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On Perturbations in the Thermal Structure of Tropical Stratosphere & Mesosphere in Winter

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The M-100 rocket temperature data for 11 winter periods have been examined to evaluate the winter characteristics of stratosphere and mesosphere over Thumba (lat., 8°32'N; long., 76°52'E). The temperature changes in the moddle atmosphere over Thumba associated with the high-latitude stratospheric winter warming (STRATWARM) events have also been studied for 8 cases. At Thumba, the winter is characterized by the annual temperature maximum in the mesosphere and annual temperature minimum in stratosphere. Superimposed on the seasonal changes, warmings in the mesospheric region and cooling in the stratospheric region are observed typically during the high-latitude STRATWARM events. The cooling effect of the STRATWARMs is observed to extend down to about 10-km level in the troposphere over Thumba during the peak of very strong events. Hence almost the whole of the middle atmosphere at this tropical region undergoes thermal changes in association with high-latitude stratospheric warming.

1 Introduction

The thermal structure of tropical as well as subtropical stratosphere of both hemispheres seems to be influenced by the dynamics of the winter time stratospheric warmings at the high-latitudes. The global extent of the high-latitude stratospheric winter warmings (STRATWARMs) was first observed by Fritz and Solves[1] for the radiance data obtained from Nimbus-3 satellite. They have shown that STRATWARMs are accompanied by stratospheric cooling over the tropics and sub-tropics of both the hemispheres. Even though more evidence was later reported in this regard from both rocket and satellite data[2-4], no systematic study on this feature has been carried out so far.

Even though there is some evidence to show that warming may occur in the equatorial stratosphere and mesosphere[2,5,6], the equatorial-counterpart of STRATWARM has not been studied systematically so far. Lack of appreciable work in this regard is mainly because of the scarcity of regular upper atmospheric data for equatorial regions. The weekly M-100 rocket launchings from Thumba (lat., 8°32'N; long., 76°52'E), since Dec. 1970, have provided ample data to look into certain aspects of this phenomenon. The present study deals with two aspects of the thermal structure of the middle atmosphere, i.e. on the thermal changes in the middle atmospheric region over Thumba in association with 8 known events of winter time stratospheric warmings of the high-latitude, and on the seasonal characteristics of stratospheric and mesospheric region over Thumba in winter. The main results are presented briefly in this paper.

2 Data and Method of Analysis

Temperature data[7] obtained from the weekly (on Wednesday) launchings of M-100 rockets from Thumba have been utilized for this study. Data are available for every 1-km interval in the altitude region of 10-80 km. The upper limit of the data is around 75-80 km. Tungsten-Rhenium wire of 40 μ dia is used as the temperature sensor in M-100 rockets. The rms errors in the temperature measurements are 1.6°C at 40 km, 5.9°C at 60 km and 11°C at 80 km (Ref. 7).

Data for 11 winters during the period of 1970/71 to 1981/82 (excluding 1974/75 winter where there were no launchings) have been utilized. The Dec.-Feb. period is taken as the winter period. A 10-yr mean is first calculated for 1-km intervals of altitude. The temperature deviations ($\pm\Delta T$) in the individual weekly data from this mean are then calculated to quantify the warmings/coolings described in the text. Fig. 1 represents a typical ΔT profile thus obtained for 4 Jan. 1974. In the above method of estimating ΔT, any fixed bias in the temperature measurement does not cause any problem, because only deviations from a mean value are considered.

The sampling interval of one week in the M-100 data places a limitation for evaluating the coupling effect of STRATWARM over Thumba during the different stages of STRATWARM events. Another limitation is that small temperature variations cannot be taken into account considering the errors of measurements. Because of these limitations the present study of the equatorial effect of high-latitude STRATWARMs is carried out for the period pertaining to the peaks of STRATWARMs only.

