issn 0065-3713

INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE

3 - Avenue Circulaire
B - 1180 BRUXELLES

AERONOMICA ACTA

A - N° 332 - 1988

Aeronomic problems of the molecular oxygen photodissociation – III. Solar spectral irradiances in the region of the O_2 Herzberg continuum, Schumann-Runge bands and continuum

by

Marcel Nicolet and Robert Kennes

BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE

3 - Ringlaan
B - 1180 BRUSSEL

FOREWORD

Aeronomic problems of the molecular oxygen photodissociation - III. "Solar spectral irradiances in the region of the O_2 Herzberg continuum, Schumann-Runge bands and continuum" will be published in Planetary Space Science, volume 36, 1988.

AVANT-PROPOS

Aeronomic problems of the molecular oxygen photodissociation - III. "Solar spectral irradiances in the region of the O_2 Herzberg continuum, Schumann-Runge bands and continuum" sera pubié dans Planetary Space Science, volume 36, 1988.

VOORWOORD

Aeronomic problems of the molecular oxygen photodissociation - III. "Solar spectral irradiances in the region of the O_2 Herzberg continuum, Schumann-Runge bands and continuum" zal gepubliceerd worden in Planetary Space Science, boekdeel 36, 1988.

VORWORT

Aeronomic problems of the molecular oxygen photodissociation - III. "Solar spectral irradiances in the region of O_2 Herzberg continuum, Schumann-Runge bands and continuum" wird publiziert werden in Planetary Space Science, Volumen 36, 1988.

AERONOMIC PROBLEMS OF THE MOLECULAR OXYGEN PHOTODISSOCIATION - III. SOLAR SPECTRAL IRRADIANCES IN THE REGION OF THE O_2 HERZBERG CONTINUUM, SCHUMANN-RUNGE BANDS AND CONTINUUM

by

Marcel NICOLET* and Robert KENNES

Institut d'Aéronomie Spatiale de Belgique
3, Avenue Circulaire, B-1180 BRUSSELS, Belgium

Abstract

Retrospective evaluation of spectral irradiances obtained during the last 10 years at wavelengths relevant to the photodissociation of molecular oxygen provides an indication of the accuracy and precision of the information available at the present time. In the spectral region of wavelengths less than 175 nm corresponding to the O_2 Schumann-Runge continuum which is absorbed in the thermosphere, all the observational results are not reliable since the global accuracy is of the order of ± 50%. In the spectral region 175-200 nm of the Schumann- Runge bands, mainly absorbed in the mesosphere, the uncertainties of all available data are not less than 20 to 30% and make it impossible to determine the exact solar activity effect on the O_2 photodissociation rate. The available measurements for the spectral region associated with the O_2 Herzberg continuum, 200-240 nm, relevant to the stratosphere have typical uncertainty limits reaching ± 10% with additional random errors of ± 10% for 1 nm intervals. The general accuracy is not yet sufficient to infer the exact part in the irradiance changes associated with solar variability. A consistent reference spectrum for a better assessment must be, therefore, adopted to describe the complex behavior displayed by the spectral solar irradiances in the spectral ranges of the photodissociation of O_2.

Résumé

L'examen des données obtenues au cours de dix dernières années sur les irradiances spectrales solaires permet d'avoir une idée de l'exactitude et de la précision des résultats. Dans la région spectrale de longueurs d'onde inférieures à 175 nm correspondant au continuum de Schumann-Runge de O_2, qui est absorbé dans la thermosphère, tous les résultats d'observation indiquent que l'irradiance ne peut- être fixée qu'à ± 50%. Dans la région de longueurs d'onde comprises entre 175 et 200 nm correspondant aux bandes de Schumann-Runge, qui est absorbée principalement dans la mésosphère, l'incertitude de l'ensemble des données s'élève jusqu'à 20 à 30 % et rend impossible une détermination, avec exactitude, de l"effet de l'activité solaire sur le taux de photodissociation de l'oxygène. Dans le domaine du continuum de Herzberg correspondant au domaine de longueurs d'onde 200 240 nm, qui est absorbé dans la stratosphère, les limites de l'incertitude systématique sont de l'ordre de ± 10% avec, en outre, des fluctuations de ± 10% lorsque les domaines spectraux sont réduits à 1 nm. Ainsi, l'exactitude requise n'est pas encore atteinte en vue de déduire la part exacte à attribuer aux effets de l'activité solaire en fonction de la longueur d'onde. Il convient d'adopter un seul spectre de référence afin de couvrir entièrement le domaine spectral de photodissociation de O_2 et de déterminer sa valeur absolue et ses variations.

* Also with : Communications and Space Sciences Laboratory, Penn State University, University Park, PA 16802.

Samenvatting

Een retrospectieve evaluatie van de spectrale belichtingssterkten, gemeten gedurende de laatste 10 jaar in het golflengtegebied relevant voor de fotodissociatie van moleculaire zuurstof, geeft een aanduiding omtrent de nauwkeurigheid en precisie van de informatie beschikbaar op heden. In het golflengte gebied beneden de 175 nm, overeenstemmend met het O_2 Schumann-Runge continuum dat geabsorbeerd wordt in de thermosfeer, zijn alle resultaten van waarnemingen onbetrouwbaar, aangezien de globale nauwkeurigheid van de orde is van ± 50%. In het gebied van de Schumann-Runge banden (175-200 nm), voornamelijk geabsorbeerd in de mesosfeer, zijn de onzekerheden op alle beschikbare gegevens niet minder dan 20 tot 30 %. Dit maakt een bepaling van de invloed van de zonne-activiteit op de fotodissociatiesnelheid van moleculaire zuurstof onmogelijk. De beschikbare metingen in het golflengtegebied, geassocieerd met het O_2 Herzberg continuum, 200-240 nm, van belang voor de stratosfeer, vertonen typische onzekerheden van de orde van 10%, met bijkomende toevallige fouten van ± 10% voor 1 nm intervallen. De algmene precisie is nog niet voldoende om de juiste bijdrage van de zonnevariabiliteit tot de veranderingen in de belichtingssterkten af te leiden. Een consistent referentiespectrum, voor een beter beoordeling moet daarom aangenomen worden teneinde een beschrijving te kunnen geven van het complex gedrag van de spectrale zonnebelichtingssterkten in het golflengtegebied van belang voor de fotodissociatie van moleculaire zuurstof.

Zusammenfassung

Die zurückblickende Schätzung der Spektralen Beleuchtigungen die für die Photodissoziation von molecularen Sauerstoff bezuglich sind, stellt die heutige Präzision und Genauigkeit unseres Kenntniss auf. In dem Spektral Gebiet von wenigen als 175 nm, dass zu dem Schumann-Runge Kontinuum gehört, der in der Thermosphäre absorbiert wird, sind keine Beobachtungen sicher: die globale genauigkeit am högsten ± 50%. In das Spektral Gebiet 175-200 nm der Schumann-Runge Banden, die meistens in der Mesosphäre absorbiert werden, sind die Ungenauigkeiten nicht weniger as 20% biss 30%; dass macht es unmöglich die genaue Effekten der Sonnen Aktivität auf die Photodissoziation von O_2 zu bestimmen. Die Beobachtungen die zu Verfügung im Spektral Gebiet des Herzberg O_2 Kontinuum, zwischen 200 un 240 nm, und die in der Stratosphäre wichtig sind, sind ± 10% unsicher mit eine aditionelle Unsicherheit von ± 10% für 1 nm Intervallen. Die generale Genauigkeit ist noch nicht gross genug um das exakte Teil zu bestimmen dass in der Irradiation von der Sonnen Variabilität abhängen. Eine gutes Referenz Spektrum muss des wegen adoptiert werden um den zusammengesetzter Zustand der Sonnen Spektralen Irradiantionen die das Sauerstoff photoionizieren, zu beschreiben.

1. INTRODUCTION

The direct photodissociation of molecular oxygen in the Earth's atmosphere depends on the solar irradiance corresponding to the O_2 Schumann-Runge continuum, to the predissociated O_2 Schumann-Runge bands, and to the O_2 Herzberg continuum.

Since the absorption cross section in the Schumann-Runge continuum beginning at 57000 cm^{-1} (175.4 nm) has an increasing value from at least 2×10^{-19} cm^2 up to not less than 10^{-17} cm^2 at the peak, the solar radiation is absorbed in the thermosphere. The absorption in the 57000 - 49500 cm^{-1} region (175 to 202 nm) corresponding to the Schumann-Runge bands decreases from about 1 to 2×10^{-19} cm^2 near 56500 - 57000 cm^{-1} to about 10^{-23} cm^2 near 49500 - 50000 cm^{-1}. The solar radiation is, therefore, mainly absorbed in the mesosphere and partly in the upper stratosphere. Finally, the absorption in the Herzberg continuum (49500 - 41250 cm^{-1}) beginning in the lower mesosphere is typically a stratospheric process since the O_2 cross section is less than 10^{-23} cm^2 and decreases to 10^{-24} cm^2 at the threshold near 242 nm.

In the present paper, we attempted to determine a consistent set of ultraviolet irradiances related only to this spectral range of direct photodissociation of O_2. Since the first publications 35 years ago by Tousey et al. (1951) and Friedman et al. (1951), the successive compilations at 10 year intervals (Detwiler et al., 1961; Ackerman, 1971; Brasseur and Simon, 1981) show that it is difficult to determine the absolute values of the solar spectral irradiances with sufficient accuracy. Nevertheless, comparisons with the most recent observations must be made to establish again a reference spectrum. In our analysis we have considered the results of observations of the solar irradiances by Heath (1980), Mentall et al., (1981), Mount and Rottman (1983, 1985, and unpublished data), Anderson et al. (1987), Mentall and Williams (1987), Labs et al. (1987) and the recent tables published in Atmospheric Ozone, Chapter 7, Radiative Processes : Solar and Terrestrial (WMO, 1985). We have adopted (Fig. 1, 2 and 3) as reference spectrum the solar irradiances of Spacelab 2 : SUSIM (Van Hoosier et al., 1987).

