

OBSERVATION OF THE ULTRAVIOLET SOLAR IRRADIANCE IN THE STRATOSPHERE

by

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Abstract

Ultraviolet solar irradiance measurements for wavelengths greater than 175 nm are reviewed. Discrepancies between recent observations are pointed out and discussed in relation to the solar flux variability. Future needs related to stratospheric chemistry are emphasized.

I. INTRODUCTION

Ultraviolet solar irradiation in wavelengths ranging from 175 to 400 nm initiates the photochemistry of the neutral constituents of stratosphere. For instance, photodissociation of molecular oxygen by radiation of wavelengths shorter than 242 nm is the initial source of odd oxygen in the upper stratosphere, leading in particular to the formation of ozone by reaction with the molecular oxygen in the presence of a third body (N_2, O_2). On the other hand ozone is destroyed by photodissociation in the Hartley continuum and the Huggins bands by radiation at wavelengths shorter than 360 nm, producing the electronically excited atomic oxygen $O(^1D)$. These atoms are in fact the most important oxidizing agent in the stratosphere (Nicolet, 1975). An accurate knowledge of the solar irradiation flux at ultraviolet wavelengths and of its variations with the solar rotational period and the 11-year cycle is thereby fundamental in stratospheric aeronomy.

The purpose of this work is to review the recent solar irradiance measurements between 175 and 400 nm. The discrepancies between the different observations will be pointed out and discussed in relation to the solar irradiation flux variability.

II. OBSERVATIONAL DATA

Solar irradiation fluxes in the wavelength interval 175-242 nm are very important for upper stratospheric aeronomy. They are mainly responsible for the photodissociation of molecular oxygen which absorbs radiation of wavelength shorter than 242 nm. Some minor constituents such as nitrogen oxides, water vapor and halocarbons also undergo photodissociation in this wavelength range. Unfortunately, the solar spectrum is not sufficiently well known especially between 175 and 204 nm corresponding to the Schumann-Runge band system. With the exception of the data of Detwiler et al. (1961) which are definitely too high, the only measurements covering this wavelength range

are those deduced very recently by Samain and Simon (1976) and those of Brueckner et al. (1976). Both determined the solar irradiance fluxes from photographic radiance measurements using the limb-darkening values measured by Samain and Simon (1976). Solar spectra were obtained with resolutions of 0.04 and 0.007 nm respectively. The data, extending up to 210 nm were integrated over 1 nm interval for comparison and are reported on fig. 1 with the other measurements covering partially the same wavelength range. Fig. 2 illustrates the ratio between all the recent observations taking as reference the values of Samain and Simon (1976). The first conclusion to be drawn is that the data of Brueckner et al (1976) are quasi systematically 25% lower than those of Samain and Simon (1976). A good agreement occurs at 175 nm with the results of Rottman (1964) and of Heroux and Swirbalus (1975), but discrepancies of the order of 50% appears around 190 nm. Such a difference has been discussed by Samain and Simon (1976) who come to the conclusion that, from 180 to 194 nm, their own data should be considered as an upper limit for the solar irradiance while those of Heroux and Swirbalus should give a lower limit. Beyond 200 nm, the most recent irradiance measurements are those obtained by Simon (1974) with a balloon borne spectrometer with a spectral bandpass of 0.6 nm. They are 40% lower than the previous balloon measurements reported by Ackerman et al. (1971) and are also lower than Broadfoot's results (1972), except between 226 and 230 nm where the agreement is within 15%. The accuracies quoted by these experimenters fall in the range ± 10 to $\pm 30\%$ for all the measurements mentioned above.

