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Formation of easterly wind maxima at 200 mb during southwest monsoon

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सार — प्रस्तुत तीन अध्ययनों में मानसून अवदाब के दक्षिण में 200 मिली बार पर पूर्वी पवन उच्चिष्ठ की संरचना की व्याख्या की जा सकती है। जब मेघ प्रणाली से उठने वाली ईशानकोणी वायुधारा अपनी दक्षिणपूर्व की ओर गति के समय अतिरिक्त पूर्वी संवेग-धारण कर ले उस समय उपरोक्त व्याख्या के लिये कोणीय संवेग के संरक्षण की सहायता ली जा सकती है। इन पवन उच्चिष्ठ में उत्तर से दक्षिण की ओर 300, 250 तथा 200 मिली बार पर तापमान प्रवणता घटती है। इनमें से एक अध्ययन में अवतलन ऊष्मा मानसून प्रकोष्ठ के भूमध्य रेखा स्थित भाग पर जैट प्रवाह को छितराती है। इस बात को प्रस्तुत ऊर्ध्वाधर अनुप्रस्थ काट द्वारा विस्तार से बताया गया है।

ABSTRACT. In three case studies presented, the formation of easterly wind maxima at 200 mb south of the monsoon depressions can be explained with the help of conservation of angular momentum when the northeasterly air stream emerging from the cloud system acquires the additional easterly momentum during its motion towards southwest. The temperature gradients from north to south occur at 300, 250 and 200 mb across these wind maxima. In one of the case studies the subsidence warming on the equatorward leg of the monsoon cell splits the jet stream, has been elucidated in the vertical cross-section presented.

1. Introduction

Koteswarm (1958) studying the easterly jet stream notified that its maximum strength exceeding 100 knots is attained over southern India at 150-100 mb levels. The magnitude of the corresponding mean wind vector at 200 mb is about 50 knots. He envisaged large scale ascents in the right entrance and left exist of this acceleration wind maxima which may be responsible for the intense convection and subsequent development of weather systems in these two sectors including the first burst of monsoon over the Kerala coast. Raman and Ramanathan (1964) on the other hand, examining the relationship between the rainfall along the west coast of India (77 deg. E) and upper tropospheric zonal winds showed that on a single day the precipitation maximum, seemed to be associated with concentration of upper tropospheric wind, reached its maximum on the next day and located about 1-3 degrees to its south. It was envisaged that the release of large amounts of latent heat from excessive cloudiness and copious precipitation cause the heating of upper troposphere, responsible for the formation of wind maxima to its south. George (1970) comparing the rainfall along the west coast the upper level winds over Madras and Trivandrum supported the views of Koteswaram and suggested the westward movement of east wind maxima and the occurrence of heavy rains alson west coast first in its left exit in south and then at stations to north coming under the right entrance. These studies were made and the contradictory hypothesis on the easterly wind maxima and its relationship with rainfall were advanced with the help of upper air data for stations Trivandrum to Bombay along the west coast and Madras along the east coast without any supporting data over the sea.

During 1979 Summer MONEX we had a unique opportunity of observations from a geostationary satellite positioned at 58 deg. E to continuously view the monsoon circulation between 40 deg. S to 40 deg. N and 30 deg. to 110 deg. E. In the present paper, an attempt is made to re-examine the inter-relationship between weather and the easterly wind maxima using cloud imageries from TIROS-N and the satellite derived cloud wind systems for higher layer 300-100 mb (Young 1980). On comparison with the rawin data of the Indian stations these were found to be in close approximation (variation 0 to 10 m/sec) with the winds at 200 mb.

2. East wind maxima at 200 mb and the weather systems

A day to day examination of the wind maxima formed over the Bay of Bengal and the Arabian Sea indicate that these can be located to the southwest of the well organised cloud systems associated with lows or depressions. In the paragraphs to follow a few cases of the formation of these east wind maxima will be discussed with the help of upper air data obtained from the radiosonde stations along the east coast.

