CHAPTER 4

A SEARCH FOR A SOLAR CYCLE - TEMPERATURE RELATIONSHIP IN THE 25-60 km REGION OF THE WESTERN HEMISPHERE
4.1 REVIEW

Extensive investigations are available in the literature on the effect of a 11-year solar cycle in temperature variations in the stratosphere over the Western Hemisphere. Most of the earlier observational studies showed that there existed a strong relationship between temperature in the stratosphere and sunspot number. Garvin (1961) studied the balloonsonde-derived temperatures at 100, 50 and 30 mb altitude levels over a few American stations during 1951 to 1960, and found that the temperature of the stratosphere was influenced by the sunspot cycle. Investigation on the temperature variations in the 25-40 km region over Berlin (52.5°N) during 1959 to 1970, Schwentek (1971) showed a significant relationship between the winter-time temperature and sunspot number. In the analysis of temperature and wind variations in the tropical upper stratosphere and lower mesosphere during the equinoctial season, Fritz and Angell (1976) found no evidence of a dependence on solar activity in tropical latitudes.

Analysis of rocket data from ten stations between 1965 and 1976 have shown that the average cooling when the active sun (1968-1970) becomes quiet (1975-1976) for the
summer season increased with altitude (Angell and Korshover, 1978). Summer-time (June to August) rocketsonde-derived temperature data at 35 and 50 km levels for 1965-1977 at seven sites between 8°S and 64°N showed a strong correlation (+0.89) with sunspot number at both the levels, with greater temperature range (4.5 K) at 35 km (Quiroz, 1979). Naström and Belmont (1980) studied the influence of 11-year solar cycle on wind and temperature at radiosonde levels and concluded that the atmospheric responses to the solar cycle vary with longitude as well as latitude. Naujokat (1981) reported long-term variations in the stratosphere of the Northern Hemisphere during two sunspot cycles, 1957 to 1977 and suggested that the observed stratospheric changes at mid-latitudes are not directly linked to the solar activity alone, but other possibilities also present to influence the stratospheric circulation on a long time scale. Schwentek and Elling (1981) showed that at heights above the tropopause, 11-year solar cycle is a significant natural time-scale in the behaviour of the Earth's atmosphere particularly in winter.

These observational evidences that the stratospheric temperature directly depends on solar activity has also been theoretically supported by many research workers. Callis and Nealy (1978) described a plausible and potentially significant physical mechanism which may link the 11-year
solar cycle with the chemistry and possible dynamics of the stratosphere. According to them, during a solar cycle period, the concentration of minor constituents and the thermal structure may be altered significantly in the 20 to 50 km altitude range. Natarajan et al. (1981) showed that the temperature data computed from their theoretical model at 35 km agree well with the observed temperature data at this level reported by Quiroz (1979), and the calculated temperature variations at 50 km are larger than the observed ones at this level.

However, the results obtained from the following recent investigations on temperature variations associated with the 11-year solar cycle, contradict the earlier results. Angell and Korshover (1983) reported that even though a large cooling of the order of 3-5 K was observed between 1970 and 1976, only small temperature changes were seen between 1976 and 1979 in which period there was a 1.5 fold increase in the sunspot number compared to 1969. They concluded that the large cooling observed between 1970 and 1976 was not associated with the decrease in sunspot number. Schwentek and Elling (1984) have shown that no significant influence of the 11-year solar cycle (1958-1982) on stratospheric temperature over Berlin has been detected upto 35 km level. Garcia et al. (1984) found only small responses in ozone, temperature and zonal winds in the stratosphere when they
compared their theoretical results for solar cycle minimum and maximum conditions.

4.2 DATA AND ANALYSIS

Meteorological rocket launching stations which come under the US - meteorological rocket network, located within 10°W - 195°W longitude represent the Western Hemisphere. Five regular rocket launching ranges were chosen from this region for the present analysis. Two of these stations, viz., Kwajalein (9°N, 195°W) and Ascension Island (8°S, 14°W) are located in the tropics, while Cape Kennedy (28°N, 81°W), White Sands Missile Range (WSMR) (32°N, 106°W) and Point Mugu (34°N, 119°W) are in the mid-latitude region. Except Ascension Island all the other four stations are located in the Northern Hemisphere. Regular temperature data are not available for a solar cycle in the high latitude region. So the present analysis is limited to the tropical and mid-latitude region.

