issn 0065-3713

INSTITUT D'AERONOMIE SPATIALE DE BELGIQUE

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AERONOMICA ACTA

A - N° 337 - 1989

SOLAR ULTRAVIOLET RADIATION WITHIN THE MIDDLE ATMOSPHERE

by

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FOREWORD

"Solar ultraviolet radiation within the middle atmosphere" summarizes a work presented at the "International Radiation Symposium" - Lille, France, 18-24 August 1988. It will be published in the proceedings of the symposium.

AVANT-PROPOS

"Solar ultraviolet radiation within the middle atmosphere" résume le texte d'une communication faite au "International Radiation Symposium" - Lille, France, 18-24 août 1988. Il sera publié dans les comptes rendus du symposium.

VOORWOORD

"Solar ultraviolet radiation within the middle atmosphere" is de samenvatting van een mededeling gegeven op het "International Radiation Symposium" - Lille, France, 18-24 augustus 1988. De tekst zal gepubliceerd worden in de verslagen van het symposium.

VORWORT

"Solar ultraviolet radiation within the middle atmosphere" ist der Zusammenfassung einer Mitteilung gegeben am "International Radiation Symposium" - Lille, France, 18-24 August 1988. Der Text wird publiziert werden in den Berichten der Tagung.

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Abstract

Ultraviolet solar radiation budget of the middle atmosphere depends upon extraterrestrial solar irradiance and its variations, its absorption by atmospheric constituents, its extinction by molecular and aerosol scattering, the scattering by the atmosphere and the reflexion by the Earth's surface. This work briefly reviews and discusses the recent observations of solar ultraviolet irradiance above the Lyman α wavelength during the declining phase of solar cycle 21. Despite major improvements in the quoted uncertainties, important discrepancies (up to 40%) between those observations are still present below 200 nm. Above this wavelength the agreement between the two Space Shuttle observations is very good, giving ultraviolet irradiance values with accuracies between 3.5 and 5.2%. Variabilities related to the 27-day rotation period and the 11-year cycle have also been revised on the basis of the most recent analysis of SBUV and SME observations.

Résumé

La quantité de rayonnement ultraviolet solaire dans l'atmosphère moyenne dépend de l'éclairement énergétique du soleil et de ses variations, de son absorption par les constituants atmosphériques, de la diffusion de la lumière par les aérosols et les molécules atmosphériques et de la réflection à la surface de la terre. Ce travail présente les observations relatives à l'éclairement énergétique du soleil aux longueurs d'ondes supérieures à Lyman α, obtenues pendant la phase descendante du cycle d'activité solaire n° 21. Malgré une amélioration importante des incertitudes des nouvelles mesures, des désaccords importants subsistent entre ces observations (jusqu'à 40%) pour le domaine spectral inférieure à 200 nm. L'accord entre les deux séries d'observations réalisées à bord de la navette spatiale est très bon au-dessus de 220 nm. Elles donnent des valeurs de l'éclairement énergétique du soleil avec une précision absolue comprise entre 3.5 et 5.2%. Les variations liées à la période de rotation solaire et au cycle solaire sont également revues sur base des analyses les plus récentes des observations de SBUV et de SME.

Samenvatting

De ultraviolette zonnestraling in de middenatmosfeer is afhankelijk van buitenaardse zonnestraling en haar variaties, haar absorptie door atmosferische bestanddelen, haar uitdoving door aërosol- en moleculaire verstrooiing, de verstrooiing door de atmosfeer en de weerkaatsing door het aardoppervlak. Dit werk bespreekt bondig de recente waarnemingen van ultraviolette zonnestraling boven Lyman α tijdens de afgaande fase van zonnecyclus 21. Ondanks grote verbeteringen in de genoteerde onzekerheden, belangrijke afwijkingen (tot 40%) tussen deze waarnemingen zijn nog steeds aanwezig onder 200 nm, is de overeenstemming tussen de twee waarnemingen van de ruimtependel zeer goed, hetgeen ultraviolette stralingswaarden oplevert met nauwkeurigheden tussen 3,5 en 5,2%. Veranderlijkheden verbonden aan de omwentelingsperiode van 27 dagen en de elfjarige cyclus werden eveneens herzien op basis van de meest recente analyse van SBUV en SME waarnemingen.

