SOLAR IRRADIANCE BETWEEN 120 AND 400 nm AND ITS VARIATIONS*

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Abstract. The solar ultraviolet irradiance measurements in the 120–400 nm wavelength range are reviewed and compared showing still important discrepancies between the irradiance values deduced from the most recent observations.

The possible variations of the solar ultraviolet irradiances with the 27-day rotation period of the Sun and with the 11-year activity cycle are presented and discussed on the basis of the available irradiation fluxes obtained during the rising phase of solar cycle 21.

The spectral features of both kinds of variation are clearly related to the solar atmospheric layer from which the corresponding radiation is emitted.

1. Introduction

The knowledge of the spectral distribution of the solar ultraviolet irradiance and its variation in time is a basic problem mainly in aeronomy but also in climatology and in solar physics. Indeed ultraviolet irradiance values are needed for the study of the photochemistry and the dynamics in planetary atmosphere, both being driven by the absorption of the solar ultraviolet radiation by the atmospheric constituents.

Solar irradiance between 120 and 400 nm is related to the photodissociation processes and the dynamics in the troposphere, the statosphere, the mesosphere and the lower thermosphere, that means from the ground level up to 130 km of altitude. In addition, the H I Lα emission line at 121.6 nm which penetrates deeply into the mesosphere initiates the photoionization processes in the *D*-region.

The purpose of this work is to review and discuss the available data on the solar irradiance between 120 and 400 nm and on the solar variability of the solar output in the same wavelength range. We will lay emphasis on the new data obtained during the solar cycle 21 up to 1980. Neither short-time variations nor long-term secular changes are considered in this work.

2. The H I Lα Emission Line (121.6 nm)

The irradiance of the H I Lα emission line was measured for the first time in 1949 (Friedman *et al.*, 1951). Since that time, many observations have been performed during the solar cycle 19 and 20 and discussed previously (see e.g., Vidal-Madjar, 1977; Simon, 1978; Simon 1980). On the basis of these measurements, a conventional value of 3×10^{11} $h\nu$ s^{-1} cm^{-2} has been adopted for aeronomical purposes, with an absolute accuracy of ±30 percent. That means that the irradiance of H I Lα would be included between 2.1 and 3.9×10^{11} $h\nu$ s^{-1} cm^{-2}.

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Variations from minimum to maximum solar activity conditions have been observed by many authors. Empirical relations with the 10.7 cm solar flux and the Zurich sunspot number have been previously proposed by Vidal-Madjar (1975). They were based on the longest record of H I Lα irradiances obtained during the solar cycle 20 from January 1969 to December 1972 by means of the University of Paris experiment on board the OSO-5 spacecraft. A second period of observation with the same experiment occurred near the minimum of solar activity from October 1974 to August 1975 from which two new empirical relations depending upon the level of the solar activity have been proposed by Vidal-Madjar and Phissanay (1980) coupling the total H I Lα irradiance with the 10.7 cm solar flux. The data obtained during the solar maximum period and near the solar minimum of cycle 20 lead to a maximum variation of 30 percent with the 27-day rotational period of the Sun and to a factor of 2 variation with the 11-year cycle. On the other hand, Vidal-Madjar and Phissanay (1980) confirm the observations of an early solar minimum in the solar EUV emission lines in April 1975 obtained by means of the EUVS experiments on board the AE-C satellite and reported by Hinteregger (1977). This EUV minimum occurs 14 months before July 1976 which corresponds to the minimum of the monthly mean value of the Zurich sunspot number and defining the start of solar cycle 21 (see e.g., White and Livingston, 1978). They also confirm the observation of Hinteregger (1977) showing the different correlations during solar cycle 20 and 21 between EUV emission lines and the 10.7 cm solar flux.

Irradiance variation measurements of H I Lα during the rising phase of the solar cycle 21 have been obtained by means of the EUVS experiment on board the AE-E satellite from June 1977 to May 1980 and published by Hinteregger *et al.* (1981). These results show an important increase of the irradiance value of the EUV lines, reaching a factor of 2 at 121.6 nm, during this period of observation. Considering an estimated value of 2.95×10^{11} $h\nu$ s^{-1} cm^{-2} in July 1976, an increase by a factor 2.8 from minimum to maximum conditions of solar activity has been proposed by Hinteregger (1981). Similar variations have been observed for the H I Lβ (102.6 nm) and He I (58.4 nm) lines. In particular, these three lines exhibit an important irradiance increase in December 1978 which is surprisingly relatively more important for the H I Lα line. This increase in irradiance values persists during 1979 (cf. Figure 1). Rocket observations reported by Mount *et al.* (1980) are also drawn on Figure 1 for comparison. It should be pointed out that a possible variation of 30 percent should be taken into account in the comparison of rocket measurements which correspond to a snapshot during the rotational period of the Sun. It appears clearly that these measurements are inconsistent with those obtained from the AE-E satellite. The possible variation from 1975 to 1979 does not exceed a factor of 2 and H I Lα irradiance values increase by only a factor 1.18 between 1976 and 1979. Table I gives the ratio between each measurement and seems to confirm that the formal beginning of solar cycle 21 in July 1976 does not correspond to the minimum condition for the H I Lα emission line. New measurements of H I Lα irradiance are still required in the future because of divergences between

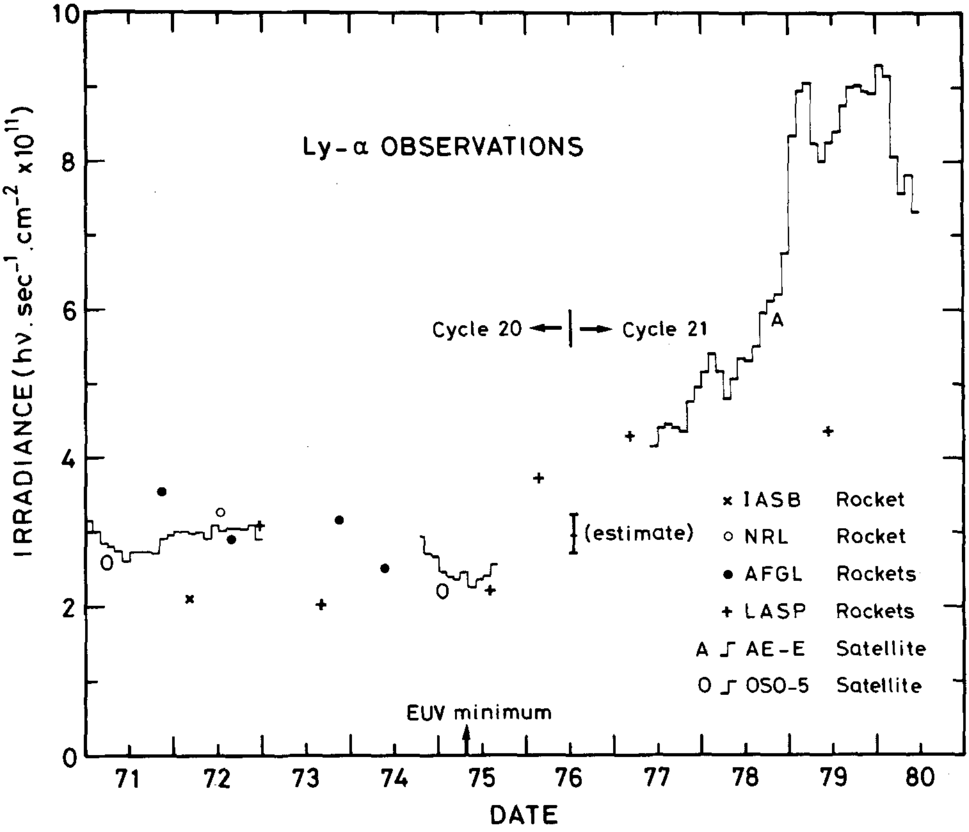

Fig. 1. Comparison of H I Lα irradiance measured since 1971. References: IASB: Ackerman and Simon (1973). NRL: Prinz (1974). AFGL: Heroux and Higgins (1977). LASP: Mount *et al.* (1980). AE-E: Hinteregger *et al.* (1981). OSO-5: Vidal-Madjar (1975), Vidal-Madjar and Phissanay (1980).

