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Equatorial stratospheric and mesospheric temperature & sunspot cycle

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सार – पांच भूमंडलीय स्थानों पर सूर्य कलंक अधिकतम (1970) एवं न्यूनतम (1976) के दौरान समताप मंडल एवं मध्यमंडल तापमान विचरणों को विश्लेषित किया गया है, वे हैं असेंन्सन द्वीप (8° द०, 14° प०), अन्तिगुआ (17° उ०, 62° प०), फोर्ट सेरमन (9° उ०, 80° प०), क्वाजलिन (9° उ०, 168° पू०) एवं थुम्बा, त्रिवेन्द्रम (8° उ०, 77° पू०)। ये अन्वेषण प्रत्येक अवधि में चारों ऋतुओं के मासिक माध्य तापमान पर आधारित हैं। अधिकतम सूर्य कलंक की अवधि में समतापमंडल एवं मध्यमंडल परतों में उष्मीय प्रभाव देखा गया है। 30 से 35 कि० मी० की ऊंचाई पर समतापमंडल परतों में उष्मा ज्यादा होती है। थुम्बा को छोड़कर सभी भूमध्य रेखीय स्टेशनों पर गर्म समतापमंडल सीमा प्रेक्षित की गई है, जहां उड़ानें सामान्यतया सूर्यास्त के बाद ली गई थीं। समतापमंडल में सौर चक्र की वजह से ताप संरचना में ऋतुक परिवर्तन बहुत कम होता है। अन्तिगुआ में गर्मियों में समतापमंडल में उत्पन्न गर्मी ज्यादा होती है परन्तु सर्दियों में फोड सेरमन एवं असेनसन द्वीप में गर्मी कुछ ज्यादा होती है। शरद ऋतु में, थुम्बा पर ऊपरी मध्य मंडल के ताप में अधिक विचरण (25 सें० के क्रम में) प्रेक्षित किए गए जबकि बसंत ऋतु में विचरण बहुत कम हुआ है। जब सूर्य ज्यादा क्रियाशील होता है तब मध्य मंडल की अधिकांश गर्मी साफ–साफ देखी गई है। समतापमंडलीय तापमान विचरण और सौर चक्र के सहसंबंध का अध्ययन करने का प्रयास किया गया है।

ABSTRACT. Stratospheric and mesospheric temperature variation during a sunspot maximum (1970) and a minimum (1976) has been analysed at five equatorial sites, *viz.*, Ascension Island (8° S, 14° W), Antigua (17° N, 62° W), Fort Sherman (9° N, 80° W), Kwajalein (9° N, 168° E) and Thumba, Trivandrum (8° N, 77° E). The investigation is based on monthly mean temperature of the four seasons in each period. The stratospheric and mesospheric layers showed a heating effect during the period of sunspot maximum. The heating is more pronounced in the stratospheric layers between 30 & 35 km altitude. A warmer stratopause is observed over all the equatorial stations except over Thumba, where the soundings were usually taken during the post-sunset period. Seasonal variation of the thermal structure due to the solar cycle is the least in the stratosphere. The warming produced in the stratopause is high in summer over Antigua, but over Fort Sherman and Ascension Island, the warming is slightly higher in winter. In the winter season, large variations of temperature (of the order of 25° C) are observed in the upper mesosphere over Thumba, while there is least variation in spring. A high degree of mesospheric warming is clearly seen when the sun is more active. An attempt has been made to study the correlation between the temperature variation of the stratopause and the solar cycle.

1. Introduction

During a sunspot cycle, variation in the solar spectrum takes place from 1260 to 2000 A. The ultraviolet intensity may be enhanced by a factor of 2 near 1800 A and by 20 per cent near 2900 A at sunspot maximum (Heath 1973). A study of the stratospheric temperature and solar cycle by Garvin (1961) revealed that the stratospheric temperatures are better related with sunspot numbers; the relationship was found to be better in summer than in winter. The study also indicated an improvement in the relationship with increasing height. He concluded that increased electromagnetic radiation associated with sunspots increases temperature of stratosphere.

The difference between the stratopause temperatures at times of large and small uv solar radiation, turned out to be about 20 °K based on Dopplick's (1970) computation for cooling rates. However, the computation of equilibrium of ozone distribution, with its dependence on both temperature and trace elements, is considered to be a complex matter. If the temperature differences are so much, they can be detected by sounding rockets. Some of the observed time variations in total as well as high level ozone could possibly be related to a variation of the temperature in upper stratosphere, through temperature dependent reaction rates (De More and Tschuikow Roux 1974).