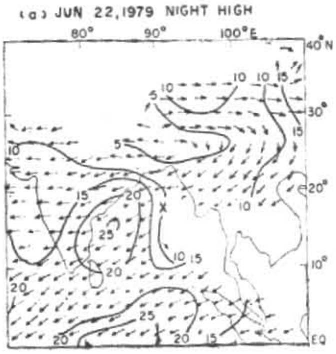


Fig. 1(a). Satellite derived wind flow pattern, 200 mb

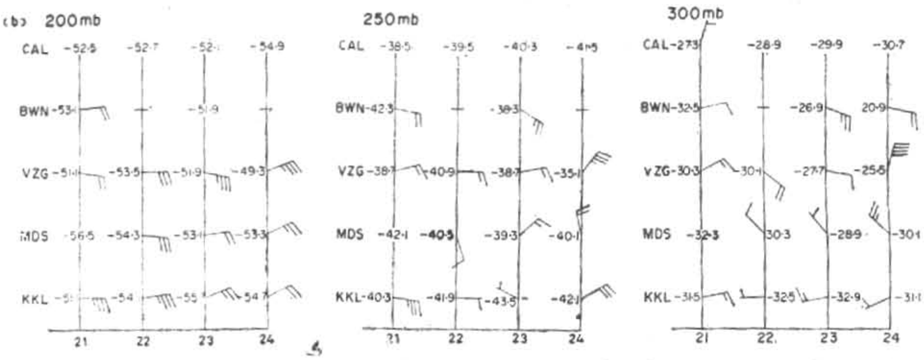


Fig. 1(b). 300, 250 and 200 mb time sections wind and temperatures of coastal radiosonde stations

2.1. 22 *June* 1979 *night picture*

Wind maxima of 25 m/sec lies between 14-15 deg. N, 82-84 deg. E [Fig. 1(a)], 4-5 deg. to the southwest of an organised cloud system [Fig. 1(c)], associated with a well marked low which concentrated into a depression on the morning of 23 June. It lies in the divergent part of the cloud system as is evident from these figures. Fig 1(b), displays the time sections of winds and temperature observed over east coast stations Karaikal, Madras, Visakhapatnam, Bhubaneswar and Calcutta from 21 June to 24 June with 00 GMT observation at 300, 250 & 200 mb levels. North to south temperature decrease is observed over Calcutta on 21 and 22 June at 300 and 250 mb levels. On 00 GMT of 23 June which corresponds to the night observation of 22 June, temperature at Bhubaneswar and Visakhapatnam rise and north to south temperature gradient towards Madras and south to north towards Calcutta are observed over Bhubaneswar at 300 and 250 mb.

2.2. 28 *and* 29 *June* 1979 *night pictures*

An east wind maximum of 30 m/sec lies between 10-12 deg. N and 81-83 deg. E [Fig. 2(b)], southwest of a depression formed over the head Bay of Bengal on the night 28 June. The wind maximum was located in the divergent cirrus bands of the main cloud system [Fig. 2(a)]. It shifts southward, strengthens to 35 m/sec and lies between 8-12 deg. N, 82-84 deg. E on the night of 29 June [Fig. 2(c)]. Fig 2(d) gives the time section of coastal stations for 00 and 18 GMT (representing night hours) from 28 to 30 June. Highest temperatures were noted at 300 and 250 mb over Visakhapatnam on 00 GMT of 29 June, over Bhubaneswar on 18 GMT of 29 June and over Calcutta on 00 GMT of 30 June in agreement with the northward movement of the depression.

3. Thermal field

From the cases examined above we observe that the wind maxima of 25 m/sec and above form during the monsoon season in the easterly current at 200 mb. southwest of the organised cloud systems associated with well marked lows and depressions. The region of maximum convective clouds extend 2 to 3 degrees around the centre of low or a depression and the region of maximum wind lies 4 to 9 degrees southwest of the main cloudy region. Over the Bay of Bengal where the upper air data were available from radiosonde stations along the east coast, it is noticed that strong temperature gradients build up at 300, 250 and 200 mb from right to left across the easterly wind maximum looking downstream. The maximum temperature occur over the region of maximum cloud build up which is obvious from the rise of temperature over the closest coastal radiosonde stations. South to north temperature gradients occur to the north of cloud system which results in the weakening of easterly current over Calcutta. This thermal structure is superimposed on the general north to south temperature gradient occurring to the south of Himalayas during the season and may further extend towards 100 mb levels over the region of organised convection.

