SOLAR ULTRAVIOLET RADIATION WITHIN THE MIDDLE ATMOSPHERE

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ABSTRACT

Ultraviolet solar radiation budget of the middle atmosphere depends upon extraterrestrial solar irradiance and its variations, its absorption by atmospheric constituents, its extinction by molecular and aerosol scattering, the scattering by the atmosphere and the reflexion by the Earth's surface. This work briefly reviews and discusses the recent observations of solar ultraviolet irradiance above the Lyman α wavelength during the declining phase of solar cycle 21. Despite major improvements in the quoted uncertainties, important discrepancies (up to 40%) between those observations are still present below 200 nm, the agreement between the two Space Shuttle observations is very good, giving ultraviolet irradiance values with accuracies between 3.5 and 5.2%. Variabilities related to the 27-day rotation period and the 11-year cycle have also been revised on the basis of the most recent analysis of SBUV and SME observations.

1. INTRODUCTION

The solar electromagnetic radiation is the primary source of energy for the terrestrial environment. The largest fraction of energy associated with the solar spectrum is situated in the visible. The ultraviolet domain for wavelengths shorter than 320 nm represents only a small fraction (2 percent) of the total incident flux. This spectral range is of fundamental importance for chemical, dynamical and radiative processes in the middle atmosphere.

Solar Lyman α and ultraviolet radiation of wavelengths larger than 180 nm are absorbed in the mesosphere and in the stratosphere. The Lyman α solar chromospheric line initiates photoionization processes in the D-region and the photodissociation, for instance, of water vapor in the mesosphere, controlling the ozone budget in the mesosphere through the production of hydroxyl radicals.

Ozone, which protects the biosphere from harmful solar ultraviolet radiation, is produced in the upper stratosphere by photodissociation of molecular oxygen by radiation of wavelengths shorter than 242 nm. It is itself photodissociated by solar radiation in the visible range and in the ultraviolet. Absorption of ultraviolet radiation of wavelengths larger than 200 nm by stratospheric ozone is responsible for the stratospheric heating. Below that wavelength, the absorption by molecular oxygen becomes predominant.

Because of the complexity of the atmospheric processes and the strong interplay and feedback between chemical composition and radiative budget, atmospheric and climate studies should include observations of visible and ultraviolet solar radiation and its variability, in close relation with the atmospheric constituents which control the penetration of solar radiation and the transfer of the outgoing thermal radiation. The ozone molecule is a key minor constituent for the stratosphere and the mesosphere. It provides the main heat source through the absorption of solar ultraviolet radiation and thus determines to a great extent the temperature profile in the stratosphere and the general circulation. Ozone therefore couples the stratosphere and the tropospheric climate through complex processes involving radiative, chemical and dynamic effects. The study of solar variability with respect to anthropogenic perturbations is of crucial importance to distinguish the impact of the various perturbations affecting the terrestrial environment in the future.

The purpose of this work is to provide a critical analysis of the recent observations of solar ultraviolet irradiance above Lyman α performed during the declining phase of solar cycle 21. A more detailed analysis of the solar variabilities is published elsewhere (Simon, 1988). The reader has to refer to previous works for solar ultraviolet solar irradiances observations performed during solar cycle 20 and the ascending phase of the solar cycle 21 (e.g. Simon, 1981; Simon and Brasseur, 1983, Lean, 1987).

2. THE LYMAN α EMISSION LINE

Since the Atmospheric Explorer E (AE-E) time series obtained during the rising phase of solar cycle 21 for which important controversy has been reported (e.g. Bossy, 1983), the only continuous observations of this solar emission line have been performed by the Solar Mesosphere Explorer (SME) launched in October 1981. The latter measurements ranging from 115 to 300 nm have been normalized on the observation obtained with a rocket flight made on May 17, 1982 (Mount and Rottman, 1983) and calibrated against the Synchroton Users Radiation Facility (SURF) at NBS. The SME results give a maximum value of the order of 4×10^{11} photons.$s^{-1}.cm^{-2}$ at the beginning of 1982 and minimum values around 2.5×10^{11} photons.s^{-1} cm^{-2} in 1986 (Rottman, 1988).

