Mausam, (1983), **34**, 3, 303-308

551.515.2 : 551.510.52

Heights of tropopauses in some tropical cyclones over the Indian areas

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(*Received 6 October 1980*)

सार — उष्णकटिबंधीय चक्रवाती झंझाओं के विकास के विभिन्न चरणों में उनके ऊपर की क्षोभसीमा की ऊंचाइयों के परिवर्तन का भारतीय क्षेत्र में बने तीन विभिन्न चक्रवाती झंझाओं के परिपेक्ष में अध्ययन किया गया है। अध्ययन से पता चलता है कि जब चक्रवाती भ्रमिल काफी ऊपर उठकर समतापमंडल में प्रविष्ट करता है तब चक्रवाती या प्रचंड चक्रवाती झंझा के ऊपर के तापमान के गिरने से क्षोभ सीमा उपर उठ सकती है फिर वह (*i*) पूर्वी द्रोणी के तापमान में वृद्धि से नीचे आ सकती है और (*ii*) क्रोड के इर्द-गिर्द परिधीय प्रतिचक्रवात में बदल सकती है।

ABSTRACT. Variation in the heights of tropopauses above tropical cyclonic storms in different stages of their evolution has been studied in the care of three different cyclonic storms formed in the Indian region. It was found that the tropopause may rise with a fall in temperature above a cyclonic or severe cyclonic storm when the cyclonic vortex extends sufficiently high into the lower stratosphere. It may sink with a rise in temperature (*i*) over an easterly trough and (*ii*) may undulate in the peripheral anticyclone surrounding the core.

1. Introduction

Koteswaram (1967), in his studies of hurricane CARLA of 1961, Dora of 1964 and Cleo of 1964 at the time of their striking the coast of USA when they are most intense observes, "The tropopause bulges upward and is coldest near the hurricane core, the bulge being more prominent in intense hurricanes than in weak ones". Plessing and Mukherjee (1978) during their study with the "International Monsoon-77" data observed that the tropopause came down at the depression stage during the formation of a cyclonic storm in the Arabian Sea. They ascribed it, after Palmen (1956), to subsidence in the troposphere above the divergence level and also in the lower stratosphere during the deepening process of the tropical storm. Ranjit Singh (paper under publication) in his study of a premonsoon cyclonic storm formed near Calcutta in June 1971 observed that the tropopause came down accompanied by a rise of temperature in the event of an upper easterly trough above a depression in the formation process of a cyclonic storm (similar to Plessing and Mukherjee). It went up with a fall in temperature above the central region of a cyclonic storm (similar to Koteswaram). These are the available few studies made on the variation of heights and temperatures of tropopauses over cyclonic storms. The present study extends to a few other cyclonic storms in the Indian region, *viz.*, the cyclonic storm of September 1971 (Tripathi & Saxena 1975), and cyclonic storm of August 1974 (Ranjit Singh — paper under publication). All the three cases inclusive of June 1971 cyclonic strom have been discussed in this paper.

2. Definition and data presentation

The tropopause is defined according to the WMO code F. No. 35 for upper air data. Two tropopauses were noticed on 00 GMT of 3 June 1971, otherwise only one tropical tropopause was observed over the Indian sub-continent in the three cases which have been studied. The tropopause heights both in millbars and geopotential metres (gpm) and temperatures in degree centigrade (°C) for radiosonde stations located nearest to the centres of these cyclonic stroms, for 00 GMT and 12 GMT have been presented in Tables 1-3. To study the changes in heights and temperatures of the neighbouring pressure levels in the troposphere and lower stratosphere, the time sections of geopotential heights and

