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High-Level Warmings Over a Tropical Station

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ABSTRACT—Examination of the available rocketsonde data for the tropical station, Thumba, India, has shown that warmings, less pronounced than in the case of middle- and high-latitude stations but of noticeable magnitude, and coolings of similar magnitude occurred in the mesospheric and upper stratospheric levels during the period, December 1970–March 1971. This was the only winter period when observations were made at the station during all of the 4 mo. No prominent change in wind has been observed in association with the warnings, however.

The maximum warming observed over a period of 1 week in the upper stratosphere was 26°C at 45 km. The upper mesosphere had been subjected to a continuous process of warming for over 3 weeks in December–January 1971 during which period the temperature rose by 48°C at 70 km. There is no definitive indication that these warmings were of the propagating type. However, they appear to have moved in the vertical at a rate of 3–5 km/day.

The temperature behavior of the lower stratosphere (50 mb) and the upper troposphere (300 mb) in the winter of 1970–71 was different than that which was observed in the preceding 2 winters.

1. INTRODUCTION

Since the discovery of the midwinter stratospheric warming by Scherhag (1952), studies of the phenomenon, including recent ones (Quiroz 1969, Johnson 1969, Miyakoda et al. 1970), have referred to the stratosphere/mesosphere of the middle and high latitudes only. Documented evidences of warming over the Tropics have been lacking. A study of radiance measurements from the Nimbus 3 satellite (Fritz and Soules 1970) has shown that the happenings in the stratosphere of the higher latitudes are related to those of the Tropics. They found that the stratospheric warmings in the higher latitudes of the winter hemisphere were accompanied by simultaneous cooling in the stratosphere of the Tropics and of the summer hemisphere. Also, the atmosphere appears to act like a standing wave in which the amplitudes of the temperature changes are larger in the middle and high latitudes of the winter hemisphere than in the Tropics and the summer hemisphere.

If warmings over the high latitudes are accompanied, as found from radiance measurements, by simultaneous cooling over the Tropics, it is anticipated that coolings over high latitudes, if any, may be accompanied by warmings over the Tropics. Since we know that intense coolings do occur over the high latitudes (Quiroz 1969) following warmings, we, therefore, anticipate that midwinter warmings also occur over the Tropics. With a view to testing the validity of these inferences, we have critically examined the rocketsonde data that are available from the limited number of rocket launchings made during the periods, March 1970 and December 1970–March 1971, from the Thumba, India, Equatorial Rocket Launching Station (8°32′15″N, 76°51′48″E). We find that occasionally warmings do indeed occur in the mesospheric and upper stratospheric levels at this tropical station. The evidences obtained to this effect and the characteristics of the warmings are presented.

2. DATA CONSIDERED

Values of temperature and wind as obtained from the British and Soviet launchings at Thumba were made available to the Indian Institute of Tropical Meteorology by the courtesy of the Thumba Equatorial Rocket Launching Station. The British made nine launchings during the 1-mo period, March 1970, and the Soviets made 17 launchings during the 4-mo period, December 1970–March 1971. Temperature and wind profiles were prepared from these data and were used in this study.

The method of temperature sensing with the British rocketsonde and the accuracy of the observations have been described by Clark (1965). The temperature sensor is made from drawn tungsten wire, 13.5 μm in diameter. With this sensor, temperature at 60 km can be measured to within 3°C in daylight and 1°C at night. The temperature sensor used on the Soviet rocketsonde is a tungsten-rhenium wire, 40 μm in diameter. The probable mean square error in determining the atmospheric temperature with this sensor is 3°C at 40 km, 5°C at 50 km, and 7°–10°C at 60–80 km.

3. ANALYSIS AND RESULTS

There is no set criterion for defining "warming." In middle and high latitudes, the amplitude in some major cases of warmings ranged from 23° to 80°C and the thickness of the warm layer ranged from 20 to 25 km (Quiroz 1971). The warmings occurred largely within time intervals of 10 days or less. Remembering that any warmings over the Tropics would be less intense than those over the middle and high latitudes, we considered in the present study that, if temperature increases 20°C or more (over an atmospheric column of thickness of about 5 km) between consecutive observations within 7–10 days of each other, the event is suggestive of the occurrence of warming. However, absence of such a feature does not insure that warming has not actually occurred between observations.

Identification of Warming

Of the nine launchings in March 1970 (the dates of which were spread nearly uniformly over the period), temperature data are available up to 60 km in seven cases and to 55 km in all cases. Temperature profiles relating to any of the nearest pairs of dates during this period did not show a temperature rise exceeding 11°C at any level, suggesting no evidence of warming at Thumba in March 1970.

