VARIABILITIES IN SOLAR U.V. IRRADIANCES DURING SOLAR CYCLE 21

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Abstract

Short and long-term variations in solar ultraviolet irradiances will be reviewed on the basis of satellite measurements performed during the declining phase of solar cycle 21. The comparison between SBUV and SME data leads to maximum 27-day variations at 205 nm of the order of 5% only during three rotational periods from 1979 to 1986, the average variation during the declining phase being much lower, namely 2%. The long-term variation deduced from the SME observations from 1982 to 1986 is of the order of 6% at 205 nm and of a factor 1.7 at Lyman α between maximum and minimum activity levels.

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 aeronomic processes taking place in the troposphere, the middle atmosphere and the thermosphere.

Because of the complexity of the atmospheric processes and the strong interplay and feedback between transport, chemical composition and radiative budget, atmospheric and climate studies should include observations of the ultraviolet solar radiation and its variability, in close relation with the atmospheric constituents which control the penetration of solar radiation. The ozone molecule is a key minor constituent for the stratosphere by photodissociation of molecular oxygen by solar radiation of wavelengths shorter than 242 nm. 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.

Consequently, the knowledge of solar ultraviolet irradiance values as well as their temporal variations is fundamental in studying the chemical, dynamical and radiative processes in the middle atmosphere. In addition, the study of solar variability is of crucial importance to distinguish between its impact on the terrestrial environment in comparison with anthropogenic perturbations.

2. SOLAR ULTRAVIOLET VARIATIONS

The ultraviolet range of the solar electromagnetic spectrum is characterized by its temporal variations which directly affect the atmosphere. Two time scales are generally considered in relation with aeronomic studies of the middle atmosphere : the 11-year activity cycle and the 27-day rotation period of the Sun.

At present, effects of long-term variation of solar ultraviolet irradiance are not conclusive because observations of changes on that time scale in both the ultraviolet solar flux and the sensitive trace species are not reliable at the level of natural changes.

Because of the difficulty in detecting the solar irradiance variation related to the solar activity cycle, the impact of the 27-day variation associated with the rotation period of the Sun was analysed in detail. Indeed, observations over short scale periods are by far more accurate in that they avoid the aging problem of the observing instrumentation. These studies are very useful in the validation of photochemical processes.

2.1. The 27-day variations

The 27-day solar rotation variations have been well documented with the SBUV satellite and the SME data base. The analysis of solar rotation induced variations from the SBUV observations has been recently reported by Donnelly (1988) showing the great uniformity in the shape of this modulation during the six years of observation from November 7, 1978 to October 29, 1984 for wavelengths between 175 and 285 nm. Several examples of variations in that spectral region have been published by Heath and Schlesinger (1986). The strongest modulation occurred in August 1982, giving a variation of 6 percent at 205 nm.

The SME data base has also been extensively analyzed using the Fast Fourier Transform technique (FFT) to isolate the solar flux modulation related to the 27-day solar rotation. The amplitude variations over the full spectral range, namely 115-300 nm, have been deduced for five years of observation from January 1, 1982 to December 31, 1986. The first results of this analysis have been reported by Simon et al. (1987). An example of the temporal variations of the peak-to-peak amplitude for modulation at Lyman α and 205 nm is presented in Figure 1. These 27-day modulations show periods of high uniformity in shape like in mid 1982. On the other hand, other periods show striking differences in shape for those two wavelengths like, for instance, in mid 1983 and the beginning of 1984.

The same technique has been applied to the SBUV time series for comparison purposes. The agreement between the two satellites during the overlapping period of time is very good for the strongest modulation taking place on August 1982 as illustrated in Figure 2. However, 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 give higher 27-day variations than SBUV, especially for the Si II lines. The agreement is very good for wavelengths between 210 and 230 nm. The best description of the 27-day variations during the declining phase of solar cycle 21 would be provided by the SME data base from 115 to 210 and from the SBUV observation from 210 to 300 nm.