The observations of Broadfoot (1972) obtained by means of a rocket borne spectrometer with a spectral resolution of 0.3 nm extend up to 320 nm. They are the most reliable contribution covering continuously the most important wavelength range for the photodissociation of ozone (fig. 3). On the other hand, Arvesen et al (1969) carried out, from an aircraft platform, measurements between 300 and 2500 nm by means of a double spectroradiometer having a resolution of 0.1 nm in the ultraviolet. Unfortunately, they have some discrepancies with Broadfoot's data between 300 and 320 nm in which occurs the limit of photodissociation of O_3 producing the excited atomic oxygen $O(^1D)$ which is particularly important for the stratospheric aeronomy (Nicolet, 1975). The values of Simon (1975) extending from 284 to 354 nm obtained by balloon observations are in

very good agreement with those of Broadfoot (1972) up to 300 nm and with those of Arvesen et al (1969) beyond 330 nm (fig. 4). In fact, Broadfoot (1972) claimed an accuracy of $\pm 10\%$ for his measurements except beyond 300 nm where the error is larger. On the other hand Arvesen et al (1969) estimate their error to be 25% at 300 nm, 6% at 320 nm and 3.2% at 400 nm. The data of Simon (1975) could therefore provide useful irradiance values between 300 and 330 nm. Other measurements obtained from aircraft are those of Thekaekara et al (1969) but the tables of irradiances integrated over 5 nm are based on an average of data coming from four different instruments. More recently, irradiances at 0.1 nm intervals were published by Thekaekara (1974) in the wavelength range 300-610 nm. Unfortunately, his results show many errors in the wavelength scale (Simon, 1975) making difficult a correct comparison with the other measurements. Observations of De Luisi (1975) from 298.1 to 400 nm were obtained from ground-based measurement but only relative calibration of the spectrometer was performed. Absolute irradiation fluxes were obtained adjusting the total energy in the wavelength range 300-400 nm on the standard solar spectral irradiance curve published by Thekaekara (1970). On the other hand, Labs and Neckel (1970) measured, from a high mountain observatory, the solar radiance near the disk centre and computed very reliable irradiation fluxes from 330 to 1250 nm integrated over 10 nm, using the limb-darkening data of David and Elste (1962). They stated a possible error of 2% below 400 nm. The accuracy of all these observations allows an estimation of the solar irradiance flux within 10% around 300 nm and within 5% around 400 nm.

A compilation of the relevant irradiation flux values discussed in this work have been recently published by Delaboudinière et al (1978).

III. DISCUSSION

A correct interpretation of the available data must take into account the flux variabilities arising from changes in solar activity. These belong to three categories determined by their time scale : firstly, variations related to flares having a very short life time; secondly, those related to the solar rotation period (27- days) and finally, those related to the 11-year

cycle. The solar irradiation flux enhancement due to the flares could be considered as negligible for wavelengths greater than 140 nm, according to Heath (1969).

Observations of the 27-day variability have only been reported by Heath (1973) and by Hinteregger et al (1977). Between 175 and 200 nm this variability appears to be less than 10% and decreases exponentially with decreasing wavenumbers, being of the order of 1% around 300 nm. It should be pointed out that a solar flux variability of 10% is lesser than the quoted measurement accuracies and is comparable to that due to the sun-earth annual distance change involving periodic solar variation of 6.6% from January (max.) to July (min.).

The solar irradiation flux variability due to the 11-year cycle is very poorly known. The inadequate time coverage of reliable data during the solar cycle 20 and the errors associated with each measurement is illustrated in fig. 5 for 200 nm. Nevertheless, Heath and Thekaekara (1977) claimed a 11-year variability of a factor of 2 at the same wavelength on the basis of their own measurements performed by satellites and by rockets since 1966. This is illustrated in fig. 6 taken from Hudson (1977) and on which the full squares and triangles solar flux ratio were obtained from broadband photometric observations and the full circles by means of double monochromator experiment. The solid curve represents the solar variability deduced by the author. It should be pointed out that there are only two points around 180 nm and that the solar flux ratio obtained around 290 nm with the double monochromators are higher by 15 - 20% than those obtained from the broadband detectors at the same wavelength. In addition, the accuracy of such ratios is not indicated. A linear regression calculation is shown by the dashed lines for each set of solar flux ratio. Extrapolation of solar flux ratio at 340 from the broadband detector measurements gives a variability of 25% between solar-cycle maximum and solar-cycle minimum irradiances. Such value (seems very high and) in contradiction with the variability based on the double monochromator data. On the other hand, extrapolation of the latter at shorter wavelength gives a

ratio of 0.68 at 200 nm.

