ASSIMILATION OF RADAR DATA FOR NUMERICAL WEATHER PREDICTION OF OGNI CYCLONE USING THE ADAS AND 3DVAR TECHNIQUE

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1. INTRODUCTION

The development of high-resolution non-hydrostatic models, the rapid increase of computer power & availability of Doppler radar Data are making great improvement in the prediction of thunderstorms and hurricanes. To be successful, a high-resolution prediction system must use all available observations, including Doppler radar data, satellite data, and traditional sounding and surface data in a data assimilation system. Such an assimilation system must produce a balance state that can provide relatively noise-free initial conditions and also contain the hydrometers and latent heating effects that eliminate the need for spinning up mesoscale and storm-scale motion during the initial periods of forecast. The center for Analysis and Prediction of Storms (CAPS) has developed Advance Regional Prediction System (ARPS) Model. It consists of two advance technique ADAS with cloud analysis and 3DVAR analysis method for assimilation of data. The system includes these principal components, 1) programs to remap and super-ob the radar and satellite data to the analysis grid, 2) A 3DVAR analysis method, 3) an ADAS system for analyzing all the data except for clouds and precipitation, 4) a cloud and hydrometer analysis which applies diabetic adjustments to the temperature field, and 5) a non-hydrostatic forecast model. The assimilation can be performed as a sequence of intermittent cycles. Also, an incremental analysis update procedure (IAU) can be employed in which the analysis increments are applied to the model state gradually over a period of time. Basically the IAU was developed for meso-scale and storm-scale motions but since this study has been done for a meso-scale cyclone OGNI, which has formed over Bay of Bengal during last week of October 2006, so life cycle used for the IAU assimilation window is of the order 30 minutes. This assimilation component is an option within the CAPS Advance Regional Prediction System.

2. THE DATA ASSIMILATION SYSTEM

a) Processing of the radar data

The data from chennai radar are brought to a common resolution by remapping the polar coordinate data to the Cartesian terrain-following model grid. This is accomplished by a least squares fit to a local polynomial function that is quadratic in the horizontal and linear in the vertical:

$$A=a_0+a_1x+a_2x^2+a_3y+a_4y^2+a_5xy+a_6z$$

where A is the analyzed variable and a_i are the polynomial coefficients. To avoid any unnatural extrapolation, the result is constrained within the range of data that go into the least-squares calculation. At grid resolutions of one to few kilometers, this process performs thinning of radar data by smoothing at close range from the radar, but acts as an interpolator at longer ranges from the radar. The same remapping method is applied to the reflectivity and radial velocity.

The remapping program can also produce a velocity azimuth display (VAD) wind profile analysis from the quality-controlled winds, and the resultant radar wind profile can be used as an input in the analysis of the large scale wind field.

The radar processing is done independently for each radar volume which makes it inherently parallel. The processing of data from multiple radars can be distributed to different processors of a cluster.

b) Cloud analysis

The initial foundation of the cloud analysis system was the original LAPS cloud analysis (Albers et al. 1995), with adaptation to a general terrain following grid and other enhancements as described by Zhang et al. (1998) and further refinements by Brewster (2002) and Hu et al. (2005a). Rules are used to combine the surface observations of cloud layers with satellite measurements of cloud top information, radar data, and thermodynamic information from the 3-dimensional analysis of state variables.

c) 3dvar analysis

The 3DVAR analysis method developed for the ARPS model, including dynamic constraints appropriate for storm-scale analysis, is documented in Gao et al. (1999, 2004). The analysis variables contain the three wind components (u, v, and w), potential temperature (θ), pressure (p) and water vapor mixing ratio (qv). In the current system, the cross-correlations between variables are not included in the background error covariance. The background error correlations for single control variables are modeled by a recursive spatial filter. The observation errors are assumed to be uncorrelated, hence observation error covariance is a diagonal matrix, and its diagonal elements are specified according to the estimated observation errors.

One unique feature of the ARPS 3DVAR is that multiple analysis passes can be used to analyze different data types with different filter scales to account for the variations in the observation spacing among different data sources.

3. OGNI CYCLONE (29 –30, OCT-2006) CASE

Indian Doppler weather radar network consists of four Doppler weather radars. These are situated along the east coast of India (Fig.1). The installation of four GEMATRONIC METEOR 1500S model Doppler radar at Chennai (in 2003), kolkata (in 2003), Machilipattanam (in 2004) and Vishakhapattnam (in 2003) has heightened the prospects for the operational implementation of numerical model to explicitly predict the evolution of storm scale phenomena. These radars have a wavelength of 10cm and can produce 360 beams radial of information per revolution angle. The area covered by one complete 360 rotation at one evolution angle is called an elevation scan. The area covered by radar beam as the antenna rotates through several elevation scan is known as volume scan. The radar data used in this study is from Chennai. This pulsed Doppler radar provides high-resolution measurement of radial velocity and velocity spectrum width to ranges of 230 km and of reflectivity to ranges of 460 km.

A low-pressure area formed over west-central Bay of Bengal off Andhra

Pradesh coast in the evening of 28 October 2006. It intensified into a depression and lay centered near (14.0^0 N, 80.5^0 E) in the morning of 29. While moving slowing in a northerly direction it intensified into a deep depression and lay centered near (15.0^0 N, 80.5^0 E) in the afternoon of the same day about 50 km east of Kavali. The system further intensified into a cyclonic storm in the evening of 29^{th}. The system moved slightly northward and till the morning of 30^{th} the movement of the system was very slow. It lay centered near lat.19.5^0N/ long.83.5^0E at 0000 UTC of September 30, 2006 about 30 km east of Kavali. Doppler weather radar at Machilipatnam showed band features with small core. The Doppler weather radars of Chennai and Machilipatnam constantly monitored the system. The satellite imageries on hourly basis helped to track 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 moved northwestward and crossed "the coast near Bapatla as deep depression around noon of October 30, 2006. After crossing the coast, the system weakened into a depression in the afternoon of same day. The depression further weakened into "a low pressure area over north Andhra Pradesh and adjoining areas in the evening of October 30, 2006.