2.2. Solar cycle variations

Despite of considerable effort during the last solar cycle, the amplitude of solar variation associated with the 11-year activity cycle is still uncertain. The SBUV spectrometer suffered from severe aging problems, mainly in the reflectivity of the diffuser plate used for solar irradiance measurements. The available data have been accordingly corrected for instrument-related changes (Donnelly, 1988) and were analyzed by Heath and Schlesinger (1986). They deduced long-term variations from an empirical relation based on temporal variation of ratios between core and wings irradiances of the Mg II lines at 280 nm. This study is intended to eliminate the effects of instrumental drift and defines the so-called Mg II index. Balloon measurements at high resolution reported by Hall and Anderson (1988) demonstrate that the value of the Mg II index is very sensitive to unique instrument characteristics (spectral bandpass and line shape). Consequently, the extension of this index to other data set has to be made very carefully and requires a critical normalization with data overlapping in time with the SBUV observations. On the other hand, the amplitude of the solar cycle variations deduced from the Mg II index are not fully confirmed by the SME results obtained during the declining phase of solar cycle 21 (since 1982) which lead to lower values in the overlapping wavelength range (160-300 nm). In addition, long-term variations between 115 and 180 nm deduced by comparison between rocket observations made during maximum levels of solar activity, namely 1979 and 1980 (Mount et al., 1980; Mount and Rottman, 1981) and those performed at solar minimum (Rottman, 1981), were of the order of 2 for Lyman α as well as around 150 nm. These high values are not supported by recent analysis of SME data, which imply variations of only 15 percent around 150 nm and of 5 percent between 180 and 210 nm (Figure 3).

3. CONCLUSIONS

If the 27-day variations are well documented with the SBUV and SME observations during the solar cycle 21, the long-term variations related to the solar activity still remain uncertain. This is due to large differences between many measurements performed from 1977 to 1985.

Nevertheless, good arguments now seem to validate the proposed solar cycle variation deduced from SME. This problem is of fundamental importance in ozone trend studies. Indeed, predictions in total ozone changes during the current solar cycle (its maximum of activity being expected in 1991) give an increase of ozone towards a maximum at that time. This means that the solar cycle variation in ultraviolet irradiance will counterbalance the predicted decrease due to anthropogenic chlorine compound emissions. After 1991 the total ozone column is predicted to decrease again with a rate still enhanced by the decline in solar ultraviolet irradiance. Consequently, reliable observations of solar variation with a precision of 1 percent over a half solar cycle are urgently needed to quantitatively discriminate between natural changes and anthropogenic perturbations in the middle atmosphere composition.

