MONITORING OF SOLAR UV-B RADIATION

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Significant stratospheric ozone reductions have been observed at mid and high latitudes in both hemisphere during the last decade. Because the UV-B (280-320 nm) solar irradiance is strongly absorbed by stratospheric ozone, the global climatology of the UV irradiance at the Earth's surface will be affected by ozone variations and trends. The UV-B wavelength interval induces also photoreactions on biological systems. Therefore, it is important to quantify future UV-B changes on global and regional scales in order to investigate the modifications induced to the biosphere.

The complexity of UV-B monitoring, less than 2% of the total solar irradiance, is related to the number of factors, in addition to the stratospheric ozone, which controls the UV penetration in the stratosphere and the troposphere down to the Earth's surface. Figure 1 shows a solar spectrum measured at the ground level around noon time (SZA = 27%) during a clear sky day (24/06/1994) and a solar extraterrestrial spectrum measured during the Spacelab 1 mission in December 1983 (upper curve). It appears clearly that the solar irradiances is totally extinct by the Earth 's atmosphere below 290-295 nm and strongly absorbed up to 320 nm.

As satellite measurements do not indicate, during the last decade, significant long or short-term variations related to the 11-year activity cycle and the 27-day rotation period

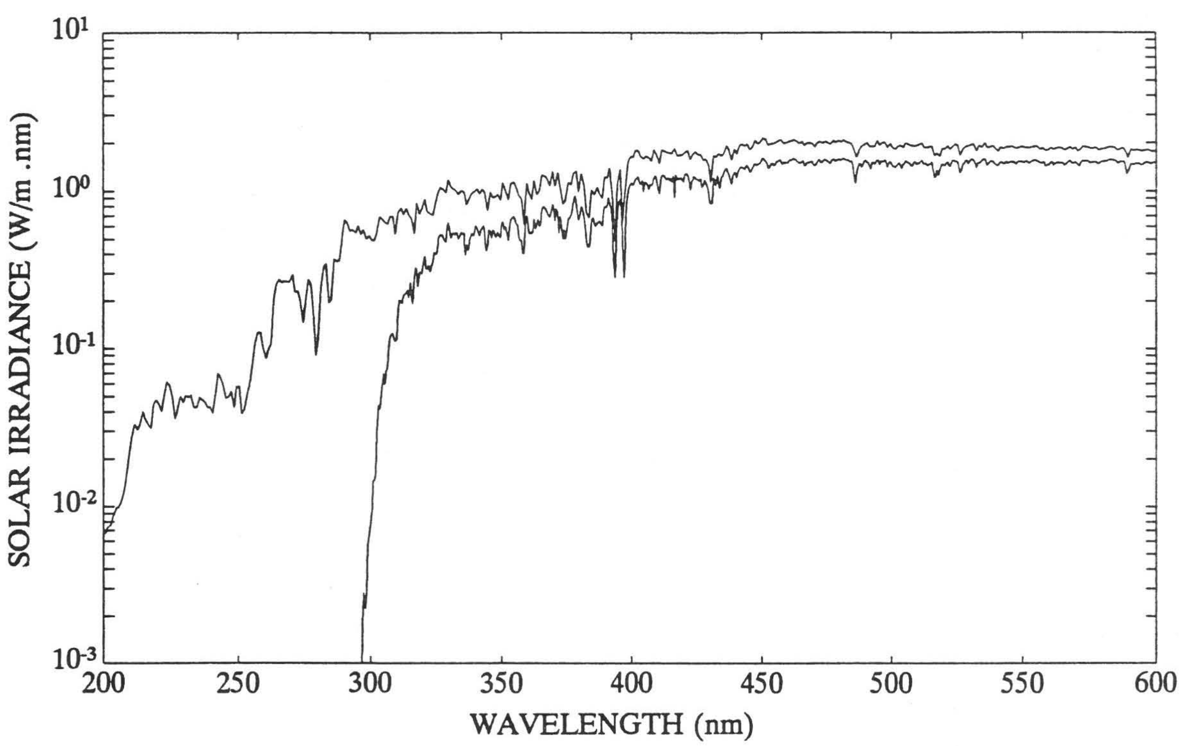


Figure 1 : The extraterrestrial solar irradiance between 200 and 600 nm (upper curve) measured during the Spacelab 1 mission (December 1983) and the solar irradiance in the same wavelength interval at the Earth's surface, measured on June 24 1994, around 12:00 UT (SZA = 27°) in Uccle

of the Sun in the UV-B range, the most pronounced extra-atmospheric factor is the temporal variation of the extraterrestrial solar irradiance linked to the Earth's orbital parameters, inducing a change of 6.6% from January (maximum) to July (minimum) each year.

The factors controlling the penetration of UV solar irradiance in the terrestrial atmosphere are defined by the equation of radiative transfer with the extinction cross sections expressed as a sum of the absorption and scattering cross sections, illustrated in figure 2.

Stratospheric contributions : The Rayleigh scattering is controlling in a lesser extend than ozone the atmosphere extinction in the UV, mainly in the lower stratosphere. The stratospheric aerosol extinction has also to be taken into account after major volcanic eruption like the Mt. Pinatubo in June 1991. The optical depth of the other trace constituents, like for example the nitrogen dioxide, is negligible because of their lower column densities by comparison with ozone.

