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Recent very severe tropical cyclones over the Bay of Bengal : Analysis with satellite data

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सार – इस शोध–पत्र में बंगाल की खाड़ी के उष्णकटिबंधीय चक्रवातों की तीव्रता का आकलन और चक्रवात के मार्ग का पूर्वानुमान लगाने में उपग्रह के आँकड़ों से बने प्रभाव को दर्शाया गया है। इस शोध–पत्र में लेखकों ने चक्रवाती तूफानों के मार्ग का, चक्रवात के बनने का और चक्रवात की गतिविधियों का पता लगाने में उपग्रह के आँकड़ों के उपयोग को अनुकूल बनाने में सुदूर संवेदी तकनीकों की हाल ही में मिली सफलता और उसके उपयोग की प्रगति पर विशेष रूप से ध्यान केन्द्रित किया है। दो चक्रवातों का विश्लेषण किया गया है – 16 से 19 मई 2004 में म्यांमार में आया प्रचंड चक्रवाती तूफान और दूसरा 26 से 31 अक्तूबर 1999 में उड़ीसा में आया चक्रवात।

चक्रवाती तूफानों के बनने और उनके आगे बढ़ने के पूर्वानुमान में अति उच्च विभेदन रेडियोमीटर (वी. एच. आर. आर.) आँकड़ों, स्केट्रोमीटर पवनों और बहिर्गामी दीर्घतरंग विकिरण (ओ. एल. आर.) के चक्रवातों के आस–पास कृत्रिम वर्ण में दर्शाए गए आँकड़ों का उपयोग करती हुई उपग्रह पर आधारित तकनीक बहुत अधिक उपयोगी पाई गई है। इस अध्ययन में बंगाल की खाड़ी में आए दो चक्रवातों के बनने और उनके आगे बढ़ने की असमानता को विशेष रूप से बताया गया है।

ABSTRACT. This paper shows the impact made by the satellite data in the intensity estimation and track prediction of tropical cyclones of Bay of Bengal. The authors in this paper have focused on the recent accomplishment and advances in the remote sensing techniques to optimize the use of satellite data in tracking, formation and movement of cyclonic storms. Two cyclones - firstly the Myanmar severe cyclonic storm of 16 to 19 May 2004 and secondly the 26 – 31 October 1999 Orissa cyclone have been analysed.

Satellite based technique using Very High Resolution Radiometer (VHRR) data, scatterometer winds and outgoing long wave radiation (OLR) data in pseudo color around the cyclones have been found to be more useful in predicting formation and movement of cyclonic storms. The present study has significantly brought out the difference in formation and movement of the two cyclones formed over the Bay of Bengal.

Key words − Tropical cyclone, Scatterometer, OLR and VHRR data.

1. Introduction

Detailed study of severe weather systems like tropical cyclones with conventional data is very difficult and the satellite-based remote sensing methods are the only possible means to study such systems in detail. Hourly Visible and IR images from Kalpana – 1, INSAT -3A satellite imageries help in improving the prediction of intensity and landfall of the cyclones. A tropical cyclone, is a warm core vortex in the atmosphere; cyclonic circulation is seen in the lower troposphere and anticyclonic in the upper troposphere. Tropical cyclones are most destructive but short-lived phenomena. Associated the storm surge, heavy wind and rain have negative consequence upon the human lives and resources. Since tropical ocean is the energy source of tropical cyclones, it is reasonable to suppose that, warmer waters can support severe cyclones. Merrill (1989) showed with different approaches that tropical cyclones are associated with warm sea surface temperature (SST) of about or greater than 26° C. Further investigations showed that the genesis of tropical cyclone are associated with number of factors such as the vertical lapse rates of the temperature, vertical wind shear, mid tropospheric relative humidity and prior existence of a center of low-level cyclonic vorticity (George and Grey 1976) besides warm SSTs. This makes the prediction of behavior of tropical cyclones a difficult task. However for tropical cyclone disaster management, it is very important to know which tropical disturbance may intensify into a tropical cyclone and its spatial distribution, movement and dissipation. Further, the different aspects related to global climate changes add new dimensions. It is now speculated among scientific community that as the global warming plays a vital role in warming of the Earth and ocean it may lead to changes in frequency, intensity,