The US Dartsonde system used in the Western Hemisphere, employs 10 μm diameter bead thermistor sensors for temperature measurements and is suitable upto 60-65 km altitude. The accuracy of measurement is within 5 K at 55 km. However, above 60 km the correction to be applied to the measured temperature is so indefinite that the bead thermistor is not a good sensor for upper mesospheric temperature measurements. The advantage of the bead thermistor over the
wire thermometer (USSR sensor) is that the former is usually employed for measuring temperature during the sunlit hours. The number of observations in a month normally varies from 8 to 14 times.

Statistical monthly mean temperature data are available in published form from the High Altitude Meteorological Rocket Data (World Data Centre-A, Meteorology), North Carolina, USA, for the period 1965 to 1976. However, the data are updated through 1981 from magnetic tapes supplied by the U.S. Department of Commerce, NOAA, Environmental Data Service, USA. Thus the temperature data are available for a time period of 17 years (1965-1981) for the three mid-latitude stations, Cape Kennedy, White Sands Missile Range and Point Mugu; for 15 years (1967-1981) for Ascension Island and for 13 years (1969-1981) for Kwajalein.

In this chapter, analysis of temperature at every 5 km levels between 25 and 60 km region, for the five stations were carried out. Since the data above 60 km are not available regularly and also less reliable due to the limitation of the temperature sensors used, the present analysis were limited between 25 and 60 km. From the monthly mean temperature data, the annual mean values were calculated to minimise the seasonal and semi-annual fluctuations and to retain the long period trend. Annual
mean values of sunspot number as well as geomagnetic planetary index (Ap-index) were collected from the Solar and Geophysical Data (WDC-A, Boulder, Colorado, USA). Correlation and regression coefficients, regression line equation, lapse rate, etc., were calculated as explained in Chapter 2 of the thesis.

4.3 RESULTS

4.3.1 Temperature variations in the (25-60 km) region

A) **Tropics**: Annual mean temperature variations at each 5 km levels between 25 and 60 km region over Ascension Island (for the period 1967 to 1981) and Kwajalein (for 1969 to 1981) are as shown in Fig. 4.1. The periods of sunspot maximum (i.e., in 1968-1969 and in 1979-1980) and that of sunspot minimum (i.e., in 1975-1976) are shown by arrows in the upper part of Fig. 4.1. In the middle stratosphere over Ascension Island, lowest temperature was noted around solar minimum and highest temperature during the maximum. This trend changed in the upper levels of both the stations where the temperature was found to be decreasing rapidly from 1969 to 1976. In this period, Ascension Island showed a decrease of 20 K, whereas Kwajalein showed a fall of 13 K, at 60 km level. When the sunspot number increased rapidly with time after 1976, the temperature was not found to vary to that extent, as compared with the temperature decrease during the descending part of the cycle (1969 to 1976).
FIG. 4.1 ANNUAL TEMPERATURE VARIATIONS IN THE 25 - 60 KM REGION OVER THE TROPICS [—- ASCENSION ISLAND, —- KWAJALEIN]
During the ascending part of the cycle (i.e., from 1976 to 1980), a slight increase of 5 K was observed at 60 km over Ascension Island, and only 1.2 K at this level over Kwajalein. Within this cycle the lowest temperature was found in 1979 (the year of sunspot maximum) over Kwajalein, above the 50 km level.

From Fig. 4.1 it can be seen that higher temperatures were generally associated with the first solar maximum period (1968-1969). A steady decrease in temperatures was noted at all levels during the descending part of the cycle, where the magnitude of the cooling increased with altitude. During the second solar maximum period (i.e., 1979-1980) there was no significant rise in temperature in proportion to the increase in sunspot number. Thus a distinct solar-related temperature variations in the 11-year cycle was not found in any layer between 25 and 60 km over the tropics.

B) Mid-latitude: Temperature variations for a period of 17 years (1965-1981) over Cape Kennedy, White Sands Missile Range (WSMR) and Point Mugu are shown in Fig. 4.2. As in the case of tropics no solar cycle-related temperature variations were detected in any level of the atmosphere (25-60 km) of the mid-latitude. In the earlier part of the cycle (i.e., 1965-1969), the temperature showed a slight increase in the middle stratosphere, whereas there was a continuous decrease in temperature above 50 km. The cooling
FIG. 4.2 ANNUAL TEMPERATURE VARIATIONS IN THE 25 - 60 KM OVER MID-LATITUDE
trend in the upper levels was found to continue till 1976 (solar minimum) but for an interruption during the first solar maximum (1968-1969). Afterwards there was only a slight warming in second solar maximum (1979-1980) eventhough the sunspot number increased to 1.5 times that in the previous maximum.

