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RESPONSE OF THE MIDDLE ATMOSPHERE TO SOLAR UV AND DYNAMICAL PERTURBATIONS

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INTRODUCTION

Recent studies of solar UV related changes of ozone and temperature have considerably improved our understanding of the solar UV and ozone relationship in the middle atmosphere on time scales of a solar rotation. These studies have shown that during periods of high solar activity, ozone in the upper stratosphere has a measurable response to changes in the solar UV flux in accordance with theoretical predictions. For example, both model predictions and observations suggest that stratospheric response to solar UV perturbations should be maximum at about 2 mb. At this level, the ozone mixing ratio and temperature increase by about 0.4 percent and 0.1 K respectively for 1 percent increase in solar flux in the spectral range of 205 nm (CHANDRA, 1986, BRASSEUR et al., 1987; KEATING et al., 1987; HOOD, 1987 and the references therein). These are relatively weak perturbations compared to dynamical perturbations since the variability in 205 nm over a solar rotation is generally very small (about 1-4 percent) even during periods of high solar activity. The solar induced changes in the stratosphere are often masked by dynamical oscillations with periods between 3-7 weeks (CHANDRA, 1986).

The problem of measuring solar response of the stratospheric ozone and temperature on time scales of a solar cycle is even more difficult. In the altitude range of 2 mb the model based calculations, based on plausible scenarios of solar UV variation, suggest a change of less than 4 percent in ozone mixing ratio and 1-2 K in temperature. In the case of total ozone, the predicted change is less than 1 percent (GARCIA et al., 1984; CHANDRA, 1985; BRASSEUR et al., 1987). Since ozone and temperature data for such studies are limited to 1 or 2 solar cycles, the solar UV related changes over a solar cycle cannot be uniquely separated from inter-annual variabilities and instrument drifts which are often present in data sets extending over a few years. Thus definitive evidence for solar UV and ozone relationship must still come from studying their relations over shorter periods.

In 1971, it was suggested by the author that the periods in solar activity are not limited to 27 days and 11 years but may have additional components in the range of 4-6 months which may influence the seasonal characteristics of the atmospheric parameters (CHANDRA, 1972). It has now become apparent that such periods in solar activity do indeed exist and are intrinsic periods of the Sun (LEAN and BRUECKNER, 1989 and the references therein). LEAN and BRUECKNER (1989) have shown that the solar activity, as inferred from the sunspot blocking function, the 10.7 cm solar radio flux(F10.7), and the sunspot number show a strong periodicity at about 155 days or 5 months. Their studies do not indicate the relative importance of this period with respect to the 27 day period. However, a recent study by HOEGY and WOLFF (1989) suggest that the amplitude of the 5 month period is comparable to the 27 day period in the F10.7 cm data and about 30-40% smaller in the solar Lyman α data obtained from the Solar Mesospheric Explorer. These authors have also reported the existence of a 7 month solar period inferred from the photoelectron current measured by the Langmuir probe on the Pioneer Venus orbiter over the time period from 1979 to 1987. It is, therefore, of interest to know if the atmospheric parameters respond to changes in solar UV flux at periods other than 27 days and if so, what are their relative sensitivities.

The purpose of this paper is to study the relative response of the middle atmosphere to solar forcing at 155 and 27 day periods as indicated from the spectral analyses of a number of solar indices. As discussed in LEAN and BRUECKNER (1989), the range of the 155 day period varies from 152 days to 160 days depending upon the time interval of data used in the spectral analysis. For convenience, this period will be referred to as a 5 month solar period.