TABLE I

LASP rocket observation of H I Lα

Date	Irradiance ($\times 10^{11}$ $h\nu$ s^{-1} cm^{-2})	Ratio	$F_{10.7}$
Dec. 13, 1972	3.08		111
Aug. 30, 1973	2.02	0.66 (73/72)	91
Jul. 28, 1975	2.20	1.09 (75/73)	75
Feb. 13, 1976	3.70	1.68 (76/75)	70
Mar. 7, 1977	4.28	1.16 (77/76)	80
Jun. 5, 1979	4.36	1.02 (79/77)	230

the most recent observations and possible differences in the variations features of this line during each solar cycle.

3. The Wavelength Interval 135–175 nm

The solar irradiance in the spectral range 125–175 nm is mainly absorbed in the lower thermosphere by the molecular oxygen. The photodissociation rate maximum occurs in the 150–155 nm wavelength interval.

This part of the solar spectrum is dominated by the Silicon continuum with additional strong emission lines. The solar radiation in this spectral interval arises from the chromospheric region ($\lambda < 152$ nm) and from the photosphere-chromosphere transition zone ($152\,\text{nm} < \lambda < 168\,\text{nm}$) where the temperature minimum occurs. Consequently, irradiance values corresponding to wavelength intervals including intense emission lines should be carefully compared, taking into account the possible variation due to the solar rotation. Figure 2 shows the measurements integrated over 1 nm intervals obtained from the end of 1972 to the beginning of the solar cycle 21 from 140 to 170 nm. The date of each observation and their quoted accuracies are given in Table II. A more complete comparison with the data obtained before 1973 has been published by Simon (1978). The new values of Rottman (1981) represent actually a mean of five rocket flights, including revised values for

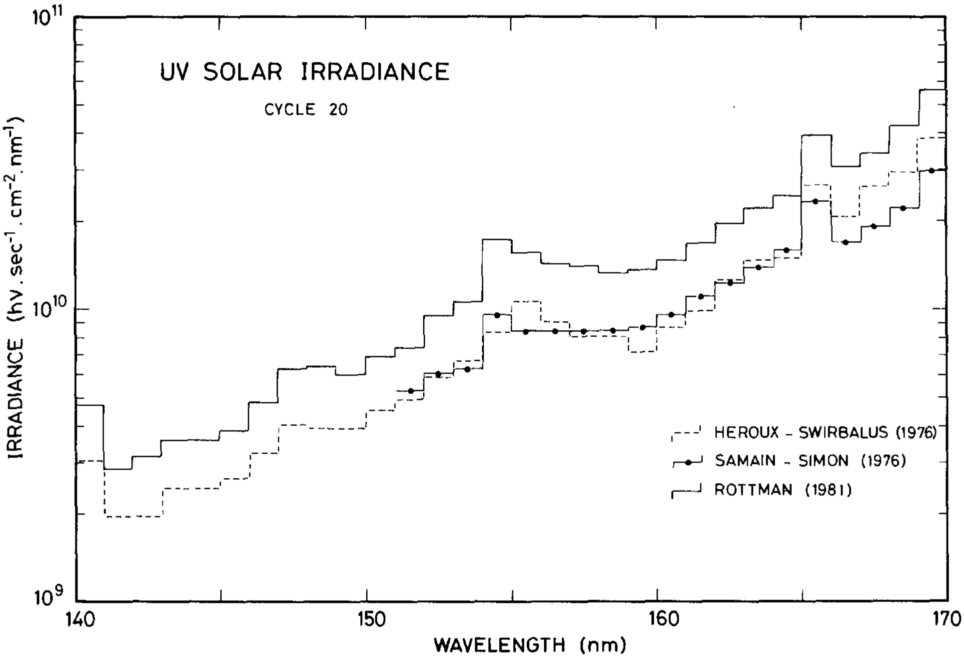

Fig. 2. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 140 to 170 nm, measured during solar cycle 20.

TABLE II

UV solar irradiance measurements relevant for aeronomy

Reference	Date of observation	Wavelength interval (nm)	Vehicle	Accuracy
Arvesen *et al.* (1969)	Aug.–Nov. 1967	300–2500	aircraft	±25 – ±3%
Ackerman *et al.* (1971)	May 10, 1968 Apr. 19, 1969 Oct. 3, 1969	194–224	balloon	±20%
Broadfoot (1972)	June 15, 1970	210–320	rocket	±10%
Simon (1974, 1975)	Sept. 23, 1972	196–230	balloon	±20%
	May 16, 1973	285–355		±15%
Samain and Simon (1976)	April 17, 1973	151–209	rocket	±30%
Brueckner *et al.* (1976)	Sept. 4, 1973	174–210	rocket	±20%
Heroux and Swirbalus (1976)	Nov. 2, 1973	123–194	rocket	±20%
Heroux and Hinteregger (1978)	April 23, 1974	25–194	rocket	±20%
Heath (1979)	Nov. 7, 1978	160–400	satellite	±10 – ±3%
Simon *et al.* (1981a)	July 1, 1976	200–240	balloon	±15%
	July 7, 1977	275–330		±10%
Hinteregger (1980)	July, 1976–Jan. 22, 1979	15–185	satellite	±20%
Mount *et al.* (1980)	June 5, 1979	120–256	rocket	±15%
Simon *et al.* (1981b)	Sept. 14, 1979	200–240	balloon	±15%
	June 24, 1980	270–330		±10%
Neckel and Labs (1981)	1960's	330–1248	ground	±1.5 – ±1%
Rottman (1981)	Dec. 13, 1972 Aug. 30, 1973 July 28, 1975 Feb. 18, 1976 March 9, 1977	120–190	rocket	±20 – ±35%

observations performed in 1972 and 1973 which supercede those proposed by Rottman (1974). The three other observations have been performed in 1975, 1976, and 1977. Rigorously speaking, the last flight belongs to the solar cycle 21 and is not representative of quiet solar conditions. The two first flights correspond to a low level of activity during solar cycle 20 while those of 1975 and 1976 correspond to a period of minimum activity. Rottman (1981) consider that the mean of these five observations is representative of minimum conditions of solar activity. Nevertheless, it seems difficult to explain why these flights give systematically higher irradiance values than those obtained by Heroux and Swirbalus (1976) and by Samain and Simon (1976) for low solar activity conditions. It seems also difficult to discuss this data in term of solar variability during solar cycle 20 because of the error associated with each measurement (±25 percent), the very poor time sampling and the lack of cross-calibration with other instruments used for solar observations during the same epoch.