For 16 of the 17 launchings in the December 1970–March 1971 period, temperature data are available up to 80 km; data are available up to 75 km in all 17 cases. The dates of launching were distributed nearly equally over the 4-mo period. Temperature profiles relating to certain nearest pairs of dates during this period show increases of 20°C and more over layers more than 5 km thick in the regions of the upper stratosphere/mesosphere, suggesting that warmings did occasionally occur at high levels over this equatorial station in the winter of 1970–71. Three instances of warming, one each for the upper stratosphere, the lower mesosphere, and the upper mesosphere, are considered below.

Warming in the upper stratosphere. The temperature profile for December 23 showed higher values than that of either the preceding date (December 16) or the following date (December 30) of observation, between 35 and 50 km (fig. 1A). The soundings on these three dates were made at night, each at about the same time. The maximum warming indicated was 26°C at 45 km. The thickness of the warm layer ($\Delta T \geq 20°C$) exceeded 4 km.

With this warming at the stratopause level on December 23, there was a simultaneous intense cooling ($\Delta T = -28°C$) at the upper mesospheric levels (65–70 km). The warmest stratopause temperature in the winter of 1970–71 (+17°C) occurred on December 23, the date of the warming.

From the profiles of December 23 and 30, one can see that a temperature increase exceeding 20°C over a depth of more than 5 km occurred in the upper mesosphere on December 30. This warming in the upper mesosphere is discussed later.

Warming in the lower mesosphere. In the layer from 45 to 65 km, the January 20 temperature values were higher than those of either the preceding date (January 13) or the following date (January 30) of observation (fig. 1B).[1] Note that the sounding on January 13 was made at night whereas those on January 20 and 30 were made during the day. Since the time of observation is not uniform, we cannot ignore the possibility that some of the temperature variations observed during this period are a result of tidal variation, a phenomenon that has been demonstrated at low latitudes (Smith et al. 1968). The maximum warming observed during this period was 37°C at 55 km (cf. profiles of January 13 and 20 in fig. 1B). The thickness of the warm layer exceeded 5 km. Intense cooling ($\Delta T = -44°C$) at the 80-km level was associated with this warming. This cooling at 80 km subsequently intensified until the lowest temperature for the season (−94°C) was reached. The temperature at 80 km fell 61°C within a period of about 2 weeks.

Warming in the upper mesosphere. The major warming observed at Thumba appears to have started between Dec. 16 and 23, 1970 and continued until sometime between Jan. 13 and 20, 1971. The period from Dec. 16, 1970, to Jan. 13, 1971, in which four launchings were made, showed continuously increasing temperatures in the upper mesosphere leading to a maximum temperature rise of 48°C over a period of 3 weeks at 70 km. The temperature profiles for Dec. 23 and 30, 1970, and Jan. 6 and 13, 1971, commencing from 50 km, depict these features (fig. 1C). All of the soundings on these dates were made at the same approximate time of night, thus ruling out the possibility that the observed temperature variations during this period of major interest were a result of tidal variations. The warm layer showing a temperature rise of 30°C or more within the first 2 weeks was 15 km thick and extended upward from 60 km. The warm layer showing a temperature rise of 45°C or more within the 3-week period of the warm spell was 12 km thick and extended upward from 68 km.

For comparison purposes, an example showing no marked temperature rise at any level is presented (fig. 1D). The profiles of February 17 and 24, and March 3 show no temperature rises of more than 9°C at any level between 20 and 70 km. These soundings were made at the same time of night.

Maximum Amplitude of Warming

Since the data are available at intervals of about a week in each month during December 1970 to March 1971, we attempted to determine the maximum amplitude of the warming for each month at each level. For this purpose, the observed temperature increase (at each level on every date of observation) from the lowest value reported within the preceding 1-mo period has been considered as the amplitude of warming. The maximum amplitude values thus obtained for each month are shown in figure 2.

The maximum amplitudes for December could not be ascertained in this manner for the obvious reason that data were not available for the previous month. Warmings appeared over larger thicknesses during the first 2 of the 3 mo investigated. The maximum amplitudes of warming are 51°C at 65 km in January, 30°C at 80 km in February, and 38°C at 75 km in March. Although the amplitude in March was higher than that in February, the vertical

[1] Two temperature profiles were reported for Jan. 20, 1971. However, only the earlier one (0430 GMT) was available for this study.