Zusammenfassung

Die ultraviolette Sonnenstrahlung in der Mittelatmosphäre ist abhängig von ausserirdischer Sonnenstrahlung und ihrer Variationen, ihrer Absorption durch atmosphärischen Bestandteilen, ihrer Auslöschung durch Aerosol - und molekulare Streuung, die Streuung durch die Atmosphäre und die Reflexion durch die Erdoberfläche. Diese Arbeit bespricht kürzlich die rezenten Beobachtungen von ultraviolette Sonnenstrahlung über Lyman α zwischen der abnehmenden Phase von Sonnenzyklus 21. Trotz grösser Verbesserungen in den notierten Unsicherheiten, wichtige Abweichungen (bis zu 40%) zwischen diesen Beobachtungen sind immer noch anwesend unter 200 nm, ist die Übereinstimmung zwischen den zwei Beobachtungen der Raumfähre sehr gut, was ultravioletten Strahlungswerter gibt mit Genauigkeiten zwischen 3,5 und 5,2%. Variabilitäten verbunden mit der Umlaufperiode von 27 Tagen und dem elfjahrigen Zyklus wurden auch revidiert auf der Grundlage der meist rezenten Analyse von SBUV und SME Beobachtungen.

1. *INTRODUCTION*

The solar electromagnetic radiation is the primary source of energy for the terrestrial environment. The largest fraction of energy associated with the solar spectrum is situated in the visible. The ultraviolet domain for wavelengths shorter than 320 nm represents only a small fraction (2 percent) of the total incident flux. This spectral range is of fundamental importance for chemical, dynamical and radiative processes in the middle atmosphere.

Solar Lyman α and ultraviolet radiation of wavelengths larger than 180 nm are absorbed in the mesosphere and in the stratosphere. The Lyman α solar chromospheric line initiates photoionization processes in the D-region and the photodissociation, for instance, of water vapor in the mesosphere, controlling the ozone budget in the mesosphere through the production of hydroxyl radicals.

Ozone, which protects the biosphere from harmful solar ultraviolet radiation, is produced in the upper stratosphere by photodissociation of molecular oxygen by radiation of wavelengths shorter than 242 nm. It is itself photodissociated by solar radiation in the visible range and in the ultraviolet. Absorption of ultraviolet radiation of wavelengths larger than 200 nm by stratospheric ozone is responsible for the stratospheric heating. Below that wavelength, the absorption by molecular oxygen becomes predominant.

Because of the complexity of the atmospheric processes and the strong interplay and feedback between chemical composition and radiative budget, atmospheric and climate studies should include observations of visible and ultraviolet solar radiation and its variability, in close relation with the atmospheric constituents which control the penetration of solar radiation and the transfer of the outgoing thermal radiation. The ozone molecule is a key minor constituent for the stratosphere and the mesosphere. It provides the main heat source through the absorption of solar ultraviolet radiation and thus determines to a great extent the temperature profile in the stratosphere and the general circulation. Ozone therefore couples the stratosphere and the tropospheric climate through complex processes involving radiative, chemical and dynamic effects. The study of solar variability with respect to anthropogenic perturbations is of crucial importance to distinguish the impact of the various perturbations affecting the terrestrial environment in the future.

The purpose of this work is to provide a critical analysis of the recent observations of solar ultraviolet irradiance above Lyman α performed during the declining phase of solar cycle 21. A more detailed analysis of the solar variabilities is published elsewhere (Simon, 1988). The reader has to refer to previous works for solar ultraviolet solar irradiances observations performed during solar cycle 20 and the ascending phase of the solar cycle 21 (e.g. Simon, 1981; Simon and Brasseur, 1983, Lean, 1987).

2. THE LYMAN α EMISSION LINE

Since the Atmospheric Explorer E (AE-E) time series obtained during the rising phase of solar cycle 21 for which important controversy has been reported (e.g. Bossy, 1983), the only continuous observations of this solar emission line have been performed by the Solar Mesosphere Explorer (SME) launched in October 1981. The latter measurements ranging from 115 to 300 nm have been normalized on the observation obtained with a rocket flight made on May 17, 1982 (Mount and Rottman, 1983) and calibrated against the Synchroton Users Radiation Facility (SURF) at NBS. The SME results give a maximum value of the order of 4×10^{11} photons.$s^{-1}.cm^{-2}$ at the beginning of 1982 and minimum values around 2.5×10^{11} photons.s^{-1} cm^{-2} in 1986 (Rottman, 1988).

Besides the SME observations, several snapshot measurements including rockets and one space shuttle flight have been performed up to 1985. They are summarized in Table 1. The Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) observation (Van Hoosier and Brueckner, 1987)

TABLE 1. Snapshot observations of the solar H I Lyman α emission line

Date	Irradiance 10^{11} $h\nu.s^{-1}.cm^{-2}$	Radio flux (10.7 cm) at 1 AU 10^{-22} $W.m^{-2}.Hz^{-1}$	Accuracy
Feb. 28, 1972 □	2.1	130	± 14%
Dec. 13, 1972 x	3.08	111	± 23%
Aug. 30, 1973 x	2.02	101	± 20%
Nov. 02, 1973 °	3.14	84	± 30%
Apr. 23, 1974 °	2.51	74	± 30%
Jul. 28, 1975 x	2.20	76	± 20%
Feb. 18, 1976 x	3.70	70	± 20%
Mar. 09, 1977 x	4.28	80	± 20%
Jun. 05, 1979 +	4.98	230	± 12%
Jul. 15, 1980 +	5.50	218	± 8%
May 17, 1982 +	3.24	142	± 8%
Jan. 12, 1983 +	3.01	135	± 25%
Jul. 25, 1983 +	2.69	137	± 8%
Aug. 03, 1985 *	3.79	79	± 3.5%

