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Perturbations in upper tropospheric easterlies and Bay cyclones

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सार—उत्तर-पश्चिमी प्रशांत महासागर और समीपस्थ हिन्द महासागर के ऊपर, 200 और 100 हे०पा० के तलों पर उच्चतर क्षोभमंडलीय हल्की पुरवाई हवाओं में, अधिक विस्तार की द्रोणियां या चक्रवाती परिसंचरण के रूप में विक्षोभों का विकास होता है। इनका तापमान निकटतम वातावरण से प्राय: 2° से 3° सेल्सियस कम होता है। ये प्रणालियां, पश्चिम की ओर चलते समय, नीचे की ओर प्रगमन करती हुई दिखाई देती हैं। जबकि ये 500 हे०पा० पर निम्न क्षोभमंडलीय चक्रवाती परिसंचरण के साथ मिल कर उन्हें सक्रिय कर देती हैं तथा अवदाब और चक्रवातों में परिवर्तित कर देती है। इस अवसर पर, उच्चतर क्षोभमण्डलीय तलों पर चक्रवाती परिसंचरण अदृश्य हो जाता है। चक्रवात की तीव्रता बढ़ने पर ये पुन: दिखाई देने लगता है। इस प्रकार के टकराव और तीव्रीकरण का प्रमाण कुछ समकालिक प्रणालियों से मिलता है।

ABSTRACT. Perturbations in the form of large amplitude troughs or closed circulations are observed to develop in the weak upper tropospheric easterlies at 200 and 100 hPa levels over northwest Pacific and adjoining Indian Ocean. Occasionally, these are 2 to 3°C colder than their immediate environment. These systems are observed to propagate downwards during their westward traversal; while over 500 hPa these interact with and activate the lower tropospheric cyclonic circulation to intensify into a depression/cyclonic storm. At this stage, the cyclonic circulation in upper tropospheric levels is observed to vanish; this may, however, re-appear subsequently on further intensification of the cyclonic storm. Evidence of such interaction and intensification is adduced with a few typical synoptic systems.

Key words — Circulation, Depression, Vergence, Vorticity, Intensification.

1. Introduction

After the withdrawal of summer monsoon from Indian region, the upper easterly jet also disappears; the upper tropospheric easterlies between 250 & 100 hPa over equatorial northwest Pacific and adjoining Indian Ocean weakens sufficiently to allow perturbations in the form of large amplitude troughs (or cyclonic vortices) to survive, propagate and interact. Similarly, the upper tropospheric easterlies are sufficiently weak before the onset of monsoon and the easterly jet appears simultaneously with the onset of monsoon (Koteswaram 1958 and others). These perturbations (generally 1 to 3°C colder than the environment) sometimes propagate downwards during their westward journey. These perturbations on descending to middle tropospheric levels (*i.e.,* 500 hPa) activate the pre-existing lower tropospheric cyclonic circulations in the underlying Inter-Tropical Convergence Zone (ITCZ) area. Under favourable ocean-atmospheric environment these initially weak perturbations are triggered to form into a depression/cyclonic storm. At this stage, the initial perturbation is observed to annihilate itself and the cyclonic circulation from the upper tropospheric levels vanishes. However, the cyclonic circulation associated with the cyclonic storm may extend to upper tropospheric levels on further intensification of the system. This process of cyclone formation takes nearly 3 to 5 days. Riehl (1948) states that tropical storms form as a consequence of interaction between disturbances at low and high altitudes within the tropics. Kanti Prasad and Krishna Rao (1974) have discussed formation of a monsoon depression over north Bay as a consequence of interaction between upper tropospheric westerlies and easterlies. Sadler (1978) has emphasized the role of Tropical Upper Tropospheric Trough (TUTT) in the development and intesification of typhoons in southwest Pacific. Koteswaram (1967) has emphasized that low pressure core mature hurricane extends throughout the troposphere and sometimes extends into the stratosphere. The upper core is found to be cold above 15 km with temperatures occasionally 8 to 10°C below normal at the tropopause level. It is posssible that on dissipation of such hurricanes the remnant upper tropospheric cold circulation may be propagating in the easterly waves. Editor Bao Chenglan (1987) has mentioned in his book '*Synoptic Meteorology in China*', that the number of typhoon forming from cut off lows or upper cold vortices including disturbances in