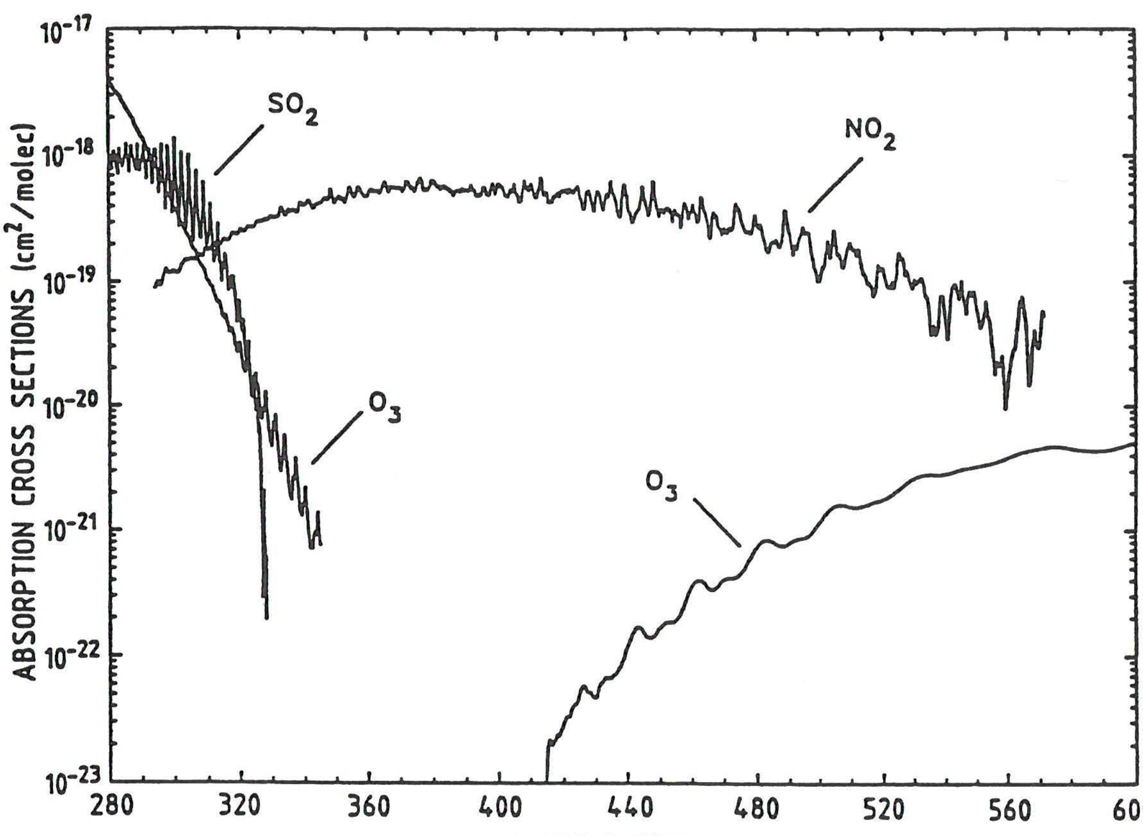


Figure 2 : Absorption cross sections of ozone, nitrogen and sulfur dioxide between 280 and 600 nm.

The solar zenith angle (SZA) is there a key parameter in the definition of the atmospheric optical path. Its diurnal, monthly and latitudinal variations induced large irradiance changes in the UV-B range. As it will be illustrated later, for a given amount of atmospheric ozone, the SZA variations produce shifts of the atmospheric cutoff wavelength larger than 10 nm around 300 nm.

In addition to the UV absorption by molecular oxygen and ozone which mainly control the penetration of UV solar irradiance in the high atmosphere, stratospheric and tropospheric factors are to be taken into account :

The climatology of ozone which has been systematically studied since the International Geophysical Year (IGY) in 1957-1958 shows large seasonal and latitudinal variations both in total abundances and in vertical distribution of concentration, producing large gradient in solar UV-B.

Tropospheric contributions : The structure and composition of the troposphere contribute significantly to the radiative transfer of the UV solar irradiance. In addition the Rayleigh scattering becomes an important process controlling the UV penetration, reaching its maximum efficiency near the surface. The presence of gaseous polluants like nitrogen and sulfure dioxide having absorption bands in the UV-B range should affect the tropospheric transmission of the UV solar irradiance with large hemispheric, latitudinal, seasonal and altitude variations in relation with the anthropogenic sources of pollution. In addition recent changes in the tropospheric ozone are related to increased emissions of hydrocarbons, carbon monoxide and nitrogen monoxide. Ozone sondings in Europe have shown ozone increases up to 10 km altitude.

The light scattering by haze, particulates and aerosols is another important factor for tropospheric radiative transfer of solar irradiance. The role of the clouds is one of the most varying parameter because of their high spatial and temporal variabilities and their different structure. Cloud extinction could reduce UV irradiance by a factor up to 5.

The role of the Earth's albedo as to be carefully taken into account when measuring and modelling the UV irradiance at the surface. This parameter is responsible for enhancement of the tropospheric radiation due to the combination of albedo and scattering effects for particular atmospheric conditions. A global amplification ratio can be defined which depends upon the relative importance of albedo and Rayleigh scattering with respect to altitude.

