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Some dynamical aspects of meso-scale rainfall events as revealed by physical initialization

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सार — हाल के वर्षों में, सदृशीकरण प्रावस्था के दौरान गतिकीय मॉडल की आरंभिक स्थिति में सुधार लाने के लिए भौतिक प्रारंभिक स्थापन का एक सशक्त माध्यम के रूप में अविर्भाव हुआ है। उच्च विभेदन भूमंडलीय स्पैक्ट्रल मॉडल इस आरंभिक विकसित स्थिति में उष्णकटिबंधीय मेसोस्केल कवरेज उपलब्ध कराने में सक्षम रहा है। इस लेख में मेसोस्केल वर्षा की घटनाओं के कुछ गतिकीय पहलुओं का अध्ययन करने के लिए मॉडल निर्गत का प्रयोग किया गया है। इस अध्ययन से प्राप्त हुई कुछ मुख्य उपलब्धियाँ इस प्रकार हैं : (*i*) अपसरण के ऊर्ध्वाधरीय प्रोफाइलों और ऊर्ध्वाधरीय उन्नत गति में मेसोस्केल वर्षा की घटनाएं सुस्पष्ट गतिकीय संरचना का संवहन करती हैं; (*ii*) मोसोस्केल की घटनाओं से इन ऊर्ध्वाधरीय प्रोफाइलों में बड़े पैमाने पर दैनिक परिवर्तन का पता चलता है और (*iii*) मेसोस्केल संगठन का ऊर्ध्वाधरीय गति क्षेत्र उष्णकटिबंधीय तूफानों की उत्पत्ति में महत्वपूर्ण भूमिका निभाता है।

ABSTRACT. In recent years, physical initialization has emerged as a powerful tool to improve initial state of dynamical model during assimilation phase. This improved initial state at high resolution global spectral model is able to provide a tropical meso-scale coverage. In this paper, model out-put is used to study some dynamical aspects of meso-scale rainfall events. Major findings of this study are : (*i*) Meso-scale rainfall event carries a distinct dynamic structure in vertical profiles of divergence and vertical upward motion, (*ii*) Meso-scale event exhibits a large diurnal variation in these vertical profiles and (*iii*) Vertical motion field of meso-scale organisation appears to play a significant role in tropical storm formation.

Key words — Meso-scale, Physical initialisation, Global spectral model.

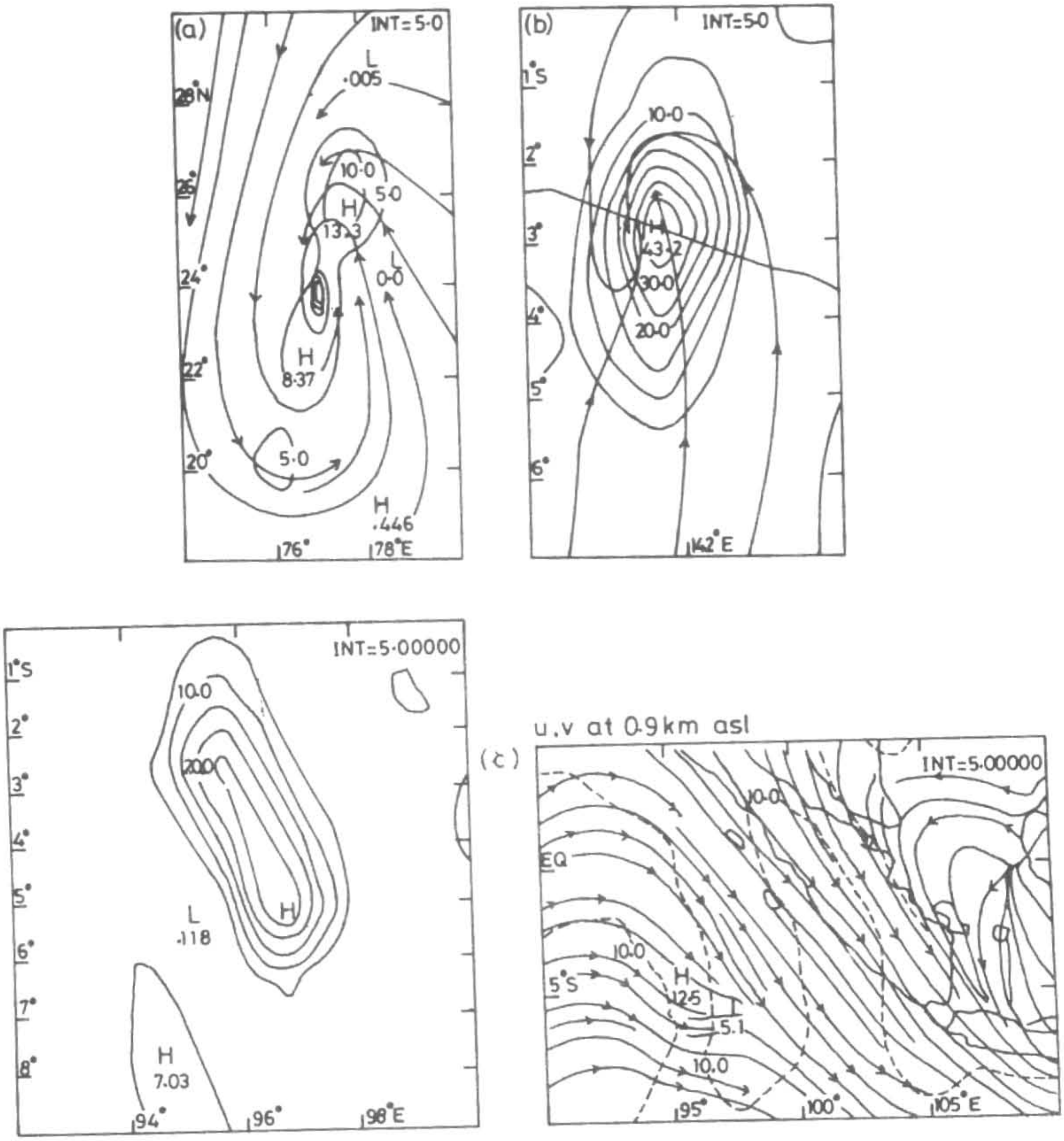
1. Introduction

In absence of meso-scale network it is difficult to study the dynamics of life cycle of meso-scale rainfall events. Recent study (Krishnamurti *et al.* 1995, Yap 1992) shows that physical initialization performed in a high resolution dynamical model is able to capture meso-scale rainfall events providing a tropical meso-scale coverage. This suggests, in absence of meso-scale data one may rely on physical initialization for interesting evolution of dynamics of meso-scale rainfall events.

