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Balloon observations of solar ultraviolet irradiance at solar minimum

by

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FOREWORD

The paper "Balloon observations of solar irradiance at solar minimum" is accepted for publication in Planetary and Space Science, 29, 1981.

AVANT-PROPOS

L'article "Balloon observations of solar irradiance at solar minimum" sera publié dans Planetary and Space Science, 29, 1981.

VOORWOORD

Het artikel "Balloon observations of solar irradiance at solar minimum" zal verschijnen in Planetary and Space Science, 29, 1981.

VORWORT

Die Arbeit "Balloon observations of solar irradiance at solar minimum" wird in Planetary and Space Science, 29, 1981 herausgegeben werden.

BALLOON OBSERVATIONS OF SOLAR ULTRAVIOLET IRRADIANCE AT SOLAR MINIMUM

by

Paul C. SIMON, Roger PASTIELS and Dennis NEVEJANS

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.

Résumé

Des observations du flux solaire entre 200 et 240 nm ont été réaliseés à partir de ballons stratosphériques en 1976 et 1977 qui correspondent à des périodes d'activité solaire minimum. Les spectres ultraviolets ont été obtenus pour différents angles zénithaux à une altitude de 41 km au moyen d'un spectromètre ayant une bande passante de 0.4 nm. Les valeurs de flux solaire à 1 U.A. confirment les résultats obtenus précédemment par ballon. Elles sont comparées avec les autres observations et discutées en fonction d'une éventuelle variation à long terme dans ce domaine de longueur d'onde.

Samenvatting

In de loop van 1976 en 1977 werd, met behulp van een ballon-experiment en gedurende een periode van kalme zon, de zonneflux gemeten voor golflengten gelegen tussen 200 en 240 nm. Op een hoogte van 41 km en bij verschillende zenithale afstanden werden spectra opgenomen door een ultraviolet spectrometer met een doorlaatband van 0,4 nm. De gemeten flux op 1 A.E. van de zon bevestigt eerder gedane ballonwaarnemingen. De fluxwaarde wordt vergeleken met andere metingen en ook wordt zijn eventuele verandering op lange termijn behandeld, althans voor dit golflengtegebied.

Zusammenfassung

Die Sonnenstrahlung zwischen 200 und 240 nm ist in 1976 und 1977, während das Sonnen Aktivitäts Minimum, mit Luftballonen gemessen worden. UV spectra sind für verschiedene Zenit Wickeln von einer Höhe 41 km, mit einen Spectrometer (0.4 nm "bandpass") beobachtet worden. Diese Messungen bestöctigen frühere Luftballon Messungen der gesamten Sonnenstrahlung. Diese Messungen sind auch mit anderen verglichen worden um lang zeitige Variationen heraus zu bringen.

INTRODUCTION

The photochemical processes, the temperature and the dynamics in the stratosphere are directly driven by the absorption of solar ultraviolet 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 percent lower than those of Simon (1974a) and 25 percent 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 percent 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 balloon 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 ultraviolet 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 percent over the entire wavelength range. As the absolute value is known with an uncertainty of ± 6 percent the final calibration is given with an accuracy of ± 10 percent and a precision of ± 4 percent. The spectrometer has been integrated in a stabilized gondola, pointing to the sun with an accuracy of the order of 10 arc min. Both flights were performed from the "Centre National 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 balloons 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 extra-terrestrial 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 percent in ozone content at the ceiling altitude have been measured with a precision better than 1 percent. 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 percent, 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.

Table 1 : Conditions of observation.

Date	Altitude (km)	Sec χ	O_2 (cm^{-2})	O_3 (cm^{-2})
July 1, 1976	41.6	1.35 - 2.04	1.22×10^{22}	2.3×10^{17}
July 7, 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	7.80	8.00
210 - 215	17.7	18.5	18.3
215 - 220	21.6	22.4	22.3
220 - 225	30.5	30.9	30.4
225 - 230	27.1*	27.1	27.2
230 - 235	29.4*	27.9	28.3
235 - 240		26.3	27.7

* 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	2.12
204.1 - 206.2	49,000 - 48,500	2.38	2.43
206.2 - 208.3	48,500 - 48,000	2.74	2.84
208.3 - 210.5	48,000 - 47,500	5.20	5.30
210.5 - 212.8	47,500 - 47,000	8.05	7.95
212.8 - 215.0	47,000 - 46,500	8.98	8.82
215.0 - 217.4	46,500 - 46,000	9.26	9.27
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	1.20
222.2 - 224.7	45,000 - 44,500	1.76	1.74
224.7 - 227.3	44,500 - 44,000	1.42	1.41
227.3 - 229.9	44,000 - 43,500	1.46	1.47
229.9 - 232.6	43,500 - 43,000	1.65	1.67
232.6 - 235.3	43,000 - 42,500	1.37	1.40
235.3 - 238.1	42,500 - 42,000	1.58	1.66
238.1 - 241.0	42,000 - 41,500	1.30	1.38

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 standard deviation of the order of 1 to 2 percent has been obtained between 210 and 230 nm. From 230 to 240 nm, it increases up to 5 percent 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 percent.

