MAUSAM, **57**, 1 (January 2006), 31-36

551.511 : 551.515.2 (541.5)

Mesoscale interactions during the genesis and intensification of October 1999 Orissa super cyclone

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सार – यह सर्वविदित तथ्य है कि पूर्ण विकसित उष्णकटिबंधीय चक्रवात में प्रायः अक्षसमानुपातिक संरचना पाई जाती है जबकि चक्रवात के बनने की अवस्था में अत्याधिक असंगति दिखाई देती है। प्रशांत महासागर में हाल ही में किए गए अध्ययनों और प्रेक्षणों से यह पता चला है कि उष्णकटिबंधीय चक्रवातों की उत्पत्ति का पता लगााने में मेसोस्केल की परस्पर क्रियाऐं महत्वपूर्ण भूमिका निभा सकती हैं। उष्णकटिबंधीय चक्रवात की उत्पत्ति के आधुनिक सिद्धांत भी उपर्युक्त पूर्वकथित तथ्य पर आधारित हैं। इस शोध–पत्र में आई. आर. उपग्रह से प्राप्त विम्बावली और बड़े पैमाने पर भ्रमिलता के क्षेत्रों का विश्लेषण प्रस्तुत किया गया है। जिनमें यह देखा गया है कि 1999 में उड़ीसा में आए महाचक्रवात की भी प्रारम्भिक अवस्थाओं में मेसोस्केल से चक्रवात के बवंडर की परस्पर क्रियाओं का पता लगा है।

ABSTRACT. It is well known that a mature tropical cyclone is known to have a nearly axisymmetric structure but that the formation stage exhibits considerable asymmetry. Recent studies and observations in the Pacific indicate that mesoscale interactions could play an important role in the genesis of tropical cyclones. Modern theories of tropical cyclone genesis are also based on this premise. In this paper, an analysis of the IR satellite imagery and large scale vorticity fields is presented, which shows that mesoscale vortex interactions occur in the early stages of the 1999 Orissa super cyclone also.

Key words − Mesoscale convection, Intensification of Super cyclone.

1. Introduction

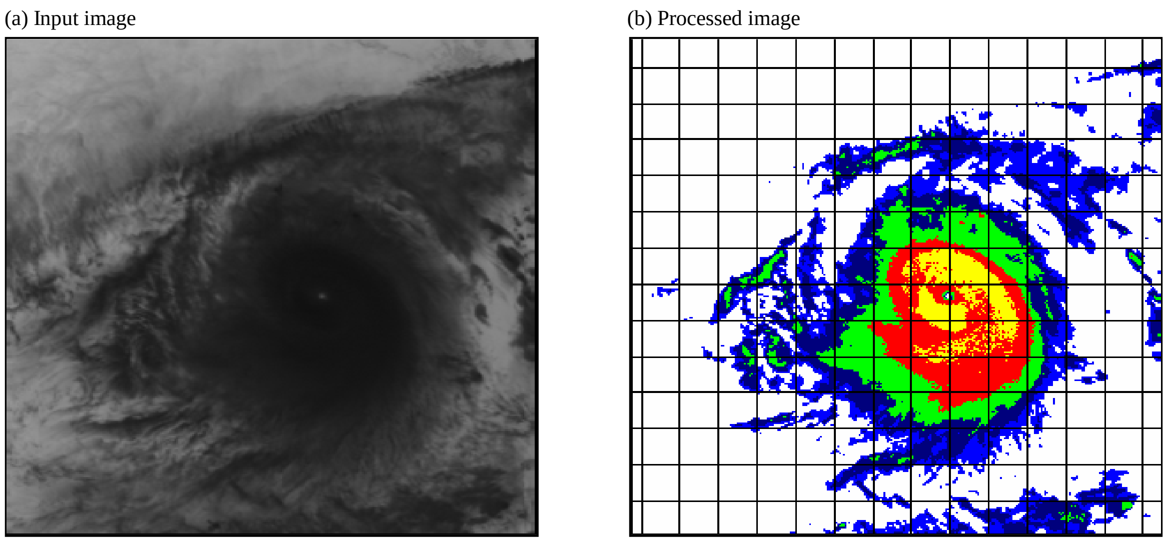
The early stages of a tropical cyclone (TC) are extremely complex and their understanding presents a challenge to researchers worldwide. While the necessary climatic conditions for formation have been known for a long time (Gray, 1968), identifying the critical factors that determine which cloud clusters will eventually develop into TCs is still the subject of research. Previous theories such as CISK (Charney and Eliassen, 1964) and WISHE (Emanuel, 1986, Rotunno and Emanuel, 1987) have considered how a deep axisymmetric initial vortex intensifies. Recent studies however point to the interaction of multiple mesoscale structures, during the early stages of formation. These include the observations of Karyampudi and Pierce (2002) and the theoretical and observational studies in the Pacific by Ritchie and Holland (1997) and Simpson *et al*. (1997). Consistent with these ideas, the hypothesis that merger of mesoscale convective vortices (MCV) is a common precursor event during TC formation has been proposed by Venkatesh (2003) and also used as a tool for predicting TC genesis (Venkatesh and Mathew, 2004) in the Bay of Bengal with some success.

