Solar cycle and equatorial stratopause temperature

K MOHANAKUMAR and S DEVANARAYANAN

Department of Physics, University of Kerala, Kariavattom, Trivandrum 695 581, India.

MS received 22 February 1982; revised 7 October 1982

Abstract. Variations in a solar activity and their effect if any on the temperature of the stratopause are studied. Monthly mean stratopause temperatures during 1969–1976 and departures from the monthly mean value of eight-year period, determined for four equatorial rocket launching stations, viz. Ascension Island, Kwajalein, Fort Sherman and Thumba, are statistically compared with sunspot number departures. To study the effects of seasonal variation on stratopause temperature, the data have been divided into winter, summer and equinoctial periods. Seasonwise study indicates that the correlation between the stratopause temperature and sunspot number is positive and just below the significant level for Thumba and positive and highly significant over all the other stations with a better relationship in equinoctial periods than in both winter and summer. The estimated regression coefficients are positive and significant.

Keywords. Solar cycle; stratopause temperature; middle atmosphere; correlation coefficient; regression coefficient.

1. Introduction

Stratopause is the level of maximum vertical temperature as a consequence of absorption of solar ultraviolet energy by ozone. This level represents the equilibrium altitude, where heat input, capacity and assorted loss mechanism combine to produce the maximum temperature. The temperature variation in this region has been thought to be caused by atmospheric heating produced by energetic particles and electromagnetic radiation from the sun. Heath (1973) indicated that during a solar cycle, the intensity of the solar spectrum may be enhanced by a factor of 2 near 1800 Å and by 20% near 2900 Å during sunspot maximum. If this is true, according to Fritz and Angell (1976) the stratopause temperature might vary with the sunspot cycle, and they reported a ~ 20% stratopause temperature difference during sunspot maximum and minimum (employing the formula $dT/dt = -0.214T + 49.8^\circ \text{K/day}$). This could be observed in the rocketsonde data.

The present study is an investigation of a relationship between the stratopause temperature and solar activity, as represented by Zürich sunspot number. The stratopause temperatures have been obtained (World Data Centre A, Meteorology) from monthly mean temperature data of four equatorial rocket launching stations, viz. Ascension Island (8° S, 14° W), Kwajalein (9° N, 168° E), Fort Sherman (9° N, 80° W) during 1969–76 and Thumba (8° N, 77° E) during December 1970–1976. These four stations are quite well spaced and distributed over the equatorial region of the globe.

2. Data and method of analysis

Stratopause mean temperatures for each month were listed after computation from the HAMR (high altitude meteorological rocket) data (World Data Centre A, Meteorol-

ogy) and the departures from the monthly mean value obtained from data for the period 1969–1976 for each month. The sunspot numbers for the same period were then taken (Solar and Geophysical Data 1971, 1977) and their departures from the mean (1969–1976 mean = 55.1) were estimated. Finally, a possible correlation coefficient between the two variables, viz. stratopause temperature and sunspot number, was found by using a standard statistical method.

In order to find the significance of the estimated correlation coefficient R between temperature of stratopause and sunspot number, the results were treated with the student's t test. Accordingly, the correlation is significant only if the calculated value is greater than the tabular value above at 95% level of significance.

Since R is only a measure of the degree of relationship between the stratopause temperature and the sunspot number one has to resort to regression analysis to establish the nature of the relationship, delineating the cause and effect. The regression coefficient of stratopause temperature on sunspot number is

$$B_{TZ} = \frac{\sum_{i=1}^N T_i Z_i}{\sum_{i=1}^N Z_i^2} \quad (1)$$

where T_i = departure of temperature from the mean, Z_i = departure of sunspot number from the mean and B_{TZ} is represented by the slope of the regression line.

The correlation coefficient, regression coefficient and the value of N used, listed in table 1, were calculated for the seasons summer (May to August), winter (November to February) and the two equinoctial periods (March–April and September–October) in the case of the stations located in the northern hemisphere, and for Ascension Island, a southern hemispheric station, where the summer and winter seasons are just opposite to those of the northern hemisphere.

3. Results and discussion

The monthly departures of sunspot number from 55.1 (the 8 year, *i.e.* 1969–1976 mean value) were plotted against time and is shown in figure 1. 1969 was the year of sunspot maximum and 1976 was the year of sunspot minimum.

The deviations of stratopause temperature from the 8-year mean monthly value for the four stations are also graphically presented in figure 1. As the active sun becomes quiet the stratopause temperature deviations change from positive to negative values, which is a common trend seen over the four stations. Nearly quasi-biennial oscillation (26 to 32 months periodicity) are present in the temperature data at all the stations after 1972. These oscillations are present in the sunspot number as well. As these oscillations are not in phase at all the stations this may explain in part the variation of the correlation coefficient from station to station resulting in poor values of R over Thumba. It is also possible that the solar activity effects appear with a delay as is evident from the work by Rajaram *et al* (1979), who found that the tropopause height at the equatorial station was correlated with the sunspot activity with a lag of three years. It is possible that the correlations over Thumba improve if a lag is introduced with respect to solar activity, *i.e.* the temperature series is correlated to the sunspot series shifted backwards by one, two or three years.

