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Observation of the solar ultraviolet radiation

by

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FOREWORD

This paper has been presented at the NATO Advanced Study Institute on Atmospheric Ozone which was held at Albufeiras (Portugal) from October 2 to October 13, 1979. It will be published in the proceedings of the conference.

AVANT-PROPOS

Cet article résume une communication présentée au "NATO Advanced Study Institute on Atmospheric Ozone" qui s'est tenu à Albufeiras (Portugal) du 2 au 13 octobre 1979. Il sera publié dans les compte-rendus de la conférence.

VOORWOORD

Dit artikel werd voorgedragen op het "NATO Advanced Study Institute on Atmospheric Ozone" dat werd gehouden te Albufeiras (Portugal) van 2 tot 13 oktober 1979. Het zal gepubliceerd worden in de verslagen van deze conferentie.

VORWORT

Diese Artikel wurde durch die "NATO Advanced Study Institute on Atmospheric Ozone" aufgetragen, die sich in Albufeiras (Portugal) enthalten hat von den 2 bis den 13 Oktober 1979. Es wird in die Vorträge der Konferenz publiciert.

OBSERVATION OF THE SOLAR ULTRAVIOLET RADIATION

by

P.C. SIMON

Abstract

Ultraviolet solar irradiance observations at Lyman α and between 175 and 400 nm are reviewed and discussed. The uncertainties between the different measurements are pointed out and the discrepancies are discussed in terms of solar variability, showing the needs of new observations in order to determine accurately the absolute value of solar ultraviolet irradiation fluxes and its possible variation with the 11-year solar cycle.

Résumé

Les différentes observations du flux solaire ultraviolet à Lyman α et entre 175 et 400 nm sont présentées et discutées. La précision des mesures et les désaccords entre les observations récentes sont analysés en tenant compte des variations éventuelles dues à l'activité du soleil, montrant la nécessité de nouvelles mesures pour déterminer avec précision la valeur absolue du flux solaire dans l'ultraviolet et sa variation avec le cycle de 11 ans.

Samenvatting

De verschillende waarnemingen van de ultraviolette zonneflux bij Lyman α en tussen 175 en 400 nm worden voorgesteld en besproken. De nauwkeurigheid van de metingen en het gebrek aan overeenstemming tussen de recente waarnemingen worden geanalyseerd met betrekking tot de veranderingen verbonden aan de zonneactiviteit. De noodzaak van nieuwe metingen voor de nauwkeurige bepaling van de absolute waarde van de zonneflux in het ultraviolet en zijn verandering in functie van de elfjarige cyclus wordt aangetoond.

Zusammenfassung

Die verschiedene Beobachtungen des Ultraviolette Sonnenstrahlung zwischen 175 und 400 nm sowie für Lyman α sind besprochen worden. Die Präzision der Messungen und der Unterschied zwischen die verschiedene Messungen ist mit die Schwankungen der Sonnenaktivität verglichen worden. Diese Arbeit zeigt dass neue Messungen mit höhere Präzisionen in die U-V Wellenlänge nötig sind, um die 11-Jahre Cyclus der Sonnenaktivität zu studieren.

I. INTRODUCTION

The photodissociation processes of atmospheric constituents in the stratosphere and in the mesosphere are initiated by the solar radiation of wavelengths greater than 175 nm. As discussed extensively by Nicolet (1979), the penetration of solar irradiances in this wavelength range is driven by the absorption of molecular oxygen and of ozone, and by the Rayleigh scattering of light. Radiations of wavelengths below 175 nm are absorbed in the thermosphere, except for the Lyman α emission line which penetrates deeply into the mesosphere, leading to the formation of the ionospheric D-region, and for the X-rays of wavelengths less than 1 nm. In order to determine the most reliable solar irradiation flux values to be used in photochemical models of the middle atmosphere, an accurate knowledge of the solar irradiances in the ultraviolet is required. Consequently, the available measurements must be critically discussed and compared.

Only full disc observation are pertinent for aeronomic purposes. Observations made with a spatial resolution on the solar disc cannot be considered because of the center-to-limb variation of the solar radiation. For instance, flux measurements made at the center of the disc for wavelengths beyond 152 nm represent only an upper limit for the corresponding irradiance values because of the limb-darkening occurring in this part of the solar spectrum (Samain et al, 1975).

Among the most serious difficulties in determining the correct value of the solar irradiance are the uncertainties associated with each observation and the lack of intercomparison of the calibration techniques used by the different experimenters. On the other hand, when comparing different sets of data, the possible variability of the solar fluxes with the 27-day rotation period of the sun and with the 11-year activity

cycle must be taken into account. Variation related to solar flares can be neglected in the considered wavelength range, except for the Lyman α emission line for which an enhancement of the order of 16% has been observed by Heath (1969) for a 3B flare and confirmed by Hall (1971) for other flare observations.

The purpose of this work is to present the recent ultraviolet solar irradiance measurements related to the middle atmosphere aeronomy, including the Lyman α solar line. The uncertainties associated with the different experimental techniques of observation will be pointed out and the discrepancies between the data will be tentatively discussed in terms of solar variability.

II. OBSERVATIONAL DATA

The Lyman α emission line

The first measurement of Lyman α irradiance was performed in 1949 by Friedman et al., (1951) using a rocket-borne photon counter and yield only an order of magnitude, between 3.7×10^{10} and 3.7×10^{11} $\text{hv} \cdot \text{sec}^{-1} \cdot \text{cm}^{-2}$, for the intensity of this very strong chromospheric line. Since that time, many measurements, using various observational techniques, and leading to a conventional value of 3×10^{11} $\text{hv} \cdot \text{sec}^{-1} \cdot \text{cm}^{-2}$ have been made. For most of the observations, the quoted accuracy is of the order of $\pm 30\%$. That means that the irradiance of Lyman α should be included between 2.1 and 3.9×10^{11} $\text{hv} \cdot \text{sec}^{-1} \cdot \text{cm}^{-2}$.

Variations of this solar line with the 11-year cycle and with the 27-day rotational period of the sun, have to be considered and seem confirmed by observations performed during the solar cycles 19 and 20. But such variations are of the same order as the absolute accuracy claimed by the different experimenters. Hence, a main problem is to determine if these observed variations are due to calibration uncertain-

ties, instrumental degradation or correspond to a real physical change of the solar output at this wavelength. The results obtained during the solar cycle 19 are summarized in table 1. These show a decrease from solar maximum conditions in 1960 to 1963, except for the value of Hinteregger (1961) which appears to be rather low in comparison with the other observations. During the same solar cycle, Weeks (1967) made an analysis of the results obtained by means of ion chambers over the interval between 1955 and 1966. His conclusion is that the variation of the Lyman α irradiance appears to be of the order of 40% over the 11-year solar cycle.

Figure 1 shows the results of measurements performed during solar cycle 20. The most reliable measurements of Lyman α variation are those obtained by means of the OSO 5 satellite (Vidal-Madjar, 1975). The experiment, which exhibits an instrumental sensitivity degradation of only 10% per year, leads to a variation of the order of 40%. Empirical relations relating the variability of Lyman α irradiance with the 10.7 cm solar flux have been proposed by Vidal-Madjar (1975).

Variations related to the 27-day rotational period of the sun were measured for the first time by Kreplin et al. (1962) who deduced from SR 1 satellite observations, variations less than 18% in July 1960. Since that time, a maximum of solar variability of the order of 30% has been proposed on the basis of the observations of Hall and Hinteregger (1970), Heath (1973), Woodgate et al. (1973) and Vidal-Madjar (1975).

Nevertheless, due to calibration and instrumental problems, any quantitative conclusion concerning the solar Lyman α variations may be subject to doubt. Table 2 presents a comparison of the OSO 5 data with rocket flight observations, showing that most of the data from rocket measurements are in good agreement with the OSO 5 results (less than 10%). Consequently, the 30% variation with the 27-day rotational period of the sun and the factor of 2 variation with the 11-year cycle