Physical initialization refers to the use of reverse algorithms consistent with the physics of dynamical model during assimilation phase which can provide a modification of initial state via incorporation of tropical "rain-rates" as input. The observed rain rates are obtained from a mix of surface and space- based system. The space-based rainfall measures are derived from outgoing long wave radiation and from the microwave radiometer-based algorithm (Olson *et al.* 1990, Krishnamurti *et al.* 1993).

The foot print of this satellite radiometer is of the order of 50 km. The transform grid resolution of the global model at the resolution T 213 (horizontal resolution of 213 waves using triangular truncation) closely matches the foot print of this satellite foot print data.

The computational areas of physical initialization process include: (*i*) calculation of surface flux of moisture following Yanai technique (Yanai *et al.* 1973); (*ii*) use of reverse similarity theory to obtain the humidity variable at the top of the constant flux layer consistent with the moisture flux; (*iii*) use of reverse cumulus parametrization algorithm to obtain vertical restructuring of the moisture variable consistent with the observed rain rates; (*iv*) a further restructuring of the moisture variable in the upper troposphere using a bisection method that minimizes the difference between satellite based and model based out going long wave radiation and finally (*v*) a Newtonian relaxation method is used during the period between -24 to 00 hours of forecast when the model is spun up to accept, as closely



Figs.1(a-c). Meso-scale rainfall events on 22 August 1200 UTC, 1992 for initialised field over (a) north central India, (b) New Guinea and (c) Indian Ocean

as possible, the observed rain rates and modified humidity field.

The details of the above process are presented by Krishnamurti *et al.* (1991).

Physical initialization algorithms are incorporated in the global spectral model of resolution T 213. In this paper, model output is used to study some dynamical features of meso-scale rainfall events. This work is an extension of the previously obtained results presented by Krishnamurti *et al.* (1995), Roy Bhowmik (1994). The outline of the global spectral model used in this study is presented by Krishnamurti *et al.* (1995).

2. Summary of past work

In recent papers (Krishnamurti) *et al.* 1995, Roy Bhowmik (1994) potential of physical initialization from the use of high resolution (T 213) global spectral model was investigated. The study established that physical initialization at