In conclusion, taking into account all the irradiance measurements with their associated accuracies, there is no conclusive evidence for a variability of a factor of 2 around 200 nm with the 11- year cycle. Lower value of the order of 30% seems more reasonable but should be experimentally proved. New spectral irradiance measurements with an adequate time coverage during the solar cycle 21 are urgently needed in this wavelength range with an improved accuracy in order to answer the question of the solar flux variability related with the stratospheric aeronomy. The required accuracy and resolution are summarized in table 1. In addition, in situ measurements of solar flux at specific stratospheric altitudes would be very useful, especially in the wavelength range corresponding to the Schumann-Runge absorption bands of molecular oxygen, with a resolution of 0.003 nm in order to compare the experimental data with the calculated solar irradiance at the corresponding altitude.

TABLE 1

	Mesosphere Higher stratosphere	Stratosphere Troposphere
Wavelength Interval (nm)	175-240	240-400
Quoted accuracy	± 10 to $\pm 30\%$	± 5 to $\pm 10\%$
Discrepancy	40 to 25%	15 to 9% (1 measurement from 230 to 285 nm)
Required accuracy	5%	5% absolute 1 to 0.1% relative
Required spectral resolution	0.1 to 1 nm (0.003 nm from 175 to 204 nm)	0.1 to 1 nm (0.01 nm for occultation measurement)
Variability (27-day)	10 to 1%	< 1%
Variability (11-year)	100% ?	50 à 20% ?

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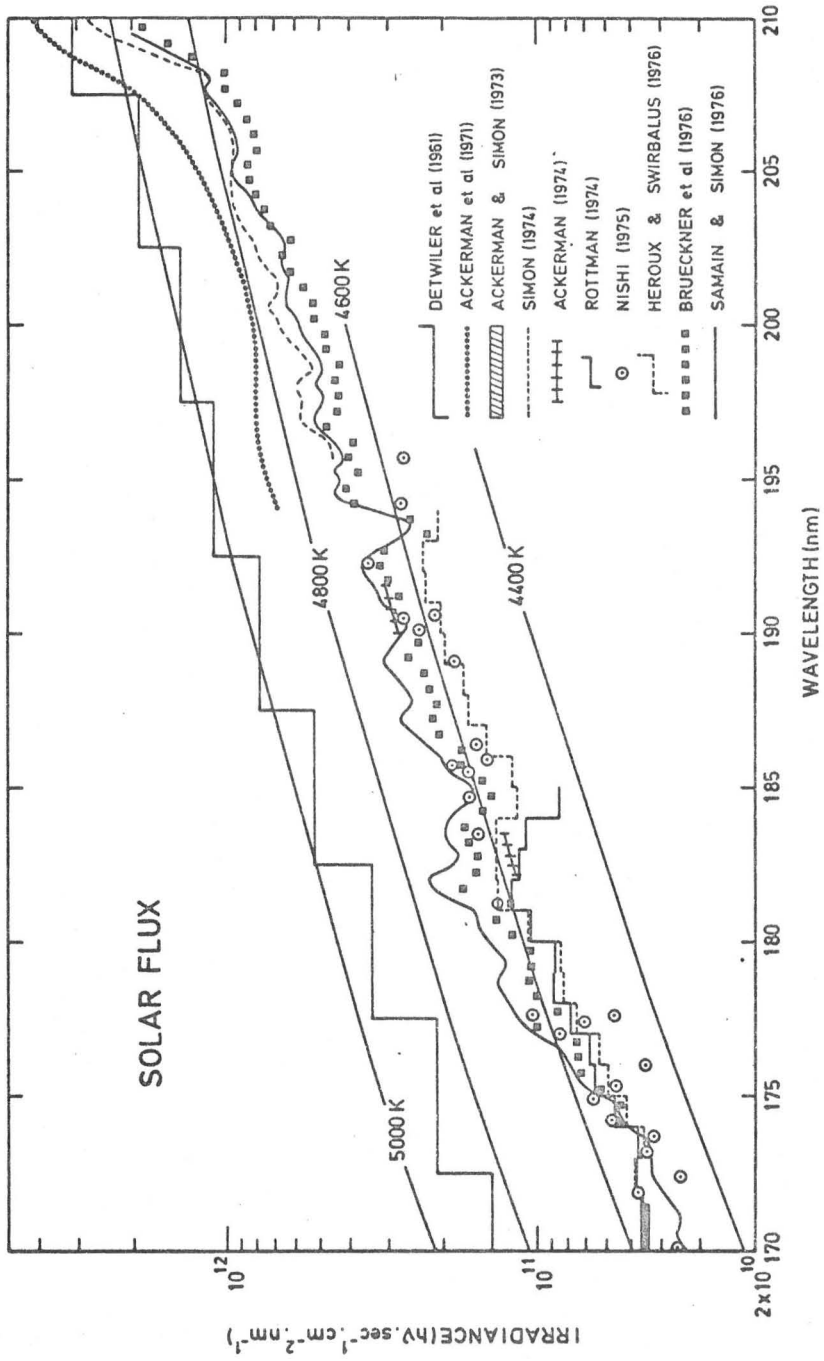