The UV irradiation induces biological photoreactions which are characterised by action spectra, specific to each process. They generally have a maximum at wavelengths shorter than 300 nm, even below 280 nm (UV-C region), and decrease sharply by several orders of magnitude in the UV-B region. Some of them exhibit also a non negligible response in the UV-A range (320-400 nm) represented by a tail in the action spectrum, having a smooth decrease in efficiency toward the visible spectrum. Consequently, the UV-B, the UV-A, not affected by atmospheric ozone change, and the visible ranges, need to be spectrally quantified for effect studies on the biota.

1. Description of the IASB UV-Visible monitaring station

In order to monitor spectrally the UV (UV-B and UV-A) and the visible ranges of the solar irradiance at the Earth's surface, a fully automatic ground based monitoring station has been developed at the "Institut d'Aéronomie Spatiale de Belgique" (IASB).
It is located in Uccle, south-western part of Brussels, in a urban residential site closed to the "Forêt de Soignes" (Lat.: 50°47'54"N, Long.: 4°21'29" E, Alt. asl : 105 m) and is fully operational since mid-March 1993.

Presently, this station consists of two instruments based on modified Jobin-Yvon HD10 double monochromators which have been optically characterised in the laboratory of optics and radiometry (bandwidth, angular and azimuthal responses, slit function) and calibrated in absolute irradiance scale by means of five standards lamps provided by the "National Institute of Standards and Technology" (NIST) in Gaithersburg, USA.
The main characteristics of these instruments are given in table 1, and an optical scheme of the modified HD10 is shown in Figure 3.

Both instruments are included in a weatherproof (waterproof and thermal regulated) container, as shown in Figure 4, and are oriented in the zenith direction. They are equipped with different entrance optics allowing a field of view of 2 π sr (180°), with a practically perfect cosine response for instrument # 1 and of 10° for instrument # 2. They provide absolute spectral measurements from 210 nm to 680 nm every 15 minutes, for solar zenith angles smaller than 100°.
Spectrum recorded by instrument # 1 provides an absolute measurement of the total (direct + diffuse) spectral irradiance received by a Lambertian surface at the Earth's surface. Instrument # 2 give an absolute measurement of the diffuse spectral irradiance in a solid angle of 5° around the zenith direction. This last measurement is important to characterise the cloud layer and to determine the total ozone contents by differential absorption technique. It will be also very useful for future correlations between diffuse UV-B irradiance and tropospheric ozone.

Moreover, a third instrument of the same type, designed to measure the direct component of the solar irradiance, is presently under testing on a sun tracker system. It will be integrated shortly into the station. The three instruments will, then, provide a data base very useful to be able to understand the influence of the atmospheric parameters (like total ozone column and concertation distribution, type of cloud layer, sun position, aerosol contents,...) on the two different components (direct and diffuse) of the UV-B, UV-A and visible ranges of the solar irradiance.
It is also planned to add to the station, instruments measuring continuously the integrated solar irradiance in different wavelength ranges like pyranometers, UV-A meters, UV-B meters or broad-band spectrometers.

Finally, ancillary measurements like total ozone contents, ozone concentration distribution and detailed description of the meteorological conditions are provided by the "Institut Royal Météorologique de Belgique".

2. Calibration and quality control of the data

A special care is taken in the quality control of the provided data's. Periodical absolute calibrations (every 2-3 months) are performed in the dark room of the Institute with the five NIST-FEL 1000 W standard lamps and the

Table 1 : Instruments

♦ MODIFIED DOUBLE MODIFIED DOUBLE MONOCHROMATORS JOBIN YVON H10-D.

	INST.#1	INST.#2	INST.#3*
FOCAL LENGTH (mm)	100	100	100
GRATINGS		HOLOGRAPHIC CONCAVE	
lines/mm	1200	1200	1200
FWHM at 300 nm (mm)	0.488	0.492	≈0.500
STEP (nm)	0.3	0.3	0.3
USUAL RANGE (nm) from	211	210	≈210
to	683	684	≈680
SCAN DURATION (s)	400	400	≈400
FIELD OF VIEW	2πsr	±5%	±1°
DIFFUSER	TEFLON	QUARTZ-TEFLON	QUARTZ
DETECTOR	PMT	PMT	PMT
type		HAMAMATSU R292	
WEATHERPROOF		YES	
AUTOMATIC		YES	
DARK CURRENT		REMOVED DURING TREATMENT	
STRAY LIGHT		NEGLIGIBLE	

*To be installed during 1995.

♦ CALIBRATION

Radiation Standards : 5 FEL 1000W lamps from NIST.
Secondary Standards : 5 200W quartz halogen lamps