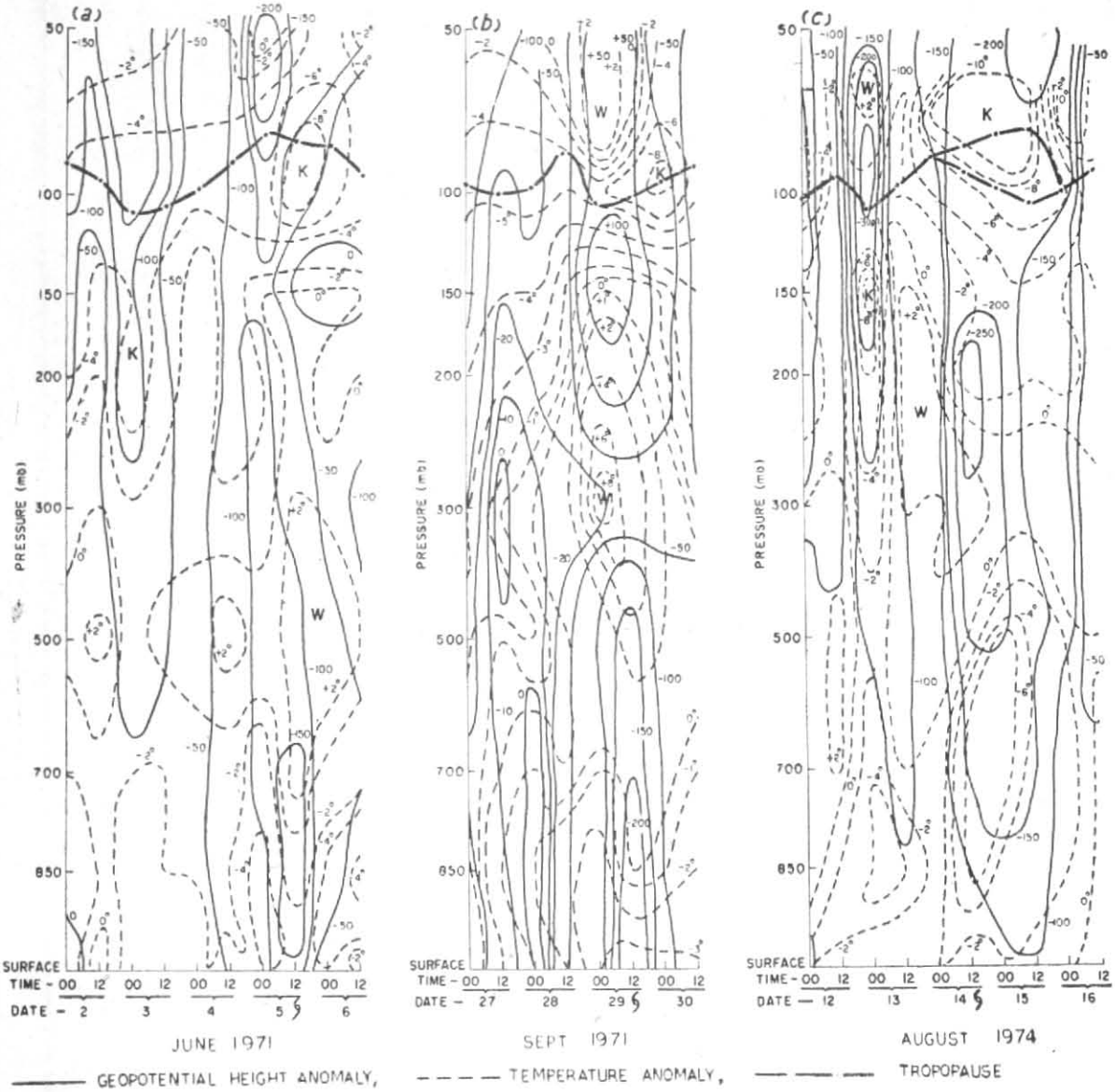

Fig. 1(a-c). Vertical time section of Calcutta for 00 and 12 GMT of (a) 2-6 June 1971, (b) 27-30 September 1971 & (c) 12-16 August 1974

temperature anomalies from their average values for 20 years (1951-70) for the standard pressure heights at station have been prepared and discussed in all the three cases. The tropopause height variation has been shown on them by the dash-dot curve by plotting the pressure height values. The tropopause surface charts corresponding to the timings of signification variation in the height have also been prepared and presented alongwith, giving synoptic maps.