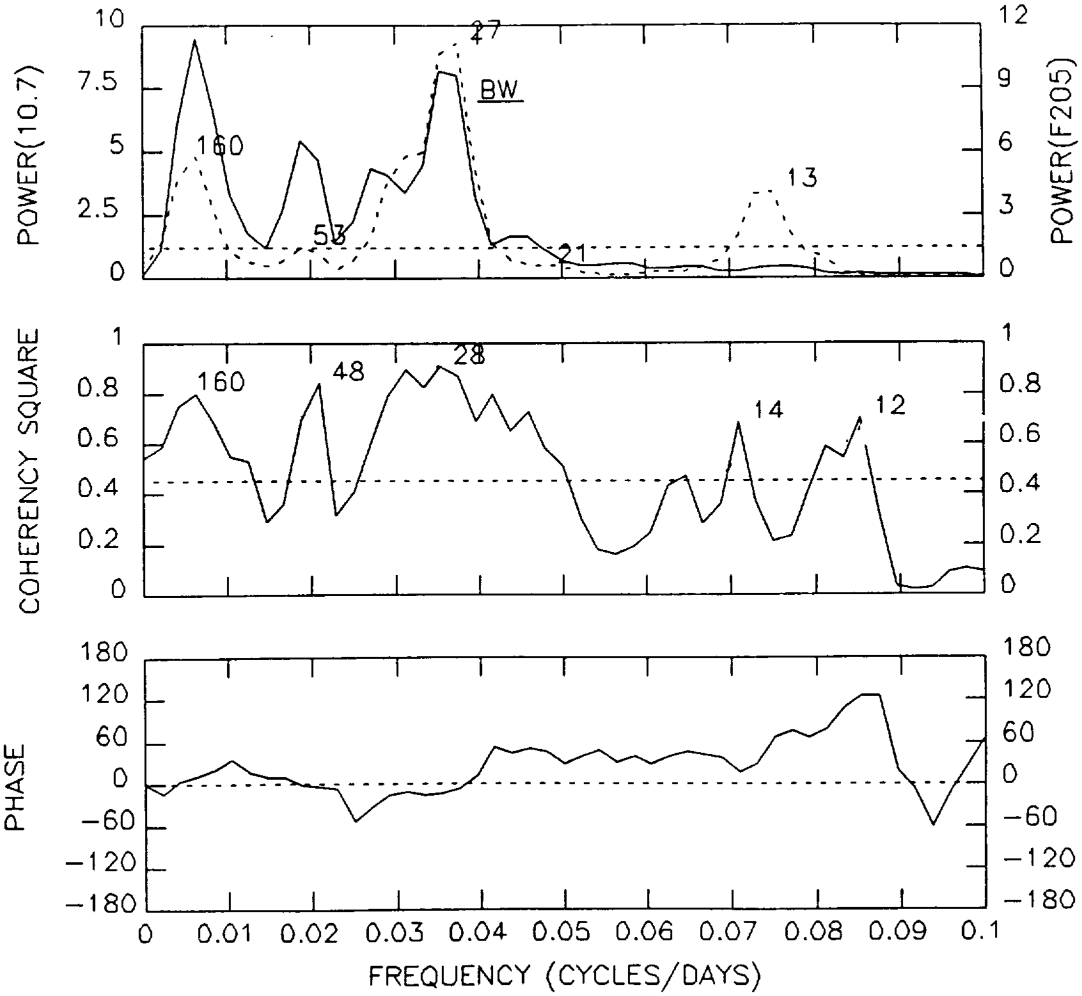
DATA SOURCE AND ANALYSIS

The data used for this study consist of daily values of ozone mixing ratio at 2 mb obtained from the Nimbus-7 SBUV instrument and the daily values of total ozone obtained from the Nimbus 7 TOMS experiment. In addition, temperature data at a number of pressure levels, derived from the NMC analyses(GELMAN et al., 1986), are used as indicators of thermal and dynamical conditions in the middle atmosphere. Both the ozone and temperature data are obtained from the NSSDC (National Space Science Data Center, Greenbelt, Md, 20771) and are zonally averaged in the latitude interval of 10 degrees from -80°S to +80° N. Many of the characteristics of these data sets have been extensively discussed in the literature (eg., CHANDRA, 1986, HOOD 1987, and the references therein). The time interval used for this study covers the period of about 6 years from January 1, 1979 to October 1984 and mostly corresponds to periods of high solar activity. The data after 1984 were not included because they correspond to periods of low solar activity and tend to increase the contribution of dynamical signals at the expense of solar signals.

