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## AERONOMICA ACTA

A - N° 241 - 1981

Balloon observations of solar ultraviolet irradiance  
during solar cycle 21

by

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B E L G I S C H   I N S T I T U U T   V O O R   R U I M T E - A E R O N O M I E

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## FOREWORD

This paper has been presented at the Symposium on the Solar Constant and the Spectral Distribution of Solar Irradiance which was held in Hamburg (FRG) on August 17-18, 1981. It will be published in the proceedings of the conference.

## AVANT-PROPOS

Cet article résume une communication présentée au Symposium sur "The Solar Constant and the Spectral Distribution of Solar Irradiance" qui s'est tenu à Hambourg (RFA) le 17 et 18 août 1981. Il sera publié dans les compte-rendus de la conférence.

## VOORWOORD

Dit artikel werd voorgedragen op het "Symposium on The Solar Constant and the Spectral Distribution of Solar Irradiance" dat werd gehouden te Hamburg (BRD) van 17 tot 18 augustus 1981. Het zal gepubliceerd worden in de verslagen van deze conferentie.

## VORWORT

Diese Arbeit wurde in Hamburg (DBR) zum Symposium "The Solar Constant and the Spectral Distribution of Solar Irradiance" (17. zum 19. August 1981) aufgetragen. Sie wird in den Vorträgen der Konferenz heraufgegeben werden.

BALLOON OBSERVATIONS OF SOLAR ULTRAVIOLET IRRADIANCE  
DURING SOLAR CYCLE 21

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Abstract

Balloon borne spectrometric observations were made during the period 1976 to 1980 around 41 km altitude in order to measure solar irradiance from 200 to 240 nm and from 270 to 330 nm. Extraterrestrial solar irradiance values were deduced from the measurements. Quantitative determinations of solar variabilities are limited by the reproductibility of these observations around 210 nm. Comparison with other observations will be made and possible long-term irradiance variations will be discussed.

Résumé

Des observations du flux solaire entre 200 et 240 nm et entre 270 et 330 nm ont été faites à l'aide de ballons stratosphériques à 41 km d'altitude de 1976 à 1980. Les flux solaires extraterrestres ont été déduits de ces mesures. La détermination quantitative des variations solaires autour de 210 nm est limitée par la reproductibilité des mesures. Les observations effectuées par d'autres laboratoires sont comparées avec les résultats de ce travail et les éventuelles variations à long terme sont discutées.

## Samenvatting

Gedurende de periode 1976 tot en met 1980 werden aan boord van stratosferische ballons spectroscopische waarnemingen verricht omtrent de zonneflux in de golflengtegebieden 200 tot 240 en 270 to 330 nm. Uit deze metingen op 41 km hoogte werden de waarden van de zonneflux buiten de aardatmosfeer afgeleid. De reproduceerbaarheid van deze metingen beperkt de quantitative bepaling van veranderingen in de zonneflux rond 210 nm. Verder worden de meetresultaten vergeleken met andere waarnemingen en worden de fluxvariaties op lange termijn behandeld.

## Zusammenfassung

Beobachtungen der Sonnenstrahlung zwischen 200 und 240 nm und zwischen 270 und 330 nm wurden mit Hilfe stratosphärischen Ballonen auf einer Höhe von 41 km während der Periode 1976-1980 gemacht. Die Sonnenausthalungen ohne atmosphärischen Absorption wurden aus diesen Messungen gerechnet. Die quantitative Sonnenvariationen in der Nähe 210 nm sind durch die Wiedererzeugbarkeit der Messungen beschränkt. Vergleichen mit anderen Beobachtungen sind durchgeführt und die möglichen langzeitlichen Variationen sind diskutiert.

## INTRODUCTION

During solar cycle 20, the only measurement of solar irradiance covering the wavelength range corresponding to the Hartley bands of ozone was performed by Broadfoot (1972) in June 1970 by means of a rocket-borne spectrometer. Irradiance values from 210 to 320 nm were published with a quoted accuracy of  $\pm 10$  percent and a bandpass of 0.3 nm. Observations at several discrete wavelengths were made in the same wavelength range by means of the BUV spectrometer on board the Nimbus 4 satellite and were published by Heath (1973). Although the bandpass of the latter instrument (1 nm) made an accurate comparison with Broadfoot's data difficult, the agreement seemed reasonably good. On the other hand, balloon observations covering the range 196-230 nm by means of a spectrometer with a bandpass of 0.6 nm were reported by Simon (1974a) giving irradiance values 30 to 15 percent lower than those published by Broadfoot (1972). The quoted accuracy is  $\pm 20$  percent. The same balloon-borne spectrometer yielded irradiance data beyond 284 nm (Simon, 1975) with an accuracy of  $\pm 15$  percent and the same bandpass. The agreement with Broadfoot (1972) is good up to 305 nm. It should be mentioned that Broadfoot (1972) quoted larger uncertainties between 300 and 320 nm. Beyond 300 nm, other measurements were made by Arvesen et al. (1969) from a Convair Jet Aircraft yielding a quoted accuracy of 25 percent at 300 nm. Disagreements reaching 40 percent exist between the data of Arvesen et al. (1969) and those of Broadfoot (1972) in the wavelength interval 300-320 nm, very important for the formation of  $O^1D$  from the photo-dissociation of  $O_3$ . Values of Simon (1975) have been widely accepted as being more reliable in this interval. On the other hand, values of Arvesen et al. (1969) suffer from uncertainties due to change in the spectral irradiance scale of the NBS in 1973. Consequently, for aeronomical purposes, the data of Simon (1974) were generally adopted from 200 to 230 nm, those of Broadfoot (1972) from 230 to 285 nm,