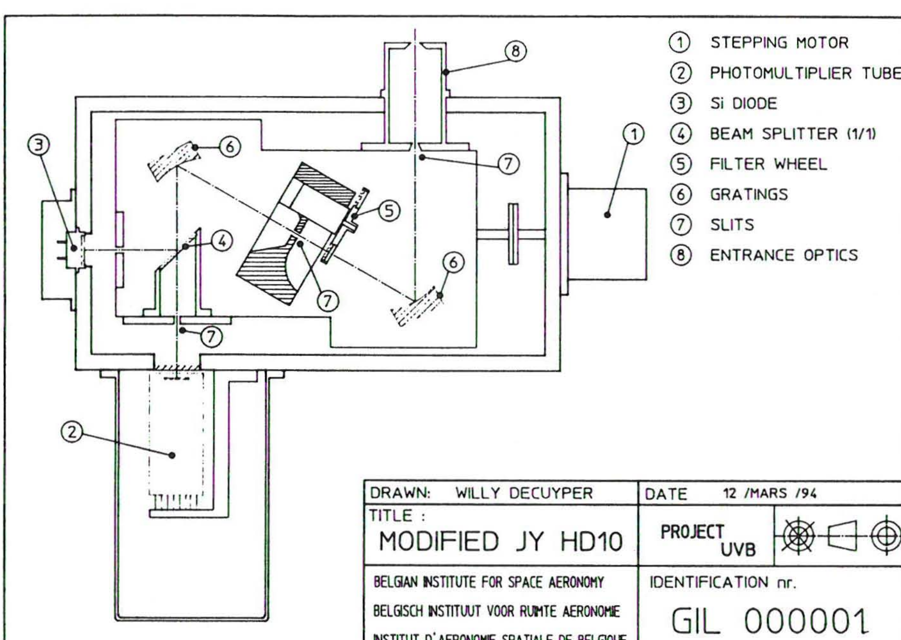


Figure 3 : Optical scheme of the modified double monochromator JY HD10

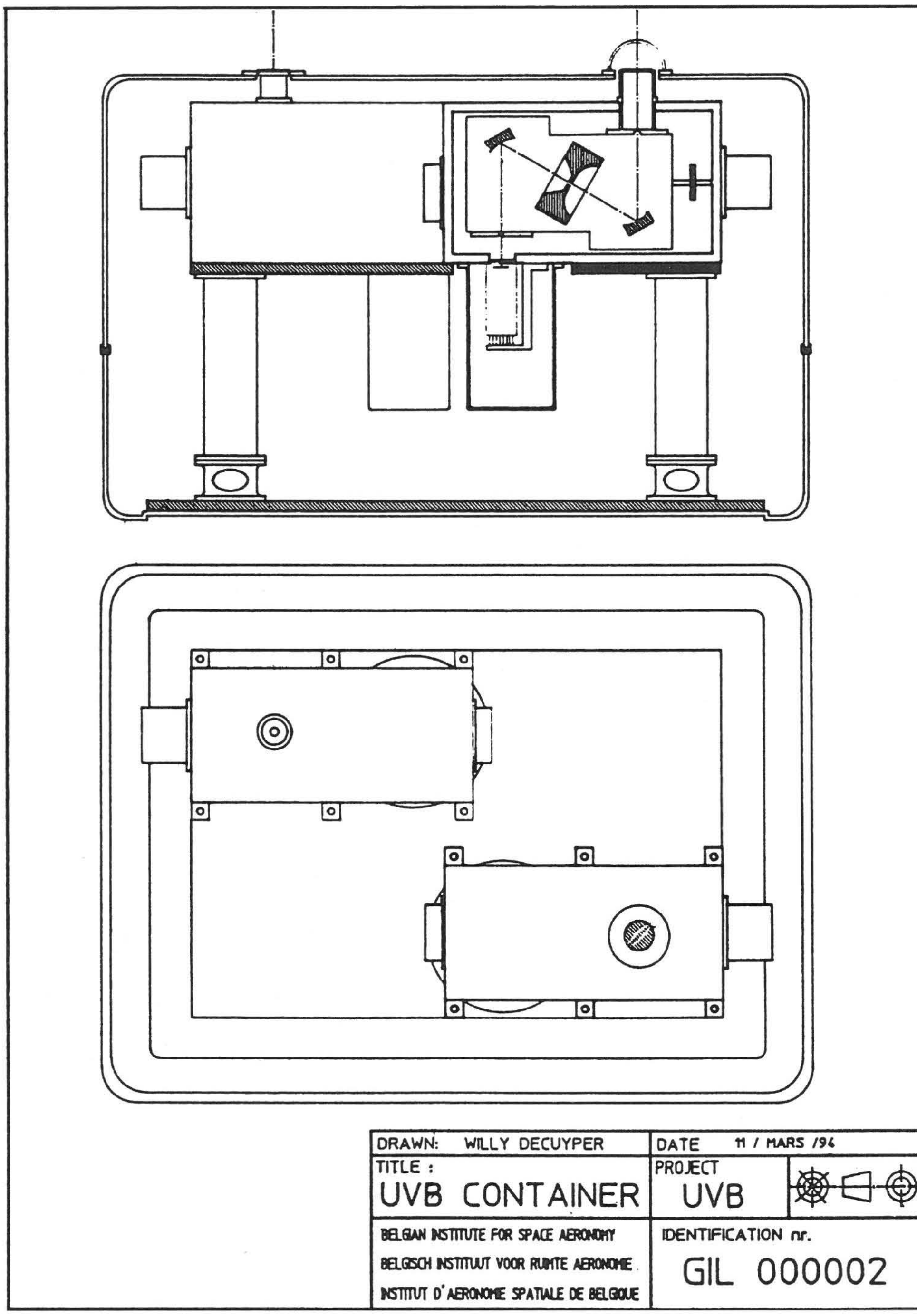
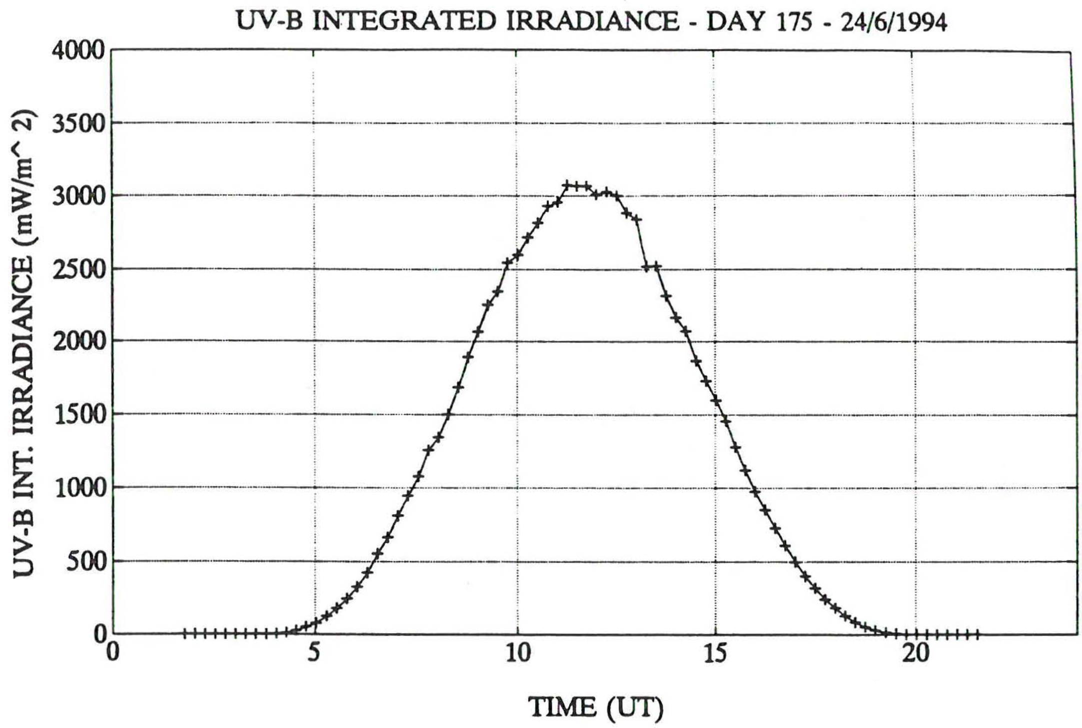