The data obtained during solar cycle 21 from 140 to 170 nm are shown on Figure 3 for comparison with the mean value proposed by Rottman (1981) for solar minimum conditions between solar cycle 20 and 21. The data of Mount *et al.* (1980)

are systematically higher by a factor decreasing from 2.3 to 1.3 with increasing wavelength. As these values have been obtained during high solar activity level, the differences could be explained in term of solar variability during the rising phase of cycle 21. This discussion will be given elsewhere. It should be pointed out that the measurements obtained from the Nimbus 7 satellite and reported by Heath (1980) correspond to intermediate conditions for the solar activity. Nevertheless they are in better agreement with the mean value proposed by Rottman (1981). Consequently, they are also systematically lower than those of Mount *et al.* (1980) by roughly 40 percent. They are even lower than the data of Rottman (1981) beyond 168 nm. This fact is in contradiction with any interpretation of divergences between the data in term of solar variability for the same reasons as mentioned above for measurements performed during the solar cycle 20.

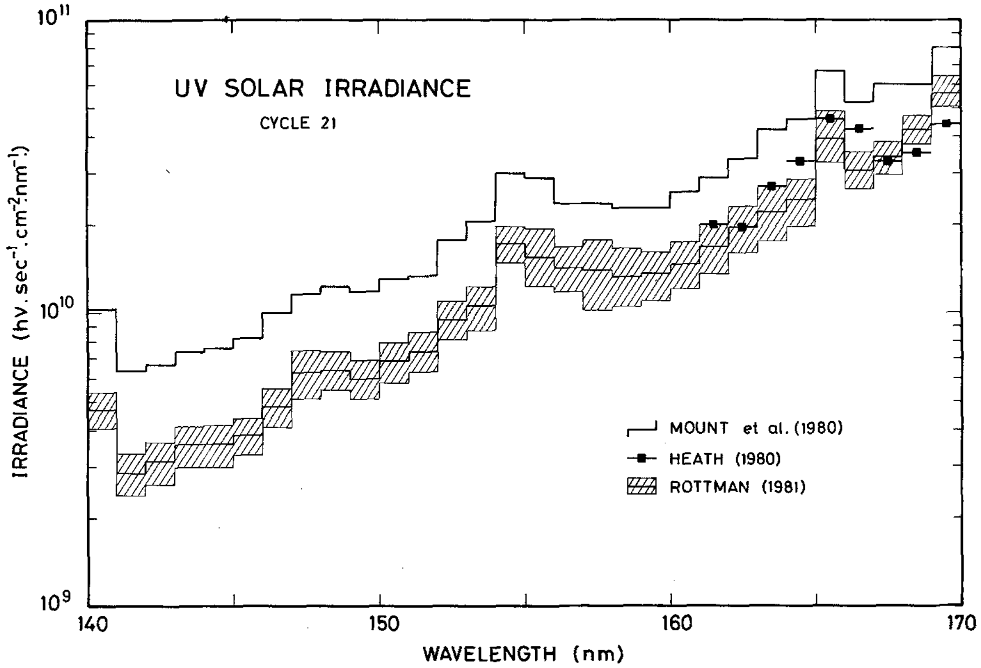

Fig. 3. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 140 to 170 nm, measured during solar cycle 21. The shaded area represent the standard deviation of the five observations of Rottman (1981).

4. The Wavelength Interval 175–240 nm

This wavelength interval is directly related to the photodissociation of molecular oxygen in the mesosphere and in the upper stratosphere.

This part of the solar spectrum is characterized by the crowding of Fraunhofer absorption lines and by the large discontinuity near 210 nm, corresponding in the Al I absorption edge. Beyond this limit, the major opacity sources in the solar atmosphere is line blanketing giving a spectrum dominated by absorption lines of neutral metals. Below 210 nm, the solar spectrum presents the same appearance but, sometimes, lines emitted from the photosphere-chromosphere transition zone become occasionally present. The measurements obtained during solar cycle 20 are given for comparison on Figure 4. A detailed discussion have been already published (Simon, 1978; Simon, 1980). Since that time, only the data of Rottman (1981) have been added giving higher irradiance values than the other observations for wavelength below 180 nm. The main conclusion is not changed: important disagreements of the order of 50 percent do not permit to deduce accurate values of solar irradiance, especially between 180 and 190 nm where the data of Samain and Simon (1976) represent an upper limit while those of Heroux and Swirbalus (1976) could give a lower limit for the solar irradiance both referring to low solar activity conditions.

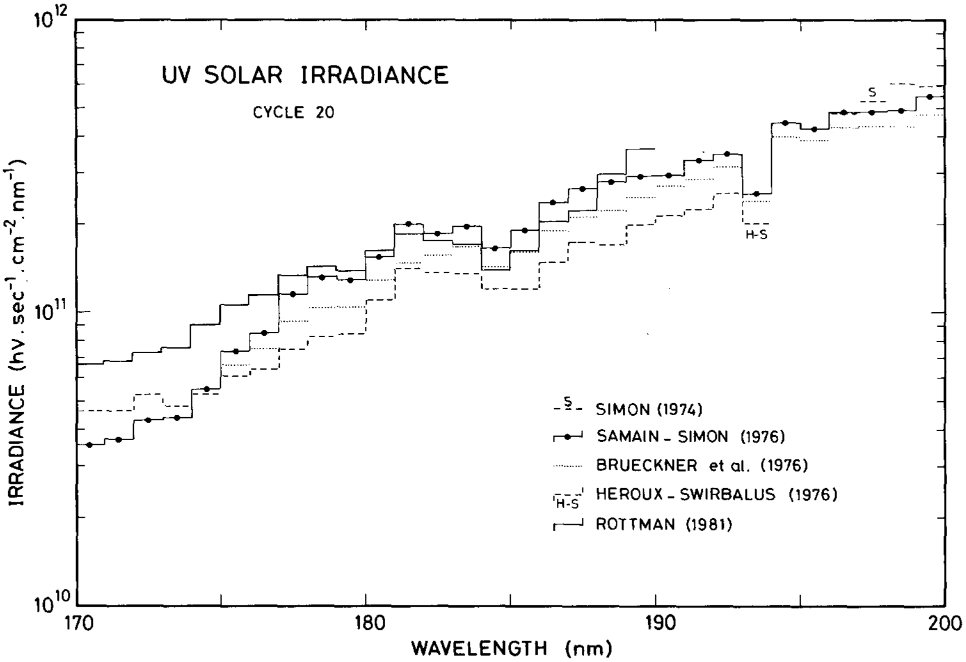

Fig. 4. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 170 to 200 nm, measured during solar cycle 20.

The new measurements of Heath (1980) and Mount *et al.* (1980) performed during the solar cycle 21 are represented on Figure 5 with those of Rottman (1981) for comparison purposes. The values of Mount *et al.* (1980) are 50 percent higher than those of Heath (1980) around 175 nm but 25 percent lower around 200 nm. Very good agreement appears only between 186 and 194 nm. Discrepancies between measurements of Heath (1980) and Mount *et al.* (1980) have probably experimental