Fig. 1.- Comparison of ultraviolet solar flux reported by various experimenters from 170 to 210 nm. Fluxes for different blackbody temperatures are also shown.

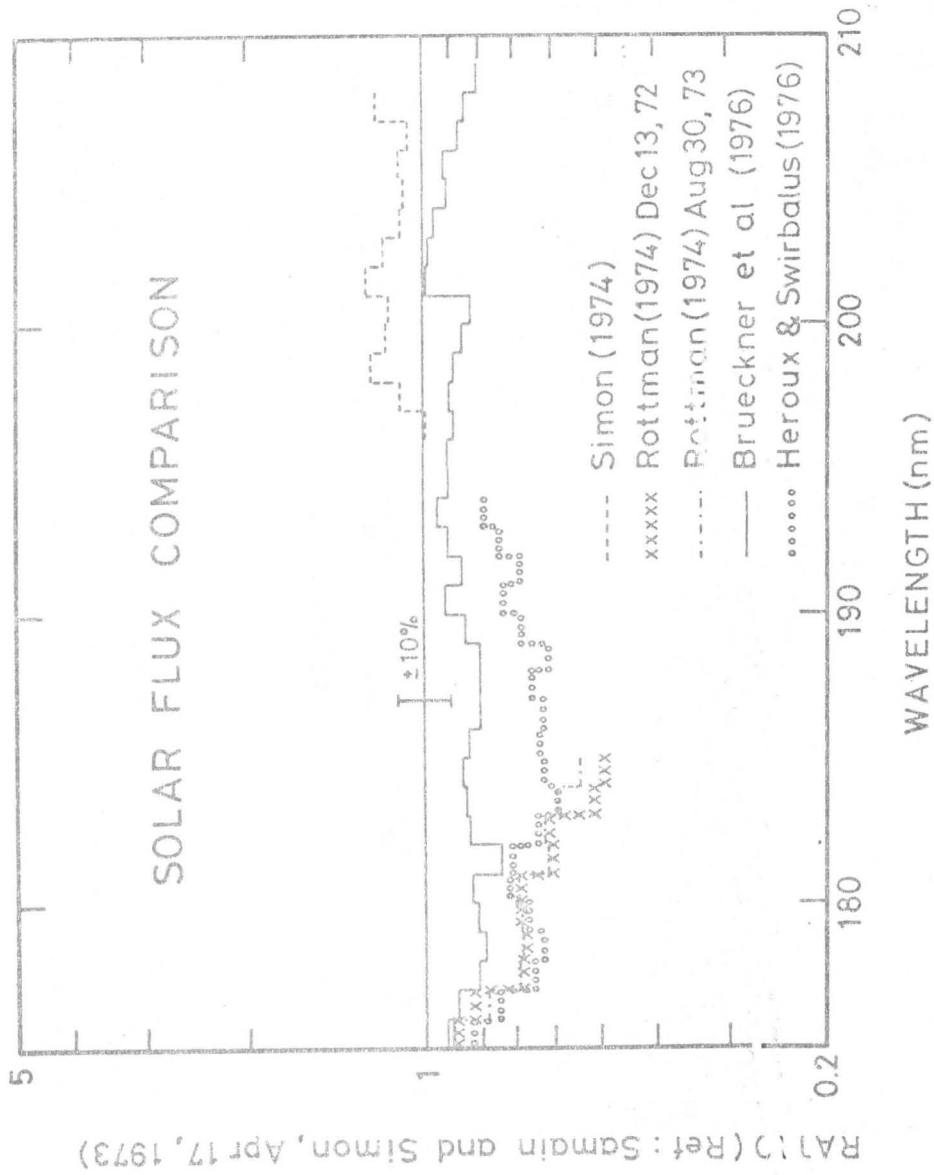


Fig. 2.- Ratio of solar irradiation flux measurements from 175 to 210 nm in comparison with the data of Samain and Simon (1976).