As an index of solar UV flux, we have used the daily values of F10.7, the solar decimeter flux measured at Ottawa, Canada. The 10.7cm index is considered to be one of the best solar indices available for studying the long term characteristics of solar UV flux in the spectral range of 160-400 nm (HEATH and SCHLESINGER, 1986). However, we will discuss some of the implications of using this index as compared to directly measured solar UV flux at 205 nm (F205), also measured from the Nimbus 7 SBUV spectrometer.

For each latitude zone, the most apparent characteristics of ozone and temperature time series are annual and semiannual components which are periodic and generally independent of solar activity. In the case of F10.7, the most apparent feature is the 11 year cycle which is modulated by periods varying from 13 days (one half solar rotation) to several months. For studying the atmospheric response to solar variability on time scales of less than six months, it is useful to remove the longer term periods which may dominate the spectral characteristics of these time series. The most expedient way to remove periods greater than six months is to subtract a 180 day running average from each of the time series. This was found to be adequate for solar indices such as F10.7 and F205 which do not have strong seasonal components. For ozone and temperature time series, subtracting a 180 day running average did not substantially reduce the annual component particularly at middle and high latitudes. The contributions of annual, semiannual and long term trends from ozone and temperature time series were, therefore, first removed using a regression model consisting of annual, semiannual and linear terms. The resulting time series were then treated the same way as F10.7 and F205, i.e., from each of the time series a 180 day running average was subtracted to emphasize periods less than six months.

SPECTRAL CHARACTERISTICS OF SOLAR DATA



LAG = 240, SERIES LENGTH = 1081, CORR COEFF = 0.66

TOT POWER X1 = 0.1E+04, TOT POWER X2 = 0.2E−01, BW = .006

Figure 1. The power spectra of F10.7 and F205 (top panel, solid and dotted lines) and the spectra of their coherency (middle panel) and phase(lower panel). The power spectra are expressed as a percentage of total power for each time series. The horizontal dotted line in the upper panel corresponds to 95 % confidence level (CL) for the spectral estimate of the first series (F10.7). In the middle panel it corresponds to 95 % CL for the coherency spectrum. The spectral bandwidth is indicated by a bar in the upper panel. The figure also lists a number of useful parameters: These are: lag (days), length of the series (days), correlation coefficient of the two series, total power(power) of the first(X1) and the second(X2) series (in arbitrary units) and bandwidth(cycles/day).

The spectral characteristics of F205 and F10.7 for periods less than six months are shown in Figure 1 (upper panel) in the form of the power spectra of the two series covering the time interval from January 79 to June 1982. Shown in this Figure are also the spectra of coherency squared and phase (middle and lower panels) of the two time series. The calculations are based on algorithms described in JENKINS and WATTS (1968) using a Tukey Hanning spectral window of 240 days and lag of the same interval. This results in a bandwidth of .006 cycles/day. Both the spectra are normalized to their respective total powers for visual comparison of the relative powers of significant periods.

Figure 1 clearly shows two major peaks at 28 and 160 days (5 months) respectively. In addition, it shows an intermediate peak at 53 days which is probably a harmonic of the 5 month period (LEAN and BRUECKNER, 1989). These periods are also present in F205. However, their relative powers are very different in F205. For example, in F10.7 the powers in the 5 month and 27 day periods are of equal magnitude. In F205, the 5 month period contains half the power of the 27 day period. The 53 day period is barely significant in F205 and the 13 day period is significant in F205, but not in F10.7. In spite of these differences, the two time series are almost in phase (bottom panel) and show significant coherency at all periods between 27 days and 5 months.

The differences in the spectral characteristics of F205 and F10.7 time series with respect to the 27 and 13.5 day periods have been extensively discussed in the literature and are attributed to the differences in the spatial and temporal characteristics of the active regions which give rise to these emissions (DONNELLY et al., 1983). The origin of the 160 day period is not well understood. It is believed to be associated with those regions of the Sun where magnetic field is concentrated in small areas such as sunspots (LEAN and BRUECKNER, 1989 and the references therein). HOEGY and WOLFF (1989) attribute this period and other longer periods to long lived flux enhancements caused by nonlinear interactions of global oscillation modes in the sun's convective envelope and radiative interior.