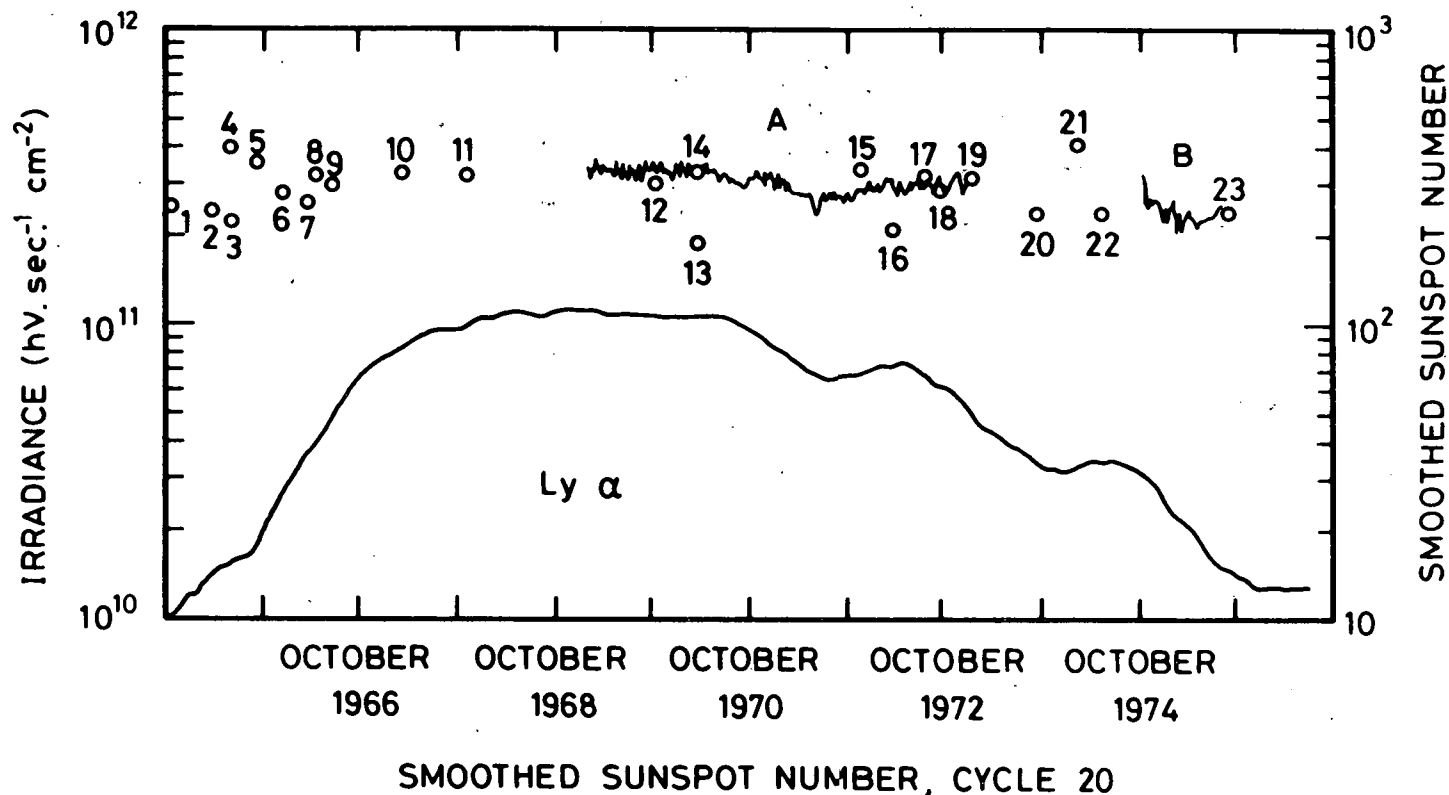


Fig. 1.- Comparison of Lyman α solar irradiation flux measurements during the solar cycle 20. The smoothed sunspot numbers are also shown. References: 1, 2, 3, 4, 5, 6 and 9, Weeks (1967); 7, Fossi et al. (1969); 8, Bruner and Parker (1969); 10, Hinteregger (1970); 11, Bruner (private communication); 12, Woodgate et al. (1973); 13, Smith (1972); 14, Dickinson (1972); 15, Higgins (1976); 16, Ackerman and Simon (1973); 17, Prinz (1974); 18, Heroux et al. (1974); 19 and 20, Rottman (1974); 21, Oshio (private communication); 22, Heroux (private communication); 23, Rottman (private communication); A, Vidal-Madjar (1975); B, Vidal-Madjar (private communication) (after Delaboudinière et al., 1977).

TABLE 1.- Observation of the Lyman alpha irradiance during solar
cycle 19.

Date	$10^{11} \text{ h sec}^{-1} \text{ cm}^{-2}$	Instrumentation	Reference
Oct 18, 1955	3,5	Ion Chamber	<u>Byram et al</u> (1956)
Oct 21, 1955	2,4	Ion Chamber	Id.
Nov 4, 1955	5,5	Ion Chamber	Id.
Dec 13, 1955	1,8	Spectrograph	<u>Miller et al</u> (1956)
Jul 20, 1956	3,7	Ion Chamber	<u>Chubb et al</u> (1957)
Jul 25, 1956	4,1	Ion Chamber	Id.
Jul 20, 1957	3,7	Ion Chamber	<u>Byram et al</u> unpu- blished data
Aug 6, 1957	2,1	Spectrograph	<u>Aboud et al</u> (1959)
Mar 23, 1958	3,9	Ion Chamber	<u>Byram et al</u> unpu- blished data
Jul 21, 1959	3,7	Ion Chamber	<u>Purcell and</u> <u>Tousey</u> (1960)
Jan 19, 1960	3,7	Ion Chamber	<u>Hinteregger</u> (1960)
Apr 19, 1960	3,7	Ion Chamber	<u>Detwiler et al</u> (1961)
Aug 20, 1960	3,4	Photoelectric	<u>Efremov et al</u> (1962)
Aug 23, 1960	2,0	Monochromator	<u>Hinteregger</u> (1961)
Aug 23, 1961	3,1	Monochromator	<u>Hall et al</u> (1963)
Dec 12, 1963	2,7	Monochromator	<u>Hall et al</u> (1965)

TABLE 2.- Lyman alpha irradiance : comparison of the OSO 5 data with
 rocket flight observations (after Vidal-Madjar, 1977)

	OSO 5 ($10^{11} \text{ h} \cdot \text{sec}^{-1} \cdot \text{cm}^{-2}$)	Rocket data	Reference for rocket data
Mar 7, 1970	4,41	- 6%	<u>Dickinson</u> (1972)
Nov 9, 1971	~ 2,8	+ 26%	<u>Higgins</u> (1976)
Feb 28, 1972	~ 3,0	- 30%	<u>Ackerman and</u> <u>Simon</u> (1973)
Jul 10, 1972	3,1	+ 8%	<u>Prinz</u> (1974)
Aug 23, 1972	2,99	- 3%	<u>Heroux et al</u> (1974)
Dec 13, 1972	2,88	+ 10%	<u>Rottman</u> (1974)

deduced from the OSO 5 satellite, should be realistic but need experimental confirmation during the following solar cycles.

The 175-240 nm wavelength interval

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

The source of the solar spectrum in this wavelength interval lies in a transition region of the solar atmosphere, between the photosphere and the chromosphere. Absorption lines which dominate the solar spectrum in the visible and in the near ultraviolet disappear progressively in the vacuum ultraviolet range in which emission lines of chromospheric origin become predominant around 150 nm. This is illustrated in figures 1 and 2 published by Samain and Simon (1976) .

Unfortunately, the solar irradiation fluxes are not sufficiently well known, especially between 175 and 200 nm, corresponding to the Schumann-Runge absorption band system of molecular oxygen. The first measurement of solar irradiance in this wavelength interval were made by Detwiler et al. (1961) in 1960 by means of a rocket-borne spectrograph, but their results appear too high, by a factor of 3, in comparison with the more recent observations. The only measurements covering all the 175-200 nm wavelength interval are those of Samain and Simon (1976) and those of Brueckner et al. (1976). They measured, respectively, the solar radiance at the center of the disk and at a selected area of the quiet sun using photographic recording techniques. These radiances were converted into solar irradiance using the center-to-limb variations measured by Samain and Simon (1976). Other values covering, partially, the same wavelength range have been obtained by Rottman (1974), Simon (1974) and Heroux and Swirbalus (1976). All this results are given in figure 2 for comparison. The agreement between

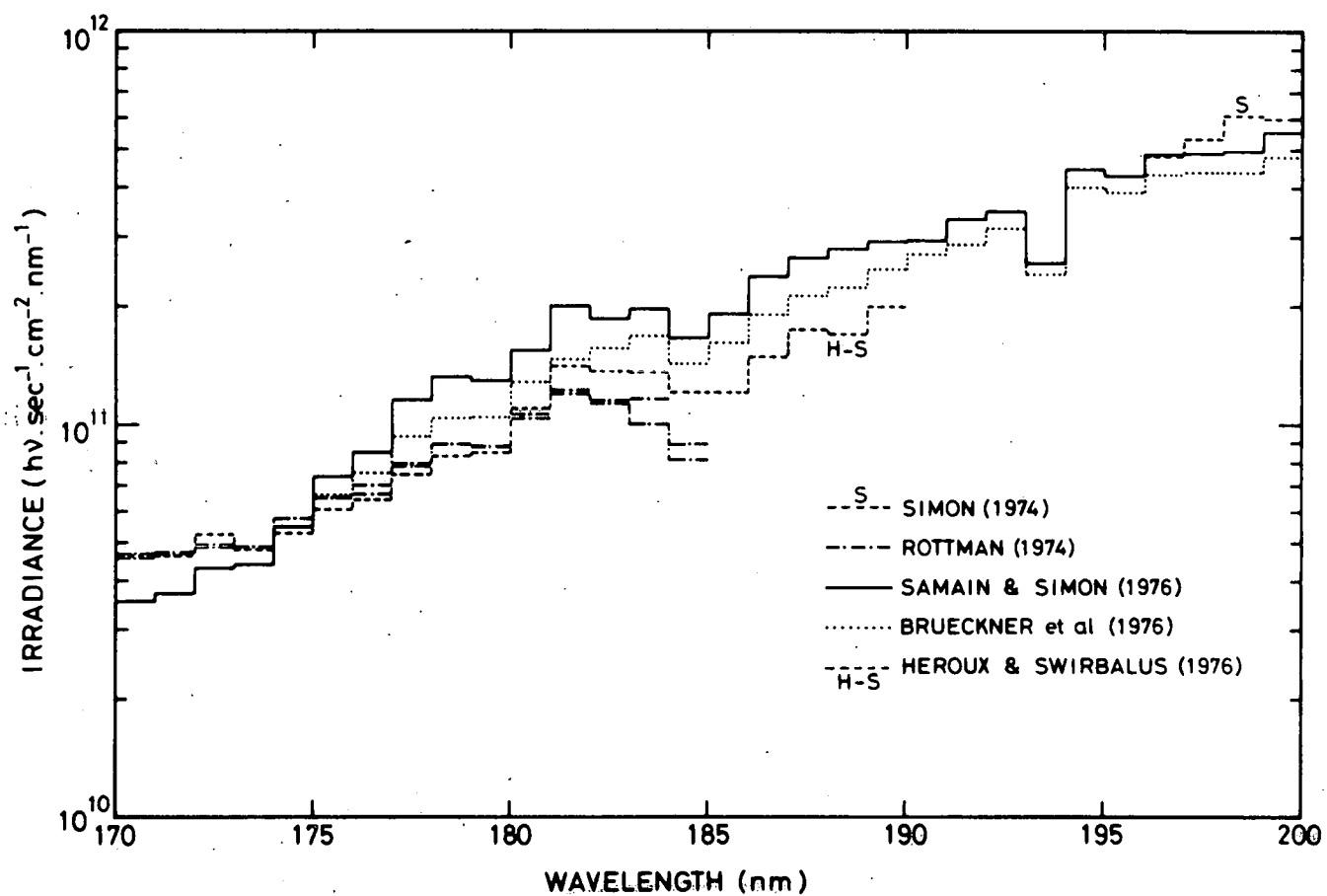


Fig. 2.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 170 to 200 nm.