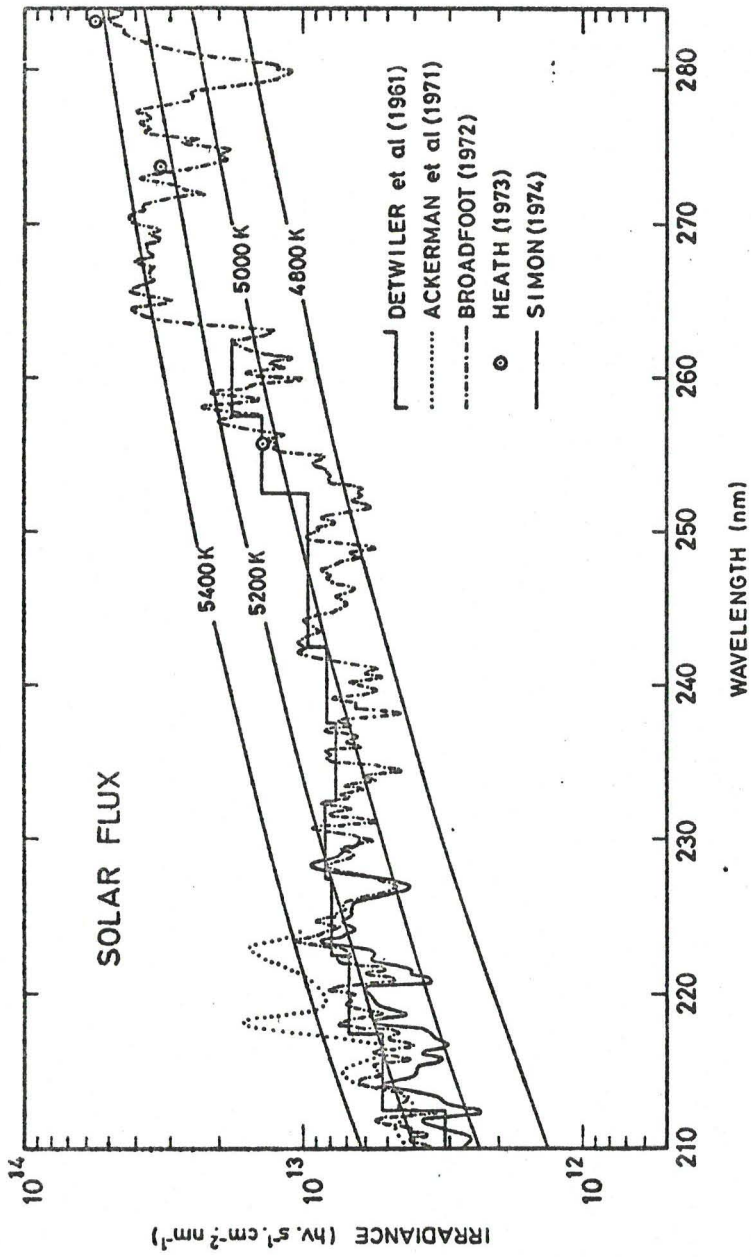


Fig. 3.- Comparison of ultraviolet solar flux reported by various experimenters from 210 to 280 nm. Fluxes for different blackbody temperatures are also shown.

