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Temperature periodicities in the mid-latitude middle atmosphere and their possible association with sunspot cycle

S Devanarayanan[1] & K Mohanakumar[2]
Department of Physics, University of Kerala, Kariavattom P.O., Trivandrum 695 581

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Metrocket temperature (T) data from 580 individual soundings in the 15-80 km region over Volgograd (49°N, 44°E, station index 34560) as well as sunspot number (R) data during 1971-82 were used for studying the temperature periodicities in the mid-latitude middle atmosphere and their possible association with sunspot cycle. These two variables T and R formed a pair of discrete time series with length $N=144$ and sampling interval $h=1$ month. Using the Blackman-Tukey approach of spectrum analysis [Blackman R B & Tukey J W, *The Measurement of Power Spectra* (Dower, New York), 1958], the auto- and cross-spectral estimates for 10-km steps in the 15-80 km altitude region were obtained between T and R as done in our earlier work [*Planet & Space Sci* (*GB*), 35 (1987) 959], with the Nyqvist frequency $f_N=0.5$ cycle/month and lag variable $m=14$ months. The estimated spectra were subjected to the x^2-test with 95% confidence level for acceptance with each harmonic fluctuation present in the spectra at 20 degrees of freedom. The presence of long-term effect of solar activity on temperature was found. The computations were carried out using the CYBER 170 facility at the Vikram Sarabhai Space Centre, Trivandrum.

1 Introduction

Tremendous efforts have been made by means of atmospheric modelling as well as experimental studies for detecting any possible trend in the middle atmospheric structure and composition. Several independent sources of data suggest that there may be a relationship between mildness of the climate and the average level of solar activity[1]. Schwentek[2] and others[3-6], using solar cycle 19 and 20 data, reported a positive response to solar activity in stratosphere, but Kokin *et al.*[7] disagreed with this observation. In the mesospheric region (50-80 km) positive correlation is reported between temperature and sunspot number variability[7-11]. Chanin *et al.*[12] reported that there is a direct response of the mesosphere to the increase in solar UV flux and that there are planetary wave-induced variations in the region. The presence of semi-annual, annual and nearly quasi-biennial oscillations in temperature over Trivandrum (8°N, 77°E) was found by the present authors[13]. Analyses showed[14] influence of 11-year solar cycle variability on the troposphere and the stratosphere in the Northern Hemisphere during winter.

2 Description of the data

2.1 Temperature

M-100 rocket data for temperature (T) over Volgograd (49°N, 44°E) were taken from published data (*Upper Atmospheric Data Bulletin*, CAO, Moscow, 1971-82). They are available once a week at 1-km intervals in the 15-80 km altitude region for the period 1971-82 from a total of 580 individual soundings.

2.2 Sunspot number

Zürich sunspot number, R, one of the parameters of quantifying the variation of the level of solar activity, was chosen as the second variable in our study. The monthly values of R were taken from *Solar Geophysical Data*, WDC-A, Boulder, Colorado, USA, for the same 12-year period as that for T.

3 Methodology

The weekly temperature data for 5-km steps (from 15 km up to 80 km altitude) were selected first and then these were used to calculate the monthly mean T for successive months over the 12-year period. The monthly mean values of both T and R data

[1]Present address: Visiting Professor of Physics, Faculty of Natural Sciences, University of Puerto Rico, Rio Piedras, PR 00931, USA.

[2]Present address: School of Marine Sciences, Cochin University of Science & Technology, Cochin 682 016.

form a pair of discrete time series denoted by $T(t)$ and $R(t)$, respectively, where t is in time units.

3.1 Auto-spectral analyses

For detecting periodicities in a time series, one of the methods employed is that of Blackman and Tukey[15], and this approach, described by us earlier[13], has been followed in the present study. The goodness-of-fit of these estimates was tested by means of the x^2-test. The number of degrees of freedom is given by $\nu=(2N-m/2)/m$, for each estimate of the spectrum, where N is the number of terms in the time series and m the maximum lag in time units. Accordingly, a result is called statistically significant if the critical level of $x^2>95\%$ CL (confidence level) for "a priori" selection of a frequency interval of a spectrum.