References :

° Heroux and Higgins (1977) }
x Rottman (1981 } Rockets
+ Mount and Rottman (1985) }
* VanHoosier and Brueckner (1987), SUSIM, Spacelab 2
□ Ackerman and Simon (1973)

performed during the Spacelab 2 mission in August 1985, during the minimum of solar activity between solar cycle 21 and 22, gives a value of 3.8×10^{11} photons.s^{-1}.cm^{-2} in contradiction with the SME minimum values obtained at the same time. This important discrepancy cannot be explained in terms of differences in radiometric scales because both experiment calibrations are traceable to the SURF.

Nevertheless the consistency of the SME time series favors its minimum value and a solar cycle variation less than a factor of 2 at Lyman α. This conclusion is supported by other studies, namely the Pioneer Venus Orbiter, suggesting close figures for both the minimum value and the solar cycle variation (Ajello et al., 1987).

3. THE 150-200 NM WAVELENGTH RANGE

In addition to the rocket and the space shuttle observations already mentioned for the Lyman α measurements, several rocket flights have been performed by the Goddard Space Flight Center (GSFC, NASA). The results were published by Mentall et al. (1985) and Mentall and Williams (1988). All measurements obtained during the solar cycle 21 are listed in Table 2. Only two observations, namely those made in June 1979 and in July 1980, have not been referred to the NBS SURF radiometric scale.

The four rocket observations performed between October 1981 and December 1984 by LASP (Mount and Rottman, 1983; 1985) and GSFC (Mentall and Williams, 1988) are in relatively good agreement. Indeed, their standard deviation is always lower than 10% over their common wavelength range (150-200 nm), except around 185 nm where it reaches 12%. A mean irradiance spectrum has been calculated and can be considered as representative of the most recent rocket measurements. It is compared with the SUSIM results integrated over 1 nm bandpass in Figure 1. The differences between the two spectra are between 30 and 40% in the 150-185 nm spectral range. They significantly decrease toward longer wavelengths. The SUSIM values are actually closer to the rocket observations performed in November 1978 and May 1980 (see table 2). The

