Planet. Space Sci., Vol. 30, No. 1, pp. 67–71, 1982
Printed in Great Britain.

0032–0633/82/010067–05$03.00/0
Pergamon Press Ltd.

BALLOON OBSERVATIONS OF SOLAR ULTRAVIOLET IRRADIANCE AT SOLAR MINIMUM

PAUL C. SIMON, ROGER PASTIELS and DENNIS NEVEJANS
Institut d'Aéronomie Spatiale de Belgique, 3, Avenue Circulaire, B-1180 Bruxelles, Belgique

(*Received* 21 *July* 1981)

Abstract—Balloon observations of solar irradiance between 200 and 240 nm have been performed in 1976 and 1977 corresponding to minimum conditions of solar activity. Ultraviolet spectra have been recorded for different zenith angles at an altitude of 41 km by means of a spectrometer with a spectral bandpass of 0.4 nm. Solar irradiances at 1 a.u. confirm previous values obtained by balloon. They are compared with other measurements and discussed in term of possible long-term variability.

INTRODUCTION

The photochemical processes, the temperature and the dynamics in the stratosphere are directly driven by the absorption of solar u.v. irradiance with a wavelength greater than 180 nm. The interval 200–240 nm which corresponds to the Herzberg continuum of molecular oxygen, is particularly important for the ozone budget in the stratosphere. Photodissociation of the molecular oxygens produces oxygen atoms which are the primary source of ozone. Other trace species like halocarbons, N_2O and HNO_3 are also photodissociated in this wavelength interval. Hence, an accurate knowledge of solar irradiance from 200 to 240 nm is required for photochemical calculations. In addition, its possible long-term variability with the solar activity cycle has to be investigated in order to distinguish any natural variability of ozone in the upper stratosphere from any other phenomena.

The solar spectrum in the 200–240 nm wavelength interval is characterized by Fraunhofer absorption lines and by the large discontinuity near 210 nm corresponding to the Al I absorption edge. Irradiance values measured in this spectral range have been previously discussed by Simon (1978) and the data reported by Simon (1974a) have been generally adopted up to 230 nm for modelling purposes while those of Broadfoot (1972) were used beyond this wavelength. Recent measurements of Mount *et al.* (1980) and Heath (1980) give systematically lower values than those of Broadfoot (1972). Also, the data of Heath (1980) are between 3 and 12% lower than those of Simon (1974a) and 25% higher than those of Mount *et al.* (1980). Consequently new measurements are needed in order to obtain more accurate values of solar irradiance between 200 and 240 nm. The question of variability in this wavelength range is not fully resolved. According to recent observations made from Nimbus 7 (Heath, 1980) variations with solar rotation are between 2 and 4% but long-term variations would be still masked by the accuracy and the precision in available observations.

The purpose of this work is to report reliable ballon observations of solar irradiance between 200 and 240 nm performed in 1976 and 1977 for minimum and low solar activity conditions. The new results will be compared with earlier measurements and will be discussed in terms of possible long-term variations for which only an upper limit is estimated.

OBSERVATIONS

The observations of the u.v. solar spectrum have been performed by means of an Ebert–Fastie spectrometer of 25 cm focal length. This instrument has been flown in 1972 and 1973 and is extensively described in a previous paper (Simon, 1974b). The only difference is that the spectral bandpass has been set at 0.4 nm instead of 0.6 nm.

The absolute calibration of the spectrometer has been performed before and after each flight. Several deuterium lamps referenced to the National Bureau of Standards spectral irradiance scale have been used for wavelengths below 300 nm. An average of calibration results has been taken. The reproducibility of calibration is within ±4% over the entire wavelength range. As the absolute value is known with an uncertainty of ±6% the final calibration is given with an accuracy of ±10% and a precision of ±4%. The spectrometer has been integrated in a stabilized gondola, pointing to the sum with an accuracy of the order of 10 arc min. Both flights were performed from the "Centre Nationale d'Etudes Spatiales" launching site situated in Gap (44°33′N, 6°05′E). The first flight took place on 1 July 1976, the second on 7 July 1977. The gondola, which had a weight of about 300 kg, was carried by Zodiac ballons of 350,000 m^3 and reached a floating altitude of about 41 km. The observation conditions are summarized in Table 1.