5. The Experiments and Results

Since the system discussed in the last section was a small core (Meso-cyclone type), no model was able to capture it. To simulate it, the Doppler data are needed. In this study, Doppler radar data from Chennai has been assimilated in to ARPS Model to see the effect of radar data (Reflectivity & Radial velocity) using both the technique namely ADAS with cloud analysis and 3DVAR analysis method. To do this, the data from Chennai Doppler radar are preprocessed on to 9 km grid in netcdf data format and then used in data assimilation cycles. The observations from chennai radar and Kalpana satellite pictures are used to evaluate the results of assimilation and forecast. The horizontal domain of grids is shown in Fig.1. The 9-km grid 901 km x 901 km in size and Chennai is in the center of domain. The vertical grid stretched from

20 m at the surface to about 400 m at the model top that is located at about 15 km.

Three sets of experiments are carried out as mentioned above. First, initial and boundary conditions from NCEP GFS without radar data are used. Second, GFS and radar data (radial velocity and reflectivity) are assimilated in ADAS. And finally**,** GFS and radar data (radial velocity and reflectivity) are assimilated using 3DVAR. In all the three experiments, the topography data of 3 sec resolution is used. Also in these experiments, the NCEP GFS Model Data of 0000UTC of 29 October 2006 is used as input. In first experiment model is being run for 24 hour forecast on a 9 km grid without radar data assimilation. In other two experiments, radar data assimilation has been done on a 9 km grid as an intermittent assimilation with every 30 minutes interval during 0000UTC to 0300 UTC. In these experiments, radial velocity data are analyzed using ARPS ADAS and 3DVAR. The reflectivity data is used in cloud analysis scheme based on the moist adiabatic temperature profile. Fig 2 shows 3-hour long assimilation window and then 21-hour forward forecast for both cases.

The experiments without Radar Data will be mentioned as cy-no, with radar data assimilation using ADAS will be termed as cy-ad and with radar data assimilation using 3DVAR will be termed as cy-3d. To see the impact of Radar Data on initial condition and forecast, vertical vorticity overlaid on wind field (knots) at 850 hPa, reflectivity (dBZ) and rainfall band starting from 0000UTC are plotted in Fig 3a-i, Fig 4a-i, and Fig 5a-i. Genesis and 3 hourly movement of cyclone for cy-no, cy-ad and cy-3d experiments are shown in Fig 3a, b, Fig 4a, b and Fig 5a, b respectively. It can be observed that reflectivity & magnitude of 850 hPa winds and vortices has been significantly enhanced with incorporation of radar data. It has also been observed that in cy-ad and cy-3d experiments wind pattern is more organized and systematic. Maximum sustain wind in cy-no experiment is 40 knots at 09Z and 35 knots at 12Z after that it is decreasing while in case of cy-ad experiment, 40 knots winds are seen right from 03Z till 18Z, it has attained maximum of 45 knots at 09Z. In cy-3d experiment it is showing 40-45 knots winds right from the beginning, and it has maintained 55 knots from 06 UTC to 12 UTC. After that it has crossed the coast. In cy-ad experiment, the point of landfall is slightly northeastward from the observed point of landfall around 21 UTC. In cy-3d landfall is slightly southward from the observed point of landfall around 12 UTC. Observed time of landfall is 0700 UTC of 30 October 2006. Observed best track along with surface wind is given in table (1). For the verification, satellite and radar pictures are drawn in Fig. 6 and Fig. 7 respectively. It is found that observations are in good agreement with the cy-3d experiment result.

6. CONCLUSION

In this study, the system is applied to a small hurricane named OGNI, which formed over Bay of Bengal, India during last week of October 2006. Three experiments are carried out to test the impact of the radar data from Chennai, India. These experiments include: (1) using NCEP GFS data to initialize the ARPS model, (2) using initial and boundary condition produced from the ADAS and the cloud analysis, (3) using initial and boundary condition produced from the 3DVAR and cloud analysis. The comparison of the experiments without and with the radar Data reveals that OGNI cyclone is in general well simulated by using the radar data with both ADAS and 3DVAR method to initialize the model. The evolution of vertical vorticity overlaid on horizontal wind at 850 hPa shows that the forecast is improved in terms of the magnitude and direction of wind speed, time and location of cyclone in the experiment with the 3DVAR method. The genesis and northward movement of cyclone is well brought out by the 3DVAR method. However, the cyclone has crossed the land well before the observed time with the 3DVAR method. Thus the numerical experiments establish the fact that assimilation of DWR Data can improve the signature of prevailing instability over the region, which in turn can help to improve the simulation of Meso-cyclonic event.

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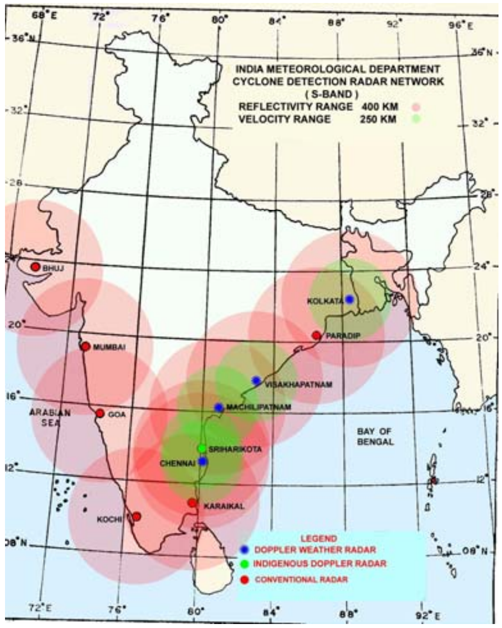

Fig 1. Location of Indian DWR along east coast shown in blue color.