these authors is good at 175 nm but beyond this wavelength, disagreement, reaching a factor of two, can occur for given wavelengths. The agreement becomes better, within 20%, around 200 nm for the observations of Simon (1974), Samain and Simon (1976) and Brueckner et al. (1976). It should be pointed out that solar irradiances determined by Samain and Simon (1976) and by Brueckner et al. (1976) are not direct measurements of the full disc. They used limb-darkening data in order to determine irradiance values from radiance data based on photographic spectra for which calibration procedures are more complicated. This method introduces certain additional errors, leading to less accurate results. On the other hand, both instruments used by Rottman (1974) and by Heroux and Swirbalus (1976) have photoelectric detectors with a solar blind CsI photocathode for which the quantum yield exhibits a rapid decay for wavelengths greater than 185 nm. This is illustrated in figure 1 published by Heroux and Swirbalus (1976). Thus, accuracies of solar irradiation flux measurements beyond this wavelength are not as good as those at lower wavelengths because the laboratory determination of the spectral sensitivity could have more important experimental uncertainties. In conclusion, one may consider that, between 180 and 190 nm, the data of Samain and Simon (1976) represent the upper limit for the solar irradiance while the data of Heroux and Swirbalus (1976) could give a lower limit. Consequently, the solar irradiation flux is only known with a precision of $\pm 25\%$ in this wavelength range and a mean value between the different observations should be introduced in the photodissociation calculations.

Beyond 200 nm, the recently published measurements of Broadfoot (1972), Simon (1974) and Simon et al. (1980) should be only considered in deducing the solar irradiation flux values. They are given in figure 3 and 4 for comparison. The previous observations of Ackerman et al. (1971), obtained by means of a balloon-borne spectrometer, are 40% higher than those obtained by Simon (1974) who used a spectrometer integrated in a stabilized gondola. This allowing direct pointing of the instrument toward the sun.

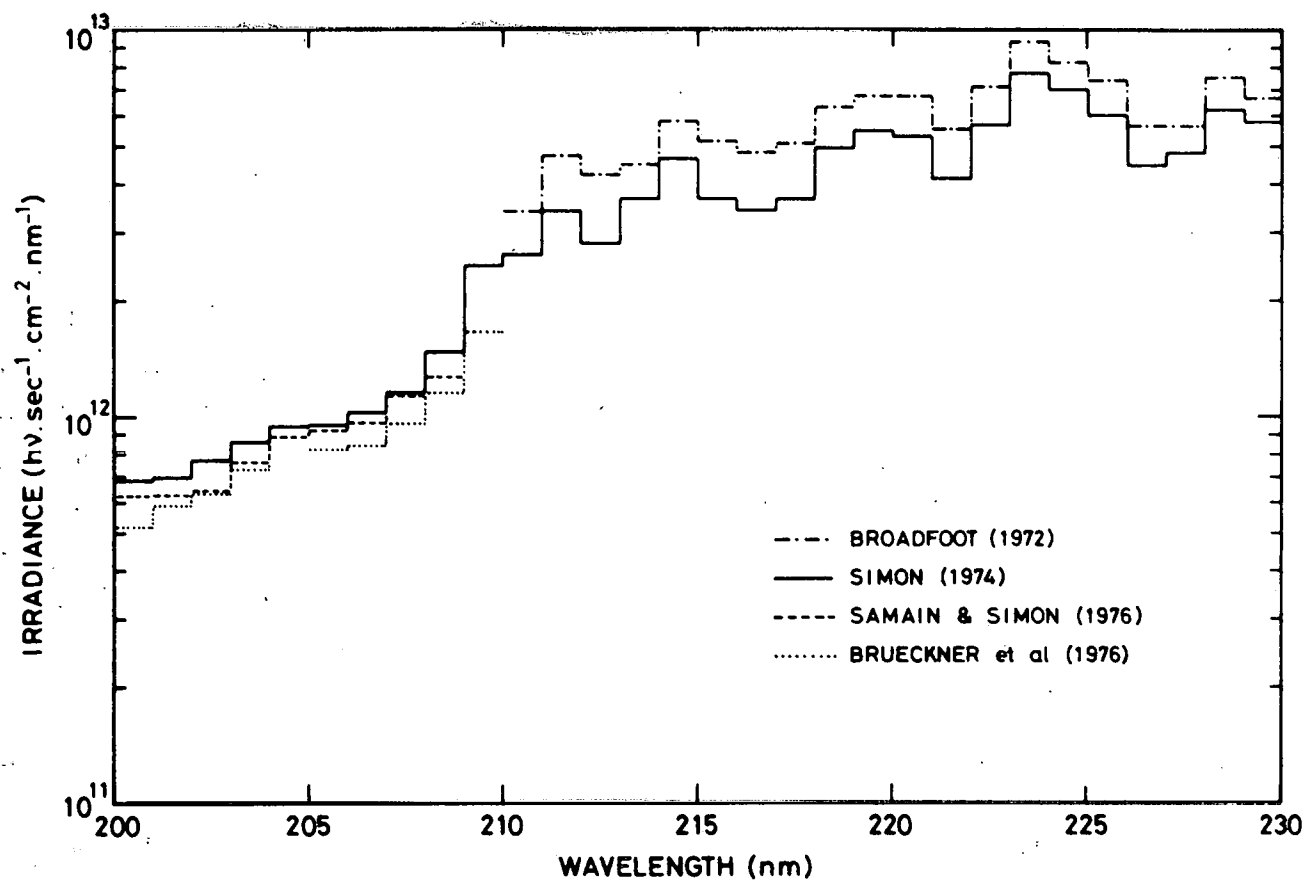


Fig. 3.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 200 to 230 nm. The measurements made by Ackerman et al (1971) and Simon et al. (1980) are not represented here for the sake of clarity.

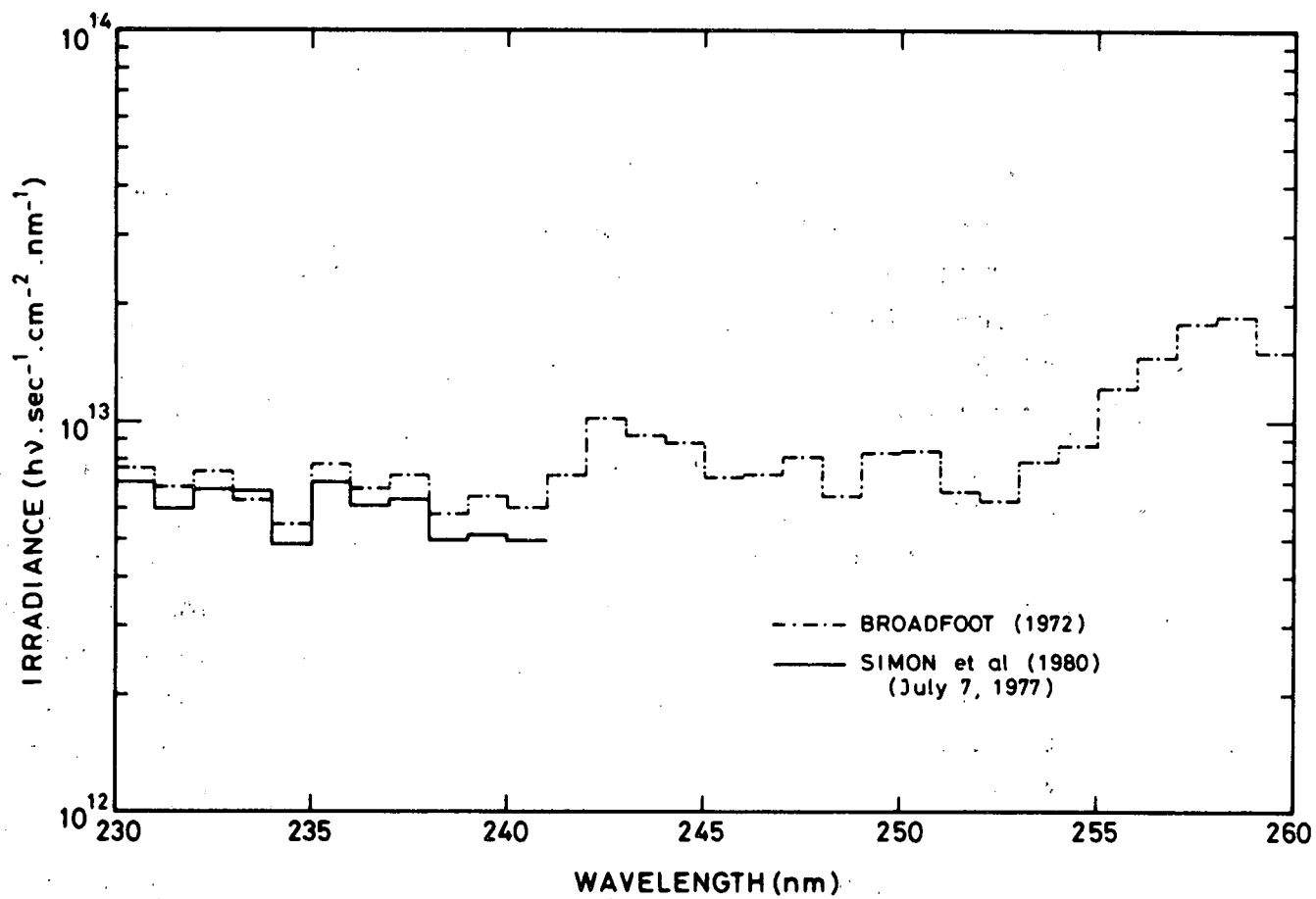


Fig. 4.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 230 to 260 nm.