Table 1. Correlation and regression coefficients

Stations	Summer				Winter				Equinoctial				All seasons	
	N	R	B_{TZ} (°C/sunspot number)	N	R	B_{TZ} (°C/sunspot number)	N	R	B_{TZ} (°C/sunspot number)	N	R	Level of significance (%)	B_{TZ} (°C/sunspot number)	
1. Ascension Island	26	0.576	0.051	27	0.698	0.062	26	0.820	0.051	79	0.689	99.9	0.055	
2. Kwajalein	25	0.597	0.055	25	0.406	0.035	26	0.609	0.054	71	0.528	99.9	0.047	
3. Fort Sherman	22	0.551	0.033	18	0.569	0.084	16	0.547	0.037	56	0.511	99.9	0.051	
4. Thumba	22	0.390	0.043	21	0.350	0.039	20	0.417	0.021	63	0.362	99.5	0.036

Figure 1. Variation of sunspot number departure and stratopause temperature departure from the respective 8-year mean, with time. (ASC - Ascension Island, KWJ - Kwajalein, FSH - Fort Sherman, THU - Thumba)

The statistical study, on the other hand, reveals that there exists a (positive) correlation (significance well above 95%) between the stratopause temperature and sunspot number for each season in all the stations except Thumba. It is also evident from table 1 that the correlations are higher during the equinoctial periods. The estimated correlation coefficients for all the seasons over Ascension Island, Kwajalein and Fort Sherman are of such magnitude that the correlation between stratopause temperature and sunspot number are highly significant (as the level of significance is above 99.9%) in the stratopause. The correlation over Thumba for all the seasons is also significant (above 99.5% level). The highest correlation (0.82) is over Ascension Island displayed during equinoctial periods, and Thumba has the lowest value (0.35) during winter. The influence of seasons on the correlation coefficient is the lowest over Fort Sherman.

The regression coefficient of stratopause temperature on sunspot number is higher in the western hemispheric stations than in the eastern hemispheric station, viz. Thumba.

During the period of sunspot maximum, increased amounts of ultraviolet radiation enter the atmosphere. These radiations are absorbed by the ozone present in the stratosphere causing an increase in the temperature of the stratosphere. Thus a higher temperature can be observed in the stratopause (Webb 1966). It is well-known that the diurnal variations observed in the stratosphere have a greater amplitude in the upper stratosphere, especially in the stratopause. A diurnal temperature variation of $\sim 4^\circ \text{K}$ is present at stratopause because heating due to ozone absorption occurs only during the day time, whereas cooling due to the emission from carbon dioxide takes place all the time (Houghton 1977). This might form a basis to explain the observations over Thumba related with the post-sunset rocket launching.

Fritz and Angell (1976) suggested that the temperature change in the tropical stratopause seems to have its greatest amplitude at the equator and to have long duration and widespread aerial extent. From the analysis of Angell and Korshower (1978) of the high altitude meteorological rocket data over ten stations for all seasons for the period 1965–1977, a 6°C lowering for summer in the layer 46–55 km is found when the nearly active sun becomes quiet. The combined station data involving all seasons and a three-year smoothing yield a temperature decrease of about 4°C in this layer from solar maximum to minimum.

Quiroz (1979) investigated temperature at two discrete levels, 35 and 50 km, for the period 1965–1977 for seven stations lying in the latitude 8°S – 64°N with solar cycle 20. His investigation yielded overall coefficients of correlation in the range $+0.7$ to $+0.9$ between upper stratospheric temperature and sunspot number. He found a decrease of the average temperature from solar maximum to minimum for summer which is 4°C at 50 km. A theoretical analysis by Callis and Nealy (1978), assuming an approximately 20% increase in the UV radiation during sunspot maximum, resulted in a temperature increase of about 15°C in the 40–50 km at this time.

A high significant correlation over stations in the western hemisphere and insignificant negative correlation over Thumba have been reported earlier (Mohanakumar and Devanarayanan 1982) and this anomaly was not explained. But the present study attributes the anomaly over Thumba to the presence of waves over the station (figure 1). During the sunspot minimum year 1976, Thumba alone displayed a sudden rise in temperature. This higher stratopause temperature actually led to the estimated correlation to be insignificant and negative whereas it was found to be significant and positive over the western hemispheric stations.

4. Conclusion

Our study on the rocketsonde data at the four equatorial meteorological rocket launching stations showed that the stratopause temperature is influenced by the sunspot cycle. The effect is more prominent during the equinoctial periods. Correlation that exists for all seasons over Ascension Island, Kwajalein, Fort Sherman was found to be highly significant. A wavy pattern is observed in the stratopause temperature over both Thumba and Kwajalein. The positive, significant values of both the correlation and regression coefficients found over all these stations indicate a relation existing between the solar cycle and the equatorial stratopause temperature.

Acknowledgements

The authors thank Dr V Narayanan of Vikram Sarabhai Space Centre, Trivandrum for assistance in the meteorological rocket data used here. They thank the referees for valuable comments and suggestions. One of them (KM) thanks the UGC for awarding a fellowship.

References

- Angell J K and Korshower J 1978 *J. Atmos. Sci.* **35** 1758
Callis L B and Nealy J E 1978 *Geophys. Res. Lett.* **5** 249
Fritz S and Angell J K 1976 *J. Geophys. Res.* **81** 1051
Heath D F 1973 *J. Geophys. Res.* **78** 2779
Houghton J T 1977 *Physics of Atmospheres* (London: Cambridge Univ. Press)
Mohanakumar K and Devanarayanan S 1982 *Mausam* **33** 405
Quiroz R S 1979 *J. Geophys. Res.* **84** 1979
Rajaram M, Singh B P and Gupta H V 1979 *Tellus* **31** 515
Webb W L 1966 *Structure of the Stratosphere and mesosphere* (New York: Academic Press)