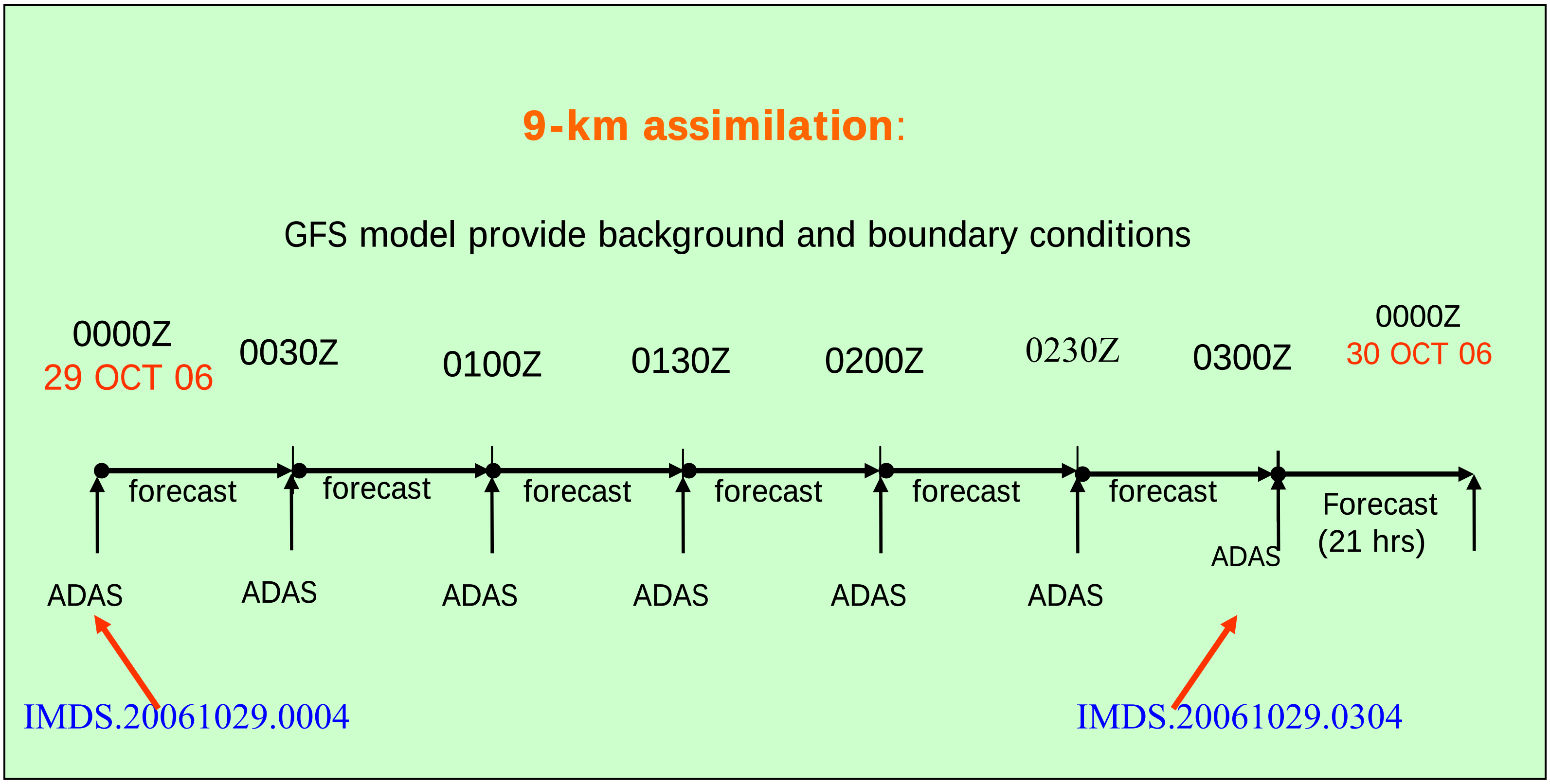

Fig.2. Procedure of the assimilation and forecast experiments on the 9 km grid for the 29-30 October, 2009 India small hurricane case.