At 60 km, there was a cooling of 17.6 K was noted during 1967 to 1979 over Cape Kennedy, while the cooling was 17.2 K and 18 K, respectively, over WSMR and Point Mugu for the period 1966 to 1976. A biennial type of temperature oscillation is noted at 40 km over WSMR during the entire period. Similar type of oscillations are seen at 35 km over Point Mugu, in the period 1969 to 1976. It may be noted that Angell and Korshover (1978, 1983) also reported such oscillations in their work.

An interesting phenomenon was noted in the temperature variations at Point Mugu. Here, the altitude at which the temperature minimum occurred is found to fall from 55 km down to 25 km with time during 1975 to 1977. On the other hand, the highest temperature was found during the first solar maximum at all levels below 50 km.

A comprehensive observation of the present analysis shows that there is a (more or less) decreasing trend in temperature at all levels within the period 1965 to 1981.
The magnitude of the rate of decrease of temperature was found to increase with altitude. The cooling found in the lower part of the mesosphere was quite higher, and it has no relation with the sunspot cycle. Since the present study over the Western Hemisphere is well limited upto 60 km level, it is not possible to arrive at any useful observation in the mesosphere. It will be rather interesting to study the temperature variations in the upper mesosphere during this period.

4.3.2 Sunspot number - temperature relationship

It is well-known that the seasonal variations of temperature in the tropical atmosphere can be negligible. Annual mean values of temperature were therefore taken for the study over the tropics. The temperature data for Ascension Island and Kwajalein were averaged to represent the temperature of the tropics in the WH. Such temperature data at 30,45 and 60 km altitude levels were plotted against the annual mean sunspot number, as shown in Fig. 4.3.

At 30 km, the temperature was found to have a rather good relationship with the sunspot number. Significant and positive correlation coefficient (+0.607) was obtained between the temperature $T$ and sunspot number $R$ at this level. The correlation between $T$ and $R$ was found to increase ($r_{TR} = 0.787$) if data on $R > 120$ are neglected. When $R > 120$, the temperature showed lower values, which deviated from the normal trend.
FIG. 4.3 A PLOT OF SUNSPOT NUMBER VERSUS ANNUAL MEAN TEMPERATURE IN THE TROPICS
At both 45 and 60 km levels, there are two distinct relationships between T and R (Fig. 4.3). When \( R < 120 \), the temperature showed a positive trend, whereas when \( R > 120 \), it showed very low values. In other words, the solar cycle has some influence on temperature when \( R < 120 \). The correlation coefficients estimated at 30 and 45 km were weak and insignificant, when the whole range of data was used, and became significant when the analysis was made with data excluding \( R > 120 \). The correlation coefficient thus increased from 0.268 to 0.549 at 45 km and 0.163 to 0.594 at 60 km. It is thus seen that good solar-temperature relation exists when the sunspot number is less than 120.

In the mid-latitude region, the seasonal variation in temperature is a dominant factor. Some of the earlier studies (e.g., Angell and Korshover, 1978; Schwentek and Elling, 1981, etc.) have found considerable differences between the summer-time and winter-time temperature variations in the mid-latitude site. So the present analysis of temperature versus sunspot number is separated into the analysis pertaining to winter and summer seasons.

The month of January is taken as the representative for winter and July for summer. The temperature data for Cape Kennedy, WSMR, and Point Mugu were averaged to get the mean temperature data of the mid-latitude region of the WH, for these two seasons. Figs. 4.4 a and 4.4 b are the plots.
FIG. 4.4a A PLOT OF SUNSPOT NUMBER VERSUS WINTER-TIME TEMPERATURE IN THE MID-LATITUDE
FIG. 4.4 b A PLOT OF SUNSPOT NUMBER AND SUMMER-TIME TEMPERATURE IN THE MID-LATITUDE
of the temperature versus sunspots number, at 30, 45 and 60 km for the winter and summer, respectively. It can be seen in Fig. 4.4 a that there is practically no relation existing between T and R at 30 km. With R <120 better correlation (+0.540) was found at 45 km. However, at 60 km the correlation was quite uncertain, because the temperature data was scattered without any specific variation with sunspot number.