SPECTRAL CHARACTERISTICS OF OZONE AND TEMPERATURE

The spectral analyses of the 2 mb ozone mixing ratio and F10.7 or F205 show a measurable response in ozone to changes in solar flux at 27 days at tropical and mid latitudes but not at high latitudes. The 2 mb ozone also shows a strong signal at about 4 months which from the time series analysis can be attributed to winter time planetary wave disturbances. However, this period has no coherency with the 5 month period in F10.7 or F205. The solar response in ozone at 27 days is significantly increased when dynamical signals are minimized by averaging over a latitude band of ±40°. This, however, does not improve the response at 5 months. Figure 2 shows the spectral characteristics of ozone mixing ratio at 2 mb with respect to F10.7 (upper panel), their coherency (middle panel) and phase (lower panel). The two time series cover the time interval from January 1979 to 1984. The data after 1984 were excluded because they correspond to very low solar activity and increase the relative contribution of dynamical signals at the expense of solar signals. In addition, ozone time series are averaged over ±40° to minimize the interference from dynamical signals. As seen in Figures 2, the normalized power spectrum of F10.7 shows strong peaks at 5 months and 27 days as in Figure 1. The relative magnitudes of these peaks are not changed by including an additional two and half years of data after June 1982. The power spectrum of ozone mixing ratio shows a strong peak at 4 months with considerable overlapping of power with 5 month period of F10.7. In comparison, the 27 day peak is only slightly above the 95% confidence limit. Notwithstanding these differences, the coherency spectrum of the two time series shows a significant peak at 27 days with almost no phase lag. The value of coherency squared at 4 or 5 month