TABLE 1

Tropical cyclone 16-19 May 2004

Date	Time (UTC)	Centre Lat. °N / Long. °E	C.I. No.	Estimated central pressure (hPa)	Satellite estimated maximum sustained surface wind (kt)	Satellite estimate pressure drop at the centre from the previous estimate (hPa)	Grade
16 May 2004	0900	17.0/91.5	1.5	1000	25	---	D
	1200	17.5/91.0	1.5	1000	25	---	D
	1800	17.5/91.0	2.0	998	30	2	DD
	2100	18.0/90.5	2.0	998	30	0	DD
17 May 2004	0000	18.5/90.5	2.0	998	30	0	DD
	0300	18.5/90.0	2.5	998	35	0	CS
	0600	18.5/90.0	2.5	998	35	0	CS
	0900	18.5/89.5	3.0	988	45	10	CS
	1200	18.5/89.0	3.0	988	45	0	CS
	1500	18.5/89.0	3.0	988	45	0	CS
	1800	18.5/89.0	3.0	986	45	2	CS
	2100	19.0/88.5	3.0	986	45	0	CS
18 May 2004	0000	19.0/88.5	3.0	986	45	0	CS
	0300	19.0/88.5	3.0	986	45	0	CS
	0600	19.0/88.5	3.5	982	55	4	SCS
	0900	19.0/89.5	3.5	980	55	2	
	1200	19.0/89.0	3.5	980	55	0	
	1500	19.0/90.0	4.0	974	65	6	VSCS
	1800	19.5/90.5	4.0	974	65	0	
	2100	19.0/91.0	4.0	972	65	2	
19 May 2004	0000	20.0/91.5	4.5	962	77	10	
	0300	20.5/92.0	5.0	952	90	10	
Total drop in Central pressure (increase in wind) between 16 May 2004 (0900 UTC) to 19 May 2004 (0300 UTC)	-	-	-	-	-	48 hPa (65 kt)	

movement and increase in the formation of the tropical cyclones. The most important elements to predict are the future track of the cyclone and the place where it would cross the coast. Many of the Indian cyclones move westwards or northwestwards. The tracks of the cyclones are difficult to predict and some of them move in these directions and later turn northwards or northeastwards. These are the recurving cyclones and forecasting their track is a very difficult problem, often involving large errors. It has been reported that errors in determining the cyclone center can be up to 110 km by satellite fixes, 20-50 km by radar observations and about 20 km by aircraft reconnaissance (Elsberry 1987, 1998). Reliance on satellite imagery has considerably increased in the past three decades. However problems continue to persist in deriving information on the fixing of centre and estimation of the intensities of the tropical cyclones, especially in pre-TC stages (Kalsi, 1992). QuikSCAT winds help to locate the center of the weak system. Cyclogenesis is very common and quite often (90% cases) in the Bay of Bengal terminate after the tropical disturbances acquire the stage of marginal cyclones (Kalsi and Jain, 1989).

2. Data

Kalpana - 1 and INSAT - 3A Visible and IR imageries data have been taken from Satellite Meteorology Division, India Meteorological Department New Delhi. In this study the OLR data from Kalpana - 1 satellite and in Graphics format from National Center for Environment Prediction (NCEP), USA have been used.

TABLE 2(a)

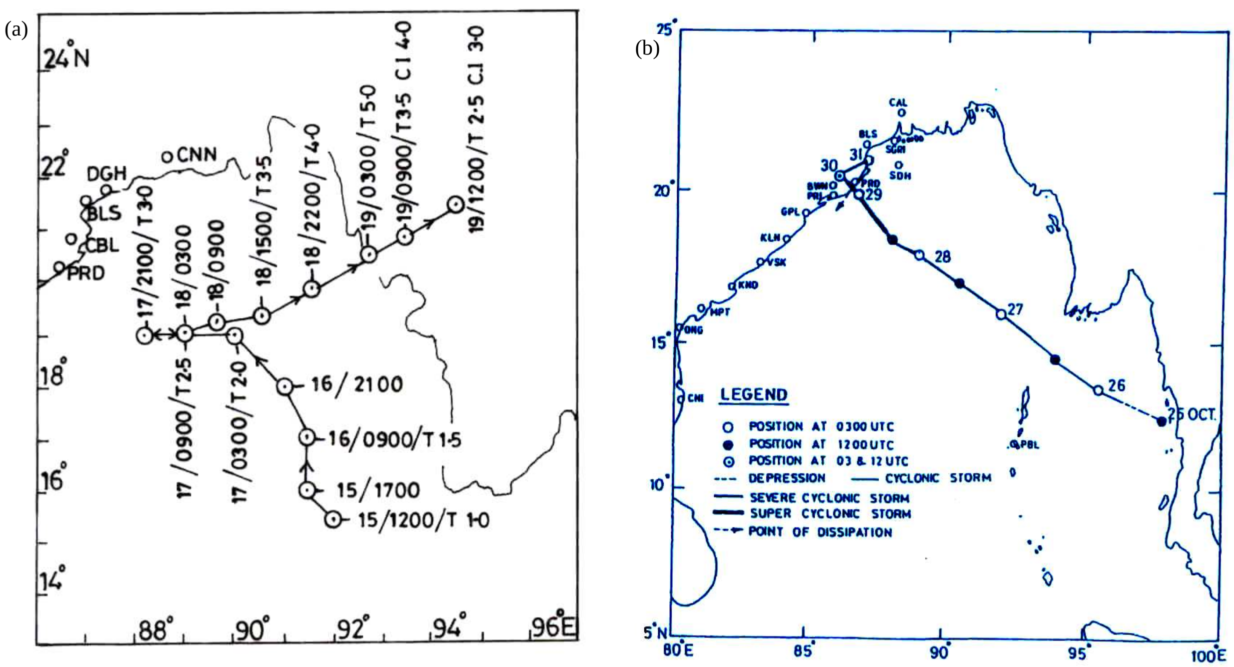
Super cyclonic storm over the Bay of Bengal from 25-31 October 1999