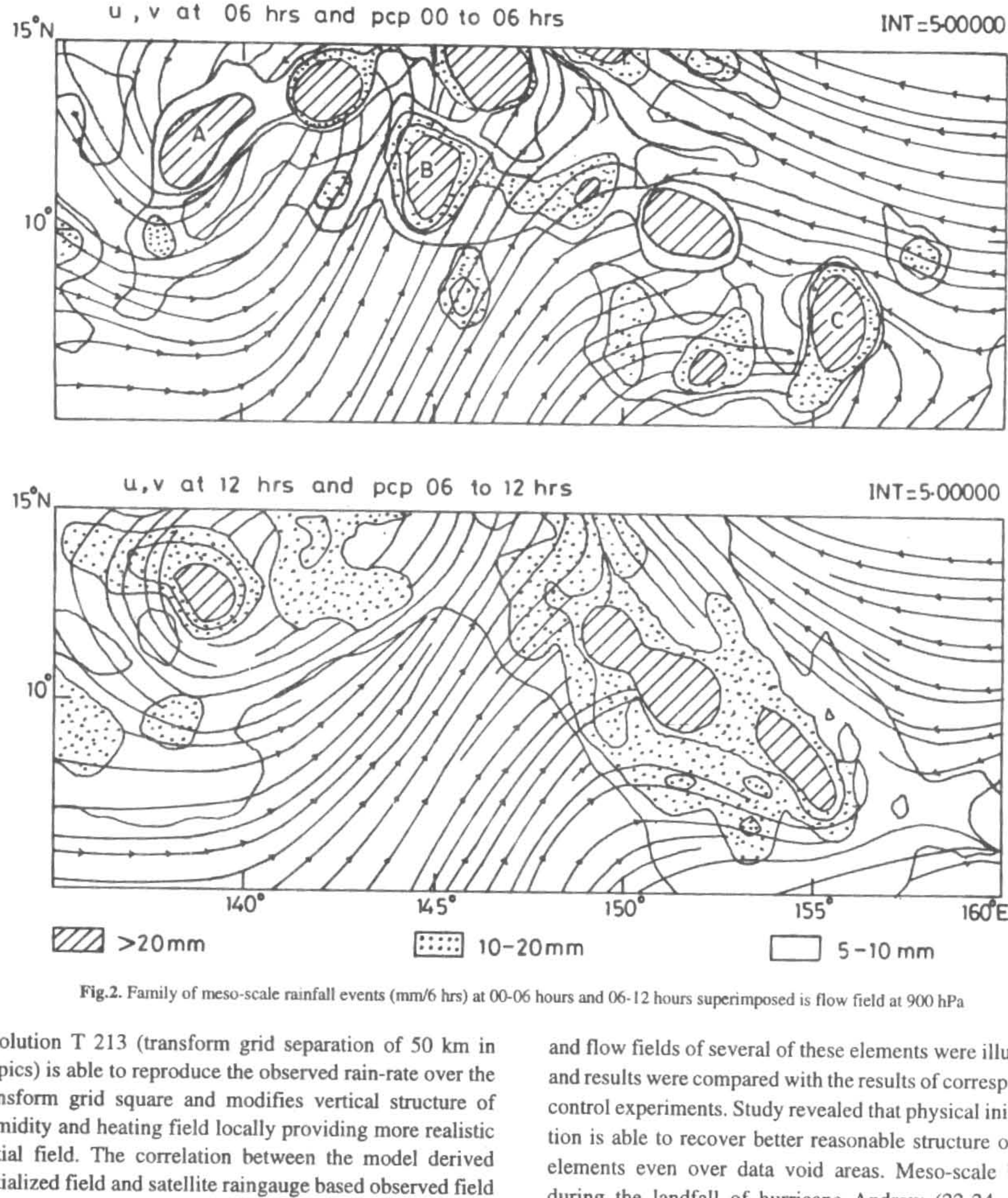
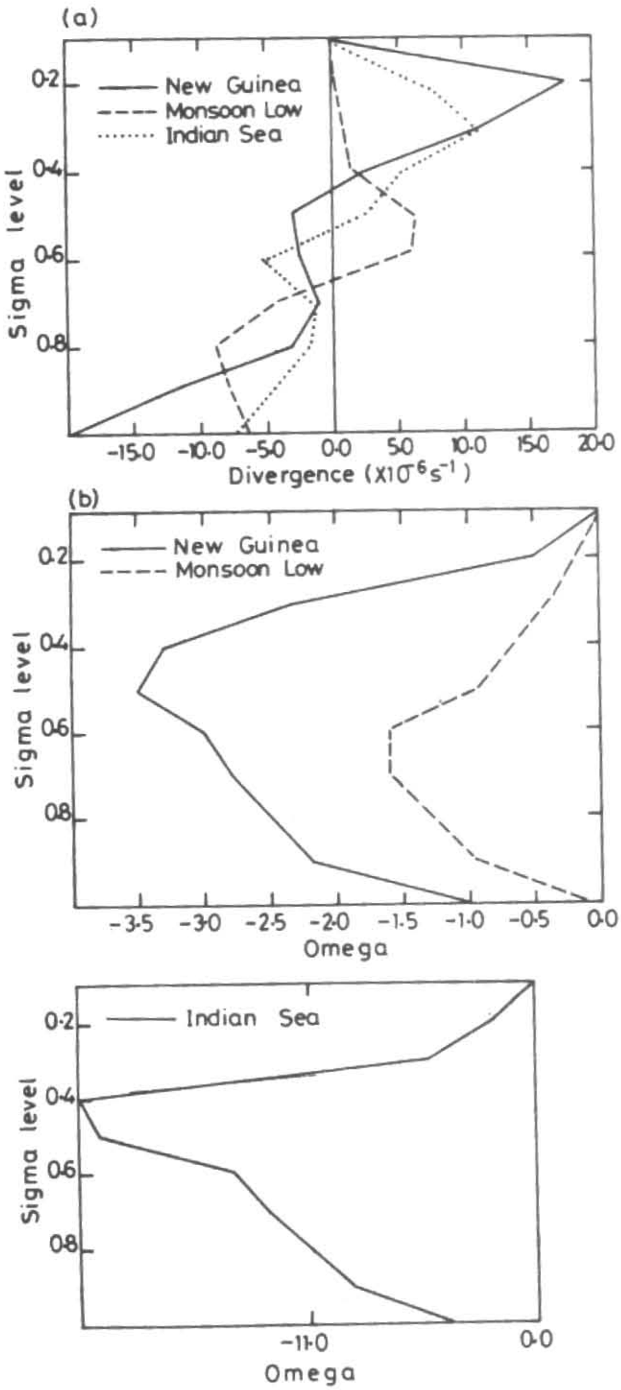


Fig.2. Family of meso-scale rainfall events (mm/6 hrs) at 00-06 hours and 06-12 hours superimposed is flow field at 900 hPa

resolution T 213 (transform grid separation of 50 km in tropics) is able to reproduce the observed rain-rate over the transform grid square and modifies vertical structure of humidity and heating field locally providing more realistic initial field. The correlation between the model derived initialized field and satellite raingauge based observed field of 24 hours rainfall total (mm/day) at 1200 UTC of 22 August 1992 over the entire global tropics is of the order of 0.85. This compares with corresponding number 0.3 for model that do not include physical initialization. This procedure improves the nowcasting skill and one day forecast skill. There were roughly 47 meso-scale rainfall elements over the entire global tropics revealed following physical initialization on 22 August 1992 at 1200 UTC. Precipitation and flow fields of several of these elements were illustrated and results were compared with the results of corresponding control experiments. Study revealed that physical initialization is able to recover better reasonable structure of these elements even over data void areas. Meso-scale history during the landfall of hurricane Andrew (22-24 August 1992) was examined.

Experiment was repeated at lower resolutions T 170 and T 106. 48 hours predicted fields of sea level pressure, 850 hPa geopotential height, temperature and winds at resolution T 213 clearly demonstrated the intensification of this hurricane, as was noted from observation. Thermal field at 850 hPa showed formation of warm-core. The amplitude of



Figs.3(a & b). Vertical profile of (a) Divergence (x 10^{-6} sec^{-1}) and (b) Omega (x 10^{-4} hPa sec^{-1}).