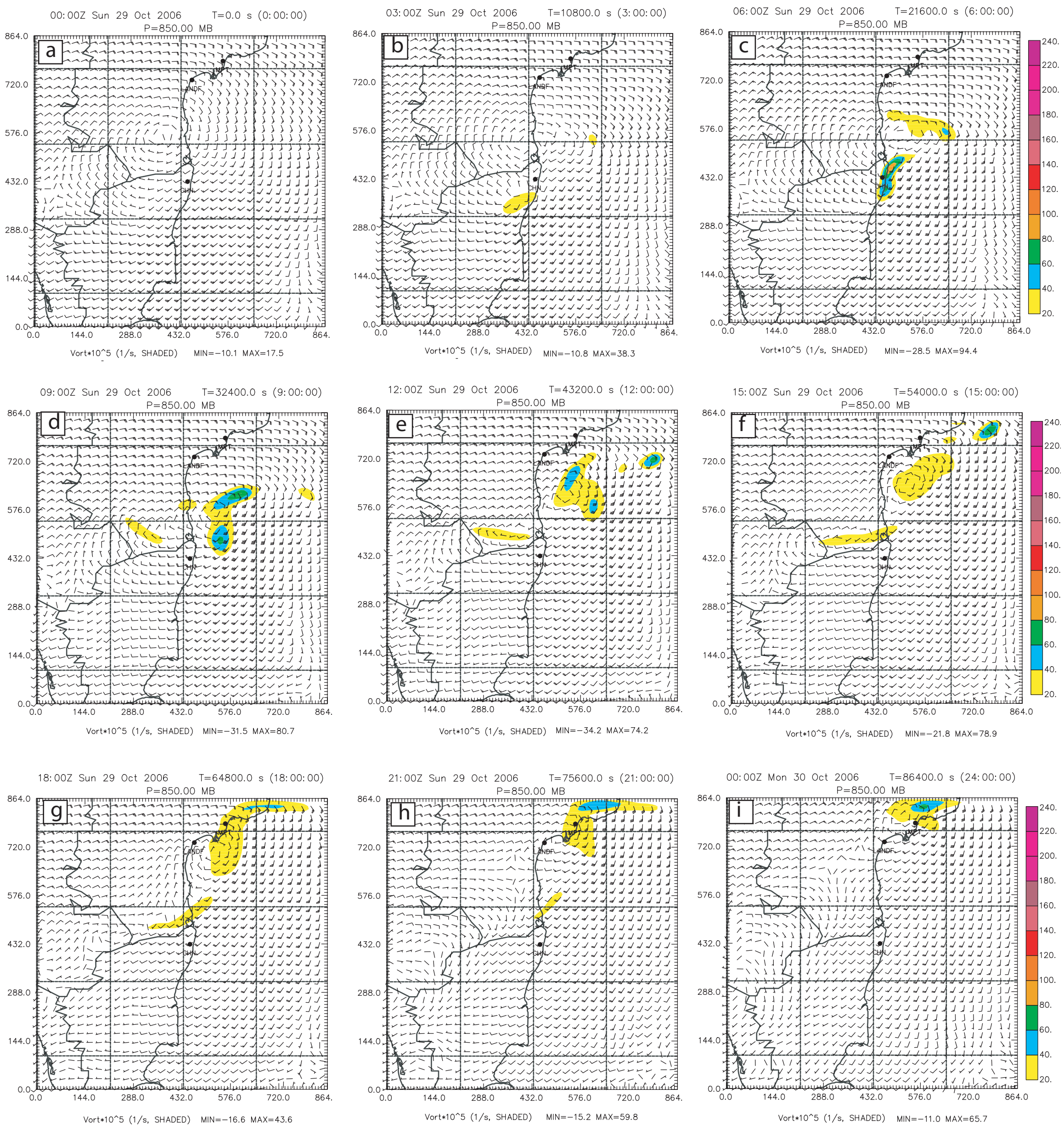

Fig. 3. Wind vectors and vorticity with non data assimilation.

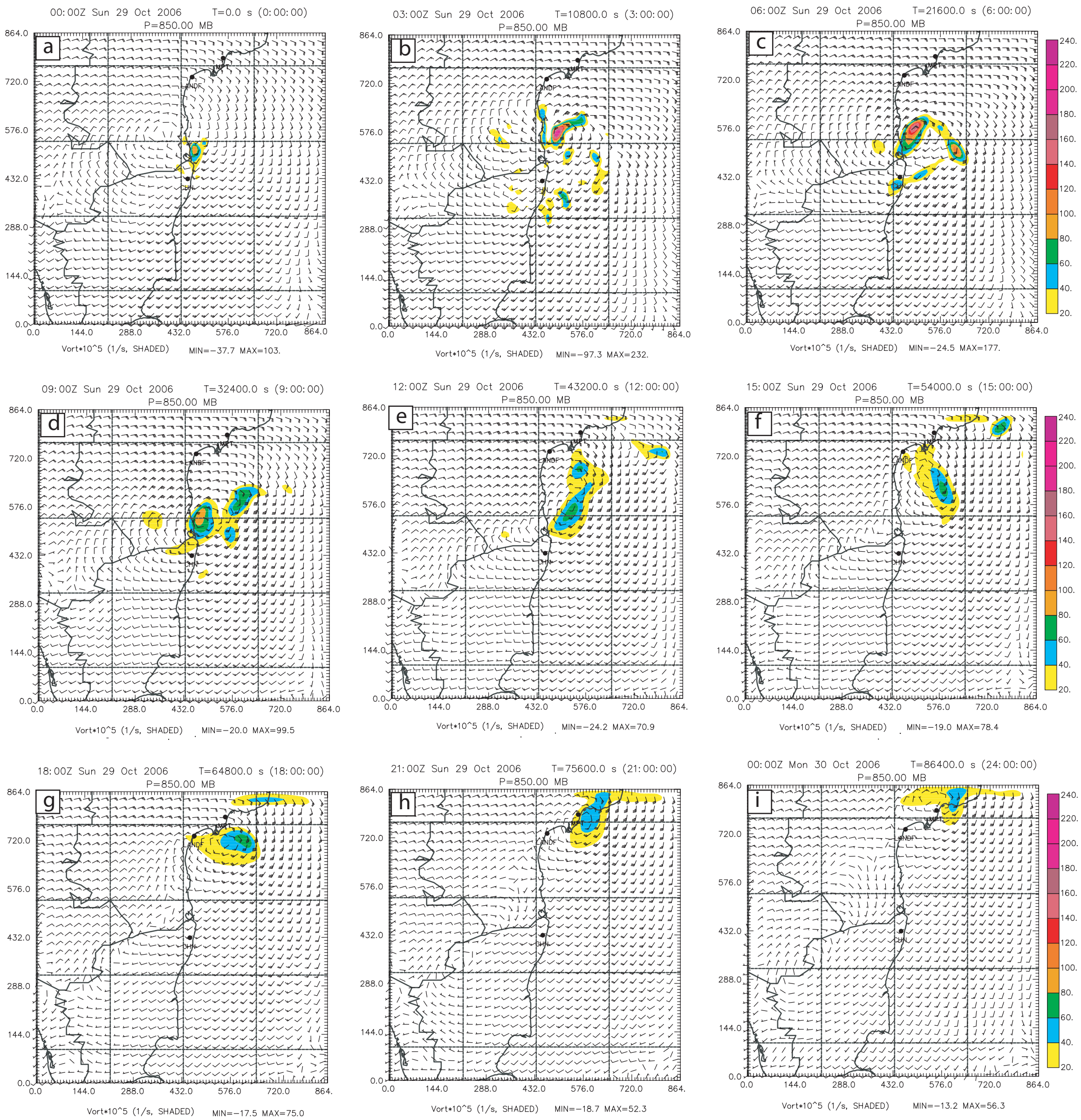

Fig. 4. Wind vectors and Vorticity with ADAS.