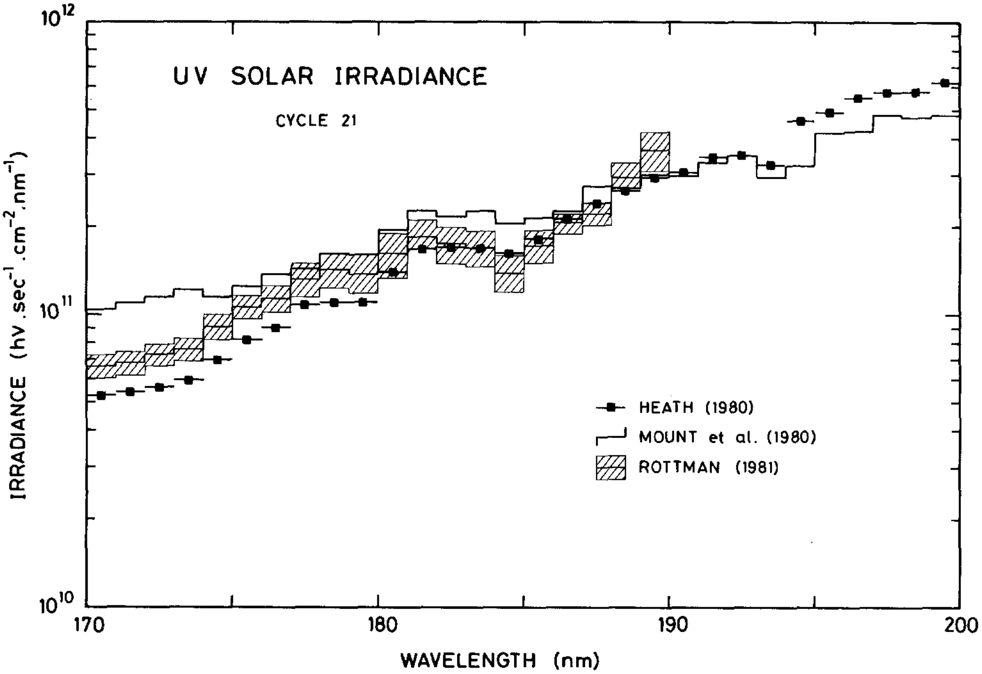

Fig. 5. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 170 to 200 nm measured during solar cycle 21. The shaded area represent the standard deviation of the five observations of Rottman (1981).

causes and are difficult to explain in term of solar variability because both lie in the second part of the rising phase of cycle 21. On the other hand, it should be pointed out that Heath (1980) is even lower than the mean values of Rottman (1981) corresponding to minimum conditions of solar activity, except around 185 nm. Consequently, quantitative variations from 180 to 200 nm with the solar activity cycle cannot be deduced from these observations.

Data between 200 and 230 nm are given in Figure 6 for solar cycle 20. Values published by Simon (1974) are now confirmed within 15 percent by new balloon measurement performed in July 1976 and described in more detail by Simon *et al.* (1981a). Measurements of Broadfoot (1972) appear higher than those of Simon (1974) by a factor decreasing from 1.30 to 1.15 between 210 and 235 nm.

New measurements from 200 to 230 nm made during cycle 21 are reported on Figure 7 and also confirm the previous balloon measurements of Simon (1974) except those of Mount *et al.* (1980) which are systematically lower by 20 percent than values of Heath (1980) and Simon *et al.* (1981b). Figure 8 gives the ratio of each irradiance measurement integrated over 5 nm intervals between 210 and 240 nm, taking as reference the value obtained in 1976 by Simon *et al.* (1981a). Systematic differences between all measurements mean that discrepancies in this wavelength range are probably also due to experimental errors and could not be interpreted as long-term solar variability mainly because once again there is no cross-calibration

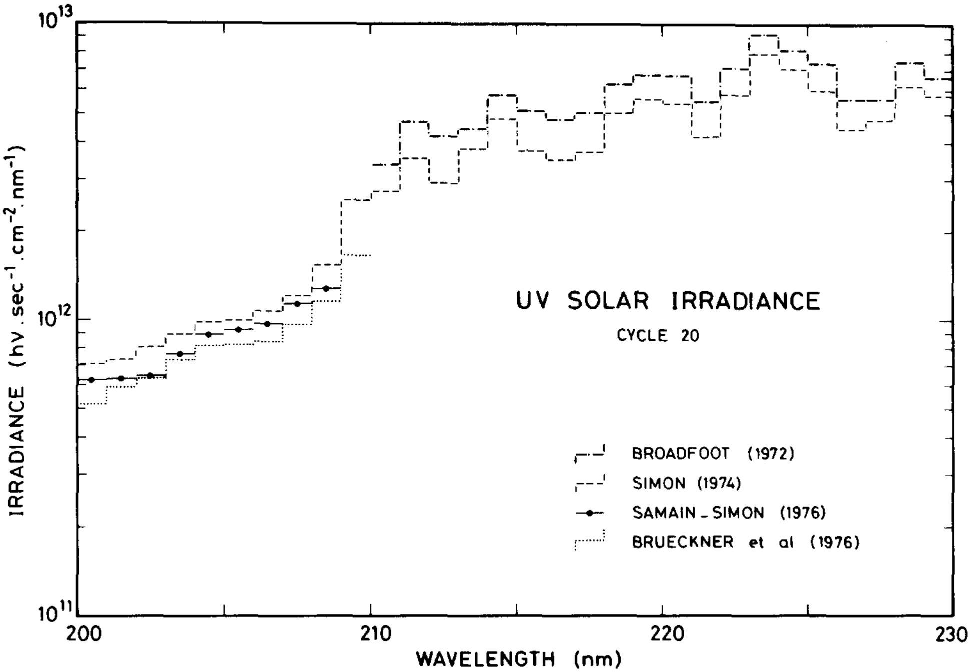

Fig. 6. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 200 to 230 nm, measured during solar cycle 20. The measurements of Ackerman *et al.* (1971) and Simon *et al.* (1981a) are not represented for the sake of clarity.

of the different solar instruments performed before or after the observations. The quoted accuracies of all measurements presented here are given in Table II.

5. The Wavelength Interval 240–400 nm

This wavelength interval is related to the photodissociation processes in the stratosphere and in the troposphere.

This part of the solar spectrum presents similar appearance as for wavelengths between 210 and 240 nm. However, for radiation beyond 300 nm, the relative opacity from lines is decreasing and the continuum is formed at the same altitude as for the visible. The solar irradiance observations are presented on Figures 9, 10, and 11 for comparison purposes. Table II gives the quoted accuracies and the dates of measurements for each authors. Data obtained by Broadfoot (1972) remain systematically higher than all the others except between 270 and 300 nm where the agreement with Heath (1980), Simon (1975), and Simon *et al.* (1981a) is within 10 percent. The same remarks as for wavelengths between 200 and 230 nm can be made on the measurements of Mount *et al.* (1980). In addition, Figure 9 clearly shows that the discrepancy between these latter values and those of Heath (1979) and Broadfoot (1972) is increasing beyond 250 nm. The lowest data of Mount *et al.*