2. THE SOLAR IRRADIANCE IN THE SPECTRAL REGION OF THE O_2 SCHUMANN-RUNGE CONTINUUM

Since almost all oxygen atoms produced by photodissociation of O_2 in the thermosphere move down to heights near the mesopause to become reattached and to form oxygen molecules again, the basic aeronomic parameter is the total production of oxygen atoms. Knowledge of the total number of photons (cm^{-2} s^{-1}) at wavelengths less than 175 nm is, therefore, required as the basic solar irradiance parameter. It should lead to a determination of the variations of the upper boundary conditions (number density of oxygen atom at the mesopause level) which must be related to solar activity conditions.

The first value of the total irradiance at $\lambda < 175$ nm was used by Nicolet and Mange (1954) and based on observations of Friedman et al. (1951) corresponding to a brightness temperature of about 4500 K, i.e. a total number of photons (Table 1) of the order of 5×10^{11} cm^{-2} s^{-1} equivalent to a total production of oxygen atoms of the order of 10^{12} cm^{-2} s^{-1}. Ten years later, higher observational values leading to a total irradiance of the order of 2.7×10^{12} photons cm^{-2} s^{-1} corresponding to a brightness temperature of the order of 4900 K, equivalent to a difference of about 400 K in the solar continuum. A strange result !

Table 2 provides, for various solar radiofluxes at 10.7 cm, the total number of photons observed at wavelengths less than 175 nm; it can be concluded that there is no direct possibility of understanding the differences since it seems that there is a lack of agreement. The low values of Heroux and Higgins (1977) of the order of 6×10^{12} photons cm^{-2} s^{-1} for low solar activity correspond to only 50 % of the values

TABLE 1.- Solar flux (Q) and brightness temperature (T_s). Total number of photons cm^{-2} s^{-1} for wavelengths less than 175 nm at the top of the Earth's atmosphere.

T_s (K)	Q ($cm^{-2}s^{-1}$)	T_s (K)	Q ($cm^{-2}s^{-1}$)
4400	3.6×10^{11}	4750	1.6×10^{12}
4450	4.5×10^{11}	4800	1.9×10^{12}
4500	5.6×10^{11}	4850	2.3×10^{12}
4550	6.9×10^{11}	4900	2.7×10^{12}
4600	8.6×10^{11}	4950	3.3×10^{12}
4700	1.3×10^{12}	5000	3.9×10^{12}

TABLE 2.- Total number of photons (Q_∞ cm^{-2} s^{-1}) in the spectral region of the Schumann-Runge continuum (175-135 nm).

DATE	Solar flux (10.7 cm)	Q_∞	Reference
1951	---	$\simeq 5 \times 10^{11}$	Friedman et al. (1951)
1961	---	$\simeq 2.5 \times 10^{12}$	Detwiler et al. (1961)
1971	---	$\simeq 1.2 \times 10^{12}$	Ackerman (1971)
1981	---	$\simeq 6.5 \times 10^{11}$	Brasseur and Simon (1981
02 Nov. 1973	84	5.7×10^{11}	Heroux and Higgins (1977)
23 Apr. 1974	74	5.2	
13 Dec. 1972	111	6.2	Rottman (1974)
		8.7	Rottman (1981)
30 Aug. 1973	91	6.0	Rottman (1974)
		7.7	Rottman (1981)
28 Jul. 1975	75	8.2	Rottman (1981)
18 Feb. 1976	70	1.0×10^{12}	
9 Mar. 1977	80	1.0	
16 Nov. 1978	132	8.0×10^{11}	Mentall et al. (1985)
5 Jun. 1979	224	1.5×10^{12}	Mount et al. (1980)
22 May 1980	270	8.4×10^{11}	Mentall et al. (1985)
15 Jul. 1980	211	1.4×10^{12}	Mount and Rottman (1981)
16 Oct. 1981	304	6.7×10^{11}	Mentall et al. (1985)
17 May 1982	139	8.0	Mount and Rottman (1983)
23 Jul. 1983	136	7.2	Mount and Rottman (1984)
29 Jul - Aug. 6, 1985	70-85	1.25×10^{12}	VanHoosier et al. (1987)

deduced from VanHoosier et al. (1987) for almost the same conditions of solar activity and also 50% of the values adopted by Ackerman (1971). How can a real solar activity effect be deduced when there are unquestionable differences of ± 50% ? A conventional value should be (1.0 ± 0.25) x 10^{12} photons cm^{-2} s^{-1} indicating that the observational accuracy must be improved. On the other hand, the variation with solar activity is not known, but should be less than a factor of 2.

In conclusion, a determination of the total thermospheric production of oxygen atoms requires more observations at wavelengths less than 175 nm with better accuracy to fix the atomic oxygen concentrations near the mesopause and its variations with solar activity.

3. THE SOLAR IRRADIANCE IN THE SPECTRAL REGION OF THE O_2 SCHUMANN-RUNGE BANDS

The spectral region of the Schumann-Runge bands of O_2 requires a special attention since the published observational solar irradiances do not allow definitive conclusions to be reached not only about the spectral distribution but also about the absolute values in order to detect the effect of solar activity. Generally, the differences between the various sets of observations cannot be less than those arising from changes in solar activity.

The reference data deduced from the observations of the Naval Research Laboratory (VanHoosier et al., 1987) were made between 120 nm and 400 nm from Spacelab-2 between July 29 and August 6, 1985 : SUSIM, Solar Ultraviolet Spectral Irradiance Monitor. The irradiances measured in the SUSIM experiment with a 0.15 nm bandpass and given (milliwats $meter^{-2}$ $nanometer^{-1}$) at each 0.05 nm are reproduced (photons cm^{-2} s^{-1} nm^{-1}) in Fig. 1, 2 and 3 from 180 to 205 nm, from 205 to 230 nm and from 230 to 255 nm, respectively. The averaged values in 1 nm intervals which may be compared with the individual irradiances (generally 3 in 1 nm intervals) shown at a certain number of wavelengths by Labs et al.

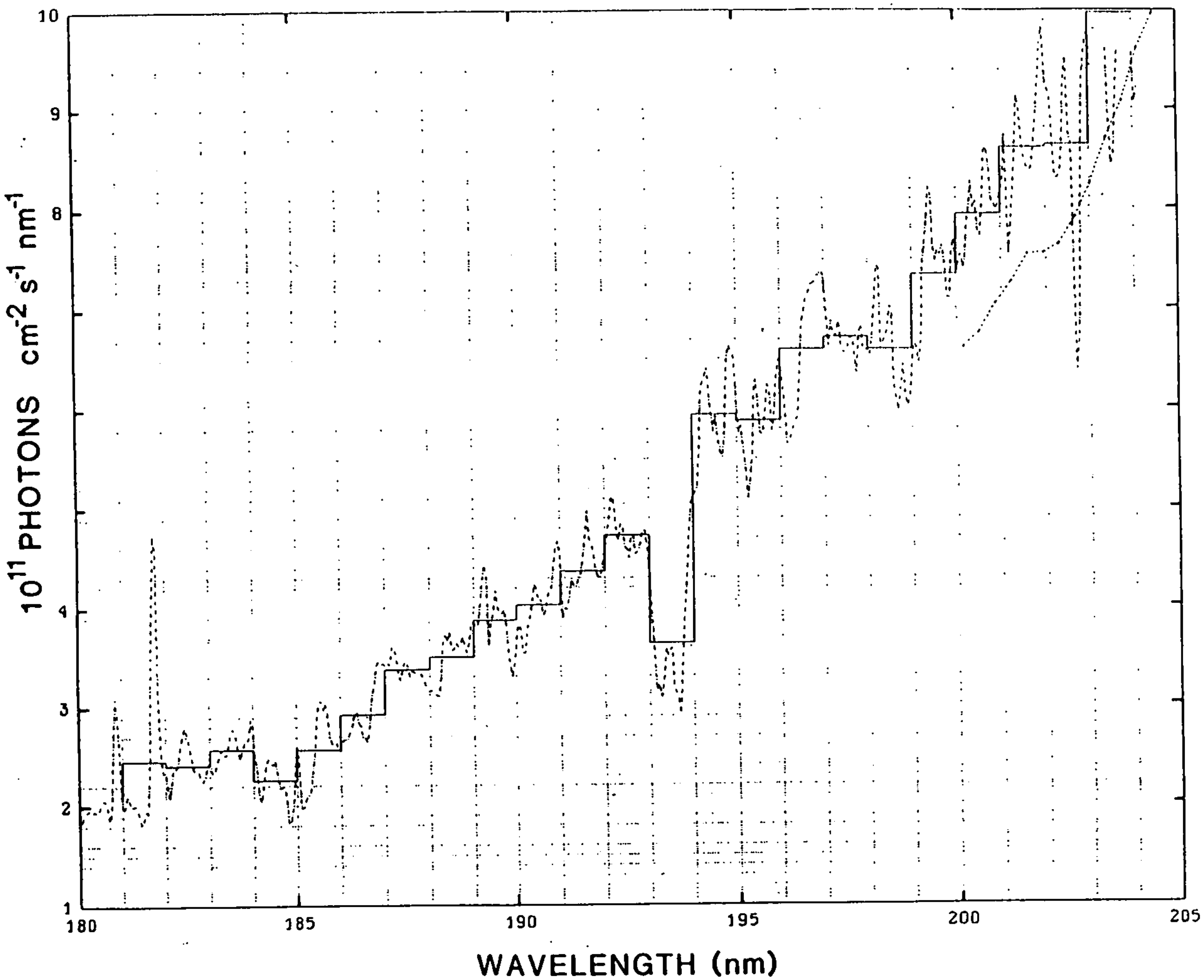

Fig. 1.- Spectral solar irradiances (photons cm^{-1} s^{-1} nm^{-1}) from 180 nm to 205 nm. The dashed lines reproduce at each 0.05 nm the irradiances from the SUSIM experiment (VanHoosier et al. 1987) in photons cm^{-2} s^{-1}. The solid lines represent averaged values in 1 nm intervals. The dotted curve beginning at 200 nm is used to connect (generally 3 values indicated by x for each nm) the irradiances given by Labs et al. (1987) at specific wavelengths.

