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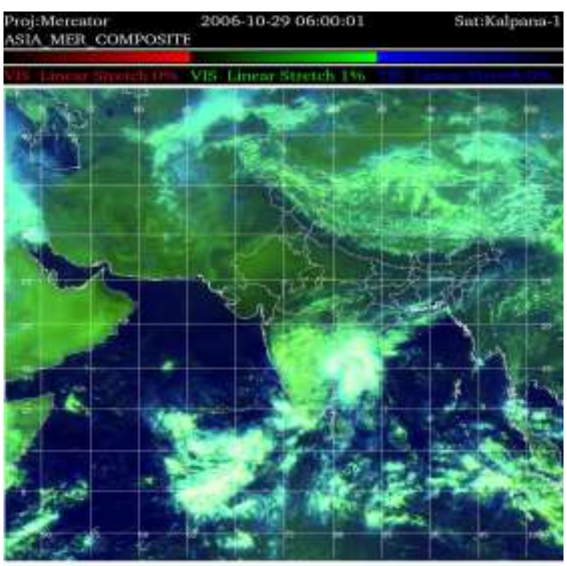
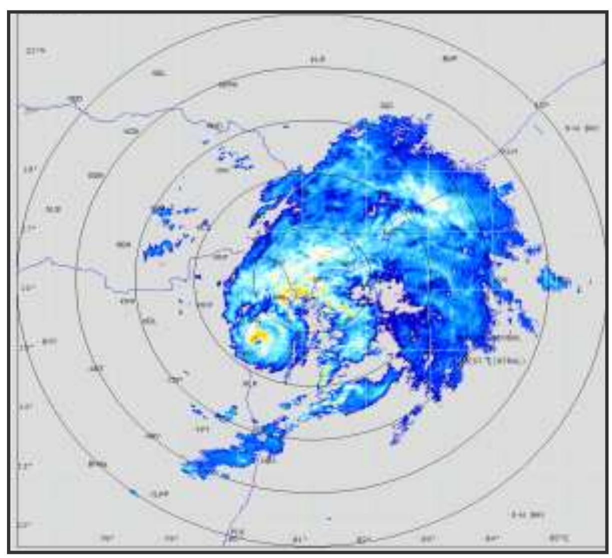
GOVERNMENT OF INDIA

INDIA METEOROLOGICAL DEPARTMENT

A REPORT ON CYCLONIC STORM "OGNI" 2006





H.R. Hatwar, V. Subrahmanyam, M. Mohapatra, S.K. Roy Bhowmik, B.K. Bandyopadhyay, Charan Singh & Kuldeep Srivastava

Cyclonic storm "OGNI"
Over
the Bay of Bengal
October 29-30, 2006

PREFACE

The cyclonic storm "OGNI" developed over westcentral Bay of Bengal in the evening of 29th October 2006 and crossed Andhra Pradesh coast between Bapatla and Ongole around 0700 UTC of 30th October as a deep depression. It caused widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy falls over coastal Andhra Pradesh leading to flood over the region. As a result, there were 24 human deaths and heavy loss of property. This cyclonic storm was very unique in its nature as it had a small core (~100 km), and short life period (~18 hours). It moved nearly northward over the sea along the coast and weakened into a deep depression before landfall. The system was mainly detected and tracked by Doppler Weather Radar (DWR) at Chennai, Sriharikota and Machilipatnam. The system could not be predicted with cyclonic storm intensity by various numerical weather prediction models. It posed a challenge to the NWP modelling and other conventional, synoptic and statistical methods to predict the intensity of such a small core and short lived system with high damage potential.

Considering all the above mentioned unique features, a meteorological monograph has been brought out. The authors have analysed and discussed many factors of the cyclonic storm 'OGNI' like genesis, intensification, movement, weakening over the sea, landfall and associated disastrous weather. The monitoring and prediction aspects of this cyclone by the synoptic and thermodynamic observations, satellite and radar observations, dynamical parameters and numerical weather prediction models and their limitations have been critically examined and discussed. The critical grey areas requiring more research and investigation have been highlighted. The augmentation in observational network and types of observations required to monitor and predict such small core and short lived systems are also suggested in this meteorological monograph. I hope, this monograph will help the readers to have valuable and authentic information on various features of cyclonic storm OGNI and will be useful not only in monitoring and forecasting of such systems in future but also for taking up further research studies.

I congratulate the authors for their valued contribution in bringing out this monograph. Many research and observational inputs were received from DWR Chennai, Machilipatnam & SHAR, from Area Cyclone Warning Centre, Chennai, Cyclone Warning Centre, Visakhapatnam, Meteorological Centre Hyderabad, Satellite & Computer Divisions at IMD HQ, which are highly appreciated and duly acknowledged. I also appreciate the efforts made by the Cyclone Warning Division at IMD Head Quarter in bringing out this valuable monograph.

R.C. Bhatia
Director General of Meteorology
India Meteorological Department

Contents

1. Introduction

A small core and short lived cyclonic storm “OGNI” developed over westcentral Bay of Bengal off Andhra Pradesh coast in the evening of 29th October, 2006. Its diameter was about 100 km and it sustained the cyclone intensity for a few hours only. The system moved in a northerly direction and weakened into a deep depression just before the landfall. It crossed Andhra Pradesh coast between Bapatla and Ongole around 0700 UTC of 30th as a deep depression. The storm caused heavy to very heavy rainfall over coastal Andhra Pradesh and flash floods over the region, resulting in loss of life and property. There was no significant damage due to strong winds and storm surge, as the storm weakened over the sea itself and crossed as a deep depression. However, the system caused flash floods due to torrential rain over coastal Andhra Pradesh. A brief history of the cyclonic storm and the rainfall and damage due to flood caused by cyclonic storm are given in section 2 and 3 respectively. The cyclonic storm “OGNI” had the following unique features.

(i) Small core (~ 100km)

(ii) Shorter life period (~18 hours)

(iii) Nearly northerly movement over the sea close to the coast

(iv) Slower than normal movement

(v) Weakening of the system into a deep depression over the sea itself before landfall

(vi) Extremely heavy rainfall due to the system leading to flood

(vii) The system was mainly detected and tracked by Doppler Weather Radar (DWR) at Chennai, Sriharikota and Machilipatnam.

The intensity estimation and prediction were the most unique problem with the cyclonic storm “OGNI”. At present, IMD utilises the Dvorak technique of development, subjective assessment based on satellite and radar advisories and environmental conditions for estimating the intensity. Some kind of check lists have been devised to work out the likely intensity changes (IMD, 2000). When the system is within the radar range, radar signatures are also taken into consideration to determine the intensity. Higher sea surface temperatures (more than 26.5^{o}C), a deep lower level moist layer, absence of strong vertical wind shear, increase in vorticity over the area and vorticity advection may be useful indicators for the development from a tropical low to a cyclonic storm and further intensification (Gray, 1992 and Frank, 1977). The position and movement of the adjacent synoptic system and westerly troughs are also derived from the satellite imageries and analysed synoptic charts. All these features taken together give an indication of whether or not the disturbance is going to intensify further.

Gray and Shea (1973) have presented the mean structure of horizontal thermal field around cyclones derived from aircraft reconnaissance data. The structure shows a warm core area at 500 hPa level ahead of the storm centre in the direction of motion of the storm. This warm area aloft is produced either by warm area advection or extension of convective rain adjacent to the cyclonic storm which provides an indication of the direction of the future movement. Though the tracks of the cyclonic storms differ widely in tropical belt, the predominant direction of movement is to the northwest/west-northwest. Some of them may recurve when they come under the influence of the westerly trough. The detailed review of the synoptic and thermodynamic characteristics associated with the genesis, movement and intensification/decay of the cyclonic storm over the north Indian Ocean are presented by Krishna Rao (1997). The review of the dynamical characteristics of movement and intensification is given by Mohanty and Gupta (1997). A review of the prediction of tropical cyclone characteristics by numerical weather Prediction (NWP) models is presented by Prasad (1997) and has been updated by Rama Rao et. al (2007). The intensity change at present is not properly captured in the numerical weather prediction models (Rama Rao, et al., 2007).

Resolution of the model, initial moisture analysis and initial correct representation of the tropical cyclone vortex through an appropriate bogussing procedure are seen to be the key factors in successful prognostic and track prediction of the cyclonic storm. The satellite based monitoring and prediction of the genesis, intensification and movement were reviewed by Kelkar (1997) and further updated by Kalsi (2006) and Bhatia et al., (2006). According to them new developments like derivation of cyclone parameters in terms of ocean surface wind fields by scatterometer, more frequent and rapid scan observations by the satellites and use of water vapour imagery with better resolutions can immensely help in not only monitoring and prediction, but also in improving the NWP model performance. Raghvan (1997) has presented an excellent review on application of radar technique in monitoring and prediction of the cyclonic storms. According to him, highly automated Doppler Weather Radars (DWRs) can improve the operational monitoring of cyclones in terms of accuracy of tracking as well as estimation of intensity of the cyclone. However, there are a few studies on the observational and modelling aspects of small core and short lived systems like “OGNI”.

Considering all the above, a case study is undertaken to find out the synoptic, dynamical and thermo-dynamical features associated with the cyclonic storm ”OGNI”. Also the performance of various diagnostic tools like DWR and INSAT-Kalpana-I observations are analysed and presented. The analysis and forecast charts of various NWP models are analysed for verifying the diagnostic and prognostic capabilities of such tools in case of small core and short lived cyclonic storm.

A brief history of the cyclonic storm is presented in Section 2. The rainfall and damage due to cyclonic storm, “OGNI” are presented in section 3. The data and method of analysis used in study are discussed in section 4. The results and discussions are presented in section 5. The broad conclusions and suggestions are presented in section 6.

2. Brief history of the system

According to Regional Specialised Meteorological Centre (RSMC) report (RSMC-Tropical Cyclone, New Delhi, 2007), a low pressure area formed over southwest Bay of Bengal off Tamilnadu coast on 28^{th} October 2006. It intensified into a depression and lay centred near lat. 14.0^{0} N and long. 80.5^{0} E at 0300 UTC of 29^{th}. While moving slowly in a northerly direction, it intensified into a deep depression and lay centred near lat. 15.0^{0} N and long. 80.5^{0} E at 0900 UTC of the same day, about 50 kms east of Kavali. The system further intensified into a cyclonic storm at 1200 UTC of 29^{th}. Till 0300 UTC of 30^{th}, the system moved very slowly in the northerly direction. It lay centred near lat.19.5^{0}N and long.83.5^{0}E at 0000 UTC of 30^{th} October 2006, about 30 km east of Kavali. DWR at Machilipatnam showed band features with small core. The DWR of Chennai, SHAR and Machilipatnam constantly monitored the system. Besides this, hourly synoptic observations were also taken from the coastal observatories, which were of immense use in the determination of landfall point and time. The cyclonic storm weakened into a deep depression at 0600 UTC of 30^{th}. It crossed Andhra Pradesh coast near Bapatla as a deep depression around 0700 UTC of 30^{th} October, 2006. After crossing the coast, the system weakened into a depression at 0900 UTC of same day. The depression further weakened into a low pressure area over north Andhra Pradesh and adjoining areas at 1200 UTC of 30^{th} October, 2006. The detailed characteristics like position intensity and movement of the system are shown in Table-1 and Fig.1.

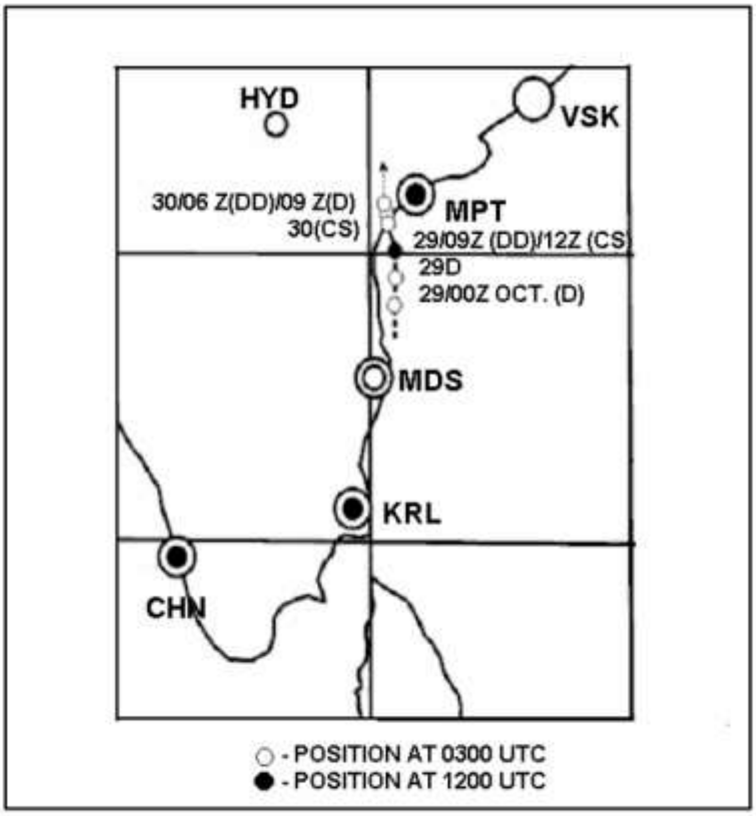


FIG. 1. Track of cyclonic storm, "OGNI" over the Bay of Bengal during 29-30 October, 2006

Table .1

Best track positions and other parameters for Bay of Bengal Cyclonic Storm "OGNI" (October 29-30, 2006)

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
29-10-2006	0000	14.0/80.5	1.5	1002	25	-	D
	0300	14.5/80.5	1.5	1002	25	-	D
	0600	14.5/80.5	1.5	1002	25	-	D
	0900	15.0/80.5	2.0	1000	30	5	DD
	1200	15.0/80.5	2.5	998	35	6	CS
	1500	15.0/80.5	2.5	998	35	6	CS
	1800	15.5/80.5	2.5	998	35	6	CS
	2100	15.5/80.5	2.5	998	35	5	CS
30-10-2006	0000	15.5/80.5	2.5	998	35	6	CS
	0300	15.6/80.3	2.5	1000	35	6	CS
	0600	15.7/80.3	2.0	1002	30	6	DD
	Crossed the coast between Bapatla and Ongole around 0700 UTC.						
	0900	15.8/80.3	--	1004	25	8	D

3. Rainfall and damage

The cyclonic storm “OGNI” mainly caused flash floods due to the heavy to extremely heavy rainfall over coastal Andhra Pradesh during October 29-31, 2006. The amounts of heavy rainfall (≥ 7cm) over Andhra Pradesh are given below:

29 OCTOBER 2006: Ongole-19, Kakinada, Amalapuram and Kandukur-13 each, Avanigadda-10, Sullurpet-9, Kavali and Repalle-8 each, Nellore and Gudur-7 each.

30 OCTOBER 2006: Avanigadda-35, Repalle-28, Machilipattinam-27, Bapatla-20, Amalapuram-16, Narsapur and Kakinada-15 each, Bhimavaram, Gudivada and Tenali-12 each, Tanuku-11, Guntur, Kaikalur and Gannavaram-10 each, koderu-9 and Mangalagiri-9 each, Ongole, Kandukur and Peddapuram-8 each, Visakhapatnam, Addanki, Eluru and Rajahmundry-7 each.

31 OCTOBER 2006: Gudivada-55, Machilipattinam-34, Avanigadda-32, Narsapur-22, Gannavaram-19, Kaikalur-16, Amalapuram and Eluru-15 each, Bhimavaram-14, Mangalagiri-13, Bapatla-12, Chintalapudi-11 and Koderu-11 each, Tanuku-10, Prakasam Barrage-9, Bhimadole and Nuzvid-8 each, Tadepalligudem-7 and Kakinada-7 each.

The spatial distribution of rainfall during 29-31st October 2006 is shown in Fig.2. It indicates that the rainfall was oriented in the southwest to northeast direction from extreme south peninsula to south Orissa coast across Tamilnadu and coastal Andhra Pradesh. The primary maxima of rainfall was located over coastal Andhra Pradesh. It moved from south to north along coastal Andhra Pradesh with increase in intensity from 29th to 31st October 2006. The analysis of observed clouds over the region indicates that the rainfall was mostly convective type. Also, the convective cloud cluster in association with the system moved in a northerly direction supporting northward movement of the system (Krishna Rao, 1997).

The following damages were reported in Andhra Pradesh.

Loss of life	: 24
Livestock	: 3, 61,553
Loss of crops	: 1, 99,986 acres
Villages submerged	: 900
Damage to houses (fully)	: 26,853
Damage to houses (partly)	: 73,218

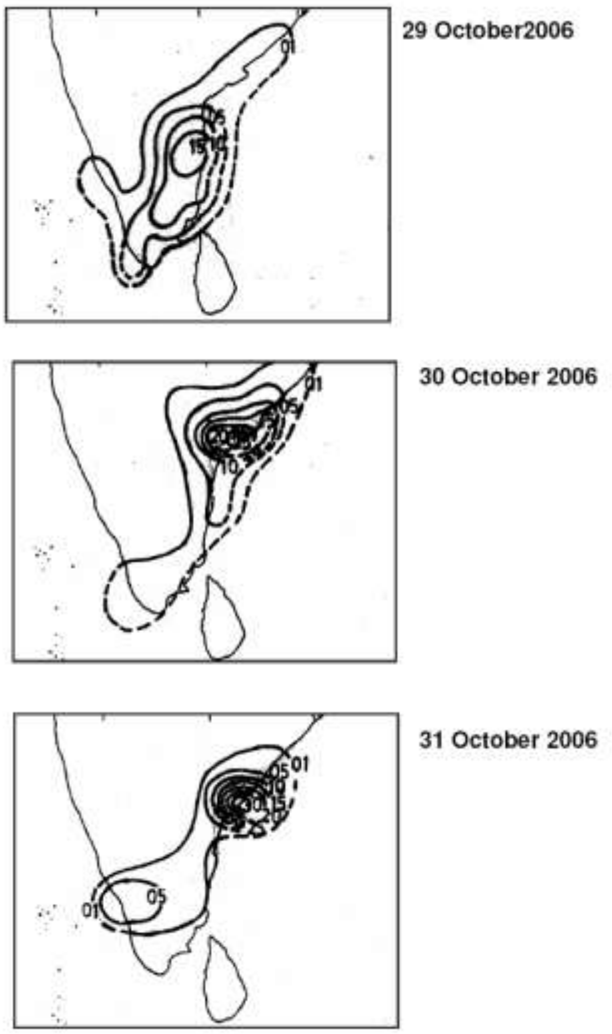


Fig.2.Isohytal analysis of 24-hours cumulative rainfall as recorded at 0300 UTC of 29th, 30th and 31st October 2006

4. Data and methodology

The genesis, intensification, movement and dissipation of the cyclonic storm, OGNI, are analysed by considering the synoptic, thermodynamic & dynamic parameters during 28-30th October 2006. The satellite and radar observations during the period are also used for this purpose. The NWP models analysis & predictions during the above period along with the simulation studies are examined to find out the efficacy of the NWP models to detect and predict the small core and short lived cyclonic storm, OGNI. The details of the data used and the methodology are discussed in Sec.4.1-4.5.

4.1. Synoptic and thermodynamic observations

The following synoptic and thermodynamic parameters during 28-30th October 2006 over Indian Region are analysed to find out the capability of synoptic and thermodynamic parameters to monitor and predict genesis, intensification/decay and movement of OGNI.

(i) Mean sea level pressure and geopotential thickness
(ii) 24-hours pressure change
(iii) Pressure departure from normal
(iv) Surface and upper air winds
(v) Surface and upper air temperatures
(vi) Relative humidity, moisture flux and Precipitable water.

4.2. Dynamical parameters

The following dynamical parameters during 28th -30th October 2006 are analysed based on daily average NCEP/NCAR reanalysis (Kalney et. al., 1996) data and LAM analysis of India Meteorological Department (IMD).

(i) Relative vorticity and vorticity advection
(ii) Convergence/divergence
(iii) Vertical wind shear
(iv) 24-hours tendency in the vertical wind shear and
(v) Vertical velocity.

4.3. Satellite imageries and its derived products.

The characteristics of the cyclone, "OGNI" are analysed by hourly INSAT imageries and derived products during 28-30th October 2006. The monitoring and prediction capabilities of satellite technique in the case of such a small core and short lived system are verified by analyzing the following.

(i) INSAT- Kalpana-I imageries
(ii) Cloud top temperatures
(iii) Cloud motion vectors in lower, middle and upper troposphere
(iv) Water vapour derived winds.
(v) Outgoing long wave radiation (OLR)
(vi) Quantitative Précipitation Estimate (QPE)

4.4. DWR imageries and other products

The DWR imageries and products from DWR Machilipatnam, Chennai and Sriharikota are analysed with respect to the following aspects of the cyclone, "OGNI" as suggested by Raghavan (1997).

(i) Kinematics of the cyclonic storm
(ii) Identification of the relative proportion of convective and stratiform precipitation and their influence on storm development
(iii) Asymmetries in the core region and outside and their relation to the motion of the cyclone
(iv) Landfall effects.

For the above purpose, the available DWR products from DWR Machilipatnam, Chennai and Sriharikota during 28th-30th October, 2006 are analysed and discussed. The products considered in the study are as follows:

(i) Plan Position Indicator (PPI) imagery for reflectivity study
(ii) Range Height Indicator (RHI) imagery
(iii) Wind distribution and
(iv) Rainfall rate.

4.5. Performance of NWP models

24-hours (Day 1) and 48-hours (Day 2) forecast based on the data of 27th, 28th and 29th are analysed to find out the present capability of the NWP models to monitor and predict such small core system, "OGNI". For this purpose, the model outputs of Limited Area Model (LAM) & Quasi Langrangian Model (QLM) and MM5 model of IMD, T-80 model of NCMRWF, UKMO model and ECMWF model are considered. The performance is evaluated with respect to genesis, intensification, movement and rainfall.

4.5.1 Model simulation studies

There was a unique opportunity for assimilation of radar data in the NWP model and carryout the simulation studies as the system moved close to the coast within radar range. Such simulation studies are carried out and results are presented and analysed. For this purpose, the impact of DWR data of Chennai is investigated in the assimilation and forecasts by Advanced Regional Prediction System (ARPS) for simulation of this cyclone. The ARPS (version 5.2.2) is used in the study.

It is a three dimensional non-hydrostatic meso-scale model. The model is developed by the Centre for Analysis and Prediction of Storm (CAPS) at the University of Oklahoma, USA to handle storm scale weather events. It includes a very sophisticated DWR parameter retrieval and data assimilation procedure (Xue, et al., 2003). IMD, New Delhi has been using this model in experimental mode for simulation of local thunderstorm events (Srivastava et al., 2008). The simulation exercise is carried-out at the model horizontal resolution of 9 km. Background and boundary conditions are obtained from the National Centre for Environment Prediction Global Forecast System (NCEP GFS), at the resolution of 1^0x1^0 lat/long. The NCEP GFS fields are interpolated for ARPS Data Assimilation System (ADAS) grid at 9 km resolution. The domain selected for the model run is shown in Fig. 3. The size of the domain is 901 km x 901 km with 9 km grid spacing and Chennai is located at the centre of the domain. The vertical grid length changed from 20 m at the surface to about 400 m at the model top which is located at about 15 km height. The detailed design of experiment is shown in Table 2. Half hourly intermittent assimilation cycles are performed within a 3 hour assimilation window from 0000 UTC to 0300 UTC. Two sets of numerical experiments are conducted. In the first experiment (termed as the "control" run), the model is run without ingesting the DWR observations in the assimilation cycle. In the second experiments (termed the "DWR" run), DWR radial wind and reflectivity observations are ingested in the model assimilation cycle. The DWR observations are first pre-processed to convert them into the desired format of model assimilation. Then radial velocity data are analyzed using ADAS, while reflectivity data are used through the cloud analysis procedure. The temperature adjustment scheme based on the moist adiabatic temperature profile is used in the cloud analysis scheme. Fig. 4 shows the 3 hours assimilation window and then 21 hours forward forecasts (valid of 00 UTC of 30th October 2006).

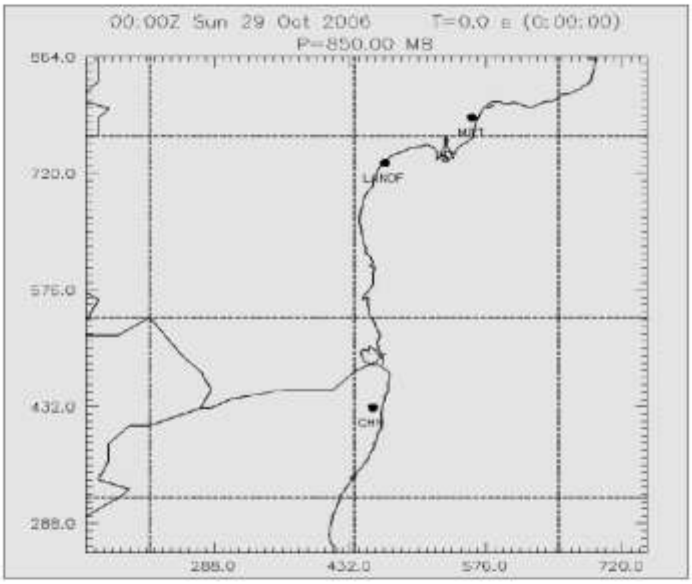


Fig.3. Domain (lat./long.) selected for model simulation

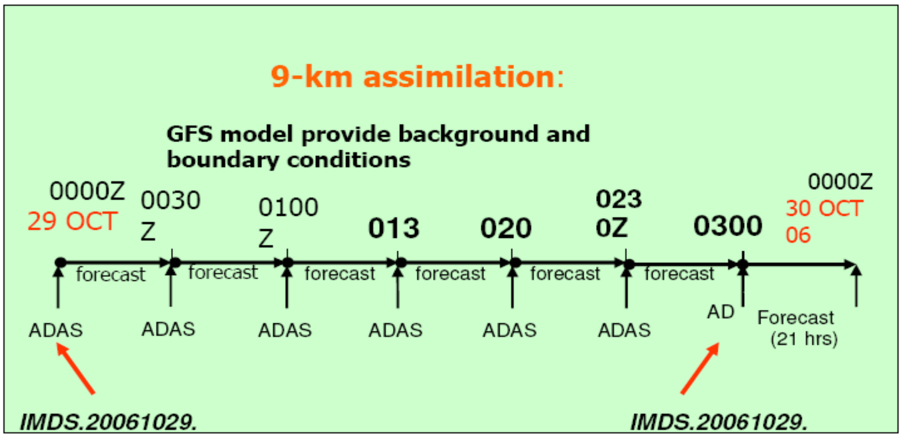


Fig. 4 The model domain.
(latitude along the center point of the domain is 14.0 ° N and Longitude along the center point is 80.0°E, latitude longitude lines are shown At 2.0° intervals).