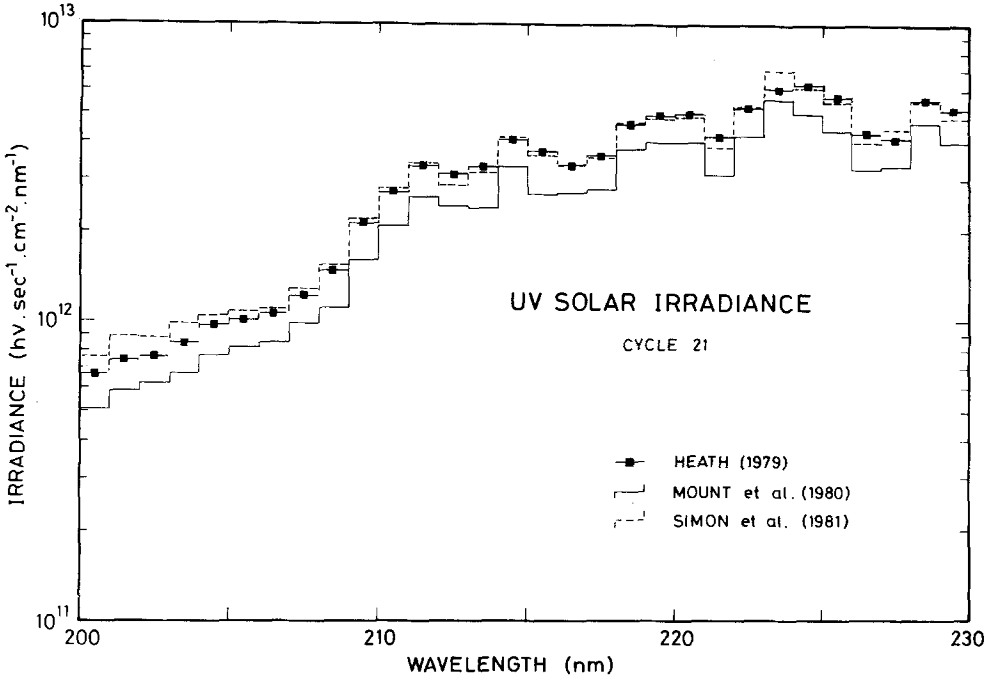

Fig. 7. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 200 to 230 nm, measured during solar cycle 21. The measurements of Simon *et al.* (1981a) are not represented for the sake of clarity.

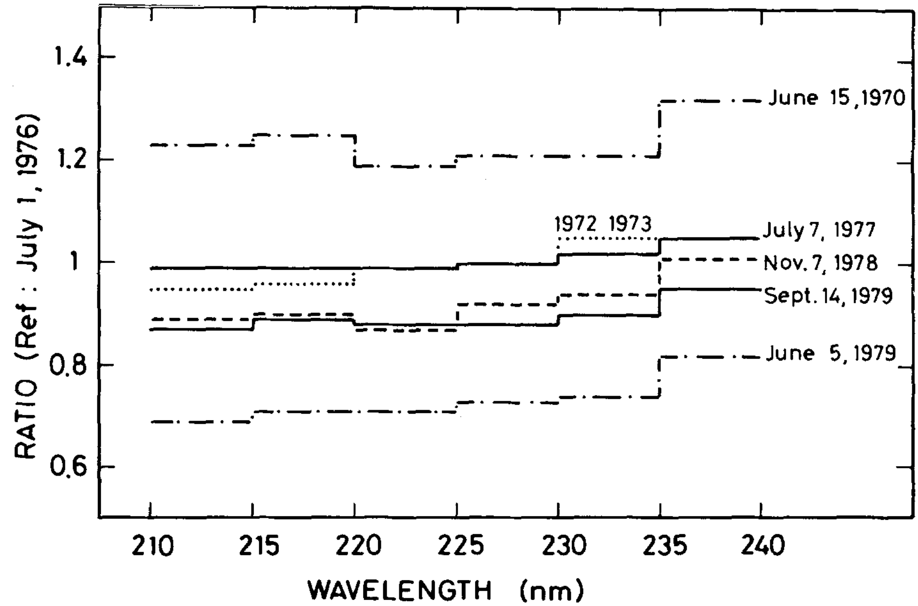

Fig. 8. Ratio of solar irradiance measurements integrated over 5 nm intervals from 210 to 240 nm in comparison with the data of Simon *et al.* (1981a) obtained the 1st July 1976. See Table II for references corresponding to the dates of observation.

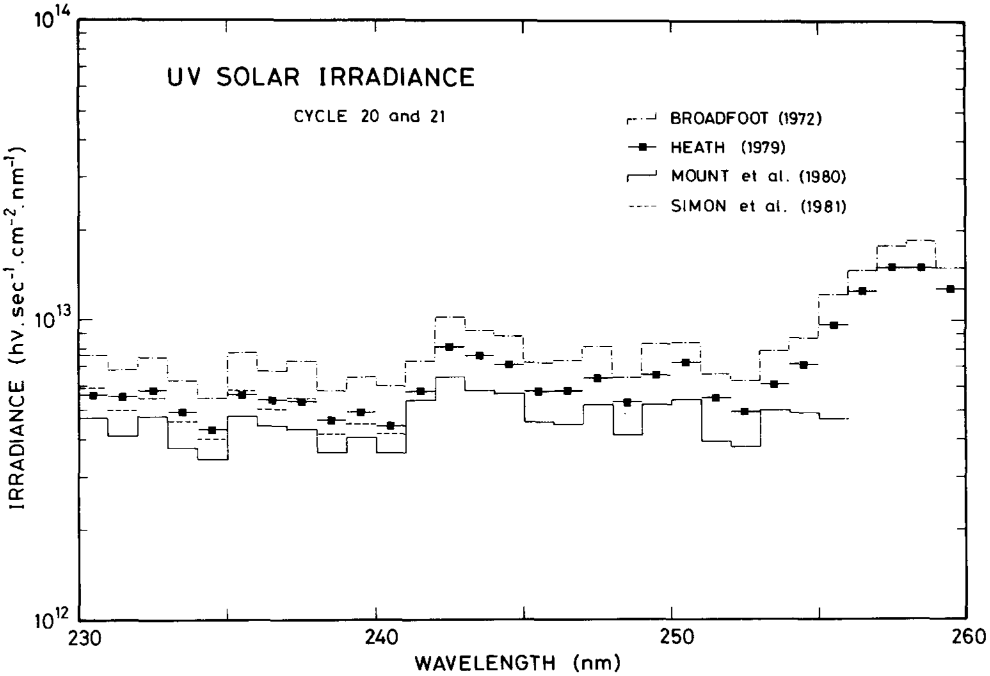

Fig. 9. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 230 to 260 nm. The measurements of Simon *et al.* (1981a) are not represented for the sake of clarity.

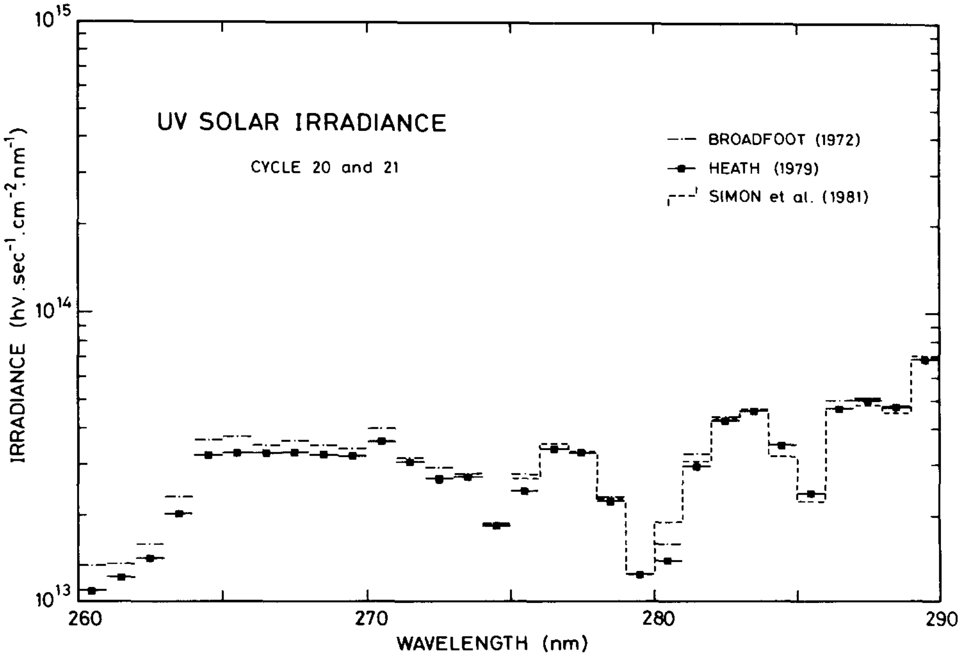

Fig. 10. Comparison of ultraviolet irradiance integrated over 1 nm intervals from 260 to 290 nm. The measurements of Simon (1975) are not represented for the sake of clarity.