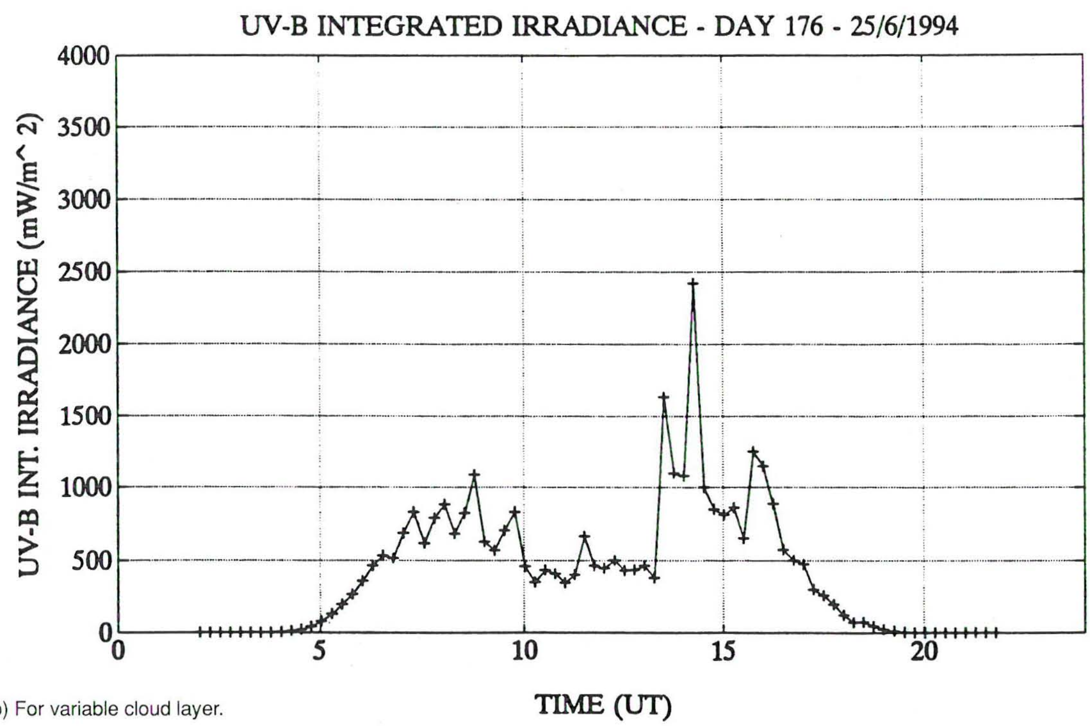
Figure 4 : Scheme of the setting up of the instruments in the UV-B weatherproof container

relative stability of the instruments is verified frequently (every 2-3 weeks) by means of the Transportable Lamp System (TLS) developed in our laboratory, to be used in field measurement configuration of the instruments. It consists in a special unit including a set of five 200 W Quartz-Halogen lamps and a Mercury low pressure source, allowing the selection of the lamps and the perfect reproducibility of their positioning above of the entrance optics of the instruments. The measured instability of this secondary standard is lower ± 2% on all the wavelength range. Consequently, we can estimate that the uncertainties on the data's are lower than ± 5%.