Besides the SME observations, several snapshot measurements including rockets and one space shuttle flight have been performed up to 1985. They are summarized in Table 1. The Solar

Ultraviolet Spectral Irradiance Monitor (SUSIM) observation (VanHoosier and Brueckner, 1987) performed during the Spacelab 2 mission in August 1985, during the minimum of solar activity between solar cycle 21 and 22, gives a value of 3.8×10^{11} photons.s^{-1}.cm^{-2} in contradiction with the SME minimum values obtained at the same time. This important discrepancy cannot be explained in terms of differences in radiometric scales because both experiment calibrations are traceable to the SURF.

Nevertheless the consistency of the SME time series favors its minimum value and a solar cycle variation less than a factor of 2 at Lyman α. This conclusion is supported by other studies, namely the Pioneer Venus Orbiter, suggesting close figures for both the minimum value and the solar cycle variation (Ajello et al., 1987).

3. THE 150-200 NM WAVELENGTH RANGE

The addition to the rocket and the space shuttle observations already mentioned for the Lyman α measurements, several rocket flights have been performed by the Goddard Space Flight Center (GSFC, NASA). The results published by Mentall et al. (1985) and Mentall and Williams (1988). All measurements obtained during the solar cycle 21 are listed in Table 2. Only two observations, namely those made in June 1979 and in July 1980, have not been referred to the NBS SURF radiametric scale.

The four rocket observations performed between October 1981 and December 1984 by LASP (Mount and Rottman, 1983; 1985) and GSFC (Mentall and Williams, 1988) are in relatively good agreement. Indeed, their standard deviation is always lower than 10% over their common wavelength range (150-200 nm), except around 185 nm where it reaches 12%. A mean irradiance spectrum has been calculated and can be considered as representative of the most recent rocket measurements. It is compared with the SUSIM results integrated over 1 nm bandpass in Figure 1. The differences between the two spectra are between 30 and 40% in the 150-185 nm spectral range. They significantly decrease toward longer wavelengths. The SUSIM values are actually closer to the rocket observations performed in November 1978 and May 1980 (see table 2). The highest values obtained in June 1979 and July 1980 were never confirmed even for comparable activity level. In addition, the solar cycle variation deduced from SME at the same wavelengths does not exceed 15 percent (Rottman, 1989). Consequently, the discrepancies cannot be explained neither in terms of solar activity nor by the experimental errors quoted for each observation.

Consequently, the absolute value of solar irradiance between 150 and 200 nm remains controversial and needs further dedicated observations in order to define accurate values of solar irradiance corresponding to moderate or low activity conditions.

4. THE 200-350 NM WAVELENGTH RANGE

This spectral range has been extensively discussed by Labs et al. (1987) when reporting the new data obtained during the Spacelab 1 mission in December 1983 with an accuracy varying from 5.2 % at 200 nm to 4% at 300 nm. Since that time, the observation performed by SUSIM during the Spacelab 2 mission in August 1985 (VanHoosier and Brueckner, 1987) confirmed the previous values published by Labs et al. (1987) and are partially reported in Figure 2. Its quoted accuracy, as already mentioned, is 3.5% over the entire spectral range.

The recent rocket observation reported by Mentall and Williams (1988) significantly differs from the previous data obtained in 1979 (Mentall et al., 1981) despite the fact that identical spectrometers and similar calibration procedures traceable to the NBS radiometric scale have been used for both sets of measurements. The latest results are in good agreement with the Spacelab 1 values beyond 260 nm as illustrated in Figure 3.

5. SOLAR ULTRAVIOLET VARIATIONS

The ultraviolet range of the solar electromagnetic spectrum is characterized by its temporal variations which directly affect the atmosphere. Two time scales are generally considered in relation with atmospheric studies : the 11-year activity cycle and the 27-day rotation period of the Sun. Despite of considerable effort during the last solar cycle, the amplitude of solar variation associated with its 11-year activity cycle is still uncertain. The Solar Backscatter Ultraviolet (SBUV) spectrometer data were analysed by Heath and Schlesinger (1986) ; they deduced a long-term variability from an empirical relation based on temporal variations of ratios between core and wings irradiance of the Mg II lines at 280 nm. Their variations are not fully confirmed by the SME results obtained since 1982 which lead to lower values in the overlapping wavelength range (175-300 nm). On the other hand, a solar cycle variation of a factor of 2 at Lyman α and around 150 nm was proposed on the basis of the comparison deduced from the rocket observations made during the maximum of solar activity, namely in June 1979 and July 1980 (Mount et al., 1980; Mount and Rottman, 1983) and those performed at solar minimum (Rottman, 1981). These values are now totally contradicted by recent analysis of SME data, leading to variations of the order of 15 percent around 150 nm and of 5 percent between 190 and 210 nm.