In the present study, the response of the temperatures of the equatorial stratosphere and mesosphere to variations of solar activity is analysed for five equatorial rocket launching stations for 1970, the year of sunspot maximum and for 1976,

TABLE 1

Correlation between stratopause temperature and sunspot number

Station	Correlation coefficients		
	Sunspot max. 1970 and mean	Sunspot min. 1976 and mean	Mean r
Ascension Island	+0.90	+0.85	+0.875
Kwajalein	+0.88	+0.93	+0.905
Fort Sherman	+0.62	+0.78	+0.700
Antigua	+0.74	+0.84	+0.790
Thumba	−0.58	+0.45	−0.065

the year of sunspot minimum. The stations are Ascension Island (8° S, 14° W), Antigua (17° N, 62° W), Fort Sherman (9° N, 80° W), Kwajalein (9° N, 168° E) and Thumba, Trivandrum (8° N, 77° E). Fort Sherman is located in the isthmus in the Panama canal zone and is near the antipode of Thumba. These five stations are quite well spaced and distributed over the equatorial region of the globe. It is seen that Ascension Island falls in the southern hemisphere whereas the remaining four stations are in the northern hemisphere.

2. Observations and data analysis

Monthly mean temperature data available at 1 km intervals from 20 km upwards, in the region comprising stratosphere and mesosphere, have been used for the analysis. The variations of temperature from the long period monthly mean (1969-1976) for the four months January, April, July and October, representing respectively, the seasons winter, spring, summer and autumn, both for 1970 (the year of sunspot maximum) and for 1976 (the year of sunspot minimum) have been analysed. Since the temperature data at Thumba are available only from 1971, in the present analysis, 1971 is chosen as the year of sunspot maximum. A study of the upper mesospheric region is restricted to a single station only, *viz.*, Thumba, since at all the other stations the rocketsonde data were confined only upto 65 km altitude.

The general procedure used for the statistical study between the stratopause temperature and sunspot number is as follows. Stratopause mean temperature data for each month are computed for sunspot maximum year (1970) and for minimum year (1976) and their departure from the long period mean (1969 to 1976) are listed. Next the sunspot numbers for the period are computed, and their departures are determined from the assumed mean, taken by us as 50. (Fig. 1). The temperature deviations are then statistically correlated with sunpot number deviations. The correlation coefficients, 'r', are evaluated using the standard expression :

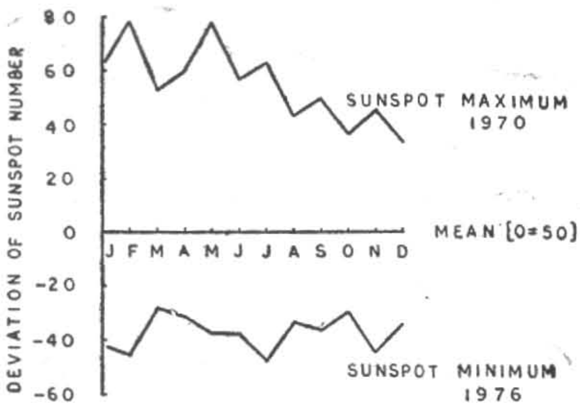

Fig. 1. Variation of sunspot number from the assumed mean (50) during sunspot max. and min.

$$r = \frac{\sum_{i=1}^{N} X_i Y_i}{\left| \sum_{i=1}^{N} X_i^2 \sum_{i=1}^{N} Y_i^2 \right|^{\frac{1}{2}}}$$

where, X_i (sunspot number deviation)

$= X_{max}$ or $X_{min} - X_{mean}$

Y_i (stratopause temperature deviation)

$= Y_{max}$ or $Y_{min} - Y_{mean}$

The results are then tabulated as shown in Table 1.

3. Results

The vertical monthly mean temperature profiles over Antigua, for the four months mentioned earlier are presented in Fig. 2. The long term mean temperature distribution for different months, monthly mean temperatures for the year 1970 (sunspot maximum) and for 1976 (sunspot minimum) are indicated by the solid, dot and dash curves, respectively.

It is seen from Fig. 2 for all seasons, upto 29 km altitude there is negligible effect of solar cycle on temperature, while above 29 km, upto 37 km there is pronounced effect on the thermal structure of the stratosphere. In this region the temperature during the sunspot maximum period is higher by about 6-8°C than that during the sunspot minimum. Just above this second region, there exists a thin layer of thickness about 2 km which is practically unaffected. The thermal structure during the solar cycle is found to vary significantly with increasing altitude above 40 km.

