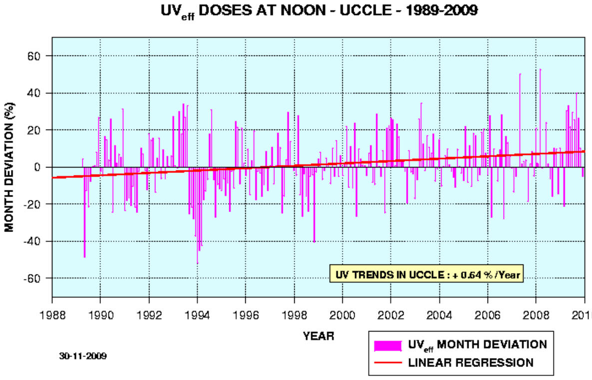


Fig. 8. UV-B trends in Brussels 1989-2002.

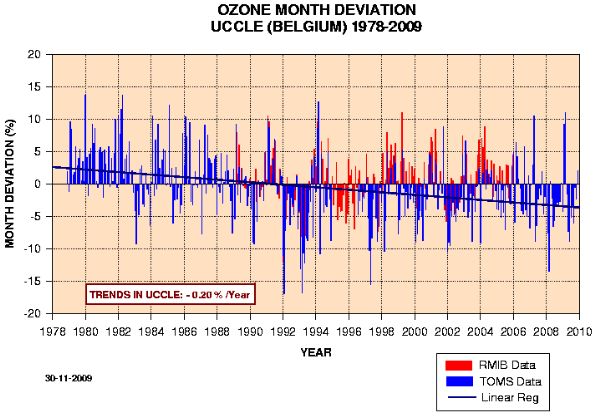


Fig. 9. Ozone trends in Brussels (1978-2002) by combining TOMS/OMI and KMI/IRM data.

Part of the UV positive trend can be ascribed to more frequent long sunny periods observed in Brussels since 2-3 years. (See for example the periods Jun → Aug 2009, Feb 2008, Apr 2007 and Jul 2006 on figure 7)

7. Future activities

The measurement of erythemal doses and the diffusion to the community of information on measured UV indices is probably very interesting, but the main expected information is an accurate predictive value of these indices at 24, 48 or 72 hours, taking into account the most reliable meteorological predictions, correct ozone values and the climatologic particularities of the different area of a country.

That is the goal of the BISA Solar radiation team for the next years: to provide UV indices prediction in real conditions.

This activity will be carried out, in collaboration with our colleagues from Luxemburg. Different tools are already tested and the first results are promising.

8. Conclusion

These results, presented above, show the consistency of both our model and experimental data. They provide a first understanding of the UV-B climatology in Belgium that could be extrapolated to the 50°-latitude area. An extended period of measurements is necessary to improve the preliminary trends given above. Nevertheless the increase of UV-B radiation seems to be real and needs to be explored in more details.

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