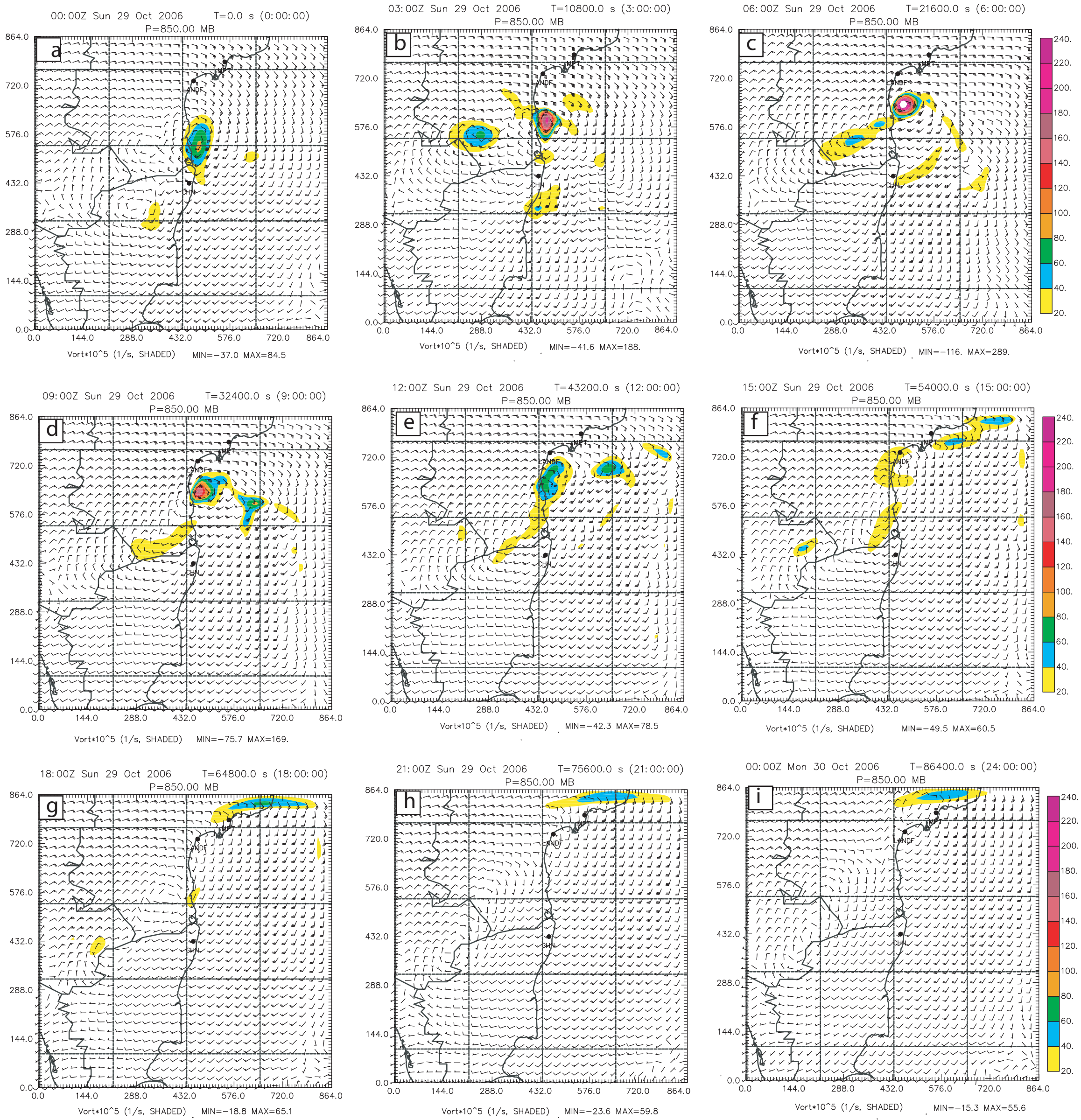

Fig. 5. Wind vectors and Vorticity with 3DVAR.