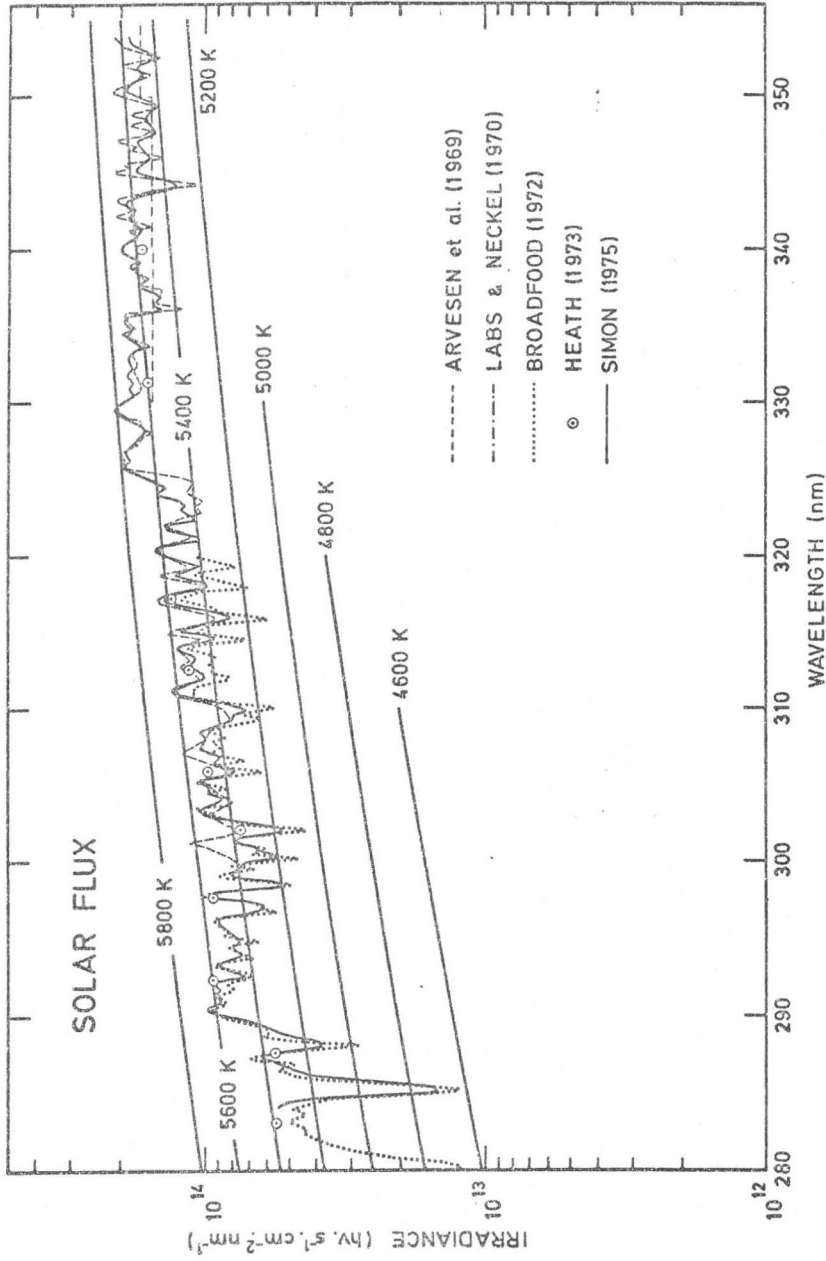


Fig. 4.- Comparison of ultraviolet solar flux reported by various experimenters from 280 to 350 nm. Fluxes for different blackbody temperatures are also shown.