Table 2: Design of experiments

Central Latitude (Chennai)	13.0°N
Central Longitude (Chennai)	80.0°E
Dimension Size (No of Grids) in X, Y & Z direction	99,99,38
Grid spacing (meters) in X, Y & Z direction	9000, 9000, 400
Run mode	3-D run
Model Initialization Option	Initialized using an analysis from the ARPS Data Analysis System (ADAS)
Time step for model integration	30 second
Boundary Conditions	Zero gradient (east, west and top), Periodic (north and south)
Turbulent Mixing Option	1.5 TKE turbulent mixing
Moist processes Option	Moist processes are activated
Microphysics Option	Kain Fritsch warm rain microphysics
Surface Physics Option	Surface fluxes are calculated from the constant surface drag coefficients, and predicted surface temperature and surface volumetric water content.
Convective Cumulus Parameterization	Kain -Fritsch Cumulus parameterization

5. Results and discussion

The synoptic observations and various weather charts are analysed and presented in section.5.1. The analysis of various dynamical parameters are presented and discussed in section.5.2. The thermo-dynamical parameters are analysed and discussed in section 5.3.The Satellite and Radar observations are presented in section 5.4 and 5.5 respectively. The various NWP model forecasts alongwith simulation studies are analysed and presented in section 5.6. A brief discussion on the salient features based on the results and analysis is presented in section 5.7.

5.1. Synoptic features

The mean sea level pressure and surface wind are presented and discussed in section 5.1.1. The 24-hours pressure change and pressure departure from normal are analysed and presented in section 5.1.2. The upper winds over Indian region are analysed and discussed in section 5.1.3. The LAM analysis of pressure, wind and geopotential heights are presented and discussed in section 5.1.4.

5.1.1. Mean Sea Level Pressure and Surface Wind

The characteristics of outer core circulation and the radius of the outer most closed isobars may suggest the intensity of the cyclone. Filling cyclones are seen to have a larger and a stronger outer core circulation. However, according to Weatherford and Gray (1988), both these measures are poorly related to intensity. However, as the data from ships of opportunity and the Buoy data were very meager during the life period of OGNI, the outer core circulation could not be properly estimated. The isobaric analyses over Indian region, during 28-30th October 2006 are shown in Fig.5. The east west shear zone established are the region consequent upon the withdrawal of southwest monsoon from entire country on 17th October and commencement of northeast monsoon rains over the southeast peninsular region thereafter. There was strong northeast monsoon circulation over the region with two embedded cyclonic circulations, one over southwest Bay of Bengal and the other over the southeast Arabian Sea. Under their influence, a low pressure area lay over southwest and adjoining central Bay of Bengal and another lay over southeast and adjoining eastcentral Arabian Sea in association with an active east-west shear zone. The Fig. 6 shows the 3-hourly surface wind and mean sea level pressure analysis during 1200 UTC of 29th to 0600 UTC of 30th October, 2006. The low over southwest Bay intensified gradually while moving northward and the low over southeast Arabian Sea weakened gradually. The system weakened gradually over the Bay of Bengal after 0300 UTC of 30th October before landfall. .

(i) 0300 UTC (ii) 1200 UTC

(a) 28-10-2006

(b) 29-10-2006

(c)30-10-2006

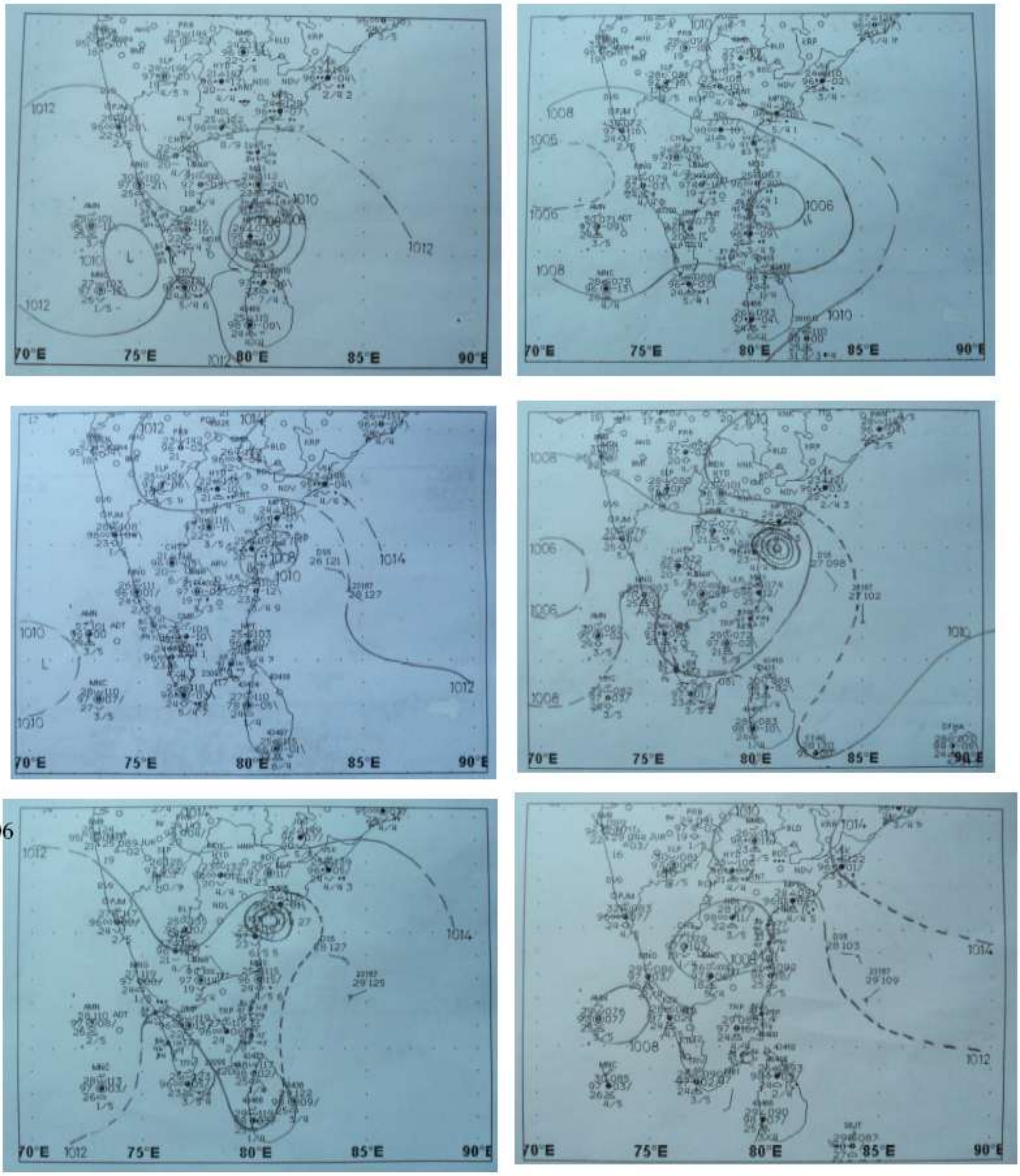


Fig.5. Isobaric analysis of (i) 0300 and (ii) 1200 UTC charts of 28-30 October 2006 over the region

According to the criteria adopted by IMD for classification of the low pressure systems over Indian region including north Indian Ocean, a low pressure system is said to be a depression if there are two closed isobars within a 6^0 X 6^0 latitude/longitude. It is called a deep depression, if there are three closed isobars and a cyclonic storm if there are 4 or more closed isobars. Over the sea surface, a low pressure system is said to be a depression, if the associated sustained maximum wind is 17-27 kts, a deep depression, if wind speed is 28-33 kts and a cyclonic storm, if the wind speed is 34-47 kts. The surface wind was not strong with wind becoming maximum (20 kts) from easterly direction at 0300 UTC of 30th near Bapatla (Fig.7).The hourly coastal observations (Fig.7.) indicate that the system crossed coast between Bapatla and Ongole in Andhra Pradesh around 0700 UTC of 30th October, 2006. Considering the mean sea level pressure analysis and wind analysis, the intensity of the system could not be properly estimated

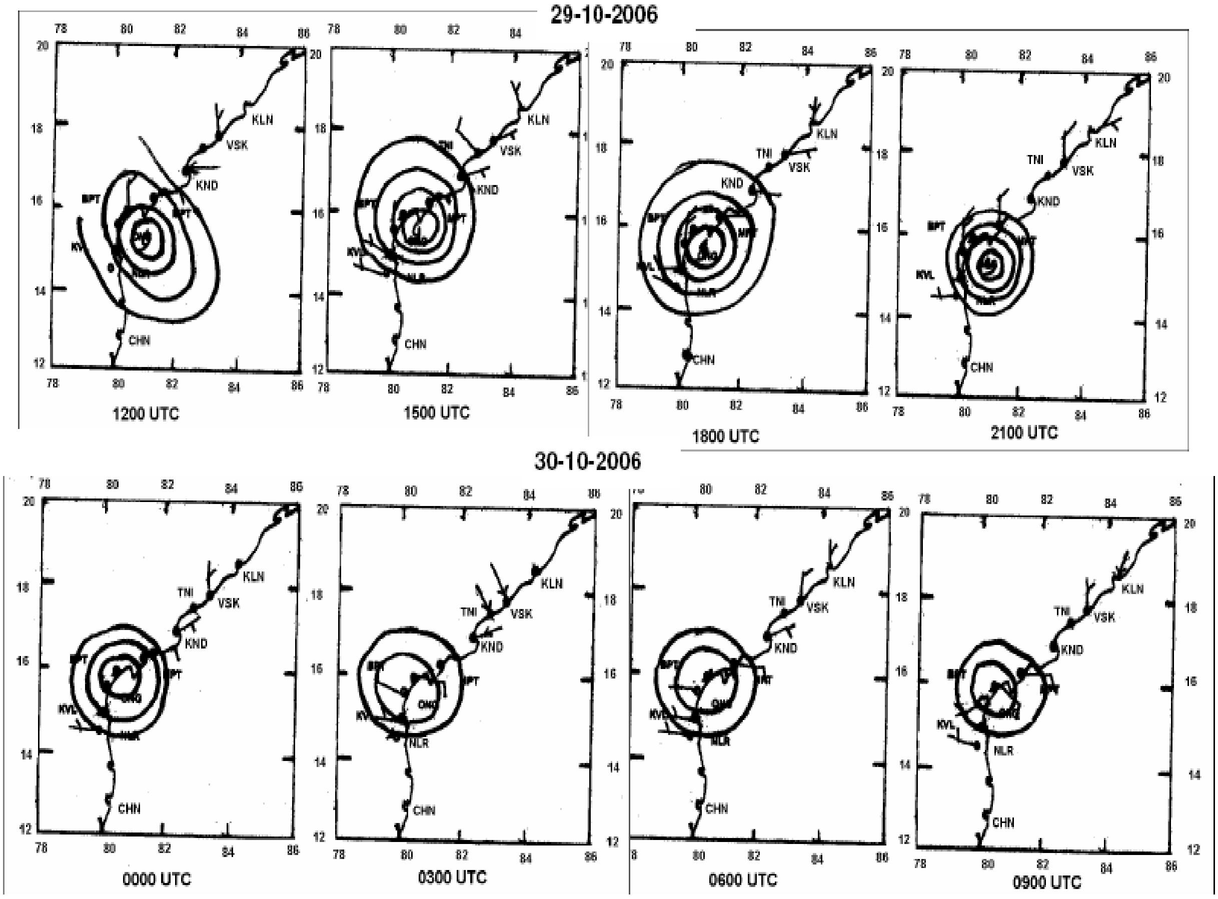


Fig. 6 (a-b) Mean sea level pressure analysis charts of 29 and 30th October 2006. The system has more pressure gradient between 1800 UTC of 29th and 0000 UTC of 30th within the 200 kms diameter.

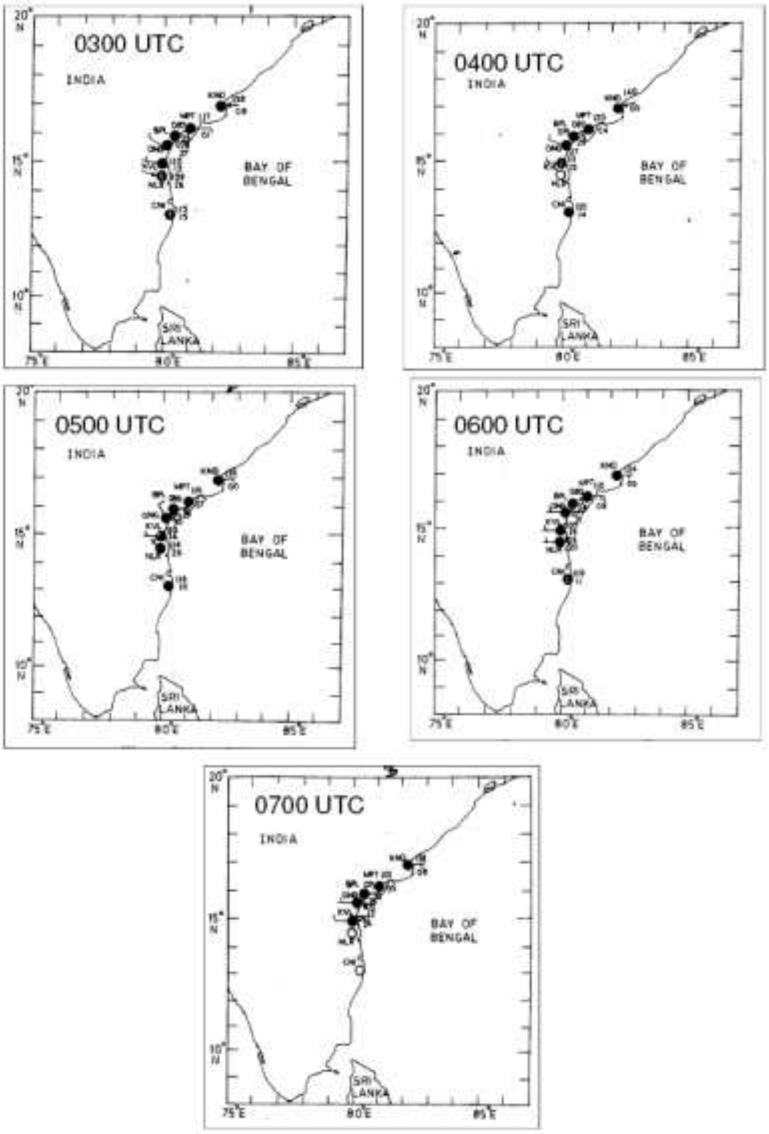


Fig. 7 . Special hourly coastal observations during the time of landfall (0300 UTC to 0700 UTC) on 30th October 2006

5.1.2. 24- hours pressure change and pressure departure from normal

24-hours pressure changes and pressure departure from normal at 0300 and 1200 UTC of 29th and 30th October, 2006 are shown in Fig.8. The 24-hours pressure change showed maximum fall of mean sea level pressure of 2 hPa over Andhra Pradesh coast throughout the period. However, the coastal observations indicated the maximum fall of pressure 4.0 hPa near Chennai at 1200 UTC of 29th October (Fig.7). The pressure fall continued till 0300 UTC of 30th and rose thereafter. The 24-hour change thus suggested gradual intensification of the system till 1500 UTC of 29th and its gradual decay from 0300 UTC of 30th. It further indicated the northward movement of the system as the 24-hours pressure fall was maximum near Ongole during 29-30 October. There was a projected tongue structure in the negative pressure change in the northerly direction from the system centre. Thus the system followed the direction of maximum negative isallobaric gradient as suggested in earlier studies (IMD, 2000).

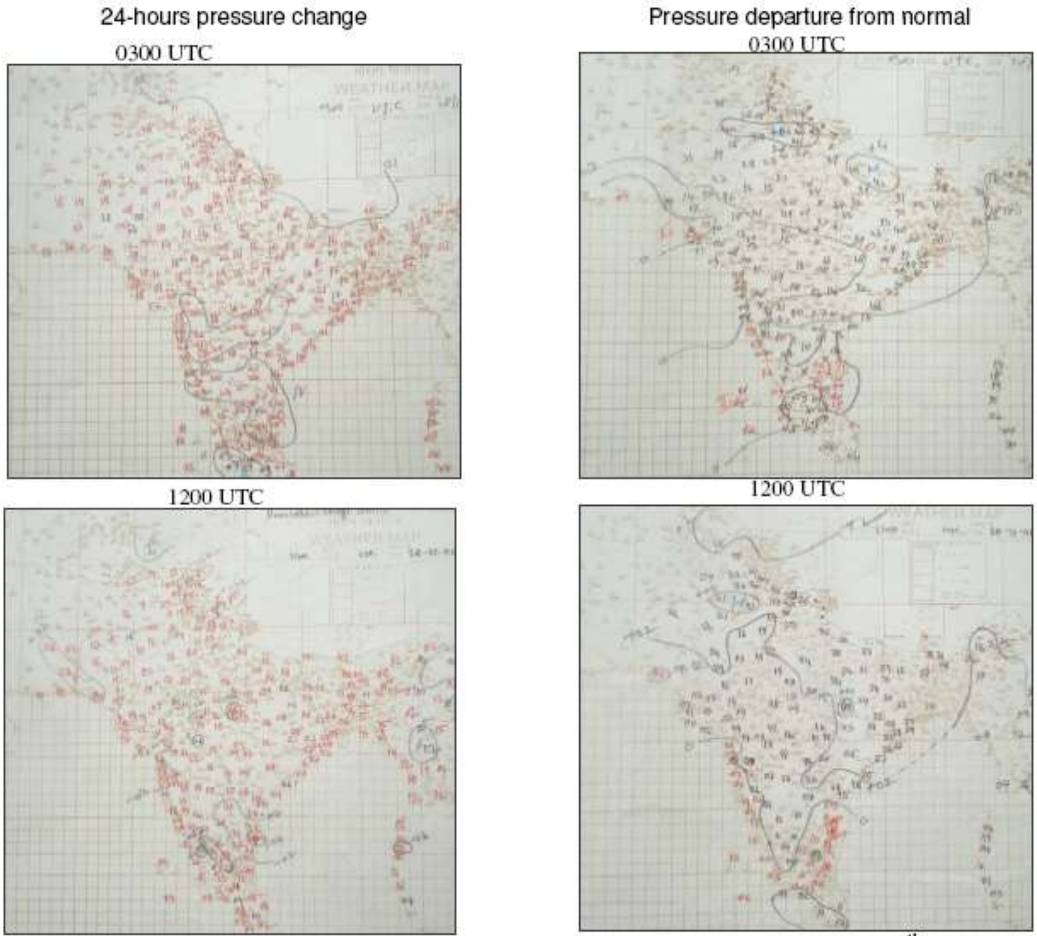


Fig.8 (a). 24-hours pressure change and departure from normal at 0300 & 1200 UTC of 28th October 2006

The negative departure was not very significant. It may be due to the fact that the system was a small core system and could not be reflected properly in the pressure departure charts. The hourly coastal observations could not be interpreted to find out the maximum negative pressure departure as the hourly normal are not available. The availability of hourly normal prepared from the barographs of the coastal observations may be very helpful to monitor the intensification/decay of such short lived and small core cyclonic storm like “OGNI” which could not be captured in 0300/1200 UTC pressure departure charts of 28-30th October.

24-hours pressure change | Pressure departure from normal

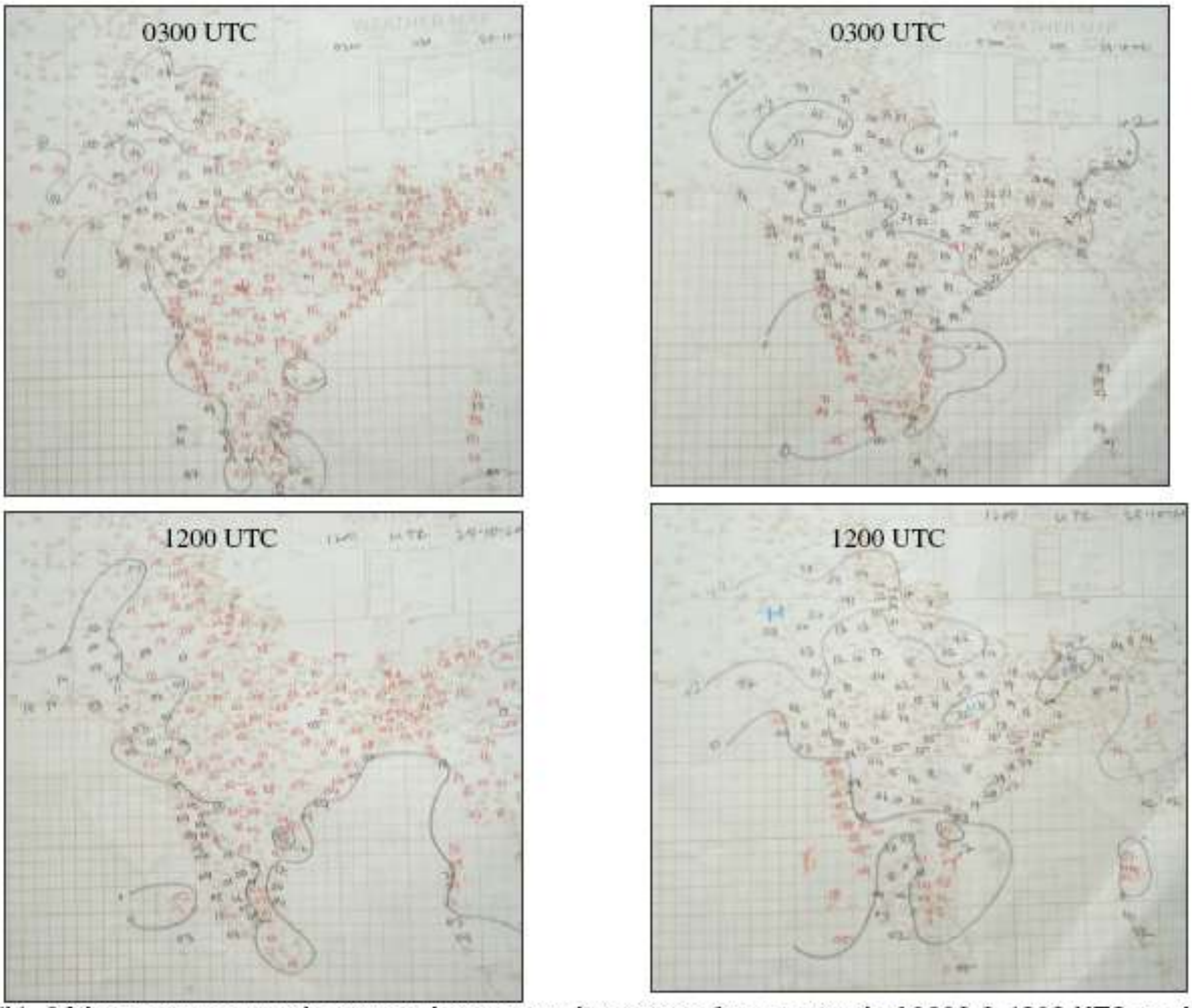


Fig. 8 (b). 24-hours pressure change and pressure departures from normal of 0300 & 1200 UTC analysis charts of 29th October, 2006

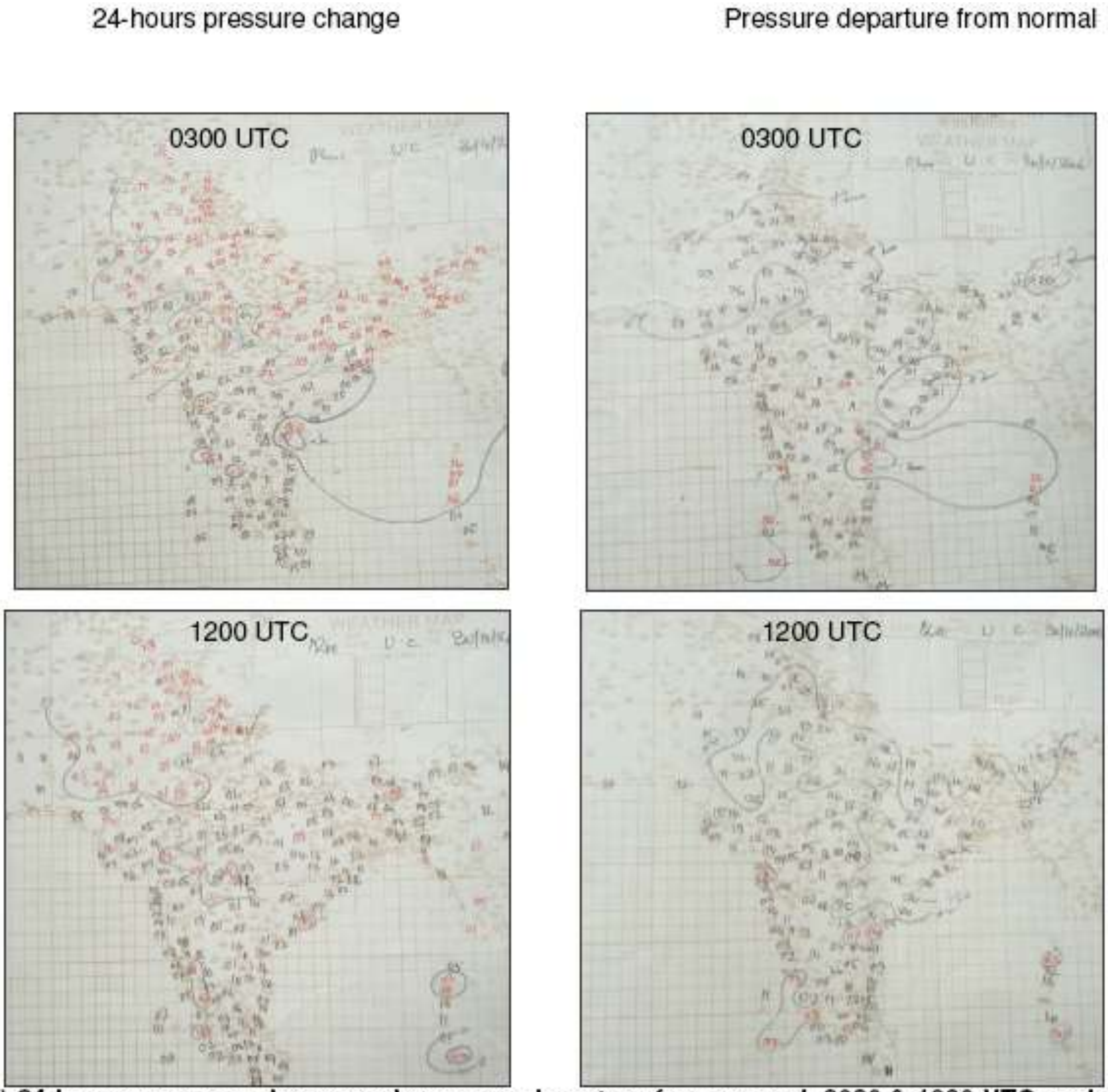


Fig.8(c) 24-hours pressure change and pressure departure from normal, 0000 & 1200 UTC analysis charts of 30th October 2006

5.1.3. Upper winds

The upper winds based on synoptic observations over Indian region for the three representative levels of 850, 500 and 200 hPa during 28-30th October, 2006 are shown in Fig.9 . Like the isobaric analysis, the wind pattern at 850 hPa suggested the existence of an active east-west shear zone in lower tropospheric levels. The associated cyclonic circulation over the southeast and adjoining westcentral Bay of Bengal extended upto mid tropospheric levels from 28th onwards. The associated cyclonic circulation with the low over southeast and adjoining westcentral Arabian Sea extended upto lower tropospheric levels during the period. In association with the depression on 29th, the upper air cyclonic circulation also extended upto mid-tropospheric level.