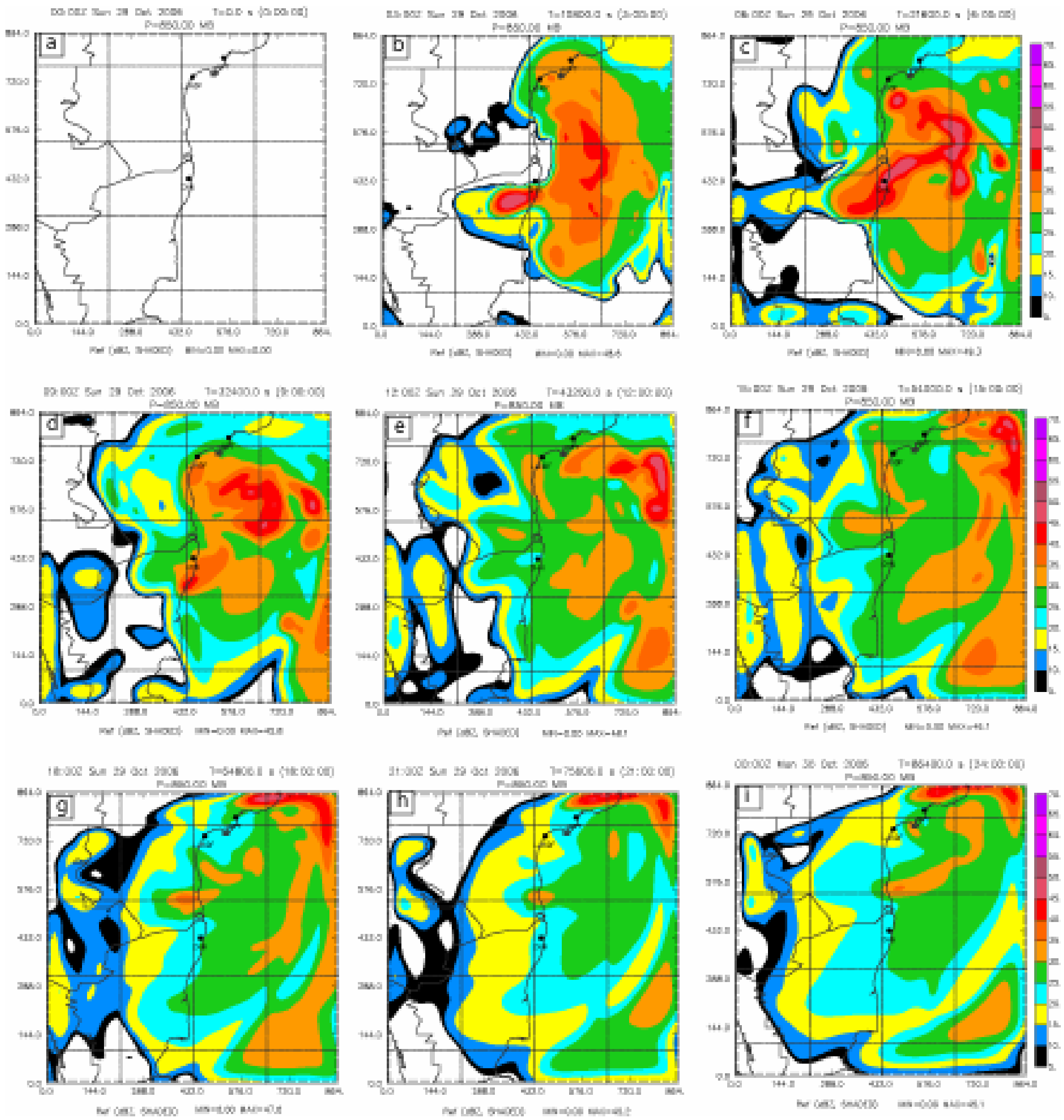

Fig. 6. Reflectivity with non data assimilation.

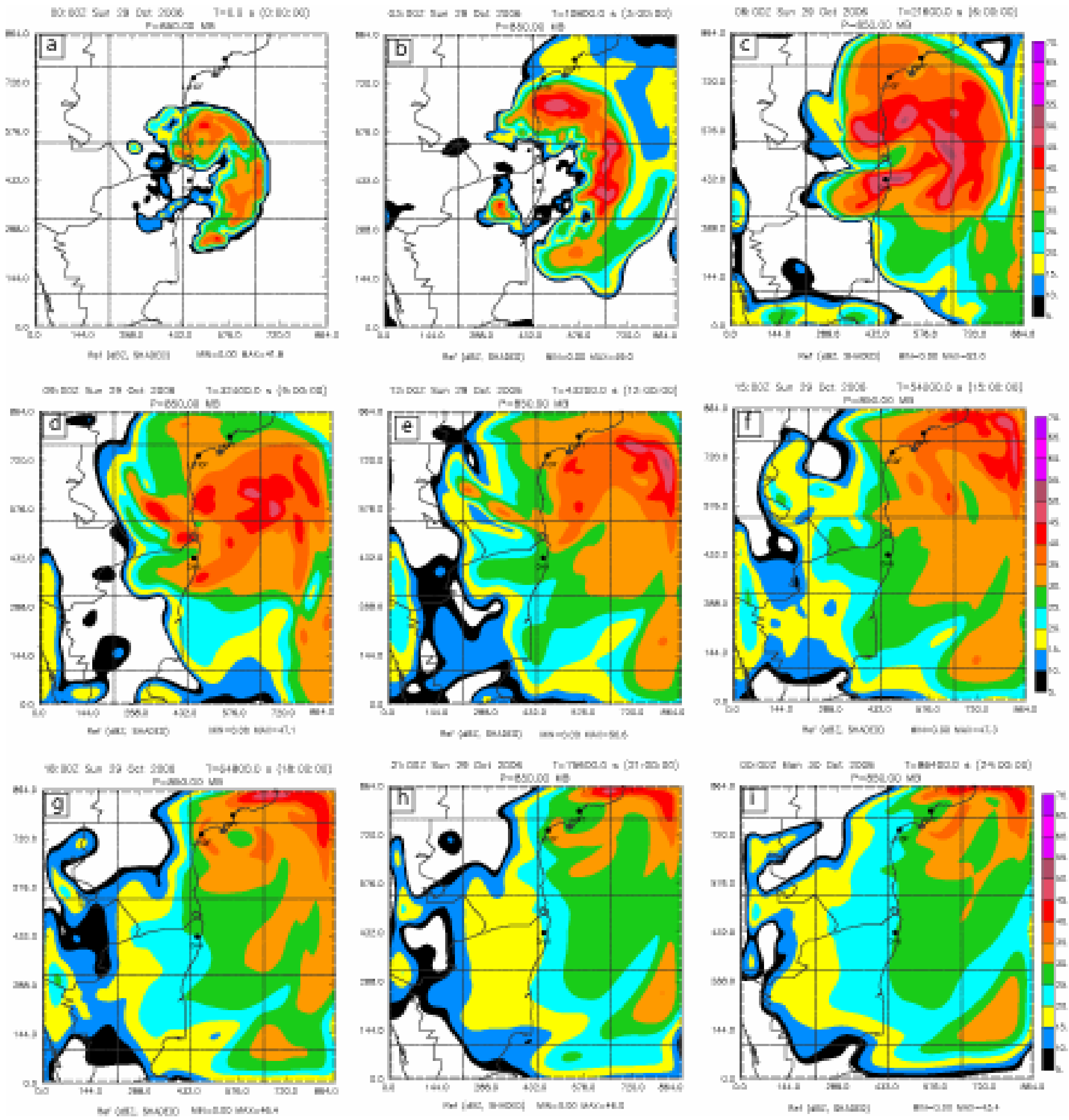

Fig.7. Reflectivity with ADAS.