The 1999 super cyclone in the Bay of Bengal was a very intense system and one would expect therefore that a clear indication of such mesoscale interaction would be present in the observed satellite data. The detailed case history of this tropical cyclone has been given by the earlier paper in this volume by Kalsi. In this paper, an observational analysis of the mesoscale structures in the early stages of the super cyclone formation is presented and we show that mesoscale interactions indeed exist.

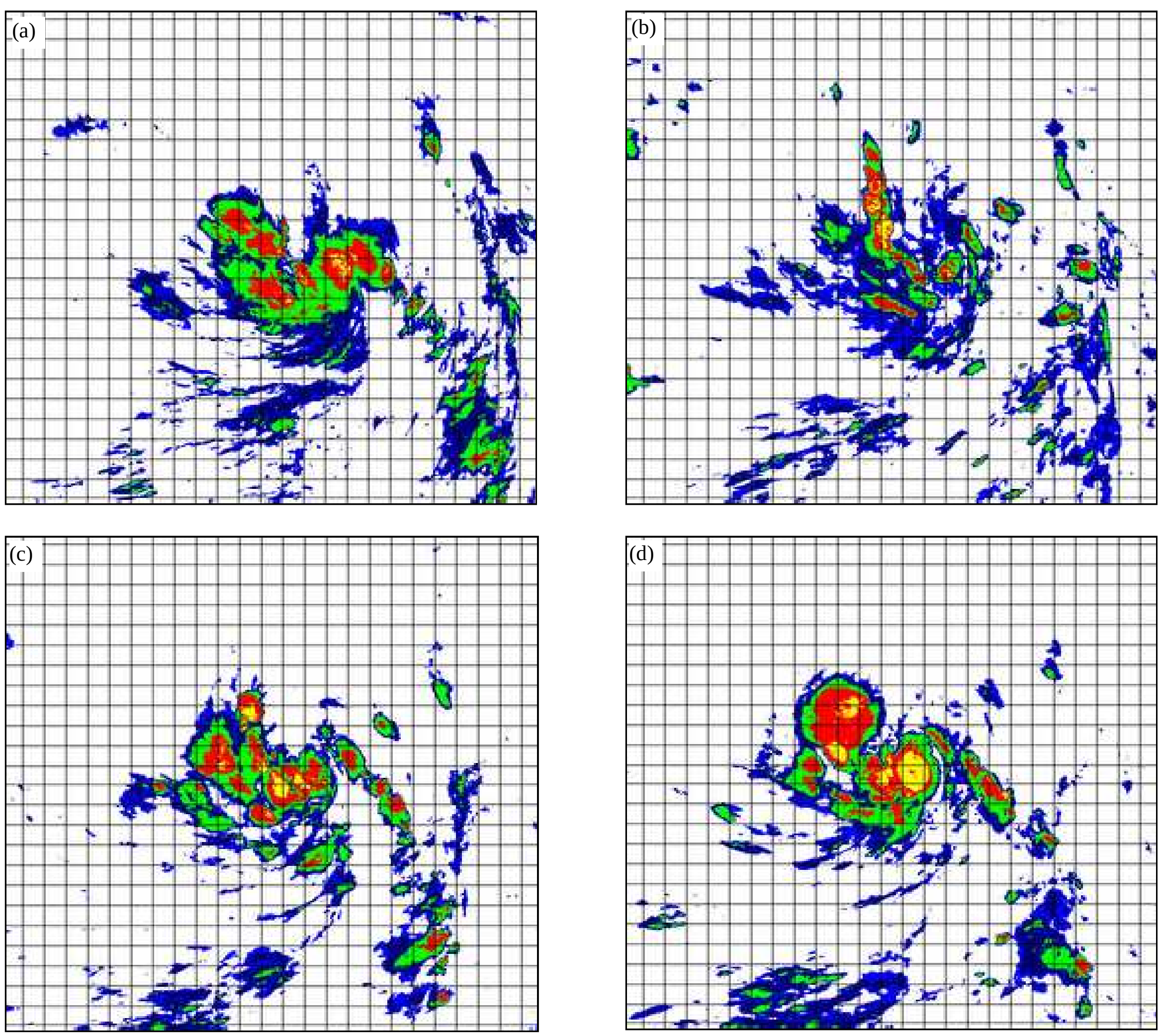
2. Data and methods

As mentioned before, Ritchie and Holland (1997) and Simpson *et al*. (1997) have documented the interaction of mesoscale vortices