WAVELENGTH DEPENDENCE OF SOLAR ROTATION AND SOLAR CYCLE UV IRRADIANCE VARIATIONS

Julius London* and Gary J. Rottman+

*Astrophysical, Planetary and Atmospheric Sciences
+Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO 80309

ABSTRACT

It is shown that for the 5–year period 1982–87 the solar irradiance decrease is estimated to be about 5–7 percent over the spectral interval 195–225 nm. This change becomes progressively smaller with increasing wavelength. For the 2-1/3 year period, January 1987 to April 1989, the irradiance increases about 6 percent at 195–205 nm and about 2 percent between 215–250 nm. Both 27–day and 13.5–day relative amplitudes peak at the time near solar maximum (1982) but remain comparatively small between 1983 and the onset of solar cycle 22. An average 280 day oscillation is noted for wavelengths up to 230 nm. No physical mechanism is offered for this variation.

INTRODUCTION

Solar radiation in the wavelength interval 195 nm–300 nm is deposited and largely absorbed in the earth's stratosphere and mesosphere. This absorbed energy is responsible for most of the photodissociation of molecular oxygen, ozone, and minor gases in that region, and the radiative heating in the layer 20–70 km. It is therefore reasonable to expect that upper atmosphere ozone and temperature variations would respond to variations in solar irradiance in this critical wavelength interval. Indeed, both models and observations provide support for such responses at different time scales (see, for instance, Gille, 1984[1]; Garcia *et al.*, 1984[2]; Hood, 1989[3]). The models are generally based on preliminary estimates of solar UV variability derived from occasional rocket observations, satellite measurements or solar proxy data. The following analysis makes use of the data set derived from the Solar Mesosphere Explorer (SME) solar UV measurements in the spectral range of 195–300 nm for the period 1 Jan 1982–13 Apr 1989. A preliminary discussion of some of the early results is contained in London *et al.* (1984).[4] Details of the observation technique, estimated accuracy and precision of the instruments are available in Rottman (1988)[5]. The present analysis summarizes the wavelength dependence of solar irradiance variations over an approximate solar cycle, solar rotation, and half solar rotation, and an estimated average 280 day period.

SOLAR CYCLE VARIATIONS

Solar middle UV irradiance exhibited an extended maximum during solar cycle 21 from 1980–82 (e.g., Hood, 1989)[3]. Irradiance minima given by the SME observations occurred very early in 1987 at all wavelengths in the range 195–300 nm. The percent decrease of the solar irradiance over the 5–year period (1982–1986) is shown in Fig. 1a for the spectral interval 195–300 nm. The maximum change of –7.2 percent (the equivalent of ~1.4% yr $^{-1}$) was found at 220–225 nm decreasing to approximately –1 percent (i.e., 0.2 percent yr^{-1} at 300 nm as the radiance source gets closer to the lower photosphere. The irradiance at all wavelengths in the interval 200–300 nm increased after early Jan 1987, somewhat steeply up to about 230 nm and more slowly at longer wavelengths. The largest increase for the period Jan 1987–Apr 1989 (see Fig. 1b) was almost 6 percent at the shorter wavelengths (2.5 percent yr^{-1} and about 2 percent (less than 1 percent yr^{-1}) between 215 and 250 nm. The long-term change beyond 250 nm is difficult to estimate because of instrument and observing problems at these wavelengths toward the end of the SME period. It should be noted that although the values shown in Figs. 1a,b are probably the best estimates available at present, they are still subject to a possible relative error of a few percent (see, for instance, Rottman, 1988)[5]. Calibration procedures set up for the SOLSTICE and SUSIM instruments planned for a fall 1991 launch are expected to minimize such a long term possible drift error. Solar irradiance variations with harmonics associated with solar rotation (i.e., 27-day and 13.5-day periods) have been reported by Lean, 1984;[6] Lean and Repoff, 1987,[7] and others.