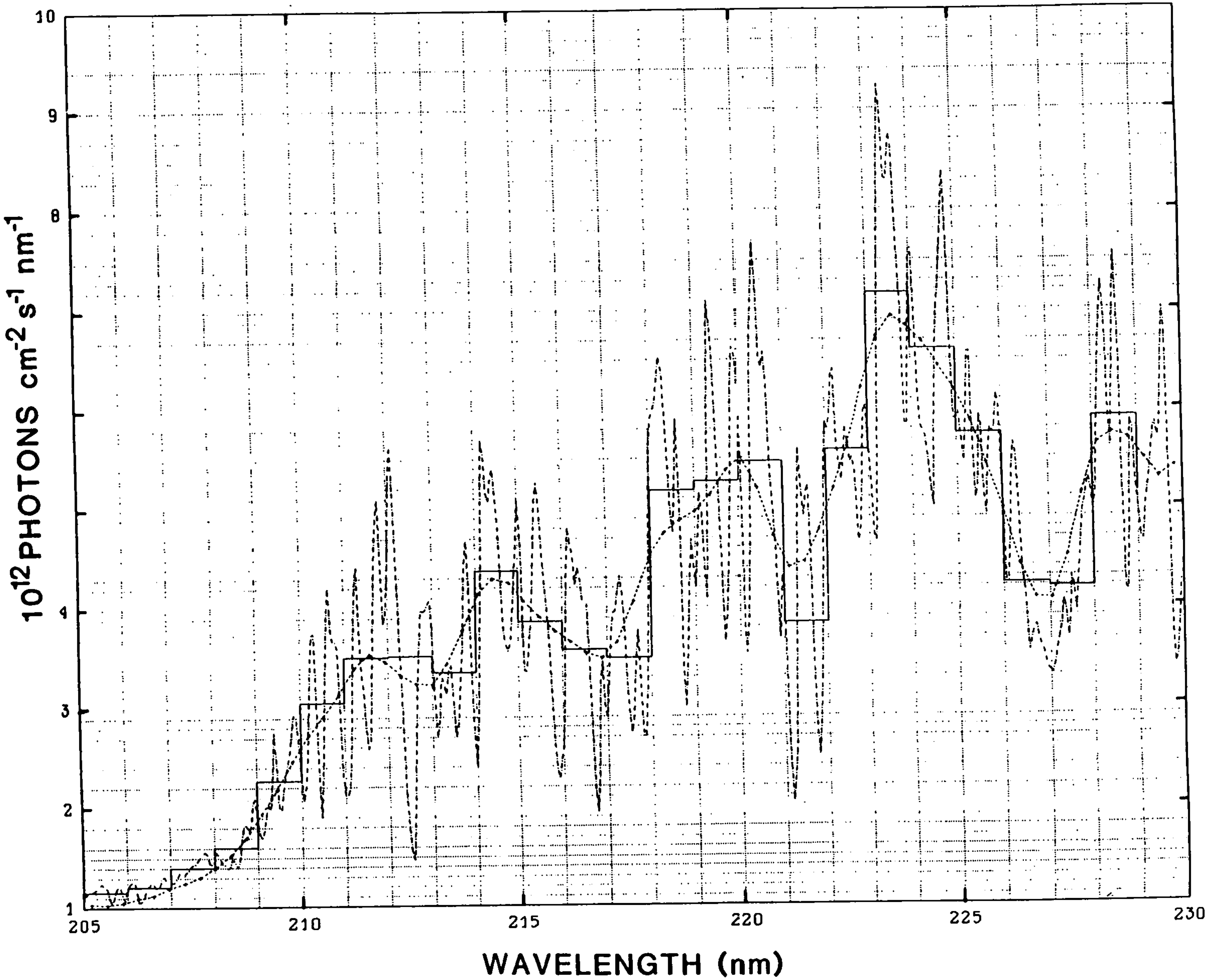

Fig. 2.- Spectral solar irradiances (photons cm^{-2} s^{-1} nm^{-1}) from 205 nm to 230 nm. As in Fig. 1.

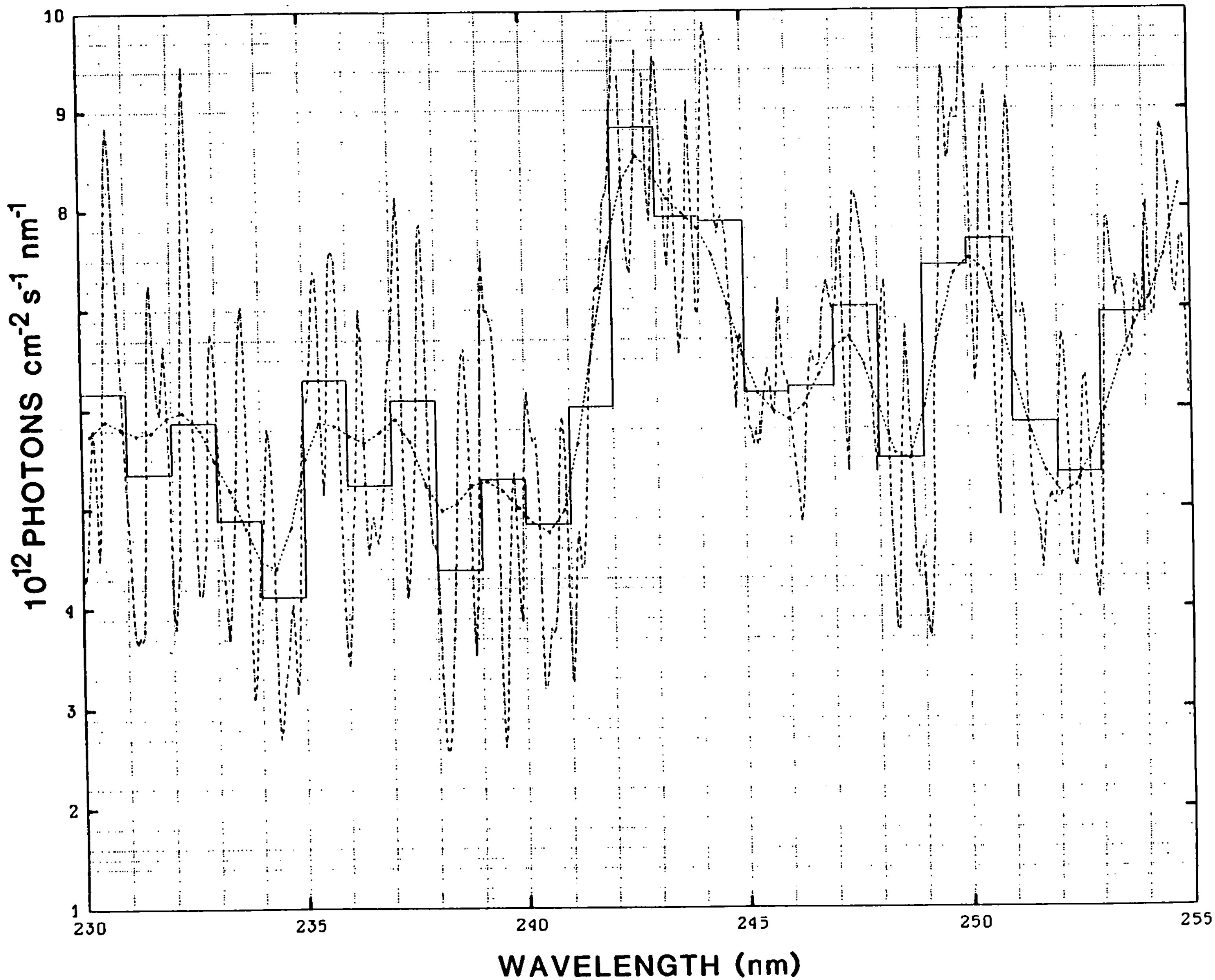

Fig. 3.- Spectral solar irradiances (photons cm^{-2} s^{-1} nm^{-1}) from 230 nm to 255 nm. As in Fig. 1 and 2.

(1987), are also depicted in the 3 figures from 200 to 255 nm.

Figure 4 compares the solar irradiance data for 500 cm^{-1} intervals between 57000 and 5000 cm^{-1}. The irradiances for such intervals as deduced from the SUSIM Spacelab-2 data lead to a different view of the solar emission in this region of the spectrum; this is illustrated in the figure where it can be seen that the values of the compilation of WMO (1985), those of Heath (1978) at high solar activity and of the compilation of Brasseur and Simon (1981) are systematically below the values deduced from SUSIM. The various ratios are reproduced in Fig. 5 : their values deduced from the Brasseur-Simon compilation and the NRL data are of the order of only 0.65 ± 0.15, from Heath 0.75 ± 0.10, from WMO 0.85 ± 0.10, and from Ackerman (1971) 1.00 ± 0.15.