The measurement of solar irradiation fluxes from balloon-based platforms must, obviously, be corrected for the residual absorption by molecular oxygen and ozone because of the floating altitude, of the order of 40 km, reached by a stratospheric balloon. Observations are made for different solar zenith angles and extraterrestrial solar irradiances can be deduced by extrapolation of measured solar fluxes to zero air mass. This can be done only if the floating altitude of the balloon is held rigorously constant 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 real stratospheric absorption. For this purpose, accurate determination of molecular oxygen and ozone concentration should be carried out during the solar flux observations, on the same gondola. Both reduction methods have been used for the data obtained in 1973 by Simon (1974), giving a good agreement, within $\pm 5\%$, between the results obtained through these two different ways. This except for wavelengths beyond 225 nm where the influence of the altitude variation is very important on solar irradiance values deduced by extrapolation to zero air mass, due to the higher ozone absorption cross section above 225 nm. Molecular oxygen content was determined through pressure measurements and ozone column density was measured by means of the solar spectra recorded between 270 and 285 nm by the same solar spectrometer.

New balloon observations have been performed in 1976 and in 1977, giving solar irradiance values between 210 and 240 nm with an accuracy of $\pm 15\%$ (Simon et al., 1980). The comparison with the previous balloon observations published by Simon (1974) and with the rocket measurement published by Broadfoot (1972) is shown on figure 5. The two recent balloon observations are, in general, in very good agreement, better than $\pm 5\%$, except beyond 235 nm. They give higher values than those published in 1974, with a maximum discrepancy of 9% for the 1976's flight and of 5% for the 1977's flight, over the 210-235 nm wavelength

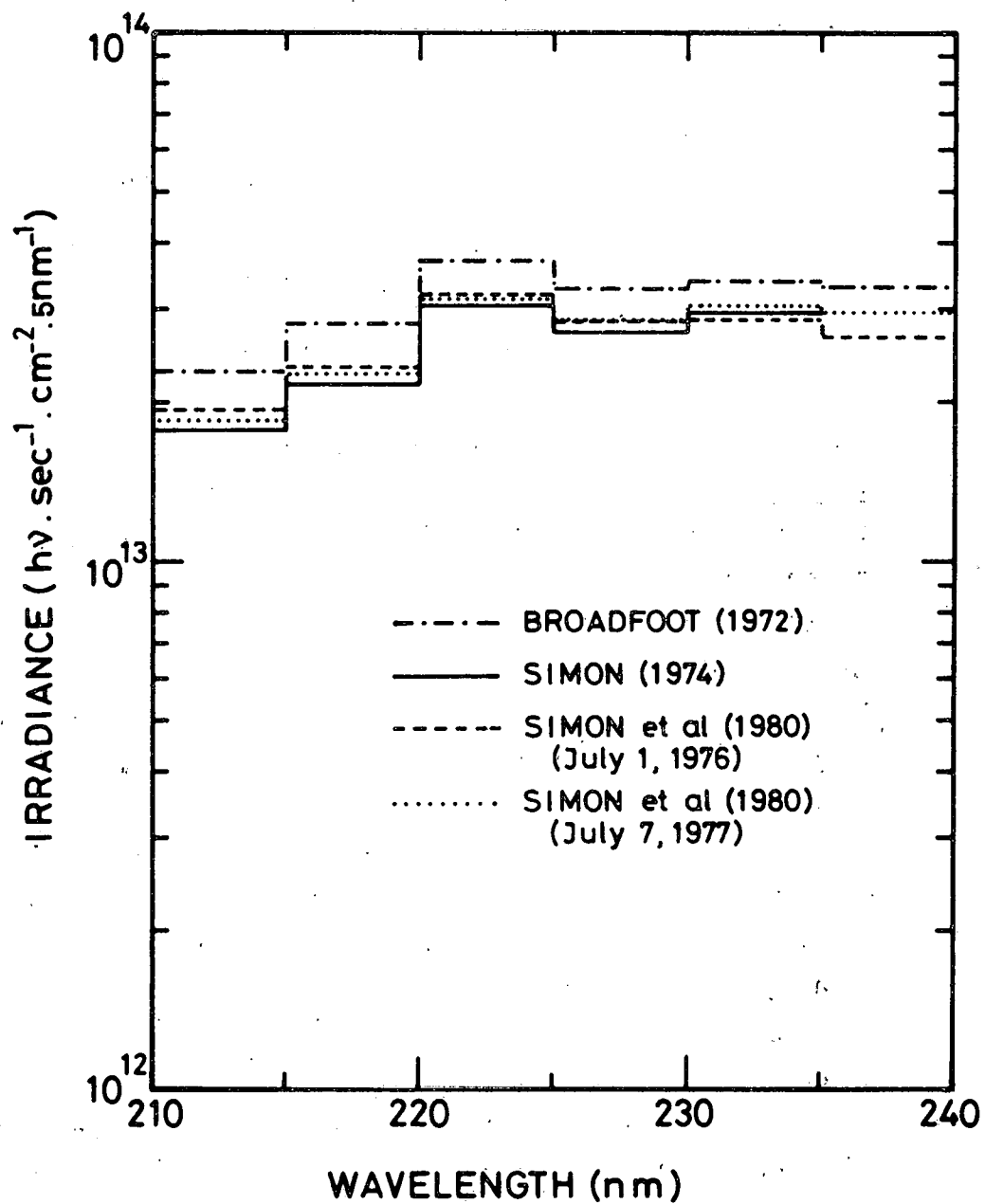


Fig. 5.- Comparison of ultraviolet solar irradiation flux integrated over 5 nm, obtained by balloon and rocket experiments between 210 and 240 nm.

interval. Broadfoot's results, given with an accuracy of $\pm 10\%$, are systematically higher by a factor varying from 23% to 12% for wavelengths increasing from 200 to 240 nm. Such disagreement could be due to different calibration techniques or could be interpreted in terms of solar variability with the 11-year cycle and will be discussed later.

The 240 - 400 nm wavelength interval

This wavelength interval mainly related to the photodissociation of ozone has been investigated by many observators involving rocket borne spectrometers measuring solar irradiance between 210 and 320 nm (Broadfoot, 1972), satellite measurements at 12 discrete wavelengths between 255 and 340 nm (Heath, 1973), balloon-borne observation between 270 and 350 nm (Simon, 1975 and Simon et al., 1980), aircraft measurements performed by Arvesen et al. (1969) from 300 nm up to the infrared and ground-based observations by Labs and Neckel (1970) between 330 nm and 1250 nm. The only measurement covering the wavelength range between 240 and 280 nm was published by Broadfoot (1972) who quoted a calibration accuracy of $\pm 10\%$. The agreement with results of Heath (1973) as rather good. These latter measurements of solar irradiances have been made with a double ultraviolet spectrometer on board the Nimbus 4 satellite, launch in April 1970. The final accuracy is limited by the accuracy of the standard source used, namely $\pm 8\%$ at 250 nm, $\pm 4\%$ at 290 and $\pm 3\%$ beyond 300 nm.

Figure 6, 7 and 8 presents measurements available beyond 280 nm. Discrepancies of the order of 25%, but reaching 40% at given wavelengths, appears is the 300-320 nm wavelength interval between Broadfoot (1972) and Arvesen et al. (1969). It should be pointed out that Broadfoot (1972) claimed an error larger than $\pm 10\%$ for only wavelengths beyond 300 nm while Arvesen et al. (1969) estimate their error to be $\pm 25\%$ at 300 nm, $\pm 6\%$ at 320 nm and $\pm 3.2\%$ at 400 nm. Conse-