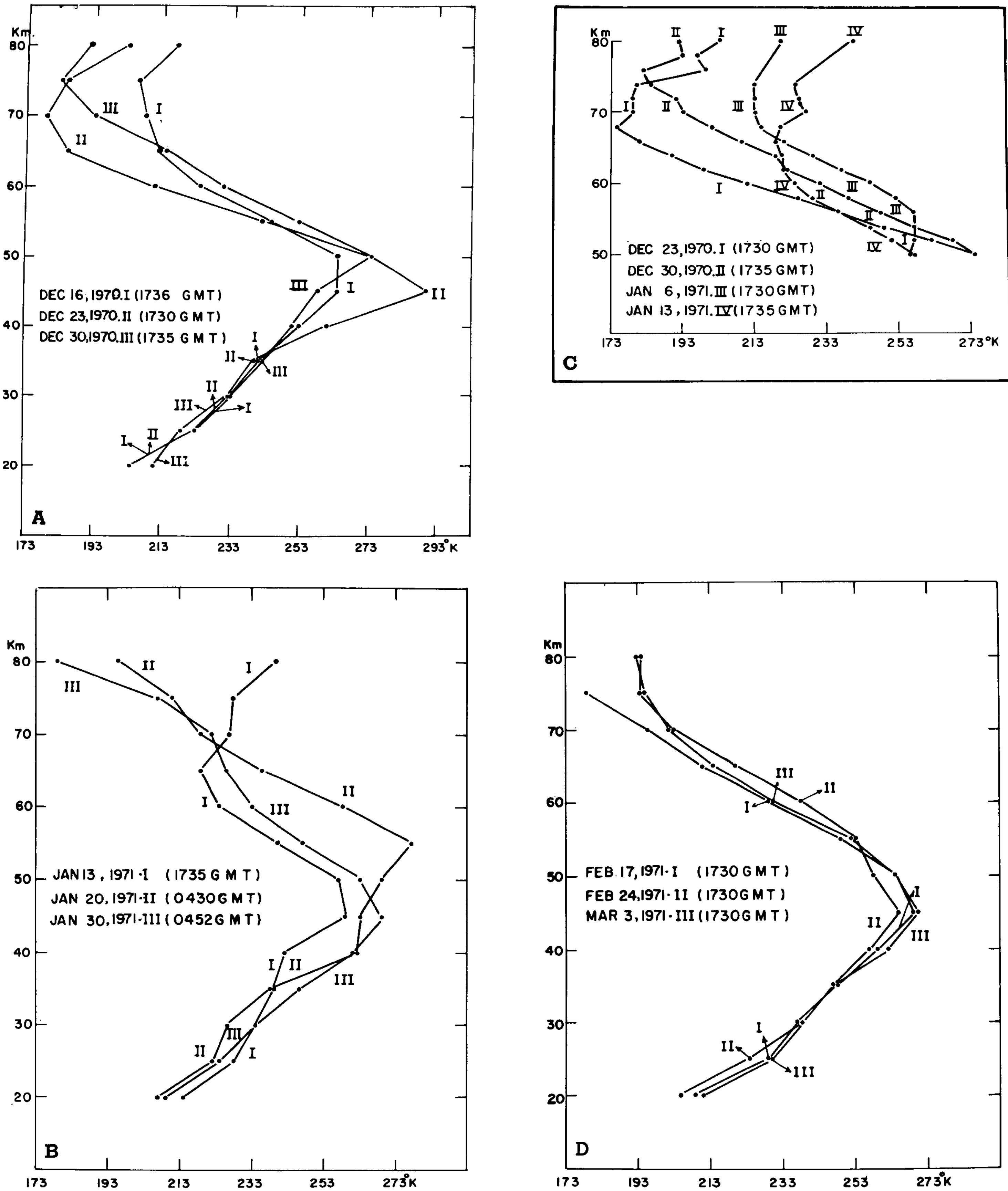

FIGURE 1.—Examples of (A) warming in the upper stratosphere (compare I and II at 45 km) and concurrent intense cooling in the upper mesosphere (compare I and II at 70 km), (B) warming in the lower mesosphere (compare I and II at 55 km) and concurrent intense cooling in the upper mesosphere (compare I and II at 80 km), (C) warming in the upper mesosphere (compare I, II, III, and IV at 70 km), and (D) no marked warming.