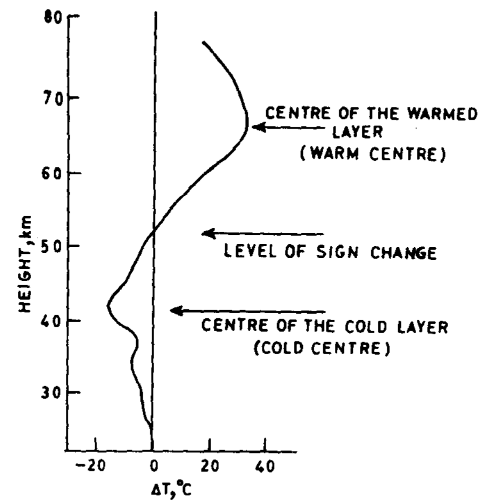

Fig. 1—A typical ΔT profile of 4 Jan. 1974 illustrating warm centre, cold centre and level of sign change

3 Results

3.1 Temperature Changes in Middle Atmospheric Region over Thumba during Mid-winter Stratospheric Warmings of High-latitude

The extent of the coupling effect of STRATWARMs over Thumba has been evaluated by considering 8 known events of STRATWARMs pertaining to the years 1970/71-1976/77 (except 1974/75), 1980/81 and 1981/82. Table 1 presents the temperature changes observed at various altitudes in the middle atmosphere over Thumba. Salient features of the perturbed thermal structure for the different regions are given below.

(i) The lowest tropopause temperature pertaining to the winter period coincide with the peak of STRATWARMs irrespective of major or minor warmings in 6 cases. In the two winters (1973/74 and 1980/81) the cooling has been found to penetrate down to 10-km level. The peak of STRATWARMs in these two cases has also been accompanied by the annual minimum temperatures for the upper tropospheric layer (10-18 km) over Thumba. It should be noted that the warming of 1980/81 stands as the strongest event since rocket observation began in 1956 (Ref. 10). The 1973/74 warming was also very strong and comparable with the 1980/81 event[10].

(ii) Temperature for the whole stratosphere decreases during the peak of both major and minor STRATWARMs. Mostly the wintertime lowest temperatures for the different levels in stratosphere over Thumba coincide with the peak of major warmings. The cooling that accompanied the two very strong events of 1973/74 and 1980/81 were so intense that the temperatures during these periods achieved the annual minimum temperatures for the various levels in the stratosphere.

(iii) In all the 8 events, mesospheric warming has

Table 1—Temperature Changes of Different Layers of Middle Atmospheric Region over Thumba during the Peak of STRATWARMs

Date of STRATWARMs peak	Nearest M-100 data availability	Nature of STRATWARMs	Observed temperature deviations ΔT (in °C) from the long term mean at different altitudes (in km): Troposphere 10	Tropopause	Stratosphere 20	25	30	35	40	45	Mesosphere: Warm centre height (h) km	ΔT at h °C
7 Jan. 71	6 Jan. 71	Major[8]	5	0	−2	0	−5(**)	−6*(**)	−12**	−13**	73	15
15 Feb. 72	17 Feb. 72	Minor[8]	0	−5*(**)	−2	−1	−5(**)	−5(*)	−3	−6	72	15
28 Jan. 73	31 Jan. 73	Major[8]	2	−11*(**)	−14**	−7(**)	−10**	−12**	−20**	−10(**)	70	12
28 Feb. 74	27 Feb. 74	Major[8]	−15**	−12**	−11**	−13**	−7*(**)	−2	−8*(**)	−11**	63	22
29 Dec. 75	31 Dec. 75	Minor[8]	−9	−14(**)	—	0	0	0	−10(*)	−5	63	14
5 Jan. 77	5 Jan. 77	Major[9]	−6(*)	−5(*)	−5	−6*	—	−3(*)	−7*	−10*	72	18
1 Feb. 81	28 Jan. 81	Major[10]	−12**	−12**	−11**	−14**	−9**	−15**	−15*(**)	−8	72	25
1 Feb. 82	3 Feb. 82	Strong[9] minor warming	−4	−13**	−7*	−11*	−4*	−6*	−10*	12*	66	20

Note: * and ** denote the lowest temperature for the winter (Dec.-Feb.) and the whole year (Dec.-Nov.), respectively.
(*) and (**) denote a difference of maximum 3°C for lowest temperature for the winter and the whole year, respectively.
*(**) denotes the lowest temperature for the winter, but differs maximum of 3°C for the lowest temperature for the whole year.

been observed over Thumba with the warm centre being around 70 km. Average temperature deviation at the warm centre was 19°C. The most intense warming ($\Delta T = 25$°C) coincided with the most intense STRATWARM.