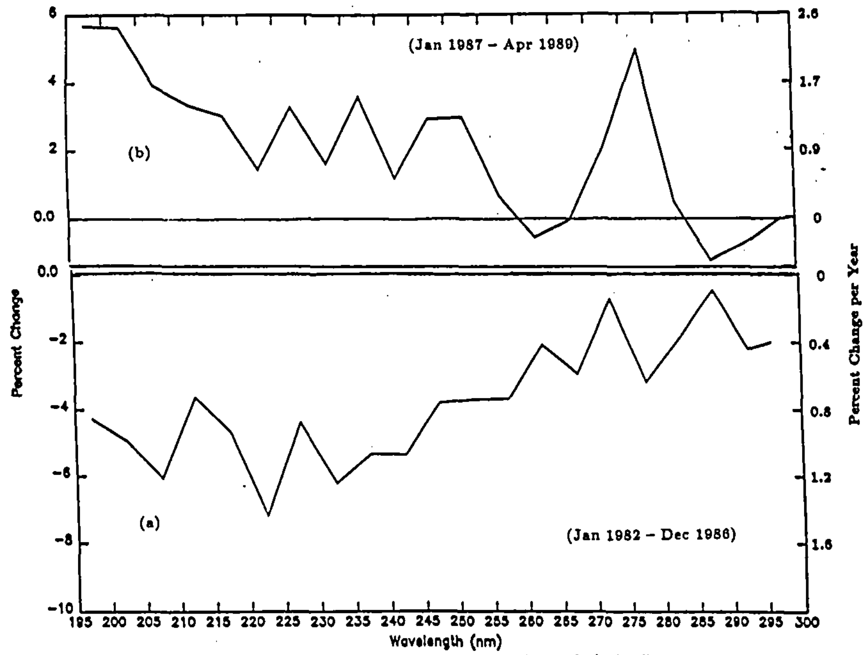


Fig. 1. Wavelength dependence of long-term change of solar irradiance from start of period
a) Jan 1982 - Dec 1986
b) Jan 1987 - Apr 1989

SOLAR ROTATION VARIATIONS

The time variation of the 27-day and 13.5-day relative amplitudes of the SME observed solar irradiance at 200–205 nm are shown in Fig. 2. The peaks shown for mid-July 1982 corresponding to 2.2% for 27-day and ~1% for 13.5-day variations occur at a time near solar maximum for cycle 21. Note that the relative amplitudes decrease significantly after 1982 and remain relatively constant over the period 1983–88 before they increase with increase with enhanced activity after the onset of cycle 22. The 13.5-day relative amplitude has, on average, about half the amplitude of the 27-day variation as shown in Fig. 2. The wavelength dependence of the 27- and 13.5-day relative amplitudes for the period of maximum solar irradiance observed by SME (8 Jul 1982–4 Aug 1982) is given in Figs. 3a,b. The 27-day relative amplitude maximum (2.2%) is found at 200–205 nm, just short of the aluminum edge where the irradiance originates from the upper photosphere. The relative amplitude decreases sharply to 1% (210–215nm), remains at that level to 250nm and then continues to decrease to less than 0.5% beyond 250nm. For the 13.5-day rotation period, the relative amplitude during the time near solar maximum is about 1% at 200nm and decreases to a few tenths percent at 300nm. Thus, at the time of solar maximum, one would expect a direct upper atmosphere response to the solar rotation irradiance signal at wavelengths below below 250 nm (see, for instance, Ekman, 1986[8]).