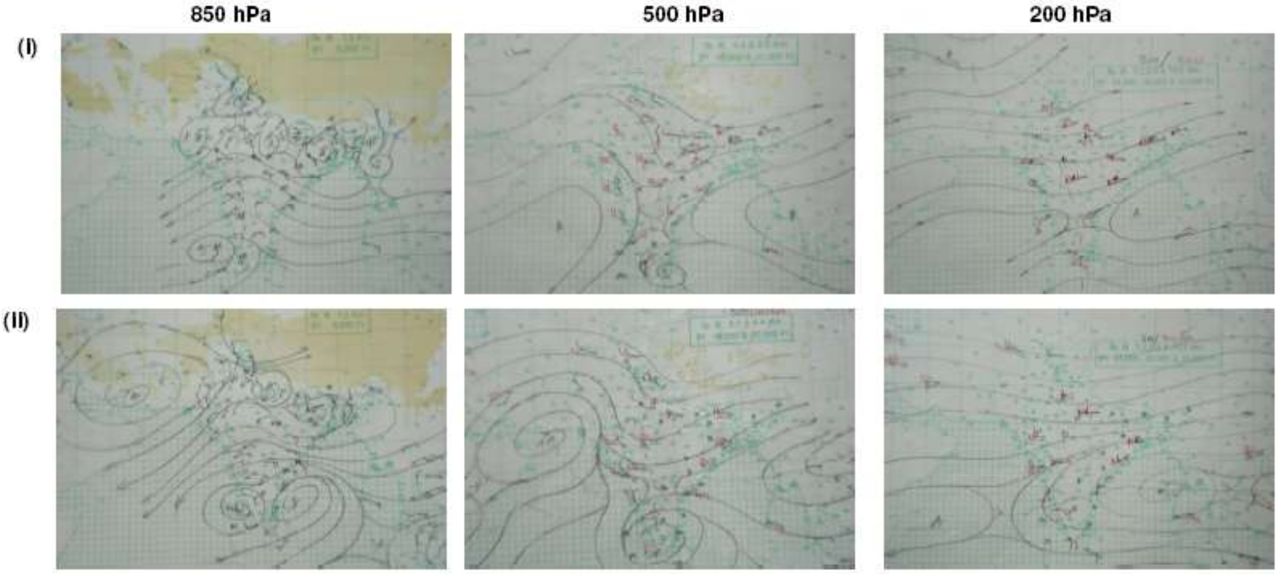


Fig.9(a). Upper air winds over Indian region at 850 hPa, 500 hPa and 200 hPa (I) at 0000 UTC and (II) at 1200 UTC of 28th October, 2006

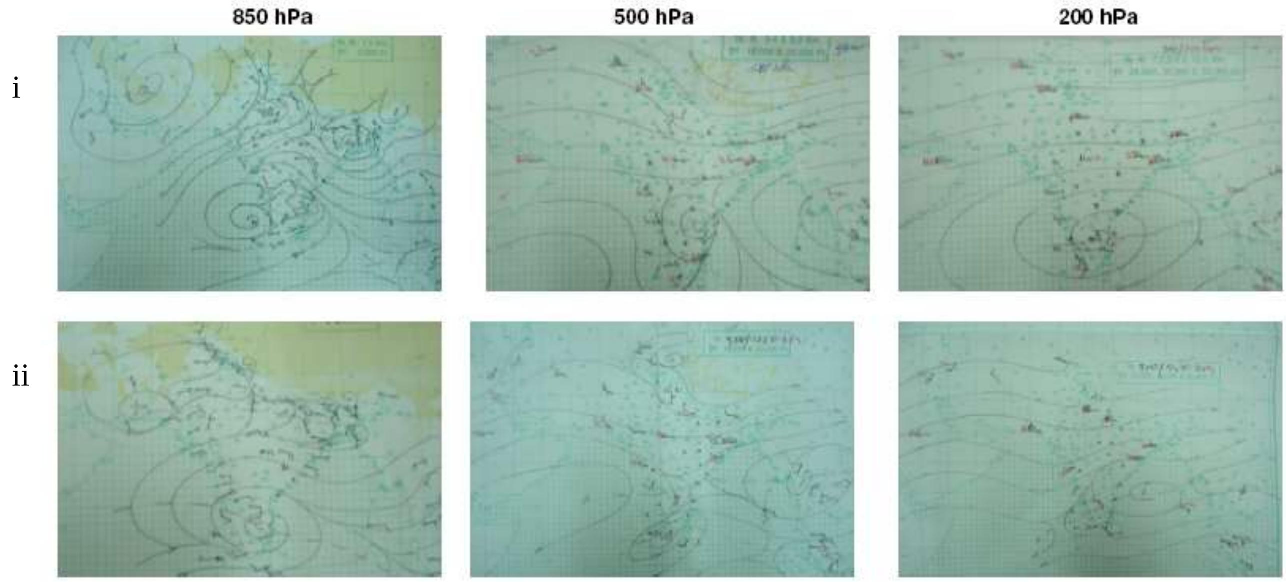


Fig.9(b). Upper air winds over Indian region at 850 hPa, 500 hPa and 200 hPa (I) at 0000 UTC and (II) at 1200 UTC of 29th October, 2006

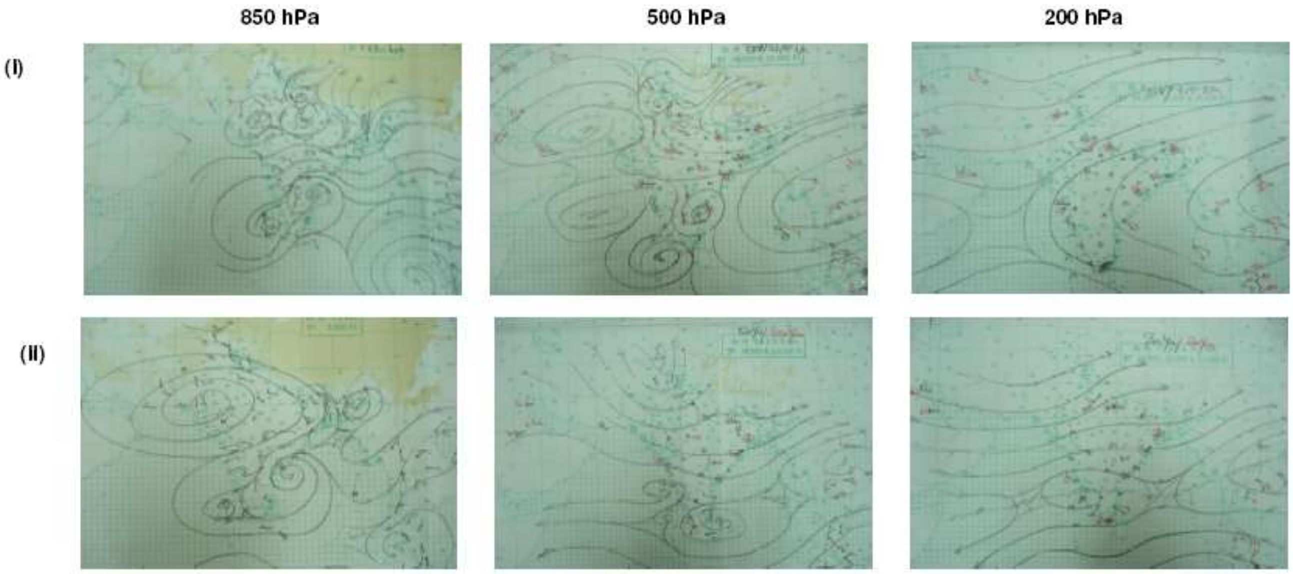


Fig.9(c). **Upper air winds over Indian region at 850 hPa, 500 hPa and 200 hPa (I) at 0000 UTC and (II) at 1200 UTC of 30th October, 2006**

As the system was a small core system, the coastal winds at lower levels were not very strong with wind speed being ~20 knots at 850 hPa level at 0000 UTC of 29th. However, the coastal winds suggested gradual intensification of the system from 0000 UTC to 1200 UTC of 29th and weakening of the system at 0000 UTC of 30th. The associated cyclonic circulation extended upto mid-tropospheric level till 30th morning. The steering wind at 200 hPa level at 0000 UTC of 29th suggested quasi-stationary slow northward movement of the system as the system was close to the ridge. The system also remained practically stationary or moved very slowly at nearly northerly direction through out its life. The system moved from 14.5^0 N and 80.5E at 0300 UTC of 29th to 15.6^0 E and 80.3^0E, at 0300 UTC of 30th, thus covering about 135 km in 24 hours at the rate of 5.5 kmph. According to Srinivasan and Ramamurthy (1973), as the storm reaches sub-tropical ridge line, the westward movement of the storm slows down. According to their study, in 80% of the occasions, the storm moves in the west-northwesterly direction, if it is 3^0or more to the south of the ridge line. When the centre is near the ridge line, there is a pre-pondered northerly motion. Hence, the cyclone “OGNI” moved according to the steering concept endorsing the earlier findings. The study further confirms that the steering current is represented by the wind flow over the storm area at a sufficiently higher level where the storm circulation disappears.

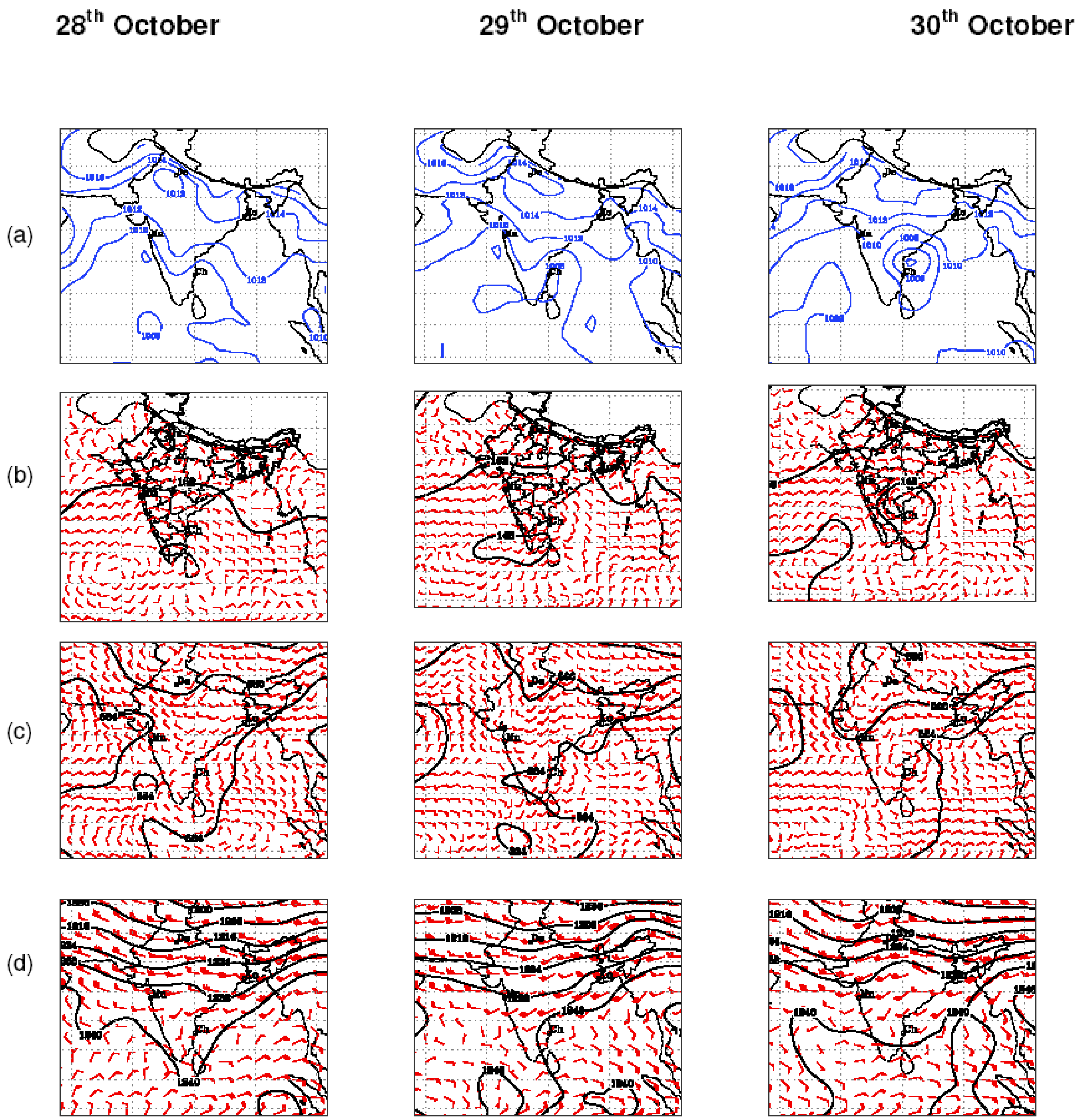


Fig. 10. Mean sea level pressure (a) and (b-d), Geopotential and wind analyses at three representative levels of 850 hPa, 500 hPa and 200 hPa at 0000 UTC during 28th-30th October 2006 over Indian region according to Limited Area Model (LAM) of IMD.

5.1.4 LAM analysis of pressure, wind and geopotential fields

The mean sea level pressure, wind and geopotential at three representative levels of 850, 500 and 200 hPa at 0000 UTC and 1200 UTC of 28-30th October 2006 are shown in Fig.10. As per IMD criteria, the system lay as an extended low pressure area at 0000 UTC of 29th and as a depression at 0000UTC of 30th. The cyclonic circulation at 850 hPa level could not be reflected in the analysis on 28th and 29th. However, the circulation was observed over westcentral Bay of Bengal off Andhra Pradesh coast at 0300 UTC of 30th with a wind speed of about 20kts. Like the pressure and wind field, the geo-potential fields also could not show the system (Fig.10). Considering upper tropospheric wind at 200hPa level, the ridge line lay to the south of the circulation centre roughly along Chennai latitude suggesting northeastward movement of the system, contrary to the observed nearly northerly movement of the system. Hence, the analysis fields of the LAM did not clearly reflect the genesis, intensification and movement of the system. The discrepancies in the LAM analysis are primarily due to the sparse data over the cyclone region as well small core nature of the system.

5.2. Dynamical parameters

The vorticity, divergence and vorticity advection over the region are presented and analysed in section 5.2.1. The vertical wind shear and vertical velocity over the region are analysed and discussed in section 5.2.2 and 5.2.3 respectively.

5.2.1 Vorticity, divergence and vorticity advection

The low level relative vorticity and divergence over Indian region at 850, 500 and 200 hPa levels at 0000 and 1200 UTC during 28-30th October 2006 as obtained from LAM analysis are shown in Fig. 11. The low level relative vorticity was negative over the central and adjoining north Bay of Bengal on 28th. It gradually increased and became positive with higher values over westcentral and adjoining southwest Bay of Bengal, south coastal Andhra Pradesh and north Tamilnadu at 0000 UTC of 29th. It then rapidly increased and became maximum, over south coastal Andhra Pradesh and adjoining westcentral Bay of Bengal at 1200 UTC of 29th and 0000 UTC of 30th. It then decreased rapidly. The spatial and temporal distributions of vorticity in lower levels were in agreement with intensity and movement of the system. The distribution of low level positive relative vorticity was oriented from southwest to northeast at 1200 UTC of 29th and 0000 UTC of 30th. However, there was only one maxima in positive vorticity to the north of system centre. This was in agreement with the rainfall distribution (Fig.2), though the centres of maxima in rainfall and low level vorticity differed a little in their locations.

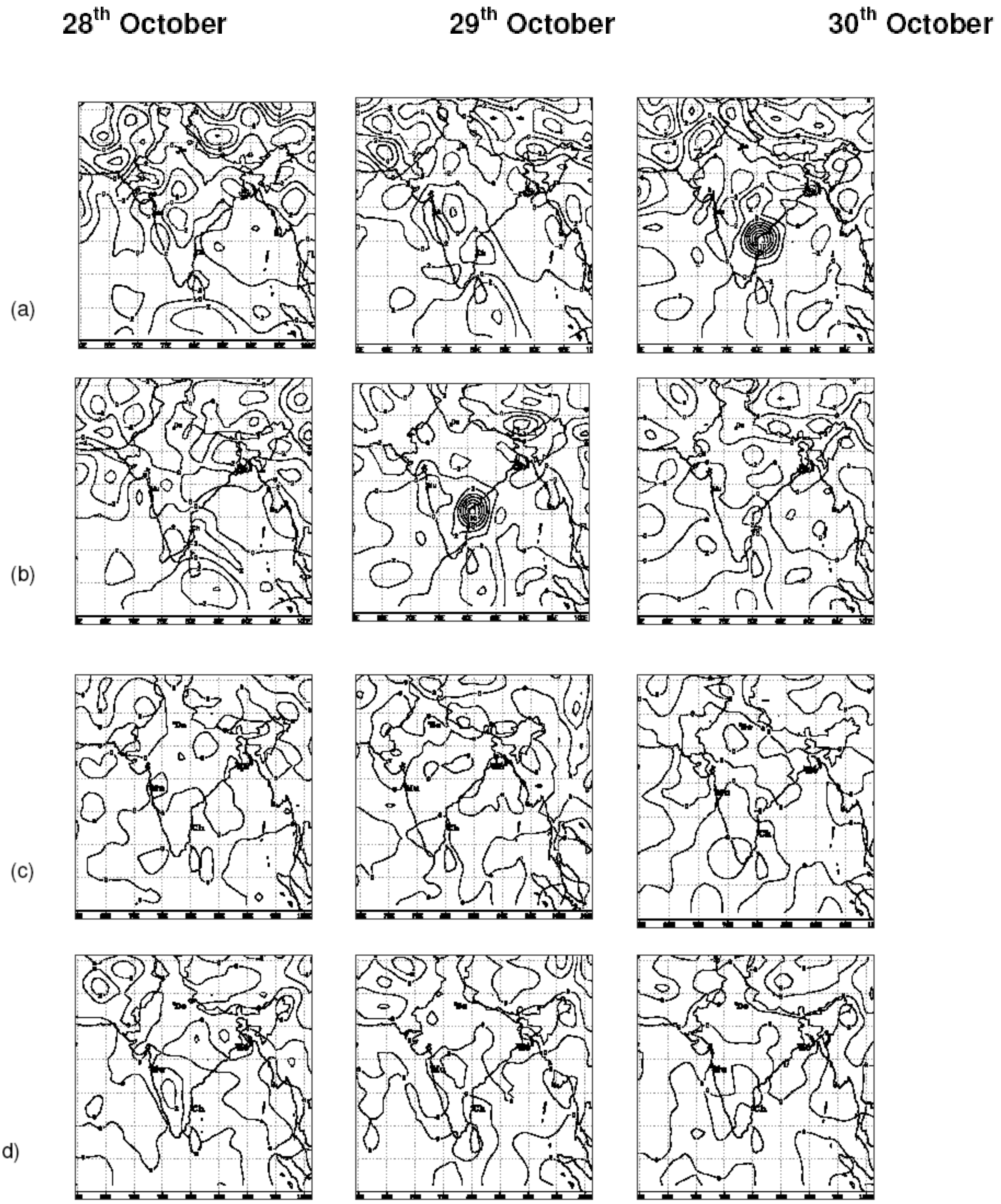


Fig. 11. Low level relative vorticity at 850 hPa according to (a) 0000 UTC and (b) 1200 UTC LAM analysis and divergence at 850 hPa according to (c) 0000 UTC and (d) 1200 UTC LAM analysis during 28th-30th October 2006 over Indian region.

According to Mc Bride (1974), the low level vorticity in developing cloud clusters is twice that in non-developing disturbances. In a developing tropical disturbance, the effect of intense convection is to generate a convergent low level wind field as air flows towards convection. This convergence produces an increase in relative vorticity. Unlike the vorticity field, the divergence/convergence field was not very pronounced over the storm region as shown in Fig. 10 (c & d).

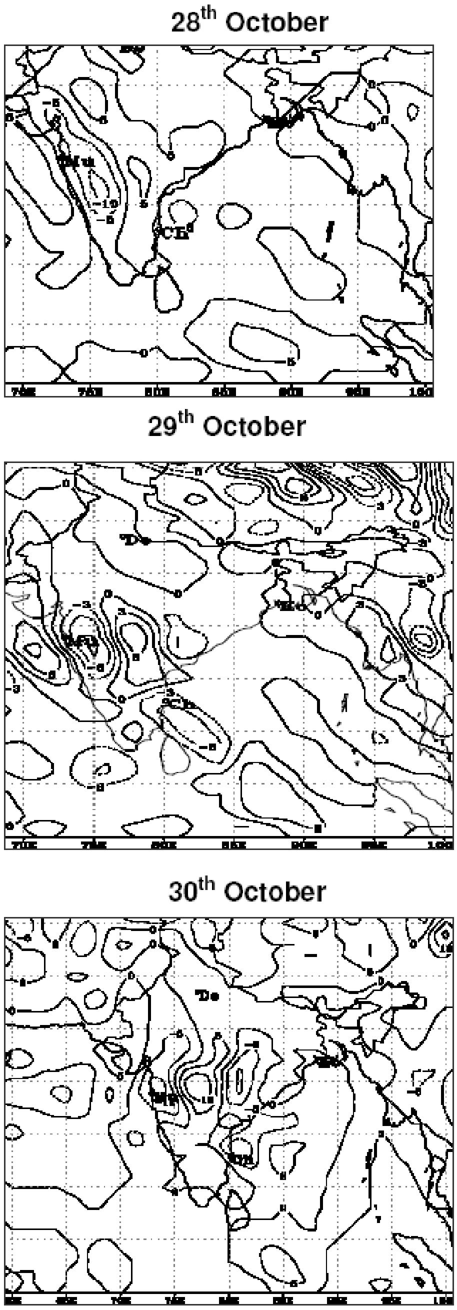


Fig.12. Vorticity advection over Indian Region at 850 hPa at 0000 UTC during 28-30 October, 2006 according to LAM analysis

According to the barotropic vorticity equation, (Holton, 1979) the barotropic vorticity depends on the (a) advection of relative vorticity (b) advection of earth vorticity and (c) vorticity change due to divergence or convergence, when the tilting, solenoidal and frictional effects are neglected in the above equation. At the first approximation, the maximum cyclonic vorticity is at the centre and decreases with increasing radius. Hence, if the cyclone is moving in a given direction, the local rate of change of cyclonic vorticity must also increase in the same direction. As the tropical cyclones generally respond like a protected symmetric vortex in a uniform, non-interacting wind flow, the motion of the storm is governed by the advection of relative vorticity. The flow simply advects the vortex along with it. The vorticity advection (Fig.12), further suggests quasi-stationary/slow movement of the system in the north-northwesterly direction as maximum advection shifted in this direction from 29th to 30th October 2006 at 850 hPa levels. As the location of increased vorticity suggests likely direction of movement of the system, the low level vorticity distribution suggested nearly northward movement of the system and landfall near Bapatla. The distribution also suggested very slow movement comparing the vorticity distribution at 1200 UTC of 29th and 0000 UTC of 30th October 2006.

5.2.2 Vertical wind shear

The utility of vertical wind shear in monitoring and prediction of the genesis and intensification/weakening of the system has been highlighted in many studies as revealed by Krishna Rao (1997). The vertical wind shear of horizontal winds between 850 and 200 hPa levels over Indian region at 0000 and 1200 UTC during 28th to 30th October 2006, according to LAM analysis are shown in Fig.13. The vertical wind shear over the system field gradually decreased from 28th to 29th and then increased on 30th. It suggested the intensification of the system from 28th to 29th and the weakening of the system on 30th. Though the vertical wind shear, could suggest the likely intensification and weakening of the system, it had least practical utility considering the short life span of the system and unavailability of 6-hourly vertical wind shear over the cyclone field. There was anti-cyclonic shear over the region which gradually intensified from 28th towards 30th morning. The close examination of the system centre and the ridge line on the vertical wind shear showed that the system lay just to the south of the ridge line on these days. Hence, there was very slow north-northwestward movement of the system. Earlier studies (Krishna Rao, 1997) also suggested that the vertical wind shear could be used as a precursor for the movement of the cyclonic storms.

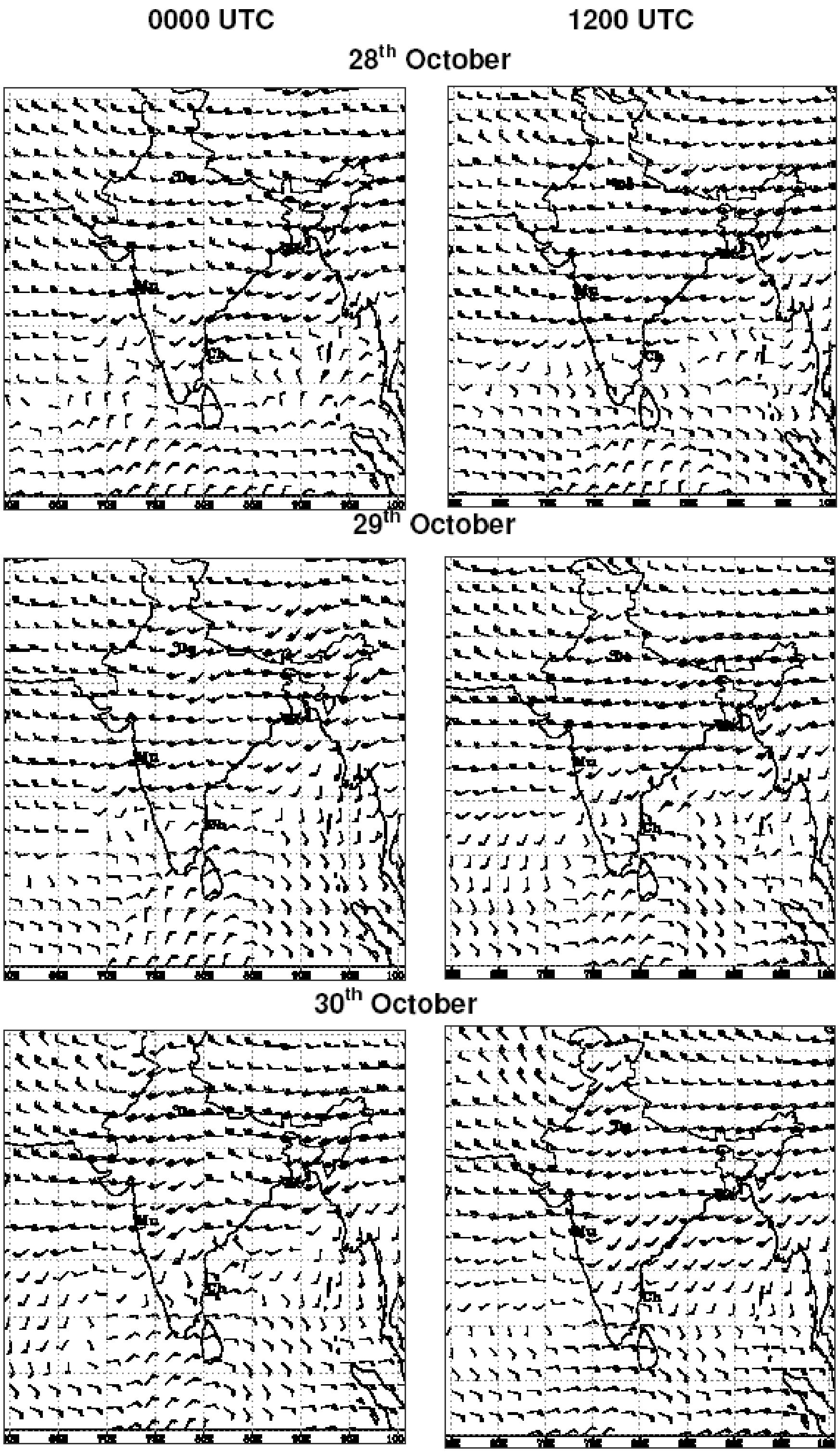


Fig.13.Vertical Wind Shear of horizontal wind (850-200 hPa) over Indian region at 0000 and 1200 UTC during 28th-30th October 2006 according to LAM analysis.