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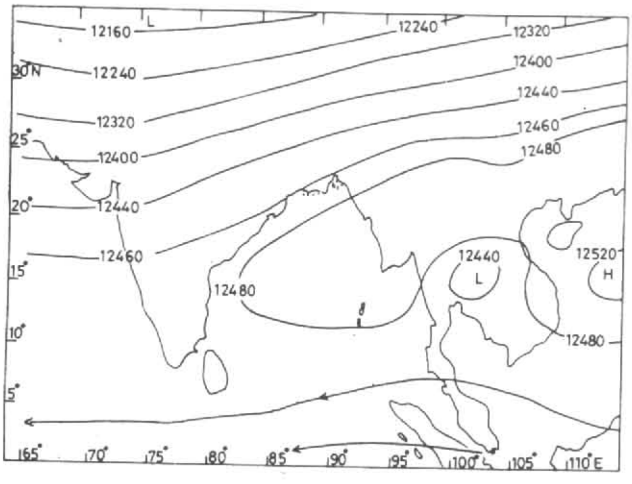


Fig. 1. 200 hPa analyis at 00 UTC of 11 October 1980

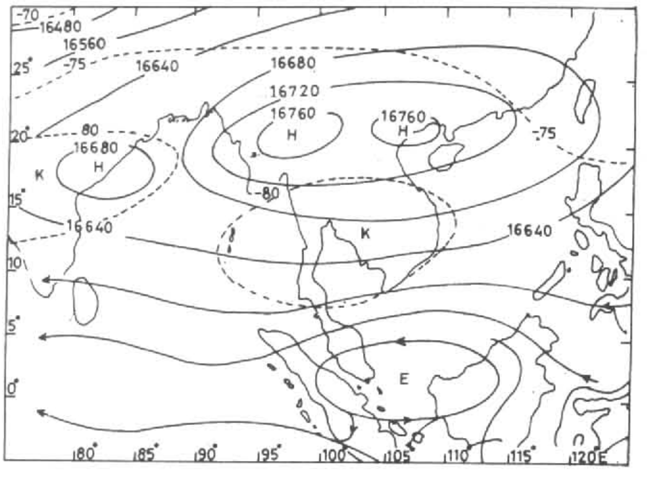


Fig. 2. 100 hPa analysis at 12 UTC of 10 October 1987

TABLE 1

Troughs/cyclonic and anticyclonic circulations at different pressure levels during 9-17 October 1980

Level (hPa)	Date (October 1980)								
	9	10	11	12	13	14	15	16	17
Surface		12N, 105E	12N, 108E	05N, 106E	07N, 100E	07N, 95E	07N, 89E	8.5N, 89E Dep. 00UTC	14N, 82.5E C.S. 00UTC
850		08N, 103E	05N, 110E	17N, 98E	08N, 90E	08N, 96E	08N, 88E	09N, 88E	
700			05N, 107E	12N, 102E 05N, 100E	—	07N, 94E	09N, 85E	08N, 85E	
500					16N, 100E	Deep trough along 90E from Eq to 13N	Deep trough along 89E from Eq to 15N	08N, 83E	
300		12N, 107E	13N, 103E	17N, 102E	Deep trough along 90E from Eq to 15N	Anticyclone to north of system	Anticyclone to north of system		
250	12N, 105E	12N, 105E	15N, 103E	15N, 102E	Deep trough in E'ly and W'ly Juxtaposition				
200	Trough along 110E from 10 to 20N	12N, 105E	16N, 103E	15N, 100E					
100	Do.	Trough along 108E	13N, 100E	12N, 100E					

Dep.—Depression, C.S.—Cyclonic storm.