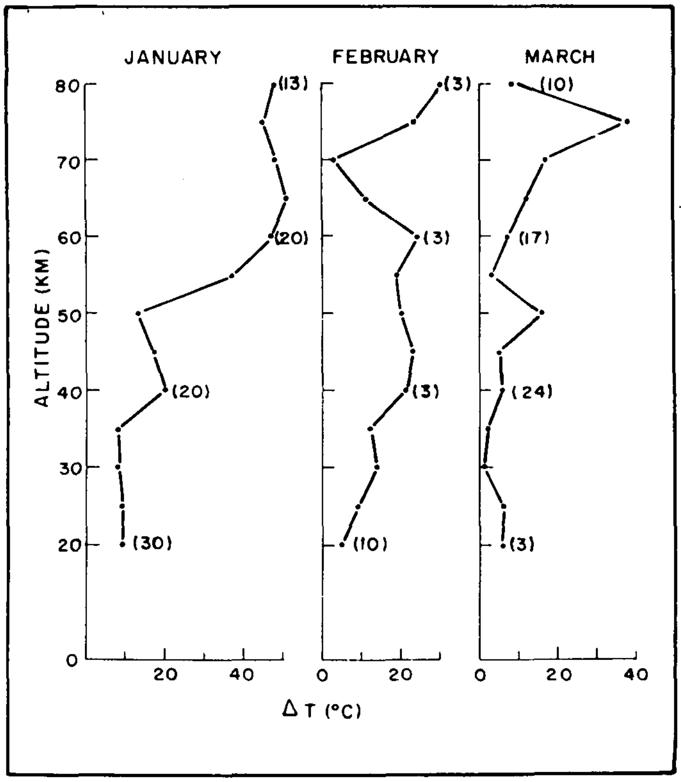

FIGURE 2.—Maximum increase in temperature in the given month over the lowest value reported within the preceding 1-mo period. Numbers in parentheses indicate dates of occurrence of maximum warming amplitude at the indicated altitude.

extent of the warming was much smaller. Figure 2 shows that warmings were most intense as well as most extensive in the vertical in the earlier part of the winter.

Course of Warming

Examination of the data has not provided a definite pattern of movement for the warming. Considering the three sets of soundings separately, as in figures 1A–1C, we see that the regions showing the highest and lowest temperatures have not shifted vertically from their mean positions by more than 5 km, suggesting that the warm and cold anomalies remain almost stationary with respect to height. However, if we make use of all the available data and construct a time section of temperature (fig. 3A), we note that the warming in the upper mesosphere on January 13 could be connected with the warming observed below 50 km on December 23. In figure 3B, we see a similar pattern in the isolines of temperature departure from the U.S. Standard Atmosphere (COESA 1966) for 15°N. But, if the dates of occurrence of the maximum amplitude of warming at different levels as marked in figure 2 are taken into account, it is difficult to overlook the inference that the warming commences, in general, in the mesosphere and propagates subsequently to lower levels. The analyses made, therefore, indicate that no unequivocal statement can be made about the sense of propagation of the phenomenon on the basis of the present limited data.

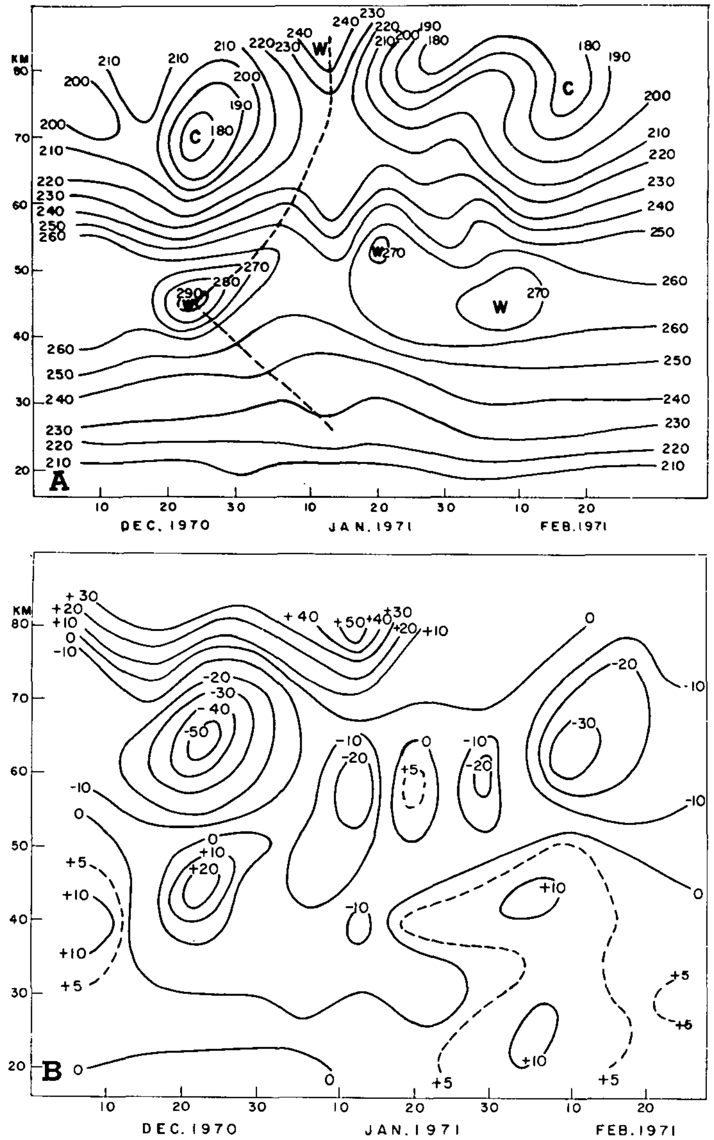

FIGURE 3.—Time section of (A) temperature for Thumba and (B) temperature departures from the U.S. Standard Atmosphere (COESA 1966) for 15°N.