DATA REDUCTION

In situ measurements of solar irradiance between 200 and 240 nm performed at a ceiling altitude of 41 km by means of balloon-borne spectrometer must be corrected for the residual absorption by molecular oxygen and ozone in order to obtain the corresponding extraterrestrial irradiance values. As observations are made for different solar zenith angles, measured solar fluxes can be easily extrapolated to zero air mass. This can be done only if the floating altitude of the balloon is held rigorously constant during the observing period in order to keep, for all recorded spectra, the same column content for molecular oxygen and ozone above the gondola. A second method consists for correcting the observed spectra by taking into account the residual atmospheric absorption. Molecular oxygen content can be deduced from pressure measurement and ozone content can be determined from absorbed solar spectra recorded between 270 and 285 nm by the same solar spectrometer. Small changes within 8% in ozone content at the ceiling altitude have been measured with a precision better than 1%. These changes correspond to altitude variations less than 340 m at 41 km. Consequently, if the small altitude variations of the gondola are neglected, extrapolation to zero air mass introduced large errors in the extraterrestrial irradiance values when the ozone optical depth is greater than 2.

The data obtained in 1973 and published by Simon (1974a) have been reanalysed using the second method. The new values are in good agreement, within ±5%, with the previous values except for wavelengths beyond 225 nm due to higher ozone optical depth. They have been extended up to 235 nm and are given in Table 2 for comparison purposes.

The measurements performed in 1976 and 1977 have also been corrected for the residual absorption: final irradiance values correspond to an average over 20 corrected spectra. A S.D. of the order of 1–2% has been obtained between 210 and 230 nm. From 230 to 240 nm, it increases up to 5% because of higher optical depth. Discussion on ozone measurements will be given elsewhere (Simon and Peetermans, 1981). The final accuracy on irradiance values from 200 to 240 nm is ±15%.

RESULTS AND DISCUSSION

Irradiance values deduced from the two balloon flights are given in Table 2 for different spectral intervals. Results from the 1976 flight are also reported in Fig. 1 with the other published

TABLE 1. CONDITIONS OF OBSERVATION

Date	Altitude (km)	Sec χ	O_2 (cm^{-2})	O_3 (cm^{-2})
1 July 1976	41.6	1.35–2.04	1.22×10^{22}	2.3×10^{17}
7 July 1977	41.5	1.62–1.91	1.22×10^{22}	2.4×10^{17}

TABLE 2a. SOLAR IRRADIANCE ($h\nu\ cm^{-2}\ s^{-1}$) OBTAINED BY BALLOON INTEGRATED OVER 5 nm INTERVALS

Wavelength interval (nm)	1972/1973	1976	1977
200–205	4.11×10^{12}	4.75×10^{12}	4.93×10^{12}
205–210	7.34×10^{12}	7.80×10^{12}	8.00×10^{12}
210–215	17.7×10^{12}	18.5×10^{12}	18.3×10^{12}
215–220	21.6×10^{12}	22.4×10^{12}	22.3×10^{12}
220–225	30.5×10^{12}	30.9×10^{12}	30.4×10^{12}
225–230	$27.1^{*}\times10^{12}$	27.1×10^{12}	27.2×10^{12}
230–235	$29.4^{*}\times10^{12}$	27.9×10^{12}	28.3×10^{12}
235–240		26.3×10^{12}	27.7×10^{12}

*Revised values.