If the comparisons (Fig. 6) are made for solar irradiances averaged in 1 nm intervals in the same region of the O_2 Schumann-Runge bands, the same conclusions are reached. The averaged ratio of the Brasseur-Simon compilation and the NRL data is still 0.65 ± 0.15 with a minimum at $\lambda < 180$ nm. The averaged values of Rottman between 1982 and 1984 correspond to a ratio of 0.80 ± 0.15 with a minimum near 180 nm. The recent values of Mental and Williams (1988) in 1983 and 1984 lead to different ratios 0.75 ± 0.05 at $\lambda < 188$ nm and 0.90 ± 0.05 at $\lambda < 190$ nm. Thus, the photodissociation rates of O_2 in the mesosphere depend, at the present time, on the adopted solar irradiances more than on possible solar activity effects which should be established according to the spectral region.

4. THE SPECTRAL IRRADIANCES IN THE SPECTRAL REGION OF THE O_2 HERZBERG CONTINUUM

The uncertainties in the spectral region 200 - 240 nm are certainly less than the differences occuring at shorter wavelengths. Figure 7 illustrates for 500 cm^{-1} intervals the ratio of the compilation of Brasseur - Simon and the values deduced from the SUSIM data. The ratio is 0.98 ± 0.12 with a subdivision 0.90 ± 0.05 for $\nu > 48000$ cm^{-1} and

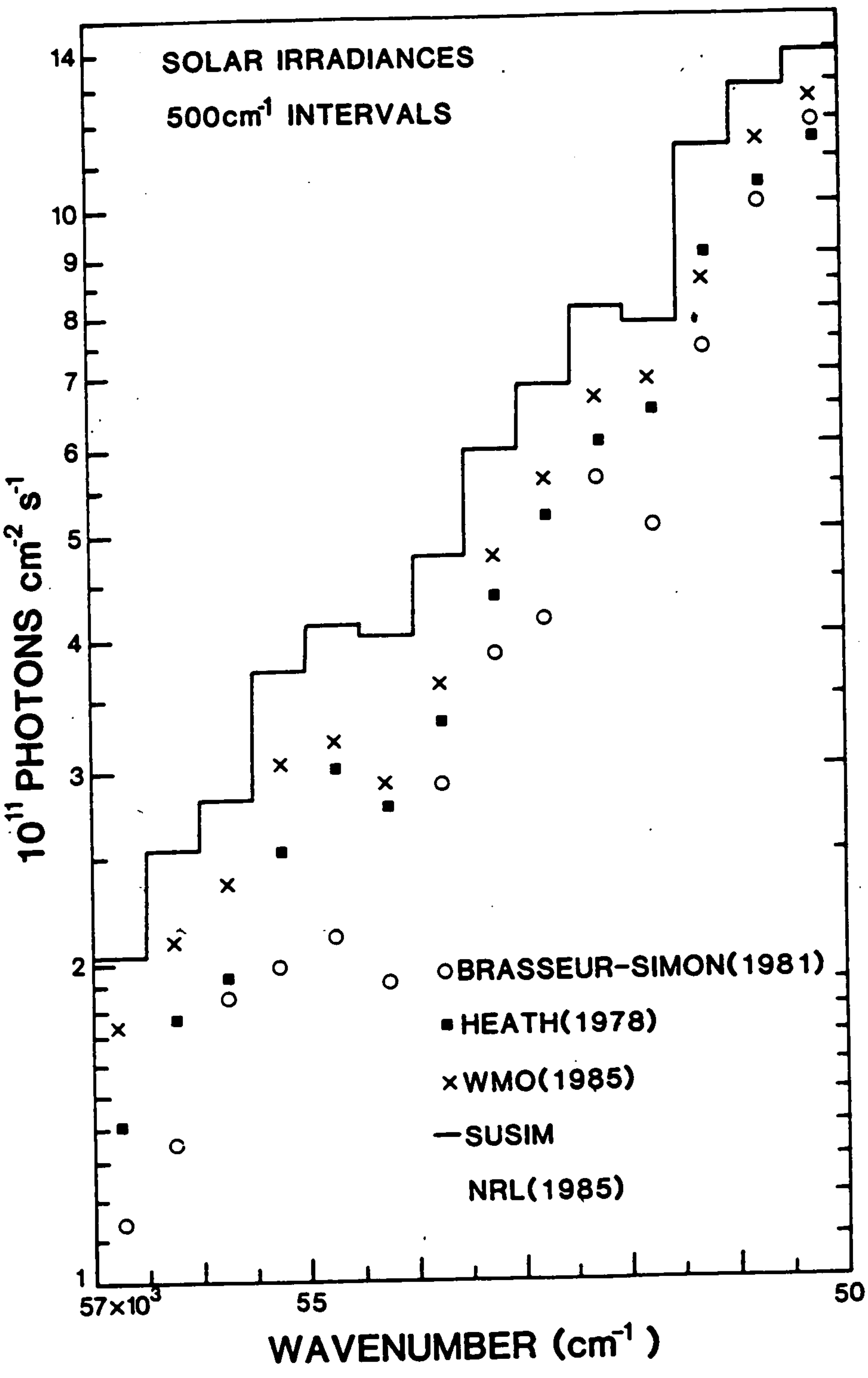

Fig. 4.- Solar spectral irradiances (photons cm^{-2} s^{-1}) between 57000 and 50000 cm^{-1} in 500 cm^{-1} intervals.

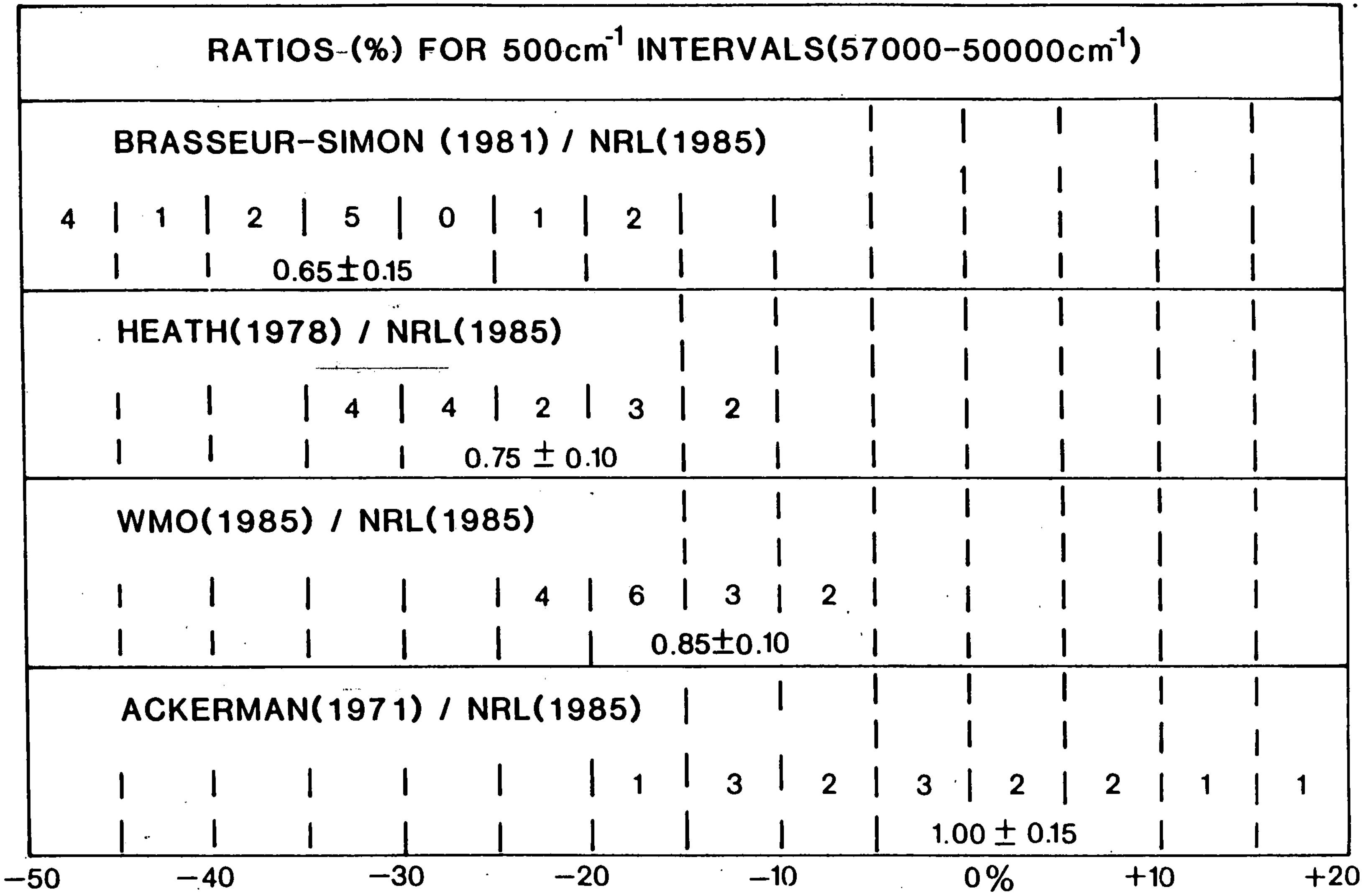

Fig. 5.- Distribution, between 57000 and 50000 cm^{-1}, of ratios of solar irradiances depicted in Fig. 1.
Numbers of intervals by steps of 5% with the averaged values and their dispersions of the ratios. Reference spectrum : SUSIM.