In the case of Antigua the stratopause temperature difference was seen to increase as the season changed from winter to summer. This is evidenced

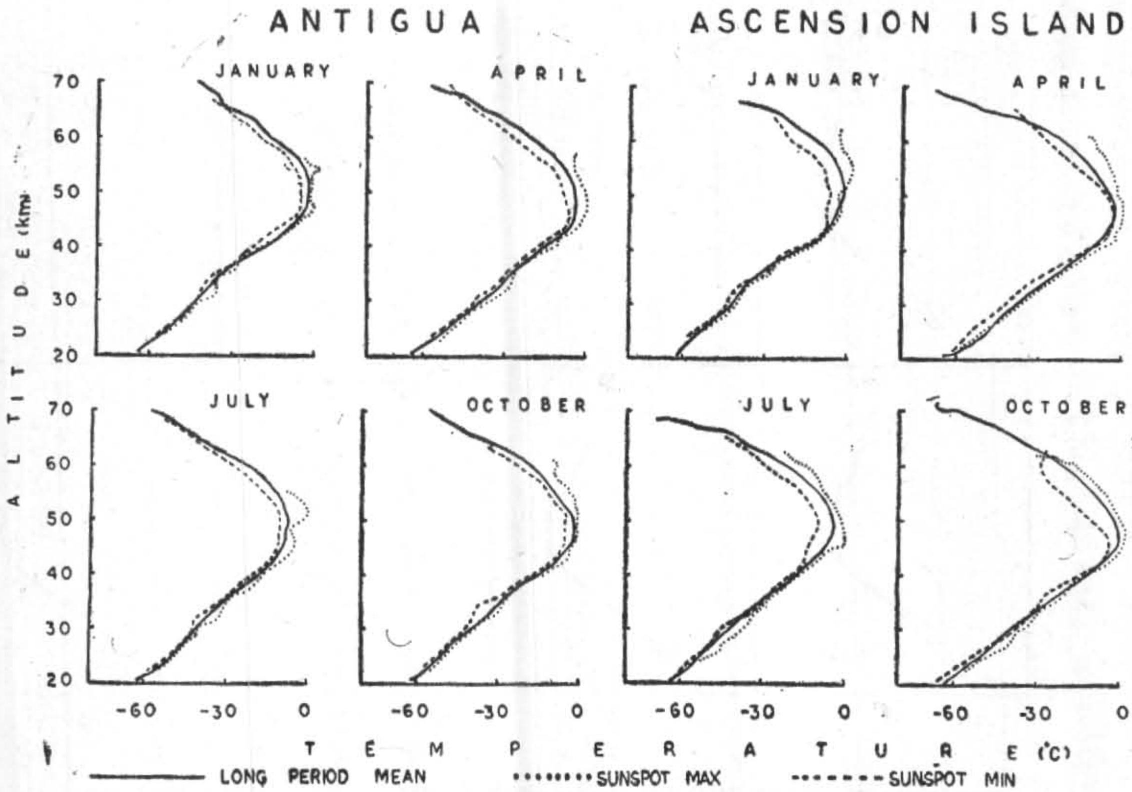

Fig. 2. Change in temperature from the long period mean with sunspot number over Antigua and variation of temperature during a solar cycle over Ascension Island

as there was a warming up of 6.9°C in July during sunspot maximum compared to a cooling of —3.9°C in May during minimum solar activity. The correlation coefficient over Antigua with sunspot cycle and stratopause temperature was +0.790 for the period considered. The seasonal effect on the vertical temperature profile at Antigua is quite small during the solar cycle.

The variation of thermal structure over Ascension Island is also presented schematically in Fig. 2. In all the seasons, the thermal structure showed warmer layers in the year of active sun. During the winter season pulses of warmer layers were observed below 44 km as shown in Fig. 2. In the mesosphere, at 62 km altitude the layer is warmer by 20° C during 1970. The temperature has undergone maximum changes in this region during January. On the other hand, the entire thickness of the stratosphere was 4-6° C warmer in April 1970 than in the sunspot minimum year 1976.

The stratopause temperature over Ascension Island showed the highest degree of warming of 6.4°C in 1970 December and a cooling of 5.2°C in January and July during 1976. The correlation coefficient over this station was +0.875 for all the seasons. The highest degree of correlation between sunspot number and stratopause temperature reported for this station corresponds to the winter season (Jan-Mar) in 1970 and it was + 0.999.