Year and dates of the cyclone	Maximum intensity	Maximum wind speed (kmph)	Maximum Satellite derived intensity in T.No.	Estimated minimum central pressure (hPa)	Date and Time of landfall with intensity	Impact of the storm
25-31 Oct	Super cyclone	216	7.0	912 hPa	Crossed Orissa coast near Paradeep between 0430 & 0630 UTC on 29 Oct	9802 people killed

TABLE 2(b)

Super cyclonic storm over Bay (25 - 31 October 1999)

Date	Time (UTC)	Centre Lat. °N / Long. °E	C.I. No.	Estimated maximum sustained wind (kt)	Grade
25 Oct 1999	0000	11.5/99.0	T 1.0	25	
	0600	12.0/98.5	T 1.5	25	D
	1200	13.0/97.8	T 1.5	25	D
	1800	13.1/96.8	T 1.5	25	D
26 Oct 1999	0000	13.4/95.8	T 2.0	30	DD
	0300	13.5/95.3	T 2.0	30	DD
	0600	13.8/94.8	T 2.5	35	CS
	0900	14.0/94.6	T 2.5	35	CS
	1200	14.6/94.1	T 3.0	40	CS
	1500	15.2/93.8	T 3.0	35	CS
	1800	15.4/93.4	T 3.0	35	CS
27 Oct 1999	0000	15.8/92.7	T 3.0	35	CS
	0300	16.1/92.0	T 3.5	55	SCS
	0600	16.4/91.4	T 3.5	55	SCS
	0900	16.8/91.0	T 3.5	55	SCS
	1200	17.0/90.8	T 3.5	55	SCS
	1500	17.0/90.6	T 4.0	65	VSCS
	1800	17.0/90.3	T 4.0	65	VSCS
	2100	17.1/90.0	T 4.0	65	VSCS
28 Oct 1999	0000	17.2/89.8	T 4.0	65	VSCS
	0300	17.8/ 89.2	T 4.5	77	VSCS
	0600	18.3/88.5	T 5.0	90	VSCS
	0900	18.5/88.2	T 5.5	102	VSCS
	1200	18.5/88.0	T 5.5	102	VSCS
	1500	18.9/87.7	T 6.0	115	VSCS
	1800	19.3/87.2	T 7.0	140	SUPER CS
	2100	19.5/87.2	T 7.0	140	SUPER CS
29 Oct 1999	0000	19.5/86.9	T 7.0	140	SUPER CS
	0300	19.9/ 86.7	T 7.0	140	SUPER CS
	0600	20.2/86.4			
30 Oct 1999	0300	20.6/86.0			
	1200	20.3/85.9			
31 Oct 1999	0300	19.8/86.2			
	1200	18.9/85.5			



Figs. 1(a&b). (a) Track of Myanmar tropical cyclone from 16 May 2004 to 19 May 2004 and (b).Track of Orissa tropical cyclone from 25 October 1999 to 31 October 1999

The QuikSCAT sea level scatterometer and Meteosat-5, mid and upper level winds in graphical format are downloaded from the Internet site given below.

http://cimss.ssec.wisc.edu/tropic/realtime/indian/winds/winds.html

http://manati.orbit.nesdis.noaa.gov/cgibin/qscat_ocean.pl

http://www.ncdc.noaa.gov/oa/satellite.html

3. Methodology and analysis

Super cyclone of Orissa 25-31 October 1999 have been analysed with scatterometer winds, OLR and Kalpana – 1 and INSAT data and the results have been compared with the 16-19 May 2004 cyclone. Table 1 and Tables 2 (a&b) show the position and intensity details of tropical cyclone 16-19 May 2004 and 25-31 October 1999 Orissa super cyclone respectively.