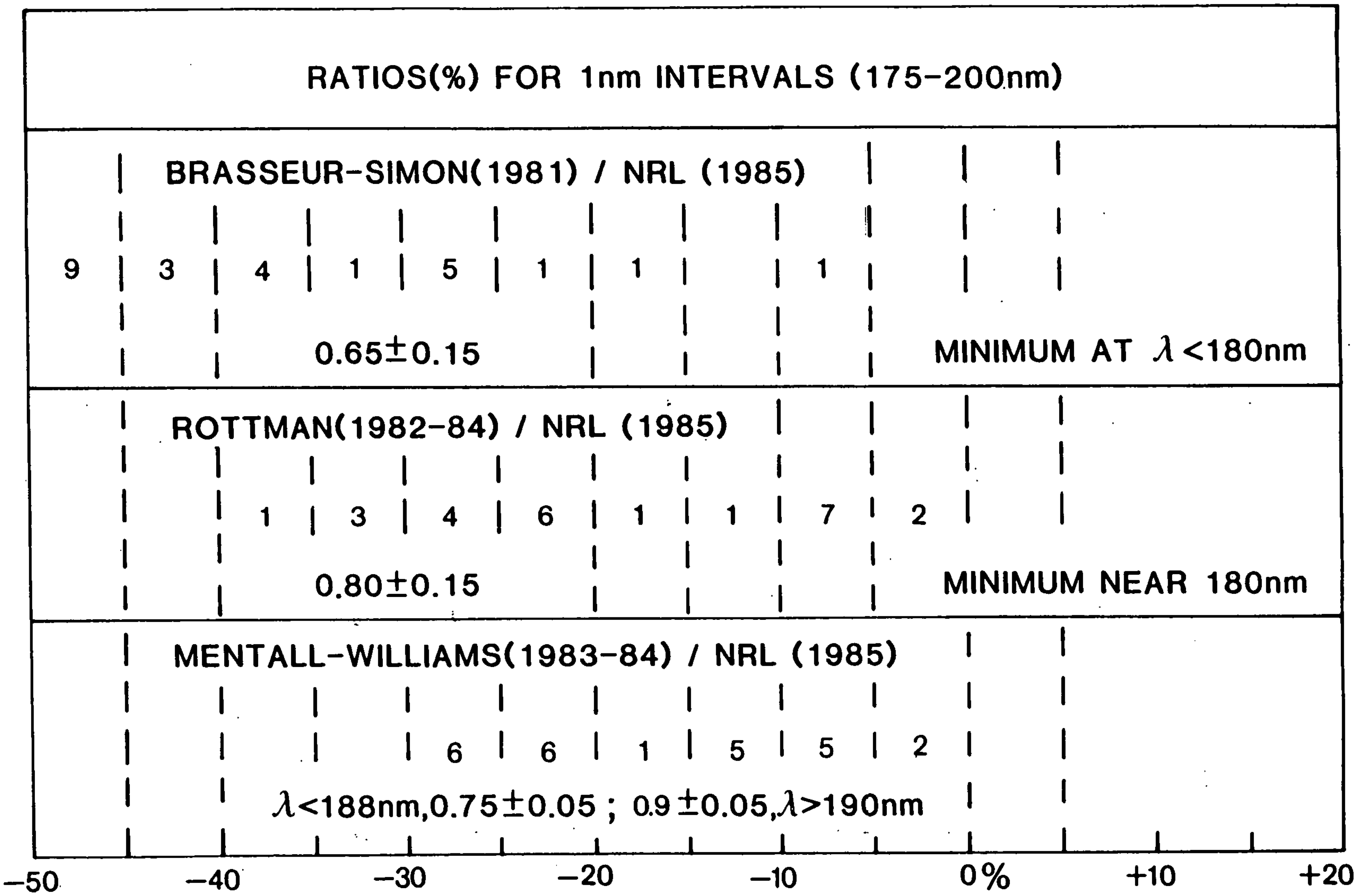

Fig. 6.- Distribution, between 57000 and 50000 cm^{-1} (175-200 nm, of ratios of solar irradiances for 1 nm intervals.
Numbers of intervals by steps of 5% with the averaged values and their dispersions of the ratios. Reference spectrum : SUSIM.

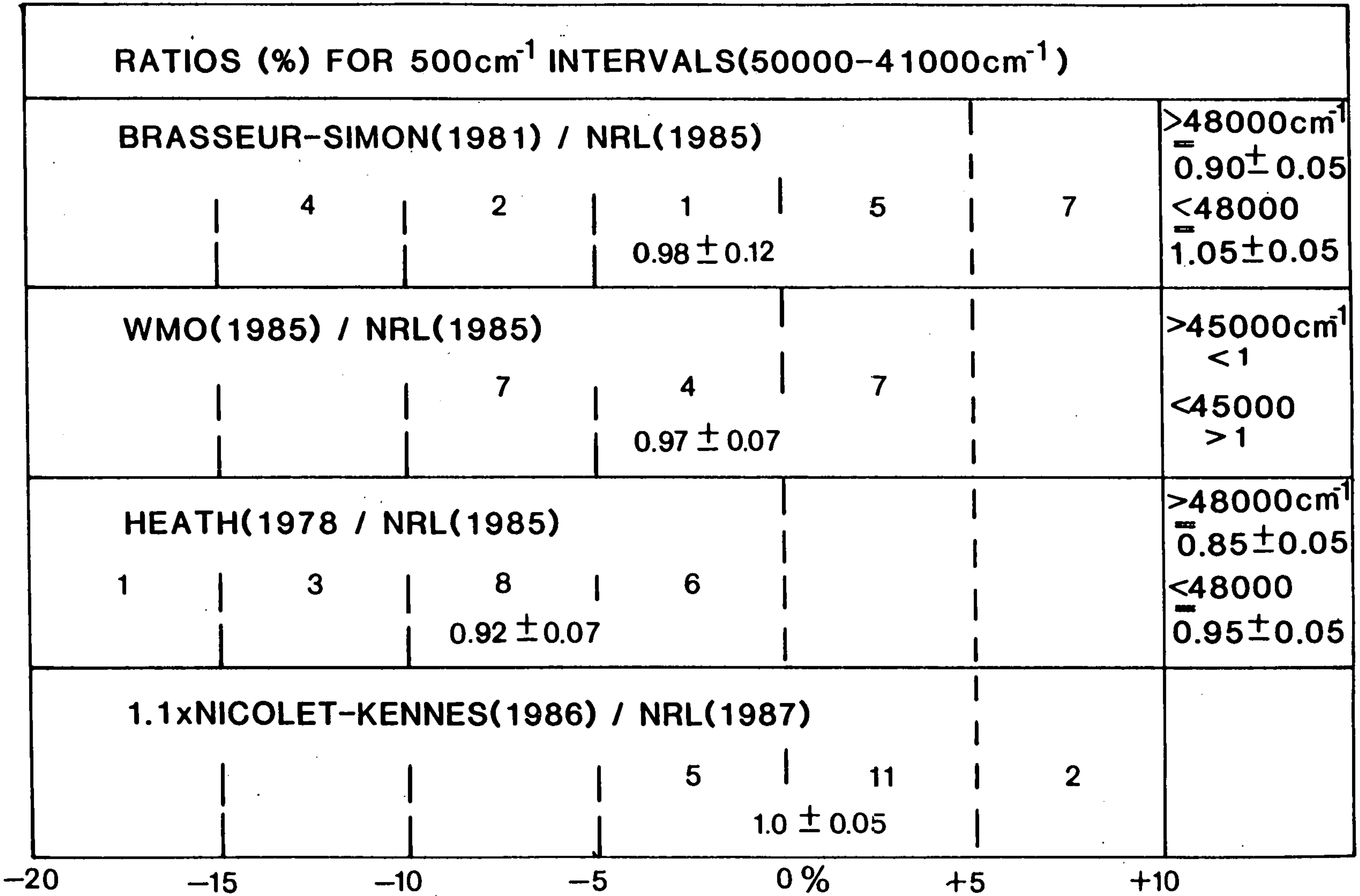

Fig. 7.- Distribution, between 50000 and 41000 cm^{-1}, of ratios of solar irradiances for 500 cm^{-1} intervals.
Numbers of intervals by steps of 5% with the averaged values and their dispersions of the ratios. Reference spectrum : SUSIM.

1.05 ± 0.05 for $\nu < 48000$ cm^{-1}. The WMO compilation corresponds to an almost identical ratio : 0.97 ± 0.17, with systematic differences < 1 for $\nu > 45000$ cm^{-1} and > 1 for $\nu < 45000$ cm^{-1}. The satellite measurements of Heath in 1978 (high solar activity) are systematically lower than the values deduced from SUSIM data (low solar activity); the mean ratio is 0.90 ± 0.07 and reaches 0.85 ± 0.05 at $\nu > 48000$ cm^{-1} and 0.95 ± 0.05 at $\nu < 48000$ cm^{-1}, Finally, the values which were adopted by Nicolet and Kennes (1986) are 10% lower than the SUSIM data. With an increase of a factor of 1.1 the ratio is 1.0 ± 0.05.

Various spectral irradiances are illustrated in Fig. 8 for intervals of 500 cm^{-1}. It is clear that the agreement is at least within ± 10%. The comparison between the irradiance deduced from Spacelab 1 (Labs et al., 1987) and from SUSIM Spacelab 2 shows an astonishingly good agreement between 48000 cm^{-1} and 40000 cm^{-1}. If there is difference greater than 10% from 50000 cm^{-1} to 48000 cm^{-1} (see Fig. 1), it is only 1.00 ± 0.04 between 48000 cm^{-1} and 41000 cm^{-1}. On the 14 ratios, 5 correspond to 1.00, 4 to ± 1.02 and 5 to 1.04. An extension to 28000 cm^{-1} for 500 cm^{-1} intervals shows an agreement of ± 5% for at least 95% of the ratios, ± 4% for 90%, ± 3% for 80%, ± 2% for 70% and ± 1% for more than 50%. The number of lines which were considered from the measurements of Labs et al. (1987) for 500 cm^{-1} increases from 20 at 48000 - 47500 cm^{-1} to 60 at 28500 - 28000 cm^{-1}.