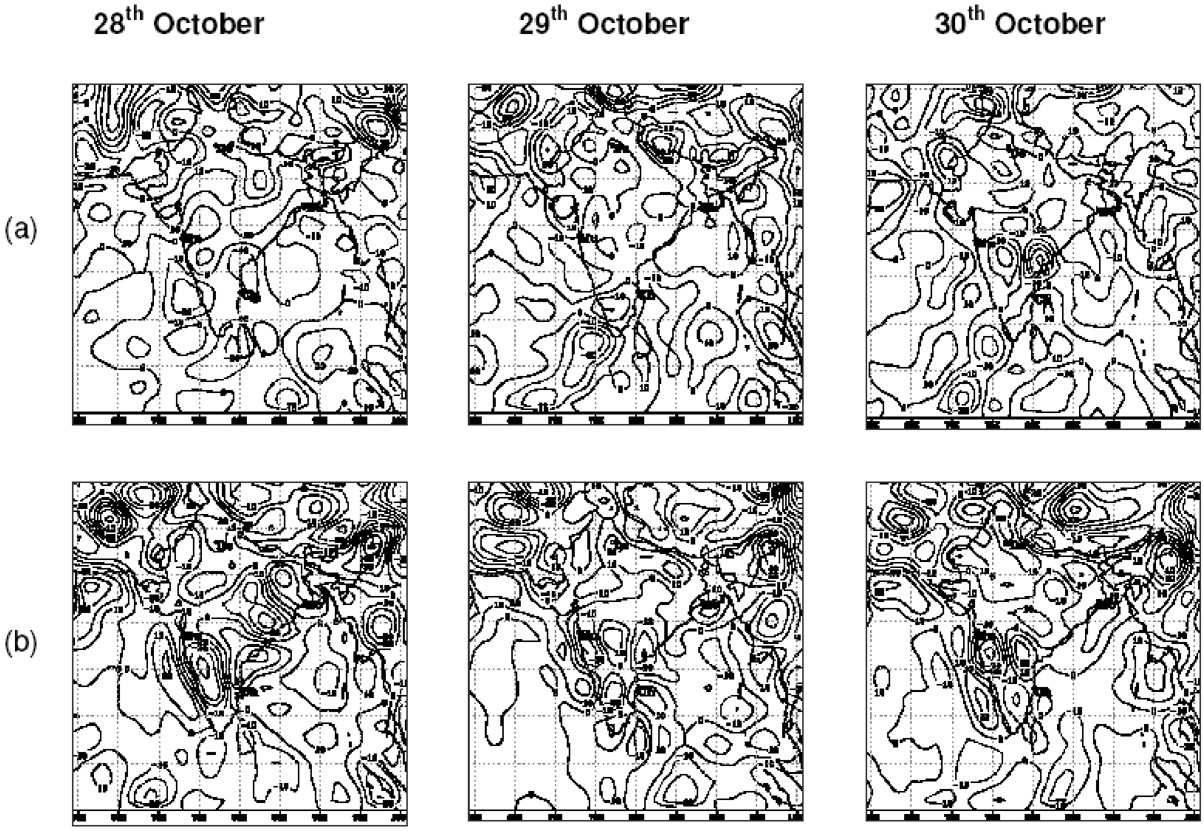


Fig.14 . Vertical velocity over Indian region at 850 hPa (a) at 0000 UTC and (b) at 1200 UTC during 28th -30th October 2006 according to LAM analysis.

5.2.3. Vertical velocity

The low level vertical velocity at 850 hPa levels according to LAM analysis based on 0000 and 1200 UTC observations during 28-30th October 2006 are shown in Fig.14. There was continuous upward vertical motion over westcentral and adjoining southwest Bay of Bengal and adjoining coastal Andhra Pradesh from 0000 UTC of 29th to 0000 UTC of 30th. The upward vertical motion increased from -20 Pascal/second at 1200 UTC of 29th to -30 Pascal/second at 0000 UTC of 30th. The surface friction in the presence of low level vorticity produces upward motion in region of positive vorticity. Hence the regions of low level positive vorticity are associated with enhanced upward motion, cumulus convection and release of latent heat. The increased heating leads to increase in horizontal convergence which, in turn increases the relative vorticity and upward vertical motion. Hence, the upward vertical motion as seen in Fig.14 was in agreement with the low level relative vorticity distribution seen in Fig.11. Though the LAM suggested the intensification and movement of the system, the unavailability of

LAM analysis during intermediate period like 1800 UTC of 29th made it difficult to decide the maximum intensity of the short lived small core system, OGNI. The distribution of vertical velocity at 1200 UTC of 29th and 0000 UTC of 30th indicated the north-northwestward movement of the velocity maxima. It confirmed the earlier findings that the system moves in the direction of increasing vertical velocity, increasing positive vorticity and increasing convection (Krishna Rao, 1997). The vertical velocity at 850 hPa suggested two maxima, one to the north-northwest of the system centre and other over southeast Arabian Sea and neighbourhood at 0000UTC of 30th. Their distribution was in agreement with the rainfall distribution (Fig.2), though the centres of rainfall maxima and vertical velocity maxima differed slightly in their locations.

5.3 Thermodynamic Parameters

The spatio-temporal distribution of relative humidity, precipitable water content, moisture flux and air temperature over Indian region during 28-30th October 2006 are analysed and presented in section 5.3.1-5.3.4.

5.3.1 Relative humidity

The relative humidity (RH) over Indian region at three representative levels of 850, 500 and 300 hPa levels based on 0000 UTC observations during 28-30th October 2006, as per LAM analysis are shown in Fig.15. According to Gray (1968), the large value of RH in lower and middle troposphere is an important parameter for cyclone genesis. The RH was more than 90% at 0000 UTC over southwest and adjoining westcentral Bay and over the adjoining land region during 28-30th October at 850 hPa levels. It was also more than 90% over south Tamilnadu, south Kerala, Srilanka and adjoining Bay of Bengal on 28th at 500 hPa level and over Tamilnadu, south coastal Andhra Pradesh and adjoining Bay of Bengal on 29th. The region of higher RH (>90%) at 500 hPa level was oriented along the east coast throughout the period. Such type of orientation was also observed at 300 hPa level, however, with relatively lower RH. There was a primary maxima in 500 hPa level at 0000 UTC of 29th October over the westcentral and adjoining southwest Bay and adjoining areas of south coastal Andhra Pradesh and north Tamilnadu (near to the north-northwest of the system centre). The orientation of RH was similar to the orientation of rainfall (Fig.2). There was no significant difference in distribution of RH of 29th and 30th except its higher value at lower and middle troposphere to indicate the intensification of the system. It, of course showed that the region of higher RH (>90%) was minimum at 1200 UTC of 29th and maximum at 0000 UTC of 30th. However, McBride and Gray (1979) have shown that though the RH is important for tropical cyclone genesis, this does not differ significantly in convective systems which intensify into tropical cyclones and those which do not.

28th October | 29th October | 30th October

(a)

(b)

(c)

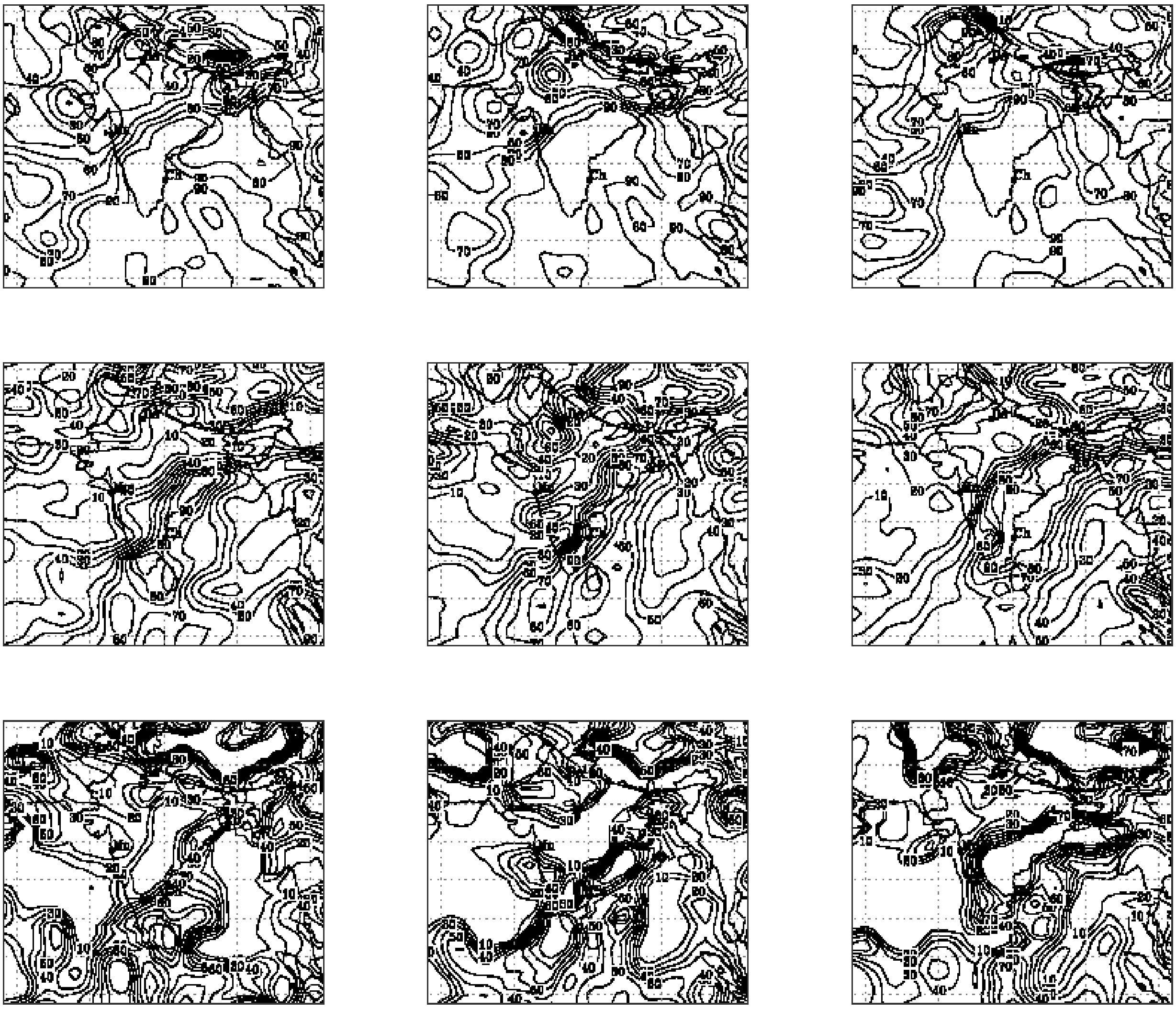


Fig. 15 . Relative humidity over Indian region at (a) 850 hPa, (b) 500 hPa and (c) 300 hPa at 0000 UTC during 28th -30th October 2006 according to LAM analysis.

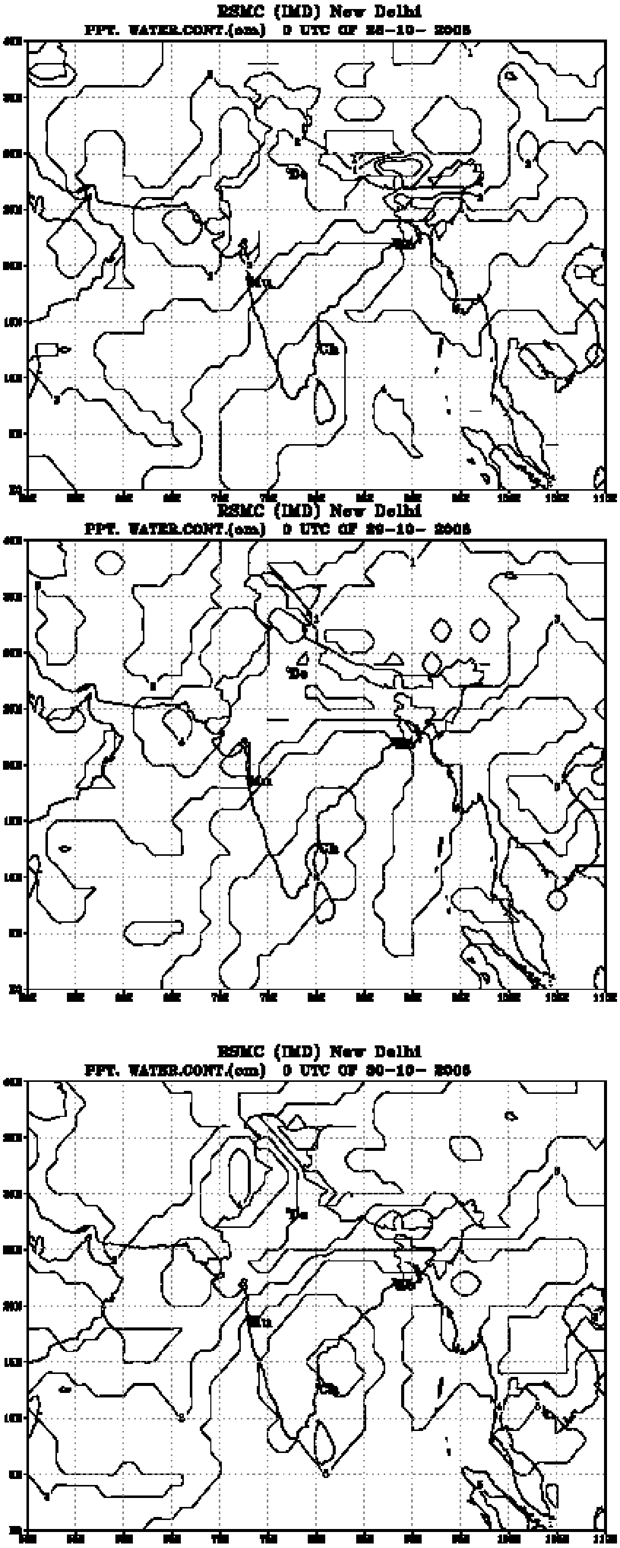


Fig.16. Precipitable water content over Indian region during 28-30th October 2006

5.3.2 Precipitable Water Content

The Precipitable water contents (PWC) of the atmosphere according to LAM analysis at 0000 UTC of 28th, 29th and 30th October 2006 are shown in fig.16. The centre of maxima in PWC lay to the southwest of the centre of the system on 29th and around the system centre on 30th. Comparing the PWC distribution and the rainfall distribution on the subsequent days during the storm period, though the pattern was similar to a large extent, the region of maxima in PWC was dislocated with respect to the centre of maximum rainfall. Also there was no significant increase in the PWC over the region of maxima from 29th to 30th unlike the rainfall.

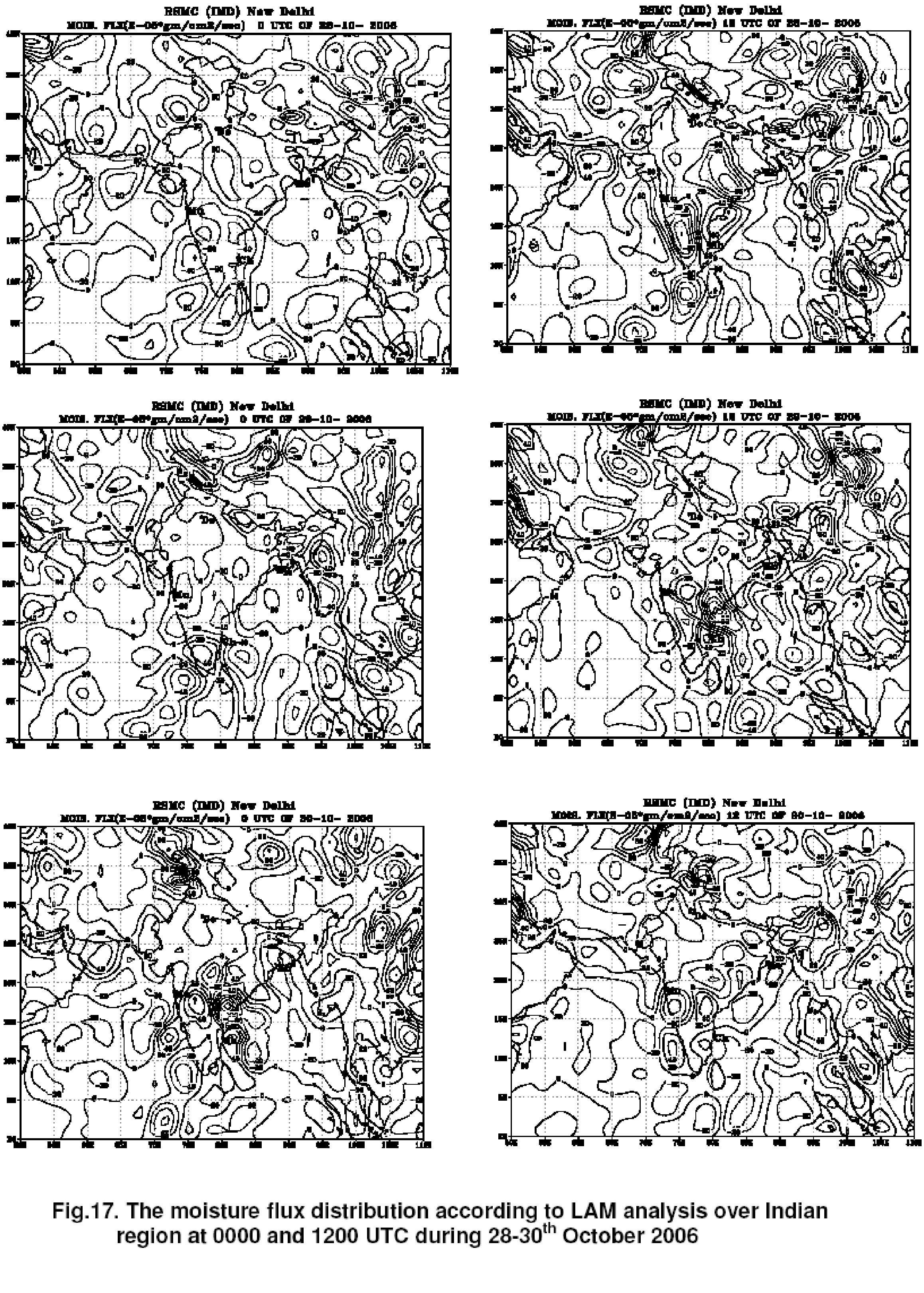


Fig.17. The moisture flux distribution according to LAM analysis over Indian region at 0000 and 1200 UTC during 28-30th October 2006

5.3.3 Moisture Flux

The moisture flux over Indian region at 0000 and 1200 UTC of 28th, 29th and 30th October 2006 are shown in Fig.17. There was moisture advection toward the centre of the system during the life period of storm. The moisture advection over the region increased from 28th onwards and became maximum between 1200 UTC of 29th and 0000 UTC of 30th. Hence, the moisture flux indicated the system to move towards Andhra Pradesh coast near Bapatla. There was another maximum in the moisture flux distribution over southeast Arabian sea on 29th and 30th, in conformity with the isobaric analysis showing the low pressure area over the southeast Arabian Sea. Considering all above, the moisture flux distribution may be considered as precursor for predicting the intensity and movement of the small core system like “OGNI”.

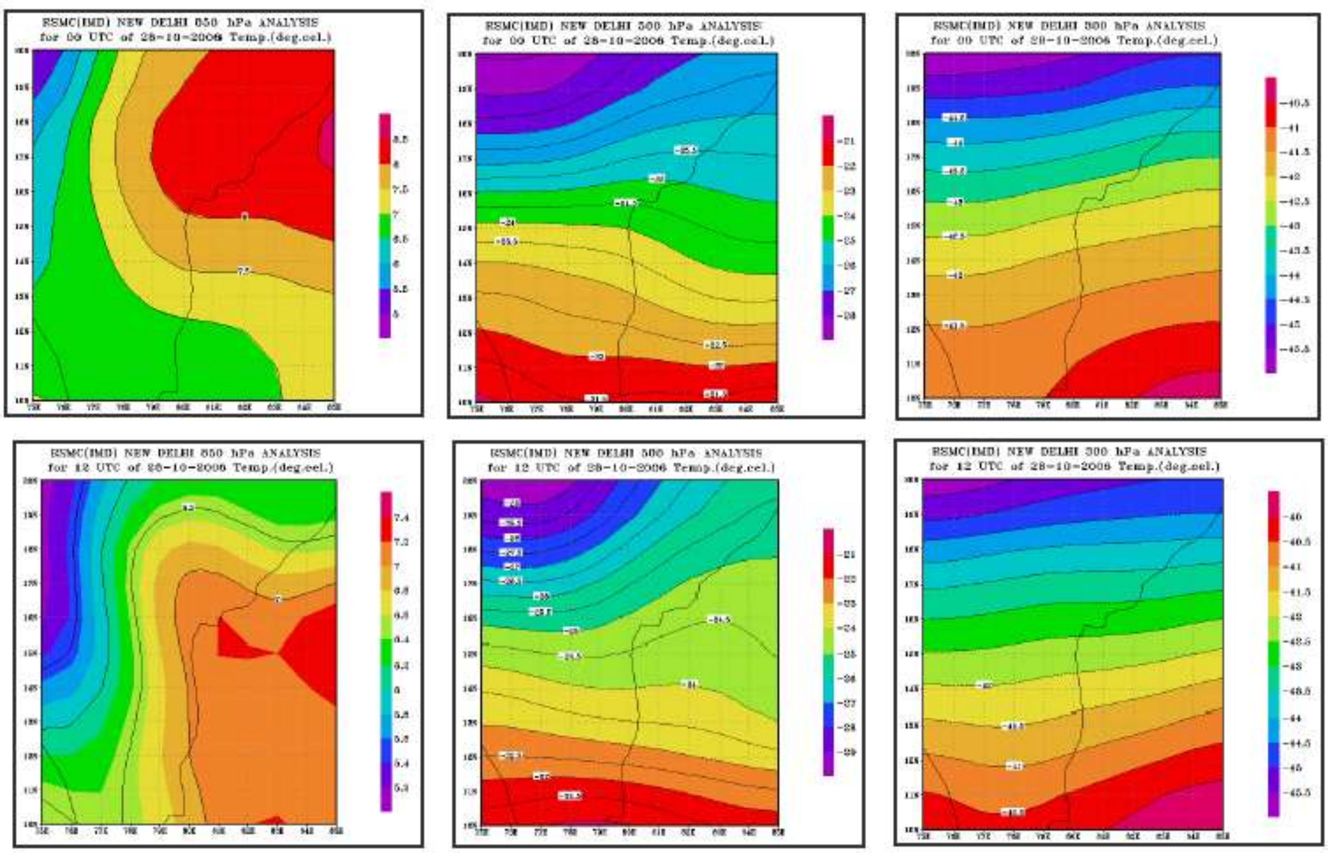


Fig. 18 (a). The air temperature over the region at 0000 and 1200 UTC of 28th October 2006 for 850, 500 and 300 hPa levels.