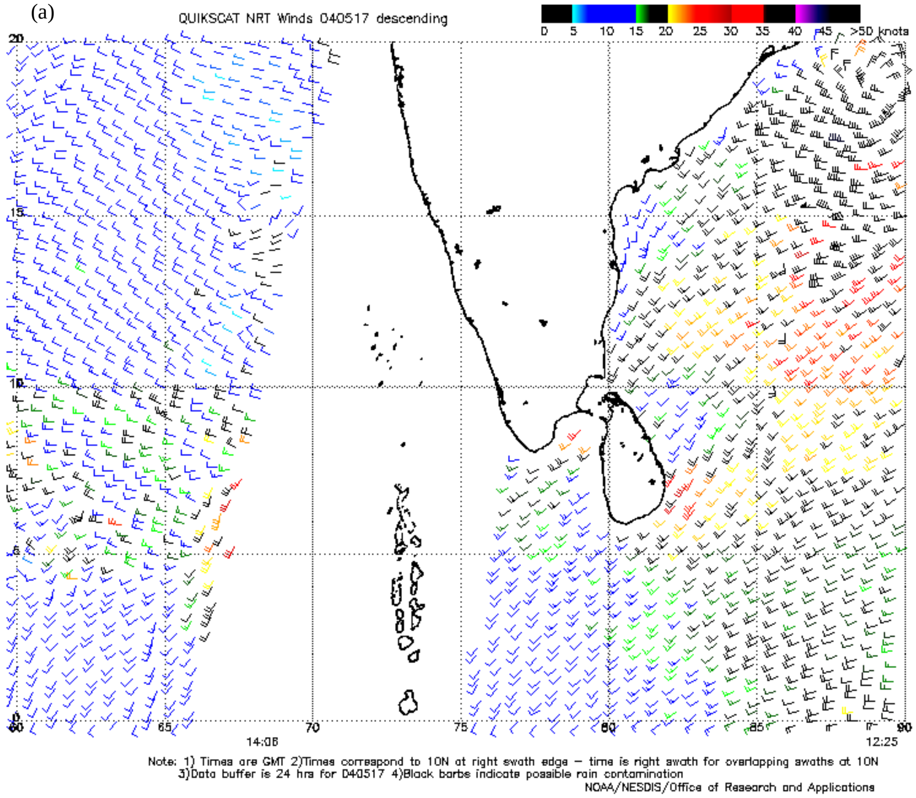
3.1. *Scatterometer winds*

Figs. 1(a&b) show the tracks of the two cyclones being studied. Scatterometer wind data, shown in [Figs. 2(a&b)] provides the view of the low-level circulation and seems to be a very good tool for determining outer wind structure during the weak tropical cyclone stage. Studies have shown that scatterometer data are unreliable above 50 kt. However; the data are also used for stronger tropical cyclones to determine the radius of 35 kt winds or more (Edson *et al*. 2002). The products are available after 2-3 hours after the pass. This lack of timeliness and disparity in data values have on occasions prevented the analyst from using scatterometer data for assessing intensity or storm structure and in making fixes that would impact the next tropical cyclone forecast. False center events have been analyzed later by ambiguity product analysis and it produced a large degree of subjectivity in the analysis.

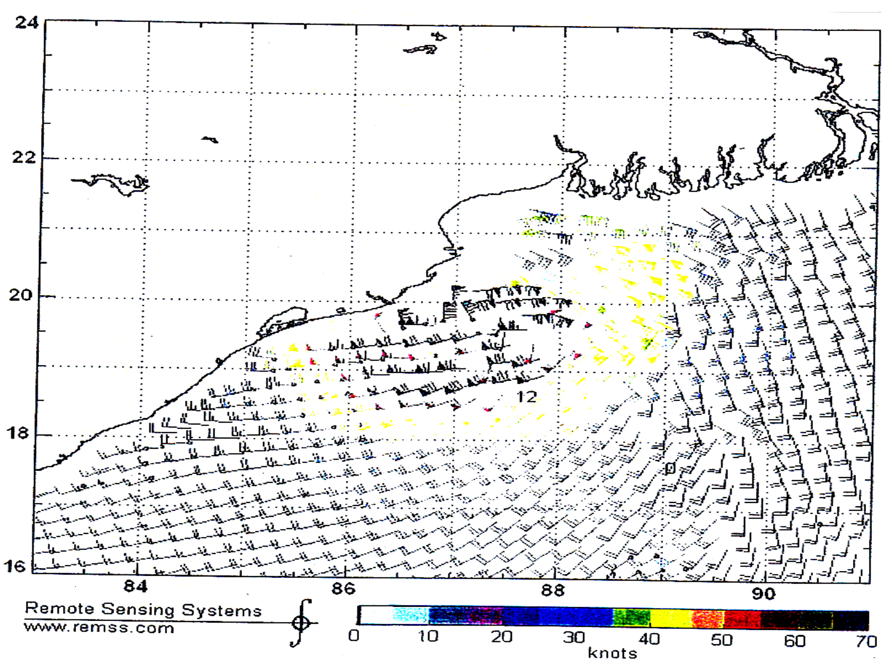
3.2. *Outgoing long wave radiation (OLR)*