A more detailed comparison between various averaged values in 1 nm intervals indicates systematic differences as large as ± 10% and random variations between ± 10% and ± 15%. The results of the analysis are depicted in Fig. 9. The averaged values in 1 nm intervals deduced from the SUSIM data were again taken as the reference data.

Starting from the data of Mentall et al. (1981) corresponding to measurements of the solar irradiance on September 15, 1980 at low solar activity (solar flux at 10.7 cm = 70 units for the whole month), the camparison of the values NRL/Mentall gives a ratio 1.10 ± 15%, i.e. a systematic difference of 10% with possible individual differences as

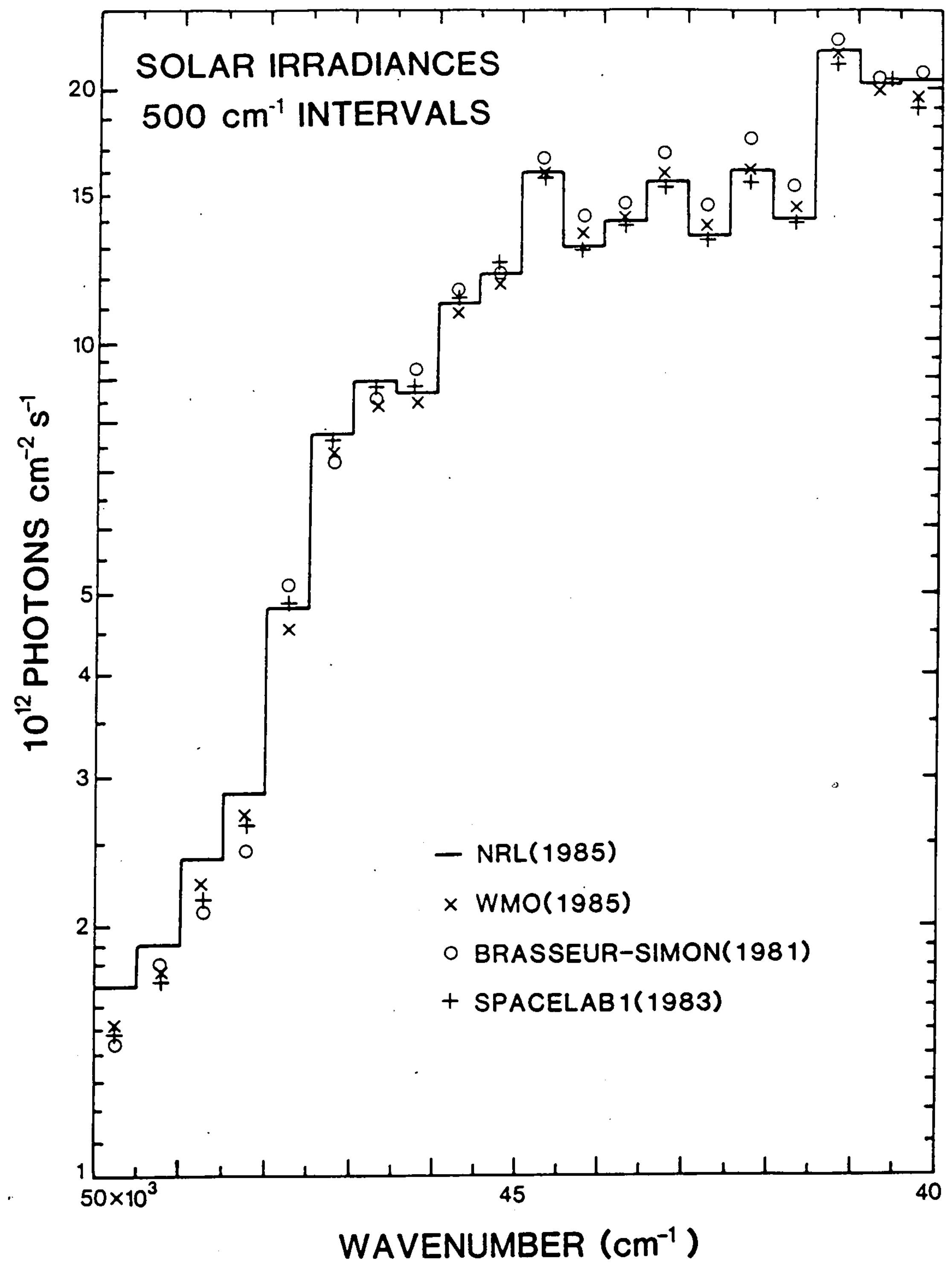

Fig. 8.- Solar spectral irradiances (photons cm^{-2} s^{-1}) between 50000 and 40000 cm^{-1} in 500 cm^{-1} intervals.

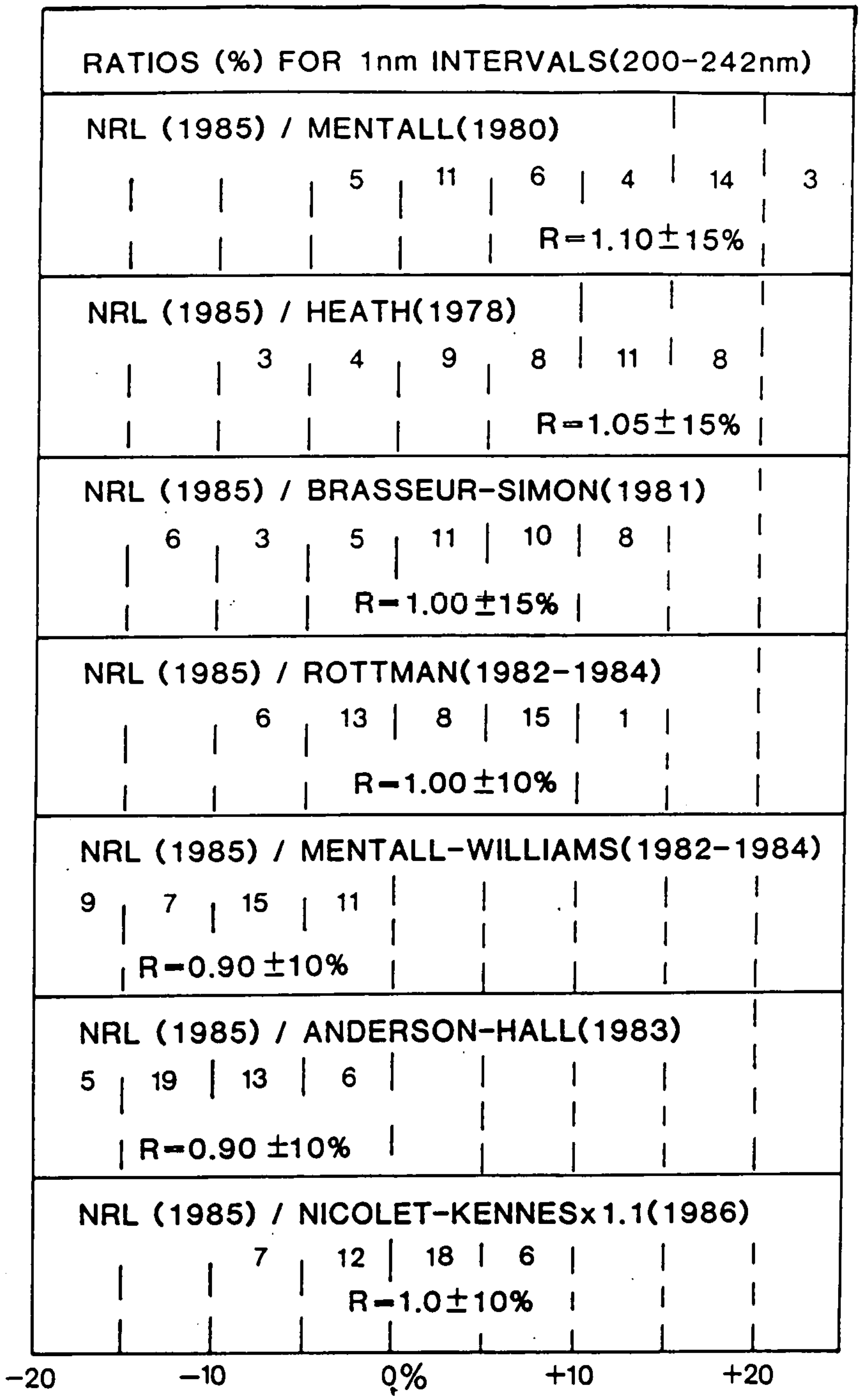

Fig. 9.- Distribution, between 200 and 242 nm, of ratios of solar irradiances for 500 cm^{-1} intervals.
Numbers of intervals by steps of 5% with the averaged values and their dispersions of the ratios R. Reference spectrum : SUSIM.

large as 10 to 15%. However, individual differences greater than 10% should be explained by an error in the comparison of the order of 0.1 nm for intervals of 1 nm since wavelength scale at some points in the spectrum may be different. It is not easy at low resolution to detect the errors particularly when an averaged value of the irradiances is deduced from the complex blends exhibited in the solar spectrum at low resolution. The differences in this spectral region of 0.06 nm to 0.07 nm between the vacuum and air wavelengths must be considered also as possible errors in the comparisons between observational data. Fig. 10 is an example of differences in 1 nm and 500 cm^{-1} intervals. The results of rocket observations of Mentall et al. (1981) are compared with the results of satellite observations made by Heath in 1978. Fig. 11 and 12 explain the differences by a comparison of irradiances based on 1 nm running means of values of Mentall et al. and of those directly deduced from Heath's data with a resolution of about 1 nm. Near 215 $\pm$ 2.5 nm the irradiances of Mentall et al. are systematically low, but show a higher resolution depicted in the maxima and minima even with a running mean of 1 nm.