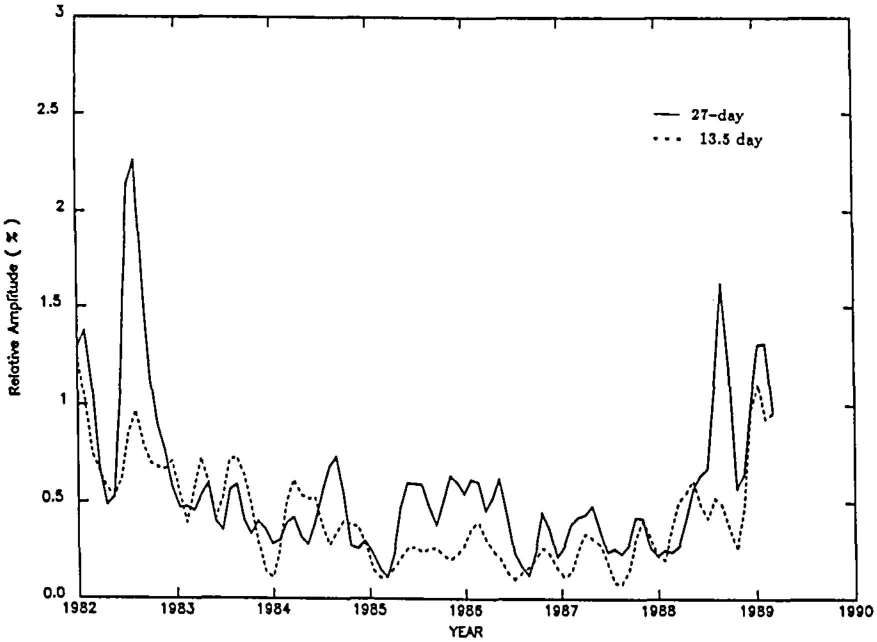
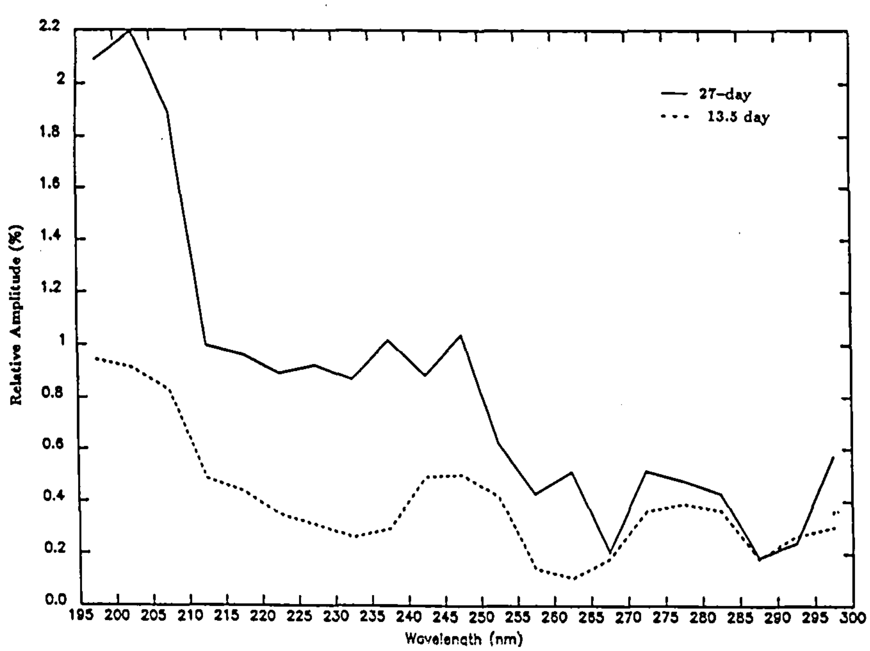


Fig. 2. Time variation of the SME observed 27–day and 13.5–day relative amplitudes at 200–205 nm

The short period irradiance variations during the 5 years 1983–88 were relatively small at all wavelengths. During this time the 13.5–day relative amplitude harmonic was about two–thirds of that for 27–days at almost all wavelengths as shown in Fig 4. The average 27–day relative amplitude for this period was 0.35 ± 0.24 percent. That for the 13.5–day variation was 0.25 ± 0.13 percent.