The Kalpana - 1 Outgoing long wave radiation (OLR) is derived from Infrared (IR) data from atmospheric window channel (10.5μ –12.5μ). Figs. 3 (a&b) show the OLR distribution on 17 and 18 May 2004 respectively. Similarly Figs. 3(c&d) show the OLR data for 27 October 1999 and 29 October 1999. [Figs. 3 (e&f)] reveal some of the typical features of tropical cyclones relating to OLR data derived from INSAT Satellite for Myanmar and Orissa cyclones respectively. The analysis of OLR data can provide a quantitative assessment of the ongoing deep convection during various

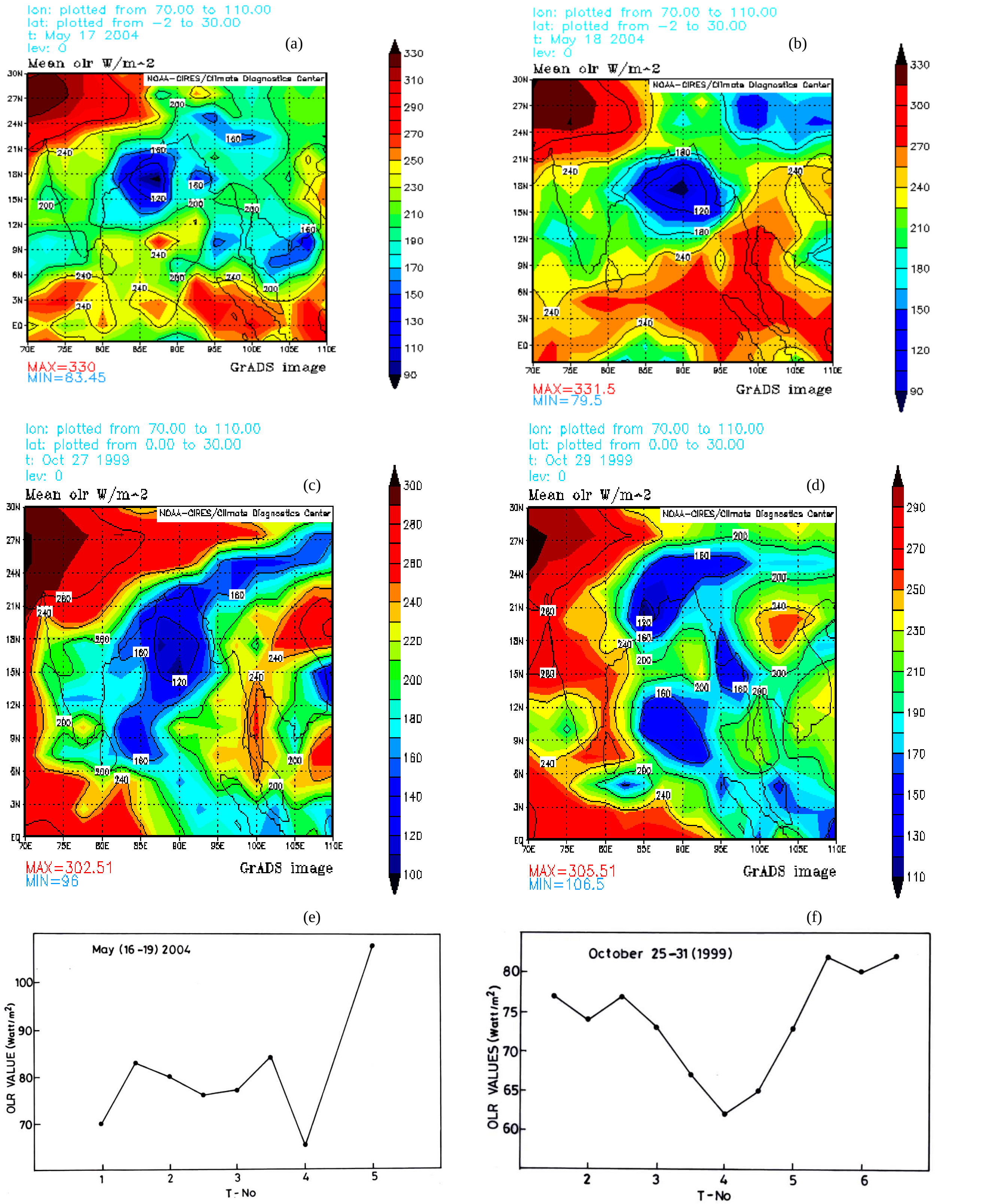
(a)