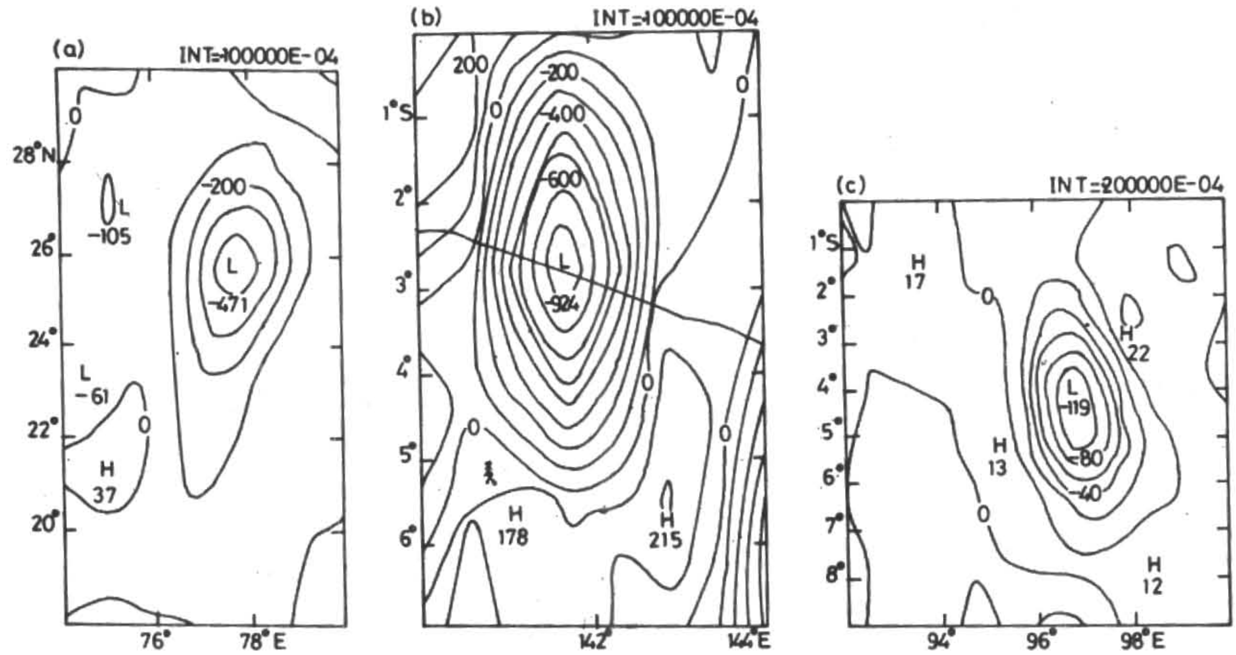
warm core was roughly 7°C. A reasonable pressure fall from 1013 hPa to 968 hPa and build up of winds (max. wind 62 ms^{-1}) was attained at 48 hours of forecast. The maximum observed surface wind was 60 to 70 ms^{-1}. Six hourly precipitation field between 24 to 30 hours of forecast was compared with radar image from weather service radar. It was observed that model at resolution T 213 could discern the eye and outer rain bands of Andrew quite similar to that of radar image. These interesting results prompted author to take up the present study.

3. Data and method

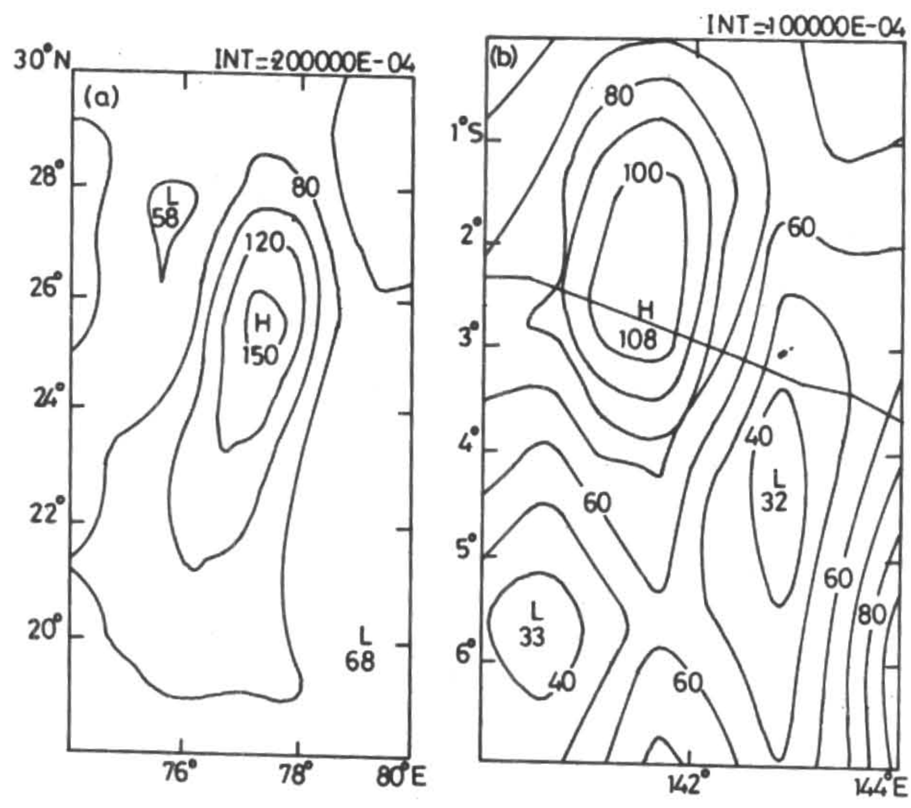
In the present study out-put data from the global spectral model of resolution T 213 is used to study some dynamical aspects of meso-scale rainfall events. In order to illustrate the dynamic structure of meso-scale rainfall events three meso-scale rainfall events as revealed in 00-03 hours forecast on 22 August 1992 at 1200 UTC are considered. Meso-scale rainfall events selected are: (*i*) a monsoon low pressure area over north India at around latitude 24° N and longitude 77° E, Fig.1(a); (*ii*) at the tip of New Guinea around latitude 3.5 ° S and longitude 141.5° E, a region of nearly equatorial eddy, Fig.1(b) and (*iii*) over Indian ocean at around latitude 5 ° S and longitude 97 ° E in association with confluence of northerly wind, Fig.1(c). Initialised flow field at 900 hPa and super- imposed rainfall amount (mm per 3 hours) of these meso-scale elements are presented in Figs.1(a-c).

Diurnal changes of the vertical profile of few meso-scale rainfall events over western Pacific are examined using results of six hourly forecast based on improved initial state from physical initialization for the area between latitude 5° N to 15° N and longitude 135° E to 160° E. The forecast carried out at global spectral model of resolution T 213. The initial state (*i.e.*, t=0) for prediction experiment was selected on 22 August 1992 at 1200 UTC (*i.e.*, 7 pm in local time). Physical initialization was carried out between -24 and 00 hours commencing on 21 August 1992 at 1200 UTC.