Rate of Propagation of the Warming

If we assume that the warming phenomenon does in fact move systematically, we may examine the rate of propagation in the vertical suggested by the data. If, for example, we assume that the rise in temperature at 45 km on December 23 is due to the effect of the warming indicated at 80 km on December 16 (fig. 1A), the rate of propagation of the warming was 5 km/day between 80 and 45 km. Adhering to a similar line of reasoning, the observed rise in temperature at 20 km on December 30 suggests that the warming phenomenon propagated between 45 and 20 km at the rate of 3.6 km/day. However, if the rise in temperature at 65 km on December 30 is due to the warming indicated at 45 km on December 23 (there is no reason for not considering this opposite way, too), the rate of propagation of warming was about 3 km/day

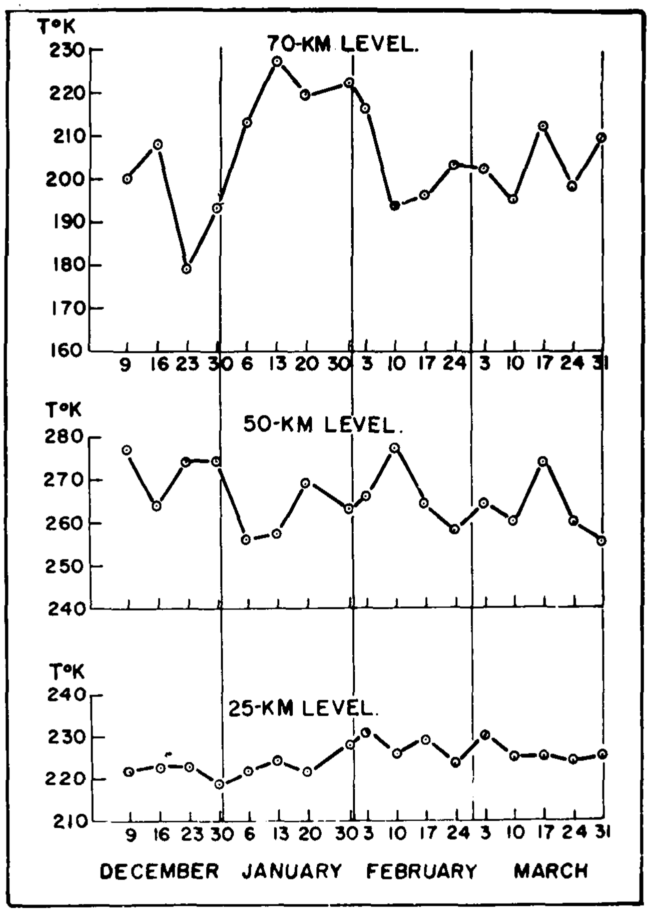

FIGURE 4.—Temperatures at indicated levels on all rocket launching dates during the period December 1970–March 1971.

between 45 and 65 km. These values compare favorably with the value of 3 km/day found by Finger and Teweles (1964) for the propagation of warming events in middle latitudes.

Concurrent Changes in Temperature at Different Levels

In the warming instances cited in December and January (figs. 1A, 1B), cooling was observed simultaneously at higher levels. To examine the interdependence of the temperature changes in the lower stratosphere, upper stratosphere/lower mesosphere, and upper mesosphere, we constructed time sections of temperature for the 25-, 50-, and 70-km levels for the period December 1970 to March 1971 (fig. 4). The temperature fluctuated least in the lower stratosphere (25 km) and most in the upper mesosphere (70 km); the ranges of the fluctuation observed at the 25-, 50-, and 70-km levels were, respectively, 12°, 22°, and 48°C. While the temperature values at 25 and 50 km appeared to be independent (correlation coefficient is −0.2, not significant at the 10-percent level), those at 50 and 70 km are seen to be interdependent (correlation coefficient is −0.63, significant at the 1-percent level) during the period December–February. The antiphase variation in temperature observed at the latter two levels is consistent with what has been noted earlier, namely, that warmings in