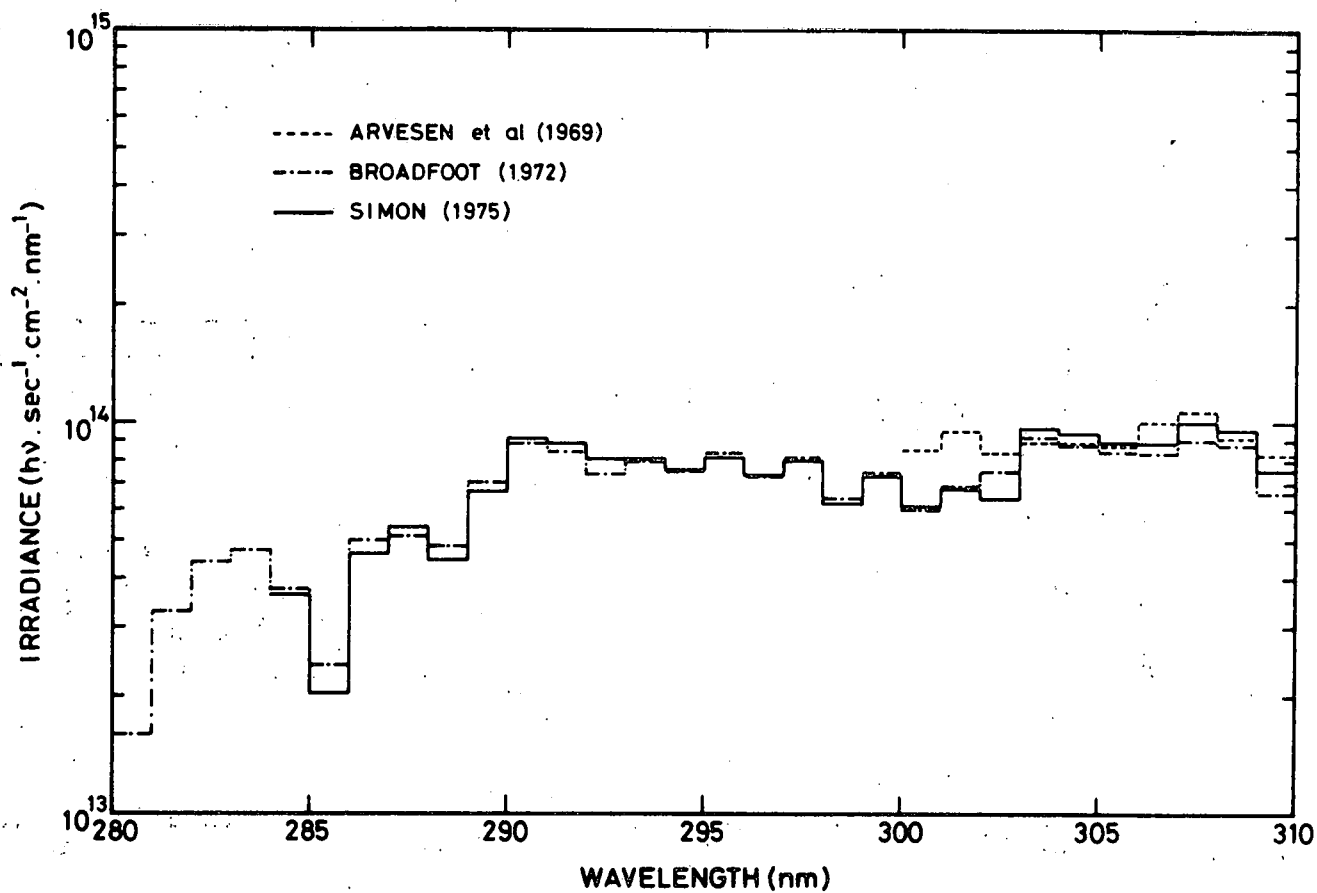


Fig. 6.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 280 to 310 nm.

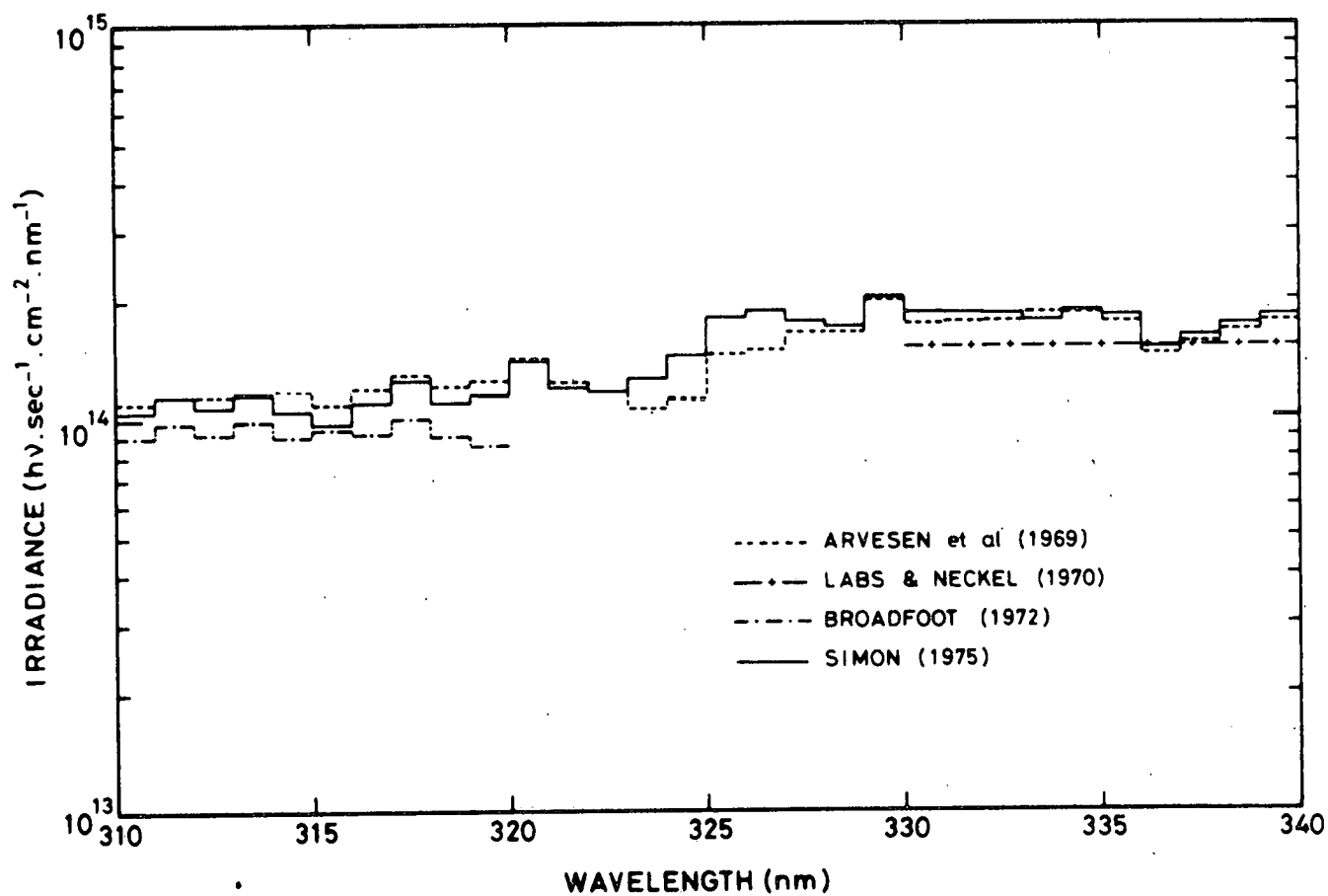


Fig. 7.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 310 to 340 nm.

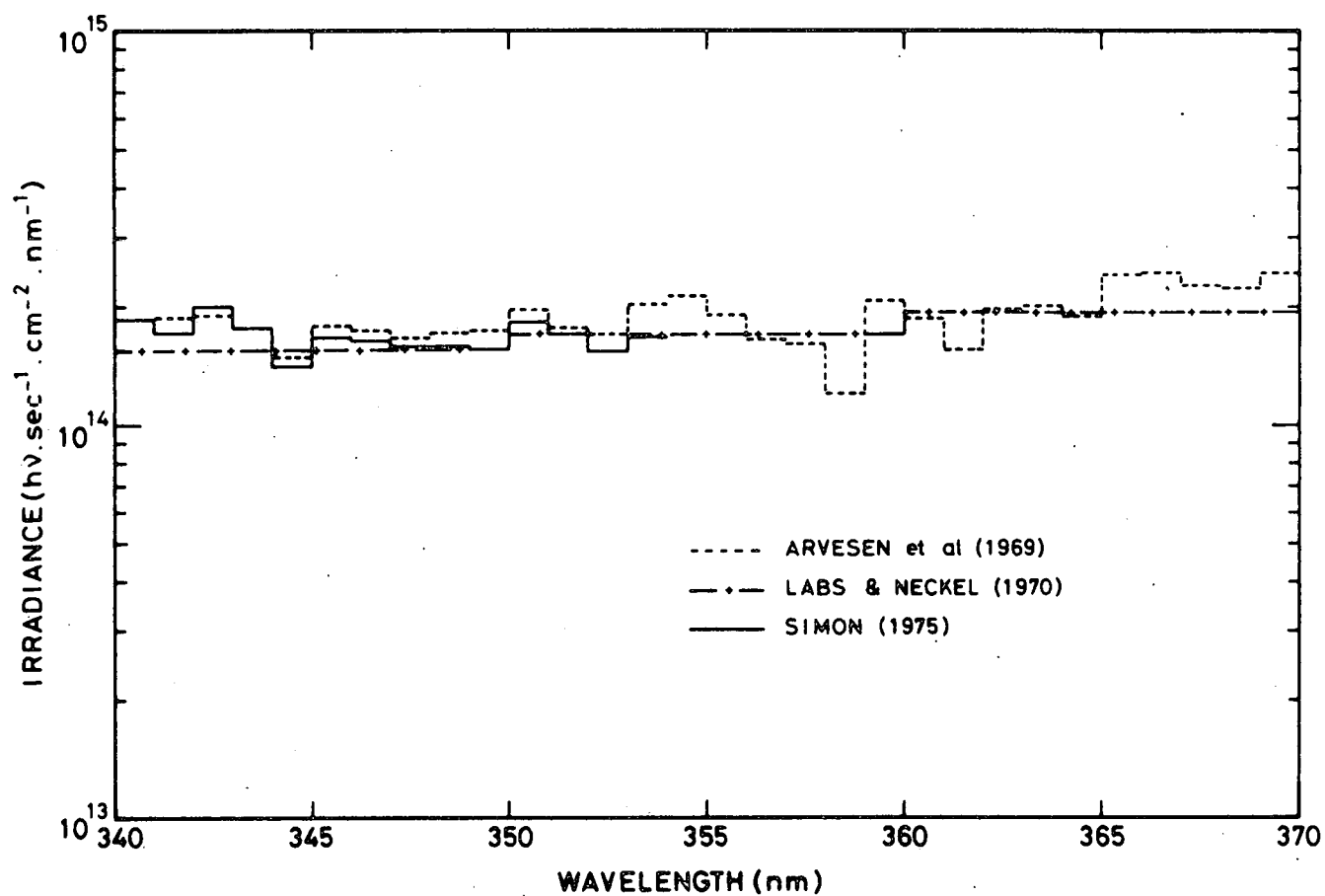


Fig. 8.- Comparison of ultraviolet solar irradiation fluxes reported by various experimenters from 340 to 370 nm.