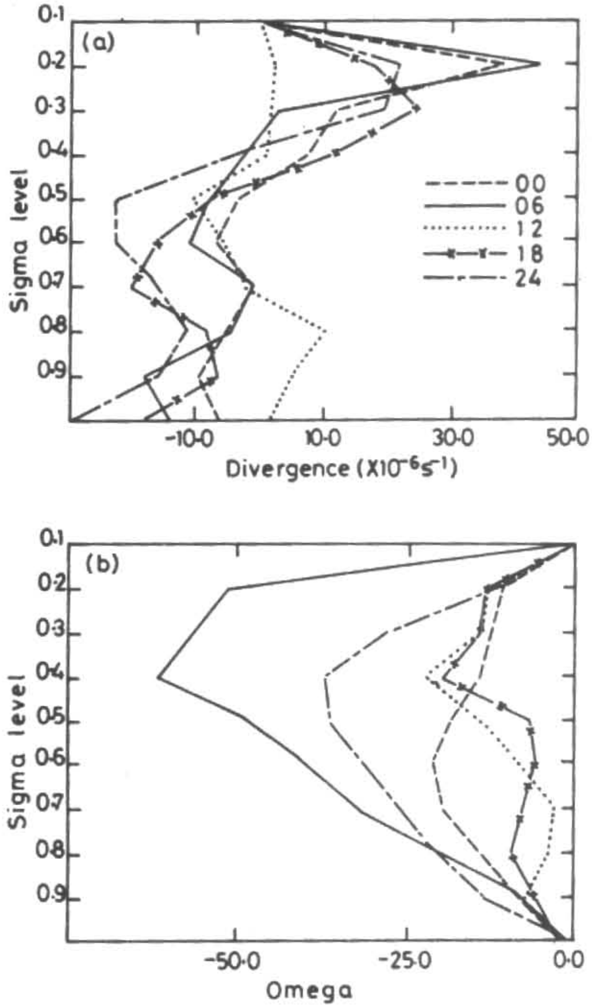
Fig.2 illustrates predicted precipitation and wind field at 900 hPa at 00-06 hours and 06-12 hours. Dark shading indicates rainfall ≥ 20 mm/6 hours and other shadings indicate rainfall amount 10 to 20 mm and 5 to 10 mm per 6 hours respectively. It is noticed that Fig. 2 is characterised by a family of active meso-scale rainfall events. From this family 3 events marked as A, B and C respectively are selected. Events A and C are long lasting, appeared as systems in easterlies and later on became tropical depression Polly centered around latitude 17.4° N and longitude 136.9° E at 1200 UTC of 25 August and tropical depression Omar centered around latitude 9.2° N and longitude 153.2° E at 0600 UTC of 24 August respectively. The event B was short lived and disappeared in 12 to 18 hours.



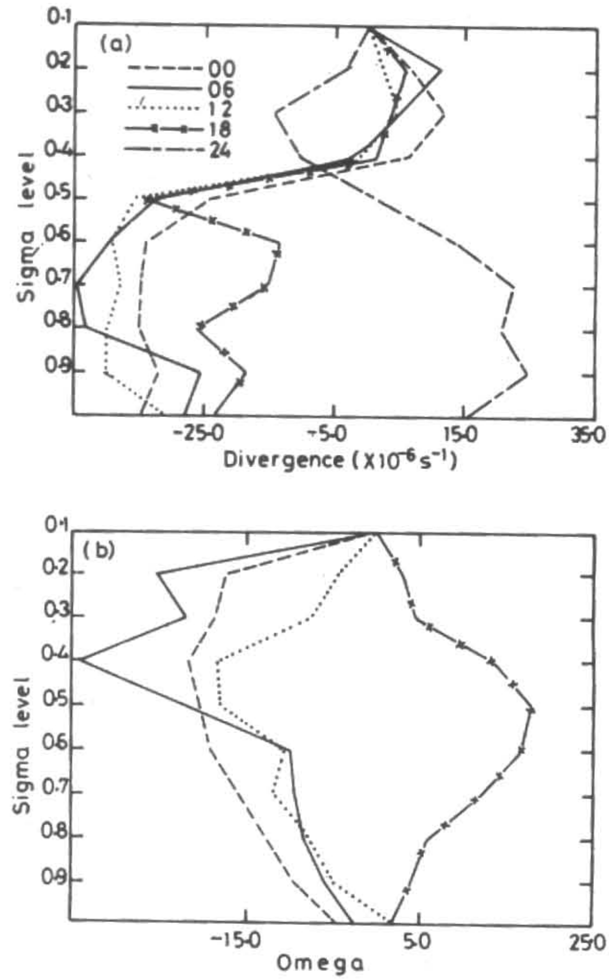
Figs.4(a-c). Horizontal field of divergence (0.1 x 10^{-4} sec^{-1}) at 900 hPa for (a) monsoon low, (b) the event near New Guinea and (c) the event over the Indian Ocean



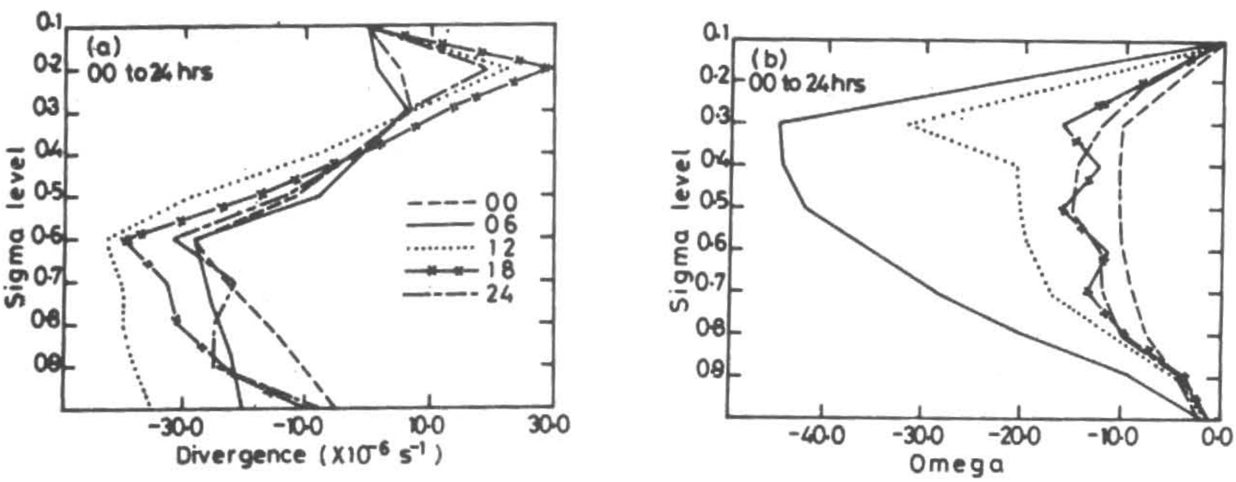
Figs.5(a & b). Horizontal field of vorticity (0.1 x 10^{-4} sec^{-1}) at 900 hPa for (a) monsoon low and (b) the event near New Guinea