Figure 5 : Diary profile of the integrated UV-B irradiance



(a) In clear sky conditions



(b) For variable cloud layer.

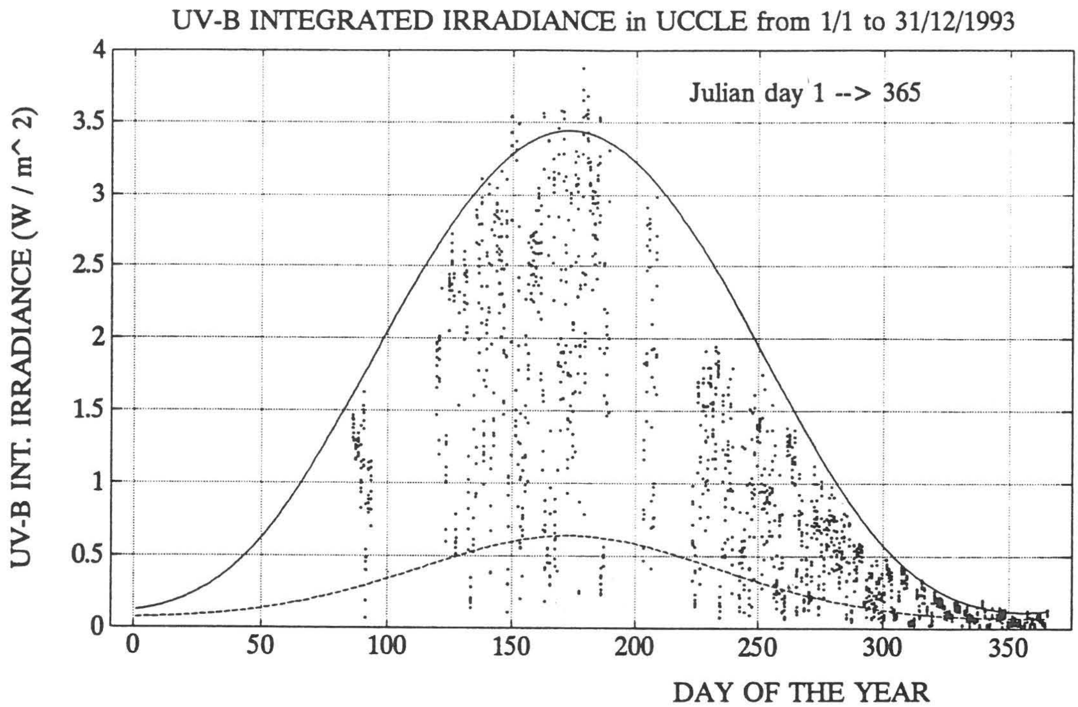


Figure 6 : Seasonal variations of the UV-B integrated irradiances in 1993
For clarity, only the integrated UV-B irradiances measured between 11:00 UT and 13:00 UT are plotted on this figure
(—) : computed values for clear sky conditions at noon; (----) : computed values for 100% cloudy conditions at noon

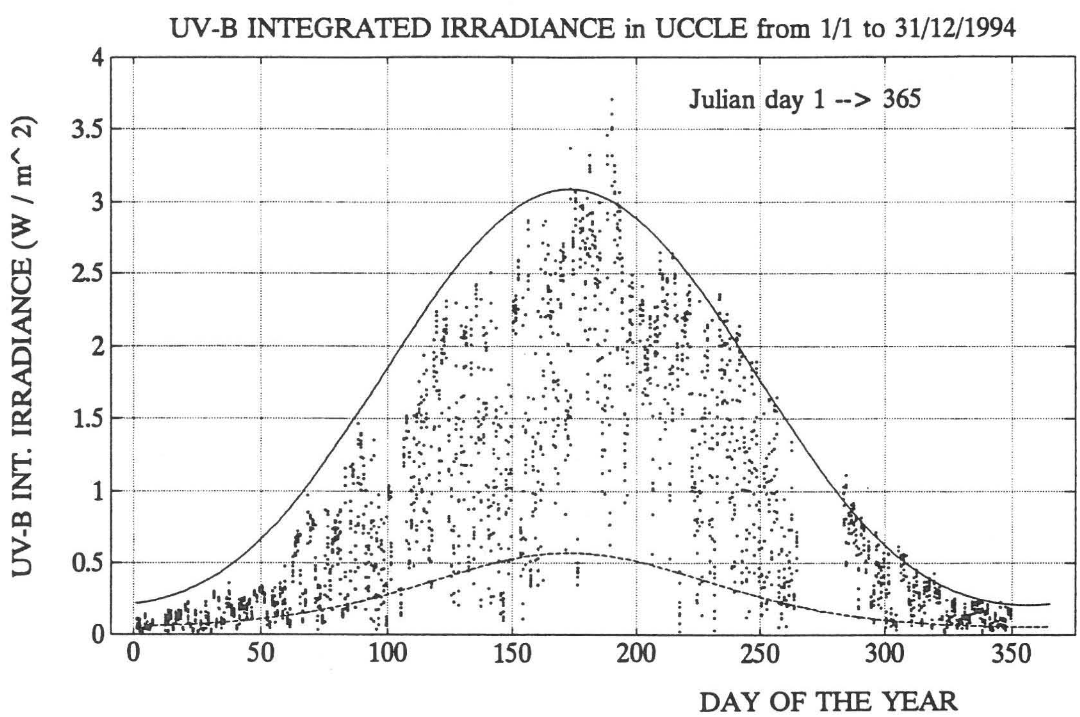


Figure 7 : Seasonal variations of the UV-B integrated irradiances in 1994
For clarity, only the integrated UV-B irradiances measured between 11:00 UT and 13:00 UT are plotted on this figure
(—) : computed values for clear sky conditions at noon; (---) : computed values for 100% cloudy conditions at noon