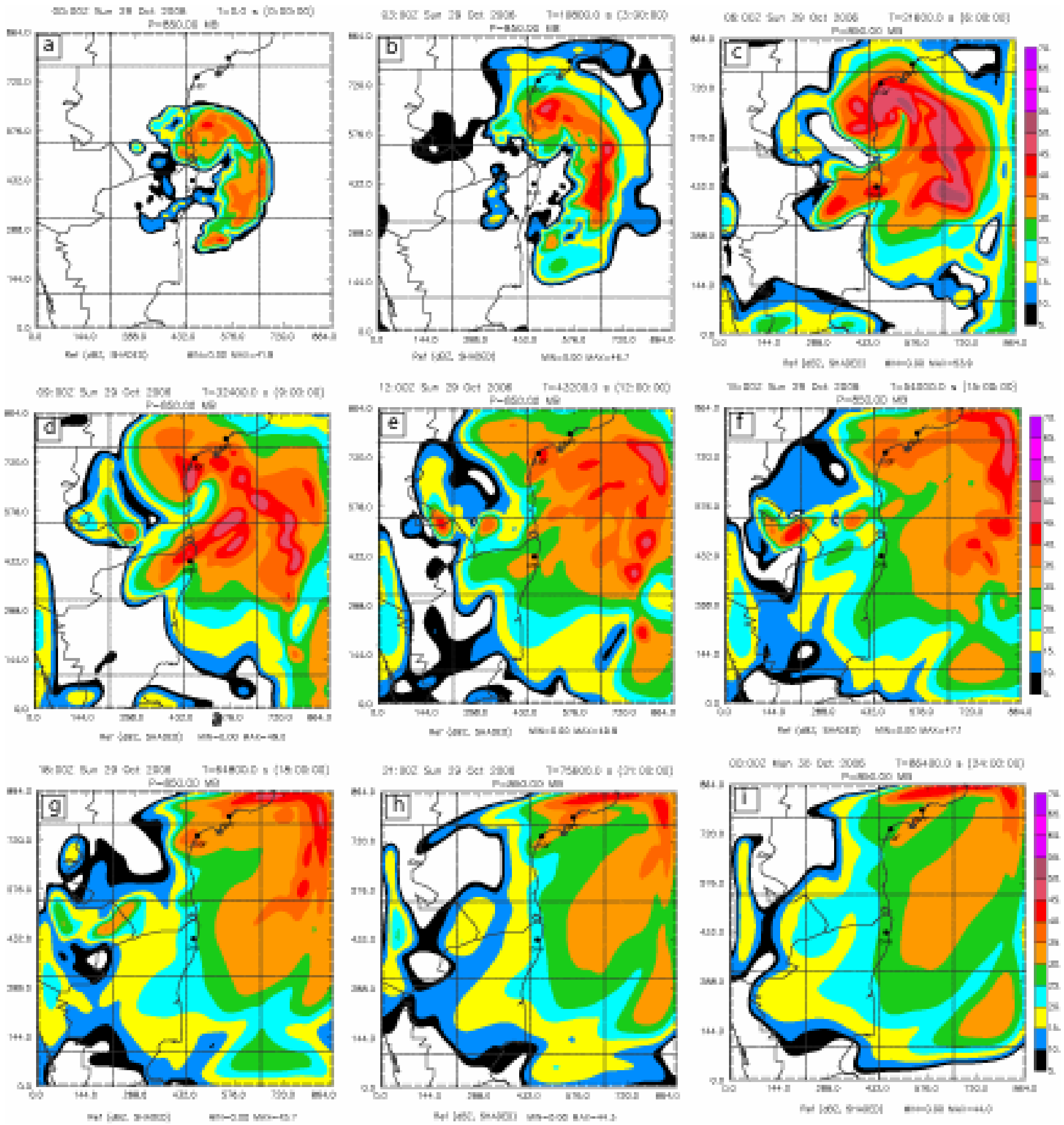

Fig. 8. Reflectivity with 3DVAR.