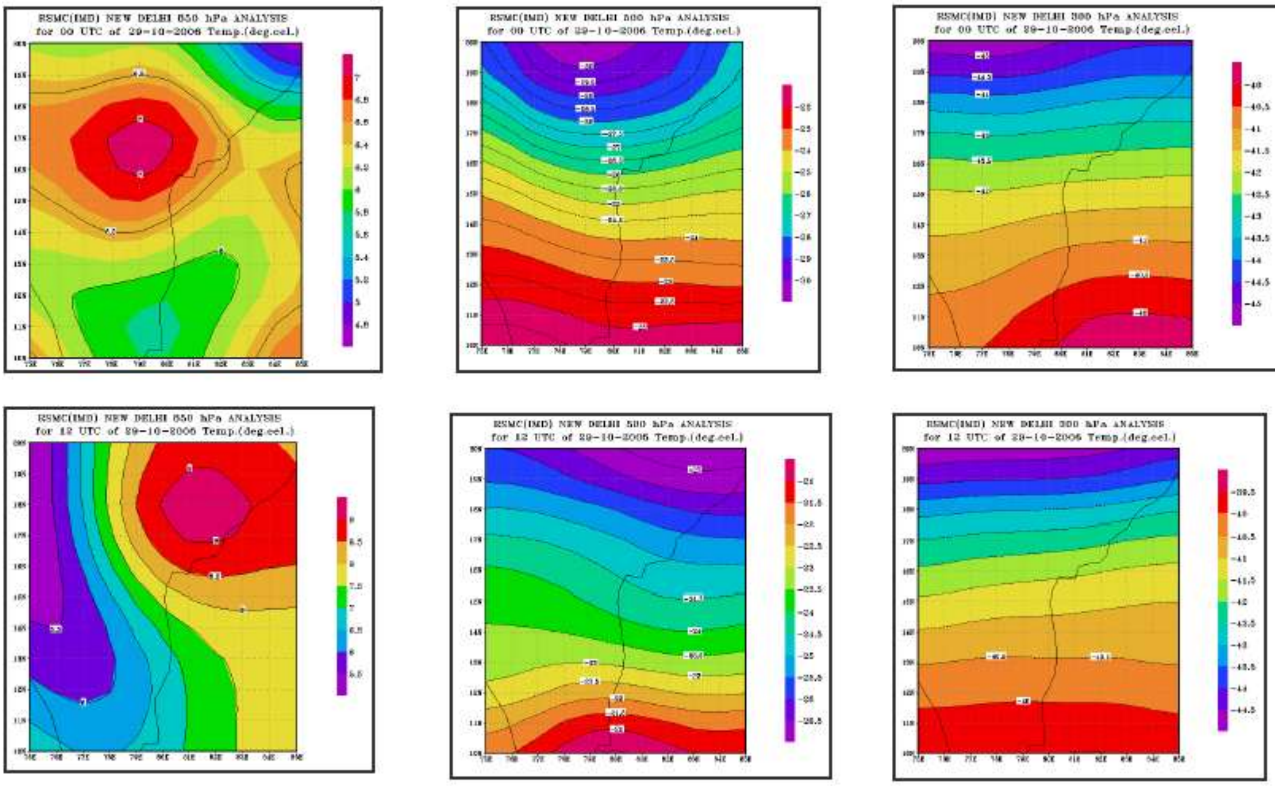


Fig. 18 (b). Same as Fig. 18(a), but for 29th October 2006

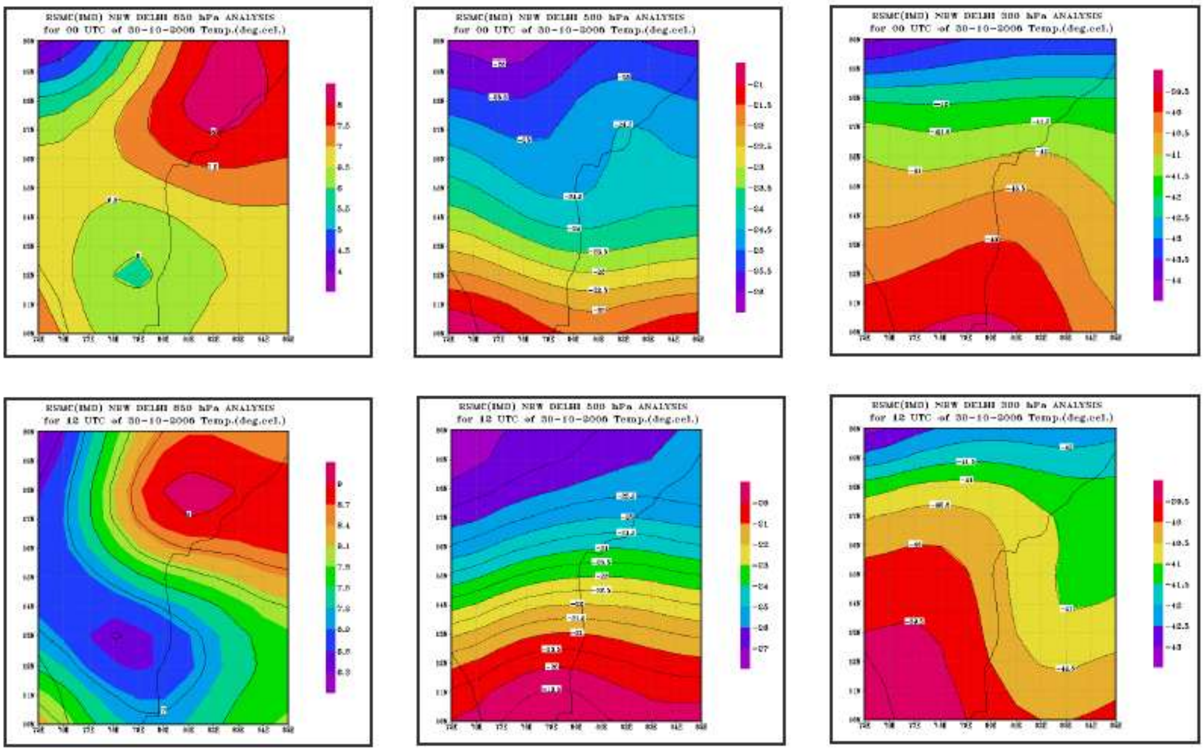


Fig. 18 (c). Same as Fig. 18 (a) but for 30th October 2006

5.3.4 Air Temperature

The air temperatures at three representative levels of 850, 500 and 300 hPa are shown in Fig.18 for 28th, 29th and 30th October 2006. There was a warm region at 850 hPa level to the north of the system centre from 0000 UTC of 29th till 1200 UTC of 30th. There was a cold region to the southwest of the system during this period. The temperature increased from south to north at middle and upper troposphere. The temperature gradient increased gradually from 0000 UTC of 28th onwards.

5.4 Satellite features

The intensity estimation of the system based on Dvorak's technique (Dvorak, 1984) are presented and analysed in section 5.4.1. The cloud top temperature alongwith distribution and intensity of convective clouds in association with the system are analysed and discussed also in this section. The satellite derived cloud motion vectors are presented and discussed in section 5.4.2. The OLR over Indian region during the life period of "OGNI" is presented and discussed in section 5.4.3. The satellite estimation of the precipitation is analysed and presented in section 5.4.4.

5.4.1 Satellite estimation of the intensity of the system

The estimation of the intensity of a tropical cyclone through satellite imagery is basically a pattern recognition process which assumes that characteristics or features of the cloud organisation are indication of the intensity. It can be dealt with through a set of systematic procedures of quantifiable and measurable cloud pattern description and models of storm development with time as was done by Dvorak (1975, 1984). The intensity of the cyclonic storm "OGNI" was estimated using the same Dvorak's technique. The INSAT Kalpana-1 imageries at 0600 UTC of 28th and 29th are shown in Fig.19 and three hourly imageries during 1200 UTC of 29th to 0600 UTC of 30th October are shown in Fig.20. The INSAT Kalpana-I infrared imageries with cloud top temperatures at 0300 and 1200 UTC of 28th, 29th and 30th October over the storm region are shown in Fig. 21. There were intense convective cloud clusters over southwest Bay and adjoining area from 27th October 2006, in association with low level circulation over the area (not shown). The meso-scale convective cloud clusters developed over the region as early as 0300 UTC of 28th and there was gradual improvement in the organisation of random meso-scale convection. A large scale convective cloud surge showing cyclonic circulation was also seen before the genesis. There was persistent convection over southwest Bay of Bengal prior to the development of the cyclone. It all endorses the earlier findings of Kalsi (1993) from the several time sequences of INAST-1B images illustrating the utility of satellite imageries to detect genesis of tropical cyclones. According to Kalsi (1993), there may not be a perceptible difference between developing and non-developing cloud clusters over the Ocean. However, the genesis phase is related by the relatively improved organisation of random meso-scale convection.

(a)

(b)

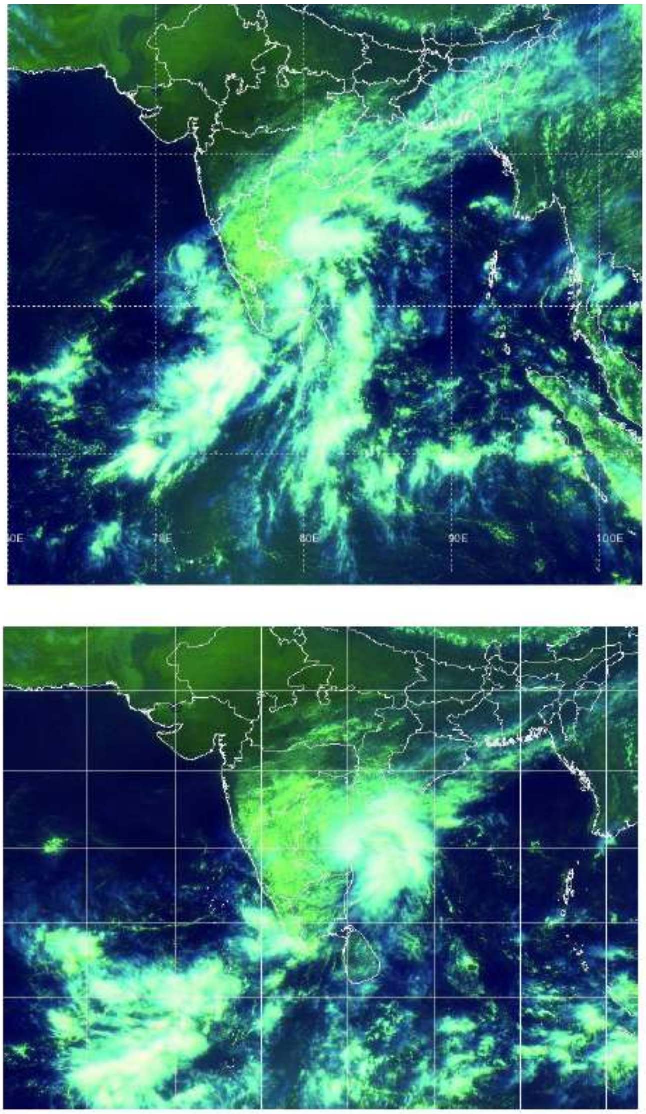


Fig. 19. Satellite KALPANA-1 imageries (a) at 0600 UTC of 28th and (b) at 0600 UTC of 29th October 2006.

The low level circulation organized into vortex at 0300 UTC of 29th October 2006, centred near lat.14.0^{0}N and long.80.0^{0}E with intensity T 1.5 (Table-3). The system was analysed as Band Pattern. The T-numbering 1.5 corresponds to the intensity of a depression. The vortex moved in a north-northwesterly direction and further organized at 0900 UTC of 29th October, centred near lat.15.0^{0}N and long.80.5^{0}E with intensity of T2.0, which is the intensity of deep depression. The system was analysed as irregular CDO Pattern. The vortex moved slowly in northerly direction and further organized at 1500 UTC of 29th October, centred near lat.15.3^{0}N and long.80.3^{0}E with intensity of T2.5, corresponding to the intensity of cyclonic storm. Then vortex moved very slowly in northerly direction and disorganized at 1000 UTC of 30th October, centred near lat. 16.0^{0}N and long. 80.3^{0}E with intensity T2.0 under the influence of high vertical wind shear. The out-flowing cirrus clouds in the northeasterly direction indicating steering and hence, weakening of the system can be seen from Fig. 20. Kalsi (1989) showed that the tropical cyclones developing in high sheared flows in the month of October finish as marginal cyclones with wind speed reaching up to 55 kts. This also happened in the case of OGNI.

Table-3. Position and intensity of the vortex over the Bay of Bengal during 29-30th October, 2006.

Date	Time (UTC)	Position (Lat. ^{0}N /Long. ^{0}E)	T- number
29-10-2006	0300	14.0^{0}N/80.0^{0}E	**T1.5**
	0600	14.5^{0}N/80.5^{0}E	T1.5
	0900	15.0^{0}N/80.5^{0}E	**T2.0**
	1200	15.3^{0}N/80.3^{0}E	T2.0
	1500	15.3^{0}N/80.3^{0}E	**T2.5**
	1800	15.4^{0}N/80.3^{0}E	T2.5
	2100	15.5^{0}N/80.3^{0}E	T2.5
30-10-2006	0000	15.7^{0}N/80.3^{0}E	T2.5
	0300	15.8^{0}N/80.3^{0}E	T2.5
	0600	15.8^{0}N/80.3^{0}E	T2.5
	1000	16.0^{0}N/80.3^{0}E	**T2.0**
	1200	16.0^{0}N/80.3^{0}E	**T1.5**

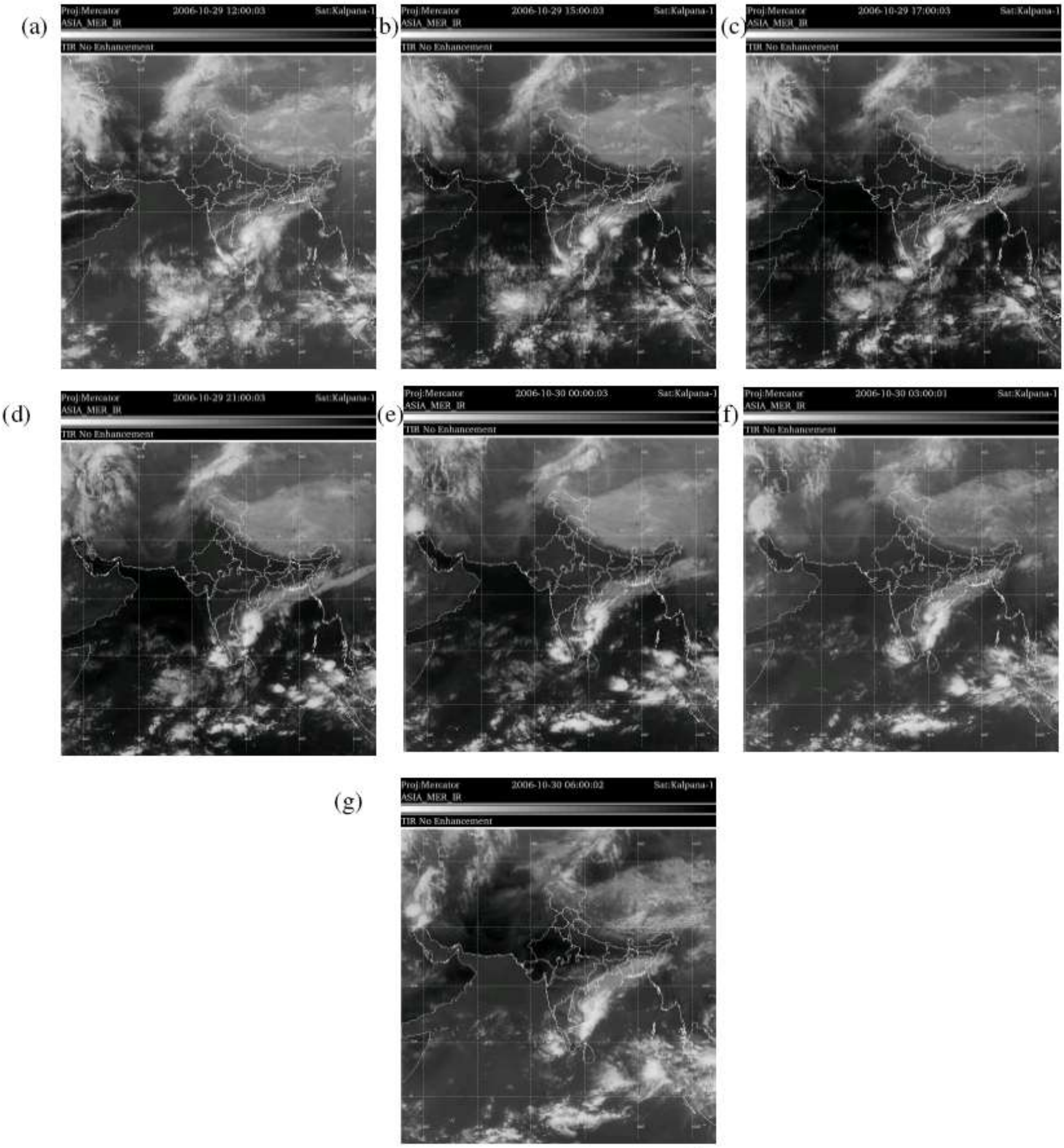


Fig.20 (a-g). 3-hourly Satellite imageries of 1200 UTC of 29th October to 0600 UTC of 30th October 2006

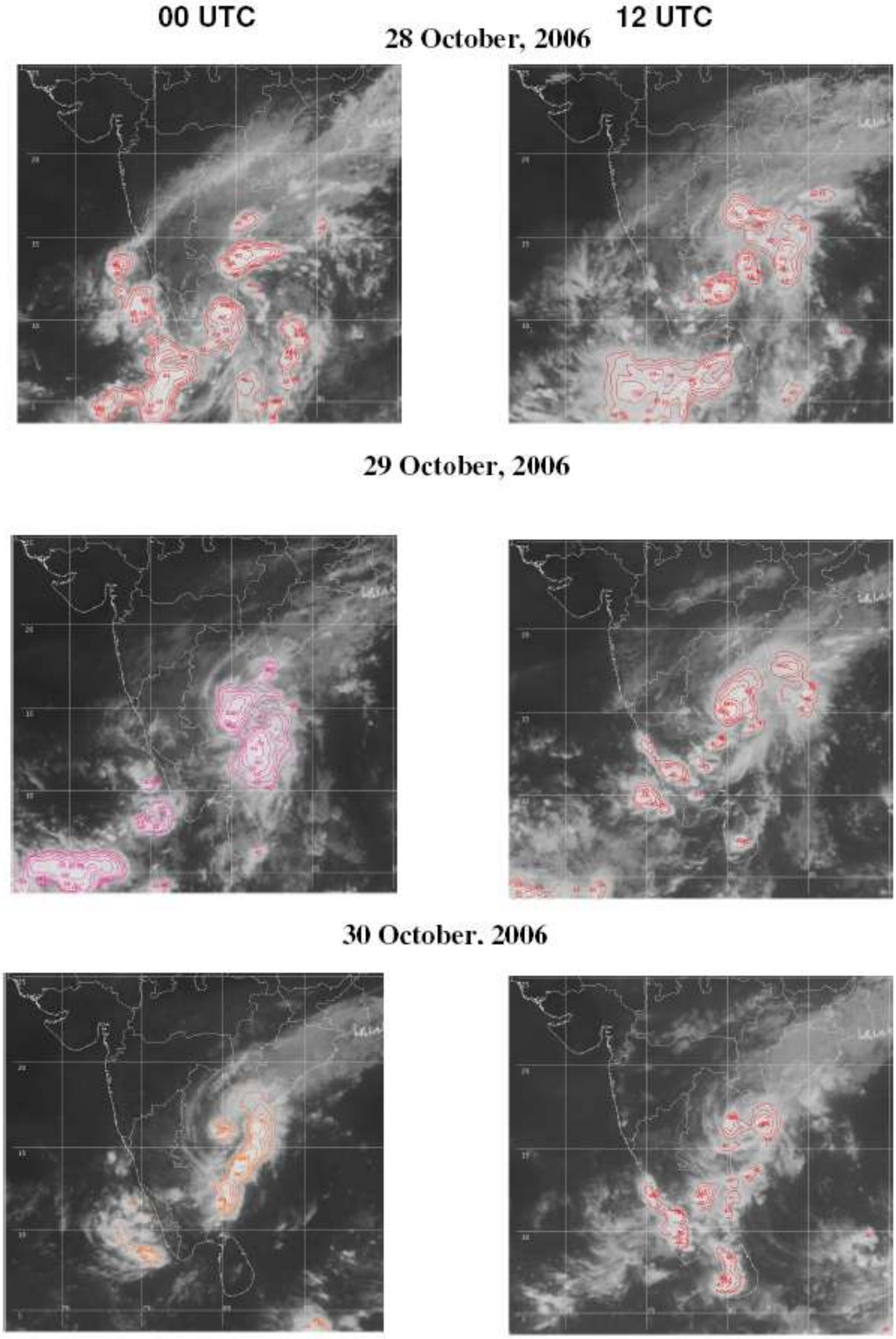


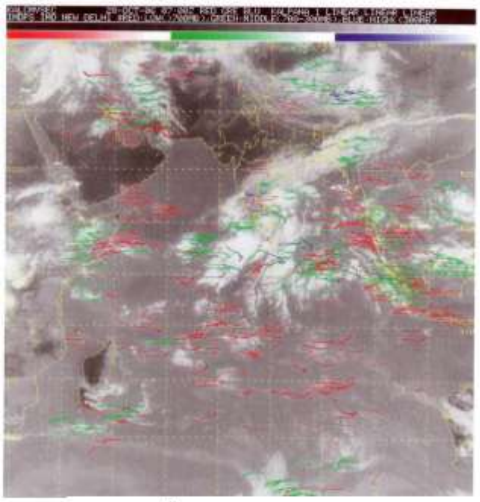
Fig. 21. Satellite IR Imageries with isotherm at 0300 and 1200 UTC of 28th, 29th and 30th October, 2006

The intensity of the system was T 2.0 at 1200 UTC, when the system was declared to be a cyclonic storm. Though the satellite estimated intensity variation showed the weakening trend from 0600 UTC of 30th, this estimation was higher compared to that based on synoptic features. It further did not indicate the landfall of the system. The above limitations may be due to the fact that the system was a small core system with limited pattern characteristics and was a short lived system. The use of Dvorak's intensity estimation scheme brought to light many of its limitations (Kelkar, 1997). The intensity of tropical cyclones undergoing rapid intensity changes or the tropical cyclones of small core like 'OGNI" tends to be underestimated. This technique fails miserably to account for explosive developments. Problems have been experienced while analyzing rapidly developing tropical cyclones in the Bay of Bengal in which the intensity increased by more than T2.0 within 24 hours in the pre-hurricane stages of evolution, which is not allowed for by the Dvorak algorithm. Basin to basin and storm to storm differences in storm behaviour and structure also get overlooked in this technique. Hence, Dvorak's technique has to be suitably modified for the Bay of Bengal and Arabian sea storms. Of course (Kalsi, 1993 and Joshi et al., 1999) showed that Dvorak's technique (Dvorak 1975, 1984) provides realistic estimates for tropical cyclones in the Bay of Bengal as well as Arabian Sea. The Dvorak technique can be calibrated using reconnaissance aircraft data over north Indian Ocean, especially the Bay of Bengal through the INDO-US experiment to be taken up during 2008-09.

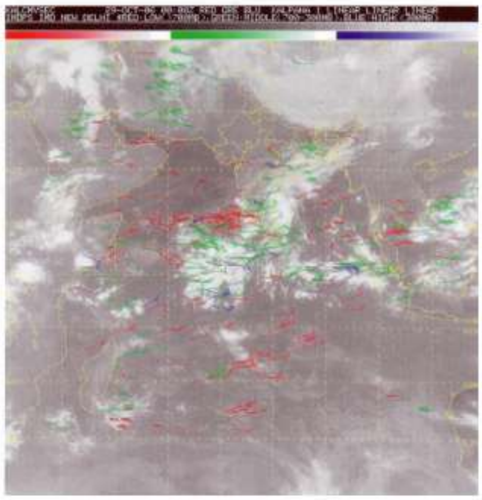
5.4.2 Cloud motion vectors and water vapour derived wind vectors

The INSAT – Kalpana-I imagery based cloud motion vectors over Indian region for lower, middle and upper atmospheric levels at 0300 UTC of 28th, 29th and 30th October 2006 are presented in Fig. 22. Considering the low level winds, the intensity and location of the vortex could not be well defined due to lack of sufficient derived winds over the region. According to Kelkar (1997), conventional cloud motion wind derivation from half hourly image displacements are not capable to provide the cyclone wind field which is also important for creating tropical cyclone bogus data sets in NWP models (Onogi, 1993). Many satellites now carry microwave payloads like scatterometer. However, as revisit frequency of these satellites is much lower than those of the operational geostationary meteorological satellites, they could not be utilised to monitor the wind field of small core and short lived cyclone, 'OGNI". The higher level winds were also meager to estimate the available steering wind over the cyclone field (Fig.22).

28th October. 2006



29th October, 2006



30th October. 2006

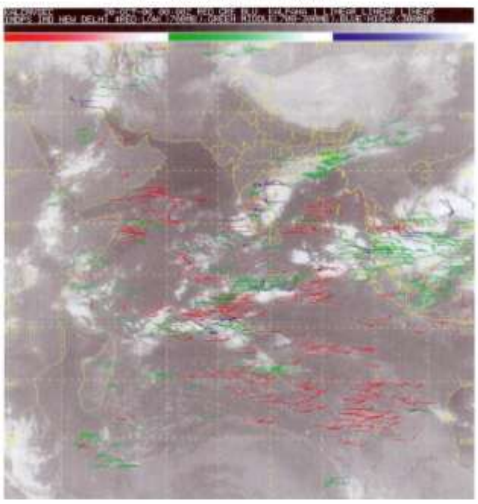


Fig.22. Satellite derived cloud motion vector wind at 0300 UTC of 28, 29 and 30 October 2006

The water vapour derived wind vectors (Fig.23) at upper tropospheric levels based on 0300 UTC of 30th October 2006 could suggest the movement of the cyclone towards Andhra Pradesh coast near Bapatla. The utility of water vapour derived winds in predicting the movement of cyclonic storms has been discussed earlier by Bhatia et al (2006).

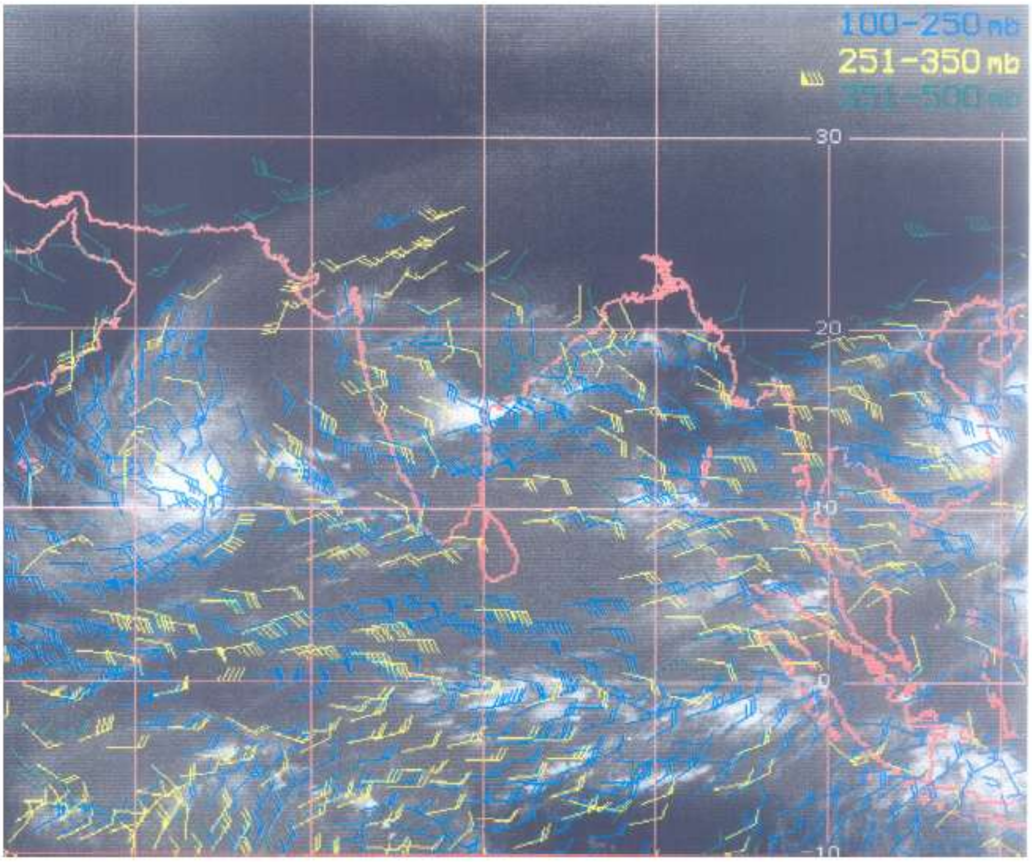


Fig.23. Water vapour derived wind over Indian region at upper troposphere levels on 30th October 2006

5.4.3 Outgoing Longwave Radiation

The OLR over Indian region at 0300 UTC of 29th and 30th October 2006 are shown in Fig. 24. The OLR suggested the presence of intense convection over southwest and adjoining westcentral Bay of Bengal, north coastal Tamilnadu and south coastal Andhra Pradesh with OLR less than 140 W/m^2 over these regions at 0300 UTC of 29th. The OLR minima lay centred near 12.0^{0}N and 81.0^{0}E. The region of maximum convection moved north-northwestwards (or nearly northward) with increased intensity then as the OLR minima lay centred near lat. 3.5^0N and long. 80.5^0E, at 0000 UTC of 30^{th}. Hence, the OLR also suggested north-northwestward (but nearly northward) movement of the system and likely landfall between Bapatla and Ongole.