4. Conservation of angular momentum

The tropical cloud systems converge large quantities of air in the lower layers which, transported upward by convection emerge as an upper air radial outflow. This is superimposed over the existing flow which gets modified under the constraints of thermal wind effect and conservation of angular momentum. An air particle which moves under conservation of absolute angular momentum from its original position into a different geographical latitude ϕ_2 must obtain an additional zonal velocity $\triangle V$ relative to the earth's surface given by :

$$\triangle V = \frac{\Omega R\,(\cos^2 \phi_1 - \cos^2\phi_2)}{\cos \phi_2}$$

Here R earth's radius $\sim$6370 km and $\Omega = 7.29 \times 10^{-5}$ rad sec^{-1} (Reiter 1963). Using the above equation winds are computed for the wind maxima. Since in the present case ϕ_2 is a southern latitude, easterly zonal velocity component will be added to the wind at latitude ϕ_1. Table 1(a) displays the computed wind along with the observed wind maxima. The computations have been made with zero zonal velocity on 28 and 29 June. The area of zero zonal velocity will lie to the norh of the centre of cloud system where westerly thermal wind balances the prevailing easterly flow. Keeping this in view the first two values are found reasonably close. It is the air emerging from the cloud out-flow which is predominantly responsible for the formation of easterly wind maxima in the three cases discussed and not the one originating from the eastern slopes of the Tibetan anticyclone is obvious from the wind field in Figs. 1(a), 2(b), 2(c)

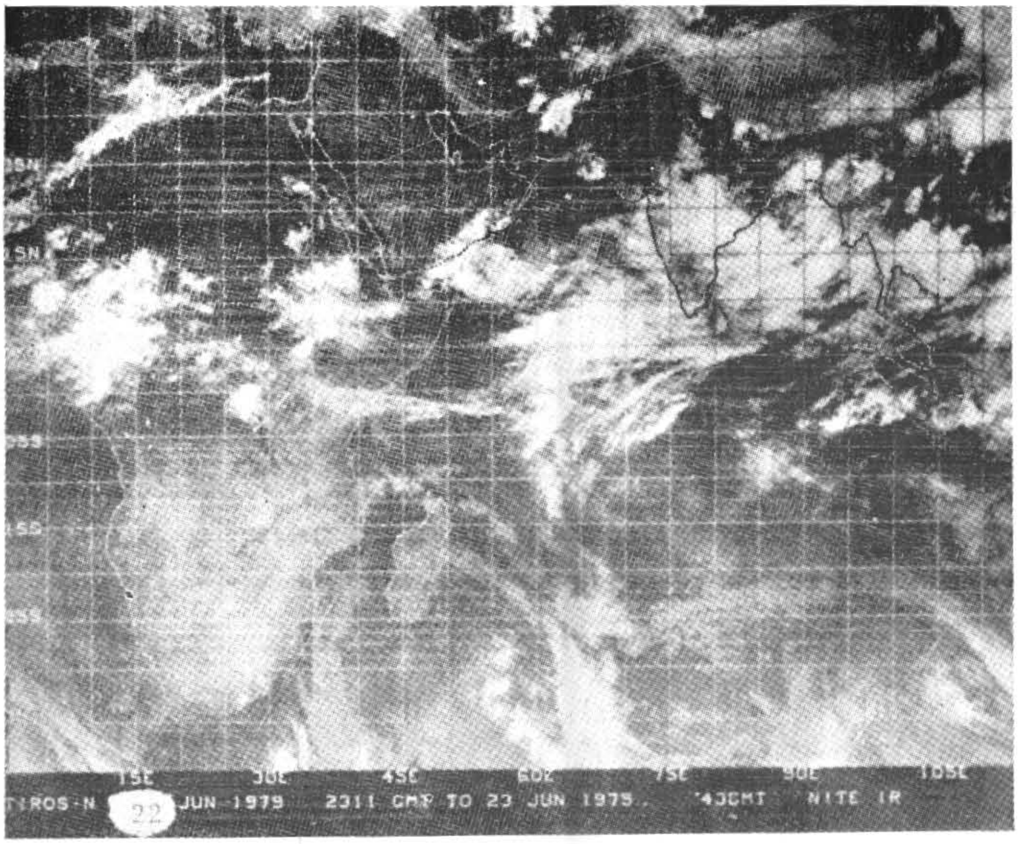


Fig. 1(c). Satellite IR imagery, 22 June 1979 (night)