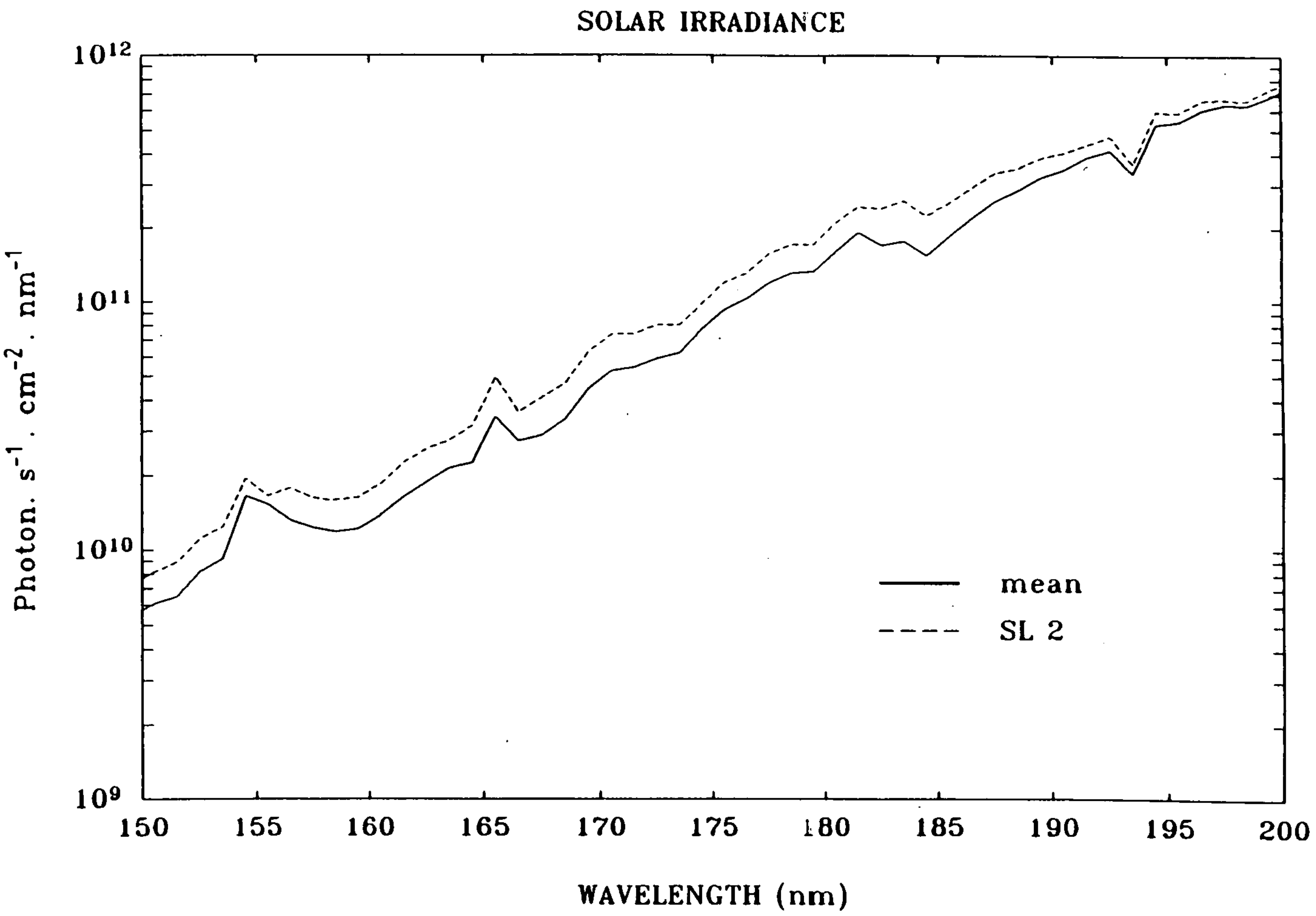

Figure 1. Comparison of solar ultraviolet irradiance integrated over 1 nm between 150 and 200 nm. The solid curve represents the average between 4 rocket observations (Mount and Rottman, 1983; 1985; Mentall and Williams, 1988) performed between May 1982 and December 1984. The dashed curve represents the SUSIM data reported by VanHoosier and Brueckner (1987) from the Spacelab 2 mission in August 1985.

TABLE 2.- Integrated solar irradiance values between 150 and 180 nm. All measurements have been obtained from rocket flights except the last in August 1985 made during the Spacelab 2 mission.

Date	Radio flux at 1 AU+ (10.7 cm)	Irradiance 150-160 nm 10^{11} hν.s^{-1} .cm^{-2}	Accuracy percent	Reference	Wavelength range of instrument
Nov. 16, 1978	129	1.30	± 8	Mentall et al. (1985)	150-185
Jun. 05, 1979	230	2.17	± 12	Mount et al. (1980)	120-255
May 22, 1980	277	1.40	± 13	Mentall et al. (1985)	150-185
Jul. 15, 1980	218	2.27	± 13	Mount and Rottman (1983)	120-318
Oct. 16, 1981	303	1.04	± 5	Mentall et al. (1985)	150-200
May 17, 1982	142	1.14	± 8	Mount and Rottman (1983)	115-317
Jul. 25, 1983	137	1.09	± 8	Mount and Rottman (1985)	115-317
Dec. 07, 1983	99	1.13	± 8	Mentall and Williams (1988)	150-260
Dec. 10, 1984	76	1.06	± 3	Mentall and williams (1988)	150-342
Aug. 03, 1985	79	1.45	± 3.5	VanHoosier and Brueckner (1987)	120-400

+ unit : 10^{-22} W.m^{-2}.Hz^{-1}.

highest values obtained in June 1979 and July 1980 were never confirmed even for comparable activity level. In addition, the solar cycle variation deduced from SME at the same wavelengths does not exceed 15 percent (Rottman, 1989). Consequently, the discrepancies cannot be explained neither in terms of solar activity nor by the experimental errors quoted for each observation.

Consequently, the absolute value of solar irradiance between 150 and 200 nm remains controversial and needs further dedicated observations in order to define accurate values of solar irradiance corresponding to moderate or low activity conditions.

4. THE 200-350 NM WAVELENGTH RANGE

This spectral range has been extensively discussed by Labs et al. (1987) when reporting the new data obtained during the Spacelab 1 mission in December 1983 with an accuracy varying from 5.2 % at 200 nm to 4% at 300 nm. Since that time, the observation performed by SUSIM during the Spacelab 2 mission in August 1985 (Van Hoosier and Brueckner, 1987) confirmed the previous values published by Labs et al. (1987) and are partially reported in Figure 2. Its quoted accuracy, as already mentioned, is 3.5% over the entire spectral range.