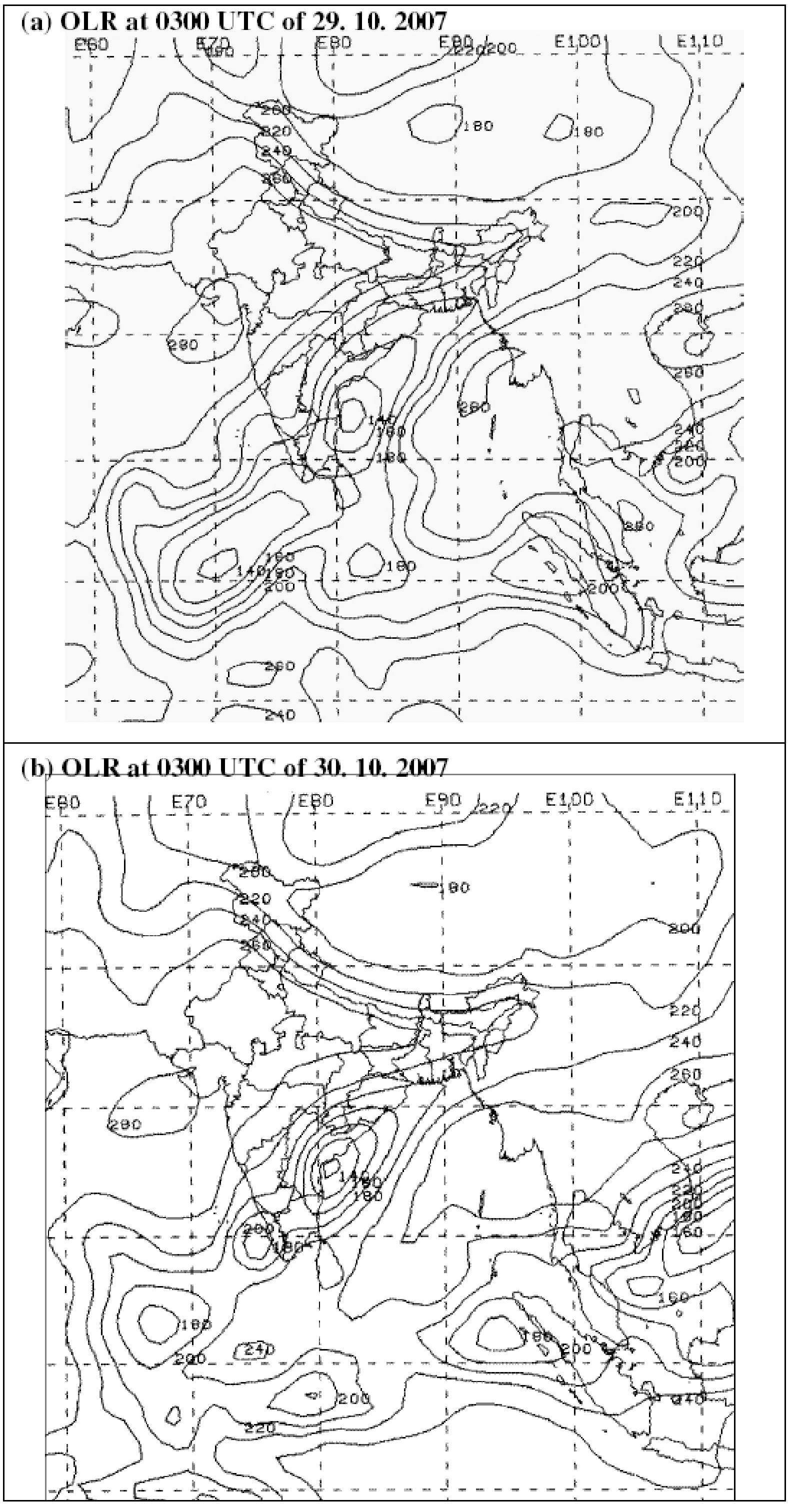


Fig.24. OLR (w/m^2) over Indian region at 0300 UTC of (a) 29^{th} October and (b) 30^{th} October, 2006

The OLR could not suggest the genesis of the system, as it was not less than 100 W/m^2 at any time during 28-30th October, 2006. According to Rao et al., (1989), who made a detailed study of a cyclonic storm over Bay of Bengal in February, 1987, based on daily analysis of INSAT derived OLR, the persistent low values of OLR (100 W/m^2) much below the expected seasonal value should be carefully watched as an advance indication of cyclogenesis. According to OLR distribution at 0300 UTC of 30th in case of OGNI, there was another secondary minima and hence maxima in convection over the southeast Arabian Sea and adjoining Kerala. The region at lower OLR was oriented from southwest to northeast extending from south Kerala/south Tamilnadu to south coastal Orissa and adjoining Bay of Bengal. This type of orientation was in agreement with that of actual rainfall (Fig.2).

5.4.4 Satellite estimated precipitation

Infrared imageries from geostationary satellites are being used to estimate convective precipitation using Arkin (1983) method. The precipitation estimates over the region in association with the system (Fig.25) was spatially dislocated and also underestimated with respect to intensity as compared to actual rainfall (Fig.2). However, the spatial pattern of estimated rainfall was similar to the actual pattern.

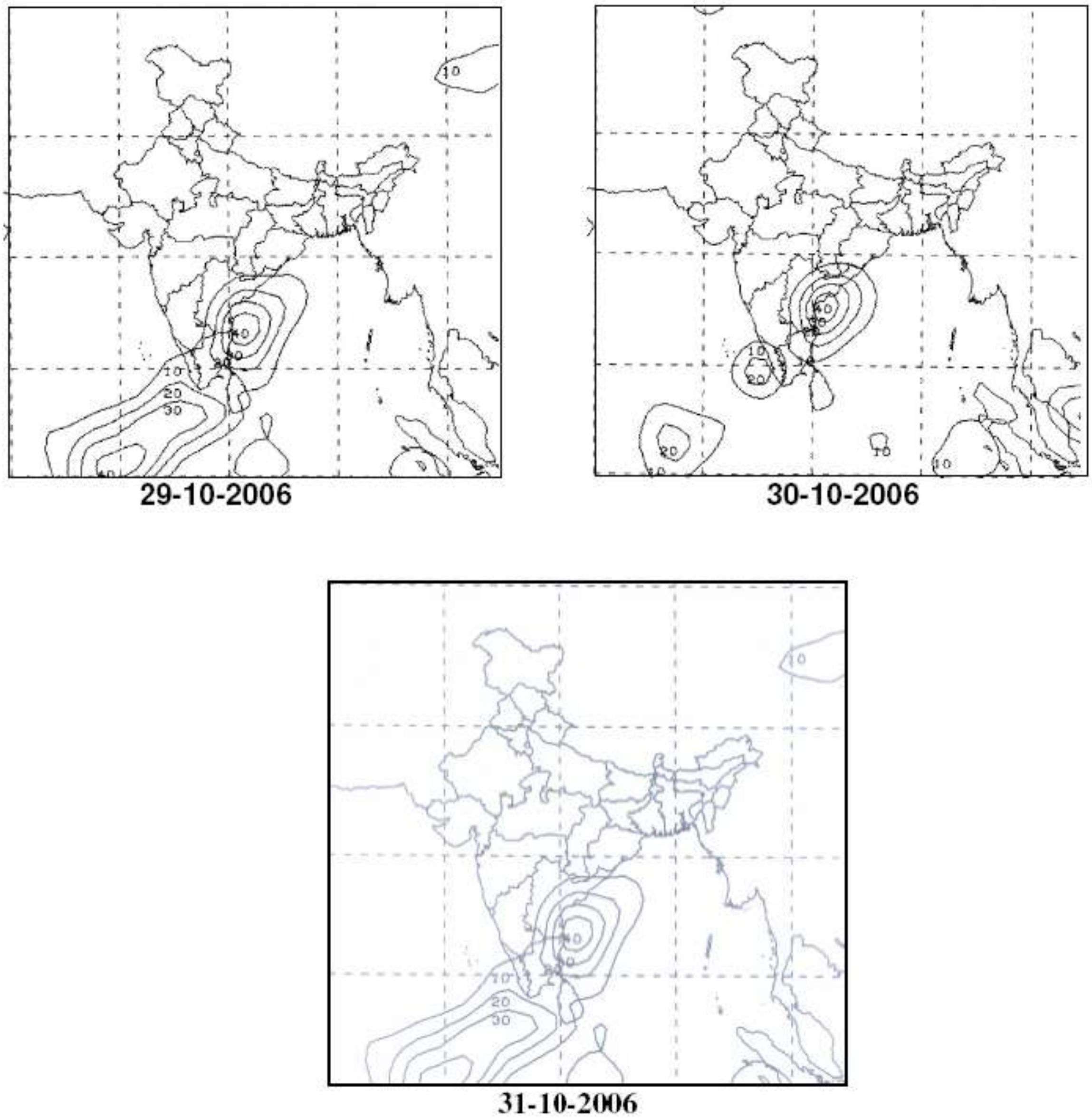


Fig.25. QPE (in mm)estimated by satellite over Indian region at 0300 UTC of 29th , 30th and 31st October 2006

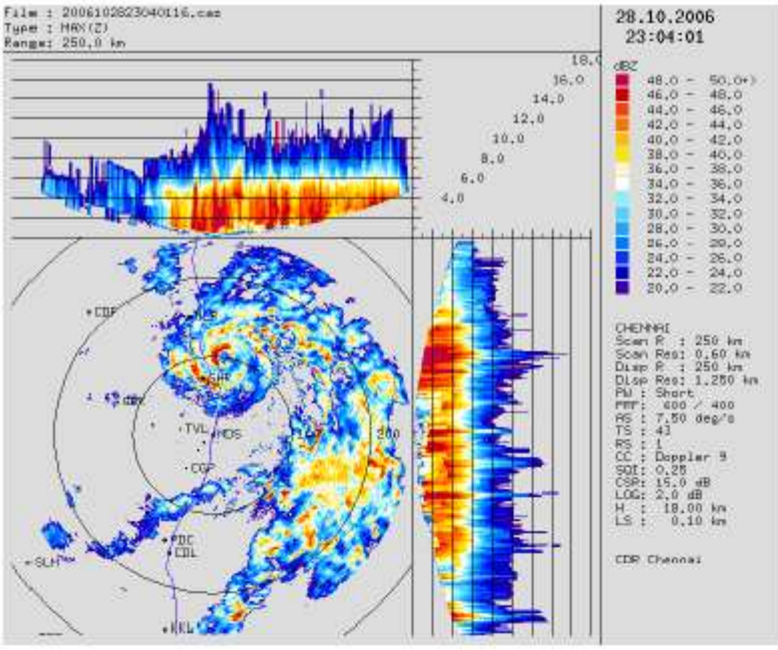
5.5. Radar features

Intensity of the system can be estimated by considering the radar reflectivity factor, velocity field and shape and structure of the eye and spiral bands. According to Meighen (1985), there is positive correlation of tropical cyclone intensity with number of spiral bands and negative correlation with crossing angles, thickness of spiral bands, eyewall thickness and eye diameter. According to Raghavan (1985), besides eye diameter, the shape of the eye (approximately to a complete circle), formation of a double eyewall, small crossing angles of the spiral bands are good qualitative indication of intensity. Similarly, the centre of the storm and its movement can be detected, considering the various features, including the centre of the eye and spiral bands (Raghavan, 1997). All these features are discussed in the following sections. The radar reflectivity factor has been analysed and presented in section 5.5.1. The velocity field as estimated by radar are presented and discussed in section 5.5.2. The spiral bands shape and size of the eye are analysed in section 5.5.3. The radar observed track of the system are analysed and discussed in section 5.5.4.

5.5.1 Reflectivity factor

According to DWR observations at cyclone detection radar (CDR) Chennai, the vortex was first noticed in radar scope around 08 UTC on 28th which was further observed keenly to ascertain persistency. On post-analysis, spiraling line echoes could be seen even in 0600 UTC of 28th in the imagery of CDR Karaikal**.** Hourly snapshots of the reflectivity factor of the system are shown in Fig.26.

According to DWR Chennai, long (> 500 km) spiraling feeder bands were seen in the reflectivity field, showing vast horizontal extent of rain field associated with the system. However vertical extent of reflectivity more than 30 dBZ (~3 mm/hr) was seen only below 7 km above ground over most parts of the system. Reflectivity in excess of 50 dBZ (~50 mm/hr) is found to be recorded in much less area compared to similar systems tracked earlier. According to Raghavan (1997), the reflectivity in the eyewall region has a maximum value of about 40-45 dBZ at low levels (850-700 hPA) and decreases rapidly beyond the freezing level. Hence, the reflectivity associated with the system is in agreement with the average reflectivity associated with the tropical cyclone with a small core. According to Raghavan (1977), the reflectivity in the eyewall region or the echotop heights in the tropical cyclone eyewalls are often lower than that in case of local severe storms. Heights inferred from the infrared imagery based on cloud top temperatures are relatively higher (Fig.21) perhaps because of a blanket of cirrus clouds which shows up in the satellite but at the same time the convection does not penetrate the tropopause.



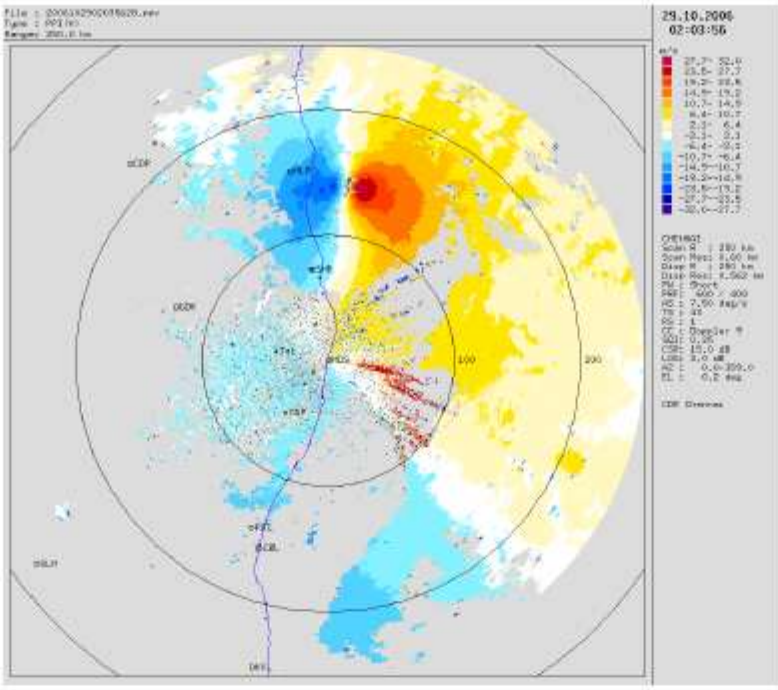


Fig. 26 (a). Radar picture taken by DWR Chennai at 23:04:01 UTC of 28th and 02:03:56 UTC of 29th October 2006

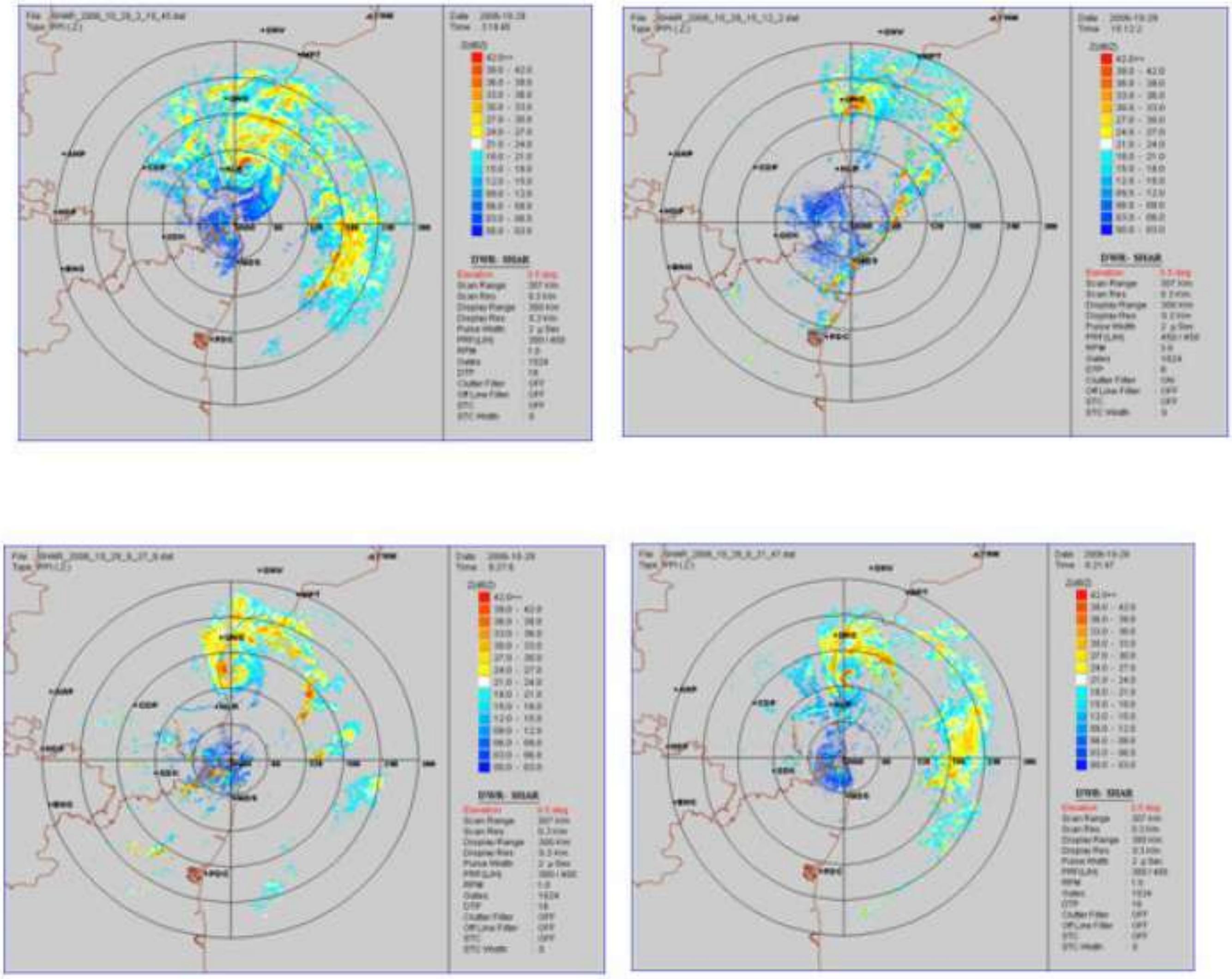


Fig. 26 (b) Radar picture taken by DWR, SHAR at 3:19:45 UTC, 9:27:6, 15:12:2 and 6:21:47 UTC of 29th October 2006

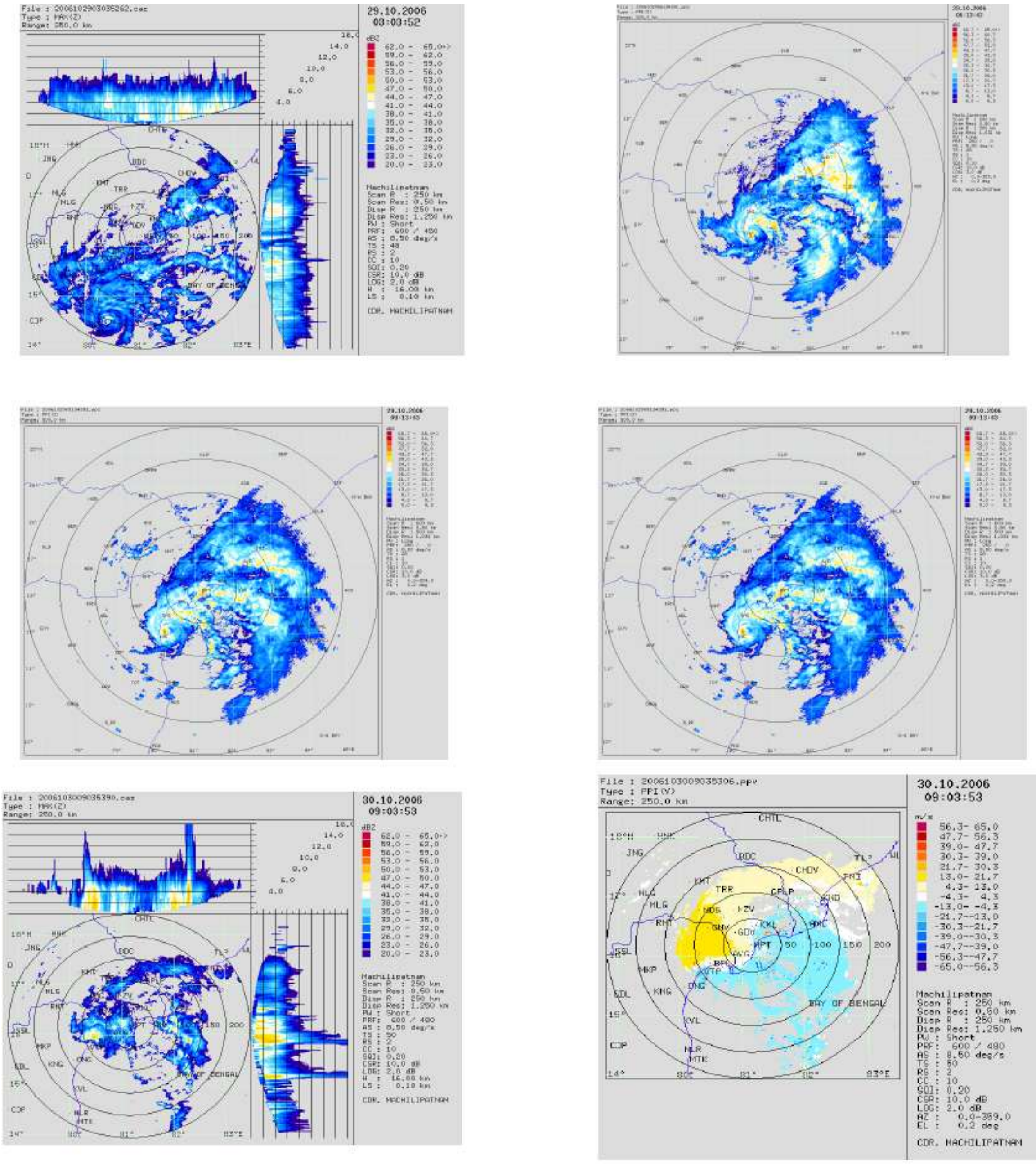


Fig.26 (c) DWR imageries from Machilipatnam at 03:03:52 UTC, 06:13:42 UTC, 09:13:43 UTC and at 12:13:48 UTC of 29 October 2006 and 09:03:53 UTC of 30 October 2006.

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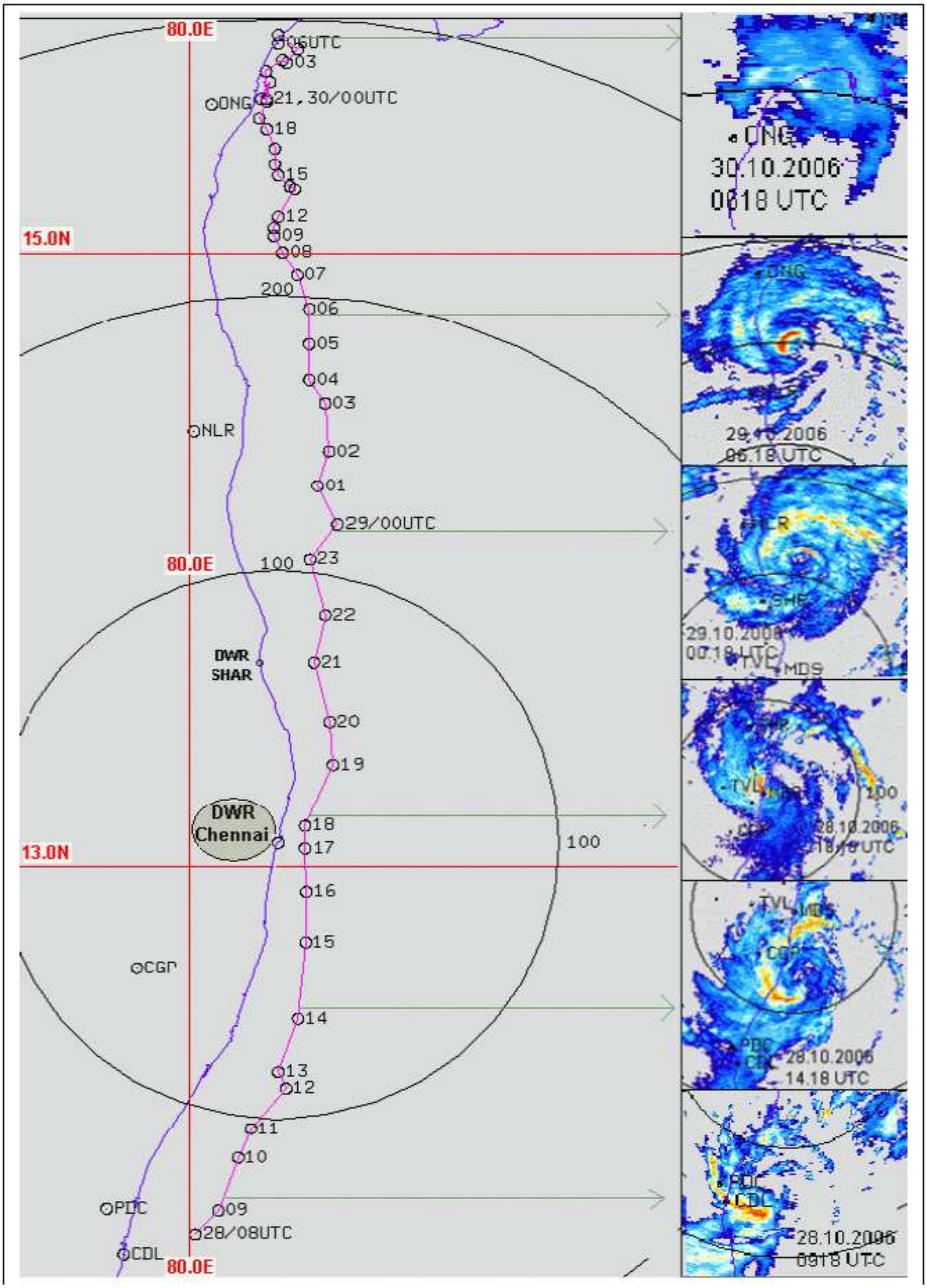


Fig. 26(d) Radar images alongwith track of DWR Chennai during 28-30 October 2006

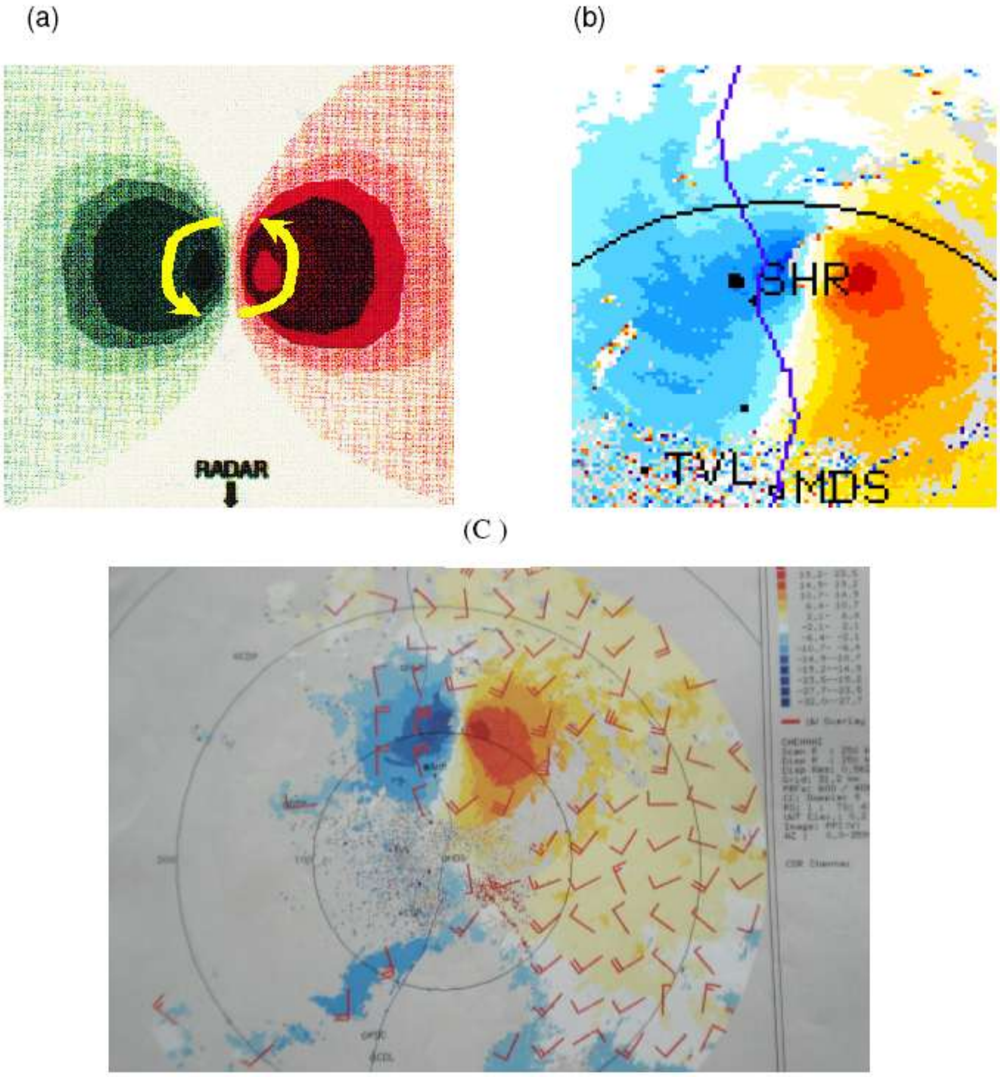


Fig.27: (a) Theoretic wind field at a cyclonic storm" OGNI" (b) actual wind field in the cyclonic storm "OGNI" and (c) wind distribution in the cyclonic storm "OGNI" region.