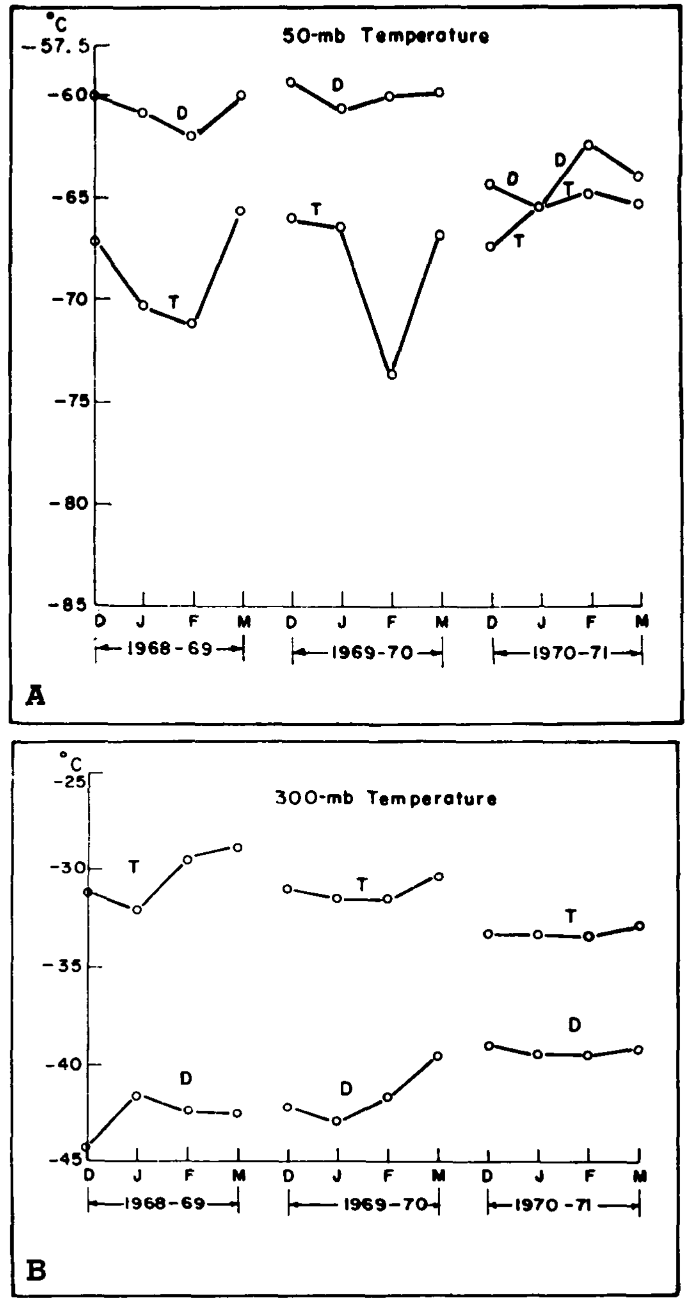

FIGURE 5.—Monthly mean (A) 50-mb and (B) 300-mb temperatures, as obtained from routine radiosonde data, for Trivandrum (T) and Delhi (D).

the upper stratosphere/lower mesosphere have been associated with simultaneous coolings in the upper mesosphere.

Temperature Behavior in Low Levels

The conventional radiosonde data from Trivandrum, India (8°29′N, 76°57′E), which is very close to Thumba, and from Delhi, India (28°35′N, 77°12′E), which is separated from Thumba by about 20° of latitude, have been examined for the 3 successive winters commencing in 1968–69. This was done to determine whether or not radiosonde data would suggest any special temperature behavior at low levels (lower stratosphere and upper troposphere) during the period 1970–71, when rocketsonde

TABLE 1.—*Monthly mean 50- to 100-mb thickness values (m) at Trivandrum and Delhi, India*

Year	Dec.	Jan.	Feb.	Mar.	Mean
		Trivandrum			
1968–69	4077	3916	3954	3908	3964
1969–70	3965	3935	3973	3993	3967
1970–71	4056	4014	4050	4054	4043
		Delhi			
1968–69	4255	4237	4231	4202	4231
1969–70	4297	4194	4207	4200	4225
1970–71	4162	4162	4134	4131	4147

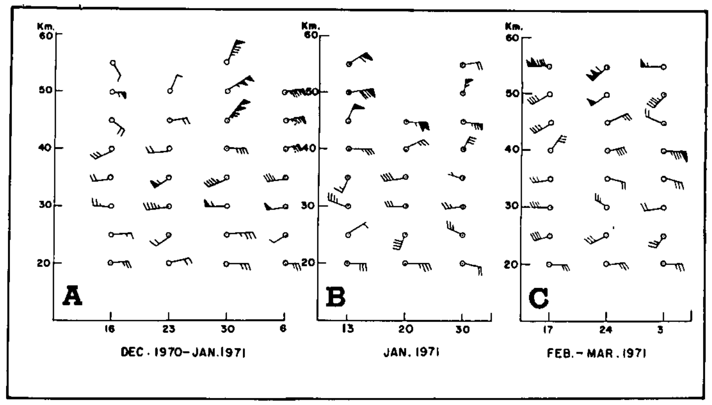

FIGURE 6.—Winds as reported at Thumba on the given dates. Full bars indicate 10 kt and flags, 50 kt.

data indicated high-level warmings at Thumba, and, if so, the meridional extent of such behavior.