RESULTS AND DISCUSSIONS

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 on figure 1 with the other published measurements. The agreement between the two balloon measurements is within 6 percent. 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 percent between 210 and 240 nm but the new irradiance values are 13 percent 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. Measurement of Mount et al. (1980) are systematically lower by 30 percent than those presented in this work while those of Broadfoot (1972) are 20 to 30 percent higher. The disagreement with 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

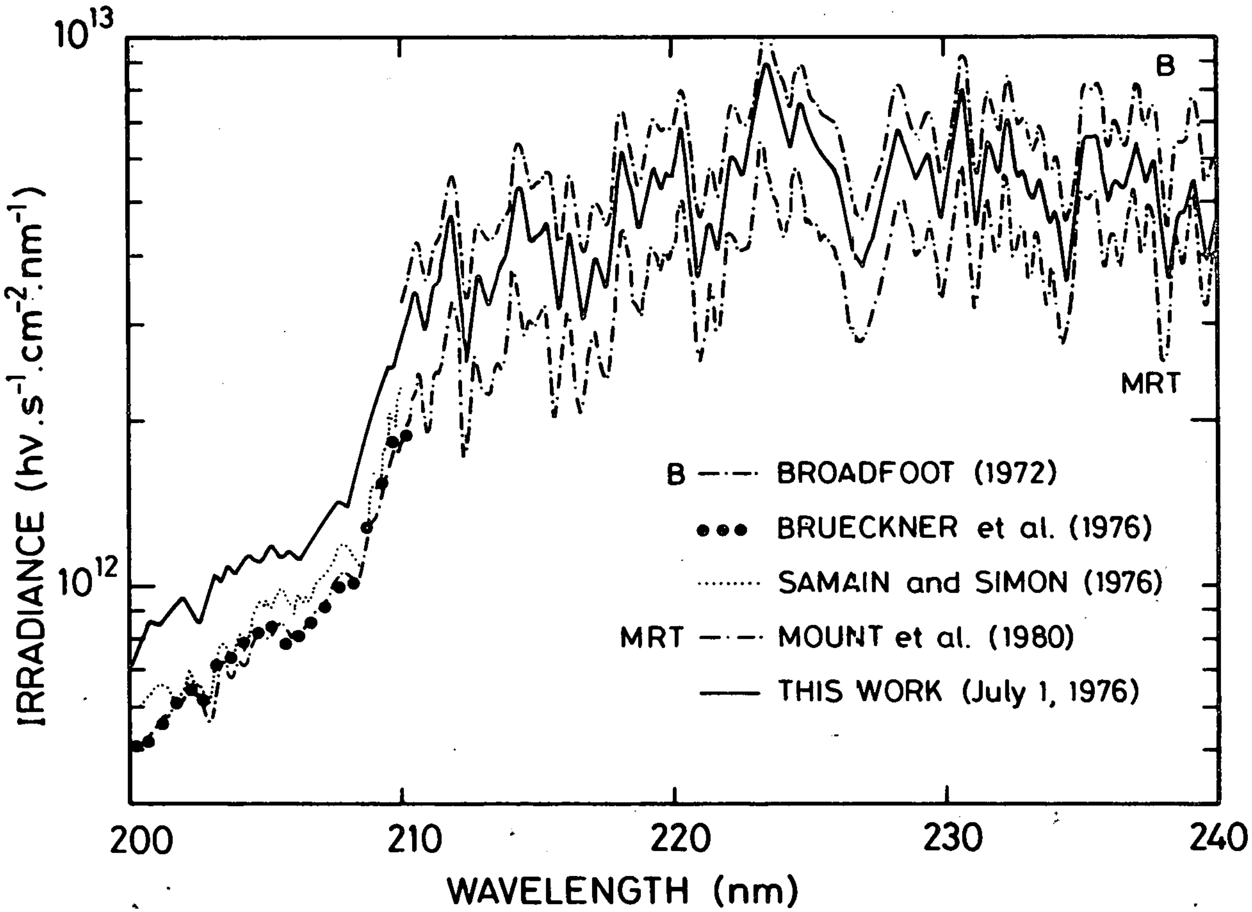

Fig. 1.- Observed solar spectral irradiance between 200 and 240 nm. Data of Samain and Simon (1976) and Mount *et al*. (1980) have been averaged over 0.4 nm for comparison purposes. Data of Heath (1980) are not represented here because they were obtained with a bandpass of 1 nm.