TABLE 2b. SOLAR IRRADIANCE ($h\nu\, cm^{-2}\, s^{-1}$) INTEGRATED OVER INTERVALS OF $500\, cm^{-1}$

Wavelength interval (nm)	Wavenumber interval (cm^{-1})	1976	1977
200.0–202.0	50,000–49,500	1.68×10^{12}	1.79×10^{12}
202.0–204.1	49,500–49,000	2.06×10^{12}	2.12×10^{12}
204.0–206.2	49,000–48,500	2.38×10^{12}	2.43×10^{12}
206.2–208.3	48,500–48,000	2.74×10^{12}	2.84×10^{12}
208.3–210.5	48,000–47,500	5.20×10^{12}	5.30×10^{12}
210.5–212.8	47,500–47,000	8.05×10^{12}	7.95×10^{12}
212.8–215.0	47,000–46,500	8.98×10^{12}	8.82×10^{12}
215.0–217.4	46,500–46,000	9.26×10^{12}	9.27×10^{12}
217.4–219.8	46,000–45,500	1.21×10^{13}	1.19×10^{13}
219.8–222.2	45,500–45,000	1.21×10^{13}	1.20×10^{13}
222.2–224.7	45,000–44,500	1.76×10^{13}	1.74×10^{13}
224.7–227.3	44,500–44,000	1.42×10^{13}	1.41×10^{13}
227.3–229.9	44,000–43,500	1.46×10^{13}	1.47×10^{13}
229.9–232.6	43,500–43,000	1.65×10^{13}	1.67×10^{13}
232.6–235.3	43,000–42,500	1.37×10^{13}	1.40×10^{13}
235.3–238.1	42,500–42,000	1.58×10^{13}	1.66×10^{13}
238.1–241.0	42,000–41,500	1.30×10^{13}	1.38×10^{13}

measurements. The agreement between the two balloon measurements is within 6%. Figure 2 presents the ratios of irradiance values integrated over 5 nm from 200 to 240 nm taking as a reference the data obtained on 1 July 1976. The 5 nm interval has been chosen in order to reduce as much as possible the effect of the different spectrometer resolutions on irradiance values. The agreement with the previous balloon observations (Simon, 1974a) is within ± 5% between 210 and 240 nm but the new irradiance values are 13% higher around 200 nm. Heath (1980) proposed lower data obtained from the Nimbus 7 satellite but they become in close agreement with the 1976 values around 235 nm. Measurements of Mount *et al.* (1980) are systematically lower by 30% than those presented in this work, while those of Broadfoot (1972) are 20—30% higher. The disagreement with

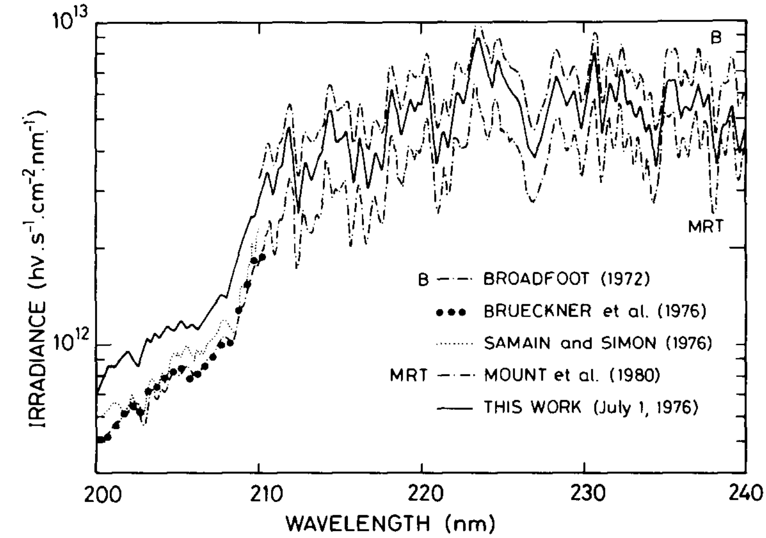

FIG. 1. OBSERVED SOLAR SPECTRAL IRRADIANCE BETWEEN 200 AND 240 nm.
Data of Samain and Simon (1976) and Mount *et al.* (1980) have been averaged over 0.4 nm for comparison purposes. Data of Health (1980) are not represented here because they were obtained with a bandpass of 1 nm.