The 27-day solar rotation modulation has been well documented with the SBUV satellite and the SME data base. This short-term variation has been more extensively studied because it is much less affected by sensitivity drifts observed for the SBUV spectrometer. If the agreement between the two satellites during the overlapping period of time is very good for the major rotation modulation on August 1982, the average during the declining phase of the solar cycle shows some appreciable differences beyond 240 nm where SBUV data are less noisy than those of SME and below 190 nm where SME data give 27-day variations higher than SBUV, especially at the Si II lines lying in the 180-182 nm interval. Figures 4 and 5 present a FFT analysis of the 27-day variations on both time series between 160 and 300 nm.

6. CONCLUSIONS

In spite of major improvements in calibration procedures, important discrepancies persist between recent solar ultraviolet irradiance measurements, mainly below 200 nm. This fact could be due to experimental difficulties encountered in that spectral range. Some basic irradiance figures like the minimum value of Lyman α need to be confirmed by new measurements during the current cycle.

If the 27-day modulation is well documented with the SME and the SBUV observations performed during the solar cyle 21, the long-term variations associated with the solar activity cycle need further studies. The preliminary SME values of 15% around 150-160 nm and of 5% at 205 nm urge new observations having a precision of 1% over a half cycle in order to provide accurate figures in relation with the ozone perturbations in the stratosphere and their climate impact. The strong variations in the 27-day modulations during the last solar cycle also emphazised the need of continuous monitoring of short-term variabilities for which their amplitudes could be as high as the solar cycle variation.

REFERENCES

Ajello J.M., A.I. Stewart, G.E. Thomas and A. Graps, 1987 : Solar cycle study of interplanetary Lyman α variations : Pioneer Venus orbiter sky background results. Ap. J., 317, 964-986.

Bossy, L., 1983 : Solar indices and solar UV irradiances. Planet. Space Sci., 29, 907-914.

Heath, D.F. and B.M. Schlesinger, 1986 : The Mg 280 nm doublet as a monitor of changes in solar ultraviolet irradiances. J. Geophys. Res., 91, 8672-8682.

Labs, D., H. Neckel, P.C. Simon and G. Thuillier, 1987 : Ultraviolet solar irradiance measurement from 200 to 388 nm during spacelab 1 mission. Solar Phys., 107, 203-219.

Lean, J., 1987 : Solar ultraviolet irradiance variations : a review. J. Geophys. Res., 92, 839-868.

Mentall, J.E. and D.E. Williams, 1988 : Solar ultraviolet irradiances on December 7, 1983 and December 1984. J. Geophys. Res., 93, 735-746.

Mentall, J.E., J.E. Frederick and J.R. Herman, 1981 : The solar irradiance from 200 to 300 nm. J. Geophys. Res., 86, 9881-9884.

Mentall, J.E., B. Guenther and D. Williams, 1985 : The solar spectral irradiance between 150 and 200 nm. J. Geophys. Res., 90, 2265-2271.

Mount, G.H. and G.J. Rottman, 1981 : The solar spectral irradiance 1200-3140 A near solar maximum : July 15, 1980. J. Geophys. Res., 86, 9193-9198.

Mount, G.H. and G.J. Rottman, 1983 : The solar absolute spectral irradiance 1150-3173 A : May 17, 1982. J. Geophys. Res., 88, 5403-5410.

Mount, G.H. and G.J. Rottman, 1985 : Solar absolute irradiance 118-300 nm : July 25, 1983. J. Geophys. Res., 90, 13031-13036.

Mount, G.H., G.J. Rottman, and J.G. Timothy, 1980 : The solar spectral irradiance 1200-2550 A at solar maximum. J. Geophys. Res., 85, 4271-4274.

Rottman, G.J., 1981 : Rocket measurements of the solar spectral irradiance during solar minimum. J. Geophys. Res., 86, 6697-6705.

Rottman, G.J., 1989 : Observations of solar UV and EUV variability. Adv. Space Res., to be published.

Simon, P.C., 1989 : Solar spectral irradiance for middle atmosphere studies. Adv. Space Res., to be published.

Simon, P.C., 1981 : Solar irradiance between 120 and 400 nm and its variations. Solar Phys., 74, 273-291

Simon, P.C. and G. Brasseur, 1983 : Photodissociation effects of solar UV radiation. Planet. Space Sci., 31, 987-999.