The temperature in summer at both 30 and 45 km showed a negative variation with sunspot number when R <60 (Fig. 4.4 b). But when 60 <R <120 there exists a better relation between T and R. Very low temperatures were obtained at all the three levels when R >120. The temperature in summer at 60 km exhibited a better response to the sunspot number when its value ranges from 60 to 120.

In general, both the tropics and mid-latITUDE the temperature and sunspot number give a good relationship when the sunspot number registered a value between 60 and 120. A physical reasoning for such a relationship could not be arrived at present. It is clear from the sunspot number data that when R >120, it is associated with the second sunspot maximum, while when 60 <R <120 is associated with the first sunspot maximum. Many earlier studies at the first sunspot maximum (1968-1971) gave a better relation with the temperature of the stratosphere (Angell and Korshover, 1978; Quiroz, 1979). This provoked them to argue about the
existence of solar cycle related temperature variations in the stratosphere. On the other hand, the study when extended at the second maximum by the present analysis points out that no direct link exists between the sunspot number and the stratospheric temperature. Thus the changes in the stratospheric temperature observed by the earlier workers were not at all associated with sunspot activity within a 11-year cycle.

4.3.3 Heating/cooling associated with solar cycle

The temperature difference between the first sunspot maximum (1968-1969) and the sunspot minimum (1975-1976), denoted as $\Delta T_1$ and that between the second sunspot maximum (1979-1980) and the minimum (1975-1976), denoted as $\Delta T_2$ were calculated at all the 5 km levels in the 25 - 60 km region for the two tropical stations are shown in Fig. 4.5 (also listed in Table 4.1). In Ascension Island the magnitude of heating in these two periods remained the same upto 35 km level. $\Delta T_1$ was found to be decreasing in the upper stratosphere and increasing sharply in the lower mesosphere. At the same time the magnitude of $\Delta T_2$ gradually decreased with altitude. A cooling was observed during 1979-1980, the second solar maximum period. At 60 km level, the magnitude of $\Delta T_1 - \Delta T_2$ was found to be of the order of 14.2 K.
FIG. 4.5 VERTICAL PROFILES OF HEATING/COOLING IN TROPICAL STATIONS ASSOCIATED WITH SOLAR MAXIMA
Table 4.1

Heating/cooling associated with the first solar maximum (1968-1969), i.e. $\Delta T_1$ and with the second solar maximum (1979-1980), i.e. $\Delta T_2$ in degree Kelvin.

<table>
<thead>
<tr>
<th>Altitude km</th>
<th>Ascension Island</th>
<th>Kwajalein</th>
<th>Cape Kennedy</th>
<th>White Sands</th>
<th>Point Mugu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta T_1$</td>
<td>$\Delta T_2$</td>
<td>$\Delta T_1$</td>
<td>$\Delta T_2$</td>
<td>$\Delta T_1$</td>
</tr>
<tr>
<td>25</td>
<td>3.0</td>
<td>3.8</td>
<td>1.6</td>
<td>0.2</td>
<td>2.7</td>
</tr>
<tr>
<td>30</td>
<td>4.5</td>
<td>4.0</td>
<td>3.5</td>
<td>1.8</td>
<td>3.0</td>
</tr>
<tr>
<td>35</td>
<td>4.0</td>
<td>3.7</td>
<td>5.8</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td>40</td>
<td>1.4</td>
<td>3.2</td>
<td>4.1</td>
<td>2.4</td>
<td>4.0</td>
</tr>
<tr>
<td>45</td>
<td>1.9</td>
<td>1.7</td>
<td>5.2</td>
<td>0.5</td>
<td>4.3</td>
</tr>
<tr>
<td>50</td>
<td>3.7</td>
<td>0.5</td>
<td>6.2</td>
<td>-1.6</td>
<td>5.8</td>
</tr>
<tr>
<td>55</td>
<td>9.7</td>
<td>-0.3</td>
<td>6.1</td>
<td>-1.7</td>
<td>7.6</td>
</tr>
<tr>
<td>60</td>
<td>15.2</td>
<td>0.9</td>
<td>9.2</td>
<td>2.0</td>
<td>13.4</td>
</tr>
</tbody>
</table>
The magnitude of $\Delta T_1 - \Delta T_2$ showed a higher value over Kwajalein, where $\Delta T_1$ increases with height and attained the first maximum at 35 km level. Between 45 and 55 km level it remained the same and is of the order of 6 K. Above 55 km $\Delta T_1$ was found to be increasing sharply. On the other hand, $\Delta T_2$ increases at lower levels and reached its peak value at 40 km and thereafter decreases continuously. A definite cooling was noted during this period, well above 45 km level. It is worth to note that above 40 km level, the behaviour of $\Delta T_1$ and $\Delta T_2$ were more or less like mirror reflections even up to 60 km level. At 60 km the difference in $\Delta T_1$ and $\Delta T_2$ was 10.5 K, which is comparatively lower than that of the Ascension Island.