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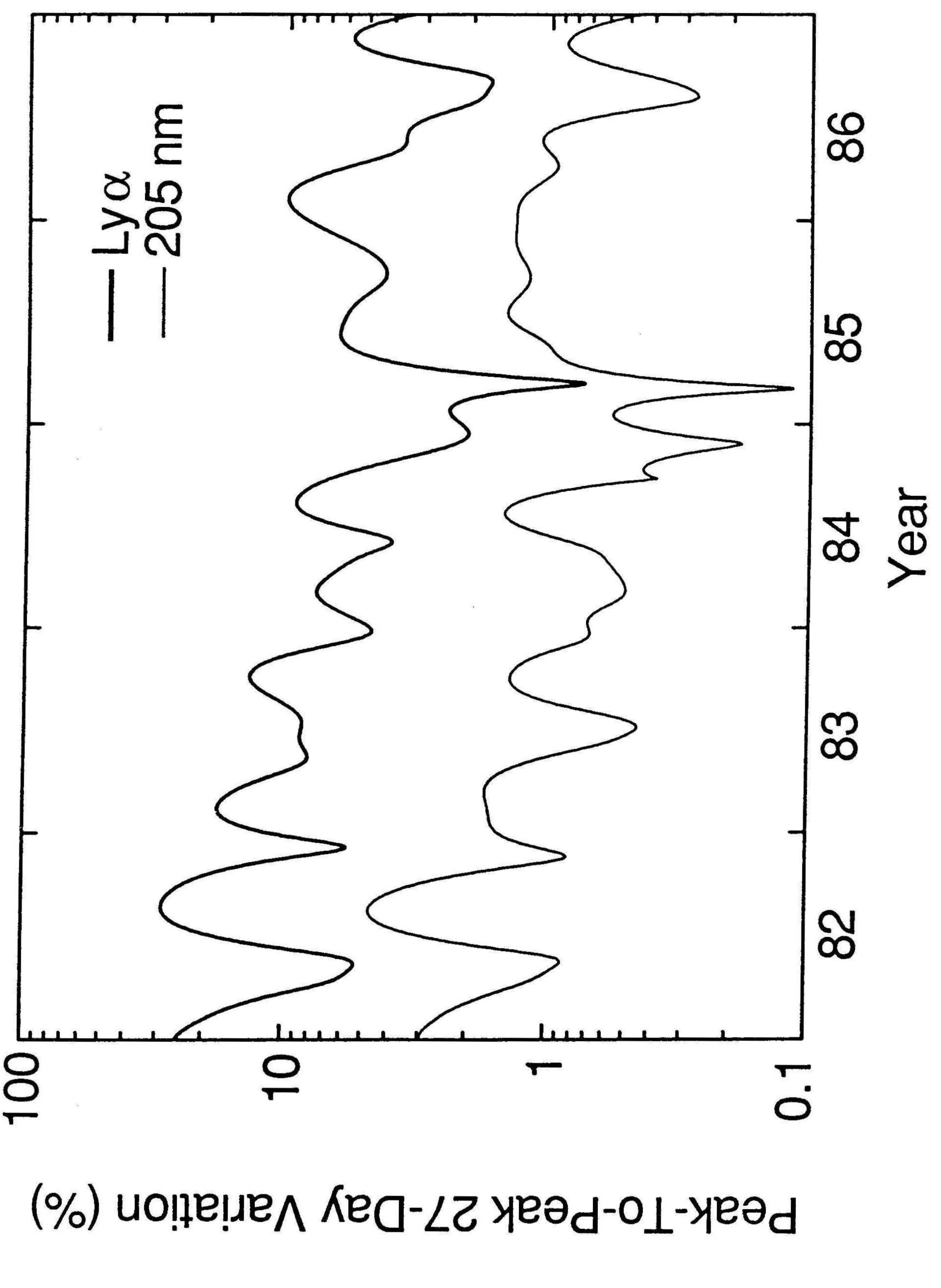
FIGURE CAPTIONS

Figure 1. Temporal variations, deduced from a FFT analysis of the SME data of the 27-day peak-to-peak amplitude of the solar-rotation induced modulation between January 1982 and December 1986, at 2 wavelengths, namely Lyman α (thick curve) and 205 nm (thin curve).