TABLE 2

Troughs/cyclonic and anticyclonic circulations at different pressure levels during 19-30 November 1987

Level (hPa)	Date (November 1987)											
	19	20	21	22	23	24	25	26	27	28	29	30
Surface	05N,108E		03N,107E 08N,90E	05N,90E	08N,90E	05N,90E	06N,92E	05N,85E	8.5N,85.5E Dep. (12UTC)	9.5N,85.5E	10N,84.5E	9.5N,84.5E
850	02N,108E	03N,106E		05N,95E	04N,95E	04N,94E	07N,84E	07N,85E	07N,84E	10N,85E	10N,84E	10N,85E
700		02N,107E	04N,105E	03N,93E	Eq 92E	04N,93E	06N,82E	08N,84E	07N,82E	10N,85E	10N,85E	10N,85E
500			Trough	03N,95E	06N,87E	Trough along 90E	05N,84E	05N,85E	08N,85E	10N,85E	10N,85E	10N,85E
300			05N,103E	Trough along 05N,100E	Trough along 90E	Trough along 85E	Trough along 85E				08N,83E	
250	08N,110E	10N,106E	05N,107E	08N,100E								
200	10N,107E	07N,113E	Cold trough by 1-2°C	Cold trough (1-2°C) along 98E								

tropical upper tropospheric trough is about 5% in westnorth Pacific and south China sea. Riehl (1950) has described the intensification process as follows:

With strengthening of east-west pressure height gradient at 200 hPa, the northerly flow is accelerated leading to divergence at the western end of the accelerated current and convergence at the eastern end. The convergence in the east leads to sinking motion and consequent release of potential energy. At the surface, pressure rises relative to the western side near the lower tropospheric wave axis, above which divergence has been initiated.

Strengthening mass convergence is implied at the surface from the inflow. Increase of mass circulation through a centre may be a precursor to intensification; especially in a full hurricane it denotes further strengthening to extreme intensity.

An attempt has been made in this paper to study the role of vortices in upper tropospheric easterlies in the formation of tropical storm in Bay of Bengal. Data of 16-18 October 1980 and 14-19 October 1987 cyclones selected out of instances during the period 1978 to 1988 have been used in this study. It was found that upper tropospheric circulation probably acts as a trigger for intensification of the lower level circulation into depression/cyclone.

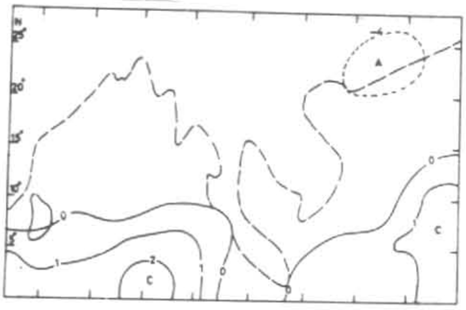
2. Data

Working charts of Northern Hemisphere Analysis Centre (NHAC), New Delhi during pre-monsoon and post-monsoon seasons were examined for the years 1978 to 1988. This sample contained four severe drought years 1979, 1982, 1986 and 1987, two excess monsoon years 1983 and 1988 and five normal monsoon years. Divergence and relative vorticity have also been computed and studied for the October 1987 cyclone.

3. Discussion

3.1. *Tropical cyclone of 16-18 October 1980*

A trough in the upper tropospheric easterlies was seen along 110°E between 10° & 20°N at 100 and 200 hPa levels and associated cyclonic circulation at 12°N, 105°E at 250 hPa on 9 October 1980 (Table 1). On 10 October the cyclonic circulation existed around 12°N & 105°E to 107°E from 300 to 200 hPa while the associated trough along 108°E at 100 hPa. A cyclonic circulation was found in the active ITCZ area on 10 October around 12°N and 105°E with associated circulation extending up to 850 hPa. On 11 October (Fig. 1) the upper tropospheric circulation existed at 200 hPa around 15°N & 103°E and with little variation it extended from 300 to 1000 hPa. The lower