quently, data between 300 and 320 nm, taken from these two observations, should be considered very carefully. On the other hand, the absolute radiometric scale used for calibration by Arvesen et al. (1969) suffers from uncertainties due to changes in the spectral irradiance scale of the National Bureau of Standards in 1973 (Kosthowski, 1974). For all these reasons, data published by Simon (1975), which are in good agreement with Broadfoot (1972) below 300 nm give useful solar irradiance in this wavelength region. In addition, new balloon observations performed in 1976 and 1977 (Simon et al., 1980) give solar irradiance within $\pm 10\%$, in agreement with the results obtained in 1972 and 1973 (figure 9). The absolute accuracy is of the order of $\pm 10\%$ and the good reproducibility of the different balloon experiments allows to conclude that the solar irradiance around 300 nm is actually known within 10%.

Other observations have been performed from a Convair Jet aircraft belonging to NASA by Thekaekara et al. (1969). The published irradiance values, integrated over 5 nm, are, in fact, an average between data coming from four different instruments. These are : a single and a double monochromator, a filter radiometer and an interferometer. Other irradiance values beyond 300 nm, with the wavelength interval of 0.1 nm, have also been published by Thekaekara (1974) but, unfortunately, an error in the wavelength scale makes it difficult to make a correct comparison with the other measurements (Simon, 1975).

Very accurate ground-based observations have been carried out by Labs and Neckel (1970) from a high mountain observatory for wavelengths beyond 330 nm. Irradiance values were deduced from radiance measurements near the disc center and converted into irradiation fluxes using the limb-darkening data of David and Elste (1962). Absolute calibration was referenced to the International Practical Temperature Scale-1968. The near ultraviolet and visible irradiance values given by Labs and Neckel (1970) for 10 nm intervals could be

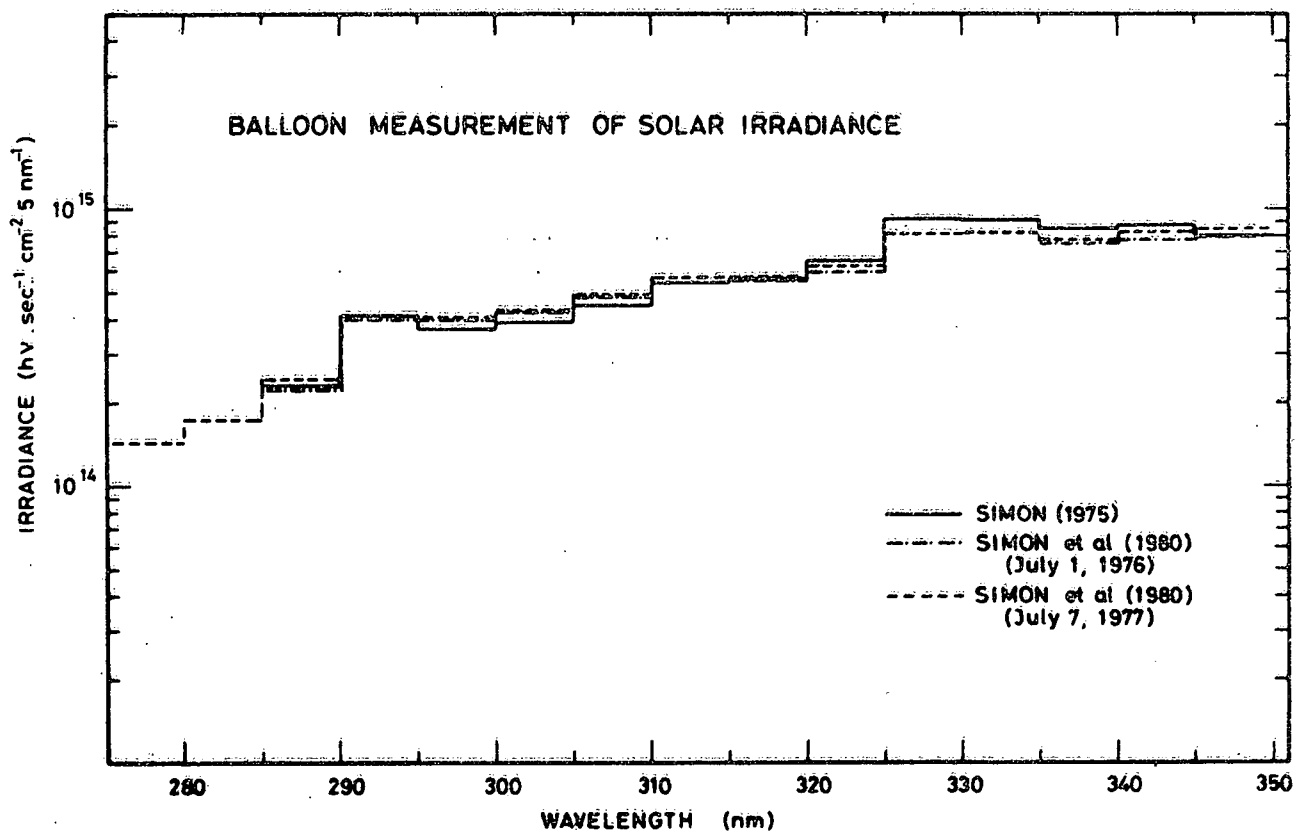


Fig. 9.- Comparison of ultraviolet solar irradiation flux integrated over 5 nm, obtained by balloon experiments between 280 and 350 nm.

used in order to adjust the data of Arvesen et al (1969), obtained with a higher resolution, into a correct radiometric scale for wavelength above 330. Nevertheless, it should be taken into account that the data of Labs and Neckel (1970), which extends up to 1250 nm, leads to a solar constant value of 1358 W.cm^{-2} which is 0.9% lower than the recent solar constant measurements obtained by Willson and Hickey (1977), giving a value of 1370 W.m^{-2} .

Variability with the 27-day rotational period

Except in the case of the Lyman- α emission line, already discussed, very few investigations on this subject have been made experimentally. Only two reliable observations are available : firstly those published by Heath (1973) based on broad-band sensors on board of the satellites Nimbus 3 and 4, which were launched, respectively, in April 1969 and April 1970, and, secondly, those published by Hinteregger et al. (1977) who observed ultraviolet flux variations during the 1974-1976 period by means of a spectrometer on board of the satellite Atmospheric Explorer C. An additional observation has been performed by Prag and Morse (1970) but results have been obtained for only one solar rotation, leading to a variation of more than 50% for the broad wavelength interval 160-210 nm. This value seems too high by comparison with data obtained by Heath (1973) and Hinteregger et al. (1977) given in figure 10. For these authors, the irradiance variation beyond 175 nm, related to the 27-day rotational period, is less than 10% and are decreasing with increasing wavelength to be of the order of 1% around 300 nm. The value for wavelengths between 175 and 210 nm is also confirmed by Brueckner et al. (1976) on the basis of plage radiance measurements. Consequently, it appears that solar variation around 200 nm with its 27-day rotational period is of the same order of magnitude as the variability due to the semi-annual change of the sun-earth distance, corresponding to a $\pm 3.3\%$ variation for the total solar irradiance.