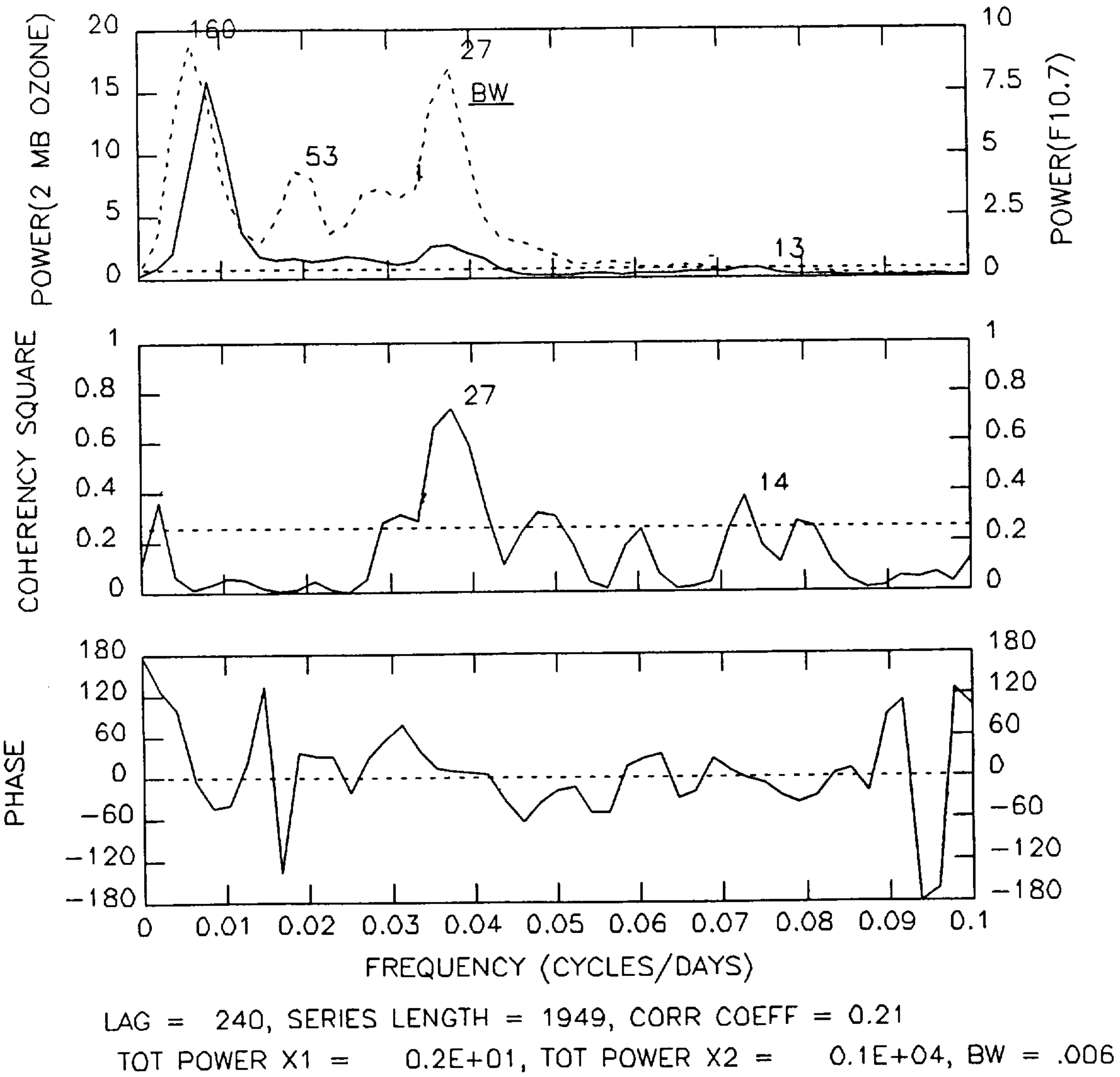


Figure 2. The same as Figure 1 except the spectra correspond to ozone mixing ratio at 2 mb (solid line) and F10.7 (dotted line) respectively. The ozone mixing ratio is averaged between ±40° latitude.