Vanhoosier, M.E. and G.E. Brueckner, 1987 : Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) : Calibration and Results from Spacelab 2, in Proceedings of the 8th Workshop on the Vacuum Ultraviolet Radiometric Calibration of Space Experiments, Boulder, March 18-19, 1987.

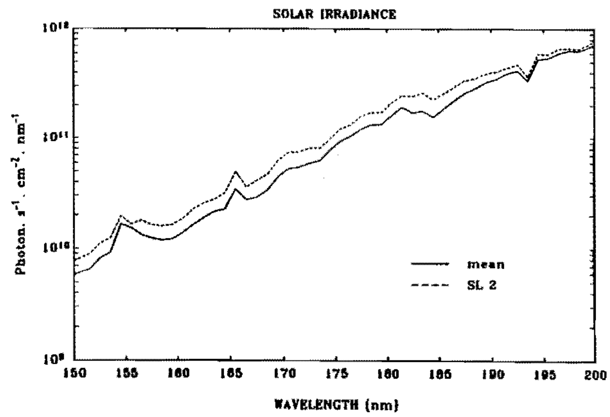

Figure 1. Comparison of solar ultraviolet irradiance integrated over 1 nm between 150 and 200 nm. The solid curve represents the average between 4 rocket observations (Mount and Rottman, 1983; 1985; Mentall and Williams, 1988) performed between May 1982 and December 1984. The dashed curve represents the SUSIM data reported by VanHoosier and Brueckner (1987) from the Spacelab 2 mission in August 1985.

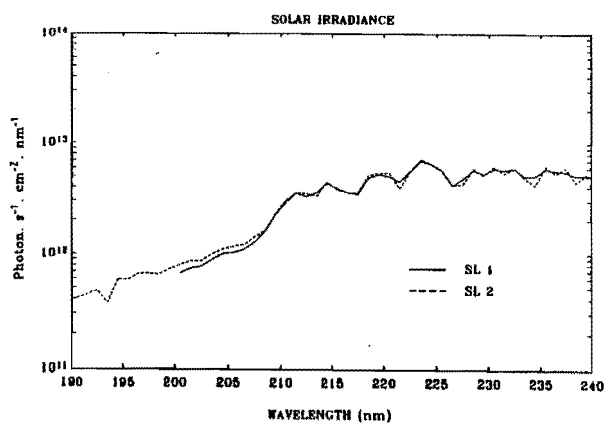

Figure 2. Comparison of the solar ultraviolet irradiances between 190 and 240 nm. The solid curve (SL 1) represents the data published by Labs et al. (1987) and the dashed curve (SL 2) the data reported by VanHoosier and Brueckner (1987) integrated over 1 nm intervals.

TABLE 1. Snapshot observations of the solar H I Lyman α emission line

Date	Irradiance (10 h s cm)	Ratio flux (10.7cm) at 1 AU 10 W.m . Hz	Accuracy
Dec. 13, 1972 x	3.08	111	± 23%
Aug. 30, 1973 x	2.02	101	± 20%
Nov. 02, 1973 •	3.14	84	± 30%
Apr. 23, 1974 •	2.51	74	± 30%
Jul. 28, 1975 x	2.20	76	± 20%
Feb. 18, 1976 x	3.70	70	± 20%
Mar. 09, 1977 x	4.28	80	± 20%
Jun. 05, 1979 +	4.98	230	± 12%
Jul. 15, 1980 +	5.50	218	± 8%
May 17, 1982 +	3.24	142	± 8%
Jan. 12, 1983 +	3.01	135	± 25%
Jul. 25, 1983 +	2.69	137	± 8%
Aug. 03, 1985 *	3.79	79	± 3.5%

References :

• Heroux and Higgins (1977)

x Rottman (1981) Rockets

+ Mount and Rottman (1985)

* VanHoosier and Brueckner (1987), SUSIM, Spacelab 2

TABLE 2.- Integrated solar irradiance values between 150 and 180 nm. Alle measurements have been obtained from rocket flights except the last in August 1985 made during the Spacelab 2 mission.

