MAUSAM, **55**, 4 (October 2004), 671-680

551.515.1 : 551.508.855

A study of 12th November 2002 cyclonic storm in the Bay of Bengal using Doppler Weather Radar

S. K. BANERJEE*, S. K. KUNDU and H. A. K. SINGH

**Meteorological Office, Pune – 411 005, India*

Cyclone Detection Radar, Kolkata, India

(*Received 26 December 2002, Modified 4 February 2004*)

सार – बंगाल की खाड़ी में बने चक्रवाती तूफान के मार्ग को निर्धारित करने के लिए भारत में पहली बार डापलर मौसम रेडार (डी.डब्ल्यू.आर.) का उपयोग किया गया है। उपरोक्त शोध पत्र में इस तूफान के कुछ महत्वपूर्ण लक्षणों को स्पष्ट करने के लिए रेडार से लिए गए चक्रवात के कुछ चुने हए चित्रों का विवेचन किया गया है।

ABSTRACT. For the first time in India, Doppler Weather Radar (DWR) has been used to track a cyclonic storm, which formed over Bay of Bengal. Selected few radar images of the cyclone have been discussed here to bring out some of the important features of this storm.

Key words – Doppler, Reflectivity, Radial velocity, PCAPPI_Z, PCAPPI_V and MAX_Z.

1. Introduction

Large number of studies has been made by various authors on cyclonic storms in Bay of Bengal using X and S band conventional radars. Bhattacharjee & De (1965) studied the cyclonic storm of 21 September 1962 in the Bay of Bengal using X band radar at Dum Dum Airport Calcutta and gave a detailed account of spirals and rainfalls associated with it. Raghavan (1977) studied the structure of immature cyclonic storms in the Bay of Bengal as observed by S band conventional radar and inferred that such storms appear to be common in the Bay of Bengal and often do not exhibit on the radar or satellite pictures all the features normally associated with tropical storms. Further the classification of such storms purely on the basis of surface and low level winds may sometimes be in error as the few observed winds may not be true representative of such cases owing to the asymmetry of wind field and suggested for careful co-ordination of synoptic, satellite and radar data for achieving better results.

In this paper authors have tried to investigate the detailed structure of cyclonic storm which crossed Sagar Island on West Bengal coast on 12 November 2002. This is the first attempt to study cyclonic storm over Bay of Bengal using Doppler Weather Radar.

2. The details about the storm

A well marked low pressure area was located on 0300 UTC of 10 November 2002 morning over SW Bay and adjacent WC Bay, which concentrated into a depression on the same date at 1200 UTC near Lat. 12.5° N and Long. 82.5° E about 230 km E-SE of Chennai. On 11 November 2002 at 0300 UTC the depression moved in a N-NE direction over WC Bay and adjoining SW Bay within half a degree of Lat. 14.0° N, Long. 83.5° E about 350 km E-NE of Chennai. At 1200 UTC of same date the system was in N-NE direction and intensified into a cyclonic storm over WC Bay near Lat. 16.0° N and Long. 84.0° E about 200 km of S-SE of Visakhapatnam. On 12 November 2002 at 0300 UTC cyclonic storm over WC Bay moved N-NE wards and lay near Lat. 20.0° N and Long. 87.0° E centred 320 km SW of Kolkata and crossed Sagar Island in the afternoon of 12 November 2002 and weakened gradually into a Deep