Over Fort Sherman the data for May and November were taken as the representative months instead of April and October for the seasons, spring and autumn, since the data were not available during April and October and are presented in Fig. 3. In all seasons except autumn, higher temperature was observed during the period of sunspot maximum. During January, the temperature below 40 km, especially 30 km, was well influenced by the solar cycle, the difference was of the order of 11° C. The stratospheric temperature difference decreases with the season changing from winter to autumn. In November the temperature below 42 km did not show much variation with solar activity. As in the case of the two earlier stations there was dominant warming in the region 30-35 km during summer and winter seasons, whereas it was not so in spring and autumn for the year 1970. The temperature at the stratopause was found to have maximum difference from the long period monthly mean of 9.7° C and 5° C, both in November respectively, when sunspots were maximum and minimum. The correlation coefficient of stratopause temperature and monthly mean sunspot number over Fort Sherman is estimated to be +0.700.

Fig. 3. also presents the thermal structure over Kwajalein for the four months : January, April, July and October. The region between 30 and 42 km showed slight warming in January during sunspot maximum. The thermal structure was

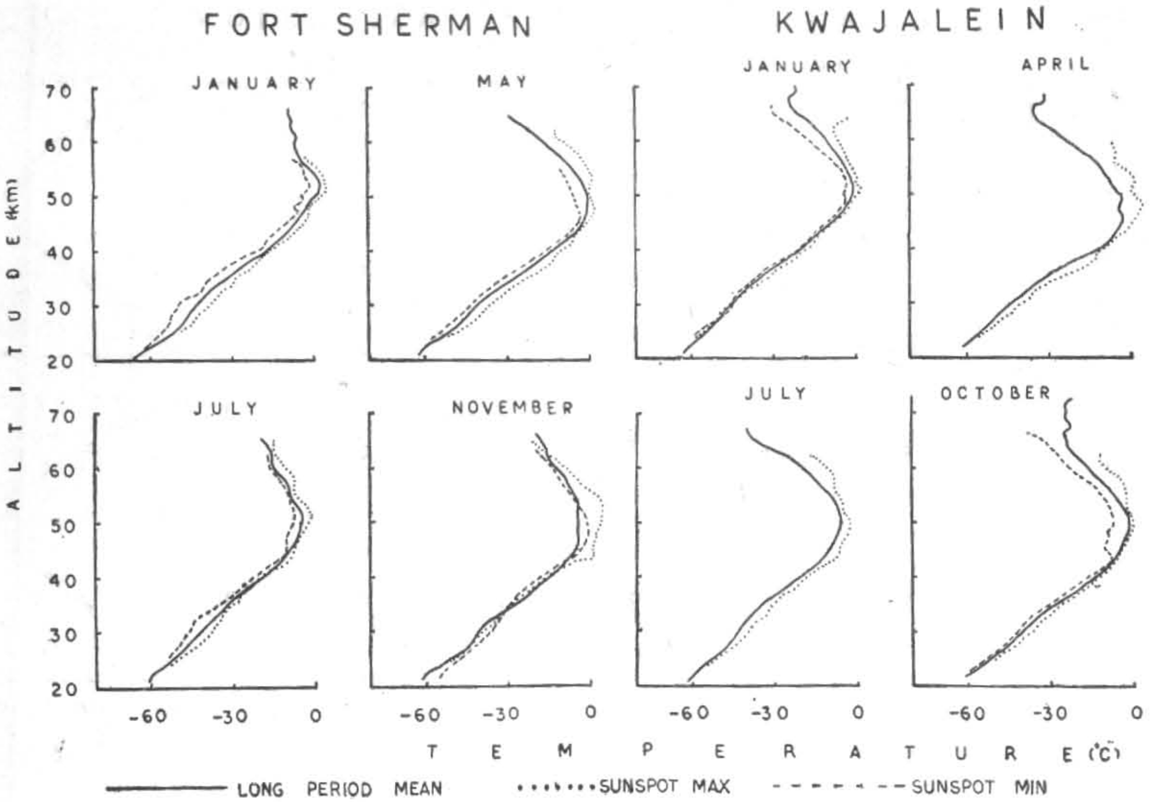

Fig. 3. Temperature departure from the long period mean during sunspot maximum and minimum over Fort Sherman and deviation of thermal structure of the stratosphere and mesosphere over Kwajalein during a sunspot cycle