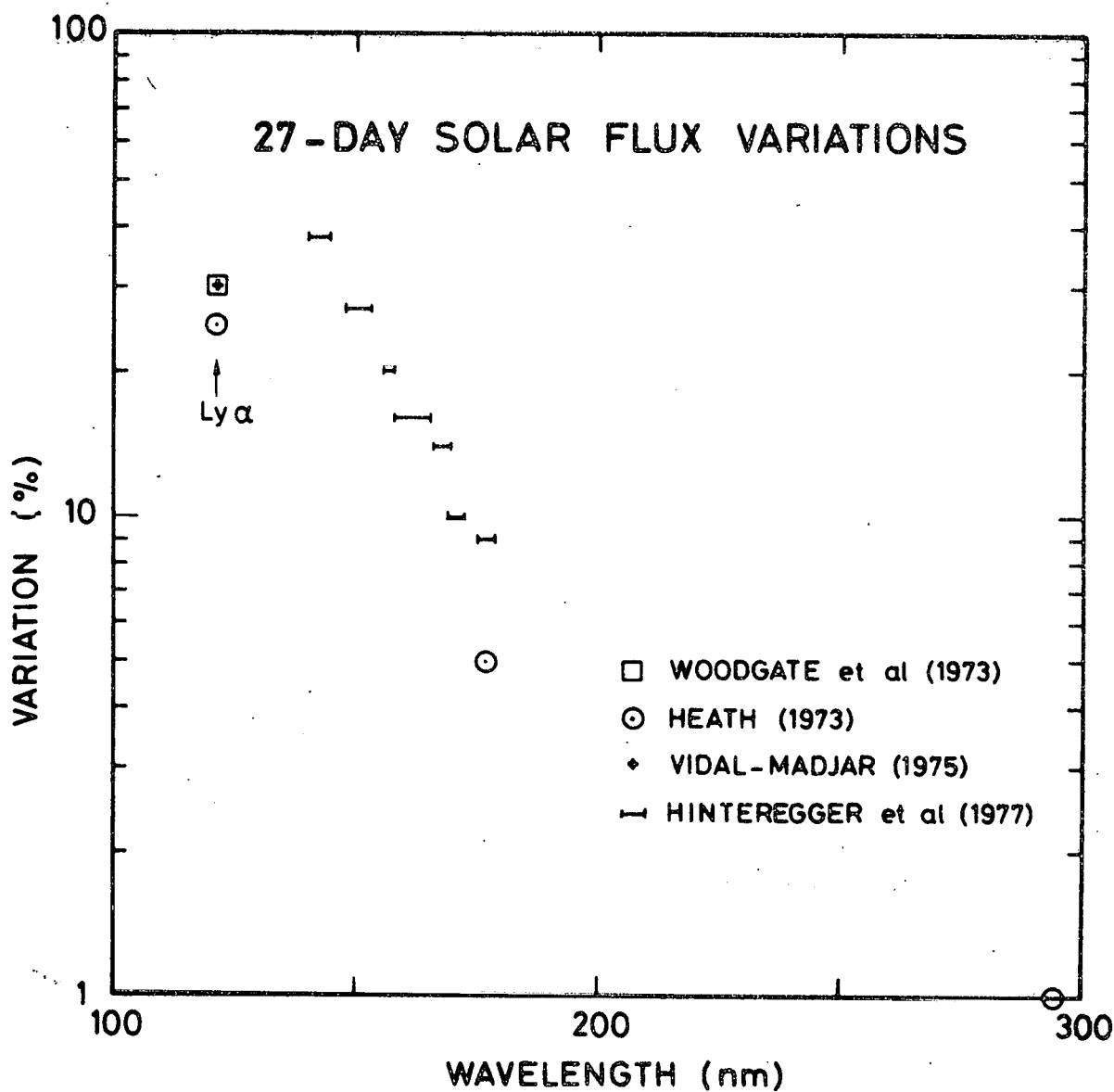


Fig. 10.- Solar flux variations related to the solar rotational period from Lyman α to 300 nm. The values of Hinteregger et al. (1977) correspond to the Carrington rotation n° 1615 (June 1974).

Variability with the 11-year cycle

The solar irradiation flux variability with the 11-year cycle is very poorly known for all the solar spectrum. Long-term variability of the extreme ultraviolet flux with the solar cycle is quite evident but, even in this wavelength range, the data available do not suffice to determine, quantitatively, any variations during the last solar cycle (Schmidtke, 1978). The situation is worse in the wavelength range related to the middle atmosphere photodissociation processes. The inadequate time coverage of reliable data during the solar cycle 20 and the errors associated with each available measurement do not permit quantitative conclusions of solar variability with the 11-year cycle as it was stated by Simon (1978) and Delaboudiniere et al. (1978). This is illustrated by figures 11 and 12.

Nevertheless, quantitative variation of the solar irradiance between 175 and 380 nm has been proposed recently by Heath and Thekaekara (1977) on the basis of broad-band photometric observations by the Monitor of Ultraviolet Solar Energy experiment (MUSE) from a rocket flight in August 1966 and from satellites Nimbus 3 and 4 in April 1969 and April 1970, respectively. Another data were obtained with the double spectrometer on board of Nimbus 4 and Explorer 55 satellites, the latter launched in November 1975. The results are shown by figure 13 based on NASA (1977) and giving the ratio of solar irradiance measured at solar minimum to that at solar maximum. The solid curve represents the proposed solar variability during the cycle 20 for wavelengths between 170 and 340 nm. The accuracies of the data obtained by the broad-band sensors are, respectively, $\pm 15\%$ and $\pm 30\%$ for the shorter and the longer wavelength detector and between $\pm 8\%$ and $\pm 3\%$ for the double monochromator. Only two different ratios are available around 180 nm and the other values obtained around 290 nm with the double monochromator are higher by a factor of 15-20% than those obtained from the broad-band detectors at the same wavelength. A

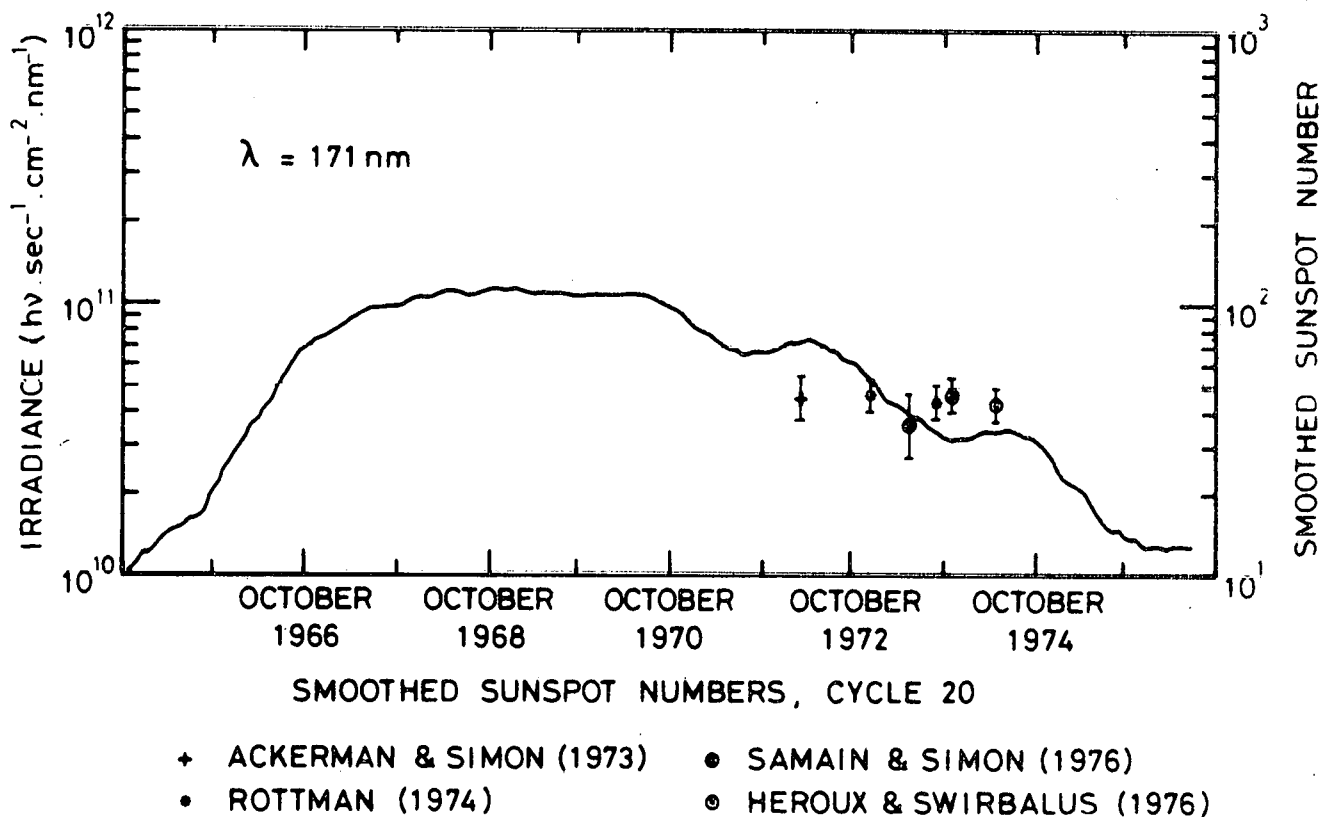


Fig. 11.- Comparison of solar irradiation flux measurements at 171 nm during the solar cycle 20. The smoothed sunspot numbers are also shown.