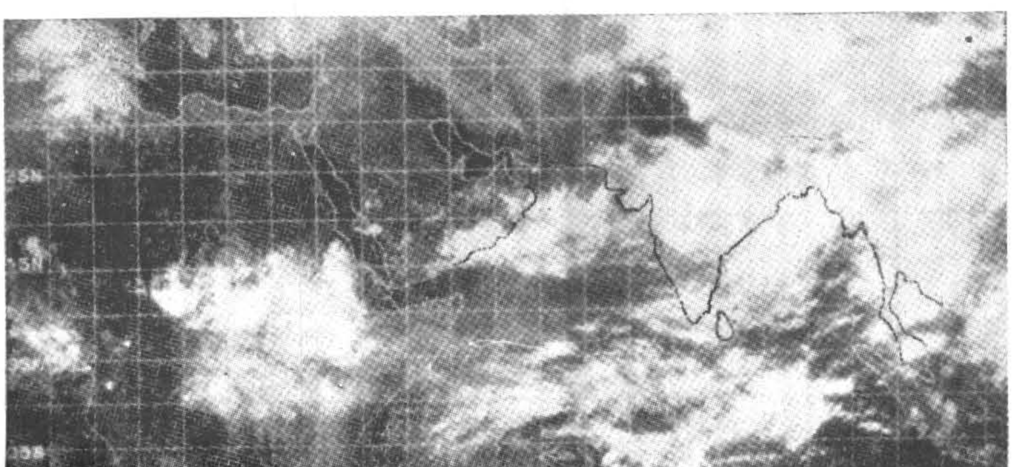


Fig. 2(a). Satellite IR imagery, 28 June 1979 (night)

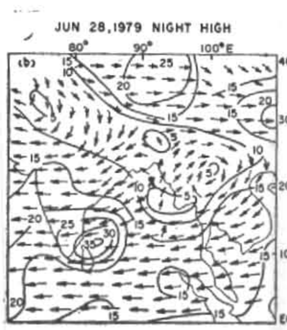


Fig. 2(b). Satellite derived wind flow pattern, 200 mb, 28 June 1979

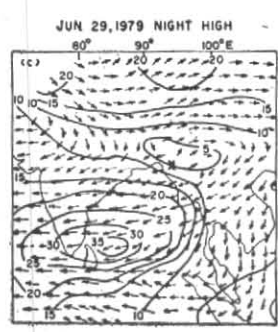


Fig. 2(c). Satellite derived wind flow pattern, 200 mb, 29 June 1979

Starting with a zero zonal velocity from the outflow region formation of easterly wind maxima of 25m/sec and ex-, ceeding it is possible within a few hours of the initial development (obvious from the observed radial flow). As, the convection intensfies during night over the tropical seas, this phenomenon can be explained better with the help of night pictures. Such configuration of the accelerating air current being divergent helps in the further development of weather systems. This is noticed from the formation of a depression on 23 June when the extension of the associated cyclonic circulation is depicted upto 200 mb by the satellite derived winds of 23 June (day). Also the second depression which formed on the night of 28 June intensifies further into deep depression over land on 30 June. This occurred after the formation of wind maxima of 40m/sec on the night of 29 June. Thus the maximum deveopment is observed to the northeast (right entrance) of these accelerating easterly jets (Koteswar ram *Loc cit*).

5. Vertical cross-section

To pursue further the problem of interaction of convective storm and the easterly jet stream, north-south vertical sections are constructed with the help of coastal stations of Trivandrum, Karaikal, Madras, Visakhapatnam, Bhubaneswar, Calcutta and Gauhati for 00 GMT of 23, 29 and 30 June [Figs. 3(a-c)]. These are analysed for wind (isotach) and temperature (anomalies from the monthly climate temperature of June 1979) field. The core of the jet stream is observed between Visakhapatnam-Madras at 100 mb on 23 June, between Visakhapatnam and Trivandrum at 150 mb on 29 June (Madras observations being absent). On 30 June a split in the jet stream is observed at 200 and 150 mb. The central core of the jet is located at 100 mb over Visakhapatnam and at 150 mb over Trivandrum. The observation at 100 mb over Madras is absent. The temperatures decrease from right to left (north to south) looking downstream below the core (Koteswaram 1958). Secondary warm regions appear in the layer 700-200 mb between Visakhapatnam and Bhubaneswar on 23 June and over Visakhapatnam on 29 June. This is the warming caused by the release of latent heat and is superposed over the normal feature of north to south temperature gradient. On 30 June this warming is displaced towards north between Bhubaneswar and Calcutta due to the northward movement of depression. The secondary warming so observed increases the circulatory motion within the vortex. Above the vortex the easterlies strengthen with height in the south and weaken in the north in keeping with the thermal wind relationship. Both these observations are obvious from the inspection of the three vertical cross-sections.