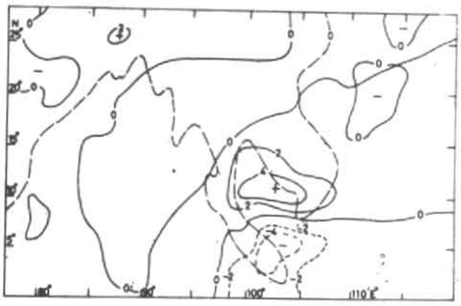


Fig. 3. Divergence (10^{-5}/sec), 300 hPa at 00 UTC of 9 October 1987

Fig. 4. Relative vorticity (10^{-5}/sec), 200 hPa at 00 UTC of 8 October 1987

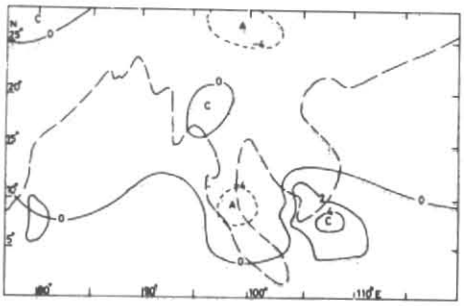


Fig. 5. Relative vorticity (10^{-5}/sec), 300 hPa at 00 UTC of 9 October 1987

tropospheric circulation around 12°N & 108°E extended from mean sea level up to 700 hPa sloping equatorwards with height. On 12 October both the circulations moved further westwards. On 13 October the upper tropospheric circulation descended to 500 hPa around 16°N & 100°E with associated trough in upper troposphere only up to 250 hPa. The mean sea level low around 7°N & 100°E had its associated cyclonic circulation only up to 850 hPa sloping steeply westwards.

However, on 14 October the upper tropospheric circulation further descended to 700 hPa around 7°N & 94°E with associated deep trough along 90°E extending from equator to 13°N at 500 hPa, and at 300 hPa anticyclone to the north of this area. The sea level low and its associated cyclonic circulation at 850 hPa readjusted itself to around 7°N, 95°E as shown in Table 1. The same situation continued on 15th with further westward movement to 7°N & 89°E. However, a depression formed at 0000 UTC between 8.5°N & 89°E on 16 October when the associated cyclonic circulation tilting westward with height extended up to 500 hPa. The system intensified into a deep depression at 1200 UTC of 16 October around 11.5°N & 85°E and into cyclonic storm at 0000 UTC of 17 October centred around 14.0°N & 82.5°E. The depression moved initially in a westnorthwesterly direction up to 1200 UTC of 16 and in northwesterly to northnorthwesterly direction thereafter. The 300 hPa anticyclone at 0000 UTC of 16 was to the northwest of the depression, the cyclone followed the easterly wave south of this anticyclone. The 250 hPa anticyclone at 0000 UTC was also supportive of this movement.

However, in its northwestward march the depression intensified into a cyclonic storm apparently under the influence of upper level divergence provided by the 250 hPa anticyclone. On 17 October, the cyclone lay at the periphery of the 300 hPa anticyclone and continuing to move along this track and struck coast on the morning of 18 October north of Masulipatnam.

3.2. *Cyclonic storm 14-19 October 1987*

A cyclonic circualtion at 100 hPa was observed on 9 October 1987 (Table 2) around 5°N and 105°E which continued on 10 October (Fig. 2). The temperatures in the zone of this circulation at 100 hPa were 2 to 3°C lower than the surrounding area. The msl circulation in the ITCZ around 8°N and 103°E had its associated cyclonic circulation up to 500 hPa which weakened on 10 October and existed only up to 700 hPa (Table 2).

However, on 11 October the 100 hPa circulation descended westward to middle tropospheric levels and merged with the lower troposphere circulation. On 12 and 13 October the circulation further organised itself, moved westward and was confined up to 300 hPa only. On 14 October the circulation became more vertical and was confined only up to 500 hPa, when the sea level low intensified into a depression at 0300 UTC around 13.0°N and 87.5°E. It moved initially in a

TABLE 3

Highest value of vergence (10^{-5}/sec) near the vortex on 0000 UTC charts (8-12 October 1987)

Level (hPa)	Date (October 1987)				
	8	9	10	11	12
200	2.5°N, 107.5°E —14	2.5, 102.5 —6	5, 97.5 —1	5, 95 10	
300	2.5°N, 107.5°E —5	5, 102.5 —54	5, 97.5 —4	5, 95 —12	7.5, 95 8
500	2.5°N, 105°E 14	2.5, 100 —12	2.5, 97.5 —6	2.5, 95 —13	7.5, 95 —9
700	2.5°N, 105°E 4	2.5, 102.5 6	2.5, 97.5 —5	5, 95 —9	10, 97.5 —9
850	2.5°N, 105°E 9	2.5, 100 3	5, 97.5 —5	5, 95 —8	5, 95 —9