The average standard deviation given here represents the average over wavelength of the time standard deviation of each 5 nm interval over the 5–year period 1983–88. The ratio of the amplitudes of the two periods indicates the relative strength of the single vs. quasi–symmetric double solar active regions (~180 longitude phase difference). During the time of peak activity (Jul–Aug 1982) this ratio was less than one–half at $\lambda \leq 235$ nm but approached unity at longer wavelengths. However, during the descending and minimum phase of solar cycle 21 there was little significant difference between the 27–day and 13.5–day oscillation in this spectral interval.

Fig. 3.
Wavelength dependence of the relative amplitudes of 27–day and 13.5–day variations for the time near peak solar activity
(8 Jul 1982 – 4 Aug 1982)



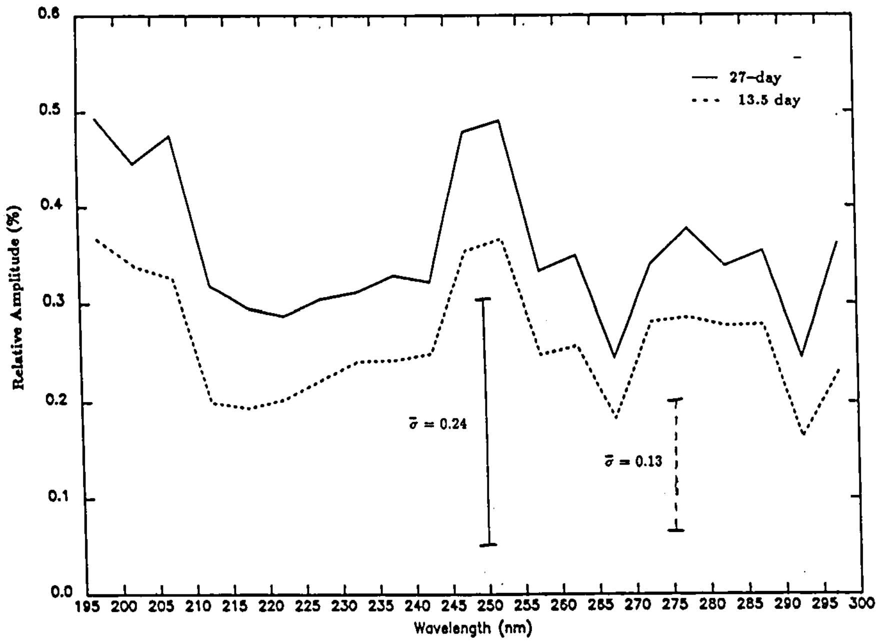


Fig. 4 Wavelength dependence of the mean relative amplitude of the 27-day and 13.5-day variations for the time of decreasing and minimum solar activity (Jan 1983 - Dec 1987)

INTERMEDIATE PERIOD VARIATIONS

In addition to solar rotation and solar cycle irradiance variations, there appears to be a quasi-periodic oscillation with an average period of 280 days. Until recently, however, there were no long-term continuous observations to verify this oscillation at wavelengths in the middle UV (see, for instance, Hood, 1988[3]; Rottman, 1988[5]). An average 280 day variation can also be seen from SME data for wavelengths from 195 nm up to about 230 nm. As an example we show such a variation for $\Delta\lambda$ = 200–205 nm.