A recent study by Schoeberl and Strobel[11] on the numerical simulation on STRATWARM shows an associated weak warming ($\leqslant$5K) in the low-latitude mesosphere. But they could not corroborate their results due to lack of observational evidences. In this regard the present Thumba results provide the first observational evidence for this theoretical prediction.

Fig. 2(a) depicts the time variation of the stratospheric winter temperatures over high-latitude[12] for 1973/74 and Fig. 2(b) is the same for the mesospheric temperatures over Thumba. The peak mesospheric warming over Thumba (on 2 January) coincided with a warming pulse in the high-latitude region. The STRATWARM peaked on 28 February and this coincided with a warming pulse in the mesosphere over Thumba. Same kind of thermal behaviour has been observed in the remaining years also. So the tropical mesospheric warmings accompany warmings in the high-latitude stratospheric region. Because the high-latitude stratospheric warmings are accompanied by cooling in mesosphere above[3,13], it is reasonable to anticipate cooling in the high-latitude mesosphere in association with the warmings in the equatorial mesosphere.

Fig. 3(a) depicts the vertical temperature profiles during the peak of 1980/81 STRATWARM and Fig. 3(b) the mean of the eight ΔT profiles at Thumba corresponding to the days nearest to the peak of

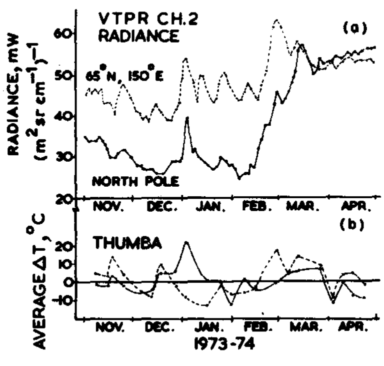

Fig. 2—(a) VTPR channel 2 radiance traces during 1973/74 winter at (65°N, 150°E) and North Pole[12] [Analysed values of radiance in mW (m^{2}sr cm^{-1})$^{-1}$ are given in Y-axis [The radiance measured in this channel is a measure of the mean temperature at 100-5 mb]; and (b) Time-scale variation of temperature deviation for 70-80 km layer (solid curve) and 60-70 km layer (dotted curve) from November to April of 1973/74 over Thumba

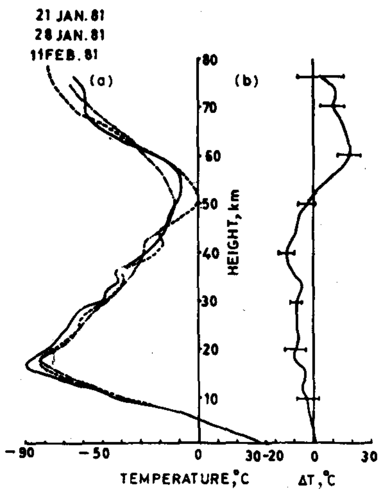

Fig. 3—(a) Temperature profile at Thumba during the peak of 1980/81 STRATWARM event, and (b) the mean of the eight ΔT profiles of Thumba corresponding to the day nearest to the peak of 8 STRATWARMs considered for comparison (Standard deviation for every 10-km levels are also shown.)

STRATWARMs for the 8 winters considered for comparison. The cold region is characterized by disturbed thermal behaviour as it is seen from the inversion levels in the cold region [Fig. 3(a)]. Thus all the eight ΔT profiles exhibit a wavy nature which causes the formation of cooling centres at two or three different levels. The wavy structure is apparent in the mean ΔT profile [Fig. 3(b)] also. Mostly one of the cooling centres is found around the stratopause region. Hence the startopause at Thumba gets extremely cold (~ -14°C) during the peak of STRATWARMs. The stratopause region during these occasions is also found to undergo isothermal layers formation with an average vertical thickness of 5 km.

As STRATWARMs are accompanied by cooling in the stratosphere and upper troposphere, and by warming in the mesosphere, temperature variation takes place in opposite direction in stratosphere and mesosphere over Thumba during the STRATWARMs and in this case the level of sign change lies around 52 km [Fig. 3(b)].