Similarly, $\Delta T_1$ and $\Delta T_2$ were calculated for the three mid-latitude stations and are shown in Fig. 4.6 and is also listed in Table 4.1. The nature of the vertical profiles of $\Delta T_1$ for the three stations are similar, but $\Delta T_2$ profiles are different. In Cape Kennedy a gradual and steady increase in $\Delta T_1$ value was found above 30 km. In the lower mesosphere it increased sharply, i.e., between 55 and 60 km, with a rate of 1.2 K/km. A sudden cooling of 6 K ($\Delta T_2$) was observed at 35 km. Afterwards $\Delta T_2$ almost remained constant with height. The difference between $\Delta T_1$ and $\Delta T_2$ at 60 km was about 12 K.

At Point Mugu there was a gradual increase in $\Delta T_1$ upto 55 km and sharp increase thereafter. The value of $\Delta T_2$
FIG. 4.6 VERTICAL PROFILES OF HEATING/COOLING IN MID-LATITUDE STATIONS ASSOCIATED WITH SOLAR MAXIMA
was negative at 35 km level, as in the case of Cape Kennedy, though less in magnitude. At the second solar maximum highest warming was found at 50 km level. At WSMR $\Delta T_1$ value increased slowly upto 45 km and at a faster rate thereafter. Over WSMR a cooling in $\Delta T_2$ was noted at 45 km whereas in the other stations it was at 35 km level. Above 45 km $\Delta T_2$ was found to be increasing with height, which is unique for WSMR when compared to a decrease in $\Delta T_2$ with height in the other stations of the WH.

Fig. 4.5 and Fig. 4.6 show that $\Delta T_1$ was positive in all levels between 25 and 60 km indicating a warmer atmosphere at the first solar maximum. But variations of $\Delta T_2$ were irregular. Eventhough, the sunspot number during the second solar maximum is 1.5 times higher in magnitude than that of the first solar maximum, the $\Delta T_2$ value did not show a relatively higher value to that of $\Delta T_1$. This is a further disagreement to the idea of direct influence of the solar activity on the temperature of the stratosphere.

4.3.4 Lapse rate variations

Lapse rate of temperature ($\Gamma$) was calculated at each 5 km levels between 25 and 60 km of the atmosphere during the periods of (i) first solar maximum (1968-1969), (ii) solar minimum (1975-1976) and (iii) second solar maximum (1979-1980), over the tropics as well as the mid-latitudes. In tropics (Fig. 4.7 a the vertical
FIG. 4.7 VERTICAL PROFILES OF LAPSE RATE VARIATIONS
distribution of $\Gamma$ during 1968-1969 shows a unique nature compared with the other two curves. Above 30 km the magnitude of $\Gamma$ during this period was much smaller than those for the other two periods. The lapse rate was negative in the stratosphere and the highest stable atmosphere was found at 35-40 km (where $\Gamma$ is highly negative). The stability of the atmosphere gradually decreases with height. The values during both the minimum and the second maximum exhibited almost the same type of variation in the entire atmosphere.

In the mid-latitude region, as seen in Fig. 4.7 b, the lapse rate during the first maximum and minimum periods showed similar variations up to 45 km. Above this level, the lapse rates during the second maximum and minimum were having similar variations. Highest stability of the mid-latitude atmosphere was also noted at 35-40 km region. A difference of 1 K/km was observed in the lapse rate at 60 km between the two maxima.