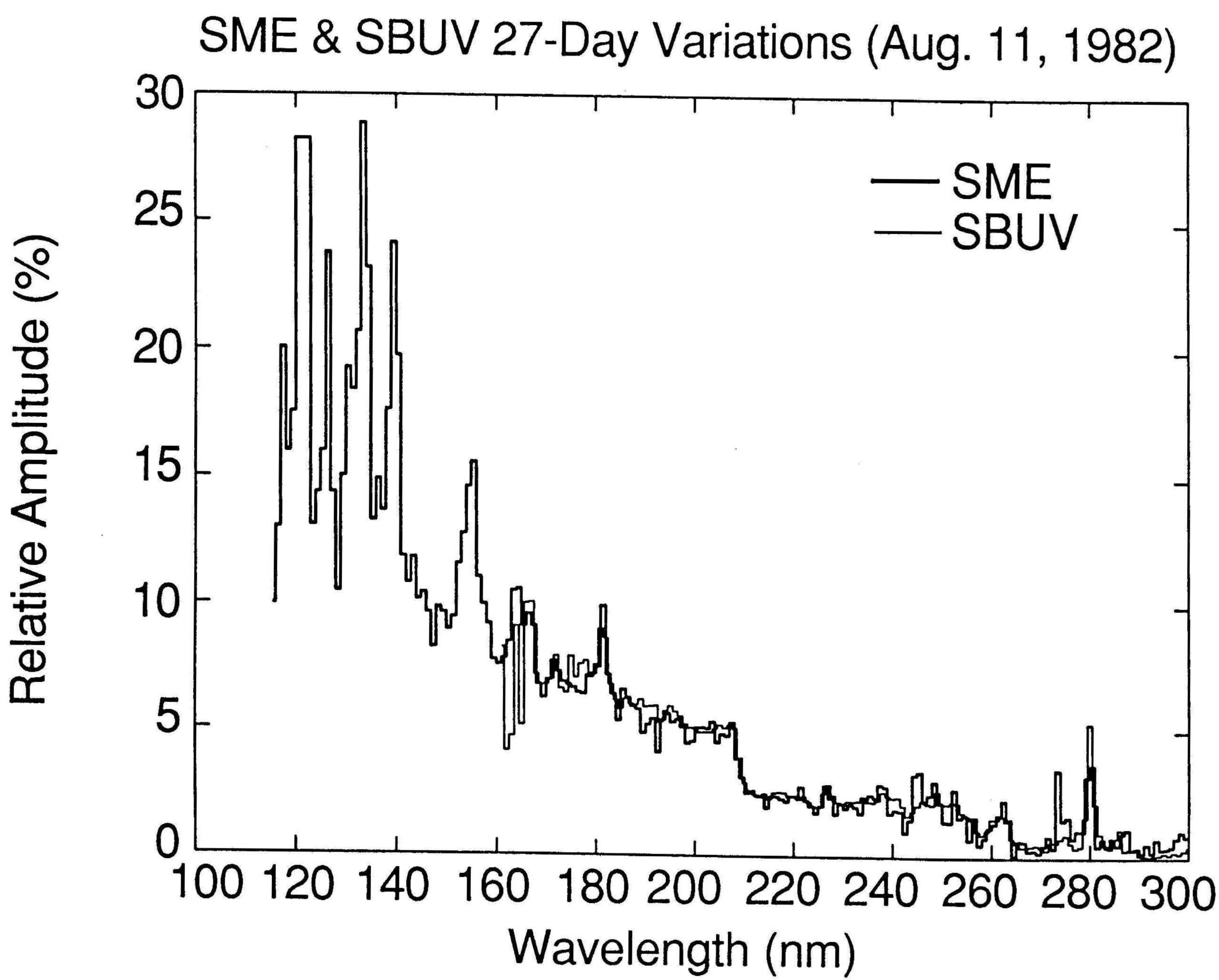
Figure 2. Comparison of the peak-to-peak amplitude for the 27-day variation deduced from SME (thick curve) and SBUV (thin curve) observations, as a function of wavelength for 1 nm intervals, for a major variationn on August 11, 1982.

Figure 3. Preliminary solar cycle variation between 1982 and 1985 deduced from the SME measurements integrated over 5 nm intervals between 125 and 300 nm (1 nm intervals). Errors bars might be as large as a factor of 2 beyond 200 nm (from Rottman, 1988).