3.2 Cross-spectral analyses

To find out whether or not $T(t)$ is dependent on $R(t)$, we resorted to cross-spectral analysis, as done in our earlier work[13],by taking $R(t)$ and $T(t)$ as the driving force and response function (both form a pair of sampled records of N data points), respectively, with spectra $S_R(f)$ and $S_T(f)$. The parameter f denotes the frequency of the harmonic present in a series. From this the output cross-spectrum $S_{RT}(f)$ is obtained. The cross-covariances of R and T for lag τ (where $\tau=0-m$) are denoted by $C(R, T, \tau)$. The relative values of $C(R, T, \tau)$ indicate how well the two sequences are correlated for a particular value of τ. If the correlation attains a peak for a specific value of τ this would indicate a very good correlation which means the two series match each other well, and a very small value or zero value for $C(R, T, \tau)$ would imply poor or no correlation. On the other hand, if coherence factor[13], $\gamma^2(f)$, for a particular harmonic f for the two variables T and R lies between 0 and 1, it indicates that the dependency of T on R is none or complete, respectively. To determine the non-randomness of the statistically obtained parameter γ^2, "Student's t-test" was used. In the present work, $N=144$, sampling interval $h=1$ month, and the Nyqvist frequency $f_N=0.5$ cycle/month. The lag variable $m\sim 10\%$ N, i.e. $m=14$ months, is large enough to provide a good spectral resolution. The estimates were made at $f=\nu f_N m$. Thus $\nu=20$ (always $<N/3$). At 95% CL this means $x^2=1.570$, obtained by interpolating in the table of x^2/ν distribution of one-tailed test of spectral peak. This represents the factor by which the ordinate values of the "null" continuum at each harmonic in the spectra is multiplied to locate the 95% CL of the spectrum. The highest resolvable periodicity was $f=28$ months (i.e. $2m$), and the lowest one was 2 months. The spectra, therefore, are composed of a maximum of 14 different frequencies and the unspecified long-period events.

The computation was carried out with Program SPECTRA using the CYBER 170/730 system at the Vikram Sarabhai Space Centre, Trivandrum.

4 Results and discussion

4.1 Auto-spectrum of $R(t)$

Auto-spectrum of sunspot number series was done and is as reported by us elsewhere[13].

4.2 Auto-spectra of $T(t)$

The power spectra of T at different altitude levels in the mid-latitude middle atmosphere are reproduced in Fig. 1. The results obtained by a comparative study of the actual spectrum along with the corresponding "null" continuum and its 95% CL are indicated in Fig. 1. The dotted curves refer to the ones with probability P_t at 95% point for the test, which corresponds to the probability of the distribution P_d give by, $P_d=(100\ m+P_t)/(m+1)$, viz. 99.7% CL in the x^2/ν distribution at $\nu=20$. The continuous curves denote red noise continua. The parameter r_1 shown in the diagram refers to the lag-one auto-(serial) correlation coefficient. The observations from Fig. 1 are: (i) At all altitude levels of the stra-

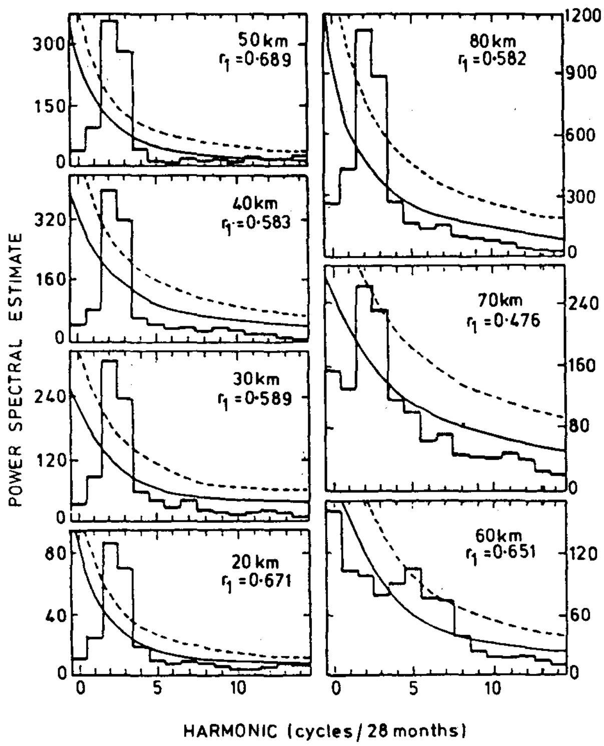

Fig. 1 – Auto-power spectra of temperature at various levels of altitude (maximum lag $m=14$ months) of the middle atmosphere over Volgograd during 1971-82

tosphere (20-50 km), the 2nd and the 3rd harmonics of the spectra were found to overshoot the 95% CL of P_t (i.e. the periodicities detected are at $f=14$ months and $f=9$ months). They showed the strong presence of annual oscillations in T over Volgograd. These oscillations were not statistically significant over Trivandrum[13] where only semi-annual oscillations were found to be significant, (ii) At 60 km altitude level, the 5th and the 7th harmonics (i.e. periodicities of 5.6 months and 4 months) were seen at CL > 95%. These are the weak manifestations of bi-annual and tri-annual oscillations in the mesosphere at 60 km, (iii) The auto-spectra of T at 80 km in the mesosphere contain "*deterministic*" oscillations identified as annual oscillations, which agree to the earlier finding[16] based on correlation and regression analyses, and (iv) Annual oscillations were present in temperature in the strato-mesospheric regions except at 60 km.