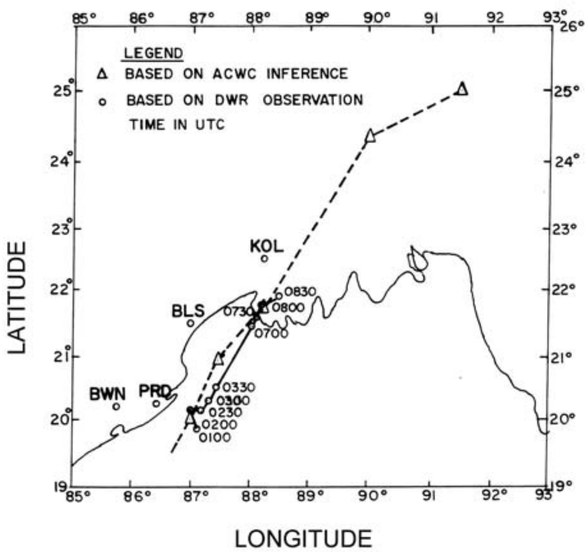

Fig. 1. Track of cyclonic storm 12 November 2002

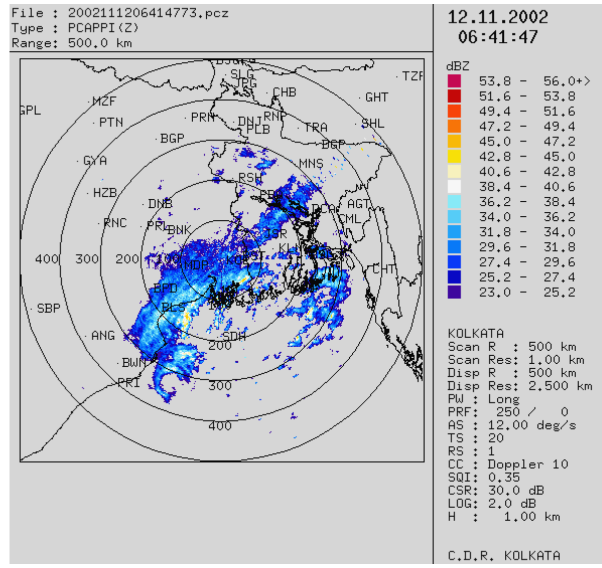

Fig. 2. Reflectivity image (Pseudo CAPPI) for 500 km

Depression and lay centred at 1200 UTC on the same date about 100 km east of Kolkata. The track of the cyclonic storm has been shown on Figs. 1 & 18.

3. Radar observations

The Doppler Weather Radar has got the capability of running continuously round the clock and taking radar observations and archiving the raw data & various products based on reflectivity and radial velocity data.

Though conventional S-Band radars are well suited for detection and tracking of a tropical storm, yet it is a well recognized fact that the conventional (non-coherent) radar is incapable of measuring damaging fields inside the tropical cyclones which are also responsible for causing storm surges and extensive damages. Unlike conventional radar which maps the reflectivity *i.e.*, precipitation field, a Doppler radar (coherent) can measure in addition to reflectivity, two more parameters (*i*) radial wind velocity '*v*' (*ii*) velocity spectrum width '*w*' which is a measure of turbulence. Manipulations of the DWR base parameter estimate of Z, V & W conveys information for direct use to forecaster and end users. Further, base parameter of DWR themselves yield information that is not possible in conventional radar. This capability permits the forecasters to view weather events in greater details. Doppler weather radar provides tremendous amount of observational information about atmosphere but requires more sophisticated interpretation of radar data in terms of atmospheric structure and processes than that required in conventional radar data.

There are many derived products like divergence, convergence, shear etc. available from a Doppler radar for use of forecaster and in understanding of kinematics of severe weather systems.

Products based on reflectivity are also available from conventional radar but there are lots of limitations of these products. Since Doppler radar measures radial velocity of the echoes in addition to return power, it is easy to eliminate ground clutter, anomalous propagation echoes, which have no relative velocity from the signal by zero velocity canceller algorithms along with beam blocking technique. Clutters nearly stationary - zero velocity with use of high pass digital filters enable DWR to eliminate targets in a narrow Band width near zero velocity. Hence, the accuracy of precipitation estimates are much better, normally by one order, from Doppler radar especially in a region where ground clutter and distance permanent echoes is a serious problem.

From radial velocity display, quite a few useful information's can be derived. When a cyclone is within effective range of radar and approaching the coast, maximum wind which occur usually around eye or centre of the storm, is represented by two equal and opposite velocity maximum. The wind measurement is useful in precisely estimating the intensity of cyclone in shorter interval. This leads to better estimation of storm surge thereby improving the warning. However, it may be kept in view that the distance of the storm is significant, as larger resolution volume at longer distance would tend to average out the maximum wind.