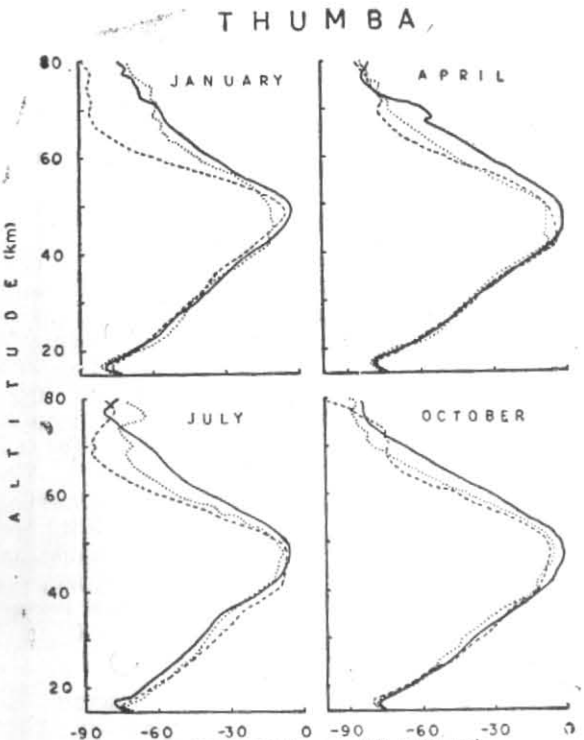

Fig. 4. Variation of vertical profiles of temperature over Thumba in 1971 and 1976

found to be least affected around 44 km in winter. A warming of 3.5° C appeared below 41-km in October 1970. The highest variation from the long period mean in the stratopause temperature was +4.8° C in April 1970 and —5.6° C in November 1976. The correlation coefficient of the stratopause temperature obtained at this station was +0.905.

All the rocket observations discussed so far were over places located in the western hemisphere. Thumba is the only station available in the eastern hemisphere equatorial region. Fig. 4 shows the thermal structure over Thumba in the months January, April, July and October for the years 1971 and 1976 along with the long period monthly mean temperature from 1971 to 1977. Unlike the previous cases, the soundings made over this station were in the region 15-80 km. This enabled study of the region between the tropopause and mesopause. The influence of the solar cycle on the thermal structure in the stratosphere showed an inverse effect compared to all the previous stations, especially in summer and autumn months. During spring no variation of temperatrue was observed below 40 km. Both in summer and autumn, the region between 25 and 45 km indicated a cooling during the maximum of solar activity (1971). A good degree of warming was seen in the mesospheric region for all the seasons, the highest being 18°C around 70 km altitude in winter 1971. The temperature variation is lower during the equinoctial months April and October.

All the equatorial rocket launching stations in the western hemisphere showed a strong influence of the solar activity on the thermal structure in both the stratosphere and lower mesosphere. But the soundings obtained from Thumba showed a comparatively different thermal structure in the stratosphere. This difference has been attributed to the collective effects of the following (Narayanan 1972) :

(1) From Thumba most sounding rockets were launched after the sunset, between 1930 & 2400 IST (*i.e.*, 1400 & 1830 GMT) while the soundings in the western hemisphere were conducted mostly during day-time. It is to be borne in mind that the variation of ultraviolet rays from the sun which influences the thermal structure of the atmosphere is prominent during day-time.

(2) The temperature sensors used in the ascents from Thumba were made of tungsten alloy, while those at other stations referred to earlier in this paper, were of thermistor type. Hence part of the longitudinal variation can be due to the difference in the response of the two types of sensors.

(3) Most of the soundings at Thumba were made every Wednesday, which means there was regularity in recording data, whereas the soundings at the western hemisphere stations were taken not at specific intervals of time.

These differences between the two sets of data clearly necessitates different analytical methods. A comparison between US and USSR rocketsondes held at Wallops Island in August 1977 gave the following results :

Mean temperature differences for the day and night pairs are less than 5° C upto 50 km. The difference progressively increases to about 14-15° C at 70 km. Comparative investigations have shown that the Soviet temperatures are low with respect to US measurements (Schmidlin 1979).

The present study on the influence of the solar cycle on temperature at every kilometre altitude in the 20 and 80 km region over the various equatorial stations leads to the following results :

(1) Below 25 km altitude, the temperature distribution is practically uneffected.