3. Case-I : Cyclonic storm of June 1971

Table 1 shows the heights (in mb and gpm) and temperatures of tropopause surface over Calcutta from 00 GMT of 2 June to 12 GMT of 6 June. The observations of 12 GMT 4th when the system intensified into a cyclonic storm and 12 GMT of 5 June when the cyclonic storm lay very close to Calcutta to its east are missing, as the ascents terminated before reaching the tropopause height on these days. Fig. 1 (a) gives the vertical time section of height and temperature anomalies for standard isobaric levels extending upto 50 mb, the top level to which the normal values are available. The tropopause surface is depicted by dash-dot curve.

The tropopause height was observed to fall by 17 mb (1040 gpm) and temperature to rise by 2 deg. C (compared to the previous 12 hours

TABLE 1

Tropopause height and temperature observations over Calcutta — June 1971

Date	2		3		4		5		6	
Time (GMT)	00	12	00	12	00	12	00	12	00	12
Tropopause										
Pressure height (mb)	090	094	111 049	105	099	—	081	—	085	094
gpm height (in units of ten metres)	1723	1705	1601 2081	1640	1681	—	1783	—	1763	1709
Temperature (°C)	—81	—80	—78 —62	—82	—80	—	—87	—	—84	—82

TABLE 2

Tropopause height and temperature observations over Calcutta — September 1971

Date	27		28		29		30	
Time (GMT)	00	12	00	12	00	12	00	12
Tropopause								
Pressure height(mb)	097	099	098	088	107	—	096	—
gpm height (in units of ten metres)	1675	1671	1673	1743	1641	—	1696	—
Temperature (°C)	—82	—82	—83	—84	—85	—	—85	—

observation) at 00 GMT of 3 June when an upper air easterly trough (inferred from the negative height and temperature anomalies) moved over the region and a depression formed over the Bay of Bengal to its south. The constant pressure surfaces showed significant falls in gpm heights on time section extending upto 50 mb and above, with maximum fall of 195 gpm at 100 mb close to and just above the tropopause surface and with practically no change of temperature from the normal. A fall in temperature (compared to the previous day observation) was observed at levels below the tropopause.

The tropopause rose thereafter. On 00 GMT of 5th when the system became a severe cyclonic storm and lay centred 100 km to the south, the tropopause at Calcutta rose to 81 mb (by 18 mb, 1020 gpm) and its temperature fell by —7 deg. C (compared to 00 GMT observation of 4th). Significant fall (depression) in the height of constant pressure surfaces was observed at and above the tropopause levels (209 gpm at 50 mb) an observation dissimilar to that at 00 GMT of 3 June. A temperature fall of —10 deg. C was observed at 80 mb level compared to 24 hours previous observation. A further fall of temperature by —3 deg. C was observed at 100 mb level (after which the ascent terminated) on 12 GMT of 5th when the cyclonic storm lay centred very close to Calcutta (about 30 km to east). This cooling could be ascribed to overshooting of *Cb* clouds as the station lay within the wall cloud region of the cyclonic storm.

Horizontal cross section charts were prepared for 00 GMT of 3 June and 00 GMT of 5 June with the available tropopause observations and analysed for height and temperature fields (Fig. 2 a & b). A low in height and warm in the temperature field lay over the region surrounding Calcutta on 00 GMT of 3rd and a high in the height and cold in the temperature field covered the region on 00 GMT of 5 June.