The record warming at 30 mb ($\sim$20 km) level during the 1980/81 STRATWARM has also been found to be coincided with the record cooling at different levels of the lower and middle stratospheric region over Thumba observed since the rocket observation started in 1970. During this STRATWARM the major warming began during the last ten days of January and reached its peak in the upper stratosphere on 1 February and in the middle stratosphere a few days later[10]. The cooling over Thumba has also undergone a similar downward propagation (Fig. 4). Such a feature of the associated downward propagation of the cooling layers is not found in a clear-cut manner in the other years.

3.2 General Thermal Patterns of Stratosphere and Mesosphere in Winter

Various aspects of the thermal structure of troposphere, stratosphere and mesosphere over Thumba have been discussed earlier[6,14-16]. Fig. 5 shows the variations of the monthly means from the long term means for every 10-km thick layer of the atmosphere. It can be seen that the seasonal pattern consists of warming for mesosphere and cooling for stratosphere in the winter months of December, January and February.

3.2.1 *Mesospheric Warming in Winter*— Superimposed on the seasonal warmings temperature fluctuations of short period are observed in all the 11 winters. Typical cases of 4 winters are shown in Fig. 6 which presents the temperature deviations in the individual weekly data from the long term means for the 10-km thick layers of stratosphere and mesosphere. All of the deviations are not above the r.m.s error of ± 11°C applicable for the upper mesosphere. However, the consistency of '+' sign for ΔT for most of the time clearly indicates a general warming of the equatorial mesosphere. General features of the mesospheric warmings are given below.

(i) Warmings of varying intensity appear during the entire winter period. The intensity of warming reaches its maximum generally in mid-winter (January). The occasion when the mesosphere attains its maximum temperature is considered as the peak of warming. The exact date of the peak of warming cannot be confirmed because of the weekly data sampling interval. The details of the peak of warmings observed from the data for 11 winters are given in Table 2. This peak of the winter warming is also the occasion for the maximum phase of the annual temperature variations in the mesosphere. (Hereafter the 'mesospheric winter warming' will be referred to by the abbreviated form 'MESOWARM'.).

(ii) The warm centres during the warmings are observed at different altitudes in the mesosphere. But it is around 72 km during the peak of MESOWARM (Table 2).

(iii) Occurrence of double warming layers is another feature of MESOWARM and in this case the upper one is found to be more intensive. Typical cases of double warming layers are presented in Fig. 7.

(iv) The long term variations of the upper mesopheric (60-80 km) warming temperatures for the

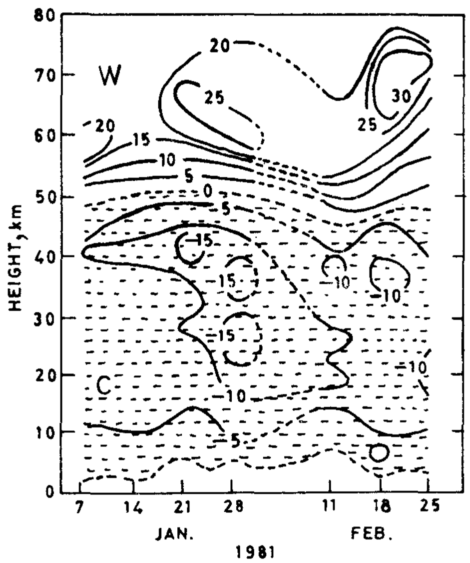

Fig. 4—Time-height cross-section of temperature at Thumba during the 1980/81 STRATWARM period (Dotted portion represents cooling. Isotachs of ΔT for 5°C are drawn.)