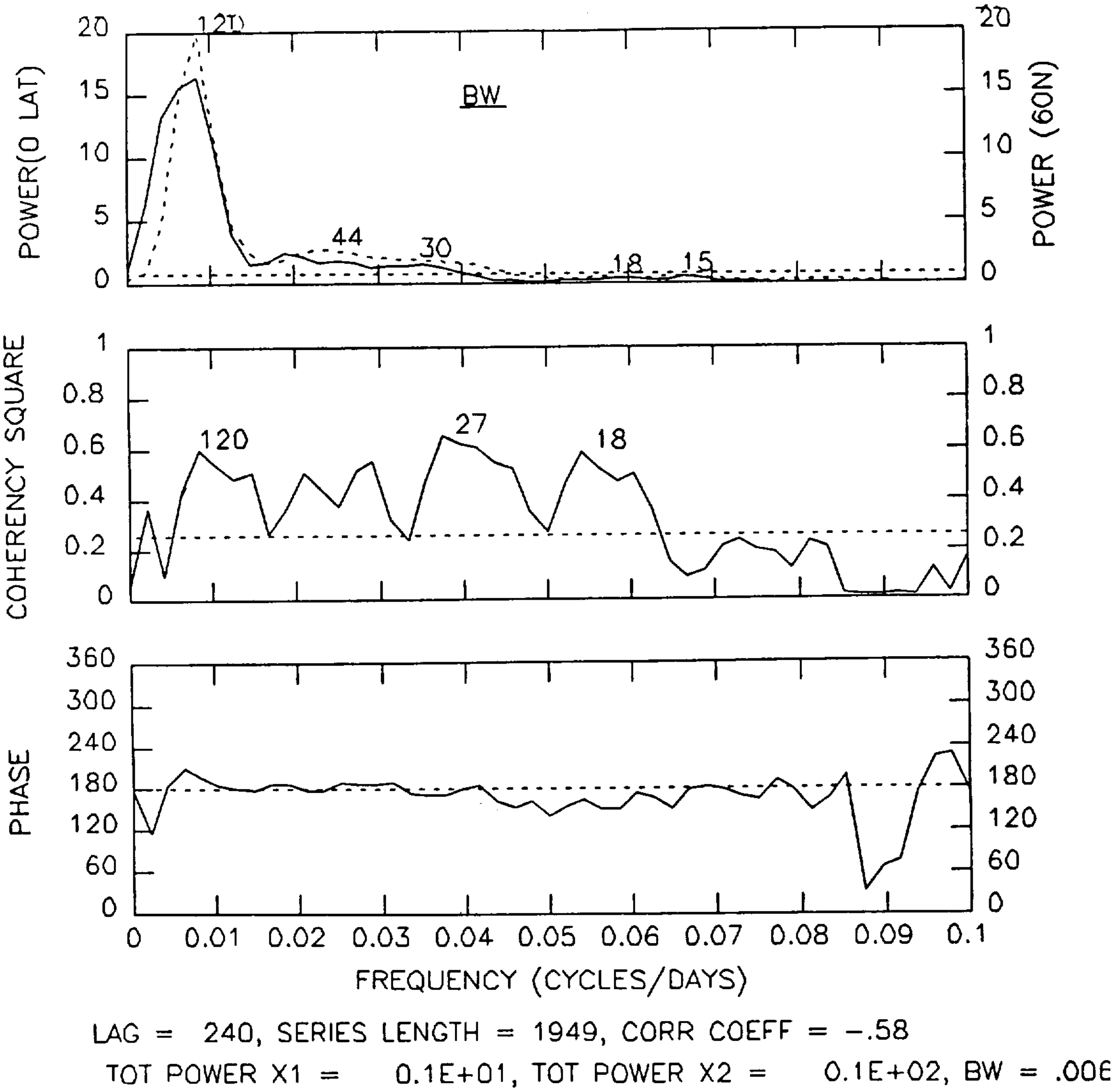


Figure 3. The same as Figure 1 except the spectra correspond to temperatures at 2 mb at the equator (solid) and 60°N.(dotted line)

periods are close to zero. A similar analysis of temperature at 2 mb shows a strong peak at 4 months as in 2 mb ozone. It, however, does not show significant coherency at 27 days or any other period indicating that temperature variances are mostly dynamical in origin and the solar signal, if any, is at a noise level.

The 4 month period seen in ozone and temperature data is a manifestation of increased planetary wave activity during the fall and spring epoches in both the hemispheres and is quasi-periodic in nature. Therefore, unlike the annual and semiannual cycles associated with the seasonal changes, this period cannot be filtered from a given time series by harmonic analysis. It manifests itself in the same way as shorter periods in the range of 3-7 weeks, i.e., it is global in extent and independent of solar activity. Its phase varies with latitude such that oscillations at high and tropical latitudes are 180° out of phase (CHANDRA, 1985 &1986). Figure 3 compares the power spectra of 2 mb temperature at 60°N and the equator and the spectra of their coherency and phase. It shows a strong period at about 4 months in both the time series and relatively broad periods in the spectral range of 3 to 7 weeks. These periods, though statistically significant, are considerably weaker than the 4 month period. The coherency and phase spectra of 2 mb temperature at 60°N and the equator in Figure 3 strongly suggest the dynamical nature of oscillations between 3-20 weeks. All periods in this range show significant coherency and are 180° out of phase with respect to high and low latitude oscillations which are characteristics of dynamical oscillations.

A similar inference about the dynamical nature of the 4 month period can be made by comparing the power spectra of total ozone and ozone mixing ratio and temperature at different pressure levels and latitudes. All these spectra indicate the dominance of a 4 month period unrelated to solar activity. They also show significant coherency between ozone and temperature at all frequencies between 27 days and 4 months both in the upper and the lower stratospheres. Their phase spectra, however, show an in phase relation in the lower stratosphere and an out of phase relation in the upper stratosphere. This phase change reflects a transition from a dynamical control to photochemical control of ozone from the lower to the upper stratosphere as discussed in CHANDRA (1986). The absence of a 5 month solar signal in the ozone data indicates that it is relatively weaker than the 27 day signal and is masked by a strong interference from a dynamical signal of comparable period unrelated to solar activity. Its relative weakness with respect to the 27 day component is consistent with the fact that the solar spectrum in the UV range is also weaker at this frequency compared to the 27 day component as indicated in Figure 1.