during the formation of tropical cyclones in the Pacific. Similar interactions can be observed in the following analyses of the Bay of Bengal super cyclone of 1999. Satellite images from geostationary satellites METEOSAT and the pixel data over the Bay of Bengal provided by EUMETSAT (http://www.eumetsat.de) have been used. Wind data (though at a coarser resolution than that of satellite images) from European Centre for Medium-Range Weather Forecasts (ECMWF) have been used to correlate the vorticity field with the structures observed in the images.

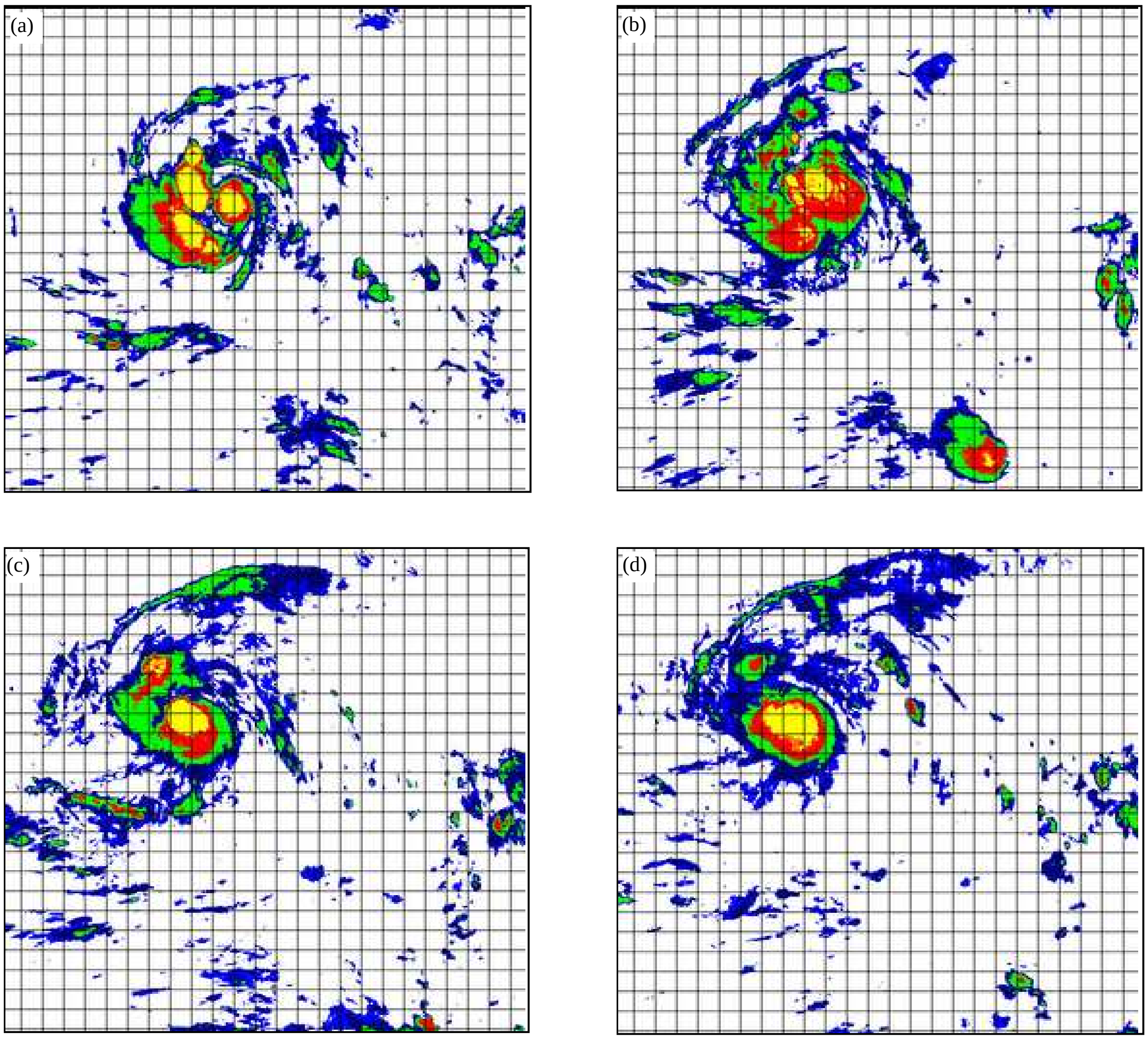
The IR data was provided by EUMETSAT as grayscale images in the TIFF format. In these images,