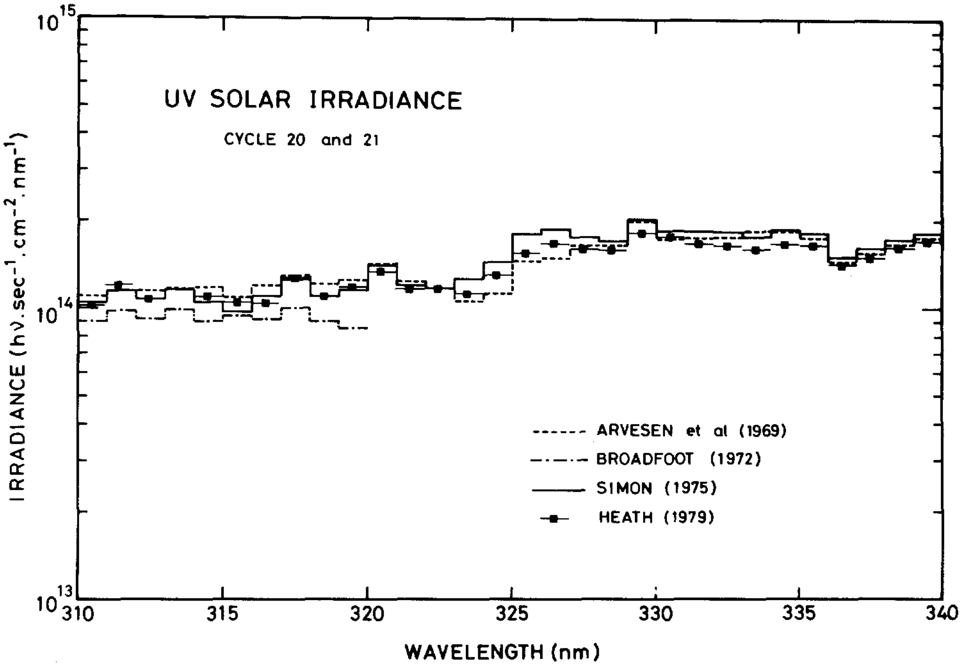

Fig. 11. Comparison of ultraviolet solar irradiance integrated over 1 nm intervals from 310 to 340 nm. The measurements of Simon *et al.* (1981a, b) are not represented for the sake of clarity.

(1980) from 200 nm to 250 nm need to be confirmed especially with observations including wavelengths around 300 nm in order to make possible the comparison with the other data available at this wavelength where the agreement is rather good and to determine if their disagreement is not due to experimental problems. Between 300 and 323 nm, data of Simon (1975) are confirmed by Simon *et al.* (1981a, b) and by Heath (1980). At longer wavelengths the latter becomes systematically 8 percent lower than the balloon observations of Simon (1975) but are generally very lightly higher than the new revised data very recently published by Neckel and Labs (1981) (cf. Table III). The data of Arvesen *et al.* (1969) suffer from uncertainties due to changes in the spectral irradiance scale of the National Bureau of Standards in 1973 (Kostkowski, 1974). The other observations published by Thekaekara *et al.* (1969) and Thekaekara (1974) have been previously discussed by Simon (1975).

6. Variability with the 27-Day Rotational Period

The irradiance variability with the 27-day rotational period is caused by the uneven distribution of plages on the solar disc. The available observations are reported on Figure 12.

Measurements of the H I Lα emission line lead to a maximum of 30 percent variation during solar cycle 20 (Vidal-Madjar, 1977). The observations made during cycle 21 from the AE-E satellite and published by Hinteregger (1981) confirm this

TABLE III

Comparison of solar irradiance ($h\nu\ \mathrm{s}^{-1}\ \mathrm{cm}^{-2}$) between 330 and 400 nm

Wavelength interval (nm)	Heath (1980)	Neckel and Labs (1981)	Ratio (H/N-L)
330–335	838×10^{12}	793×10^{12}	1.06
335–340	797	763	1.04
340–345	841	792	1.06
345–350	832	799	1.04
350–355	940	926	1.02
355–360	851	842	1.01
360–365	939	930	1.01
365–370	1141	1140	1.00
370–375	1017	941	1.08
375–380	1144	1163	0.98
380–385	945	938	1.01
385–390	1029	1001	1.03
390–395	1045	1066	0.98
395–400	1290	1329	0.97

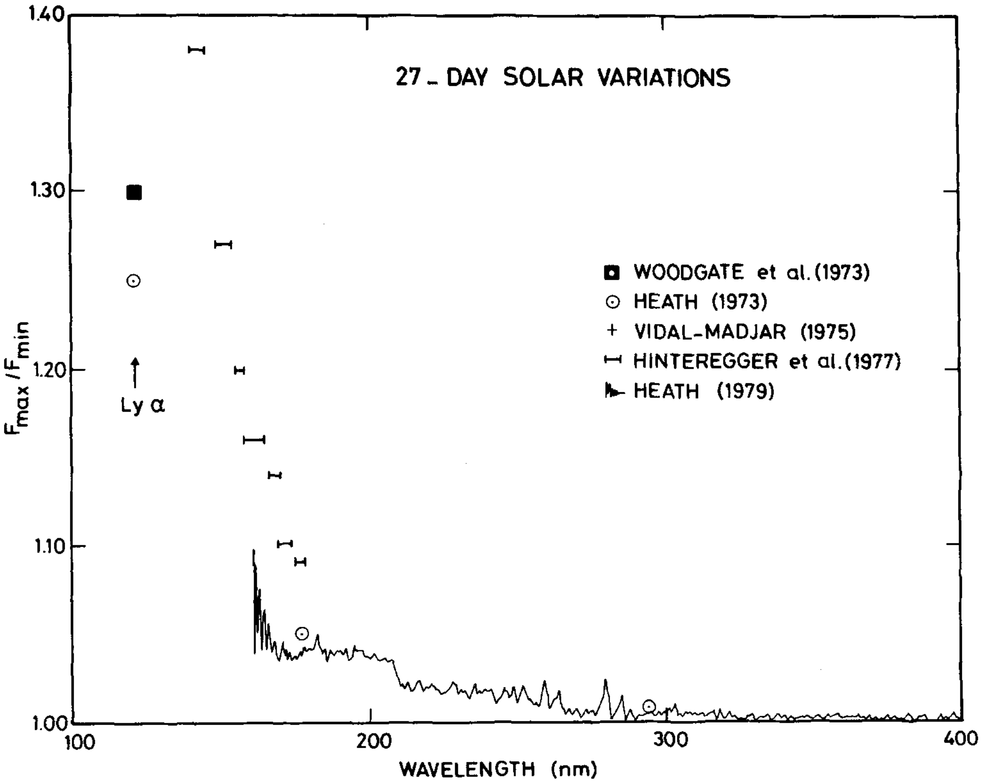

Fig. 12. Solar irradiance variation related to the 27-day rotational period of the Sun from H I Lα to 400 nm. The values of Hinteregger *et al.* (1977) correspond to the Carrington rotation No. 1615 (June 1974) and those of Heath (1980) to Dec. 2, 1978, Jan. 2, 1979, and Feb. 5, 1979 for maximum values and to Dec. 21, 1978, Jan. 18, 1979, and Feb. 27, 1979 for minimum values.

value with some exceptions as in December 1979 where a variation of 40 percent over one solar rotation has been observed. H I Lα irradiance variability with the 27-day rotational period is generally well correlated in amplitude and phase with other chromospheric lines as for instance H I Lβ and He I.