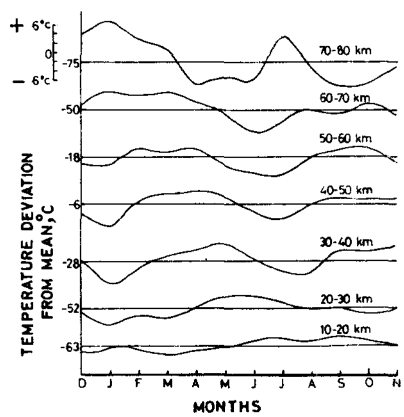

Fig. 5—Plots of mean annual variation of ΔT for the 10-km average layers (from 10 to 80 km) deviations in the monthly means from the long term means

Table 2—Details of the Peak of MESOWARMs over Thumba

Year	Date of MESOWARM peaked	Warm Centre		
		Height km	ΔT °C	Average ΔT for 10 km around the warm centre
1970/71	13 Jan. 71	74	38	36
1971/72	19 Jan. 72	78	29	25
1972/73	17 Jan. 73	76*	26	23
1973/74	2 Jan. 74	76	32	24
1975/76	31 Dec. 75	72	14	11
1976/77	27 Jan. 77	63	28	25
1977/78	4 Jan. 78	67	33	30
1978/79	24 Jan. 79	73	36	32
1979/80	27 Feb. 80	63	37	35
1980/81	18 Feb. 81	72	31	28
1981/82	16 Dec. 81	70	27	23

* .he highest value of ΔT is observed at 76 km where the rocket data terminate. So the warm centre could not be confirmed.