Figs. 1(a&b). Pseudo coloring based on IR temperatures. (a) Input image and (b) Processed image



Figs. 2(a-d). Orissa Cyclone : 25 October, 1999. (a) 0600 UTC, (b) 1200 UTC, (c) 1800 UTC and (d) 2300 UTC. Longitude/Latitude limits: 83° E – 108° E / 0° – 25° N



Figs. 3(a-d). Orissa Cyclone : (a) 26 October, 1800 UTC, (b) 27 October, 0000 UTC, (c) 27 October, 0800 UTC and (d) 27 October, 1200 UTC. Longitude/Latitude limits: 83° E – 108° E / 0° – 25° N

regions of low temperature are dark, while regions of high temperature are bright. The RGB value at a pixel is called the count which corresponds to the radiance which is in turn dependent on the temperature. These images were converted to pseudo colour images in the following way. First the count values C at every pixel were converted to radiances R (W/m^2) by the formula $R = \alpha(C - C_0)$ where α and C_0 are calibration constants. The radiance was converted to temperature (T) using the relation

$$R = \exp\left(A + \frac{B}{T}\right)$$

where A and B are the best fit values for the EUMETSAT data. The values are A = 6.7348, B = -1272.20, α = 0.080 and C_0 = 6.

The temperature levels chosen for the shading were 190, 200, 210, 220 and 230 Kelvin. The colouring of the temperature levels was as follows: Yellow (< 190 K); Red (190 – 200 K); Green (200 - 210 K); Dark Blue (210 - 220 K); Blue (220 - 230 K). These thresholds highlight mesoscale convective systems. The effect of pseudo colouring is illustrated in Figs. 1(a&b). One can see that the structure which is difficult to make out from the input image is quite clear from the processed image.

3. Interaction of the mesoscale structures

In this section we study the mesoscale structures during the period 25 to 27 October 1999, when the depression underwent intensification and became a very severe cyclonic storm.