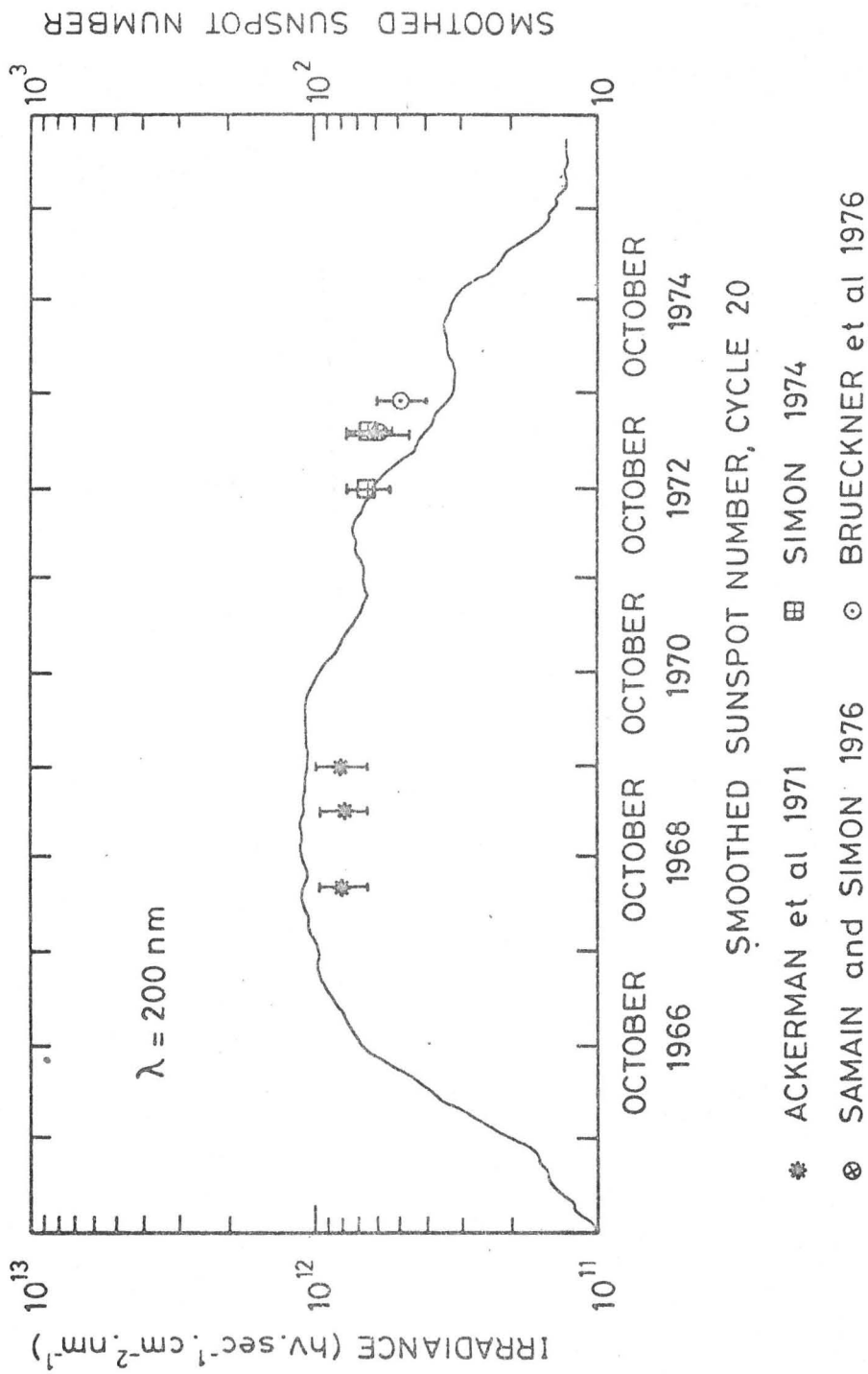


Fig. 5.- Comparison of solar irradiation flux measurements at 200 nm during the solar cycle 20. The smoothed sunspot numbers are also shown (after Delaboudinière et al, 1978).