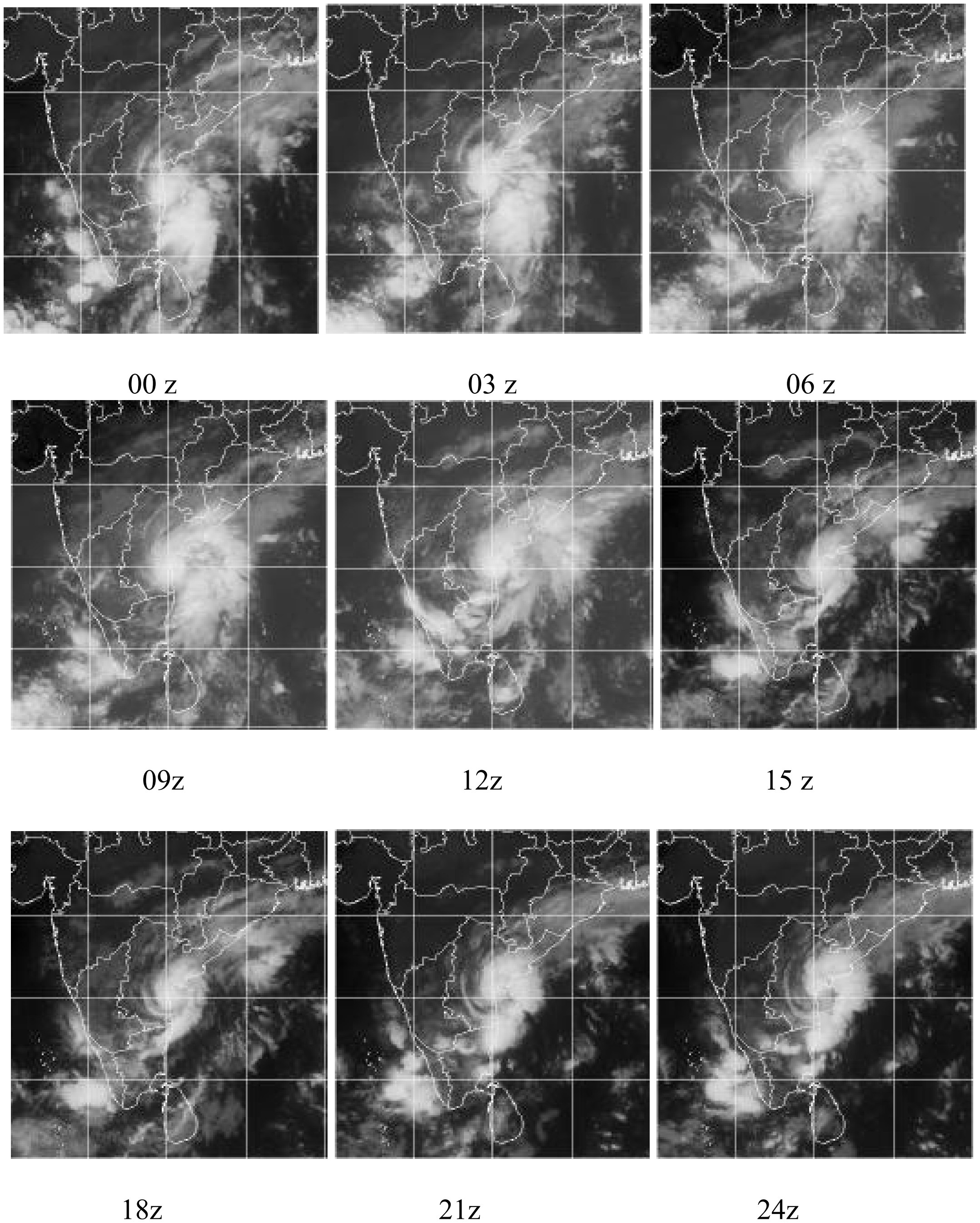

Fig. 9. Satellite pictures of 29 October 2006.

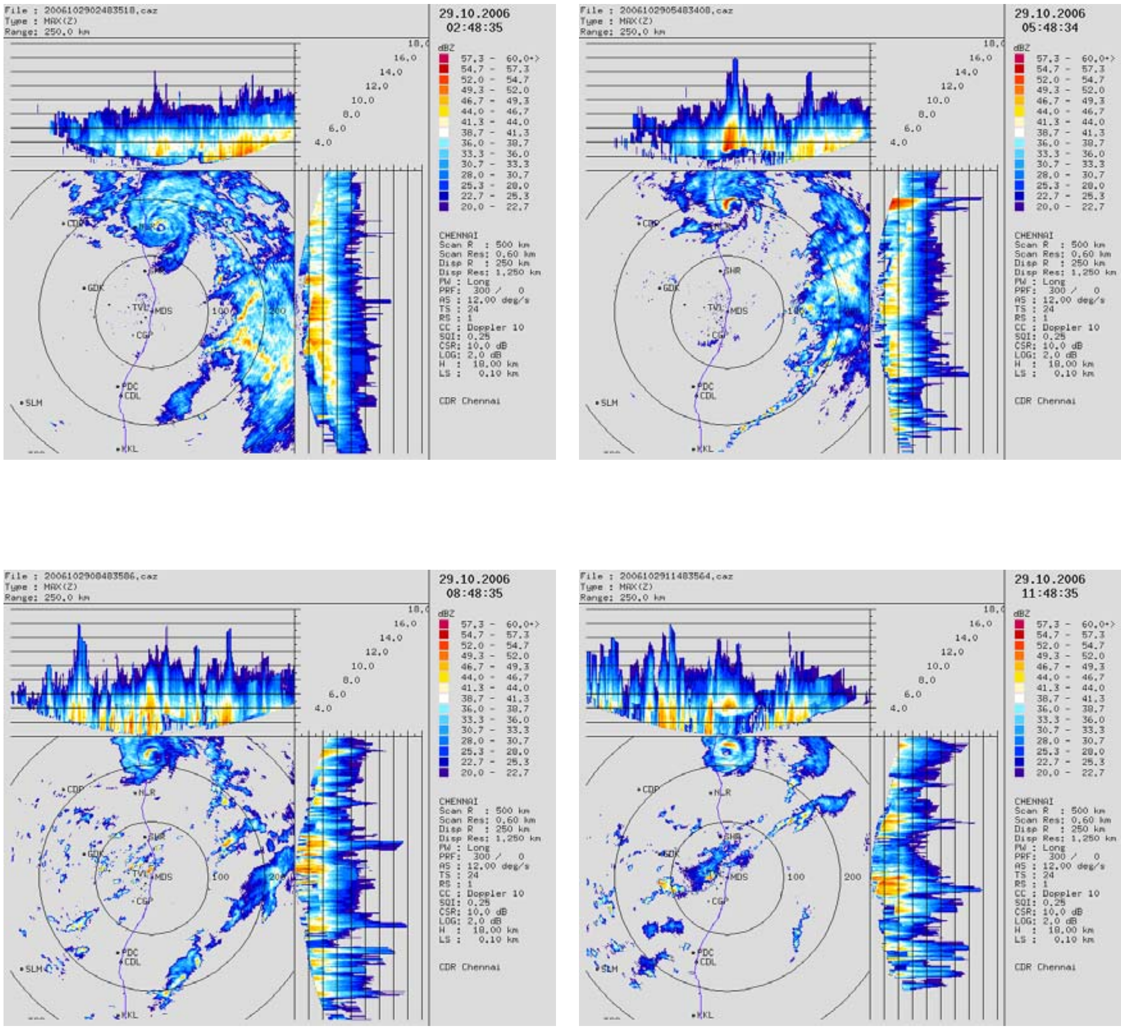

Fig. 10. Radar pictures of Chennai radar on 29 October 2006.

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