4.3.5 Solar and Geomagnetic effects on stratospheric temperature

An attempt has been made in this section to find if there is any combined effect of solar and geomagnetic activities on the stratospheric temperature. Mean upper stratospheric temperature was obtained by averaging the temperatures at all 5 km levels between 25 and 50 km. Mean upper stratospheric temperature variations in the tropics
and mid-latitudes during 1965-1981 were plotted and is shown in Fig. 4.8. Annual values of sunspot number and Ap-index (i.e., the geomagnetic planetary index, characterised by the geomagnetic activity) were also plotted. There was a peak in 1969 in the mid-latitude and correspondingly in 1970 in the tropics. Meanwhile both the R and Ap values increased from the minimum to the first maximum in 1968. R remained constant till 1970, while the Ap index showed a fall first and then remained constant till 1971. The temperature in both the tropics and mid-latitude decreased steeply during the descending part of the solar cycle and attained its lowest value in 1976, the year of solar minimum. Ap-index increased again and attained the peak in 1974 and decreased thereafter. Afterwards it again rised steeply in 1978 and further decreased to a second minimum in 1980. Meanwhile R was in its second maximum in 1979. During the ascending part (1976 to 1979) of the cycle, the temperature in the tropical stratosphere showed a second maximum, while in the case of mid-latitude temperature became low in 1979.

In the stratosphere over the tropics weak and insignificant correlations between temperature and both the solar and geomagnetic activity parameters. However, in the mid-latitude region, there was a significant and negative correlation (-0.586) between temperature and Ap-index, and
FIG. 4.8 STRATOSPHERIC MEAN TEMPERATURE IN THE TROPIES AND MID-LATITUDE AND THE VARIATIONS IN SUNSPOT NUMBER AND Ap-INDEX

[---TEMP. OF TROPICS, ----TEMP. OF MID-LATITUDE,
----------SUNSPOT NUMBER, ........... Ap-INDEX]
insignificant correlation with the sunspot number. From Fig. 4.8 it can be seen that only during the descending part of the sunspot cycle the temperature showed an in-phase relation with sunspot number and an out-of-phase relationship with Ap-index. During the other parts of the solar cycle the temperature of the stratosphere showed a good response neither to the sunspot number nor to the Ap-index, especially in the tropics. But in the mid-latitude region, the stratospheric temperature showed some negative relationship with the geomagnetic activity index (Ap) variations.

A plot of annual mean Ap-index versus temperature of the mid-latitude stratosphere (25-50 km) is reproduced in Fig. 4.9. Accordingly when the geomagnetic activity was lower the temperature was found to be higher. In other words, stratosphere became cooler during strong geomagnetically active period. The regression coefficient (i.e., the slope of the regression line) has a value of -0.315 K/Ap-index. This indicates that in the mid-latitude region, the stratospheric temperature has an out-of-phase relationship with Ap-index to a certain extent.

4.3.6 Mesospheric temperature variations

Monthly mean temperature data available upto the upper mesosphere are quite meagre and are not available for all the months in the WH. However, temperature data upto 85 km are available during the month of June both in
$T_c = b_T A_{n-\langle A \rangle} + \langle T \rangle$

$= -0.315 A_n + 250.6$

**FIG. 4.9** A PLOT OF $A_p$-INDEX VERSUS STRATOSPHERIC MEAN TEMPERATURE IN THE MID-LATITUDE
1976 and in 1979 for Cape Kennedy. For Point Mugu and WSMR, the data are available for 1976 and 1979 in the month of May and July, respectively, up to the upper mesosphere. The monthly mean temperature for the solar minimum (1976) and maximum (1979) for the three mid-latitude stations are shown for 25 to 85 km in Fig. 4.10.

Only Cape Kennedy registered a definite warming in the mesosphere during the solar maximum. Maximum warming of 17 K was found at 60 km as well as at 75 km region with none at 80 km. The other two stations did not show any convincing evidence of a mesospheric warming during the active period of the sun. WSMR exhibited a slight warming of the order of 2 K in the stratosphere, while Point Mugu showed a slight cooling in the middle mesosphere during 1979. From the present analysis it is difficult to draw any information on the existence of a definite relationship between the mesospheric warming and solar activity within the cycle.