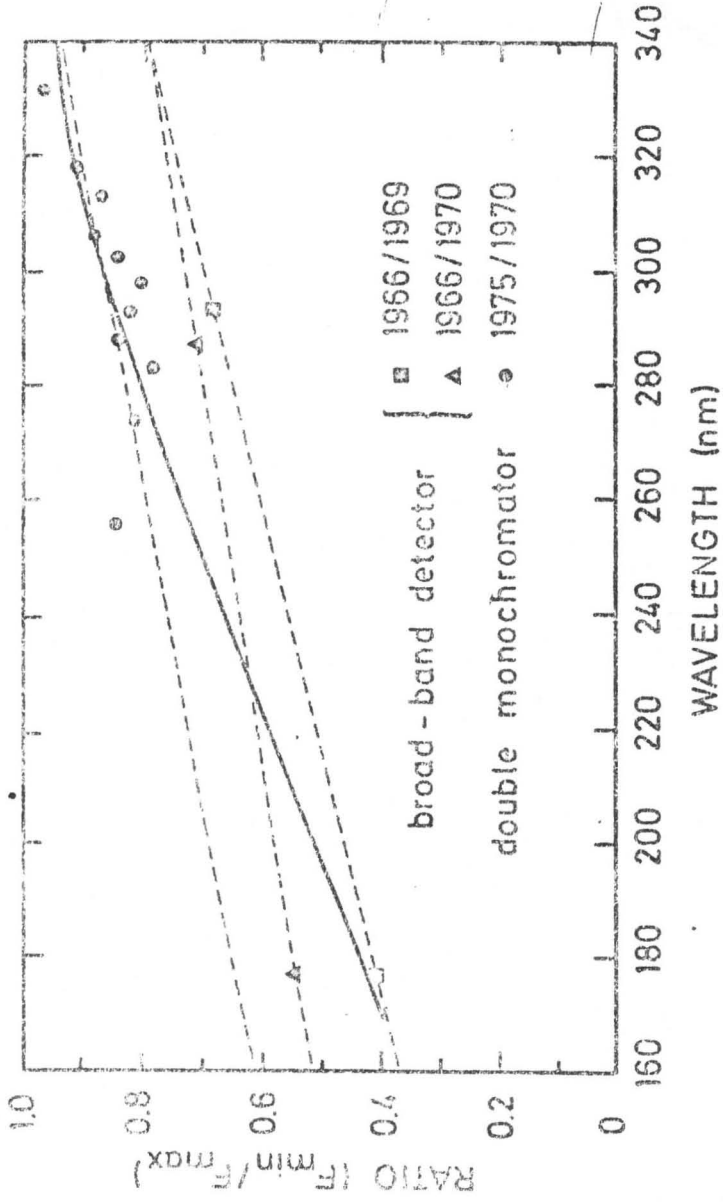


Fig. 13.- Ratio of solar flux measured near solar-cycle minimum to that measured near solar-cycle maximum versus wavelength (see text for explanations).