Very few observations have been made at longer wavelengths. Heath (1973) published reliable data obtained from broad-band sensors on board satellites Nimbus 3 and 4, launched respectively in April 69 and in April 1970. Other observations performed during solar cycle 20 have been carried out by Hinteregger *et al.* (1977) who measured ultraviolet irradiance variations during the 1974–1976 period by means of the EUVS experiment on board the AE-C satellite. Maximum values observed in June 1974 have been drawn on Figure 12. An additional

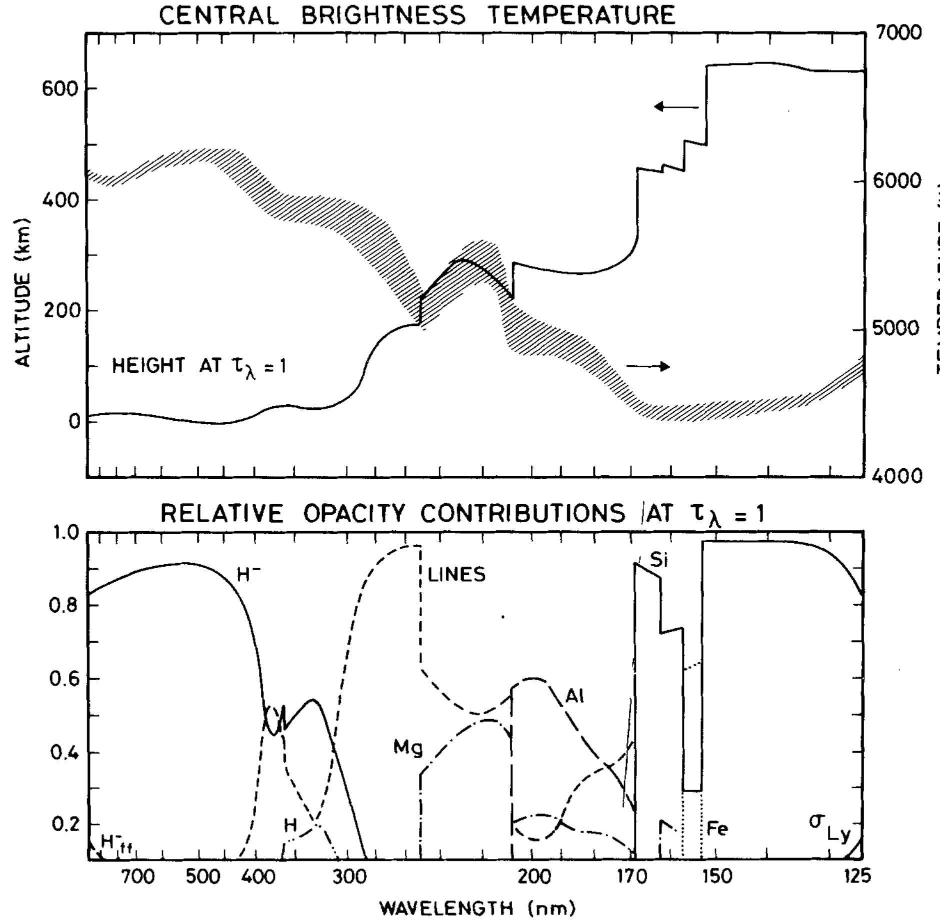

Fig. 13. Continuum brightness temperature at the disc centre (shaded area) and height in the solar atmosphere for optical depth $\tau_\lambda = 1$ above $\tau_{500} = 1$ as a function of wavelength. The lower panel illustrates the relative contribution to the opacity at that height. ($\tau_\lambda = 1$). The symbols H, Si, Al, Mg, and Fe refer to neutral atom bound-free absorption, σ_{Ly} to scattering in the H I Lα line wing, and 'lines' to a smoothly varying approximation to the effects of line blanketing. From Vernazza *et al.* (1976).

observation has been performed by Prag and Morse (1970) but their results were obtained only for one solar rotation, leading to a variation of more than 50 percent for the broad wavelength interval 160–210 nm. This value is inconsistent with the data obtained by Heath (1973) and Hinteregger *et al.* (1977) and also with the new observations between 160 and 400 nm obtained by Heath (1980) with the SBUV experiment on board the Nimbus 7 satellite. The latter data represent the ratio of maximum irradiance average over three orbits with minimum irradiance average over three other orbits, measured in December 1978, January and February 1979.

The main spectral features of variation are the discontinuities corresponding to the Si I ^1D at 168.3 nm and to the Al I absorption edge at 207.6 nm and peaks for instance at 280 nm corresponding to the Mg II h and k lines. Variations with the 27-day rotational period are therefore strongly correlated with the solar spectral features related to radiations emitted from different layers in the solar atmosphere. Figure 13, taken from Vernazza *et al.* (1976) shows the approximate height in the solar atmosphere where the radiation is formed as a function of wavelength. The reference level is taken for an optical depth at 500 nm equal to 1. The shaded area gives the corresponding observed continuum brightness temperature at the disc centre. The lower panel gives the relative opacity contribution at the same height due to the H, Si, Al, Mg, and Fe neutral atom bound-free absorptions.

Figure 12 shows clearly that the 27-day variations are decreasing with increasing wavelengths up to 170 nm. Between 170 and 210 nm, the mean variation is nearly constant and is of the same order of magnitude as the variability due to the semi-annual change of the Sun–Earth distance leading to a ±3.3 percent variation for the total irradiance.

Beyond 210 nm, variations are generally lower than 2 percent and are decreasing with increasing wavelengths, except for specific wavelengths for which the magnitude of the variations depends on the strength of the Fraunhofer lines.

7. Variability with the 11-Year Cycle

The solar irradiance variability with the 11-year cycle is very poorly known for all the solar spectrum. The inadequate time coverage of reliable data, specially during solar cycle 20, the uncertainties associated with each measurement and the lack of cross-calibration of the different instruments used for irradiance observations do not permit quantitative conclusion on long-term solar variability (Delaboudinière *et al.*, 1978; Simon, 1978).

During solar cycle 21, the only available measurement of long-term variation has been published by Hinteregger (1981). The 137–185 nm wavelength interval was measured from July 1976 to March 1979 by means of one channel of the EUVS experiment on board the AE-E satellite, with a 6 arc min × 6 arc min field of view around the centre of the solar disc. Consequently, these measurements have to be converted into full-disc equivalent values of irradiance. The ratios of the January

22, 1979 irradiances with the average of irradiance values over 24 sets of observations in July 1976 from days with Zurich sunspot number equal to 0 and with the 10.7 cm solar flux lower than 70 are given on Figure 14. The wavelength dependence of the long-term variability appears clearly from these data. Three different spectral features can be distinguished: the first for wavelengths shortward 150 nm, the second between 150 and 170 nm, and the third for wavelengths longward 170 nm. These three spectral intervals correspond roughly to solar radiations emitted from different altitudes in the solar atmosphere as it is illustrated on Figure 13. The shortward wavelength range corresponds to the chromospheric region of the solar spectrum below the edge of Si I ^3P at 152.5 nm where the solar disc exhibits limb brightening while the longward wavelength range correspond to the photospheric region of the solar spectrum beyond the Si I ^1D discontinuity at 168.3 nm. The region between these two Silicon edges corresponds to the photosphere-chromosphere transition zone where the temperature minimum in the solar atmosphere occurs (cf. Figure 13). The mean-to-center intensity ratios determined in the same wavelength range by Samain and Simon (1976) has also been drawn on Figure 14 in order to illustrate the correlation between the long-term variability features with the layers of the solar atmosphere from which the radiation arises.