4.4 DISCUSSION

The wavelength region of the solar spectrum which is important for the lower mesosphere and the stratosphere are of the following. The radiation in the Schumann - Runge bands (175 to 200 nm) can reach up to the stratopause, and its variability can therefore influence the entire mesosphere. The rate of photodissociation of molecular oxygen can vary
FIG. 4.10 MIDDLE ATMOSPHERIC (25 - 85 km) TEMPERATURE DISTRIBUTION DURING SOLAR MINIMUM (1976) AND SOLAR MAXIMUM (1979)
by about 15-20 per cent over the 11-year solar cycle (Brasseur and Solomon, 1984). The variability of Herzberg continuum (200 to 242 nm) which penetrates into the stratosphere, is considerably weaker. Since an important part of the photodissociation in this spectral region come from the atmospheric window near 200 nm has a maximum variation of about 15 per cent. The solar flux at wavelengths beyond 250 nm including the Huggins band, which are responsible for the formation of ozone in the stratosphere, shows only very small variations with the solar cycle (Brasseur and Solomon, loc. cit.). Dütch (1979) has also concluded that no valid statistical correlation has yet been detected between total ozone and solar activity.

It is a well known fact that the solar flux $F$ varies with 11-year solar cycle, but it considerably depends on wavelength with greater variations at wavelengths less than about 200 nm. Measurements of the solar constant for the last two decades showed that its value did not vary much in this period (Fröhlich, 1977; Brusa and Fröhlich, 1982). As Schwentek and Elling (1981) suggested, the expression for the integrated flux of solar radiation

$$ S_0 = \int_0^\infty F(\lambda) \, d\lambda, $$

can be splitted as

$$ S_0 = \int_0^{190 \text{ nm}} F(\lambda) \, d\lambda + \int_{190 \text{ nm}}^{300 \text{ nm}} F(\lambda) \, d\lambda + \int_{300 \text{ nm}}^\infty F(\lambda) \, d\lambda \quad \ldots \quad 4.1 $$

where the first term on r.h.s. can further be split up into
a number of integrals according to various relationships between solar spectral regions and spectral lines and their corresponding constituents in the earth's atmosphere.

Expression 4.1 can be schematically represented as in Fig. 4.11 to explain the consistency of solar constant and the relation between sunspot number and stratospheric temperature during the 11-year solar cycle.

\[ S_o = \text{E.U.V.} + \text{U.V.} + \text{VISIBLE I.R.} \]

Fig. 4.11

Fig. 4.11 represents the solar flux variation at different wavelength regions of the solar spectrum during the active phase of the sun. In this period the solar flux in the E.U.V. (\(\lambda<190 \text{ nm}\)) increases significantly. The solar flux in the near ultra-violet, (i.e., \(190 \text{ nm} < \lambda < 300 \text{ nm}\)) shows only very small variations during this period. At the same time, the solar spectrum in the visible and infra-red regions (i.e., \(\lambda > 300 \text{ nm}\)) may show a decrease in its value, however it be smaller. Thus within a solar cycle, the solar flux at shorter wavelengths change markedly, which may be compensated by a change in the solar flux in the visible and infra-red regions. So when we consider the entire spectrum of the solar radiation, it can be seen that the integrated flux of radiation, \(S_o\) should not change considerably, within a solar cycle. This, however, explains the near-constancy of the solar constant.
As seen in Fig. 4.11, the variation of the solar spectrum in the 190 nm to 300 nm, which is significant to the stratosphere, is very small within a solar cycle. Thus it seems that during a 11-year solar cycle there should not be a large variation in the spectral range 250 nm to 300 nm which is mainly involved in the formation of the stratosphere. Thus the temperature variations observed in the stratosphere may not directly be associated with the variation in the sunspot cycle. Therefore, in modelling the temperature profile of the stratosphere, a possible influence of solar activity as represented by sunspot number, may be ruled out.

However, it is possible that the stratospheric region can be affected by changes that taking place in the upper mesosphere and the thermosphere during a solar cycle. Normally, high solar activity levels are accompanied by the increased injection of energetic particles such as aurorae and solar proton events. Such events can increase atmospheric ionisation and produce Joule heating and chemical perturbations (Horne, 1980). These process can influence the dynamics and chemistry of the thermosphere, and possibly also those in lower altitudes through long transport (Brasseur et al., 1983).

The lower levels of the mesosphere, in all the five stations, showed a large cooling during the descending...
part (1969 to 1976) of the solar cycle. It is evident from the present study that such a cooling was not associated with the decrease in sunspot number. The physical reason for such a large degree of cooling observed in the lower mesosphere over the Western Hemisphere is not understood.