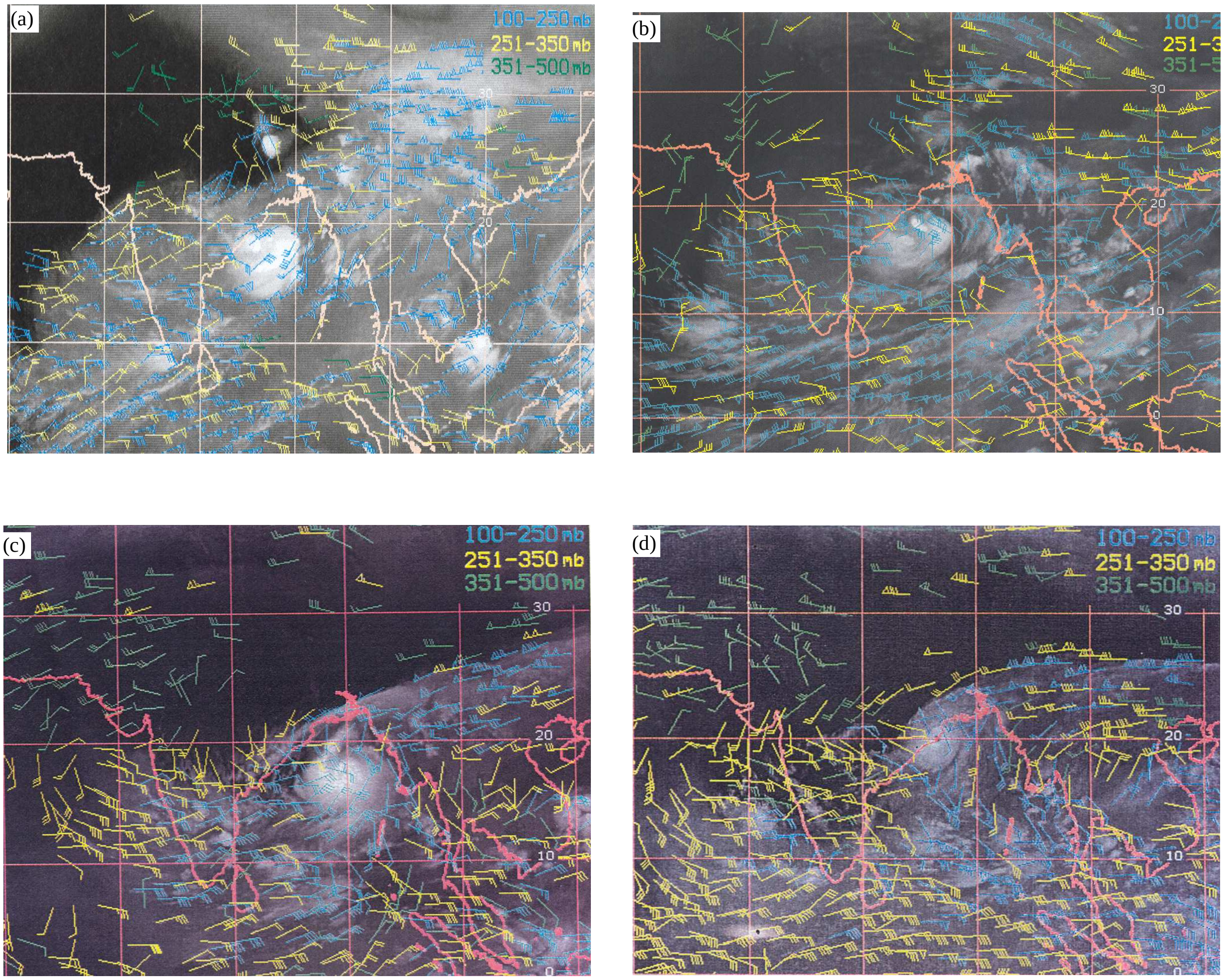
(b)



Figs. 2(a&b). (a) QuikSCAT winds for the Myanmar tropical cyclone on 17 May 2004 and (b) QuikSCAT winds for the Orissa cyclone on 28 October 1999



Figs. 3(a-f). (a) NCEP OLR data plot for 17 May 2004, (b) NCEP OLR data plot for 18 May 2004, (c) NCEP OLR data plot for 27 Oct 1999, (d) NCEP OLR data plot for 29 Oct 1999, (e) INSAT Satellite derived OLR data for Myanmar (16-19 May 2004) Cyclone and (f) INSAT Satellite derived OLR data for Orissa (25-31 October 1999) Cyclone