Figure 1



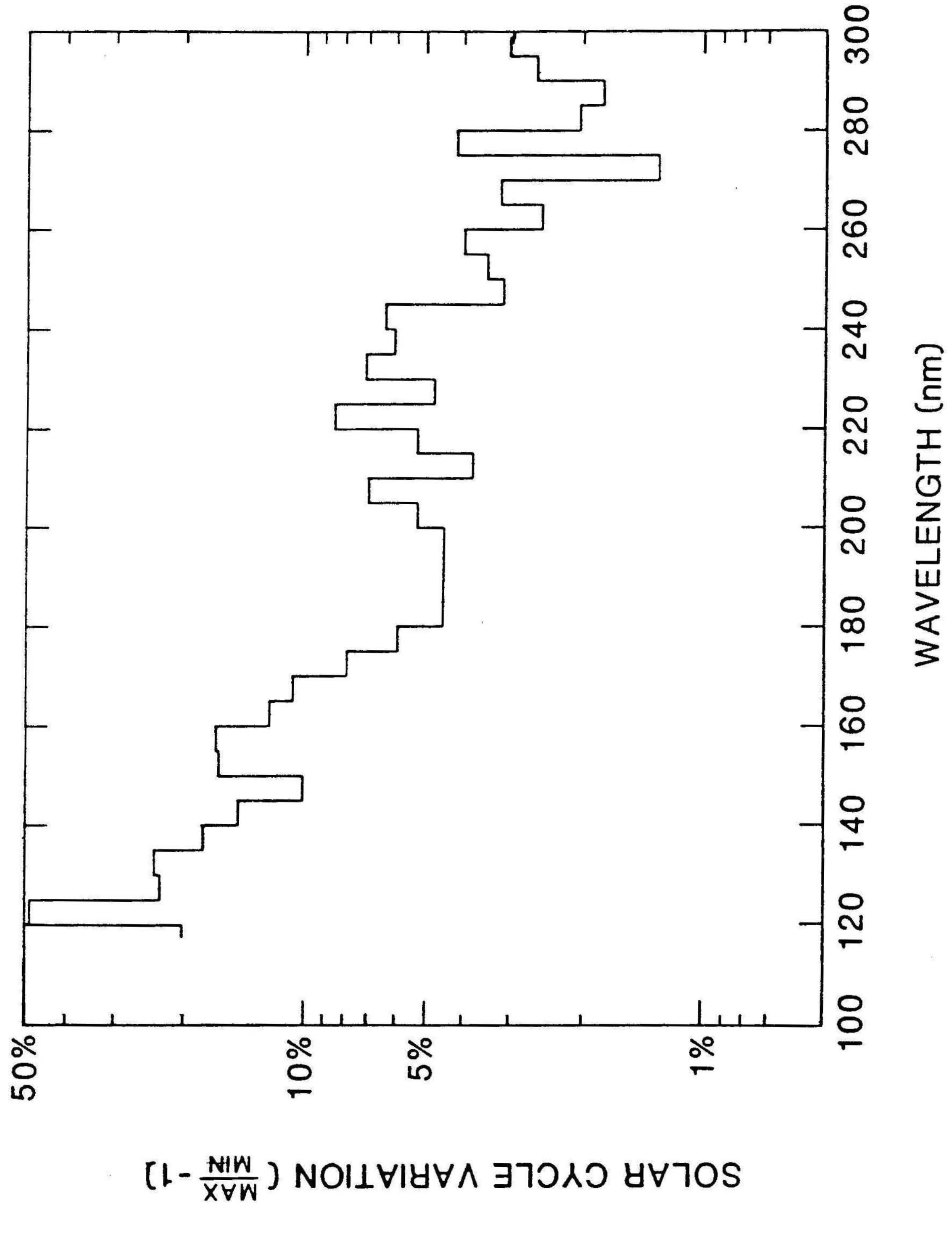
Lyα
205 nm
82
83
84
85
86
Year
100
10
1
0.1
Peak-To-Peak 27-Day Variation (%)



SME & SBUV 27-Day Variations (Aug. 11, 1982)
Relative Amplitude (%)
Wavelength (nm)
SME
SBUV
0
5
10
15
20
25
30
100 120 140 160 180 200 220 240 260 280 300

Figure 2

Figure 3



WAVELENGTH (nm)
100
120
140
160
180
200
220
240
260
280
300
SOLAR CYCLE VARIATION (MAX/MIN - 1)
50%
10%
5%
1%

DISCUSSION :

Question 1 from Michael McElroy

The fact that you see comparable solar cycle variability at 200 nm and 245 nm is interesting in connection with the question of whether there might be a secular charge in the yield of NO from decomposition of N_2O. Are there solar physics arguments to support the observation that the variability has comparable amplitude from 200 to 240 nm ?

Answer :

There is no argument neither to support nor to contradict the observed solar cycle variability between 200 and 240 nm, except that the amplitude of the 27-day modulation clearly shows a decrease by a factor 2 at the 208nm aluminium edge, for strong modulations. On the other hand, the physical processes leading to the 11-year activity cycle are not yet understood and therefore there is no physical reason to reject the SME 11-year variability between 200 and 240 nm.

Question 2 from Jean-Claude Gérard

Does the discrepancy between the LASP rocket measurements of the Max/Min irradiance ratio and the SME data also extend to the present solar cycle ?

Answer :

The SME results obtained during the rising phase of the current cycle confirm the results presented here. Unfortunately, SME died in April 1989, before the maximum of the current cycle was reached. There is no rocket launches scheduled in 1990-1991. The next opportunity to confirm the 11-year cycle variations will be UARS and the ATLAS programme.