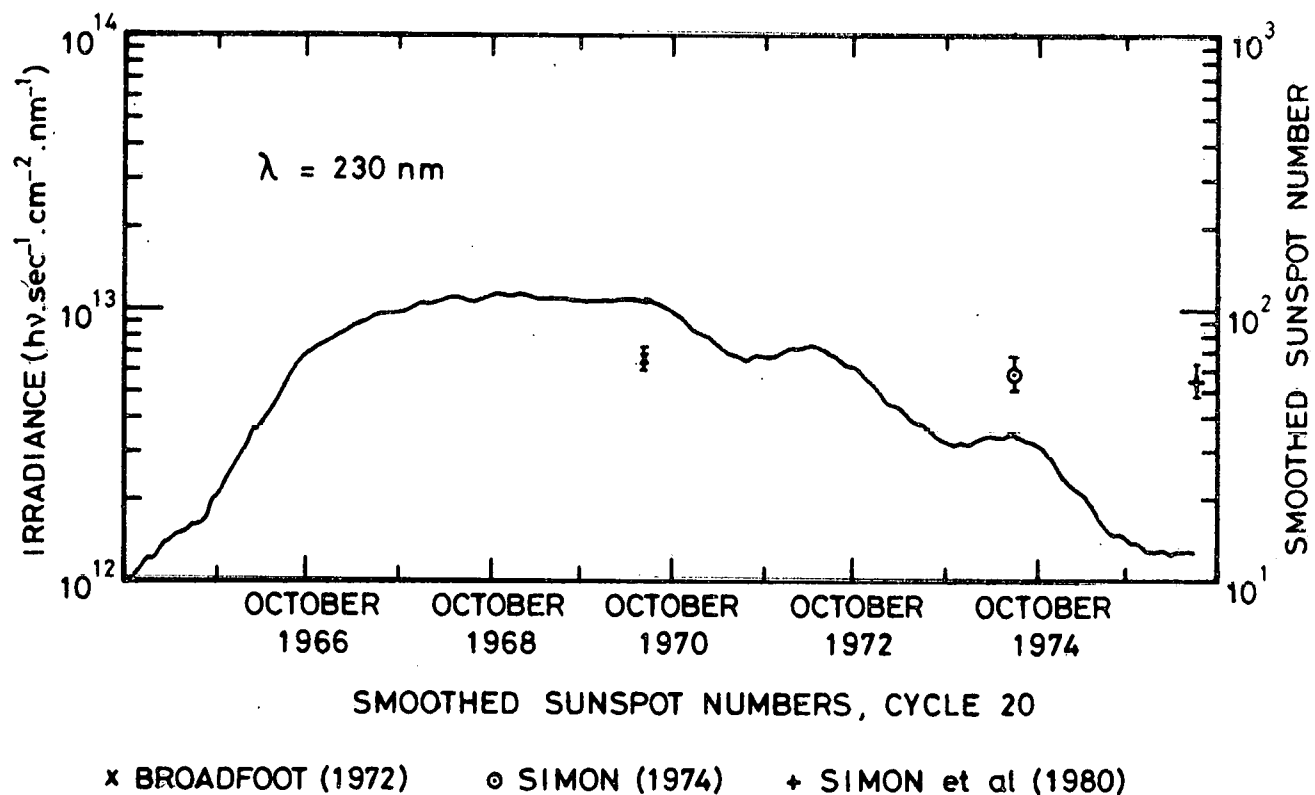


Fig. 12.- Comparison of solar irradiation flux measurements at 230 nm during the solar cycle 20. The smoothed sunspot numbers are also shown.

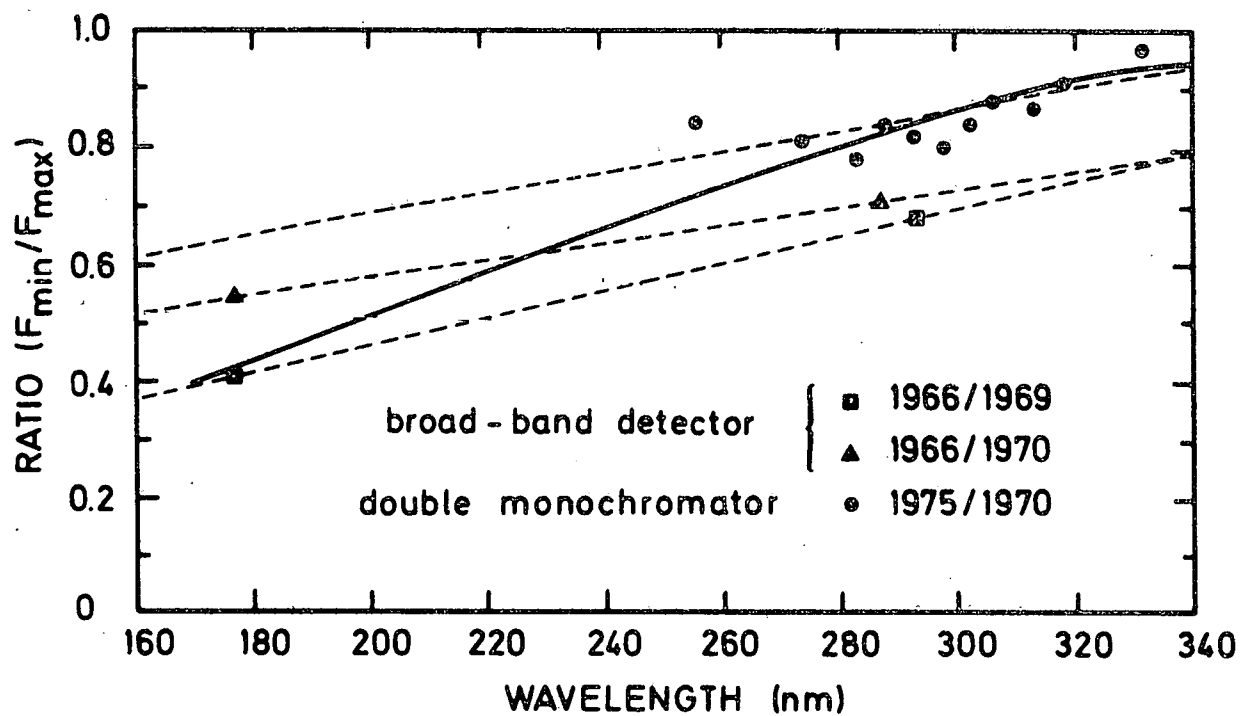


Fig. 13.- Ratio of solar flux measured near solar-cycle minimum to that measured near solar-cycle maximum versus wavelength (see text for explanations).

linear regression calculation is illustrated by the dashed lines for each type of measurements. Extrapolation to 320 nm of the solar irradiance ratio, obtained from the broad-band detectors data, give a variability ratio of 25% which disagrees with the variability ratio of 5% at the same wavelength based on the double monochromator measurements. In addition, extrapolation of these latter observation to 200 nm leads to a variability ratio of only 0.68 but there is no experimental evidence for either a linear dependance or for other functions of the solar variability dependance with the wavelength. Taking into account the possible experimental errors on the irradiance observations and the lack of data related to the solar activity, the validity of this curve needs to be confirmed by new measurements during solar cycle 21, with accurate cross-calibration making possible the intercomparison between the new data. The factor of 2 of variability claimed by Heath and Thekaekara (1977) seems also too high because there is no astrophysical reasons leading to variations with the 11-year cycle at 200 nm comparable to those observed for the Lyman α chromospheric line. This represents the maximum possible long-term variability in the extreme-ultraviolet wavelength range.

These comments seem to be confirmed by the new observations made by means of a balloon-borne spectrometer in 1976 and 1977 already mentioned (Simon et al, 1980) and corresponding to a period of solar minimum activity. Comparing these data with those of Broadfoot (1972), obtained for solar maximum activity, variations between 210 and 240 nm could be included between 23% and 12%, the ratio decreasing with increasing wavelength, if the differences between these authors are interpreted as only variability of the solar output and not as experimental uncertainties which are of the order of $\pm 15\%$. Such a variation range shows the need of new measurements with both better accuracy and precision between 175 and 240 nm in order to deduce correct quantitative variabilities in this wavelength interval. Around 300 nm, there is no more conclusive evidence of variabilities of the order

of 15%, due also to the uncertainties associated with each available measurement. Around 400 nm and in the visible range new observations of solar irradiance performed by Shaw and Fröhlich (1979) by means of a filter radiometer located at the Mauna Loa observatory in Hawaii do not cover a sufficiently large period of time: only 6 months of results were published and do not allow quantitative long-term variation determinations in this part of the solar spectrum.

III. CONCLUSION

The ultraviolet solar irradiation flux observations related to the middle atmosphere have been extensively described and the current position of the accuracies and of the discrepancies between the different measurements is summarized in table 3. Uncertainties of laboratory radiometric standard sources and specific requirements for the future observations are also given.

The discrepancies are rather large and cannot be unambiguously interpreted as being caused by solar variabilities, due to the experimental errors associated with each measurement, to the inadequate time coverage during solar cycle 20, and to the lack of intercomparison of the calibration results of the instruments. The laboratory radiometric standards have a smaller uncertainty than the present measurement, and future observation accuracy requirements could be fulfilled :

- i) if a carefully calibration in the laboratory is made, allowing the transfer of the standard source accuracy to the instrument with little degradation, and
- ii) if the errors introduced by the measurements on the sun itself, in space environment, are reduced by appropriate techniques eliminating the degradation of the calibration accuracy.

The cleanliness of the experiment is certainly an important factor to improve the validity of the future observations (Madden, 1978). A different method consists to measure directly the aging of the instrument

TABLE 3.- Uncertainties on solar ultraviolet irradiance measurements and
future needs

$\Delta\lambda(\text{nm})$	Ly α	175 - 210	210 - 240	240 - 330	330 - 400
Quoted accuracy	$\pm 30\%$	$\pm 30\% - \pm 20\%$	$\pm 20\% - \pm 10\%$	$\pm 10\% - \pm 4\%$	$\pm 10\% - \pm 4\%$
Discrepancies between relevant observations	100%	50%	30%	25%	15%
Uncertainties on available stan- dard sources	5%	5%	5%	3%	2%
Required accuracy	10%	5%	5%	5 to 2%	
Required precision	5%	1%	1%	1 to 0.3%	

sensitivity during the preflight storage, the measuring mode in space and after the flight. This implies that the instrument includes an in-flight calibration source and will be recoverable after the solar observation. The Space Shuttle, having a relatively short mission in space, without any severe limitation in weight and in power supply, seems a promising method since it allows the control of the ground calibration validity during and after the space observations. In addition, it could be now conceivable to recover a free-flyer instrument after a long survey of the sun and to measure in the laboratory its degradation in order to see which components are really aging in space environment, improving our knowledge on the proper choice of the materials.

Moreover, observations with different experimental techniques are required to eliminate the systematic errors. However intercomparison of calibration results for the various instruments should be performed before the flights to ensure a proper intercomparison of irradiance results after the flights.

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

Such a measurement strategy for the near future could be applied to the "Solar ultraviolet Spectral Irradiance Measurement" and the "Solar Spectrum" experiments both on board the Space Shuttle, to the ultraviolet spectrometer on board the satellite "Solar Mesospheric Explorer", and to the rocket and the balloon observations performed during the same period by various laboratories.

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