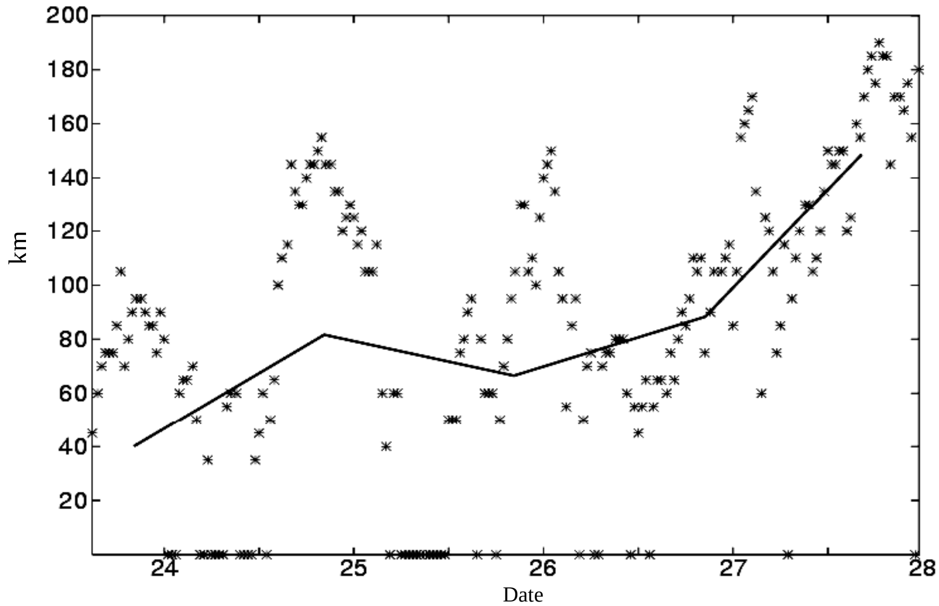
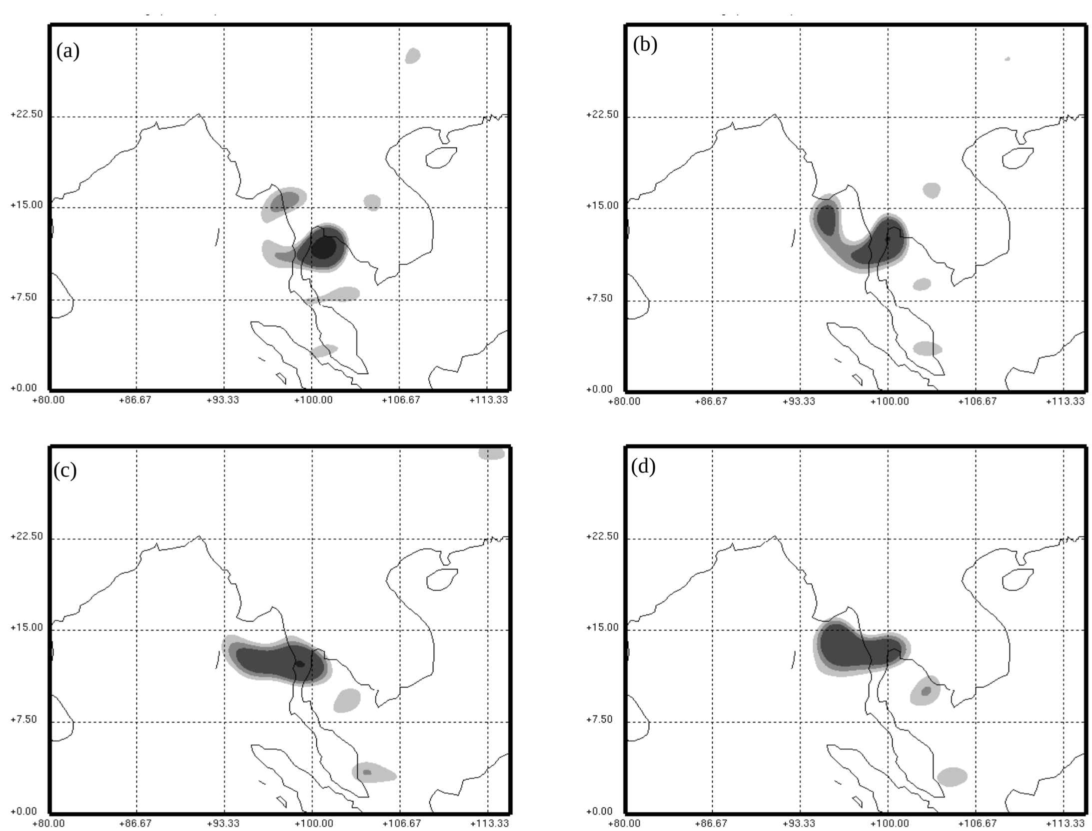