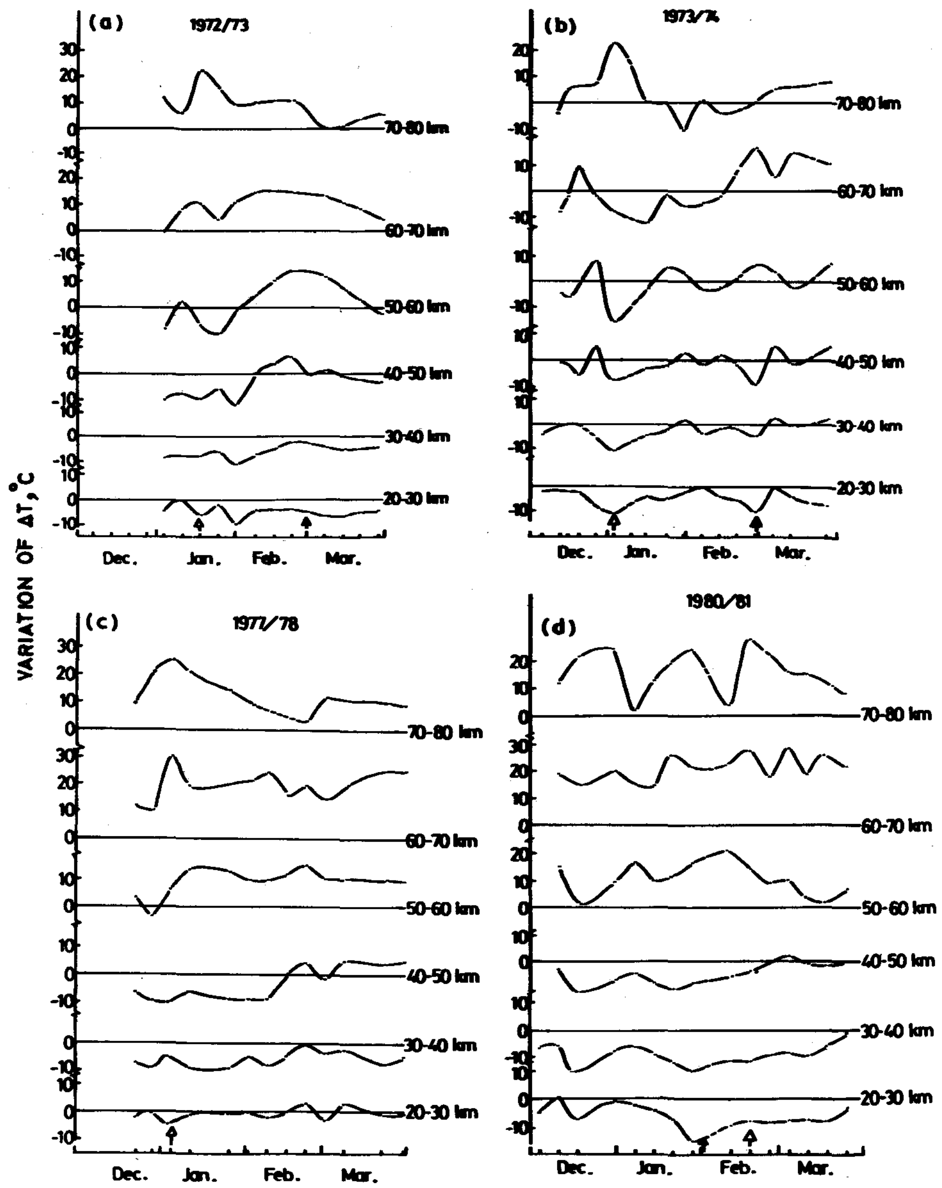

Fig. 6—Time-scale variation of temperature deviations (ΔT in °C) for the 4 winters (The dates corresponding to the peak of MESOWARMs are shown with arrows. The shaded arrows represent the dates corresponding to the peak of STRATWARMs. The small vertical lines in X-axis indicate the dates of rocket observations.)

period 1971-83 indicate a broad in-phase change with the level of solar activity in its 11-year cycle. Fig. 8 represents the inter-annual variation of ΔT and the mean temperatures of January which is considered as the representative month for winter. In the 60-80 km layer there is a temperature difference of 30°C between the years of solar maximum and minimum. The lower mesospheric temperatures do not show a similar solar cycle variation in a clear-cut manner. As far as the stratospheric layers are concerned there exists no such long term variation. A correlation study on the mesospheric temperatures and the sunspot numbers has been recently reported[17].

3.3 Perturbed Thermal Structure of Stratosphere during MESOWARMs

Fig. 1 shows the ΔT profile which corresponds to the peak of MESOWARM (on 4 Jan.) for 1973/74 winter. The warm and cold centres represent the levels of maximum warming and cooling respectively. In Fig. 1 the warm centre is at 67 km. Below this, the intensity of warming decreases and reaches the nodal point at around 52 km below which the phase of temperature variations reverses, which means warming in mesosphere and cooling in stratosphere. This feature observed in 1970/71 winter has been discussed earlier[5].

The mean of the eleven ΔT profiles pertaining to the

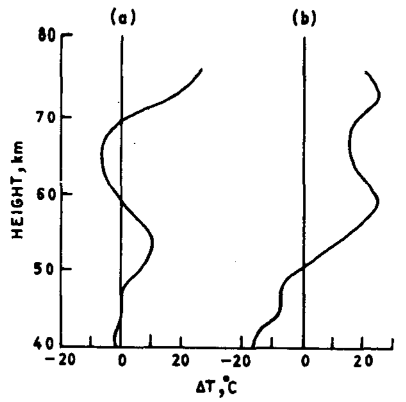

Fig. 7—Typical ΔT profiles showing double warming layers during MESOWARM [(a) on 20 Jan. 1971, the upper warm centre is above 75 km and the lower one is at 65 km; and (b) on 11 Jan. 1978, the warm centres are at 73 km and 59 km.]

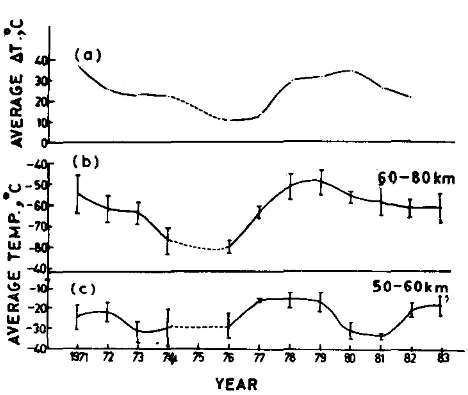

Fig. 8—(a) Inter-annual variation of the ΔT value around the warm centre pertaining to the peak of MESOWARMs; (b) the inter-annual variation of the mean January temperatures for the layers 60-80 km; and (c) for 50-60 km

peak of MESOWARMs for the 11 winters is presented in Fig. 9. The salient features of the temperature variations in stratosphere during MESOWARM are given below. These features are based on the mesospheric warming events in which ΔT at the warm centre exceeds 20°C.

(i) The centres of warm and cold layers are separated by an average vertical distance of 26 km.

(ii) The region of sign change is around 53 km. This level varies in phase with the variation of the height of the warm centre (Table 3).