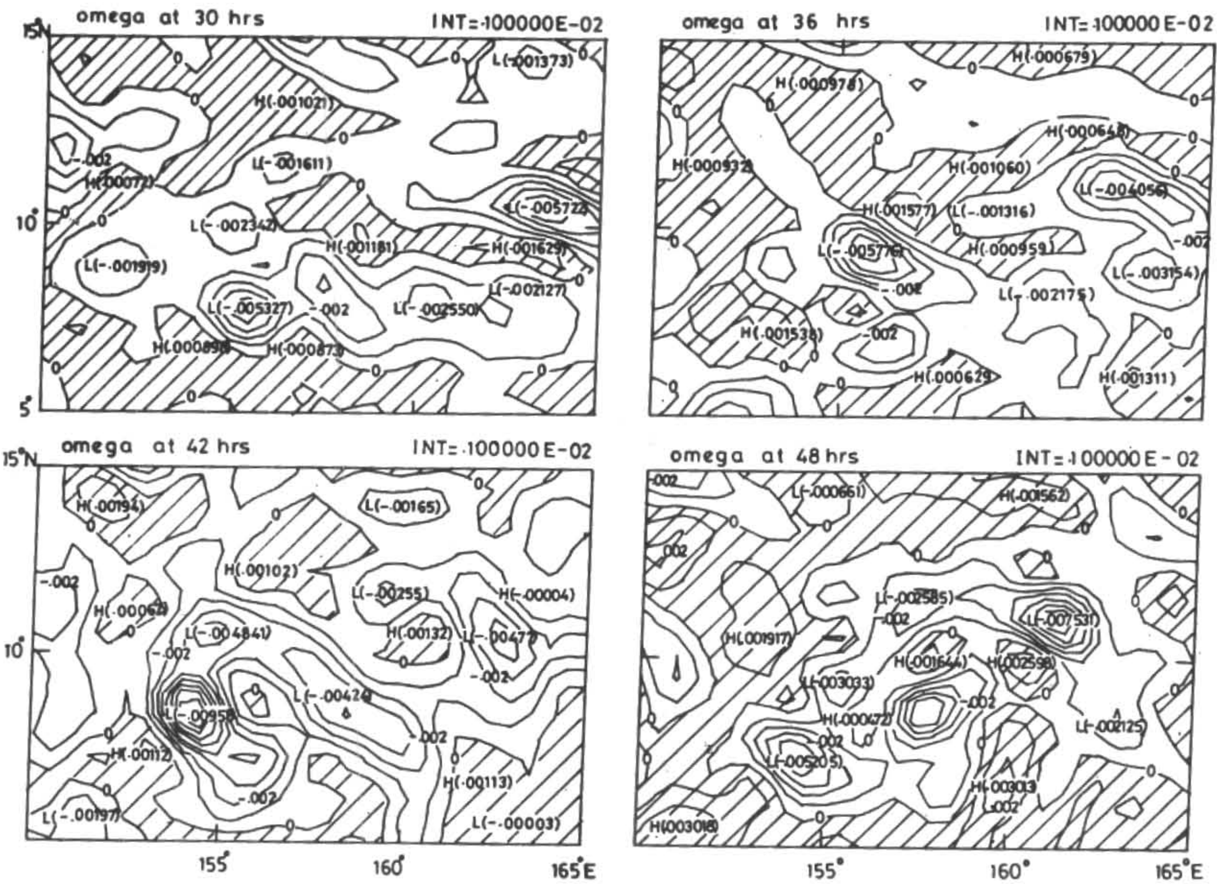
Figs.6(a & b). Six hourly changes in vertical profile of element 'A' during 00-24 hours;(a) Divergence (x 10^{-6} sec^{-1}) and (b) Omega (x 10^{-4} hPa sec^{-1})



Figs.7(a & b). Six hourly changes in vertical profile of element 'B' during 00-24 hours; (a) Divergence (x 10^{-6} sec^{-1}) and (b) Omega (x 10^{-4} hPa sec^{-1})



Figs.8(a & b). Six hourly changes in vertical profile of element 'C' during 00-24 hours; (a) Divergence (x 10^{-6} sec^{-1}) and (b) Omega (x 10^{-4} hPa sec^{-1})