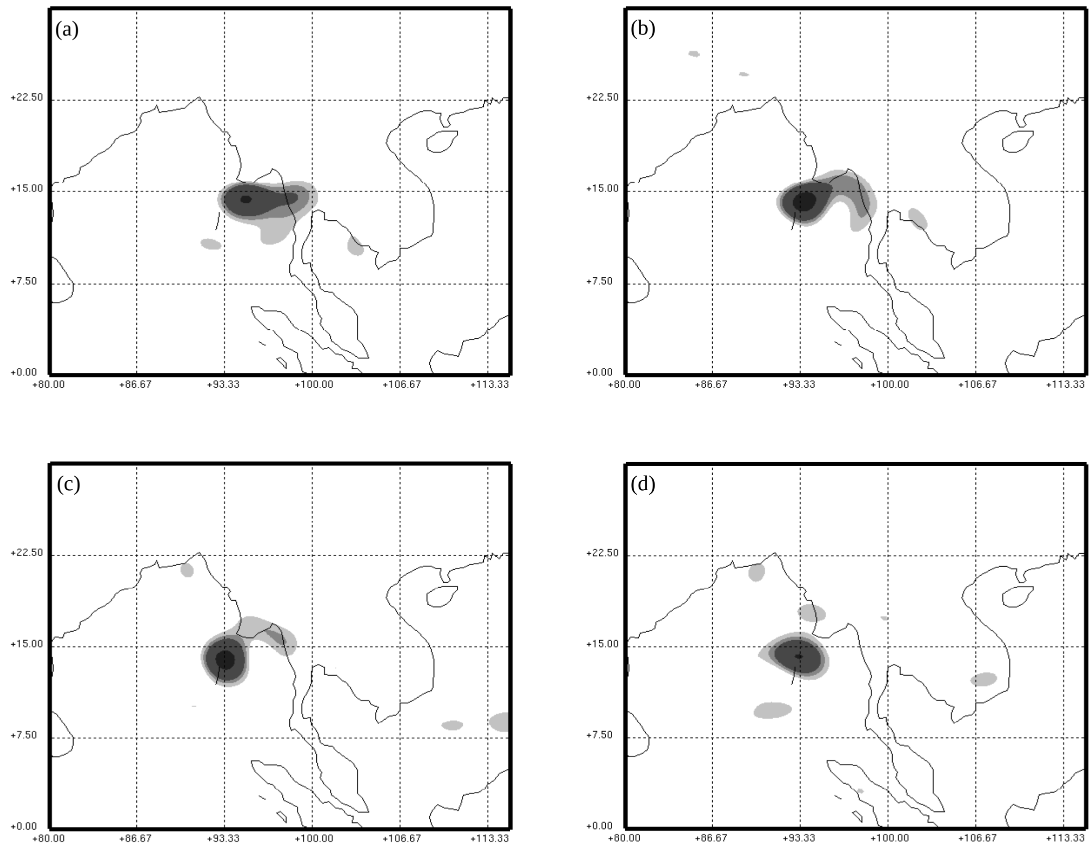