(iii) The cold centres during the peak of MESOWARM are generally found to be around the stratopause region and, as a result of this the stratopause gets extremely cold (~ -14°C) during the peak of MESOWARMs.

During MESOWARMs, temperature increases in mesosphere and decreases in stratosphere. Hence the thermal changes associated with MESOWARMs are

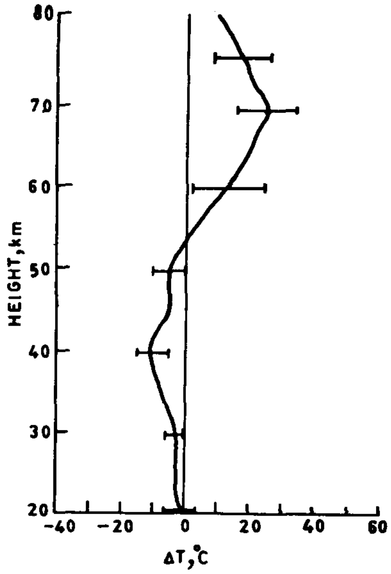

Fig. 9—Mean of the eleven ΔT profiles pertaining to the peak of MESOWARMs for the 11 winters (Standard deviation for every 10-km levels are also shown.)

not confined to mesosphere alone but extend to stratosphere also. The temperature changes during STRATWARMs have been found to be extended up to upper mesosphere and hence Labitzke[13] has suggested that the word "warming" is misnomer if the whole region of stratosphere and mesosphere is considered. It is rather temperature changes of opposite sign, taking place at the same time at different levels. A similar type of explanation is suggested for the MESOWARMs also.

3.3.1 *The Winter Stratosphere*—As mentioned earlier the whole stratospheric region undergoes cooling in winter. The upper stratospheric warming which occurred in 1970/71 winter[5] seems to be an exceptional event, because temperature increase of the same order could not be observed in any of the remaining years. In all the years (except 1970/71) the annual maximum in the seasonal temperature variation of stratosphere takes place during periods other than winter. But it is in winter that the stratosphere achieves its annual minimum temperatures. As already stated in the above sections, the lowest temperatures in the various layers of stratosphere occur in association with either the peak of MESOWARMs or of STRATWARMs. Hence the occurrence of the extreme cold stratosphere over Thumba in winter reflects the presence of warming either in the mesosphere above or in the stratosphere of the high-latitude.

4 Conclusions

(i) The general thermal pattern of the stratosphere and mesosphere over Thumba in winter is the warming

Table 3—Relative Variation of the Level of Sign Change with the Variation of the Warm Centre in Mesosphere

[Based on the Warming Events Where ΔT at the Warm Centre Exceeds 20°C. Average Values of Height Are Given]

Warm centre at layers km	Height of the warm centre km	Level of sign change km	Height of the cold centre km	Vertical distance between warm and cold centre km	No. of obser-vations
60-70	64	50	40	24	20
70-80	73	54	45	28	12
at the peak of MESOWARMs	71	52	43	28	9

in mesosphere and cooling in stratosphere. Superimposed on the seasonal warming mesospheric layer undergoes temperature fluctuations of short period indicating the occurrence of warming events in the mesosphere.

(ii) STRATWARMs are accompanied not only by cooling in the stratosphere over Thumba but also by warming in the mesosphere. The cooling even penetrates to about 10-km level in the troposphere in association with the peak of very strong STRATWARMs and such occasions are also characterized for the periods of annual minimum temperature for the upper troposphere and different layers of the stratosphere over Thumba. In short, almost the whole of the middle atmosphere over Thumba responds to STRATWARMs.

Various aspects of the coupling effect of STRATWARMs over Thumba, like the exact extent of coolings/warmings and the time constant in the interaction between the two latitudinal regions could not be studied mainly because of the limitations in the M-100 data sampling interval. Various features of the MESOWARM phenomenon are also yet to be investigated. The linkage that involves STRATWARM and STRATWARM event associated warming at equatorial mesosphere has yet to be established. However, equatorial sources like equatorial waves cannot be ruled out. For any comprehensive investigation on the various aspects of this phenomenon a planned rocket data collection with more frequent intervals of sampling are definitely required.

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