those of Simon (1975) from 285 to 330 nm and those of Arvesen et al. (1969) adjusted on the irradiation flux values obtained by Labs and Neckel (1970) beyond 330 nm (cfr. Delaboudinière et al., 1978).

Since 1976, corresponding to the beginning of solar cycle 21, several measurements have been performed in order to improve our knowledge of solar fluxes beyond 200 nm. They include observation by means of the Nimbus 7 satellite (Heath, 1980), rockets (Mount et al., 1980; Mount and Rottman, 1981) and stratospheric balloons (Simon et al., 1981).

The purpose of this work is to report briefly new observations of solar ultraviolet irradiance in the wavelength intervals 200-240 nm and 270-330 nm, performed by balloon flights occurring during the rising phase of solar cycle 21, namely between 1976 and 1980. These new results will be compared with earlier measurements and will be discussed in terms of a possible long-term variation of the solar output.

## 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 absolute calibration of the spectrometer has been performed before and after each flight. Two different types of calibration sources have been used, namely deuterium and quartz-halogen lamps. Both are referenced to the National Bureau of Standards spectral irradiance scale. These two transfer standards overlap between 250 and 320 nm. In fact, beyond 280 nm, the spectrometer signal obtained from

deuterium lamps decreases rapidly and only the quartz-halogen lamps give higher signal-to-noise ratios. In addition, the latter standards allow the adjustment of the deuterium irradiance scale by comparison in the overlap wavelength interval, in order to take into account any change due to aging of deuterium lamps during five years of measurement.

Several lamps of each type have been used and for each flight an average of the calibration results has been adopted. In the 200-240 nm wavelength interval, the reproducibility of calibration is within  $\pm 4$  percent. As the absolute value is known with an uncertainty of  $\pm 6$  percent, the final calibration is given with an accuracy of  $\pm 10$  percent and a precision of  $\pm 4$  percent. Because in the 280-330 nm wavelength interval a reproducibility within  $\pm 2$  percent and lower uncertainties for the irradiance scale of quartz-halogen sources ( $\pm 3$  percent) are obtained one reaches an accuracy of  $\pm 5$  percent for the final calibration.

Three flights were performed from Gap (44°27'N, 6°02'E) on 1 July 1976, 7 July 1977 and 24 June 1980. The 4th flight took place from Aire-sur-l'Adour (43°42'N, 0°15'W) on 14 September 1979. The gondola of about 300 kg was carried by Zodiac balloons of 350.000 m<sup>3</sup> launched by the "Centre National d'Etudes Spatiales" (France). The ceiling altitude was about 41 km for each flight.

#### DATA REDUCTION

For the 4 flights, the observed solar spectra have been corrected for the residual atmospheric absorption at the floating altitude deduced from simultaneous pressure and ozone measurements. This method of data reduction is discussed more extensively in a previous paper (Simon et al., 1981). The extraterrestrial irradiance values are

averaged over about 20 corrected spectra. The final accuracy on the solar irradiance values is  $\pm 15$  percent from 200 to 240 nm and  $\pm 10$  percent from 270 to 330 nm. The corresponding precision is respectively of the order of  $\pm 6$  percent and  $\pm 4$  percent.

## RESULTS AND DISCUSSION

Figure 1 presents the ratios of irradiance values integrated over 5 nm from 210 to 240 nm taking as a reference the data obtained by Simon et al. (1981) 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 data of Simon (1974a) are not represented for the sake of clarity. They agree within  $\pm 5$  percent with 1976 values in this wavelength range.

Systematic divergences clearly appear between most of the measurements. They are probably due to experimental errors. Differences between all the balloon flights do not exceed 12 percent. The two last flights are in very close agreement, within 5 percent, with the data obtained by Heath (1980). They confirm that values of Broadfoot (1972) have to be lowered by at least 25 percent in this wavelength range. The lowest values of Mount et al. (1980) do not seem reliable because they are not confirmed by the last rocket flight reported by Mount and Rottman (1981), using a similar spectrometer.