The recent rocket observation reported by Mentall and Williams (1988) significantly differs from the previous data obtained in 1979 (Mentall et al., 1981) despite the fact that identical spectrometers and similar calibration procedures traceable to the NBS radiometric scale have been used for both sets of measurements. The latest results are in good agreement with the Spacelab 1 values beyond 260 nm as illustrated in Figure 3.

5. SOLAR ULTRAVIOLET VARIATIONS

The ultraviolet range of the solar electromagnetic spectrum is characterized by its temporal variations which directly affect the

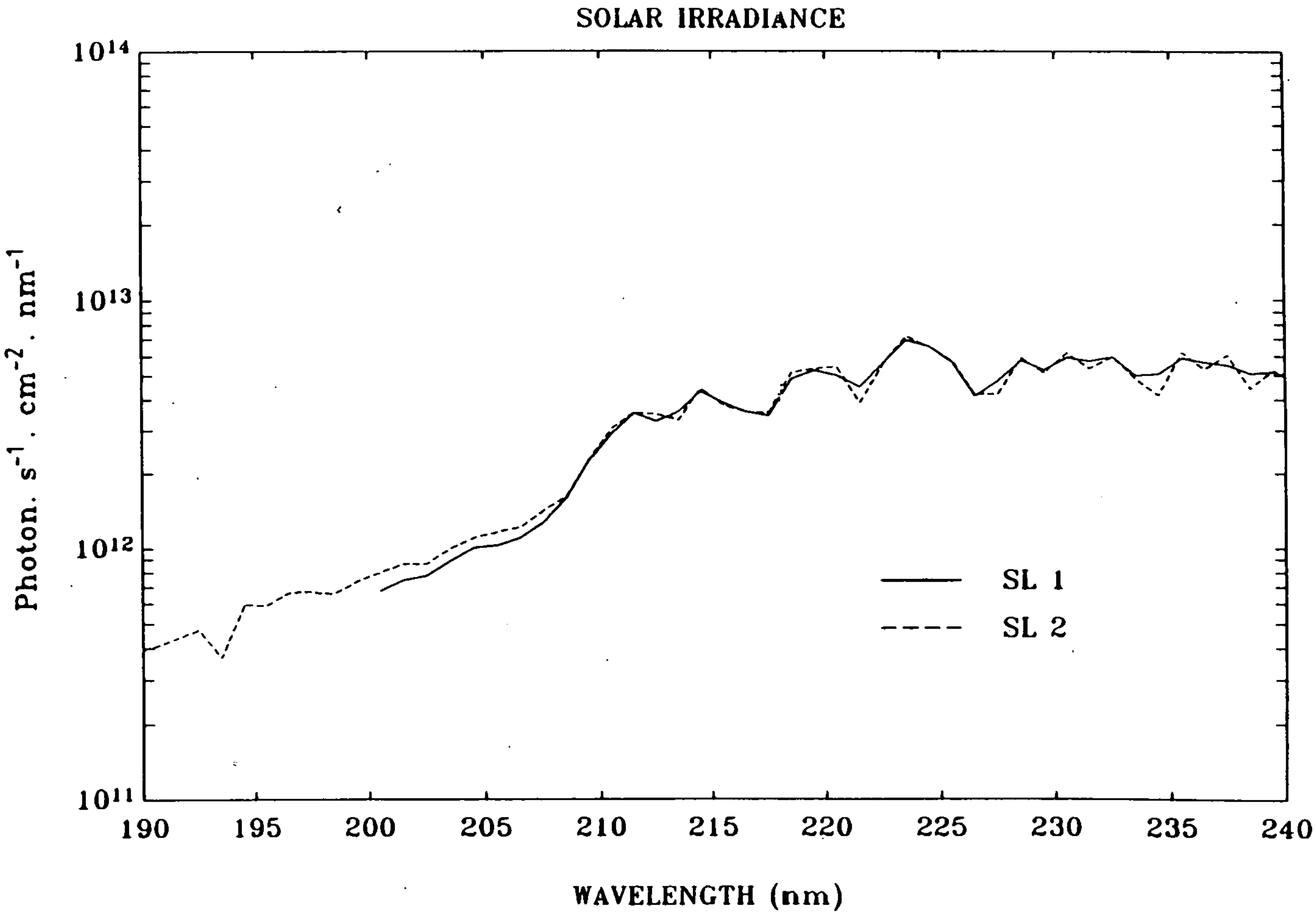

Figure 2. Comparison of the solar ultraviolet irradiances between 190 and 240 nm. The solid curve (SL 1) represents the data published by Labs et al. (1987) and the dashed curve (SL 2) the data reported by VanHoosier and Brueckner (1987) integrated over 1 nm intervals.