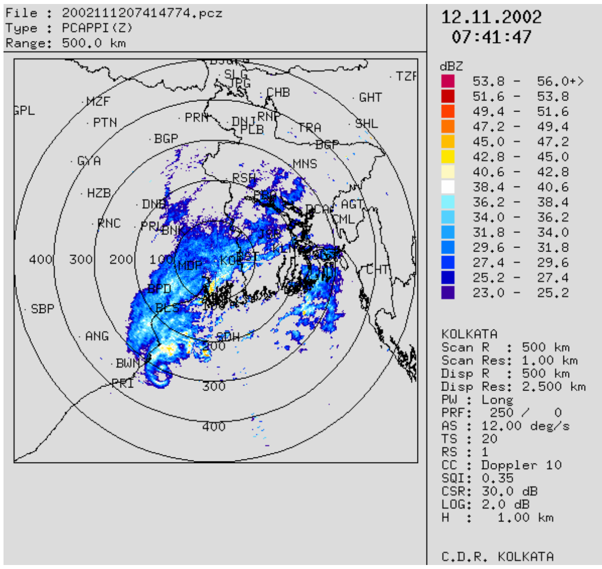

Fig. 3. Reflectivity image (Pseudo CAPPI) for 500 km

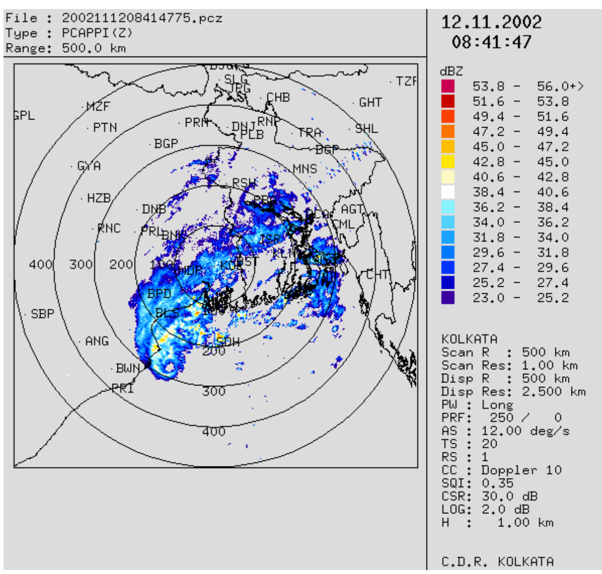

Fig. 4. Reflectivity image (Pseudo CAPPI) for 500 km

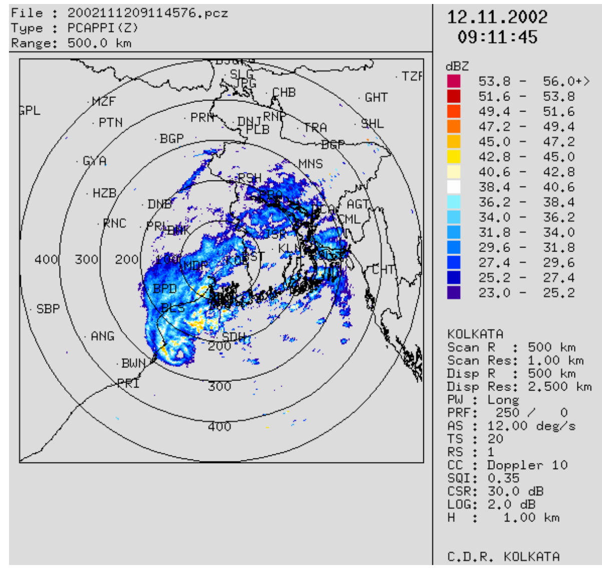

Fig. 5. Reflectivity image (Pseudo CAPPI) for 500 km

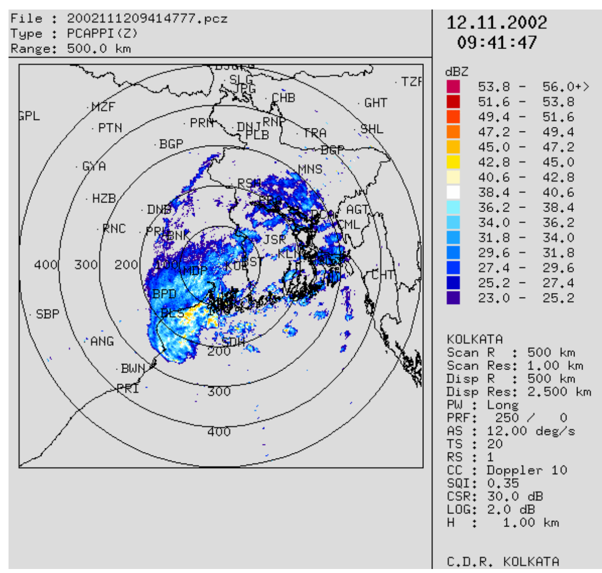

Fig. 6. Reflectivity image (Pseudo CAPPI) for 500 km

Further, with uniform wind technique (UWT), prevailing wind field within the range of radar can be mapped depicting the total horizontal wind pattern at the height of radar beam at that particular distance. For the case of 12 November 2002 cyclone of Bay of Bengal, winds indicated by DWR were found to match well with upper air wind plotted at various synoptic hours. In the volume velocity processing (VVP), a technique, which is based on the assumption that wind is linear within analysis volume, provides better results, as the wind is rarely uniform over large volumes scanned by radar. Using this technique vertical profile of the horizontal wind centred around 25 km radius over the radar site can be estimated.