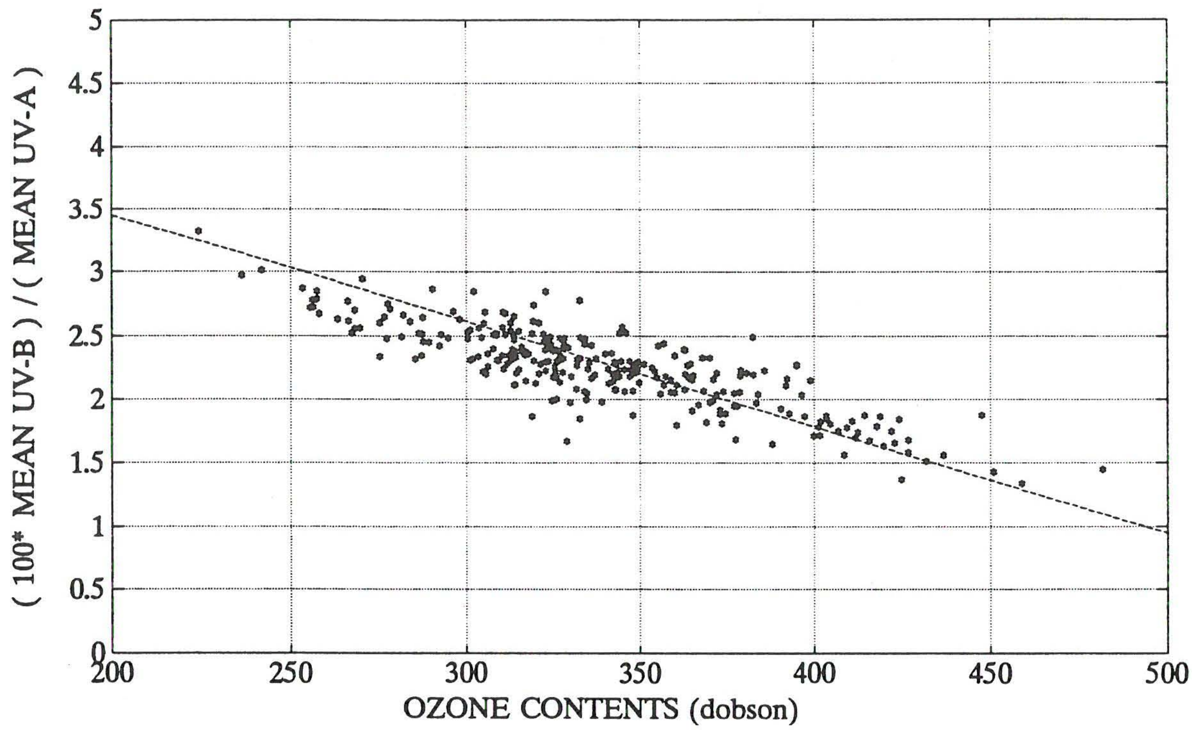


Figure 8 : Anticorrelation between UV-B irradiances corrected for cloud layer (UV-BUV-A) and ozone contents