Figs. 4(a-d). (a&b) METEOSAT-5 water vapour channel wind data plot for upper level Myanmar (17-18 May 2004) Cyclone and (c&d) METEOSAT-5 water vapour channel wind data plot for upper level for Orissa (28-29 October 1999) Cyclone

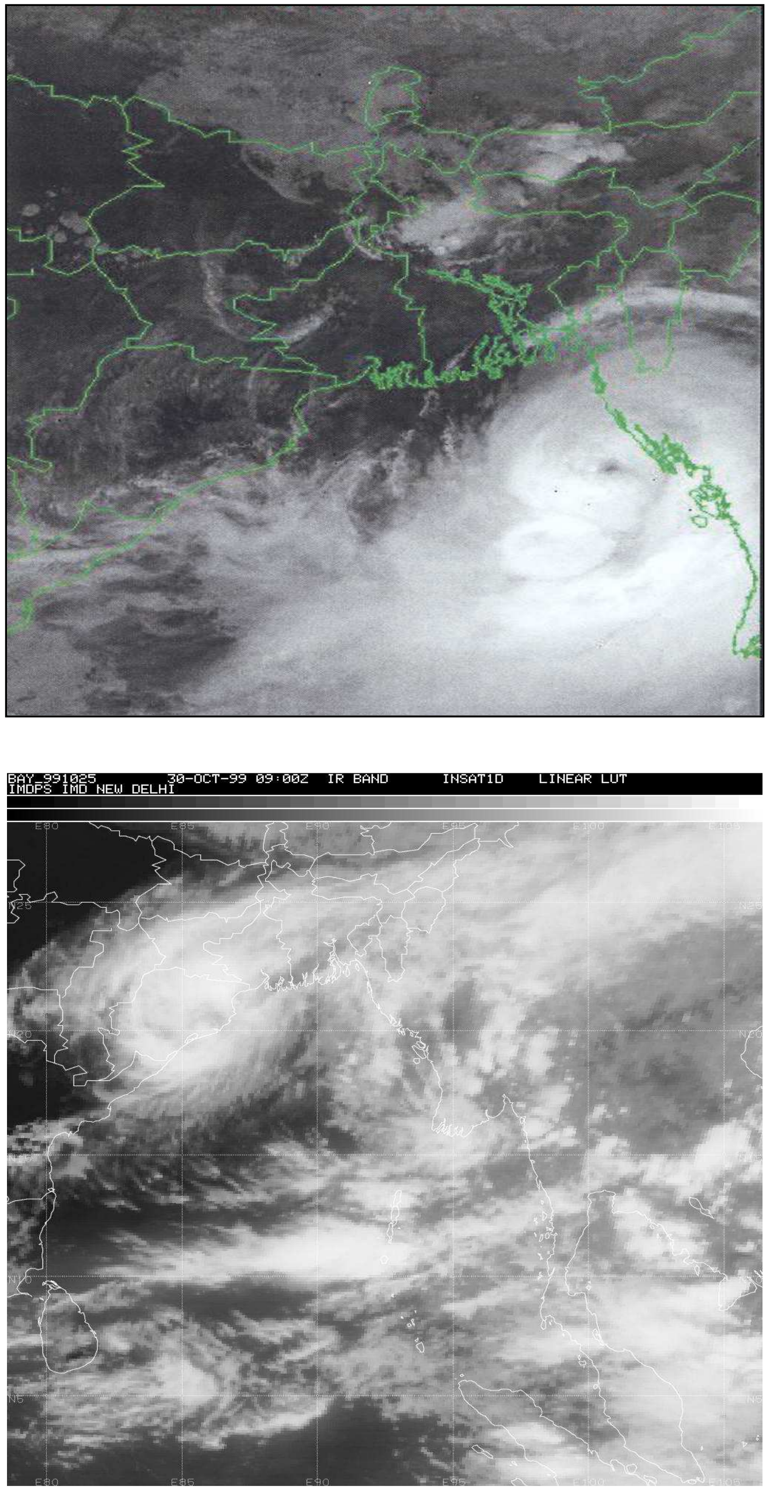
stages of the tropical cyclone development. For the severe cyclonic storm of 16 – 19 May, 2004 the maximum intensity was T 5.0 with minimum OLR in the central region being 107 W/m^2. Similarly in the case of the October 1999 super cyclone maximum T. No reached was nearly T 7.0 and associated OLR in the central region was 82 W/m^2.