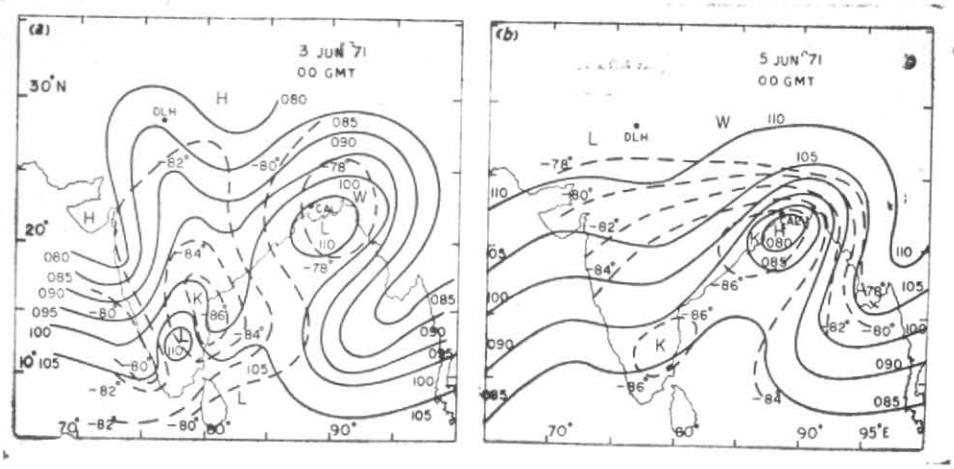

Fig. 2 (a &b). Tropopause surface chart (a) 00 GMT of 3 June, (b) 00GMT of 5 June 1971 (Full lines show isopleths of height in mb, dashed line mark the isotherms in °C)

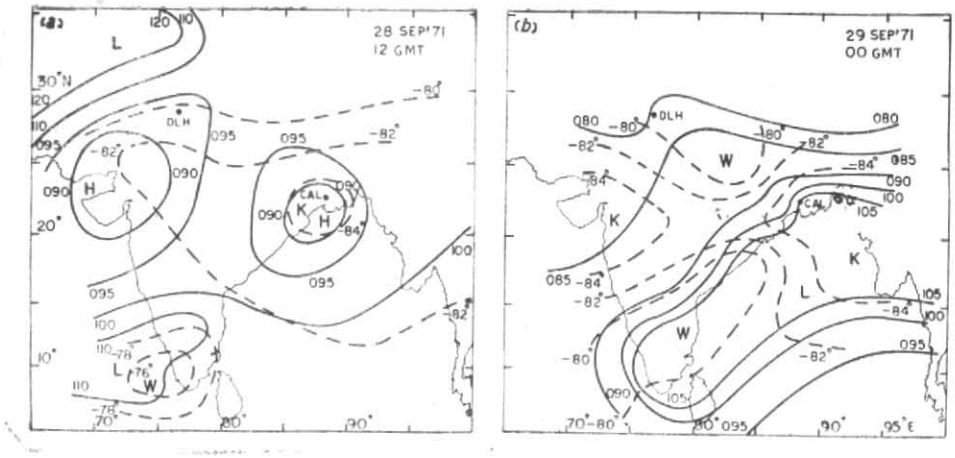

Fig. 3 (a & b). Same as Fig. 2 (a & b) except for (a) 12 GMT of 28 September 1971 and (b) 00 GMT of 29 September 1971

4. Case-II : Cyclonic storm of September 1971

The tropopause over Calcutta rose to 88 mb (by 10 mb or 700 gpm) and temperature fall to —84 deg. C (by 1 deg. C compared with the previous 12 hrs observation) when the system intensified into a cyclonic storm at 12 GMT of 28 September centred about 170 km south from Calcutta (Table 2). At 00 GMT of 29th when the system intensified into a severe cyclonic storm and lay centred about 130 km south-south-east of Calcutta, the tropopause at Calcutta lowered down to 107 mb (by 19 mb or 1020 gpm) with a further fall of temperature to —85 deg. C (by 1 deg. C). A rise in the gpm heights of the adjacent pressure levels was observed here, during both cyclonic and severe cyclonic storm stages [Fig. 1 (b)]. The rise was maximum (105 gpm from normal) at 150 mb (below the tropopause) in the severe cyclonic storm stage indicating the peripheral anticyclone round the cyclonic core. The maximum in gpm height anomalies lay above the maximum in temperature anomalies (8 deg. C) at 300 mb. The temperature at 150 and 100 mb level however did not show any significant change. Thus in this case the tropopause rose over the peripheral anticyclone in the cyclonic storm stage and lowered in the severe cyclonic storm stage. The constant pressure surface showed an upward bulge more significantly at severe cyclonic storm stage both below (upto 200 mb) and above (upto 50 mb) the tropopause. On the tropopause surface charts [Fig. 3 (a & b)] we observe a high in the height and a cold in the temperature field at 12 GMT of 28 September, and a low in the height and a cold in the temperature field at 00 GMT of 29 September centred at Calcutta on the synoptic scale. As we do not have observation at 12 GMT of 29th we do not know the tropopause height over the core of the cyclone which was about 25 km south of Calcutta at that time.