Date	Radio flux at 1 AU (10.7 cm)	Irradiance 150-160 nm 10^{11}hV.s^{-1}.cm^{-2}	Accuracy percent	Reference	Wavelength range of instrument
Nov. 16, 1978	129	1.30	± 8	Mentall et al. (1985)	150-185
Jun. 05, 1979	230	2.17	± 12	Mount et al. (1980)	120-255
May 22, 1980	277	1.40	± 13	Mentall et al. (1985)	150-185
Jul. 15, 1980	218	2.27	± 13	Mount and Rottman (1983)	120-318
Oct. 16, 1981	303	1.04	± 5	Mentall et al. (1985)	150-200
May 17, 1982	142	1.14	± 8	Mount and Rottman (1983)	115-317
Jul. 25, 1983	137	1.09	± 8	Mount and Rottman (1985)	115-317
Dec. 07, 1983	99	1.13	± 8	Mentall and Williams (1988)	150-260
Dec. 10, 1984	76	1.06	± 3	Mentall and williams (1988)	150-342
Aug. 03, 1985	79	1.45	± 3.5	VanHoosier and Brueckner (1987)	120-400

+ unit : 10^{22} W.m^{-2}.Hz^{-1}.

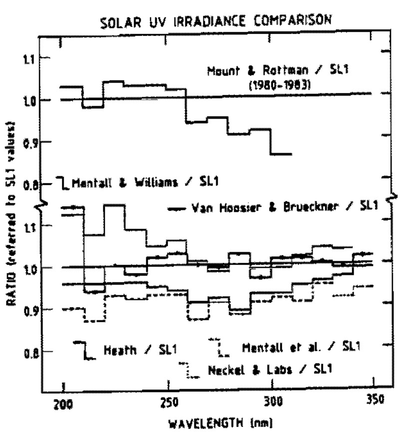

Fig. 3.

Comparison of 10 nm spectral averages of solar irradiances measurements between 200 and 350 nm with the Spacelab 1 results (SL 1).

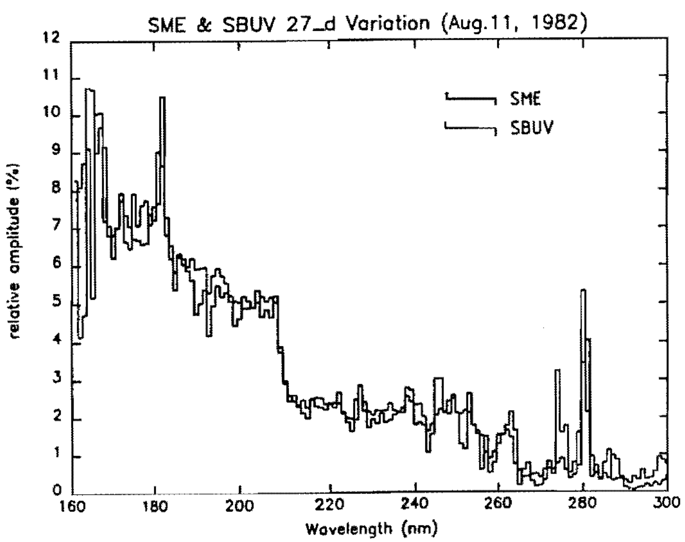

Figure 4. Comparison of 27-day variation deduced from SME and SBUV observations as a function of wavelength, for a major variation on August 11, 1982.

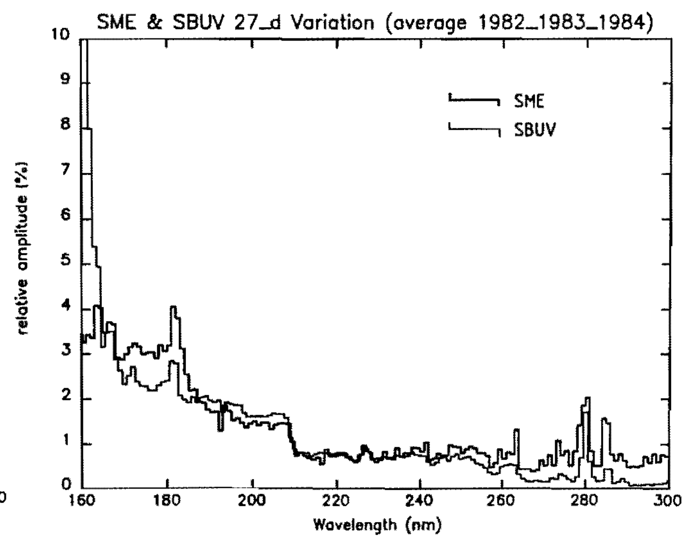

Figure 5. Comparison of 27-day variation averaged over 1982, 1983 and 1984, deduced from SME and SBUV observations, as a function of wavelength.