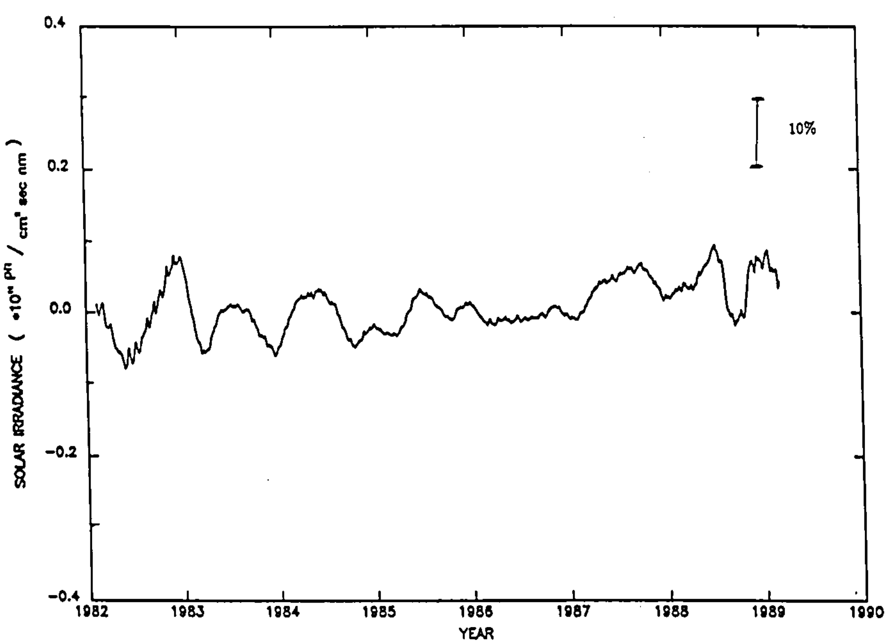


Fig. 5. Detrended 81-day smoothed variation of solar irradiance 200-205 nm from SME observations

A four term Fourier series was used to detrend the 200–205nm irradiance data for the entire period of observations. The residuals were then subject to an 81-day running mean. The resulting curve is shown in Fig. 5. Again, the largest irradiance range (about 15%) occurs in mid–1982. The oscillation goes to zero in 1987 and then apparently increases by the end of the observed period. We do not know of any physical mechanism for this oscillation, but since it is found at shorter wavelengths, including Ly–α and at F10.7 cm irradiance (Pap *et al.*, 1990),[9] it is likely to be related to plage area enhancement of quasi–periodic behavior in the convection zone. It is not known how the upper atmosphere would (or does) respond to such an oscillation.

ACKNOWLEDGEMENTS

We would like to thank Barry Knapp and Kristin Hoyer for reprocessing some of the SME data and for programming assistance. Support is acknowledged from the Upper Atmosphere Research Program of the National Aeronautics and Space Administration under grant NAS5–27263.

REFERENCES

1. Gille, J. C., C. M. Smythe, and D. F. Heath, "Observed ozone response to variations in solar ultraviolet radiation," *Science*, **225**, 315-317, 1984.
2. Garcia, R. R., S. Solomon, R. G. Roble, and D. W. Rusch, "A numerical response of the middle atmosphere to the 11–year solar cycle," *Planet. Space Sci.,* **32**, 411–423, 1984.
3. Hood, L. L., "Stratospheric effects of solar ultraviolet variations on the solar rotation time scale," *Middle Atmosphere Program, Handbook*, **29**, International Symposium on Solar Activity Forcing of the Mid–Atmosphere, 79–81, September 1989.
4. London, J., G. G. Bjarnason, and G. J. Rottman, "18 months of UV irradiance observations from the Solar Mesosophere Explorer," *Geophys. Res. Lett.*, **11**, 54–56, 1984.
5. Rottman, G. J., "Observations of solar UV and EUV variability," *Adv. Space Res.*, , (7)53–(77)66, 1988.
6. Lean, J. L., "Estimating the variability of the solar flux between 200 and 300 nm," *J. Geophys. Res.*, **89**, 1–9. 1984.
7. Lean, J. L. and T. P. Repoff, "A statistical analysis of solar flux variations over time scales of solar rotation: 1978–1982," *J. Geophys. Res.*, **92**, 5555–5563, 1987.
8. Eckman, R. S., "The response of ozone to short–term variations in the solar ultraviolet irradiance. 2. Observations and interpretation," *J. Geophys. Res.*, **91**, 6705–6721, 1986.
9. Pap, J., J. London, and G. J. Rottman, "Variability of solar Lyman–alpha and total solar irradiance." (Submitted to *Astronomy and Astrophysics Main Journal*), 1990.