On 00 GMT of 30 June a third warm region is observed in the layer 200-150 mb over Madras. As the depression is located to the north of Calcutta, this warming seems to build up due to the subsidence in the equatorward leg of monsoon cell (Koteswaram 1960). This is confirmed from the higher value of pressure over Madras (1005 mb). This warming has been responsible for splitting the easterly jet stream into two as stated earlier. The easterly wind maximum at 200 mb over Trivandrum is the extension of wind maximum observed in the same latitudinal strip over the Bay of Bengal by the GEOS-1 satellite. The drastic reduction in the easterlies over Madras suggests that the subsidence warming may be located to its south. The large difference between the computed and the observed values of wind maximum on the night of 29 June in section 4 (Table 1a) can be explained with the help of subsidence warming discussed here. The values are recomputed at 200 mb for the vertical cross-section from 23 deg. N to Visakhapatnam and from Madras (Lat. 13 deg. N) to Trivandrum (Table 1b). The high level satellite wind data relate to heights of cirrus outflow. Since the winds were computed by tracking the cirrus cloud tops, the upper level data relate to the levels at which such clouds are formed between 300-100 mb. Therefore, some smoothing is introduced when they are compared with the rawin data on single level of 200 mb. The satellite winds of 29 June night hence, do not depict the split in jet stream noticed on the cross section of 00 GMT, of 30 June. However, this resolves the anomaly which had crept up earlier by computing tht values with respect of 23 deg. N in Table 1 (a & b). We can in a similar way explain the latitudinal stretching and longitudinal extension of these jet maxima from such warmings caused by subsidence and the release of latent heat over the equatorial region.

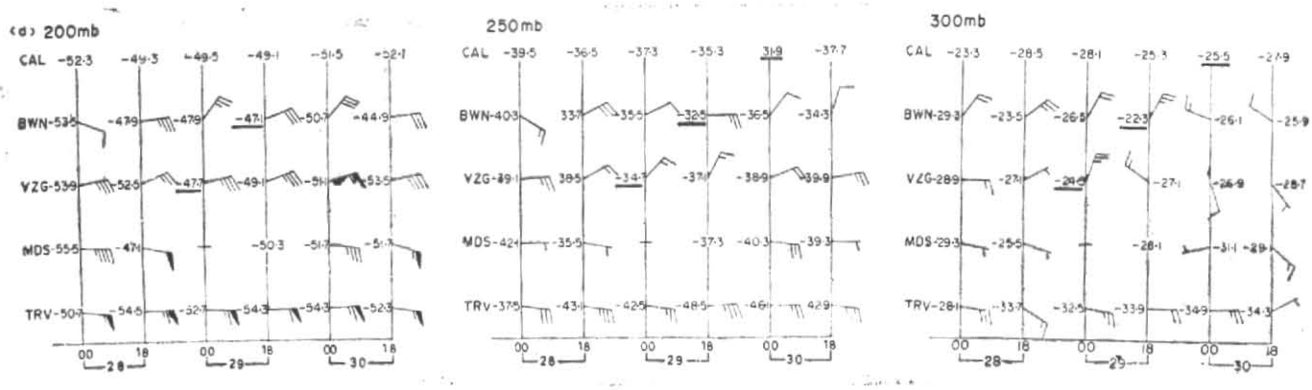
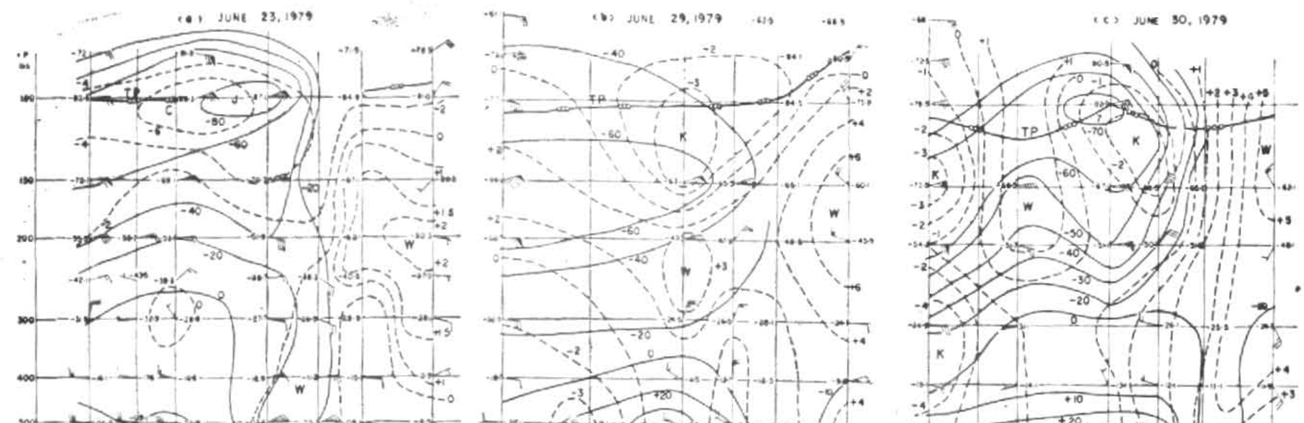