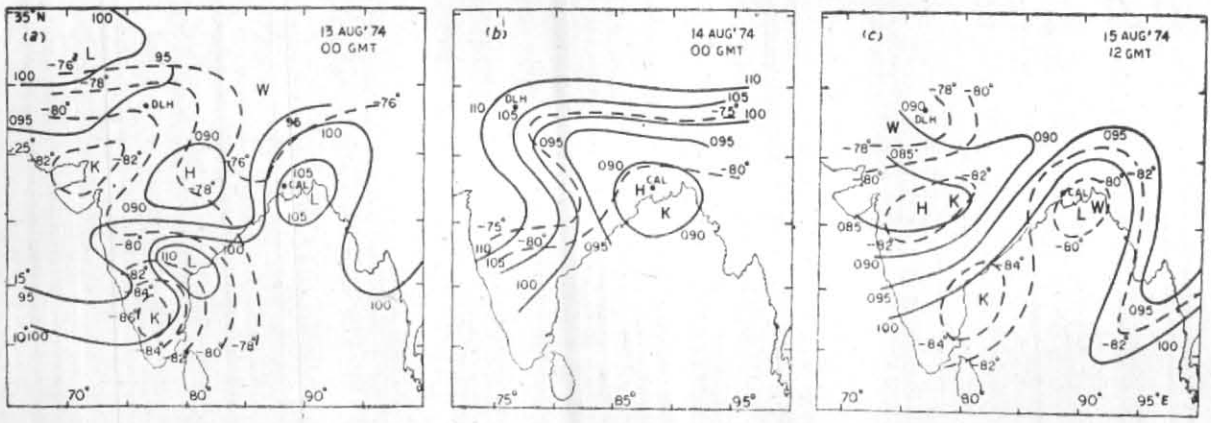

Fig. 4 (a-c). Same as Fig. 2 (a & b) except for (a) 00 GMT of 13 August, (b) 00 GMT of 14 August and (c) 12 GMT of 15 August 1974

TABLE 3

Tropopause height and temperature observations over Calcutta—August 1974

Date	12		13		14		15		16	
Time (GMT)	00	12	00	12	00	12	00	12	00	12
Tropopause										
Pressure height(mb)	101	095	108	—	088	—	—	104	100	093
gpm height (in units of ten metres)	1658	1750	1600	—	1742	—	—	1640	1661	1717
Temperature (°C)	—81	—79	—77	—	—81	—	—	—80	—81	—80

5. Case-III : Cyclonic storm of August 1974

In this case the tropopause came down to 108 mb level (by 13 mb or 1500 gpm) and temperature rose to —77 deg. C (by 2 deg. C compared with the 12 hours previous observation) on 00 GMT of 13th (Table 3) in the depression stage when an upper air easterly trough moved over the region (inferred from the negative height and temperature anomalies). The 100 mb surface showed the maximum depression (310 gpm from normal) though no temperature change was observed at this level. However, significant temperature fall was observed at 150 mb (by 9 deg. C) and at 200 mb (by 5 deg. C from the previous observation) below the tropopause.