Most of the models which are used for estimating storm surge associated with tropical storm are based on following broad parameters.

(*i*) Coastal bathymetry
(*ii*) Intensity of storm
(*iii*) Radius of maximum wind
(*iv*) Speed of the storm
(*v*) Direction of approach to the coast
(*vi*) Position of land fall
(*vii*) Time of land (high tide/low tide)
(*viii*) Fall in pressure

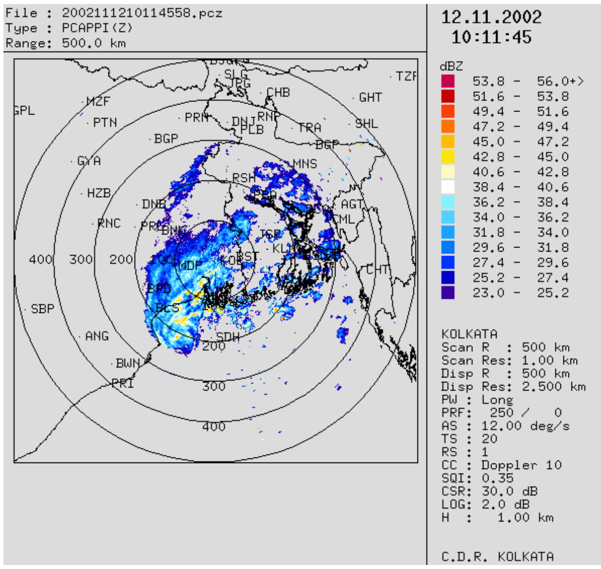

Fig. 7. Reflectivity image (Pseudo CAPPI) for 500 km

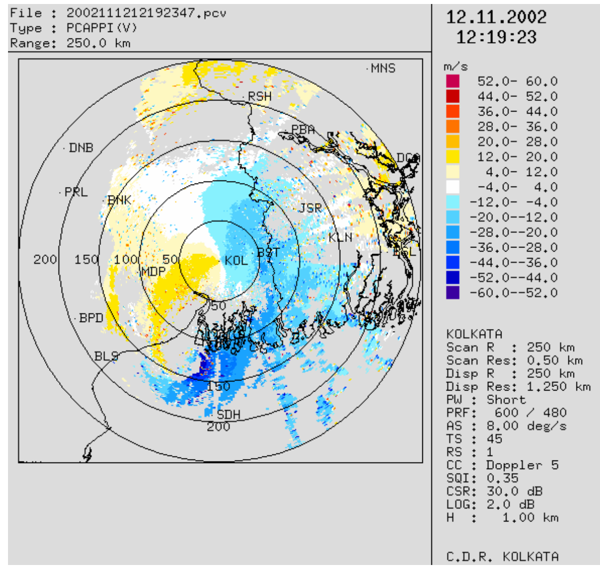

Fig. 9. Velocity image (Pseudo CAPPI) for 250 km

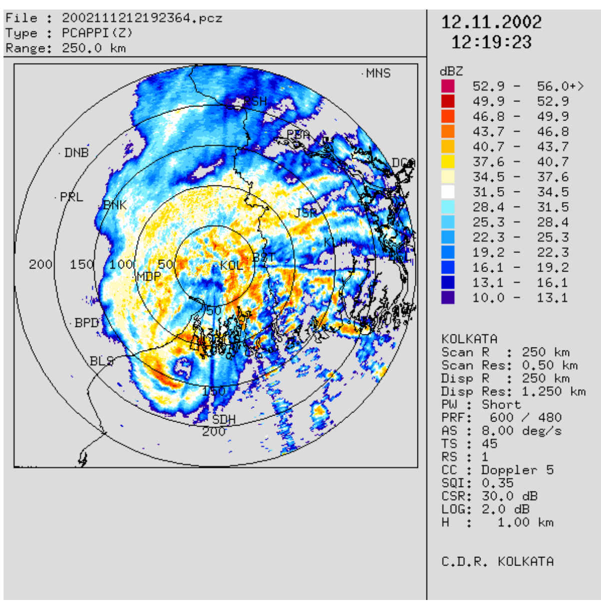

Fig. 8. Reflectivity image (Pseudo CAPPI) for 250 km

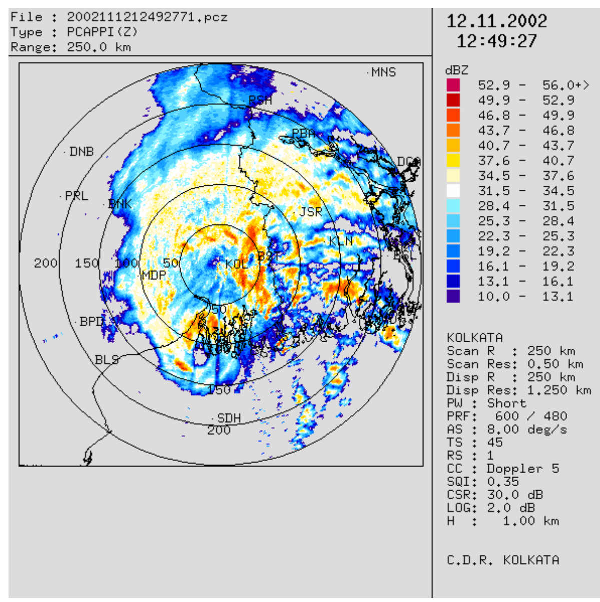

Fig. 10. Reflectivity image (Pseudo CAPPI) for 250 km

Out of above, sea bathymetry does not change much and is known for a particular location, rest can be provided by Doppler radar except, the time of landfall (whether high/low tide), fall in surface pressure and direction of approach to coast. With a suitable algorithm, it is possible to generate a storm surge forecast for a tropical cyclone for a specific location with above DWR inputs. This needs to be explored for Indian Sub-continent's Land-sea area in conjunction with synoptic, radar and satellite data (provides T numbers from which centre pressure and fall in pressure in the centre of tropical cyclone can be estimated).

The Doppler Weather Radar, METEOR 1500S installed at Kolkata has got an Antenna dish diameter of 8.5 m, Beam width of 1 degree at 3 dB points, Polarization linear Horizontal, Operating frequency 2875 MHz (2700 to 2900 MHz), Peak Transmitter power 750 KW, long pulse 2 micro second, short pulse 1 micro second, Minimum Detectable Digital Signal -110 dBm at Low Noise Amplifier input, Pulse Repetition Frequency 250 to 1200 Hz, Stagger ratio 5/4, 4/3, 3/2 (selectable), Maximum unambiguous velocity +/– 60 m/s (with 5/4 stagger ratio) and Effective dynamic range of 95 dB.