A comparison (Fig. 9) with the satellite data of Heath (1980) on November 7, 1978 at relatively high solar activity (solar radio flux at 10.7 cm, 175 units) indicates a ratio NRL/Heath = 1.05 $\pm$ 15%, i.e. systematically lower values in the opposite variation of solar activity. The compilation of Brasseur and Simon (1981) shows an agreement (Fig. 9) with a ratio NRL/Brasseur-Simon = 1.00 but with differences reaching 10 - 15%, i.e. a modest precision. The averaged values of 4 observations (Mount and Rottman, 1983, for solar radioflux at 10.7 cm 140 units on May 17, 1982; Mount and Rottman, 1985, for solar radioflux at 10.7 cm 140 units for July 25, 1983, and Rottman (unpublished) for solar radiofluxes 102 on December 7, 1983 and 77 on December 10, 1984) give (Fig. 9) a ratio NRL/Rottman (1982-1984) 1.00 $\pm$ 10% i.e. a ratio with a normal precision of $\pm$ 10%.

Two recent determinations by Mentall and Williams (1988) based on rocket flights on December 7, 1984 (Solar radioflux at 10.7 cm = 102) and

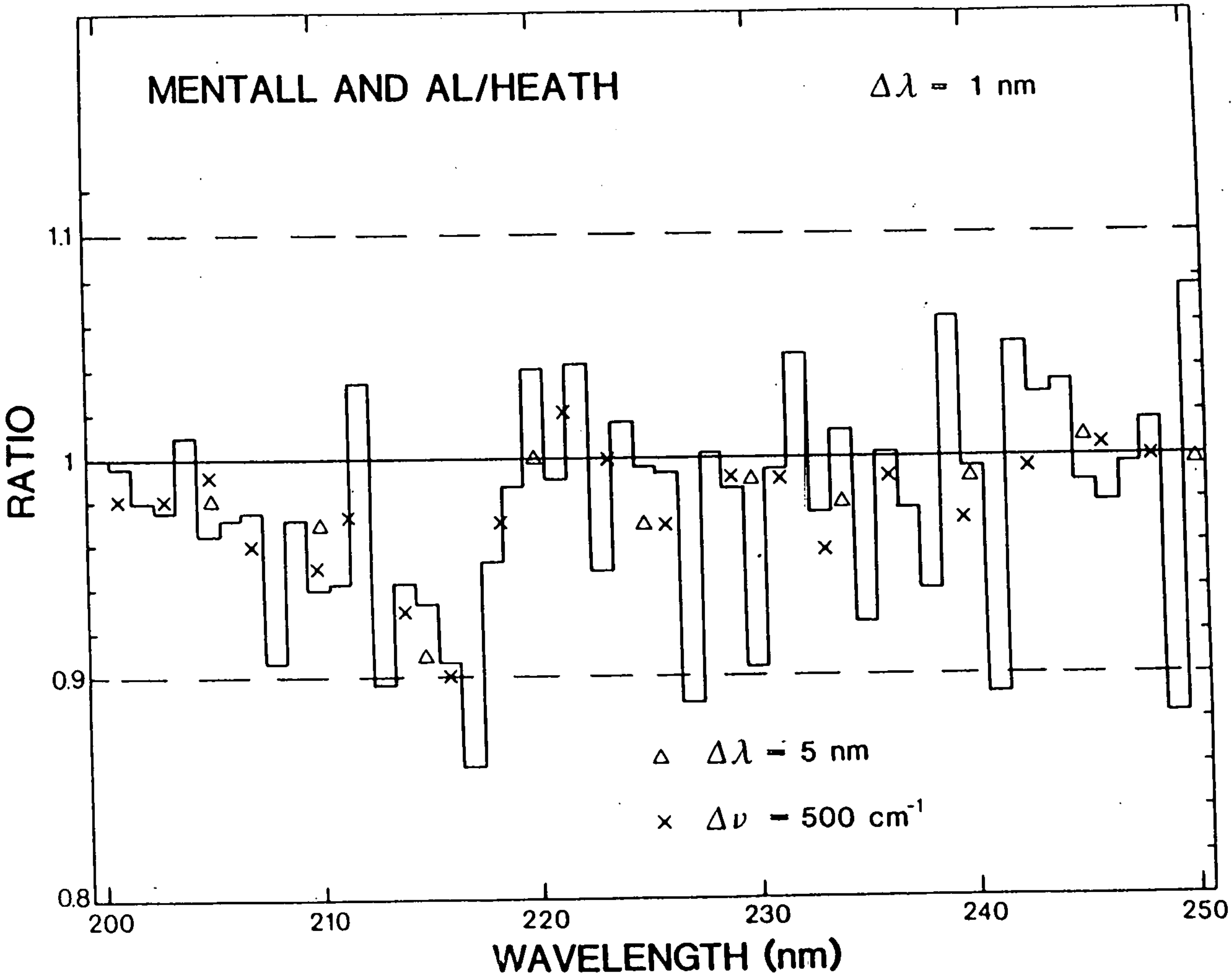

Fig. 10.- Ratios of irradiances between 200 and 250 nm.
For 1 nm intervals the ratio of the averaged irradiances of Mentall *et al.* (1980) and Heath (1978) is about 0.95 $\pm$ 10% as it can be seen in the Figure. The agreement is better for 500 cm^{-1} intervals or 5 nm intervals.

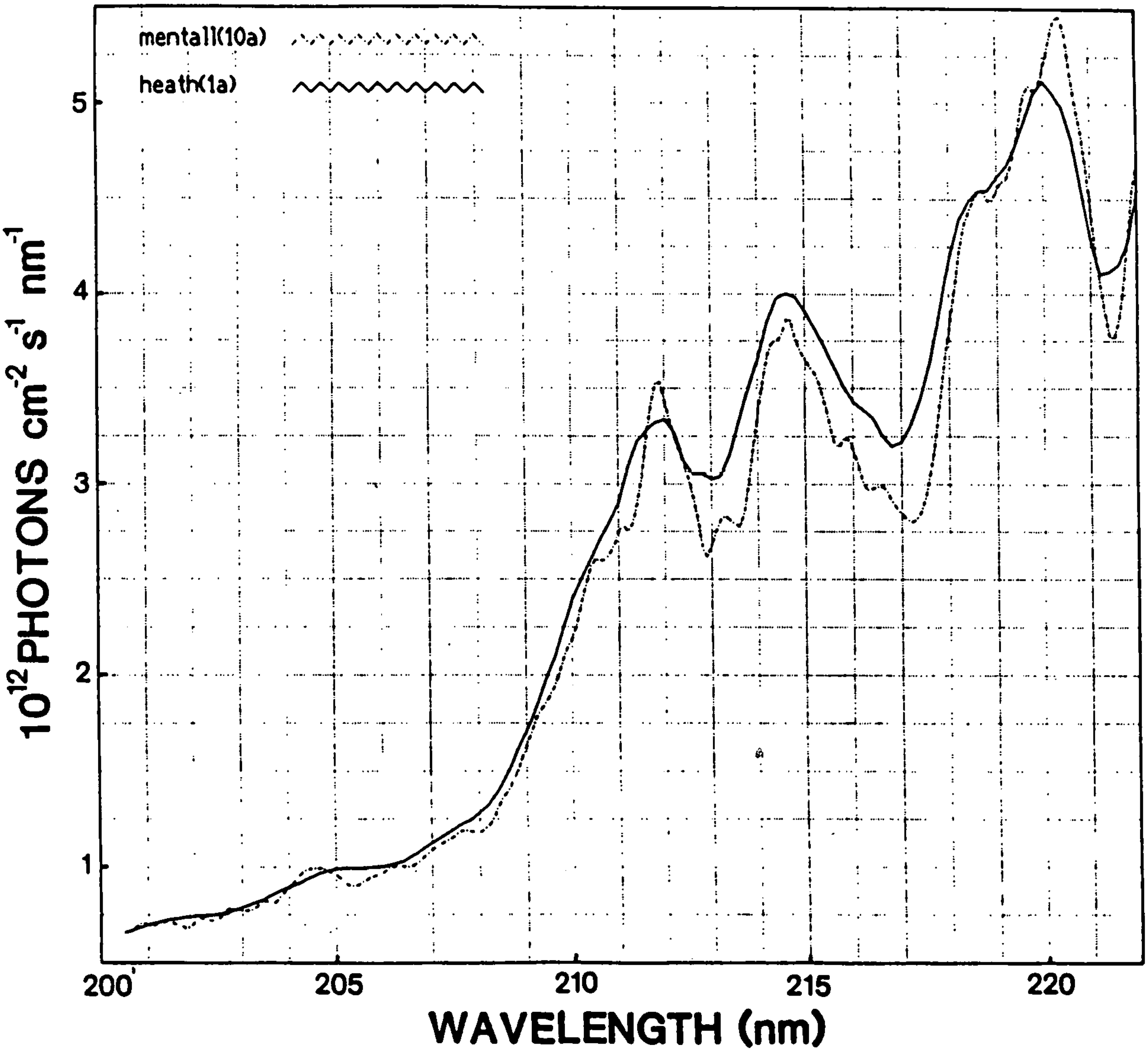

Fig. 11.- Comparison between solar irradiances from 200 to 222 nm.
The irradiances obtained by Mentall et al. (1980) represented by 1 nm running means and compared with the irradiances obtained by Heath in 1978. Agreement except near 215 ± 3 nm.