Figure 2 represents the same comparison for integrated irradiance values over 5 nm between 270 and 330 nm, taking as a reference the data obtained by balloon on 14 September 1979. The agreement between all the observations is rather good ( $\pm 10$  percent) up to 295 nm. Beyond this wavelength, the data of Mount and Rottman (1981) become significantly lower than the others, as those of Broadfoot (1972) do beyond 305 nm. Balloon observations also exhibit larger



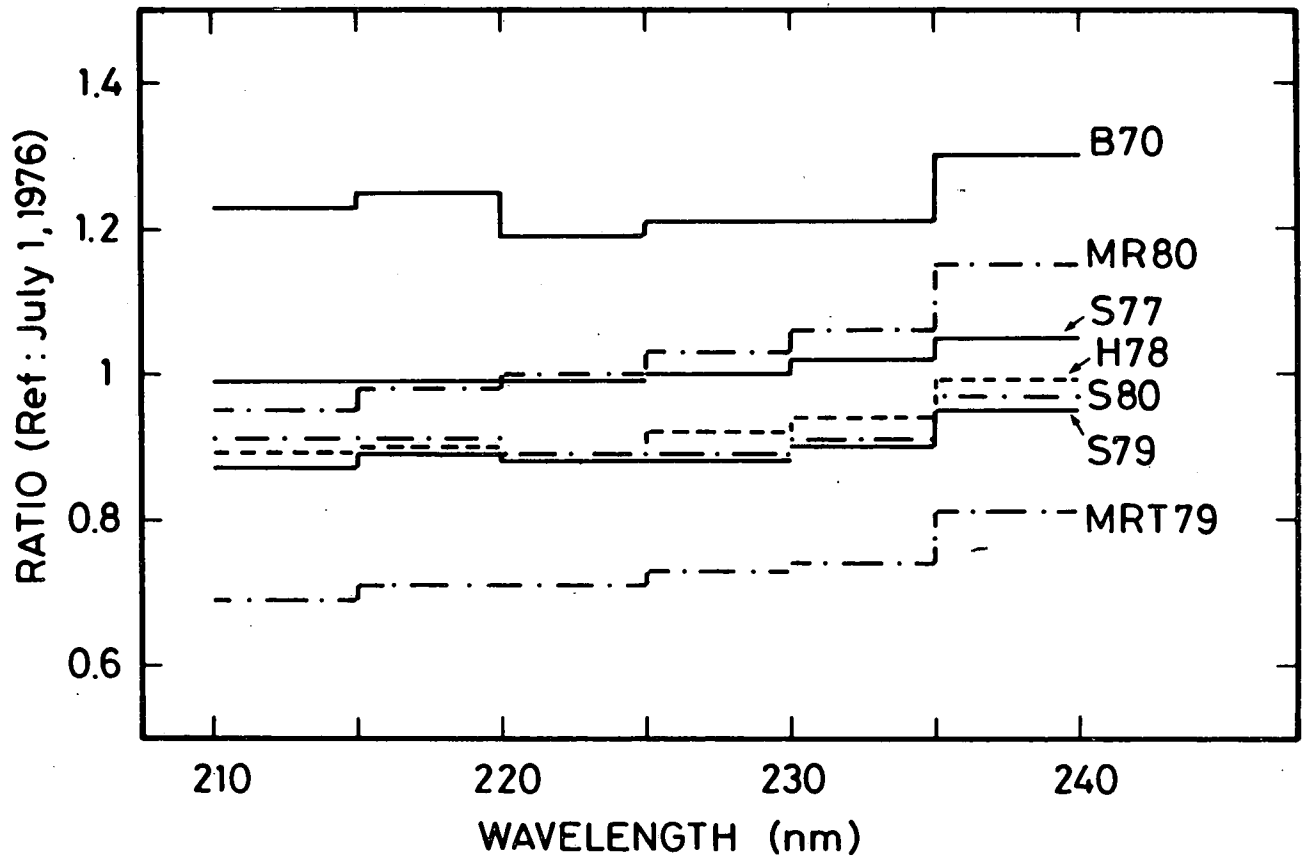


Fig. 1.- Observed solar irradiance in the spectral range 210-240 nm expressed as ratios relative to the balloon observation on 1 July 1976. Values are integrated over 5 nm intervals. The labeling is as follows : Broadfoot (1972); MR80 : Mount and Rottman (1981); S77, S79, S80 : This work; H78 : Heath (1980), MRT79 : Mount et al., (1980).