CONCLUDING REMARKS

In this paper, we have studied the response of the stratospheric ozone and temperature at time scales of solar periodicities at 27 days and 5 months. The study which was based on six years of data from 1979 to 1984, covered the most active period during solar cycle 21. The spectral and cross spectral analyses of these data showed a significant solar response in ozone mixing ratio at 2 mb at 27 days with a phase lag of less than a day. No such response was observed at the 5 month period. The temperature between 2 and 70 mb did not show significant response to solar forcing at either 27 days or at 5 months. These results are consistent with the earlier conclusions of the author (CHANDRA, 1985 and 1986) that the solar induced perturbations in temperature are too weak to be detected against the background dynamical disturbances which are several times larger and independent of solar activity. The lack of solar UV response in ozone at 5 months may also be attributed to the dominance of a 4 month period in ozone and temperature data whose phase and amplitude, like other dynamical perturbations, are latitude dependent. This, coupled with the possibility that the UV component of the 5 month period may be weaker than the corresponding 27 day component, makes the detection of a solar response in atmospheric data much more difficult.

References

Brasseur, G., A. De Rudder, G. M. Keating, and M. C. Pitts, Response of middle atmosphere to short term solar ultraviolet variations, 2, Theory, J. Geophys. Res.,92, 903, 1987.

Chandra, S. Qusi-seasonal variations in the Sun, Symposium on Significant Accomplishments in Sciences, Goddard Space Flight Center, Jan, 14, 1971;NASA-SP-286 :pp 164-170, 1972.

Chandra, S., The solar and dynamically induced oscillations in the stratosphere, J. Geophys. Res., 91, 2719, 1986

Chandra, S., Solar induced oscillations in the stratosphere: A myth or reality, J. Geophys. Res, 90, 2331, 1985.

Donnelly, D. F., D. F. Heath, J. L. Lean, and G. J. Rottman, Differences in the temporal variations of solar uv flux, 10.7 cm solar radio flux, sunspot number, and Ca-K plage data caused by solar rotation and active region evolution. J. Geophys Res. 88, 9883, 1983.

Garcia, R. S., S. Solomon, R. G. Roble, and D. W. Rush, A numerical study of the response of the middle atmosphere to the 11 year solar cycle, Planet. Space Sci.,32, 411, 1984.

Gelman, M. E., A. J. Miller, K. W. Johnson and R. M. Nagatani, Detection of long term trends in global stratospheric temperature from NMC analyses derived from NOAA satellite data, Advances In Space Res. 6, 17, 1986.

Heath, D. F., and B. M. Schlesinger, The Mg-280 nm doublet as a monitor of changes in solar ultraviolet irradiance, J. Geophys. Res., 91, 8672, 1986.

Hoegy, W. R., and C. L. Wolff, A seven month solar cycle observed with the Langmuir probe on Pioneer Venus Orbiter, J. Geophys. Res., 1989 (Submitted)

Hood, L. L., Solar ultraviolet induced variations in the stratosphere and mesosphere, J. Geophys. 92, 876, 1988.

Jenkins, G. M., and D. G. Watts, Spectral analysis and its applications, Holden Day, Oakland, Calif., 1968.

Keating, G. M., M. C. Pitts, G. Brasseur, and A. De Rudder, Response of the middle atmosphere to short term solar ultraviolet variations: 1. Observations, J. Geophys. Res. 92, 889, 1987.

Lean, J. L., and G. E. Brueckner, Intermediate-term solar periodicities: 100-500 days, The Astrophys. J., 337, 568,1989