4.3 Cross-spectral estimates

The estimates for the different layers are reproduced in Fig. 2. The "co-spectra", $C_{RT}(f)$, which are the real parts, measure the extent to which the particular harmonics found to be present have the same phase in the two time series considered (or of opposite sign, i.e. with a phase shift of half a cycle). These are shown as continuous lines. The discontinuous lines refer to the "quadrature spectra", $Q_{RT}(f)$, representing the rhythms having a phase difference of a quarter cycle (in either direction) between the time series. The following conclusions are drawn from Fig. 2: (i) Co-spectral estimates are all negative in the entire stratosphere while the signs of quadrature spectra are all positive. The latter indicate peaks at 3rd and 4th harmonics, (ii) Near the stratopause, C_{RT} is negative and Q_{RT} is positive up to 7th harmonics, and beyond that their signs reverse for all higher harmonics, (iii) Both C_{RT} and Q_{RT} show positive values in the mid-mesosphere with maxima at long-periodicities as well as for 1st harmonic, (iv) Near the mesopause the co-spectrum is positive whereas the quadrature spectrum is negative. This feature is opposite to the one seen in the stratopause, (v) Both C_{RT} and Q_{RT} are positive and have definite maxima for the first two harmonics in the middle mesosphere. This corroborates the observations based on correlational and linear regression analyses[16]. The correlation between T and R was found to be maximum (0.954) in the mean mesosphere, and the regression coefficient of T on R was positive and high in magnitude at 65 km. The present study indicates no quasi-biennial oscillations (QBOs) in temperature in the middle atmosphere, disagreeing with the results of Labitzke and van Loon[14] during winter. The absence of QBOs in our study over Volgograd, we believe, may be due to the features of the circulation in the tropospheric and mesospheric regions. Obviously, this requires further study of atmospheric dynamics which could involve other parameters, such as the large scale variations of the atmospheric constituents in tropo-, strato- and meso-spheres, (v) Metrocket temperature as a function of a double or more solar cycle is probably necessary before the existence of a sunspot cycle-temperature variation can be ascertained, and (vi) All the periodicities observed are sub-harmonics of the 11-year solar cycle, and so there is an association of middle atmospheric temperature changes with the 11-year sunspot cycle. Further, none of the periodicities reported here is a probable harmonic of the 27-day solar rotation period. The results of the present analysis seem to be critical in validating as well as for further development of the existing numerical atmospheric models.

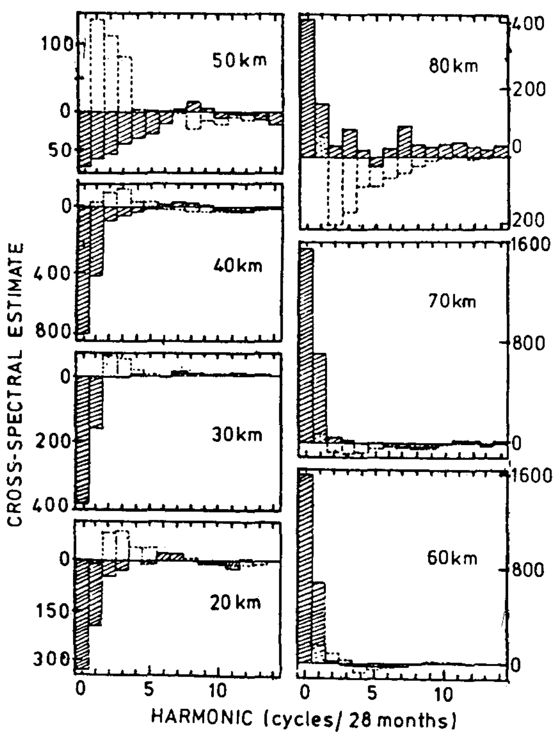

Fig. 2 – Cross-spectra of temperature on sunspot number over Volgograd at various altitudes during a solar cycle

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