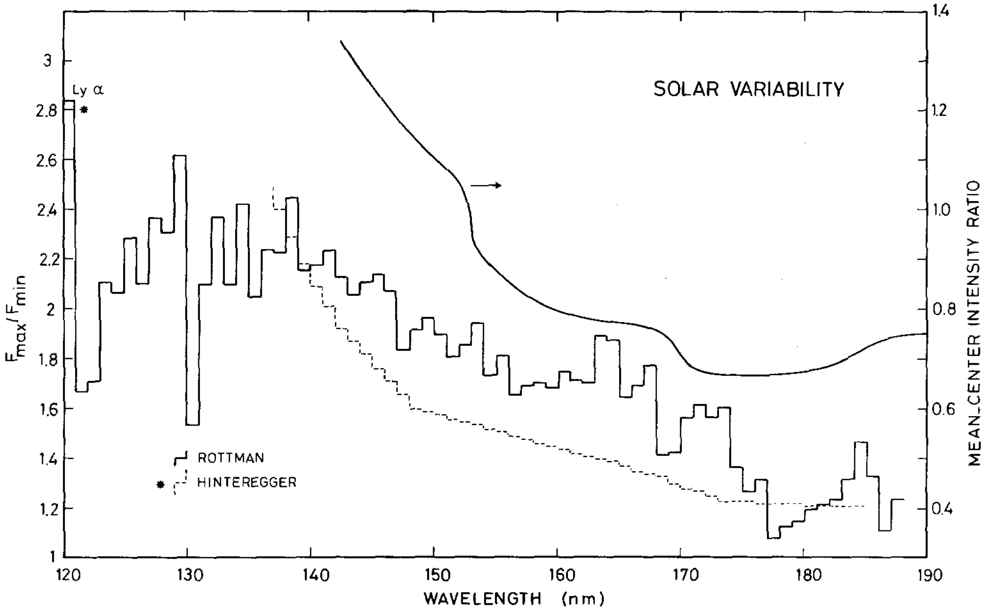

Fig. 14. Solar irradiance variability ($F_{\max}/F_{\min}$) related to the rising phase of solar cycle 21, from 120 to 185 nm. The mean-to-center intensity ratios taken from Samain and Simon (1976) are also given for discussion (see text).

Ratio of the observation made in June 1979 and published by Mount *et al.* (1980) with the irradiance values proposed by Rottman (1981) for minimum conditions of the solar activity is also shown on Figure 14 for comparison purposes. The reliability of these latter data has already been discussed but their ratio shows a variability during the rising phase of cycle 21 higher than those observed by Hinteregger (1980).

The observations of Hinteregger (1981) lead to long-term variability of the order of 20 percent at 185 nm. Consequently, the previous factor of 2 variation around 200 nm suggested by Heath and Thekaekara (1977) and extensively discussed by Simon (1980) is not confirmed.

Theoretical calculations have been made very recently by Cook *et al.* (1980) in order to attempt to correlate the available observations of solar variability with a simple two component model of the solar irradiance between 117.5 and 210 nm. It assumes that the irradiance variability is caused only by the fraction of the solar surface covered by plages. The agreement with the variability published by Hinteregger (1980) is reasonably good but this simple model is not recommended to replace irradiance variability measurements.

Possible long-term variability beyond 210 nm has been investigated by means of balloon measurements performed since 1976 with identical instruments (Simon *et al.*, 1981a, b; Thuillier and Simon, 1981). Comparison of the data between 210 and 240 nm does not permit to detect any variability which is still masked by the precision of 10 percent in available observations. Very recently, Heath (1981) reported a solar irradiance decrease around 210 nm of the order of 8 percent during 10 months of observation starting in November 1978. Such possible variability needs to be confirmed by further observations and also would be compared with possible cooling of the Sun's atmosphere observed by Livingstone (1978). In all cases, the previous long-term variability suggested by Heath and Thekaekara (1977) is no more confirmed in this wavelength range.

Around 300 nm, there is no experimental evidence of long-term variability higher than the uncertainties of reliable observations (see Table II). In addition, the continuum of the solar spectrum at 300 nm is emitted from the same region as the visible continuum (cf. Figure 13). Consequently, any variation of irradiance in the visible would correspond to similar change at 300 nm. According to the solar model atmosphere of Kurucz (1979), 1 percent variation of the solar irradiance at 500 nm would correspond to about 1.2 percent variation at 300 nm. Consequently, any observation of long-term variability beyond 300 nm requires a precision better than 1 percent.

8. Conclusion

The current position of irradiance measurement accuracies and of discrepancies between the different relevant observations is summarized in Table IV for wavelengths from 120 to 400 nm. Possible long-term variations with the 27-day rotational period and the 11-year activity cycle of the Sun are also given on the basis of recent observations performed during solar cycle 21. The requirements for future measurements related to aeronomy and climatology are specified with the uncertainties of the available laboratory radiometric standard sources (Madden, 1978).

TABLE IV

Uncertainties on solar ultraviolet irradiance measurements and future needs

$\Delta\lambda$ (nm)	H I Lα	135–175	175–200	200–240	240–330	330–400
Quoted accuracy	30%	30–20%	30–20%	20–10%	10–4%	4%
Discrepancies between relevant observations	2	2	50%	50–20%	15%	10%
Variability (27-day)	30%	30–4%	4%	4–2%	2–1%	<1%
Variability (11-year)	3%	200–20%	20–<10%	<10%	<2%	<1%
Required accuracy	10%	5%	5%	5%	5 to 2%	
Required precision	5%	5–1%	1%	1%	<1%	
Uncertainties on available standard sources	5%	5%	5%	5%	3%	2%

The basic problems encountered up to now in the measurement of the solar irradiance and of its variations are the uncertainties associated with each observation, the inadequate time coverage of reliable data even during the rising phase of solar cycle 21, the lack of intercomparison of calibration techniques used by different experimenters and the important gap between the measurement accuracy and the current accuracy of the available laboratory radiometric standards. In addition, the precision of long-term observations does not permit to deduce quantitative variations with the 11-year cycle lower than 10–15 percent.

Improvements in future ultraviolet irradiance measurements will be only achieved if the following steps are taken:

(1) A careful calibration in the laboratory should be made, allowing the transfer of the radiometric standard accuracy to the instrument with as small a degradation as possible.

(2) The errors introduced by the measurements on the Sun itself should be reduced by appropriate techniques, thus allowing a measure, or elimination, of the degradation of the calibration accuracy in the space environment.

(3) Observations with different experimental techniques should be made in order to eliminate systematic errors. Intercomparisons of the calibration instrument, referring to a common standard source, should be performed *before* the flights, to ensure a proper intercomparison of irradiance results after the flights.

The question of variability of solar irradiance could be solved if new observations are performed with a correct time sampling by means of repeated measurements having a very high precision. Variability measurements made from satellites will be useful only if the aging of the instrument sensitivity can be checked in orbit or if cross-calibrated observations with balloon, rocket, or shuttle-borne instruments are performed.

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