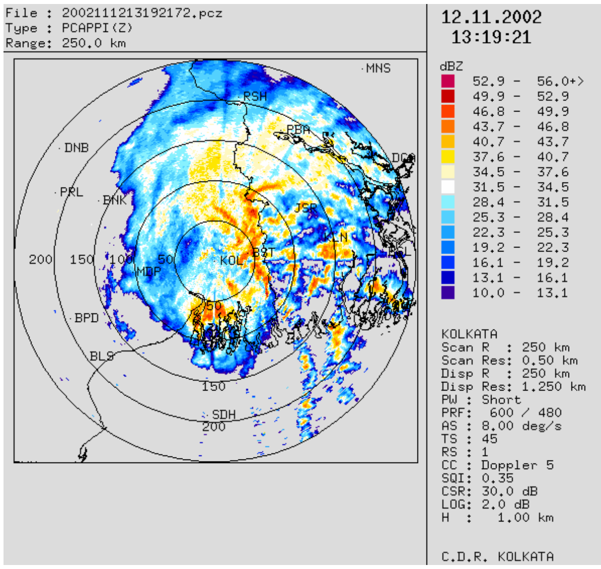

Fig. 11. Reflectivity image (Pseudo CAPPI) for 250 km

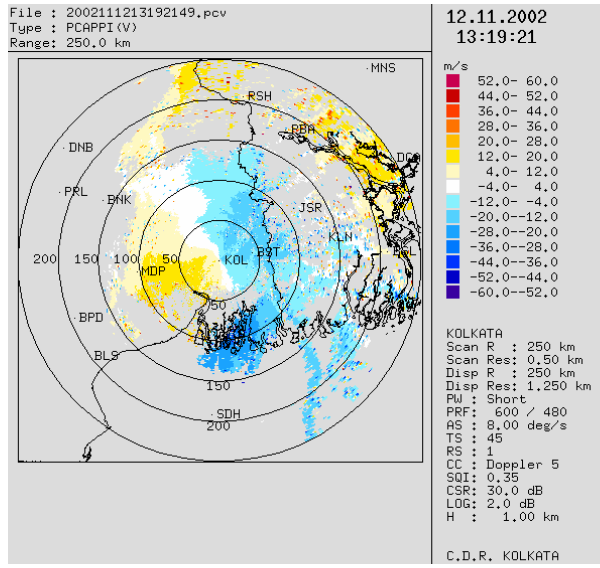

Fig. 13. Velocity image (Pseudo CAPPI) for 250 km

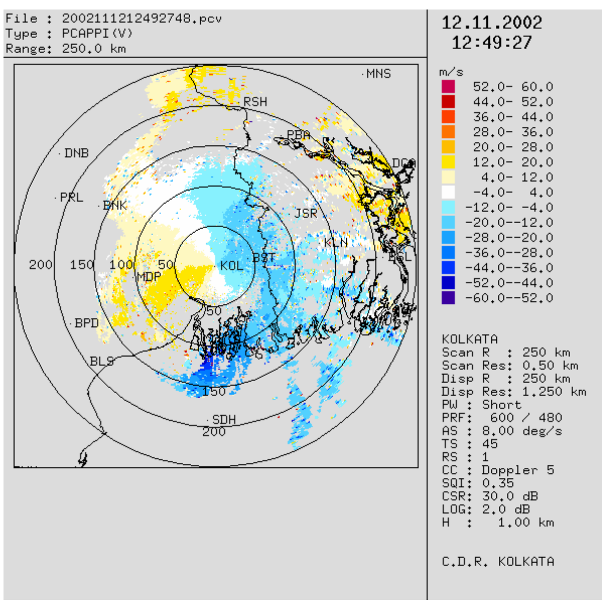

Fig. 12. Velocity image (Pseudo CAPPI) for 250 km

The DWR system computer configuration consists of

(*i*) Three Windows NT based PCs running RAVIS (Radar Visualization) software for real time displays of Z (log reflectivity in dBZ), V (mean radial velocity in m/s) and W (spectrum width in m/s) data using three 2K × 2K LCD display monitors.

(*ii*) One UNIX based Rainbow Main workstation running RAINBOW software for operative control and display of processed meteorological data.

(*iii*) One UNIX based Rainbow Display workstation running RAINBOW software for display of processed meteorological data.

(*iv*) Two Windows NT based PCs are used as maintenance terminal and archiving PC. One of these PC is also used for DWR data dissemination through internet.

The DWR Kolkata had tracked the cyclone of 12th November 2002 continuously, since 0641 hr UTC of 12th November 2002 when the cyclonic storm was about 350 km S-SW of Kolkata till it crossed the coast near Sagar Island on 12 November 2002 afternoon (1319 hr UTC).

4. Salient features of the cyclone as seen by Doppler Weather Radar, Kolkata

In the Pseudo Constant Altitude Plan Position Indicator (Reflectivity) image for 500 km range *i.e.*, PCAPPI_Z_500 km image of 0641 hr UTC (Fig. 2) of 12th November 2002, one arc could be seen at 350 km south-west from radar site, similar to vortex formation with reflectivity ranging from 28 to 38 dBZ. After an hour at 0741 hr UTC (Fig. 3) of same date, a closed eye could be seen at 320 km with maximum reflectivity between 42 to 44 dBZ and about 70 km N-NE from centre of storm. At 0841 hr UTC (Fig. 4), it was observed that the storm had moved in Northeastward direction. The eye and spiral became more prominent and organised and was located at a distance of 270 km from radar site. At 0911 hr UTC (Fig. 5), the eye size became slightly reduced and took a D shape, it was about 250 km SW of radar site. The 0941 hr