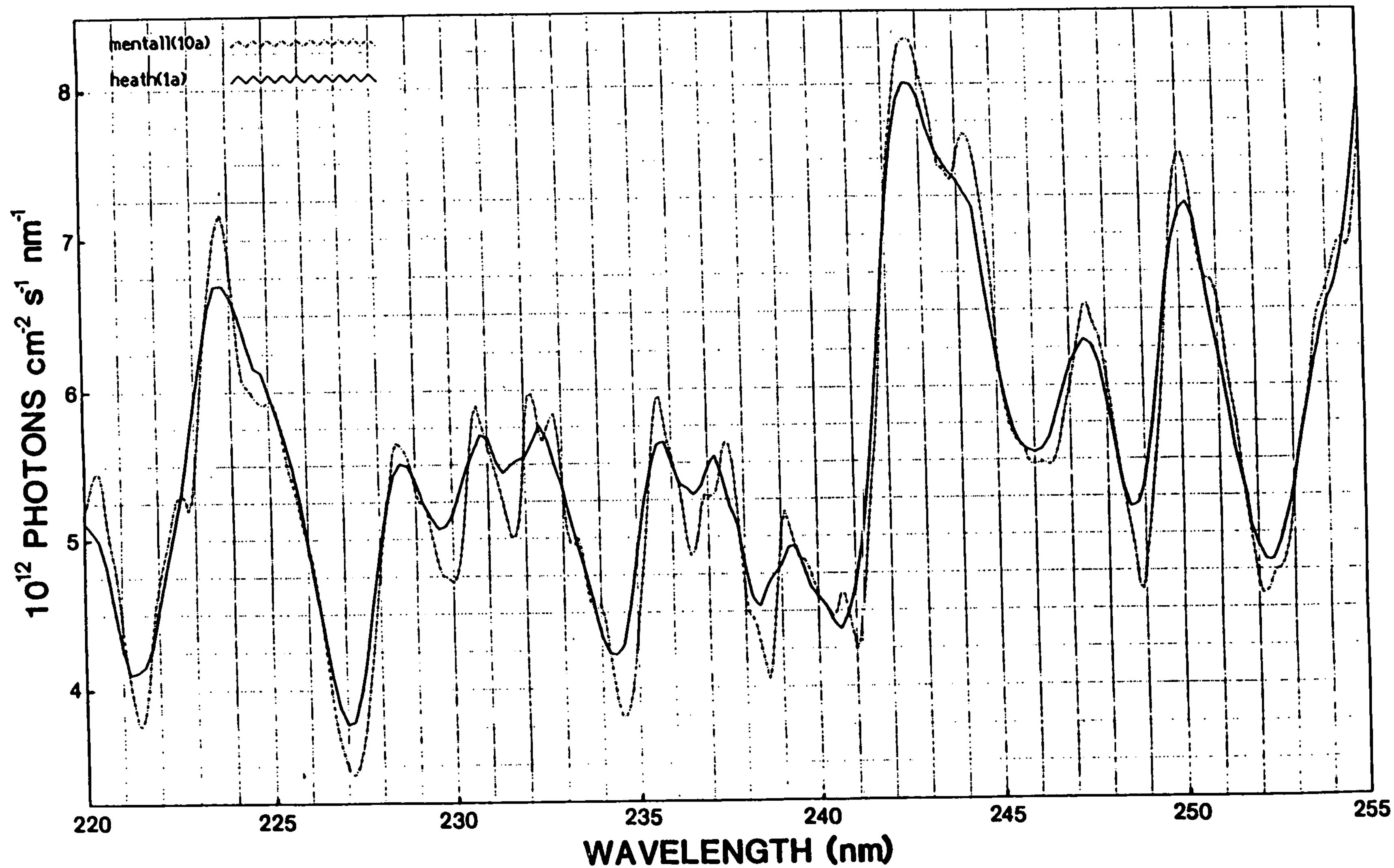

Fig. 12.- Comparison between solar irradiances from 220 to 255 nm. Irradiances as in Fig. 11. Even with 1 nm running means the averaged values deduced from Mentall et al. (1980) have higher peaks and deeper minima than the irradiances obtained by Heath.

on December 10, 1984 (Solar radioflux at 10.7 cm = 77) give a ratio NRL/Mentall - Williams = 0.90 ± 0.10, i.e. a systematic difference of 10% (Fig. 9) with a random precision of ± 10% normal for comparison on 1 nm intervals. A recent analysis by Anderson and Hall (1988, unpublished) based on observations made at 40 km (April 1983) shows (Fig. 9) that the ratio NRL/Anderson - Hall corresponds to 0.90 ± 10%.

In conclusion, in the region of the O_2 Herzberg continuum, 200 - 240 nm, the absolute accuracy of spectral solar irradiances is confined to ± 10% for the recent observations (1978-1988); the precision of individual measurements is approximately ± 10% for averaged values in intervals of 1 nm.

CONCLUSION

The SUSIM irradiance (NRL Spacelab 2), which were taken in the present investigation on the solar UV radiation as reference solar irradiances adapted to various spectral intervals, will be used in subsequent publications on the direct photodissociation of molecular oxygen in the mesosphere and stratosphere.

ACKNOWLEDGEMENTS

During the preparation of this paper we benefitted from helpful discussions and effective cooperation. M. Nicolet is particularly grateful to G. Anderson, L. Hall, J. Mentall and M. VanHoosier for providing original versions of their data. The preparation of this work was supported by the Office of Naval Research, under grant number N0014-8GK-0265-P0002, with the Communications and Space Sciences Laboratory of the Penn State University and by the Commission of the European Communities, Directorate-General for Science, Research and Development, Environment Research Programme.

REFERENCES

Ackerman, M., Ultraviolet solar radiation related to mesospheric processes, in Mesospheric Models and Related Experiments, edited by G. Fiocco, pp. 149-159, D. Reidel Dordrecht, 1971.

Anderson, G.P., Hall, L.A. and Shettle, E.P., High resolution solar irradiance measurements : 200 - 310 nm, IUGG Assembly, Vancouver, and to be published 1988.

Brasseur, G. and Simon, P.C., Stratospheric chemical and thermal response to long-term variability in solar UV irradiance, J. Geophys. Res. **86**, 17343, 1981.

Detwiler, C.R., Garrett, D.L., Purcell, J.D. and Tousey, R., The intensity distribution in the ultraviolet solar spectrum, Ann. Géophys. **17**, 263, 1961.

Friedman, H., Lichtman, S.W. and Byram, E.T., Photon counter measurements of solar X-rays and extreme ultraviolet light, Phys. Rev. **83**, 1025, 1951.

Heath, D.F., A review of observational evidence of short and long term ultraviolet flux variability of the sun, Proc. Intern. Conf. on Sun and Climate, CNES, Toulouse, Sept. 30 - Oct. 3, pp. 445 - 450, 1980.

Heroux, L. and Higgins, J.E., Summary of full-disk solar fluxes between 250 and 1940 A. J. Geophys. Res. **82**, 3307, 1977.

Labs, D., Neckel, H., Simon, P.C. and Thuillier, G., Ultraviolet solar irradiance measurement from 200 to 358 nm during Spacelab 1 mission. Solar Physics **107**, 203, 1987.

Mentall, J.E., Frederick, J.E. and Herman, J.R., The solar irradiance from 200 - 300 nm. J. Geophys. Res. **86**, 9881, 1981.

Mentall, J.E., Guenter, B. and Williams, D., The solar irradiance between 150 and 200 nm. J. Geophys. Res. **90**, 2265, 1985.

Mentall, J.E. and Williams, D.E., Solar ultraviolet irradiances on December 7, 1983 and December 10, 1984. J. Geophys. Res. **93**, 735, 1988.

Mount, G.H. and Rottman, G.J., The solar spectral irradiance 1200 - 3184 A near solar maximum : 15 July 1980. J. Geophys. Res. **86**, 9193, 1981.

Mount, G.H. and Rottman, G.J., Solar absolute irradiance 1150 - 3173 A : May 17, 1982. J. Geophys. Res. **88**, 5403, 1981.

Mount, G.H. and Rottman, G.J., The solar absolute spectral irradiance at 1216 A and 1800 - 3173 A : January 12, 1983, J. Geophys. Res. **88**, 6807, 1983b.

Mount, G.H. and Rottman, G.J., The solar absolute spectral irradiance 118 - 300 nm : July 25, 1983. J. Geophys. Res. **90**, 13031, 1985.

Nicolet, M. and Kennes, R., Aeronomic problems of the molecular oxygen photodissociation I. The O_2 Herzberg continuum, Planet. Space Sci. **34**, 1043, 1987.

Nicolet, M. and Mange, P., The dissociation of oxygen in the high atmosphere. J. Geophys. Res. **59**, 15, 1954.

Rottman, G.R., Disc values of the solar ultraviolet flux, 1150 to 1900 A, EOS, **56**, 1157, 1974.

Rottman, G.R., Rocket measurements of solar spectral irradiance during solar minimum, 1972 - 1977, J. Geophys. Res. **86**, 6697, 1981.

Tousey, R., Watanabe, K. and Purcell, J.D., Measurements of solar extreme ultraviolet and X-rays from rockets by means of a $CaSO_4$: Mn phosphor. Phys. Rev. **83**, 792, 1951.

VanHoosier, M.E., Bartoe, J.-D.F., Brueckner, G.E. and Prinz, D.K., Solar irradiance measurements 120 nm - 400 nm from Spacelab-2 (Results from the SUSIM Experiment), IUGG Assembly, Vancouver and to be published 1988.

WMO, Atmospheric Ozone, Report No 16, Chapter 7, Radiative processes : Solar and terrestrial, pp. 349 - 392, 1985.