Fig. 4. Evolution of the characteristic size of the systems: *L* in kilometres is plotted on the *y*-axis. *x*-axis represents the date (October 1999). The 24 hour mean is plotted as a thick line



Figs. 5(a-d). Large scale relative vorticity contours at 850 hPa : Contour levels are 1×10^{-5}, 5×10^{-5}, 1×10^{-4}, 2.5×10^{-4} and 5×10^{-4} in units of sec^{-1} from light gray to black. 25 October 1999 : (a) 0000 UTC, (b) 0600 UTC, (c) 1200 UTC and (d) 1800 UTC



Figs. 6(a-d). Same as Figs. 5(a-d) but for 26 October 1999 : (a) 0000 UTC, (b) 0600 UTC, (c) 1200 UTC and (d) 1800 UTC

In Fig. 2 the presence of many mesoscale systems and also the growth of areas of deep convection (yellow regions) can be seen on the 25th. Merger of some of the small systems can also be seen [Figs. 2 (c&d)].

On the 26th, when cyclonic strength had been reached [Fig. 3 (a)] the area covered by regions of deep convection is seen to be considerably greater as compared to the 25th (Fig. 2). Also three clear structures can be distinguished. Merger of these systems took place during the transition to a severe cyclonic storm [27, 0000 UTC, Fig. 3 (b)] and a very severe cyclonic storm [27, 1200 UTC, Fig. 3 (d)].

One can also see that in the depression stage, the cloud field is asymmetric and becomes nearly axisymmetric as the intensification proceeds.

From the quantitative analysis of the images the number of systems, characteristic sizes and average distances of the systems from the centroid were obtained. The variation of size is shown in Fig. 4.

The diurnal variation of the sizes is noticeable between 23rd and 26th. The daily average of the sizes is around 60 km on the 23rd. This increases to around 80 km for the 24th and 25th. From 26th onwards, the size keeps increasing steadily up to 28th. This is consistent with the observations from the processed images.

4. Vorticity fields

The large scale vorticity fields on 25th and 26th, at 850 hPa pressure level are shown in Figs. 5 & 6.

A merger is seen during 0600 UTC - 1800 UTC on 25th [Figs. 5(a-d)]. This process is completed by 1200 UTC, 26th [Figs. 6(a-d)] with the formation of a single large nearly axisymmetric region of vorticity with a large vertical extent (other levels have not been shown). One can see that this description matches to a large extent with what was inferred from the processed satellite images in the previous section.

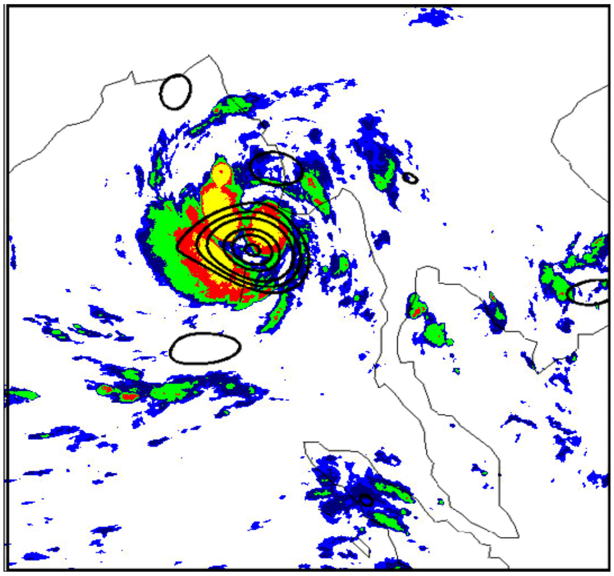


Fig. 7. Large scale relative vorticity contours (850 hPa) superimposed on the processed cloud image on 26 October 1999, 1800 UTC

Vorticity contours superimposed on the pseudo-colored IR images are shown in Fig. 7. The pseudo-colouring of the cloud images has been done and the vorticity contours for the same time are plotted as thick dark lines over them. One can see that there is a reasonable correlation between the two fields.

5. Conclusion

An analysis of the early stages of the 1999 super cyclone in the Bay of Bengal has been presented. The presence of mesoscale structures and their interaction have been shown from processed IR images and to some extent from vorticity fields. These suggest that merger of mesoscale convective vortices play an important role in the formation of tropical cyclones in the Bay of Bengal also. Such interactions have been observed in the Pacific by Ritchie and Holland (1997) and Simpson *et al*. (1997). Studies of the later stages of the super cyclone using a global NWP model are reported in a companion paper (Venkatesh *et al*.) in this volume.

Acknowledgements

The author would like to acknowledge the useful discussions with Dr. Joseph Mathew and Dr. U. N. Sinha while this work was carried out. EUMETSAT is gratefully acknowledged for providing the METEOSAT IR satellite data.

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