5.5.2. Velocity field

Interpreting radial velocity image of a cyclone is a bit tricky than comprehending reflectivity image. Doppler radars are capable of measuring the component of actual wind in the direction of line joining the space under probe to the radar (*radial component of wind*). That is why the measured wind parameter is purposefully termed as radial-velocity. The maximum recorded radial-velocity is more or less equal to the actual wind associated with the system at that level. Radial velocity field of a purely circular wind system would look like Fig.27 (a). An actual image pertaining to the cyclone under discussion is shown in Fig.27 (b). This shape is often referred to as 'Double-D' Structure or 'Doughnut' shape, a typical signature of a cyclone seen in the radial velocity image. The DWR derived wind field around the system centre as shown in Fig. 27 (c). Contrary to the reflectivity field, the velocity filed has shown a relatively narrow core in which the maximum wind sharply reduced to nominal values beyond about 40 to 50 km from the centre. Arial extent of high wind speed is relatively less. The half of the system closer to the coast depicted less velocity. Maximum reliable record of wind speed is about 38 m/s (137 kmph) at levels between 3 to 4 km amsl during 0618 UTC to 1218 UTC of 29th October.

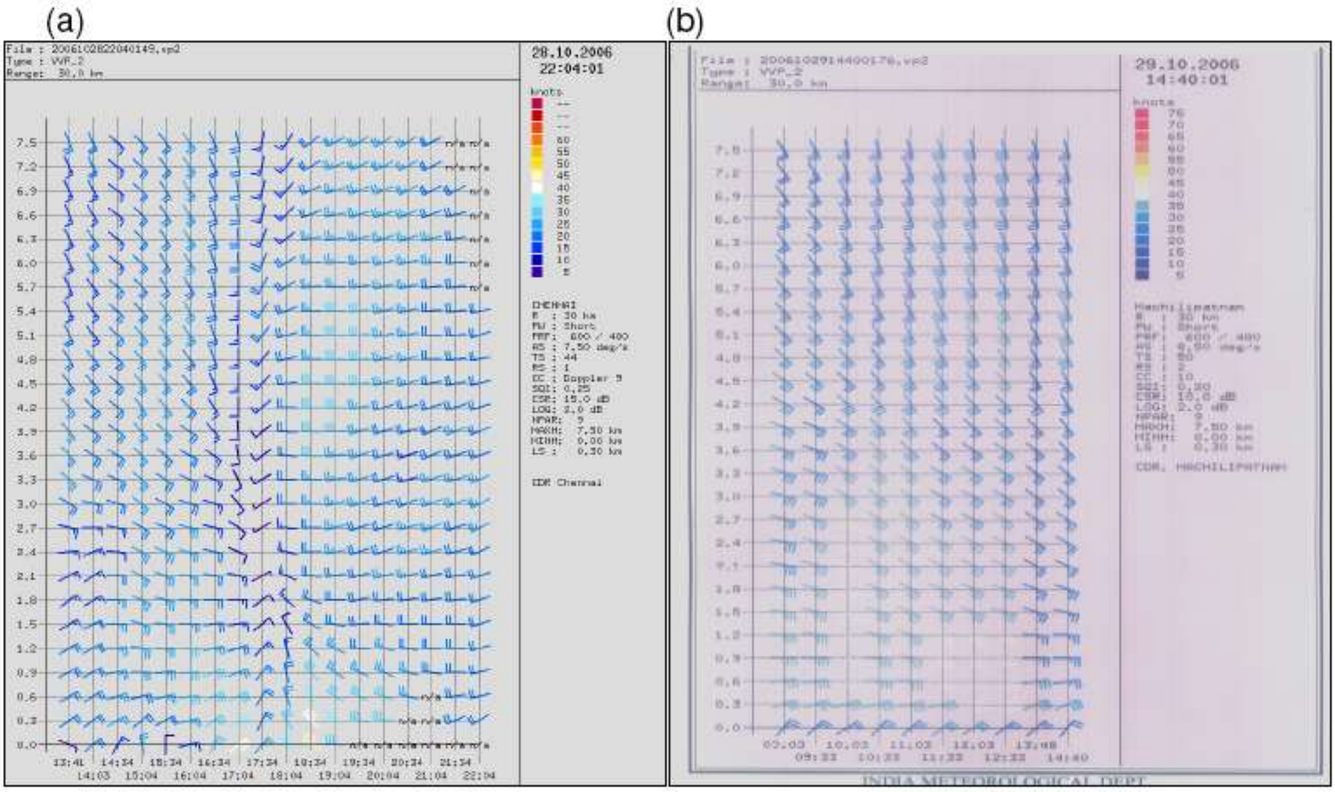


Fig.28. Vertical wind profile as observed by (a) DWR Chennai and (b) DWR Machilipatnam

The (VVP2) is a derived wind product giving wind similar to RSRW data, valid over a cylinder of 30 km radius around the station and is plotted in the form of a vertical time section with wind-barb notation. In that product, backing of wind over Chennai in association with approach of the system from south, movement of the system very close to station and nearly northerly movement of the system are very well captured

(Fig.28). Maximum derived wind speed seen in VVP2 product over Chennai was 45 kts at 1834 UTC of 28th, just when the rear of the system crossed Chennai. The VVP2 products also indicate that the wind field was shallow and did not penetrate much deep into upper levels.

5.5.3 Spiral bands and eye of the storm

According to DWR, SHAR, (Table-4), the eye was first observed at 2109 UTC of 28th with a diameter of 25 km. The eye was circular with diameter of 17 km at 2241 UTC of 28th. Double eye like centre was seen with weak inner eye diameter as 7.5 km and outer eye diameter as 30 km at 1003 UTC of 29th. The double eye structure remained till 1103 UTC of 29th with inner and outer diameters of 10 and 25 km respectively. The elliptical eye was seen at 1149 UTC of 29th with minor and major axis of 20 and 28 km respectively. Raghavan et al (1989) have demonstrated the varying and irregular geometry of the eye of a weak tropical cyclone in the Bay of Bengal. While the eye of an intense tropical cyclone tends to be circular, the ellipses, polygon or irregular shapes, are also quite common. The shape of the eye may also be distorted due to radar observational limitations. Raghavan and Veeraraghavan (1979) have shown the elliptical eye with major axis pointing towards a radar due to the radar pulse width and finite beam width effects. However, these problems were not encountered in the present case as the system was well within the radar range.

The velocity maxima are located on the eyewall of the cyclone. From the Fig.(27 & 28) maximum wind velocity and hence intensity of the cyclone can be determined in addition to the position of the cyclone centre. Raghavan et al (1989) have suggested radius of maximum reflectivity (RMR) as a measure of the size of the eye. However, there were some limitations like (i) eyewall was not available always (ii) eyewall was not symmetrical always (iii) hydrometeors were not present at all relevant points and (iv) the pattern was distorted before the landfall as well as in the initial stage. According to Raghavan (1990, 1993), when a storm intensifies, the innermost spiral band tends to reduce its crossing angle. At the end of the band, an eye wall forms approximately in the form of an arc of a circle. Gradually, this may separate from the band into a distinct ring as a part of ring with an echo free (or nearly echo free) area inside, namely the eye. This normally occurs at about the time when a tropical cyclone becomes severe. Holland (1987) discussed the mechanism by which such a transformation could occur. However, Individual tropical cyclones differ widely in structure. There can be cases of intense tropical storms without forming an eye (Weatherford and Gray, 1988). On the other hand, a false eye can develop at the end of the spiral band in a weak tropical storm without being at the centre of the system and may contain a separate pressure minimum on the high pressure side of the spiral band. (Simpson, 1956, Barclay, 1972 and Raghavan, 1977).

5.5.4 Radar observed track of the system

According to DWR Chennai, the system skirted Indian coast for about 500 km in two days. Initially, the system moved fairly fast (>20kmph) but eventually slowed down hours before and after crossing the coast. The centres of the system as observed by DWR, Chennai are shown in Fig. 26(d). It indicates that the system moved north-northeastwards skirting the coast till 0011 UTC of 29th. It then moved in a north-northwesterly direction (nearly northerly direction) till landfall. The radar track is largely in good agreement with operational synoptic track of IMD with some deviations especially in initial stages and the period of landfall. It may be due to the fact that where the complete circular eyewall is observed, the geometrical centre of the ring is identified and taken as the centre of the tropical cyclone, although the point of MSLP or wind centre may not necessarily coincide with it (Raghavan, 1997). When the eyewall is partial or of irregular shape with unsymmetrical distribution of radar reflectivity as happened during initial stage and before landfall of OGNI, the centre determination becomes a little ambiguous. Meighen (1985) has shown that fixes obtained by the reflectivity-weighted centroid of the eyewall rather than the geometric centres give the smoother track. The physical basis for this may be that the wind centre tends to be located closer to the arc of maximum reflectivity in the eyewall.

There was no eye visible in the satellite imageries (Fig. 19&20). Hence, the difference in centre location based on satellite and radar could not be calculated.

According to Shapiro (1983), the sector of maximum wind and reflectivity appears to be generally to the left in the slow moving tropical cyclones and to the right of the fast moving ones. Since the speed of the motion of the tropical cyclone usually increases with latitude, the apparent dependence of the position of the reflectivity and isotach maxima on latitude is explained. Mohapatra et al (2001) analyzing the rainfall due to super cyclonic storm which crossed Orissa coast near Paradip (near 20.0^{o}N) have shown that maximum rainfall and maximum wind occurred on the right sector of the storm. But in most of the cyclones in southern Bay of Bengal (south of 20.0^{0}N), maxima of the above quantities have been found in the left sector (Biswas et al., 1988, Raghavan, 1990, Raghavan and Veeraraghavan,1979, Sivaramakrishnan and Sridharan, 1989). Hence, the characteristics of OGNI with respect to location of maximum reflectivity region, maximum wind and rain rate seem to be unusual.

In the case of unsymmetrical eyewalls as in the case of OGNI, the direction in which the eye wall reflectivity is highest seen in some cases to be the preferred direction of motion (Senn, 1966). However, others do not find it reliable (Meighen, 1985, Raghavan et al, 1980) always. However, the echo concentration was more in the forward right quadrant (Fig.26) of the system. The occurrence of pre-cyclone squall lines over coastal Andhra Pradesh also suggested qualitatively the system to move towards coastal Andhra Pradesh. Raghavan et al (1980) have found that in all the cases in which pre-cyclone squall lines were observed, their observations were roughly perpendicular to the direction of motion of tropical cyclone at that time.

Table - 4. Radar Information of DWR Machilipatnam, Chennai and SHAR

Date/ Time (UTC)	MACHILIPATNAM				CHENNAI				SHAR			
	Azimuth In deg.	Range In km	Lat. ^{0}N	Long^{0}E	Azimuth In deg.	Range In km	Lat. ^{0}N	Long^{0}E	Azimuth In deg.	Range in km	Lat. ^{0}N	Long^{0}E
280900	-	-	-	-	189	136	11.88	80.10	180	180	12.04	80.22
281200	-	-	-	-	178	090	12.27	80.32	178	150	12.31	80.27
281500	-	-	-	-	165	38	12.75	80.38	177	133	12.58	80.36
281800	195	325	13.2	80.3	060	11	13.13	80.38	165	65	13.10	80.38
282100	197	295	13.67	80.42	011	66	13.66	80.4	108	21	13.60	80.40
290000	197	240	14.1	80.45	010	117	14.12	80.49	025	52	14.08	80.42
290300	201	203	14.5	80.5	006	160	14.51	80.45	012	097	14.51	80.41
290600	208	176	14.8	80.4	003	194	14.82	80.39	004	132	14.85	80.30
290900	219	154	15.05	80.27	000	220	15.06	80.28	000	155	15.04	80.21
291200	221	151	15.12	80.28	000	227	15.12	80.29	001	161	15.09	80.25
291500	221	136	15.3	80.3	000	242	15.26	80.29	002	183	15.30	80.30
291800	230	127	15.42	80.28	359	263	15.41	80.25	001	193	15.40	80.25
292100	234	123	15.5	80.25	359	270	15.51	80.25	002	206	15.51	80.30
300000	235	118	15.55	80.25	359	270	15.51	80.25	000	211	15.55	80.23
300300	234	109	15.57	80.28	001	283	15.63	80.32	-	-	-	-
300600	241	103	15.7	80.3	000	290	15.69	80.29	002	222	15.60	80.25
300900	247	104	15.8	80.3	-	-	-	-	-	-	-	-

5.6 Numerical Weather Prediction (NWP) models guidance

Though various models produced the cyclonic circulation at lower levels during 28th -30th October, these circulations were spatially dislocated, being more towards the southwest (Fig.29). Also no model predicted wind speed of more than 20 kts over the region in association with the system.

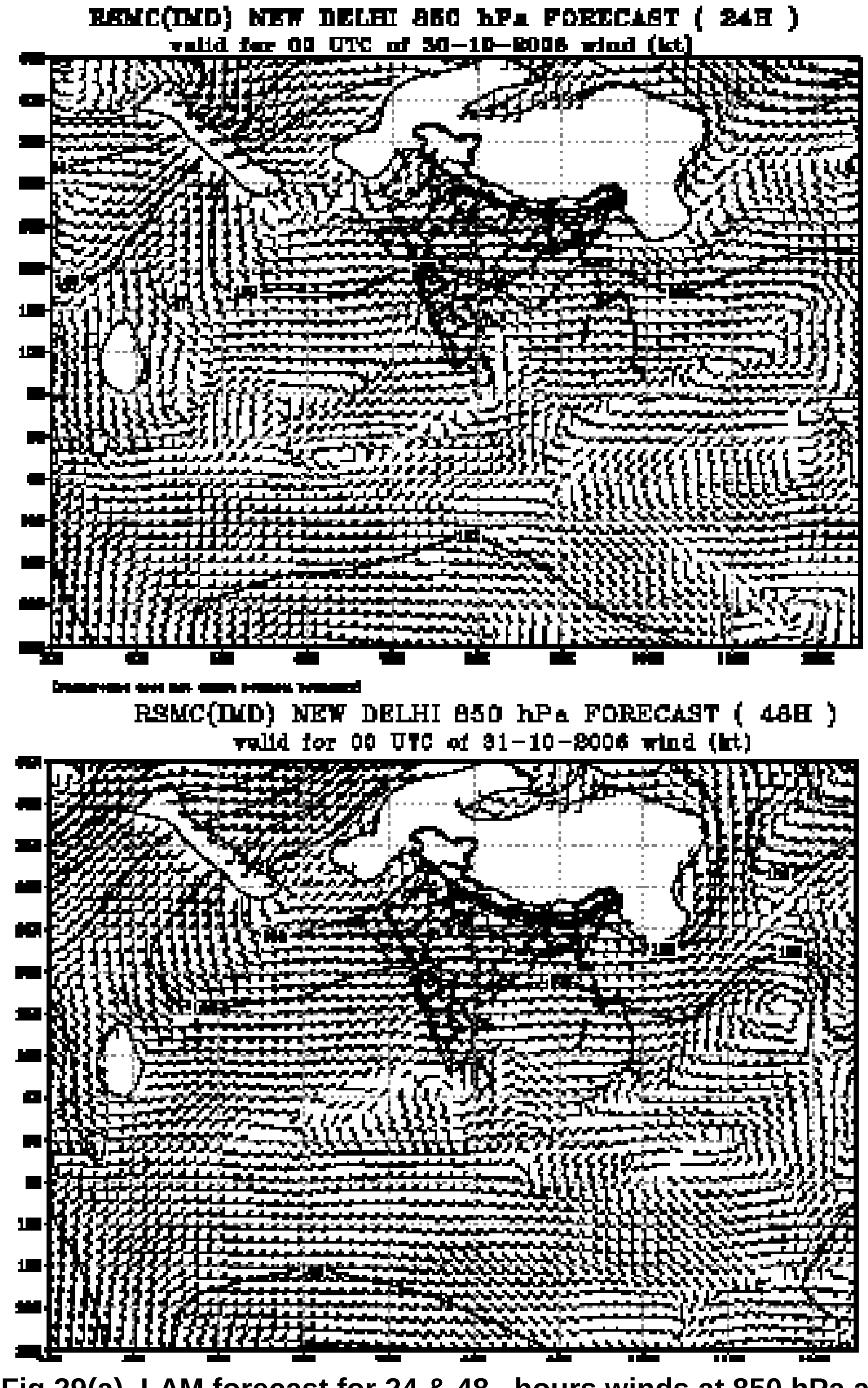
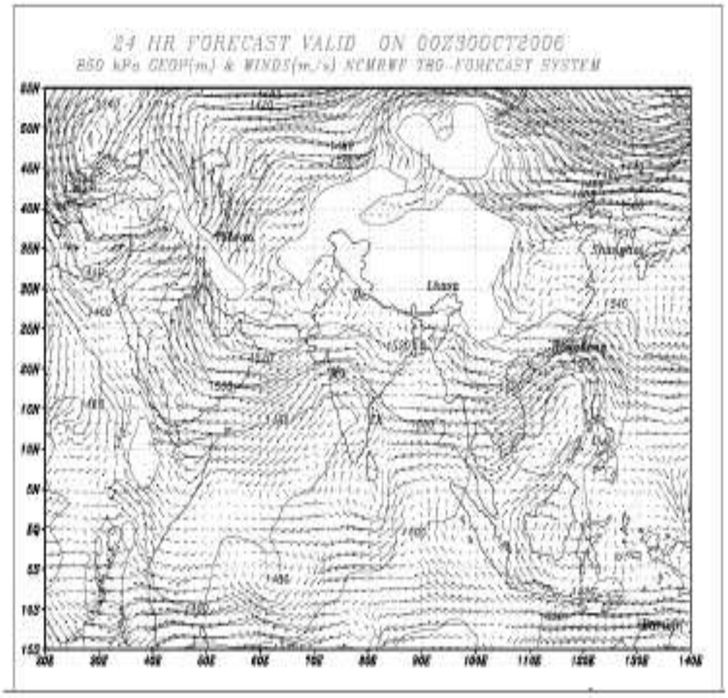


Fig.29(a). LAM forecast for 24 & 48 –hours winds at 850 hPa and rainfall forecast based on 0000 UTC of 29th October 2006



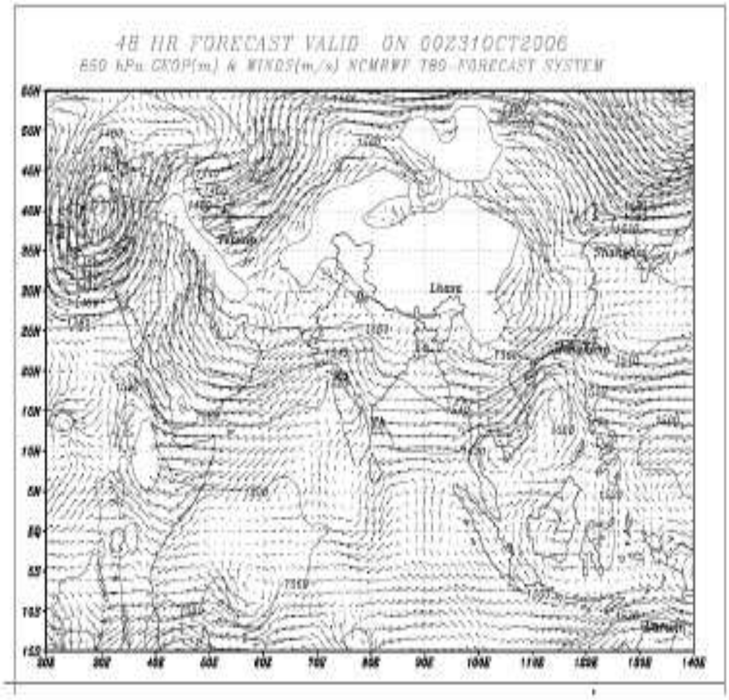
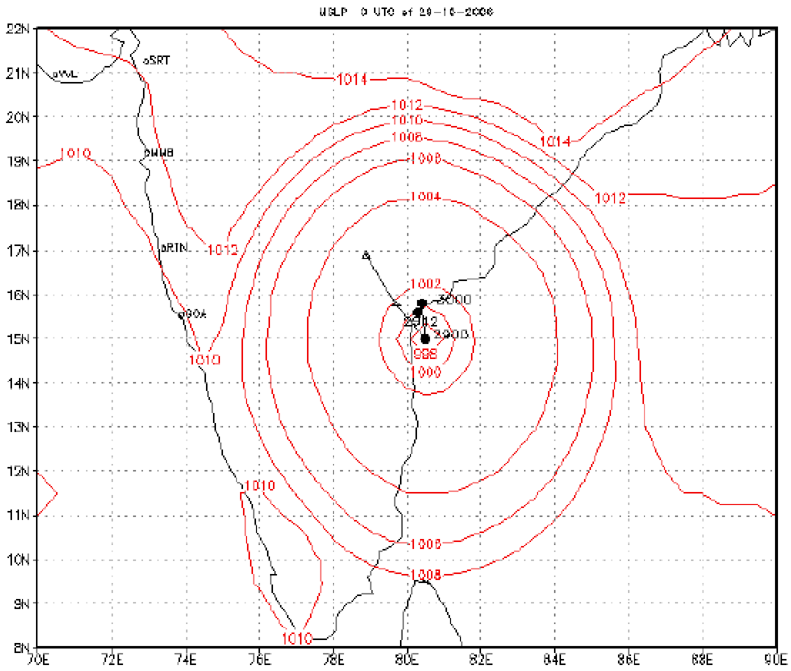
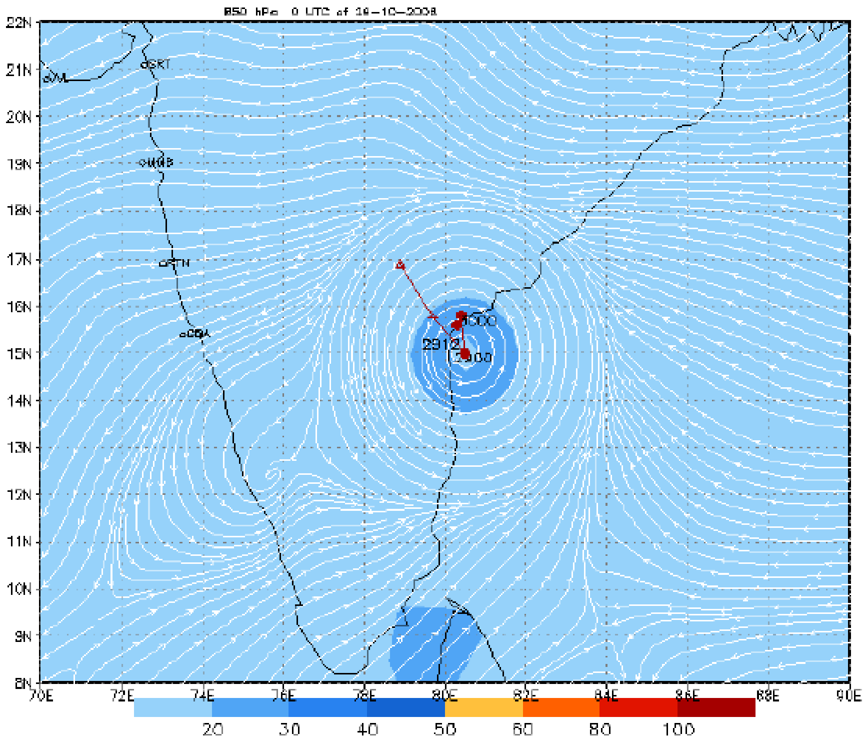


Fig.29(b). LAM forecast for 24 & 48 –hours winds at 850 hPa and rainfall forecast based on 0000 UTC of 29th October 2006



▲ Forecast Position
● Actual position

Fig. 30 Mean sea level pressure analysis and cyclone track forecast by QLM based on 0000 UTC of 29th October 2006.