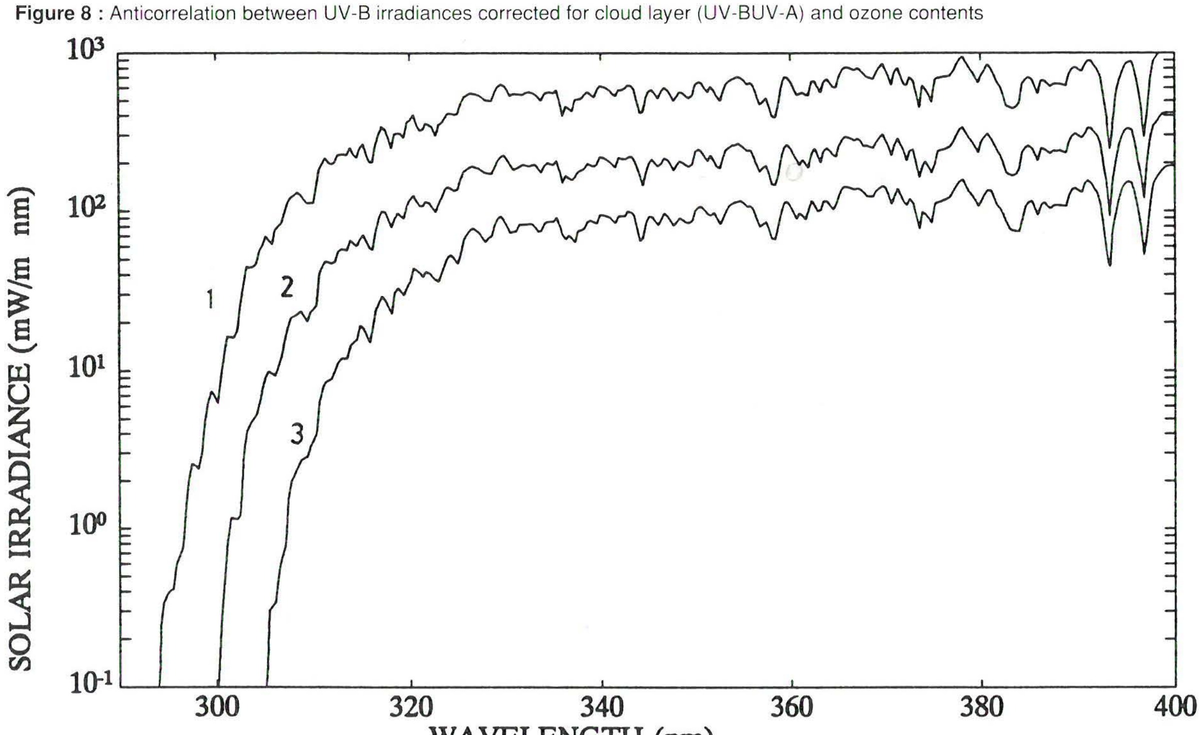


Figure 9 : Influence of the Solar Zenith Angle (SZA) on the atmospheric cutoff wavelength (CWL) for clear sky conditions and mean ozone contents (≈ 300 dobson)
1. 24/06/1994, 11:47 UT; SZA = 27°22'; CWL = 293.9 nm; 2. 27/03/1994, 11:47 UT; SZA = 48°30'; CWL = 298.5 nm; 3. 14/12/1994, 11:47 UT; SZA = 73°49'; CWL = 304.9 nm

Moreover, as member of the European UV-B Monitoring Working Group, our Institute has played an active role in three global intercomparison campaigns of the European UV-B instruments (Thessaloniki (GR) - 1991; Thessaloniki (GR) - 1992; Garmisch-Partenkirchen (G) - 1993) and organised in 1994 a laboratory session to characterise and calibrate all the UV-B instruments with the same procedures. The results of these campaigns confirm the uncertainties of +/-5% quoted before.

3. Preliminary results from the UV-VIS monitoring station

Our UV-Visible solar irradiance monitoring station being fully operational since less than two years, it is, therefore, impossible to present, at this time, any conclusion about trends of the UV-B level at the Earth's surface in the Brussels area. A ten years period of continuous measurements is a minimum requirement to be able to measure trends and to dissociate long term variations from variations caused by punctual phenomena.
Nevertheless, it is possible to make some comments on the data produced during this two years period and to illustrate the influence of some of the main parameters controlling the UV-B penetration in the atmosphere.
For the clarity of this section, we will mainly discuss the integrated values of the UV-B solar irradiances, each scan being integrated over the UV-B (280-320 nm) and the UVB-A (320-400 nm) ranges. The following comments and conclusions can be easily extended and remain valid for individual spectral values.

Figure 5 illustrates a typical profile of the integrated UV-B irradiance during a clear day (a) and during a variable cloudy day (b). The influence of the SZA is clearly illustrated by graphe (a) of Figure 5, where SZA is the only variable parameter during this day. The graphe (b) of figure 5 shows the impact of a variable cloud layer. Figure 5 illustrates also the important variations in the UV-B irradiance at ground level induced by different meteorological conditions.

Figures 6 and 7 show the seasonal variations measured during 1993 and 1994. The solid lines represent the computed values of the integrated UV-B irradiance, at noon time, for clear sky and mean ozone contents. By comparing the two set of values, we observed that the values calculated for 1993 are higher than the corresponding values for 1994. This variation can be attributed to the effect of the irruption of Mt. Pinatubo in June 1991, its effect on the ozone depletion being more important during 1993 than during 1994 especially during the first months of 1993.

The dashed lines on both figures represent the integrated UV-B irradiance calculated for cloudy conditions, with a higher level in 1993 than in 1994.

Measurements situated above the solid lines are the result of an amplification of the solar irradiance due to specific atmospheric conditions.

Assuming that the extinction factor induced by the cloud layer is constant over the all UV range (280-400 nm), it is possible to take into account the different meteorological conditions by computing the ratio UV-B/UV-A.

Figure 8 shows a representation of this ratio (UV-B/UV-A) as a function of the total ozone contents and establish very clearly an anticorrelation between these two variables.

Finally, the impact of the SZA on the atmospheric cutoff wavelength is illustrated in Figure 9, for the noon time of three clear days, with comparable ozone contents, but solar zenith angles ranging from 27° to 73°. The corresponding cutoff wavelengths shift from 294 to 305 nm, which induces an important variation of the photobiological reactions.

Conclusion

As mentioned before, it is presently impossible to give information about trends of the UV-B solar irradiance at the Earth's surface from the monitoring station in Brussels.

Nevertheless, we are able, with our two years measurement data base to illustrate and understand the impact of the most important atmospheric parameters controlling the solar UV penetration in the atmosphere. We are also able to provide, to potential users, reliable spectral and/or integrated experimental data useful for the study of the impact of UV-B radiation on the biosphere and for modelling purposes.

An extended period of continuous measurements, combined with a careful quality control of the data and an international cooperation between the different stations is the only way to detect and quantify trends in the UV-B solar irradiance at the Earth's surface on global and regional scales.

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