Temperature analysis (lower stratosphere and upper troposphere). The monthly mean 1200 GMT temperatures for the 50-mb (lower stratosphere) and 300-mb (upper troposphere) levels are shown in figures 5A and 5B. At Trivandrum, the winter of 1970–71 was the warmest of the 3 winters considered in the lower stratosphere (fig. 5A). Further, February, which showed the minimum temperature of the preceding 2 winters, was the warmest month in the winter of 1970–71. Temperatures at Delhi, however, were much lower during 1970–71 than during the previous 2 winters. The meridional temperature difference, which is positive, ranged from 5.7° to 13.6° C in the preceding 2 winters. However, during the winter of 1970–71 when high-level warmings are definitely known to have occurred over one of the stations, namely Trivandrum (Thumba), the meridional temperature difference at low levels was least and ranged only from 0° to 3°C. Further, it was in January of 1971, when the indicated warming was maximum, that the magnitude of the meridional difference reached its minimum value of 0°C.

In the upper troposphere (fig. 5B), the temperatures at Trivandrum were lower and those at Delhi were higher in the winter of 1970–71 than they were during the preceding 2 winters; this is the opposite of what was noted in the lower stratosphere. The meridional difference in temperature, which is negative in contrast to the positive difference observed at the 50-mb level (because the tropopause at Delhi is lower than that at Trivandrum), again reached a minimum during 1970–71. The above findings point out that the temperature behavior of the lower stratosphere and upper troposphere in the winter of 1970–71 was different from what it had been in the preceding 2 winters.

Thickness analysis (lower stratosphere). The 1200 GMT monthly mean thickness values of the 50- to 100-mb layer for the winter of 1970–71 are examined and compared with the 2 preceding winters at Trivandrum and Delhi (table 1). The 1970–71 thickness values at Trivandrum (Thumba) were generally larger (average difference about 80 m) than those of the previous 2 yr. The minimum thickness value obtained during 1970–71 is higher than the highest value obtained during the preceding 2 yr, if December 1968 is not considered. However, the opposite is true for Delhi. The maximum thickness value obtained at Delhi during 1970–71 is lower than the lowest value obtained in the preceding 2 yr. The above analysis points out that the lower stratosphere at Trivandrum (Thumba) was definitely warmer in the winter of 1970–71 than in the preceding 2 winters. The lower stratosphere at Delhi was, on the contrary, colder.

Wind Reversal in the Lower Mesosphere

An examination of the Thumba rocket wind data, which are available concurrently with temperature, revealed no noticeable changes in wind on warming occasions with the exception of the December 23 sounding. On that occasion, the wind in the lower mesosphere became exceptionally weak from the east. However, an examination of the winter period as a whole revealed that the wind in the region of 45–55 km in the first half of the winter was different from that in the second half. We found that the wind was more often easterly in the first half and westerly in the second half. To illustrate this feature, we constructed wind profiles (figs. 6A–6C) for the dates already considered in figures 1A–1D.

In December (fig. 6A) and January (fig. 6B), the easterly component was dominant between 45 and 55 km; whereas in February–March (fig. 6C), the westerly component was dominant. These features are consistent with what is known about the semiannual wind cycle near the stratopause in the Tropics (Webb 1966) and do not suggest a specific connection with the observed warming.

4. DISCUSSION

Maximum warmings of 51°C over a period of a month during December 1970–January 1971 and of 37°C over a period of a week during January 1971 became evident at mesospheric levels over tropical station Thumba. Warmings of lesser magnitude occurred in stratospheric levels also. Major cooling events occurred in December and January, and these were more intense than the major warmings in those months.