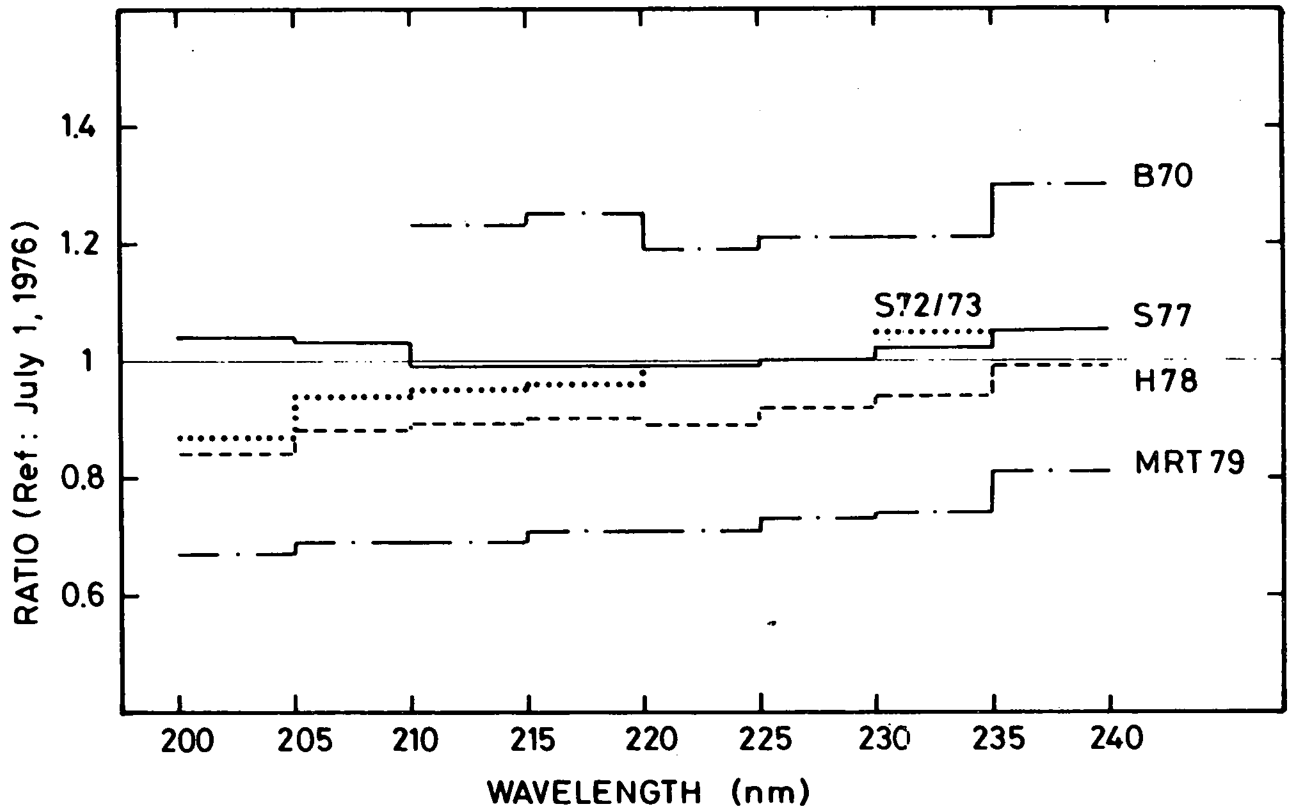

Fig. 2.- Ratio of solar irradiance measurements integrated over 5 nm intervals from 200 to 240 nm in comparison with the data obtained on 1 July 1976. The labeling is as follows : B70 - Broadfoot (1972), S72/73 - Simon (1974a), H78 - Heath (1980), MRT 79 -Mount *et al*. (1980), S77 - this work, July 7, 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 percent lower around 210 nm than those obtained at minimum conditions in 1976, i.e. within their quoted accuracies (10 - 15 percent). 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 percent can be tentatively proposed in the 210-240 nm wavelength interval but such variability could also be negligable.

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) within their quoted accuracies. It appears clearly that values of Broadfoot (1972) generaly 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 percent are badly needed in order to determine the possible long-term variability beyond 210 nm.

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