Fig. 2(d). 300, 250 and 200 mb time sections wind and temperatures of coastal radiosonde stations



Figs. 3(a-c). Vertical cross-section of wind and temperature anomaly (°C) for stations around 85°E: (a) 00 GMT, 23 June 1979, (b) 00 GMT of 29 June 1979 & (c) 00 GMT of 30 June 1979 (Isotachs solid, Isolines of temperatures anomaly dashed lines, TP—Tropopause)

TABLES 1 (a&b)

Date (June) Night obs.	Lat. of the centre of the cloud system or zero wind (°N)	Initial wind speed (m/sec)	Lat. of the wind max.) (°N)	Additional zonaly velocit (m/sec)	Computed value of wind maxima (m/sec)	Observed value of wind maxima (m/sec)
(a) Computed and observed wind maxima						
22th	19	10	15	18.6	28.6	25
28th	20	0	11	38.1	38.1	35
29th	23	0	10	57	57	40
(b) Values for Visakhapatnam and Trivandrum						
30th (00 GMT)	23 (VSK	0	17°43′	23.5	23.5	26
	13) (TRV)	18	08°29′	13.5	31.5	33

Finally, the jet streams observed between Visakhapatnam-Madras at 100 mb on 23 June and similarly on the 28 and 29 June appear to be the vertical extension of the wind maxima observed at 200 mb on the respective nights.

6. Discussion

In almost all the cases where wind maxima have been reported on high level charts of *Young's Atlas* and particularly over the Bay of Bengal on the daytime charts of 19, 20, 21, 22 June 1979 and on the night-time charts of 21, 22, 27, 28, 29 June 1979, they are associated with the well developed cloud system to their northeast. Out of these, three cases on the night charts of 22, 28 and 29 June 1979 are identified when some obvious conclusions can be drawn in the event of strong convection associated with the intensifying depressions. In all the three cases, spots of opposing divergent winds are observed over the systems and the release of latent heat has modified the temperatures of the coastal stations.

Accelerating easterly wind maxima and the divergent north-easterly current in their right rear are helpful in the development process. But in the present three cases it is obvious that the divergent currents have invariably originated from above the cloud region and the jet maxima form from the confluence between those currents and the basic easterly flow south of the subtropical anticyclones. The formation of jet maxima by this process occurs on a synoptic scale and can be explained from the principle of conservation of angular momentum (Reiter 1963). The results are obtained forthwith, in the first two cases. But in the third case the subsidence warming observed between 200-150 mb further modified the flow and explains the mode of the southward displacement of the outflow and positioning of the wind maxima. The formation of wind maxima through this mechanism cause further enhancement of the upper air divergence and therefore the process of development once started appears to be self-amplifying thereafter.

The satellite wind data for the upper troposphere are available for the average height of 200 mb. Therefore explanation for the actual increase in the easterly wind speeds caused by the outflow from the depressions at different heights is still wanting.

7. Conclusion

Easterly wind maxima at 200 mb level over the Bay of Bengal and the Arabian Sea are mostly observed southwest of well organised cloud systems associated with the well marked lows or depressions during monsoon season. In the three cases studied their formation has been explained with the help of conservation of angular momentum when the northeasterly air stream emerging from the cloud system acquires the easterly momentum during its southwest motion. Right to left temperature gradients are observed at 300, 250 and 200 mb looking down stream. Maximum temperature may occur over the region of maximum cloud build up. In the third case study the split in the easterly jet stream observed on 30 June is due to its interaction with the convective storm owing to the subsidence warming on the equatorward leg of the meridional monsoon cell in the vertical.

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