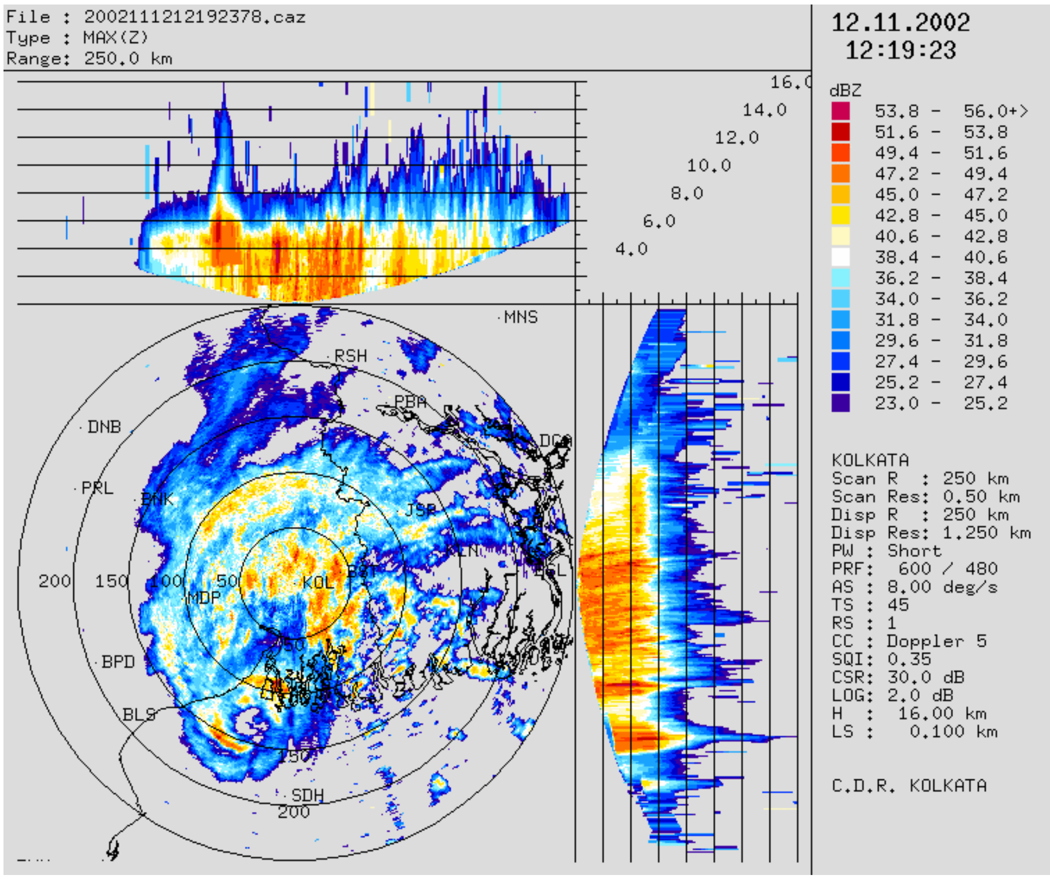

Fig. 14. Maximum Reflectivity image for 250 km / Height 16 km

UTC (Fig. 6) and 1011 hr UTC (Fig. 7) PCAPPI_Z_500 images did not show the eye as it was covered by cloud cells.

At 1219 hr UTC (Fig. 8), in the PCAPPI_Z_250 km image a closed eye could be seen at 130 km S-SW of radar site. The spiral bands were still embedded in cloud mass and were not seen distinctly.

The diameter of eye was around 20 to 25 km. The eye was not clear as some low altitude weak echo cells were present inside the eye region giving it a dumble shape. The maximum reflectivity (43.7 to 49.9 dBZ) was seen, both on the northeast and southwest sectors of the storm centre and reflectivity was little higher on the southwest sectors *i.e.,* on left quadrant of the eye wall region.

The velocity image PCAPPI_V_250 km of 1219 hr UTC (Fig. 9) of 12th November 2002 showed that the maximum radial wind velocity was between 44 & 52 m/s on the right quadrant close to the storm centre. The approaching wind data as per convention was indicated with darker shades and the receding wind data was shown by lighter shades on the velocity images. The maximum velocity of receding wind was between 12 & 20 m/s and was located on the left quadrant little away from the storm centre. There was no instance of velocity folding as the volume scanning was done with dual PRF ratio capable of measuring maximum unambiguous radial velocity of +/- 60 m/s upto a range of 250 km. The radial wind velocity data has been generated by the radar using pulse pair processing technique.

The PCAPPI_Z_250 km image of 1319 hr UTC (Fig. 11) showed the cyclone approaching landfall near Sagar Islands of West Bengal coast. The eye was centred at Lat. 21.7° and Long. 88.3° at a distance of 95 km & azimuth 182° from radar. The maximum reflectivity seen was between 46.8 & 49.9 dBZ. The intervening PCAPPI_Z image of 1249 hr UTC (Fig. 10) had shown a clear eye at a distance of 116 km & azimuth 192.5° from radar. Most of the rain cloud area lay in the right front quadrant of the cyclone. The PCAPPI_V_250 km image of 1319 hr UTC (Fig. 13) near the time of landfall