▲ Forecast Position
● Actual position

Fig. 31 850 hPa level wind analysis and cyclone track by QLM, based on 0000 UTC of 29th October 2006.

Earlier studies also have confirmed that the intensity is not very well computed and mostly underestimated in NWP models (Gupta and Ramesh, 1999, Rama Rao et al., 2007). Further due to small core and short life of the tropical cyclone, OGNI, intensity predicted by the models was further underestimated.

The forecast track of QLM of IMD along with MSLP analysis at 0000 UTC of 29th October 2006 is shown in Fig.30. It suggested the northwestward movement of the deep depression, and likely crossing of the coast near 15.6^0N against the near northerly movement of the system. The stream line analysis (Fig.31) suggested the wind speed of 30-40 kts at 0000 UTC of 29th October 2006 around the centre after bogussing. The rainfall prediction was highly underestimated by LAM of IMD and T-80 model of NCMRWF (Fig. 32). Like the circulation centres, the model rainfall maxima (Fig.32) were also not in agreement with the actual rainfall maxima (Fig.2).

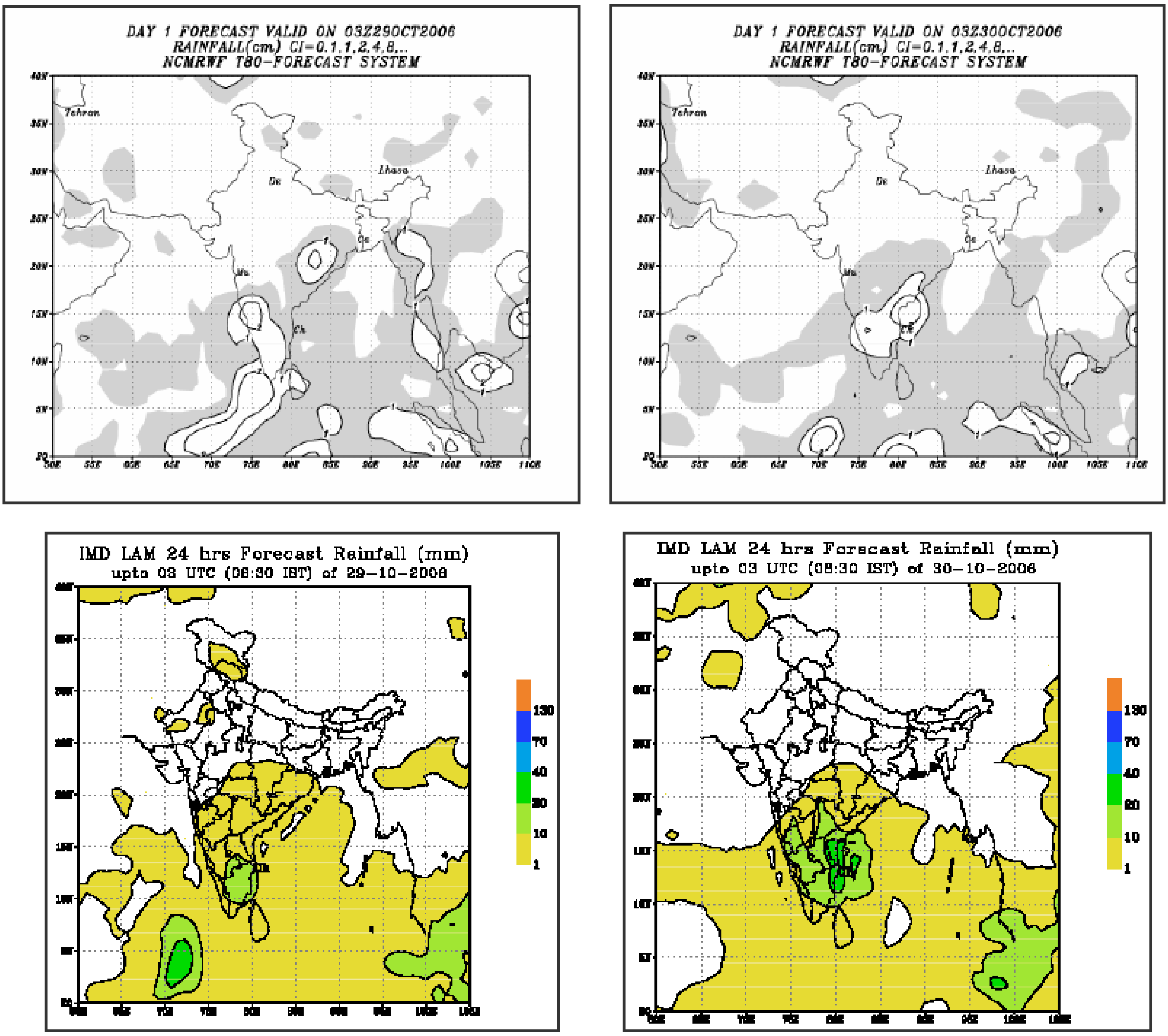


Fig.32 (a). The 24-hours rainfall (Day 1 forecast over Indian region valid at 0300 UTC of 29th and 30th October 2006 according to T-80 model of NCMRWF and LAM of IMD

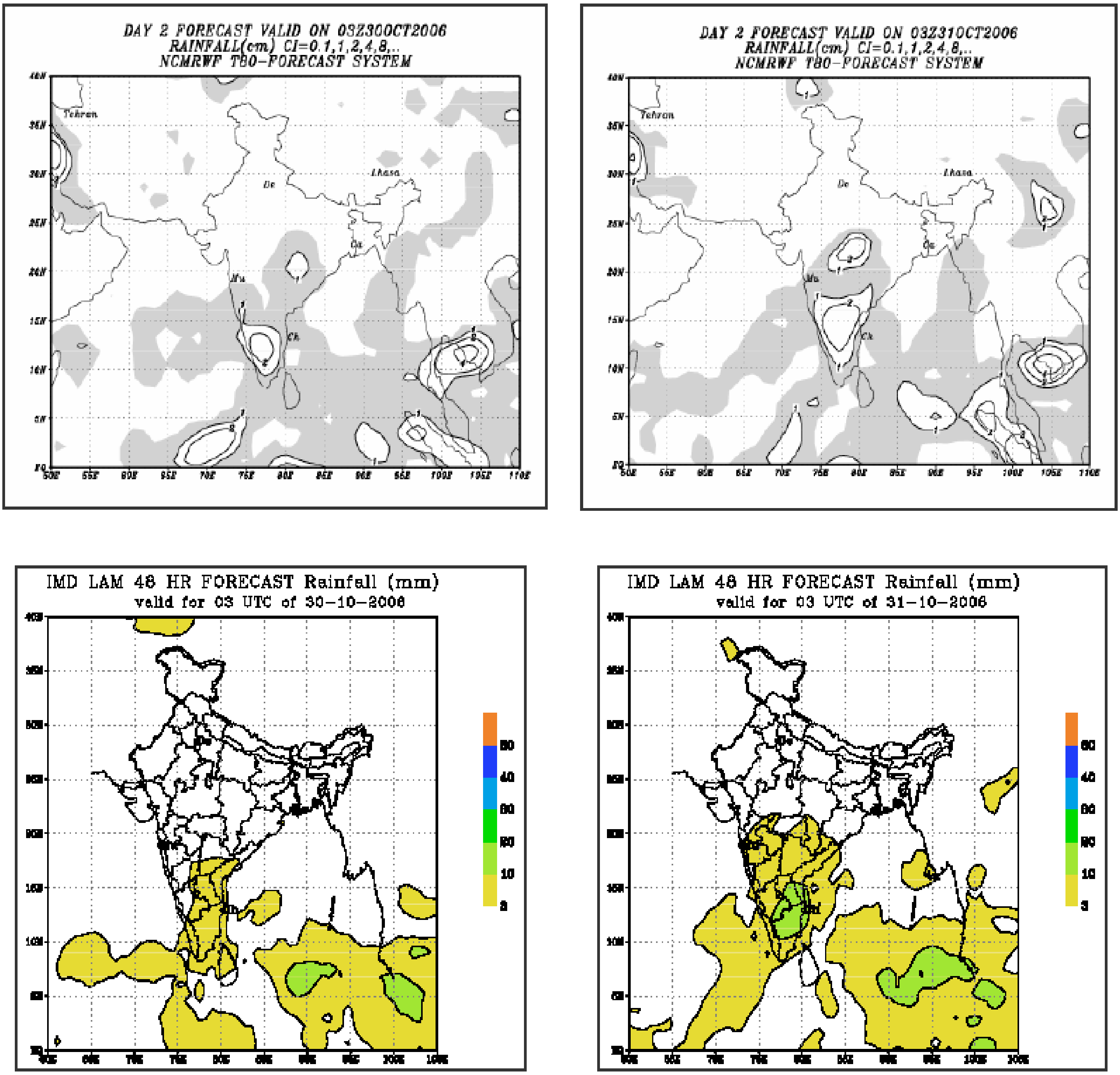


Fig. 32 (b). Same as Fig.32(a) but with 48-hours rainfall valid at 0300 UTC of 30th and 31st October 2006

5.6.1. Model simulation

As discussed in data and methodology section (4.5), the ARPS model simulated wind fields at 850 hPa with superimposed vorticity fields for the control run and DWR run at 3 hourly intervals starting from 0000 UTC of 29 October are illustrated in Fig. 33. The left column in the figure indicates results of control experiment and figures in the right column show results of DWR experiment. At 0000 UTC of 29 October, both control and DWR experiments show the system over the land near lat 14.1 ^{o} N and long 79.5 ^{o} E. The control run shows a very weak circulation; where as the corresponding DWR run could produce strong south-southeasterly winds of order 30 knots to the southeast sector of the system. It is very interesting to note that at 0300 UTC, the system in the DWR simulation lay over the Bay of Bengal very close to the observed position accompanied with a very strong wind of order 30 to 40 kts around the centre. The system is seen as a very small core system with strong vorticity field occurring at the center of the system, where as, the control run continued to show the system as a weak circulation. However, with the ADAS procedure, the location of the system is found to be shifted to the east near the observed position. At 0600 UTC, the DWR simulation displays a strong wind field over a small area around the centre of the system with a strong vorticity field over the center. The corresponding control experiments maintain the system as a weak circulation. Until 0900 UTC, the DWR simulation could retain the intensity of the system (strong wind and vorticity fields), but thereafter the system in the DWR run shows a weakening trend during the northward movement of the system. The inter-comparison of results between control and DWR run showed a significant difference in the wind and vorticity fields at 850 hPa during the forecast period from 00 hour to 6 hours. In the DWR experiment, the southerly wind is strengthened by 10 to 25 knots (25 knots in control compared to 40 knots in DWR) in the analysis and forecasts with the insertion of the DWR observations. It could simulate realistically strong wind and vorticity fields at 850 hPa over a small domain close to the center of the system.

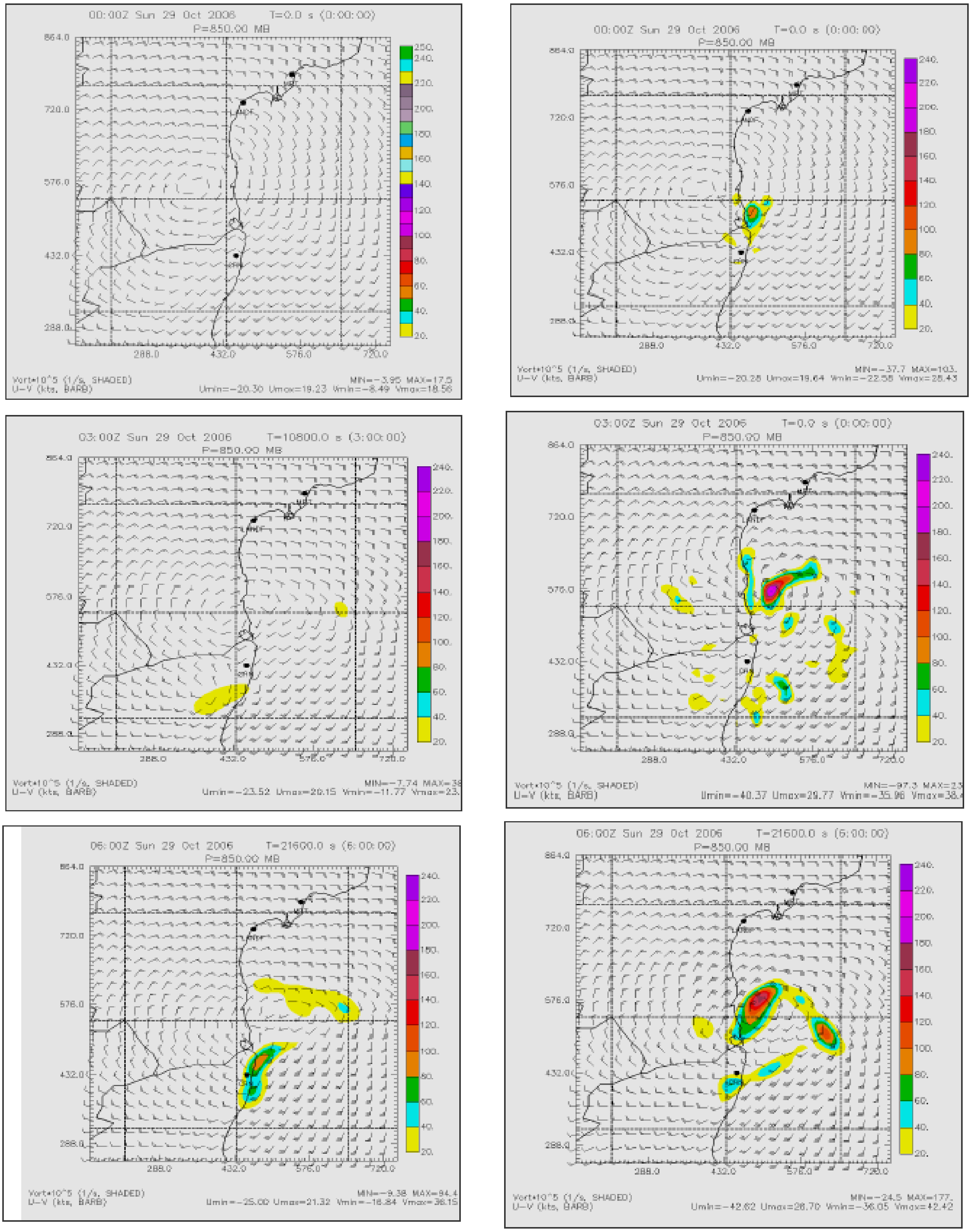


Fig. 33 (a) Three hourly forecast wind fields (knots) at 850 hPa superimposed vorticity field ($x10^{-5}$ s^{-1}). The left column for the control run and the right column for the DWR run.

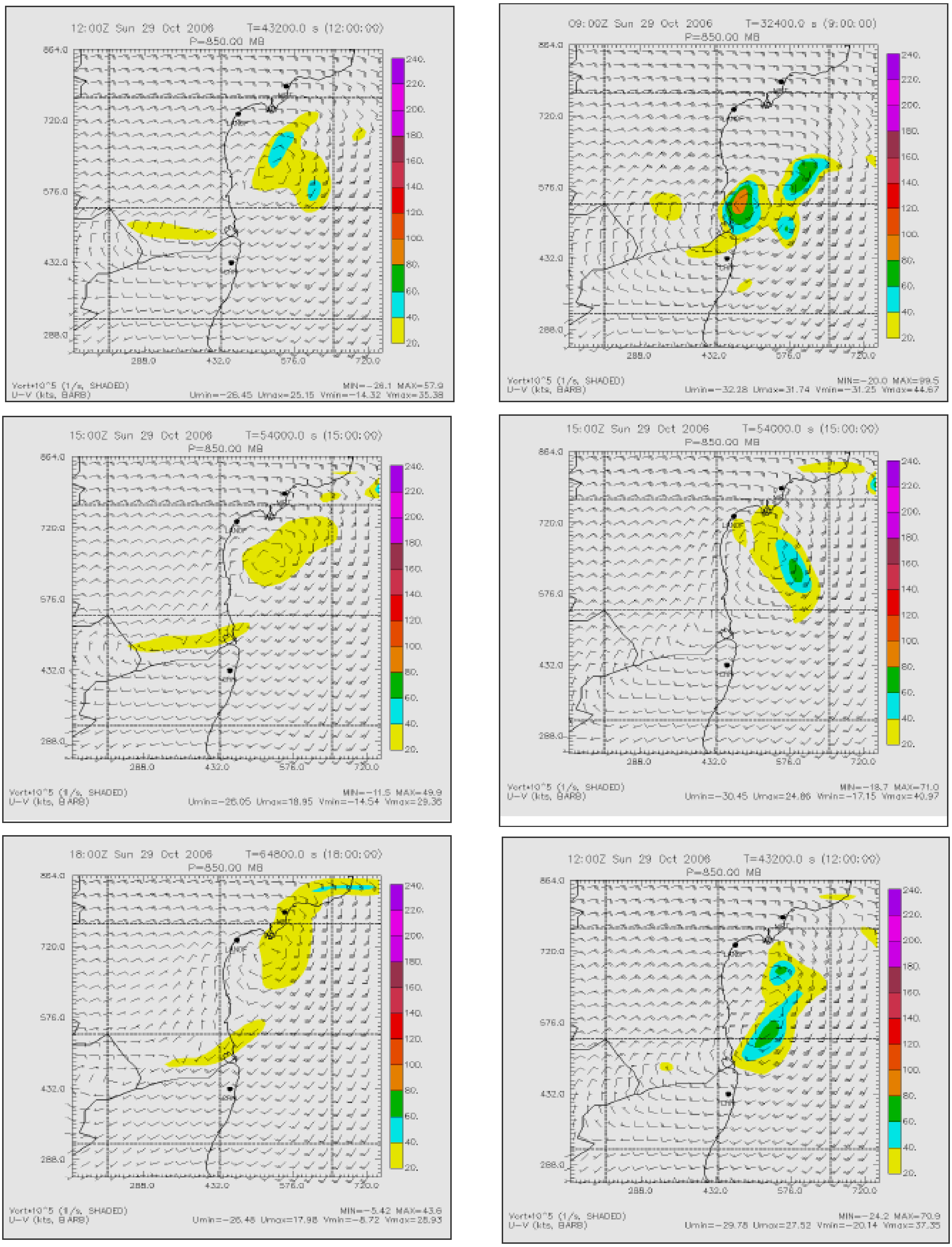


Fig. 33(b.)Three hourly forecast wind fields (knots) at 850 hPa superimposed vorticity field ($x10^{-5}$ s^{-1}). The left column for the control run and the right column for the DWR run.

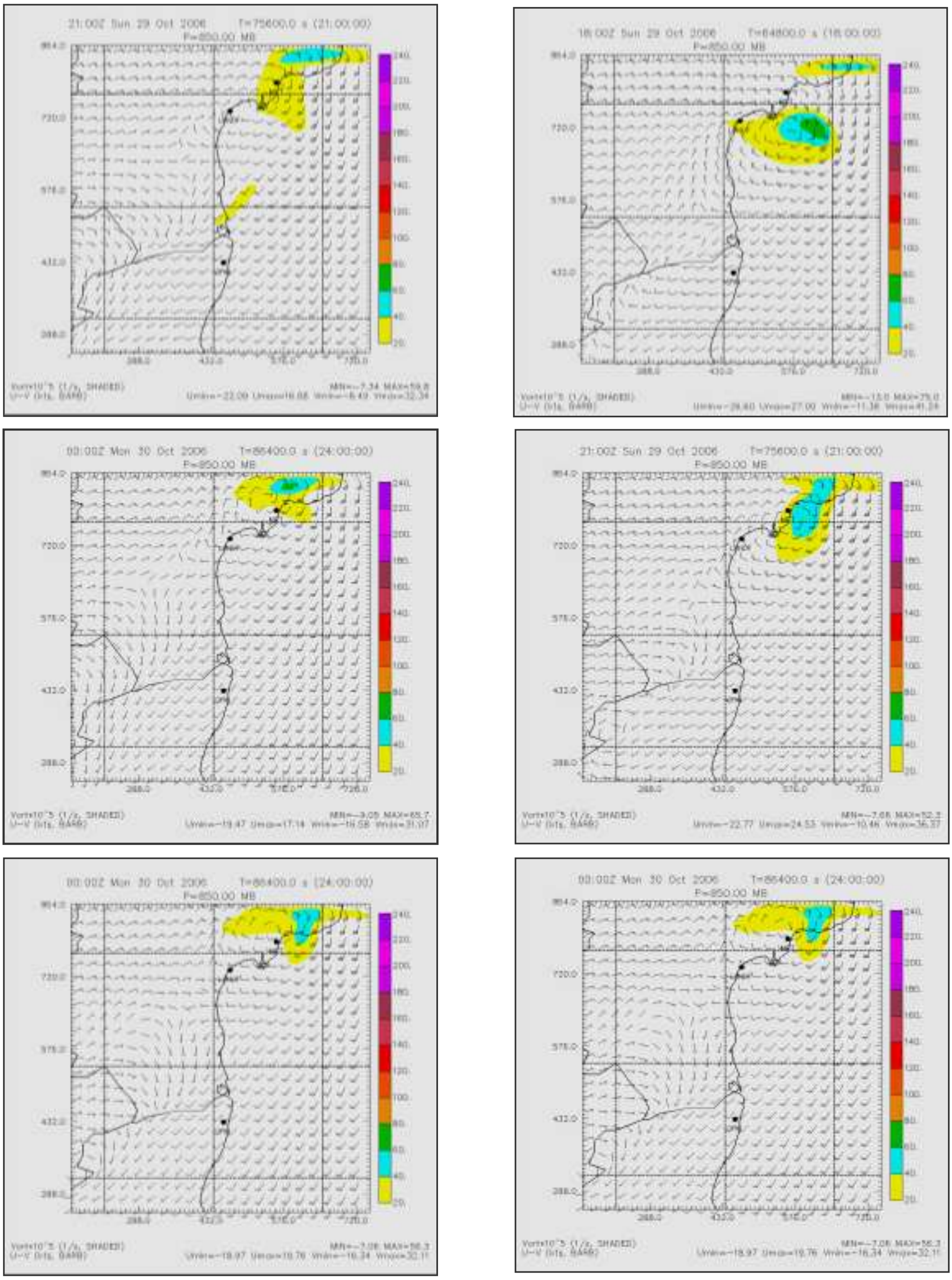


Fig. 33(c) Three hourly forecast wind fields (knots) at 850 hPa superimposed vorticity field (x10^{-5} s^{-1}). The left column for the control run and the right column for the DWR run.

5.7 Summary

Under the influence of an active northeast monsoon condition, an east-west shear zone extended from southeast and adjoining eastcentral Arabian Sea to southwest and adjoining westcentral Bay of Bengal. There were two embedded cyclonic circulations, one over southeast and adjoining eastcentral Arabian Sea and the other over southwest and adjoining westcentral Bay of Bengal. Hence, there was a band of convective and convergent flow over the region with the subtropical ridge to the north. The low level convergence associated with the upper level difluence meant the synoptic situation was conducive for convective development. Satellite imageries showed the presence of meso-scale cloud clusters. These clusters organized themselves to form the vortex over this region on 28th. Accordingly, there were two low pressure areas, one over southwest and adjoining westcentral Bay of Bengal and another over southeast and adjoining eastcentral Arabian Sea on 28th October. The vortex over southwest and adjoining westcentral Bay of Bengal concentrated into a depression at 0300 UTC of 29th and into a cyclonic storm at 1200 UTC of the same day. The system was associated with a small core and short life and could be detected by DWRs and coastal hourly observations. Its intensity was overestimated/underestimated by the Dvorak's technique.

Considering all the above, the cyclonic storm OGNI was similar to the midget cyclone developing over the northwest Pacific Ocean and South China Sea as discussed by Leung, et al., (2000). According to Lander (2000), the intensity of midget cyclones (or very small) is often underestimated (especially in early stages).The characteristics of the midget tropical cyclones in the tropics have been discussed by Lander (2000). The effect of monsoon gyre on tropical cyclones in the western north Pacific, considering a case study has been discussed by Lander (1991). The environmental condition leading to formation of midget tropical cyclones considering a case study has been discussed by Harr et al., (1996). Sharma and Badekar (1962) discussed earlier such a midget cyclone near Chennai on 20th November 1960. Gupta et al (1990) have discussed another such small core vortex near Chennai on 8th December 1987, considering various synoptic, radar and satellite observations.

6. Conclusions and suggestions

The following broad conclusions are drawn from the analysis of various features of the cyclonic storm, OGNI

(i) The cyclonic storm "OGNI" developed over westcentral Bay of Bengal at 1200 UTC of 29th October 2006 and crossed Andhra Pradesh coast between Bapatla and Ongole around 0700 UTC of 30th October as a deep depression. It caused widespread rainfall with scattered heavy to very heavy falls and isolated extremely heavy falls over coastal Andhra Pradesh leading to flash flood over the region and hence loss of life and property. This cyclonic storm was very unique in nature as it had a small core (~100 km) and short life period (~18 hours). It moved nearly northward over the sea along the coast and weakened into a deep depression before landfall. The characteristics of OGNI with respect to location of maximum reflectivity, maximum wind and rainfall also seem to be unusual. It was similar to the midget cyclones over northwest Pacific Ocean.

(ii) The cyclonic storm OGNI could be mainly detected by the DWR. Hence, the deployment and networking of DWRs, utilisation of their outputs alongwith satellite imagery and surface & upper air data at ACWC/CWC can improve the further monitoring and prediction of cyclones.

(iii) The inputs from satellite imageries provide the confidence to estimate the intensity of the system. However, there is a need to suitably modify Dvorak's technique (1984) for the cyclonic storms over the north Indian Ocean.

(iv) The location and intensity could not be determined objectively by the existing synoptic observational network, which is inadequate on the high seas and along the coast line. Thus, there is a strong requirement for strengthening the network including the augmentation of ocean observing system (Ocean data Buoys) for the detection and monitoring of tropical cyclone genesis, intensification/weakening and movement. Further, the availability of hourly normal MSLP prepared from barograph of the coastal observatories may be helpful to monitor intensity of short lived and small core cyclonic storm like OGNI. The availability of NWP model analysis in every 3-hourly intervals can help in monitoring the short lived systems like OGNI.

(v) Most of the models including LAM run by IMD, T-80 and MM5 run by NCMRWF, UKMO and ECMWF could not identify and predict the genesis, intensification/weakening of the cyclone, OGNI, though they could visualize the cyclonic circulation at lower tropospheric levels with location varying from actual centre of the system. The intensity was under-estimated in all the models. However, the simulation studies with ARPS using NCEP data and DWR data assimilation yielded promising results. The simulation results were however, limited due to data ingest from only one radar. The networking of radar resulting in the data ingest from all available radars near the cyclone can further improve the monitoring and prediction by NWP models. Further, investigation is required for a variety of different storm types and with single Doppler retrieval as well as dual Doppler retrievals algorithms utilizing observations from an improved network of DWR. Also the estimation of satellite radiance, water vapour derived winds, AWS and Ocean Buoy data in the models with very fine resolution can improve the performance of NWP models of IMD.

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