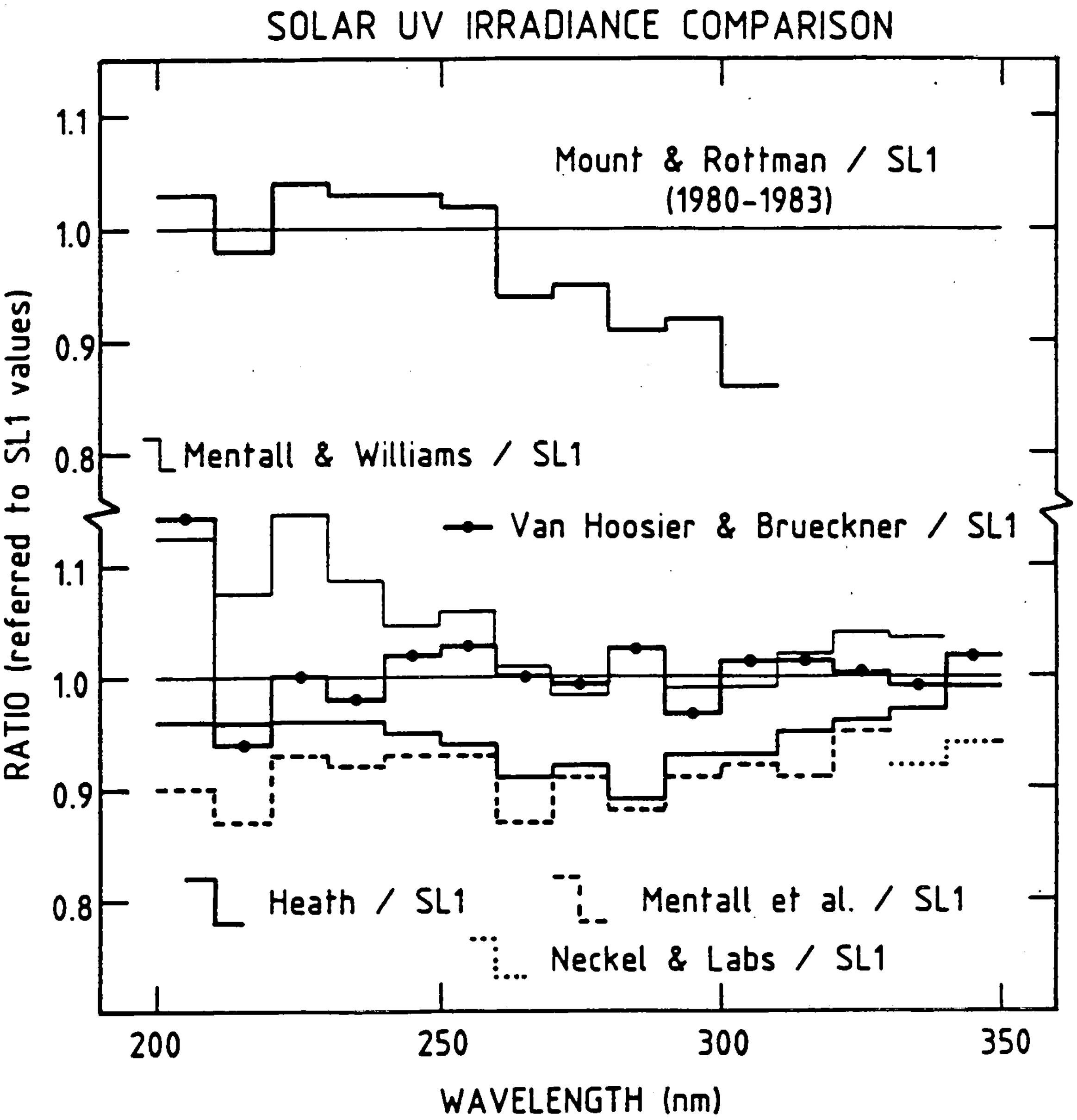

Figure 3. Comparison of 10 nm spectral averages of solar irradiances measurements between 200 and 350 nm with the Spacelab 1 results (SL 1).

atmosphere. Two time scales are generally considered in relation with atmospheric studies : the 11-year activity cycle and the 27-day rotation period of the Sun. Despite of considerable effort during the last solar cycle, the amplitude of solar variation associated with its 11-year activity cycle is still uncertain. The Solar Backscatter Ultraviolet (SBUV) spectrometer data were analysed by Heath and Schlesinger (1986) ; they deduced a long-term variability from an empirical relation based on temporal variations of ratios between core and wings irradiance of the Mg II lines at 280 nm. Their variations are not fully confirmed by the SME results obtained since 1982 which lead to lower values in the overlapping wavelength range (175-300 nm). On the other hand, a solar cycle variation of a factor of 2 at Lyman α and around 150 nm was proposed on the basis of the comparison deduced from the rocket observations made during the maximum of solar activity, namely in June 1979 and July 1980 (Mount et al., 1980; Mount and Rottman, 1983) and those performed at solar minimum (Rottman, 1981). These values are now totally contradicted by recent analysis of SME data, leading to variations of the order of 15 percent around 150 nm and of 5 percent between 190 and 210 nm.