The occurrence of more intense warming in the first half of the winter period (December and January) and the occurrence of cooling in the upper mesosphere concurrently with warming in the stratosphere, as have been definitively indicated at Thumba, are features also commonly reported with stratospheric/mesospheric warmings at middle- and high-latitude stations. In the present study, the maximum thickness of the warm layer was 15 km. Considering that this value applies to the altitude region of at least a 20°C temperature increase, we feel that this overall warm layer thickness compares favorably with the values cited for middle and high latitudes by Quiroz (1971). There are, however, certain differences between the warmings over Thumba and those reported over the middle- and high-latitude stations. Some of the differences are indicated as follows:

1. Whereas strengthening of the wind field and or wind reversal from westerly to easterly, due to development in or movement into the vicinity at stratospheric levels of an anticyclonic center, has been commonly reported in association with warmings in middle and high latitudes, such changes in wind were not observed over Thumba. This suggests that the mechanisms responsible for the warmings in the two cases could be different.
2. No marked warmings have been observed at Thumba in the lower stratosphere. In contrast, however, the warmings observed at middle- and high-latitude stations are often of larger amplitude and located at lower levels. As an extreme case, it may be noted that at one of the northernmost stations, Heiss Island, U.S.S.R. (81°N), the reported temperature increase was as high as 85°C and the height at which it was located was as low as 32 km (Quiroz 1969).
3. There are also differences in the temperature structure in the mesosphere. The marked wavelike temperature structure observed in the winter soundings at the high-latitude stations (Theon et al. 1967) is conspicuously absent in the soundings at Thumba.

It has been hypothesized that the circulation changes that produce sudden warming events in low levels at high latitudes may originate near the mesopause over the tropical winter hemisphere (Webb 1966). It is of interest to know, therefore, whether there were any warming events at high latitudes during the period corresponding to the warming events at Thumba. Indeed, a major warming did occur in high latitudes in late December 1970 to early January 1971 as noted by Quiroz (1971) and Labitzke (1972). Also, a reversal of polar circulation had taken place at the 10-mb level by about Jan. 18, 1971 (Labitzke 1972). The present study, which helps point out the definite occurrence of warming over a tropical station at higher levels during the period December 1970 to January 1971, supports the concept that the midwinter stratospheric warmings observed in lower levels at high latitudes may be associated in some manner with warmings at higher levels in the low latitudes of the winter hemisphere. As no other information of this nature is available at present, data from more years will have to be examined before definitive conclusions become possible.

Three facts are apparent. First, of the 3 consecutive winters considered, temperatures over Trivandrum were the highest and those over Delhi were the lowest for the respective stations in the lower stratosphere during the winter of 1970–71. Second, there was a small but definite increase in the thickness values (about 80 m) in the lower stratosphere at Thumba during 1970–71. Third, there was an anomaly in the meridional difference of temperature during that period. These facts suggest the following:

1. The warmings that were observed at Thumba in the upper stratosphere/mesosphere in the winter of 1970–71 and the temperature rise indicated in the lower stratosphere during the same winter could have a common cause.
2. Warmings at Thumba, if any, in the other 2 winters would not have been as marked as they were during 1970–71.
3. The warmings observed in 1970–71 would have been limited to within 20° meridionally. Further, the simultaneous occurrence of a colder troposphere (300 mb) and warmer stratosphere (50 mb) at Trivandrum during the winter of 1970–71 suggests that there could be an association between high-level warmings and tropospheric events in the Indian Tropics. The existence of such a possibility at high latitudes was first suggested by Miyakoda (1963) who found correspondence between the warming in the stratosphere and cooling in the troposphere.

As already stated, the observed cooling events have been more intense than the warmings in the mesosphere at Thumba. The maximum amplitude of cooling, 61°C at 80 km, was reached over a 2-week period from Jan. 13, 1971 (fig. 1B). This feature, in light of what has been pointed out by Fritz and Soules (1970), does suggest occurrence of simultaneous warmings over some high-latitude stations at lower levels, and this conjecture by the authors is supported by the recent findings of Quiroz (1971) and Labitzke (1972).

5. CONCLUSIONS

This study has suggested that the tropical mesosphere and stratosphere are also subject to a similar but less pronounced type of warming as the mesosphere and stratosphere of middle and high latitudes. There is, however, no definitive indication whether the warmings discussed in the present study are stationary or moving.

It has been evident in the case of warmings noted in the middle and high latitudes that the temperature maxima are dynamically induced. In the absence of any knowledge of the upper stratospheric circulation in the tropical Indian region, it cannot be determined whether the warmings at Thumba were the result of such dynamical causes or due to something entirely different. It may be noted, however, that, according to the warming criterion adopted in the present study, major circulation effects may not necessarily be expected on the occasions of warming. With a layer of warming only 5 km thick, large pressure changes may not occur from hydrostatic considerations. In any case, single-station analysis does not provide enough information for describing the influence of temperature changes on the meridional pressure gradient and, therefore, on the circulation. It is hoped that conventional radiosonde ascents, when improved to furnish data more systematically from higher levels than at present, will be of value in this regard.

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