Figs.9(a-d). Six hourly omega isopleths (0.1×10^{-2} hPa sec^{-1}) at 900 hPa

4. Results and discussion

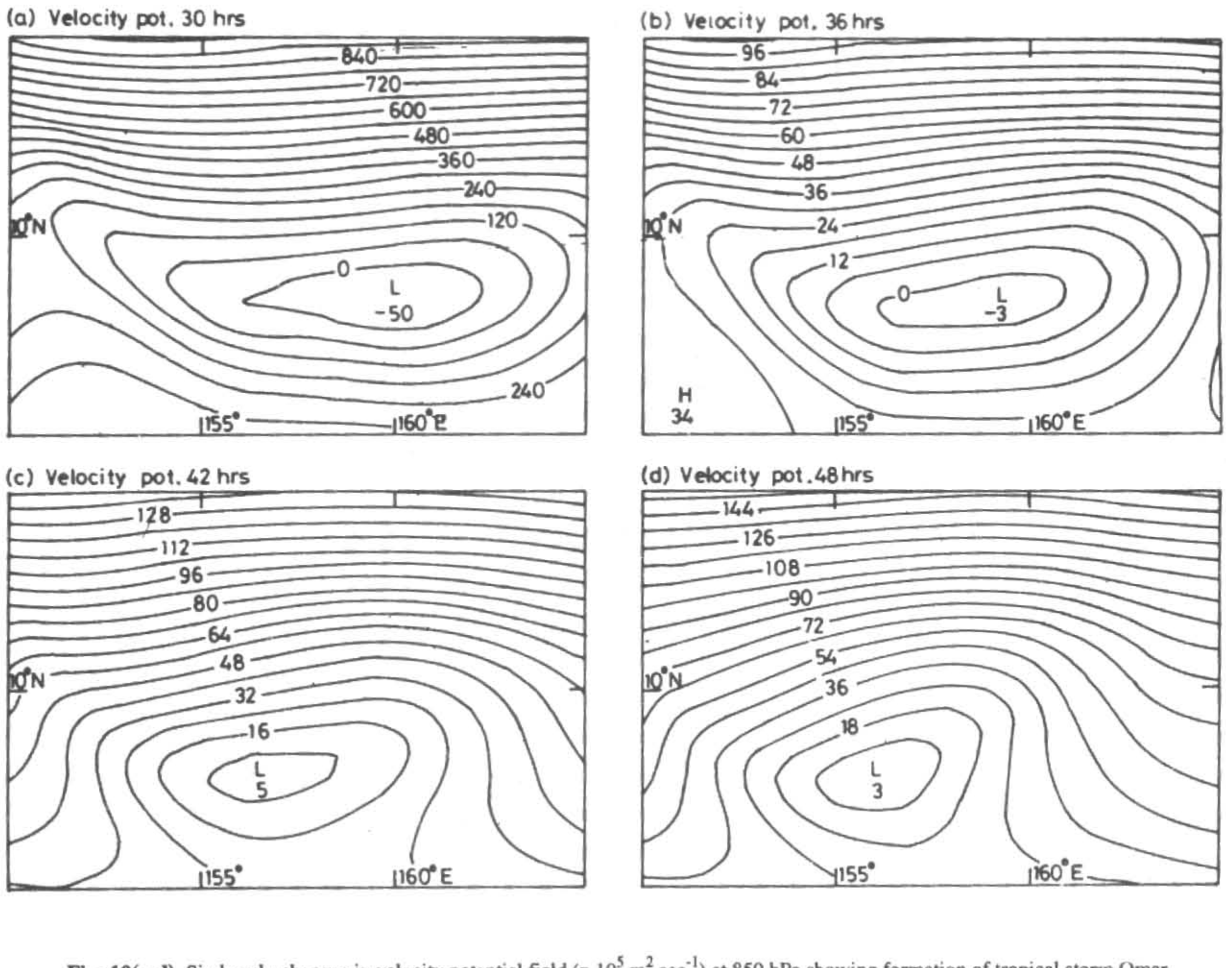
4.1. *Dynamic structure of meso-scale rainfall events*

Results of vertical structure of divergence and omaga (vertical upward motion) over a 4° latitude/longitude square centered over each of the meso-scale rainfall events over north India, New Guinea and Indian Ocean are presented in Figs.3(a & b) respectively.

The divergence profile shows that there is a layer of convergence which extends up to lower/mid tropospheric levels with divergence prevailing in the upper troposphere. For the monsoon low, convergence is maximum at 800 hPa and magnitude is of order -9×10^{-6} per second and maximum divergence of magnitude 8×10^{-6} per second occurs at 500 hPa.

It is interesting to note that both the meso-scale events over equatorial zone (that is, the events over Indian Ocean and New Guinea) exhibit two maxima in divergence profile, with primary peak at the surface and secondary between 600 and 500 hPa. For the event over Indian Ocean maximum convergence of order -8×10^{-6} per second occurs at the surface, nearing the zero between 700 and 600 hPa and attains maximum divergence of order 12×10^{-6} per second at 300 hPa. The pattern is similar to that of New Guinea where maximum convergence of order -20×10^{-6} per second is at the surface and maximum divergence of order 17×10^{-6} per second at 200 hPa. Convergence extends all the way up to 400 hPa. The corresponding profile of vertical upward motion shows that for monsoon low the maximum omega of order -1.5×10^{-3} per second occurs at 700 hPa.

For the meso-scale event near New Guinea maximum omega of order -3.5×10^{-3} per second at 500 hPa and for the event in Indian Ocean maximum is of order -22×10^{-3} per second at 400 hPa. Corresponding horizontal field of divergence at 900 hPa are presented in Figs.4(a-c) and vorticity field in Figs.5(a & b). As the system over Indian Ocean was in association with the confluence of northerly winds, no organised field of vorticity is noticed and hence not presented here. It is observed that for both the meso-scale rainfall events in equatorial zone, highest rainfall point is coinciding with the corresponding maximum convergence/vorticity point. But for monsoon low maximum rainfall is to the south sector.



Figs.10(a-d). Six hourly changes in velocity potential field (x 10^5 m^2 sec^{-1}) at 850 hPa showing formation of tropical storm Omar