(2) Around 30-35 km is the region in which the thermal structure is very much influenced by the solar cycle. For example, a difference of 11° C from the long period monthly mean was observed during winter and 10° C during summer over Fort Sherman, 6-7° C difference has been over Antigua and 4-6° C over Kwajalein and Ascension Island.

(3) The thermal structure around 40 km was least influenced by the variation of sunspot number.

(4) Above 45 km, the difference between temperatures during sunspot maximum and minimum increases with altitude.

(5) In the mesosphere, especially in the upper mesosphere, the solar cycle variation has highly influenced the temperature.

(6) Observed temperature differences were higher during winter and summer months and the least in equinoctial months.

(7) From the stratopause temperature and solar cycle it is seen that the correlation coefficient is significant over Antigua (+0.790), Ascension Island (+0.875), Fort Sherman (+0.700) and Kwajalein (+0.905), in contrast to the correlation coefficient over Thumba having a low negative value (—0.065).

4. Discussion

It is seen that at all the stations in the western hemisphere, there is similarity in the variation of temperature with sunspot number in both the stratosphere and lower mesosphere, and this suggests that the variable solar ultraviolet emission could be the cause for the temperature variation. Fritz and Angell (1976) have found that the temperature change in the stratopause near the equator was even larger than the observed changes near 8-9° latitude. The dynamical effects which influence the tropical stratopause temperature seem to be predominant at the equator and to have long duration and at the same time extending to wide area.

A study of the 10.7 cm solar radio flux and temperature obtained at Thumba during December 1970 to December 1971 from a series of 51 rocket soundings, shows (Ramakrishna and Seshamani 1973) that there is a strong positive correlation between these two parameters and the mesospheric heating effects caused by daily variations in solar EUV emission. No specific relation between solar emission and air temperature at heights below 50 km has been reported. A study of temperature and wind during a solar cycle (Fritz and Angell 1976), over Ascension Island, Fort Sherman and Alaska in the region 40-55 km during 1966-1970 indicates that the observed temperature variation in the tropics near the stratopause (49 km) is not directly related to variation of solar ultraviolet emission, in conformity with the findings at Thumba by Ramakrishna and Seshamani (1973). But one has to consider the fact that observations at Thumba were well after sunset and, therefore, yielded only night temperatures. The analysis (Ramakrishna and Seshamani 1976) of mesospheric temperature data at Fort Churchill, Canada made both at day and night and the correlation of these with the K_p index revealing a marked difference between the day and night groups, the day time data giving positive correlation coefficients, while night time data gave negative coefficients. This finding points out unambiguously that mere comparison of western and eastern hemispheres data may not lead to any fruitful interpretation.

Analysis of data from 10 rocket launching stations for all seasons between 1965 and 1976 gave temperature averages in three stratospheric layers, *viz*,. 26-35, 36-45 and 46-55 km altitude (Angell and Korshover 1978). Accordingly the average cooling as the active sun (1968-1970) becomes quiet (1975-1976) for summer increases with altitude, for example, 4.5° C, 5 °C and 6° C in the layers 26-35, 36-45, 46-55 km, respectively. The combined station data involving all seasons and 3-year smoothing yield a 'western hemisphere' temperature decrease from solar maximum to minimum of about 3° C, 3.5° C and 4° C for the layers 26-35, 36-45 and 46-55 km, respectively.

Quiroz (1979) investigated the temperature data at two specific levels (35 and 50 km) during solar cycle 20 (1965-1977) taken at seven stations in the latitudes between 8° S and 64° N. His investigation has yielded values in the range $+0.7$ to $+0.9$, for the over-all correlation coefficient, between upper stratoshperic temperature and sunspot number, which are dependent on both altitude and degree of smoothing of the temperature data. The reported decrease in average temperature as sunspot number changes from maximum to minimum for summer is 5.5°C and 4° C at 35 and 50 km, respectively. Heath (1973) estimated a temperature increase at sunspot maximum of about 15° C in the 40-50 km region, and in the 20-30 km layer, the increase was only about 1° C.

According to Angell and Korshover (1978) the behaviour of the lower atmosphere is partly responsible for the long-range temperature variation seen in the higher stratosphere, and that the contribution from the lower atmosphere would be difficult to isolate. The increase in the temprature with sunspot number has been attributed to atmospheric absorption of solar EUV (190-912 A) in the altitude range 120-150 km (Ramakrishna and Seshamani 1973). It is highly likely that the variation in solar activity is an important factor in controlling the temperature in certain layers of the equatorial stratosphere and mesosphere.

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