The 27-day solar rotation modulation has been well documented with the SBUV satellite and the SME data base. This short-term variation has been more extensively studied because it is much less affected by sensitivity drifts observed for the SBUV spectrometer. If the agreement between the two satellites during the overlapping period of time is very good for the major rotation modulation on August 1982, the average during the declining phase of the solar cycle shows some appreciable differences beyond 240 nm where SBUV data are less noisy than those of SME and below 190 nm where SME data give 27-day variations higher than SBUV, especially at the Si II lines lying in the 180-182 nm interval. Figures 4 and 5 present a FFT analysis of the 27-day variations on both time series between 160 and 300 nm.

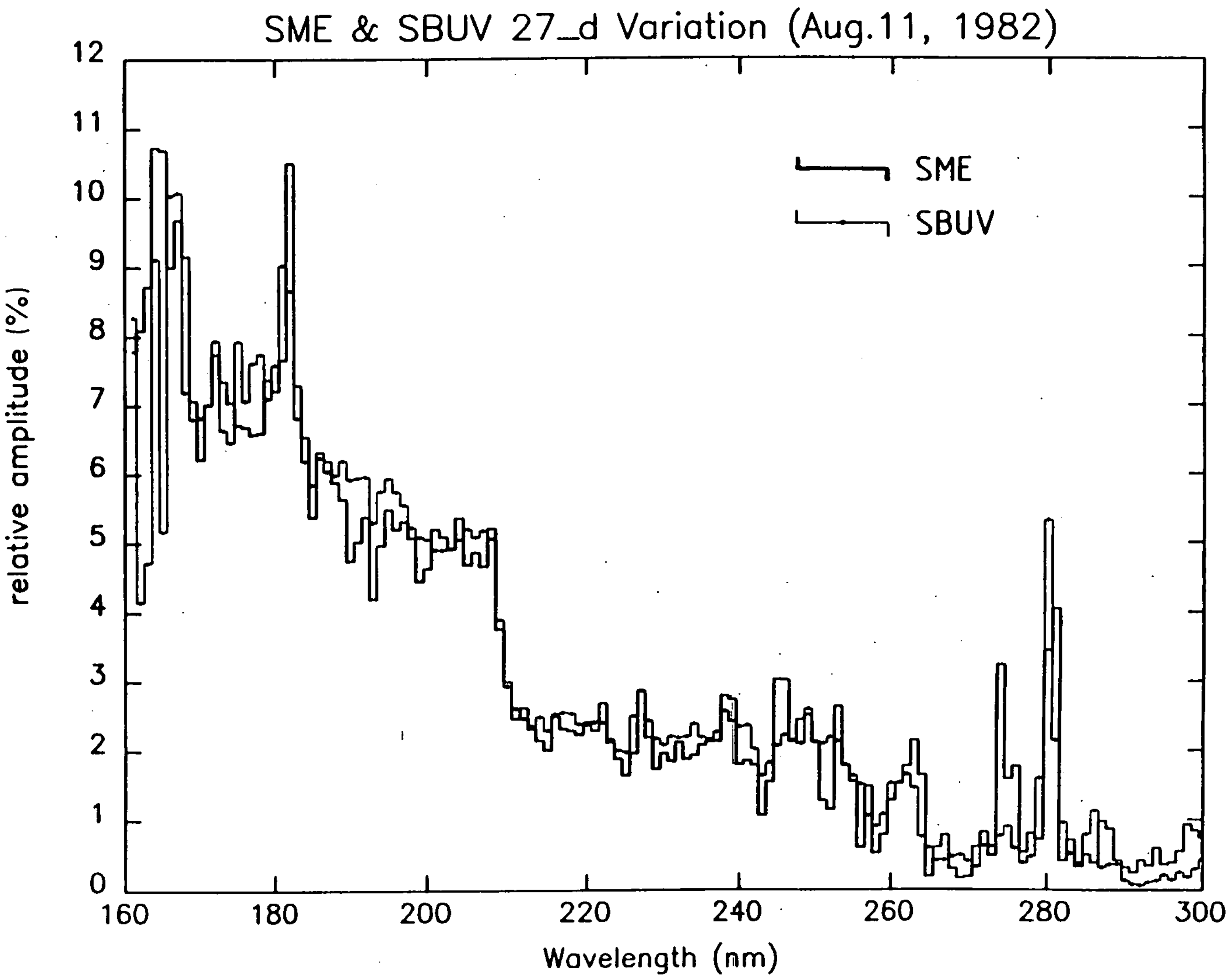

Figure 4. Comparison of 27-day variation deduced from SME and SBUV observations as a function of wavelength, for a major variation on August 11, 1982.