The direction of upper level (100-250 hPa) winds provide valuable information for the future prediction of the track of the cyclone. These winds are helpful to decide the large-scale atmospheric flow in which the system is embedded. Meteosat water vapour channel provides estimate of upper tropospheric winds. Figs. 4(a&b) shows the Meteosat water vapour channel winds for 17 & 18 May 2004, Myanmar cyclone. Correspondingly Figs. 4(c&d) shows the same in respect of Orissa super cyclone on 28 and 29 October 1999 respectively. The Myanmar cyclone is embedded in the upper tropospheric westerly flow which led to its recurvature [Fig. 4(d)]. The Orissa super cyclone lies under in different wind field of the upper tropospheric ridge.

The hourly satellite imageries are useful in predicting the development of a cyclone and its intensity. In the initial stage whenever a cloud cluster of significant dimension (600 km × 600 km), is observed which persist for 12 hours, then a watch is kept for the formation of vortex over that area of Indian Ocean. With the help of animation a point is fixed around which a cloud mass rotates. This point is called cloud system center. Both IR and Visible cloud imageries systematic patterns of clouds

(a)

(b)



Figs. 5 (a&b). Satellite imagery for NOAA-15 High Resolution Picture Transmission (HRPT) on (a) 19 May, 2004 (0100 UTC) at the time of peak intensity of Myanmar cyclone and (b) INSAT-1D Satellite imagery showing the decaying phases of Orissa Super cyclone on 30 October 1999 (0900 UTC) and followed and by using the technique given by Dvorak (1984) the intensity of the system is directly correlated with the sequence of satellite image patterns. Figs. 5(a&b) show satellite imageries from NOAA-15 (HRPT) for the Myanmar and Orissa cyclones respectively. Myanmar cyclone has a visible 'eye' as it is in its most intense stage. The Orissa cyclone had already a land fall by 30 October 1999 when this picture [Fig. 5(b)] was taken. Its eye was destroyed by this picture time but the central overcast is still intact even after landfall.

3.3. *Observational features*

During 16 - 19 May 2004 for Myanmar cyclone the following features were observed :

(*i*) The vortex formed over East Central Bay and moved North-Westerly or Westerly direction up to 0300 UTC of 18 May 2004 and then remained stationary up to 1800 UTC of 18 May 2004. The vortex then recurved in North–Easterly direction and crossed Myanmar coast in the early hours of 19 May 2004.

(*ii*) The winds at 200 hPa Meteosat - 5 before 18 May 2004 [Figs. 4(a&b)] were easterlies and under the influence of these easterlies the vortex moved in North – Westerly / Westerly direction. On 18 May, 2004 winds at 200 hPa changed from Northwesterly to Southwesterly over vortex field (Position of the ridge line was along 22° north). Therefore the vortex recurved in North Easterly direction. The Orissa cyclone lies directly under the sub-tropical ridge on 29 October [Fig. 4(d)] and hence it had slowed down before landfall and for the next 36 hours remained almost stationary.

3.4 *Damage potential*

The study of the tropical cyclonic disturbance and storm surge over the coastal area is important for vulnerability assessment (damage potential) in the area. The Vulnerability Parameter (VP) is defined as :

$$VP = f\,(F, t \text{ and } P)$$

Where, F is the cyclone frequency (No. of cyclones per year). t is the coastal topography (usually t is measured as height of the coast above sea level) and P is the population per square meter.

The damage during the past quarter century in the coastal State of Andhra Pradesh in India has been normalized for inflation, population growth and increase in real income in an attempt to identify the factors involved. Evidence from this analysis support the view that increase in vulnerability due to special factors has occurred rather than any actual increased in cyclone frequency or intensity.

The damage potential in the case of Orissa cyclone was more because the height of the coast above mean sea level is very less in comparison to Myanmar coast. The frequency of cyclone striking over Orissa coast is very high in comparison to Myanmar coast.

During 25 to 31, October 1999 Orissa cyclone remained over sea for more than 5 days and Myanmar cyclone of May 16 – 19, 2004 remained over sea approximately for three days. During this stay of the cyclone all the favorable conditions of cyclogenesis were fulfilled.

4. Conclusions

(*i*) The Orissa cyclone life span was more over the sea in comparison to Myanmar cyclone. The Orissa cyclone remained south of ridge line as a result it moved continuously in northwesterly direction while Myanmar cyclone moved initially in northwesterly direction and remained practically stationary near the col region from 0600 UTC of 17 May 2004 to 0600 UTC of 18 May 2004 and then recurved in northeasterly direction and crossed the Myanmar coast.

(*ii*) In both cyclone cases we have observed two minima in Kalpana - 1 OLR data plots indicating initial genesis and peak intensity.

(*iii*) Upper winds from Meteosat - 5 at 200 hPa remained easterly throughout the life period of Orissa cyclone and in Myanmar cyclone the winds at 200 hPa on 18 May 2004 were observed southwesterly as a result the vortex recurved in northeasterly direction.

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