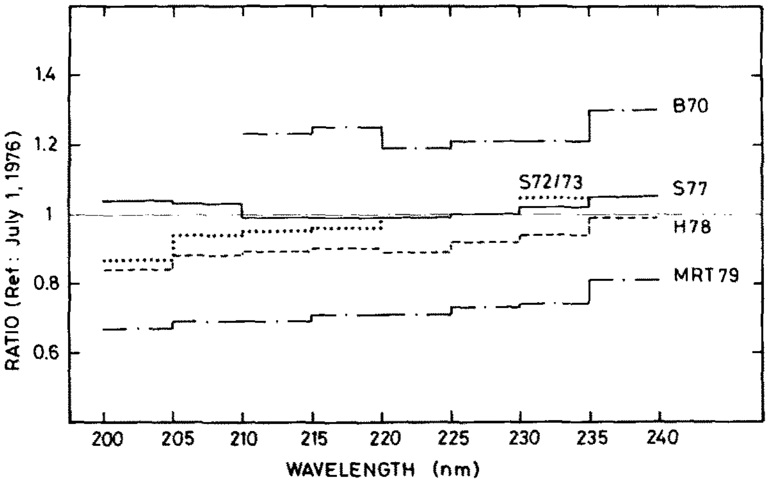

FIG. 2. RATIO OF SOLAR IRRADIANCE MEASUREMENTS INTEGRATED OVER 5 nm INTERVALS FROM 200 TO 240 nm IN COMPARISON WITH THE DATA OBTAINED ON 1 JULY 1976.
The labeling is as follows: B70-Broadfoot (1972), S72/73-Simon (1974a), H78-Heath (1980), MRT 79-Mount *et al.* (1980), S77-this work, 7 July 1977.

published values for wavelengths below 210 nm [for instance with data of Samain and Simon (1976) and Brueckner *et al.* (1976)] is important.

It is difficult to deduce quantitatively any long-term variability of solar irradiance around 210 nm from these observations. The measurements performed by balloon in 1972, 1973, 1976 and 1977 are in close agreement between 210 and 235 nm and correspond to low and minimum activity conditions of the Sun. Unfortunately, the large discrepancies between measurements of Broadfoot (1972) and Mount *et al.* (1980) both obtained for maximum conditions of solar activity respectively for solar cycles 20 and 21 do not solve the question of the possible variability with the solar cycle in this wavelength range. On the other hand, data obtained by Heath (1980) in November 1978 for intermediate activity level are only 10% lower around 210 nm than those obtained at minimum conditions in 1976, i.e. within their quoted accuracies (10–15%). Consequently, the systematic divergences in available observations are probably due to experimental errors. The lack of calibration inter-comparison between the different instruments used for the various observations makes impossible any quantitative determination of long-term variability from 1970 to 1979 which is still masked by the accuracy of each measurement. Only an upper limit of 20% can be tentatively proposed in the 210–240 nm wavelength interval but such variability could also be negligible.

In conclusion, values proposed by Simon (1974a) are confirmed between 210 and 240 nm by the new balloon observations and by the satellite measurements presented by Heath (1980) withinn their quote accuracies. It appears clearly that values of Broadfoot (1972) generally adopted beyond 230 nm for photodissociation rate calculations are too high and should be reduced on the basis of the new measurements. Values of Mount *et al.* (1980) need to be confirmed because they are systematically lower than other available measurements. Further observations with a precision better than 5% are badly needed in order to determine the possible long-term variability beyond 210 nm.

REFERENCES

Broadfoot, A. L. (1972). The solar spectrum 2100–3200 Å. *Astrophys. J.* **173**, 681.

Brueckner, G. E., Bartoe, J. D. F., Kjeldseth Moe, O. and van Hoosier, M. E. (1976). Absolute solar ultraviolet intensities and their variations with solar activity. Part I: the wavelength region 1750–2100 Å. *Astrophys. J.* **209**, 935.

Heath, D. F. (1980). Spatial and temporal variability of ozone as seen from speca, in *Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone* (Ed. A. C. Aikin), p. 45.

Mount, G. H., Rottman, G. J. and Thimothy, J. G. (1980). The solar spectral irradiance 1200–2550 Å at solar maximum. *J. geophys. Res.* **85**, 4271.

Samain, D. and Simon, P. C. (1976). Solar flux determination in the spectral range 150–210 nm. *Solar Phys.* **49**, 33.

Simon, P. C. (1974a). Balloon measurements of solar fluxes between 1960 and 2300 Å, in *Proceedings of the Third Conf. on the Climatic Impact Assessment Program* (Eds. Broderick and Hard), p. 137.
Simon, P. C. (1974b). Observation de l'absorption du rayonnement ultra-violet solaire par ballons stratosphériques. *Bull. Acad. Belg. Cl. Sci.* **60**, 617.
Simon, P. C. (1978). Irradiation solar flux measurements between 120 and 400 nm. Current position and future needs. *Planet. Space Sci.* **26**, 355.
Simon, P. C. and Peetermans, W. (1981). Ozone trend in the upper stratosphere: results from solar U.V. absorption measurements from 1976 to 1980, 3rd Scientific Assembly of IAMAP, Hamburg.