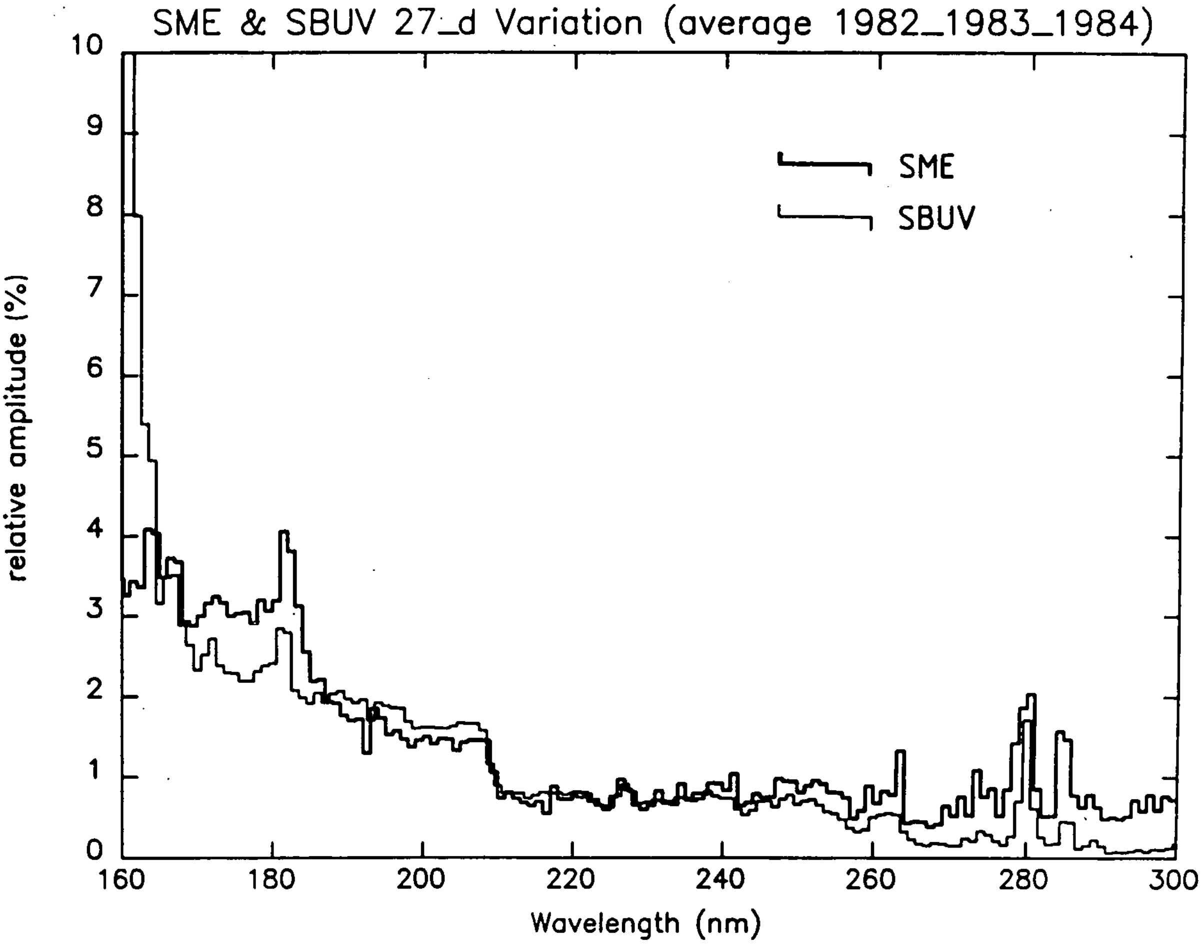

Figure 5. Comparison of 27-day variation averaged over 1982, 1983 and 1984, deduced from SME and SBUV observations, as a function of wavelength.

6. CONCLUSIONS

In spite of major improvements in calibration procedures, important discrepancies persist between recent solar ultraviolet irradiance measurements, mainly below 200 nm. This fact could be due to experimental difficulties encountered in that spectral range. Some basic irradiance figures like the minimum value of Lyman α need to be confirmed by new measurements during the current cycle.

If the 27-day modulation is well documented with the SME and the SBUV observations performed during the solar cyle 21, the long-term variations associated with the solar activity cycle need further studies. The preliminary SME values of 15% around 150-160 nm and of 5% at 205 nm urge new observations having a precision of 1% over a half cycle in order to provide accurate figures in relation with the ozone perturbations in the stratosphere and their climate impact. The strong variations in the 27-day modulations during the last solar cycle also emphazised the need of continuous monitoring of short-term variabilities for which their amplitudes could be as high as the solar cycle variation.

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