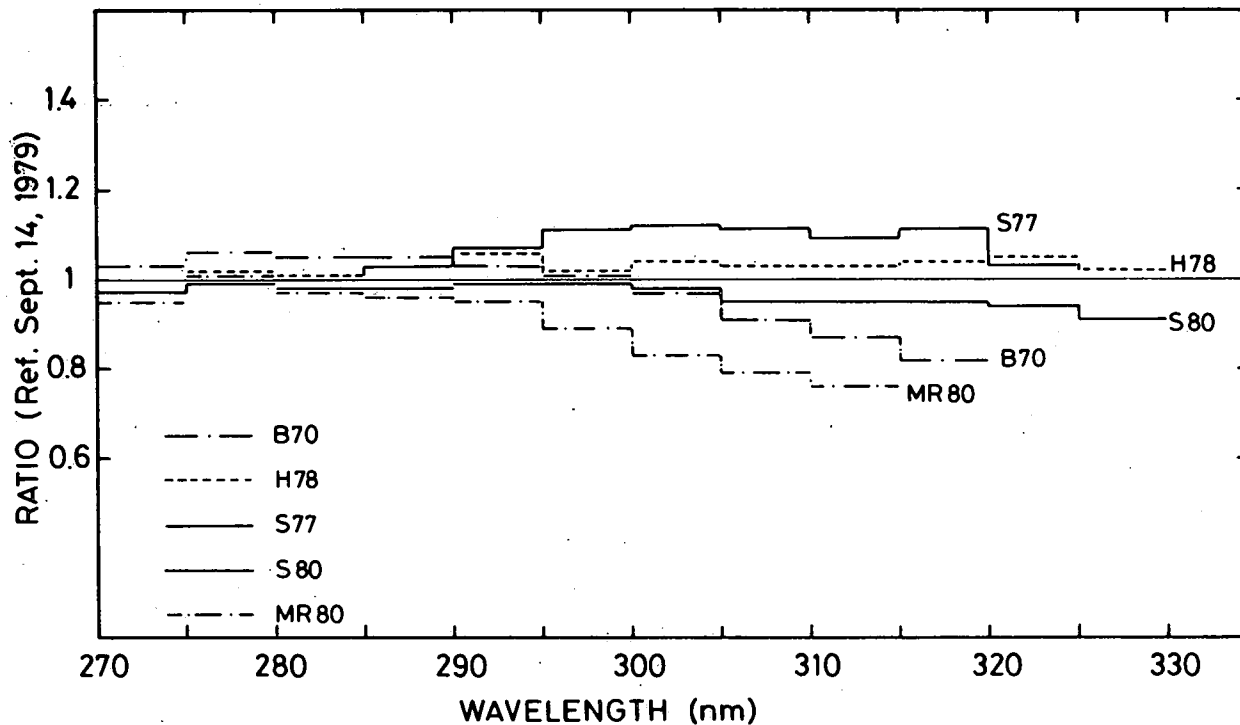


Fig. 2.- Observed solar irradiance in the spectral range 270-330 nm expressed as ratios relative to the balloon observation on 14 September 1979. Values are integrated over 5 nm intervals. The labeling is as follows : B70 : Broadfoot (1972); MR80 : Mount and Rottman (1981); S77, S80 : This work; H 78 : Heath (1980); MRT79 : Mount et al., (1980).

discrepancies, up to 15 percent, at longer wavelengths nevertheless the agreement with the values obtained by Heath (1980) is within 5 percent for the 1979 balloon observation.

Up to now, only two new measurements are available between 240 and 270 nm, namely those of Heath (1980) and those of Mount and Rottman (1981). Both are systematically lower in this wavelength interval than those of Broadfoot (1972). They diverge by 15 percent between 240 and 250 nm and agree quite well around 270 nm.

Consequently, Broadfoot's values generally used from 230 to 300 nm in stratospheric aeronomy should be lowered on the basis of the various balloon data and of the Nimbus 7 observation.

It is difficult to deduce quantitatively any long-term variability of solar irradiance between 210 and 240 nm lower than 10-15 percent from these balloon observations. They cover the entire rising phase of solar cycle 21 but their disagreements do not exceed 12 percent, i.e. within their quoted precision ( $\pm 6$  percent). Unfortunately, the data of Mount et al. (1980) obtained at solar maximum do not solve the problem because they are not reliable (Mount and Rottman, 1981). On the other hand, the data obtained by Heath (1980) in November 1978 for an intermediate activity level are only 10 percent lower than those obtained by balloon in 1976 from 210 and 240 nm, i.e. within their quoted accuracies (10 - 15 percent). Consequently, the systematic divergences in available observations are probably due to experimental errors. The long-term variability beyond 210 nm is still masked by the accuracy and the precision of each measurement. Such variability could be negligible.

In conclusion, from the new measurements performed since 1976, solar irradiance values are probably known with an accuracy of  $\pm 15$  percent around 210 nm and  $\pm 5$  percent at 300 nm. Further

observations with a precision better than  $\pm 2.5$  percent are still needed in order to determine the possible long-term variability beyond 210 nm.

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