The system intensified into a cyclonic storm at 00 GMT of 14th. The tropopause rose to 88 mb (by 20 mb or 1420 gpm) and temperature fall to —81 deg. C (by 4 deg. C compared with the 24 hrs earlier observation). The geopotential height and temperature anomalies of the adjoining constant pressure levels though they rose considerably were still negative [Fig. 1 (c)]. The ascents did not reach the tropopause level on 12 GMT of 14th and 00 GMT of 15th, when they terminated at 175 mb and 500 mb level respectively. On 12 GMT of 15 August, when the system in severe cyclonic storm stage was centred about 125 km SSW of Calcutta a fall in the height of tropopause to 104 mb (by 16 mb or 1020 gpm) with a rise of temperature by 1 deg. C was observed similar to the one of September 1971 and represents conditions over the peripheral anticyclone. This observation of the tropopause height was as per definition of the first tropopause as the level at which the average lapse rate decreases to 2 deg. C/km or less. The significant temperature fall was observed at 80 mb and at temperature —82 deg. C. From this consideration the levels of reversal of lapse rate was lifted upward (by 16 mb or 1020 gpm) compared with the 00 GMT of 14th. The negative temperature anomaly of —7 deg. C at 100 mb however suggest that geopotential height may still be decreasing with height and the lowest negative anomalies may lie at 50 mb above tropopause.

On the tropopause chart of 00 GMT of 13th (Fig. 4a) a low in the height and warm in the temperature field were located over the region surrounding Calcutta. On 00 GMT of 14th (Fig. 4b) a high in height and a cold in tempera-

ture field were observed where as at 12 GMT of 15th (Fig. 4 c) a low in the height and a warm in the temperature field were observed over the region.

6. Discussion

The results of the case studies No. 1 and No. 3 were similar if we tentatively accept the tropopause as the level of reversal of lapse rate separating the troposphere and stratosphere. The tropopause came down with a rise in temperature in the event of an upper air easterly divergent trough above an underlying depression. The minima in the negative anomalies of geopotential heights of the adjacent constant pressure surface lies above and that in temperature below the tropopause.

A gradual rise in the height of tropopause and fall in its temperature has been observed as the system passed into cyclonic storm and finally into severe cyclonic storm stage in June 1971 and August 1974. In both the above cases the systems were warm cored upto 200 mb and even beyond. This was probably responsible for the lifting up of the surface of temperature reversal. The cooling observed still above (just below the tropopause) may be attributed to the overshooting of *Cb* clouds in the wall could region of the cyclonic storm (Malkus 1959, Koteswaram 1967). This cooling spreads around (Mukherjee & Chaudhary 1978) and the effect is observed at synoptic scale on the tropopause surface charts. This cooling may again be responsible for the increased negative geopotential anomalies and consequently the extension (or inducement of a fresh low) of the cyclonic circulation beyond the tropopause into the lower stratosphere (Ranjit Singh, paper under publication — Hydrostatic response of constant pressure surface to the cooling below).

In the case of September 1971 cyclonic storm, the positive geopotential anomalies with maximum at 150 mb suggest the conditions over the peripheral anticyclone surrounding the inner core where the tropopause first rose and then sank. Such undulations are possible when the station comes under rainbands and adjoining clear areas spiralling round the central core. The conditions in the eye wall are not known since the ascent failed when the eye came close to the station.

7. Conclusion

From these three different case studies we may conclude that :

(1) Tropopause comes down with a rise in temperature when an easterly trough passes over the station.

(2) It rises with a fall in temperature, above a cyclonic or severe cyclonic storm when the cyclonic vortex extends sufficiently high upto and beyond tropopause into the lower stratosphere.

(3) It may undulate in the peripheral anticyclone surrounding the core.

Acknowledgement

The author thanks Dr. R. P. Sarker, Deputy Director General of Meteorology for encouragement and support. Thanks are also due to Dr. A. K. Mukherjee, Deputy Director General of Meteorology for guiding him in this research. The author also thanks Shri P. V. Joseph, Director and Shri A. K. Banerjee, Meteorologist for helpful discussions. Thanks are also due to Shri P. S. Ray and his colleagues for preparing diagrams and Shri D. B. Jagtap for typing the manuscripts.

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