TABLE 4

Highest values of vorticity (10^{-5}/sec) near the vortex on 0000 UTC charts (8-14 October 1987)

Latitude (°N) and Longitude (°E) (x, y=X°N, Y°E)

Level (hPa)	Date (October 1987)						
	8	9	10	11	12	13	14
200	5, 117.5 17*	7.5, 112.5 13	10, 100 11	5, 100 11	10, 97.5 0	10, 92.5 —3	10, 90 —2
300	2.5, 115 22*	7.5, 107.5 47*	5, 105 22*	7.5, 100 15	10, 95 11	10, 95 —5	10, 90 0
500	5, 110 12	2.5, 107.5 13	5, 105 17	7.5, 100 24*	10, 97.5 18	10, 95 23	10, 90 11
700	7.5, 110 3	7.5, 107.5 12	7.5, 105 22	7.5, 102.5 18	10, 97.5 26*	10, 95 20	10, 90 18
850	7.5, 110 —2	12.5, 100 14	7.5, 105 10	7.5, 102.5 20	10, 97.5 15	10, 95 31*	12.5, 90 41*

Asterisks(*) show the location and date of highest values of relative vorticity (10^{-5}/sec) during the period considered

northwesterly direction up to 1200 UTC of 14 and thereafter in a westnorthwesterly direction. On 0300 UTC of 15 October, it was located around 14.5°N and 83.5°E when it intensified into a cyclonic storm. It had a gentle slope westnorthwestward with height and moved in a westnorthwesterly direction. Negative divergence at 200 hPa was observed on 8 October 1987 around 2.5°N and 107.5°E. On 9th October divergence value (10^{-5}/sec) at 300 hPa increased from -5 to -54 around 5°N and 102.5°E (Fig. 3). This negative divergence value had increased in lower levels with movement of westward passing circulation (Table 3). On 11 October, positive divergence value was noticed over upper troposphere whereas negative values existed in lower and middle tropospheric level leading to initiation of outflow in upper troposphere and inflow in lower levels.

Similarly relative vorticity (10^{-5}/sec) value was +17 and +22 at 2000 hPa & 300 hPa on 8 October 1987 around 5°N, 117.5°E and 2.5°N, 115°E respectively which on 9th becomes +27 at 300 hPa over 110°E (Figs.4 & 5). During passing time on 11 October at 500 hPa the relative vorticity value becomes +24 which was 17 on 10th. Cyclonic vorticity increased over 700 hPa and 850 hPa on 12 and 13 October 1987 (Table 4). However, zero vorticity was observed at 200 hPa on 12 October 1987 which becomes anticyclonic on 13th onwards. At the same time cyclonic vorticity enhanced in lower tropospheric levels. The decrease of relative vorticity in upper tropospheric levels and increase in the lower tropospheric levels may be the indication of merging of upper air circulation with lower level circulation.

3.3. It has taken nearly 3 to 5 days for the formation of a depression and 4 to 6 days for the tropical storm since the appearance of the perturbation in upper tropospheric easterlies. The cyclonic storm of 19 to 30 November 1984 and that 17 to 24 May 1985 was also exhibited similar characteristics in formation and intensification.

4. Conclusion

During the pre-monsoon and post-monsoon months, perturbations in the form of large amplitude troughs or circulations in the upper tropospheric easterlies over equatorial northwest Pacific region could trigger the formation of a depression/cyclonic storm through interaction with a pre-existing sea level low pressure system with associated lower tropospheric circulation embedded in the ITCZ. The interaction of perturbations in upper tropospheric easterlies with the irregularly arranged circulations in lower troposphere above a sea level low pressure in ITCZ region helps in aligning the circulation in the vertical and consequent accentuation into depression/cyclonic storm. The presence of an approaching trough in the middle and upper tropospheric mid-latitude westerlies could be helpful in further intensification of the cyclonic storm and its movement northward and recurvature north-northeastward. The intensification of a tropical storm into a severe cyclonic storm, probably to hurricane strength could also be helped by an upper air easterly trough as in the case of 29 November 1984 storm.

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