4.2. *Diurnal changes in vertical profile of meso-scale rainfall events*

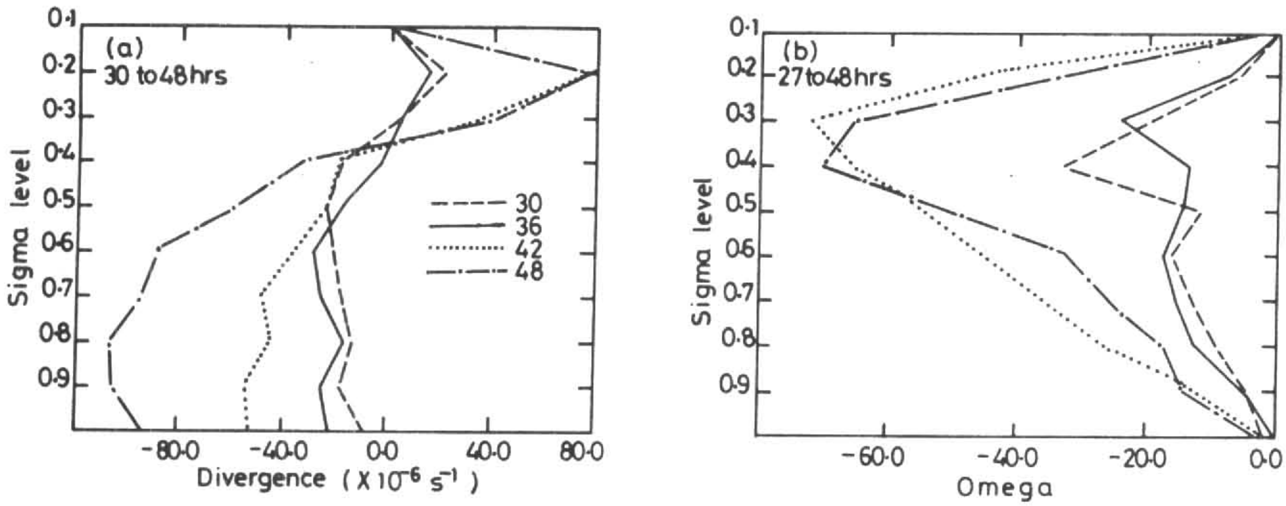
Every six hourly changes in the vertical profiles of divergence and omega of element A, B and C (in Fig.2) during 00-24 hours are presented in Figs. 6(a & b), 7(a & b) and 8(a & b) respectively. It is noticed that for all the cases there have been well marked enhancement in the omega profile during 00-06 hours and weakening during 12-18 hours.

For the element A enhancement in the divergence profile occurs during 00-06 hours and for elements B and C during 00-12 hours, weakening occurs at 12 hours for A and during 12-18 hours for B and C. This shows that there is a marked enhancement in the vertical profile during mid night to early morning hours and weakening in the noon to afternoon hours which is consistent with the general belief that oceanic intense precipitation shows a maximum in the early morning hours. This may be because of radiative effect due to differential heating over cloudy and cloud free region.

4.3. *Role of meso-scale organisation in the formation of tropical storm*

In tropics, within easterly waves there always exists a population of meso-convective cloud elements. The prevailing lower tropospheric flow advects these meso-convective cloud systems. As a consequence the location of such elements organises along a quasi-circular geometry. A current hypothesis on tropical storm formation (Holland and Dietachmayer 1993, Lander and Holland 1993, Ritche and Holland 1993) emphasizes a notion on sweeping of vorticity of meso-convective cloud clusters by the prevailing tropical flows. In our earlier study (Krishnamurti *et al.* 1995) this hypothesis is examined following meso-scale precipating elements during formation of tropical storm Omar and schematically illustrated how sweeping and coalescing of meso-scale precipating elements within a tropical wave can undergo an intensification into a tropical storm.

A clear understanding of the process that leads to formation of meso-scale vortex to meso-scale convection complexes is yet to emerge. The conventional view point is that



Figs.11(a & b). Six hourly changes in vertical profile of (a) Divergence (x 10^{-6} sec^{-1}) and (b) Omega (x 10^{-4} hPa sec^{-1})) during 30-48 hours of the meso-scale element 'C'

cumulonimbus convection is required to provide the latent heat release. There is also inadequate knowledge regarding the relative importance of cumulus convection and meso-scale ascending motion in the genesis of cyclone. This is because of absence of observational data over oceanic areas. Houze (1992) emphasizes that effect of meso-scale vertical motion is to raise the level of maximum heating. Here the meso-scale history of vertical ascending motion field during formation of tropical storm Omar is examined. This storm formed and moved over western Pacific during the period 24 August through 6 September,1992. The period of our interest is during formative stage of the tropical strom Omar. In Figs.9 (a- d) the six hourly predicted omega field at 900 hPa is presented. Here, area without shading indicates ascending motion.

A considerable meso-scale activity of ascending motion field is noted. It was possible to tag these meso-scale elements by numerical levels and follow them during formation of storm Omar. The starting hour 30 of forecast corresponds to 23 August at 0600 UTC. During the following 18 hours tropical storm Omar forms from tropical depression. Initially at 30 hour 4 taged meso-scale elements of vertical upward motion 1,2,3 and 4 are observed. At 36 hour element 1 moved north-west, element 2 in same location but more intense and a new element 5 is seen south of the element 1. At 42 hour elements 1 and 2 are less marked and element 3 is seen more marked. At 48 hour element 5 moved further north west, both of elements 4 and 5 further intensified, all these elements are located along the storm's circulation centre and the system became more intense. Corresponding six hourly changes in velocity potential field at 850 hPa are presented in Figs.10(a-d).

It appears that meso-scale ascending motion elements swept by a weak vortex which undergoes a strengthening as these meso-scale elements organise leading to enhancement of circulation. It is also observed a strong enhancement in vertical profile of divergence and omega in Figs.11 (a & b) of the parent vortex (element 'C') during 42 to 48 hours. This enhancement occurs as these meso-scale elements are being swept into the storm circulation. This study emphasizes the role of meso-scale vertical motion which was more critical during development of storm Omar.

5. Conclusions

Following conclusions can be drawn from this study:

(*i*) Meso-scale rainfall event carries a robust picture of lower- tropospheric convergence and upper tropospheric divergence. Meso- scale events over the equatorial zone exhibit two maxima in their vertical profile of convergence, one at the surface and other between 600 and 500 hPa. For the monsoon low maximum convergence is at 800 hPa.

(*ii*) For the monsoon low maximum omega (vertical upward motion) occurs at 700 hPa whereas for the events over equatorial zone maximum omega occurs between 500 and 400 hPa.

(*iii*) Meso-scale rainfall events over oceanic areas show interesting diurnal variation in their vertical profile of divergence and omega. Marked enhancement of vertical structure occurs during mid-night to early morning hours.

(*iv*) Vertical motion field of meso-scale organisation appears to play a significant role in tropical storm formation following sweeping along a quasi-circular geometry.

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