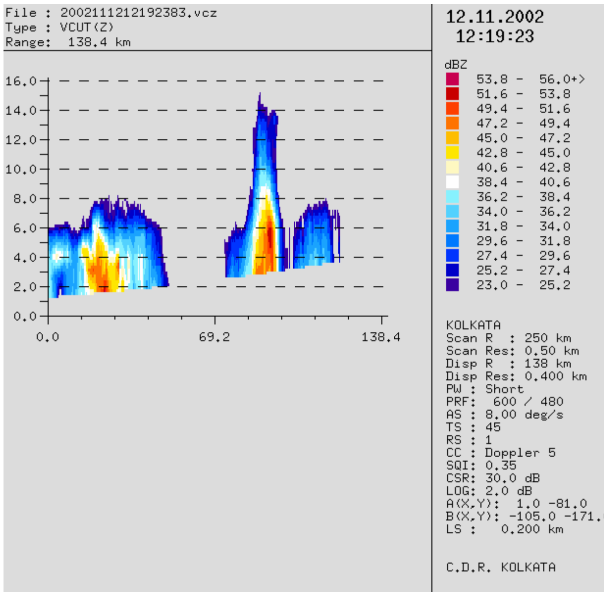

Fig. 15. Vertical cut image of reflectivity with display range of 138 km

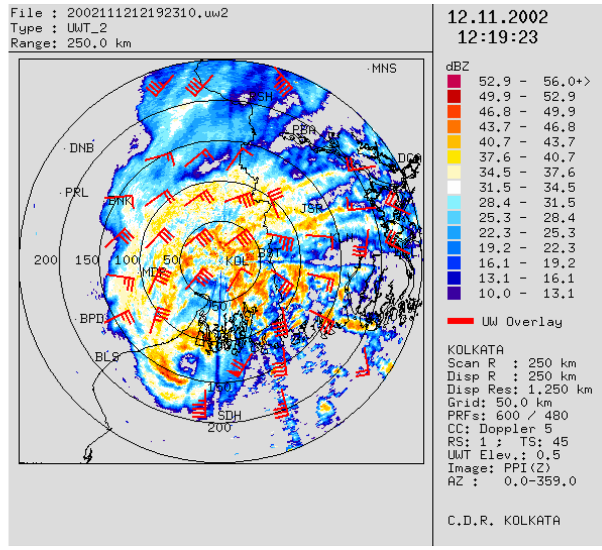

Fig. 16. Horizontal wind velocity image with PPI (Z) underlay range 250 km

indicated that the maximum velocity of incoming wind near the eye wall region to be between 28 & 36 m/s. The intervening PCAPPI_V image for 1249 hr UTC (Fig. 12) had earlier shown a maximum velocity in the range of 36 to 44 m/s. Therefore the wind velocity was falling gradually and at the time of landfall it had fallen considerably in comparison to the value of 44 to 52 m/s prevailing an hour earlier. This maximum wind parameter will be useful in estimating the storm surge level at the time of landfall.

In order to see the height of the clouds, a MAX_Z_250 km image (Fig. 14) was generated. The MAX_Z product takes a polar volume raw data set of reflectivity as input converts it to a Cartesian volume and generates three partial images and combines them to form the final displayed image. These three partial images are :

(*i*) A top view of the highest measured values of reflectivity in *Z*- direction. This PPI type image shows the highest measured value of reflectivity for each vertical column, seen from the top of the Cartesian volume. The shade of each pixel represents the highest value of reflectivity in dBZ as indicated in the legend of the image. The height of the vertical column has been selected as 16 km and the displayed range is 250 km.

(*ii*) A north-south view of the highest measured values of reflectivity in *Y*-direction. This image is appended above the top view and shows the highest measured value of reflectivity for each horizontal line seen from north to south. In this image the height of cloud cells and corresponding dBZ values can be seen. However cells located on same vertical axis (as seen on top view image) cannot be isolated as they get superimposed. One has to refer to east-west partial image for viewing them separately.

(*iii*) An east - west view of the highest measured values of reflectivity in *X*-direction. This image is appended to the right of the top view and shows the highest measured value of reflectivity for each horizontal line seen from east to west. In this image the height of the cloud cells along with reflectivity values in dBZ can be seen. However cells located on same horizontal axis cannot be isolated in this image as they get superimposed. One has to refer to the north-south partial image for viewing them separately.

The MAX_Z image showed eye of the cyclone as a region filled with some weak cloud echoes and not a totally cloud free region. In general the cloud echo heights were between 8 & 10 km, however near the outer eye wall region it was around 8 to 14 km. The rear eye wall region clouds were taller.

In order to see the shape of eye wall, a VCUT (vertical cut) image was generated from the MAX_Z_250 image of 1219 hr UTC (Fig. 14). The VCUT image (Fig. 15) indicated that the eye walls were of vertical nature with a little tilt on to left side *i.e.*, towards the approaching coast. The diameter of the eye was around 25 km. The maximum reflectivity value seen on eye wall regions was between 46.8 & 49.9 dBZ.

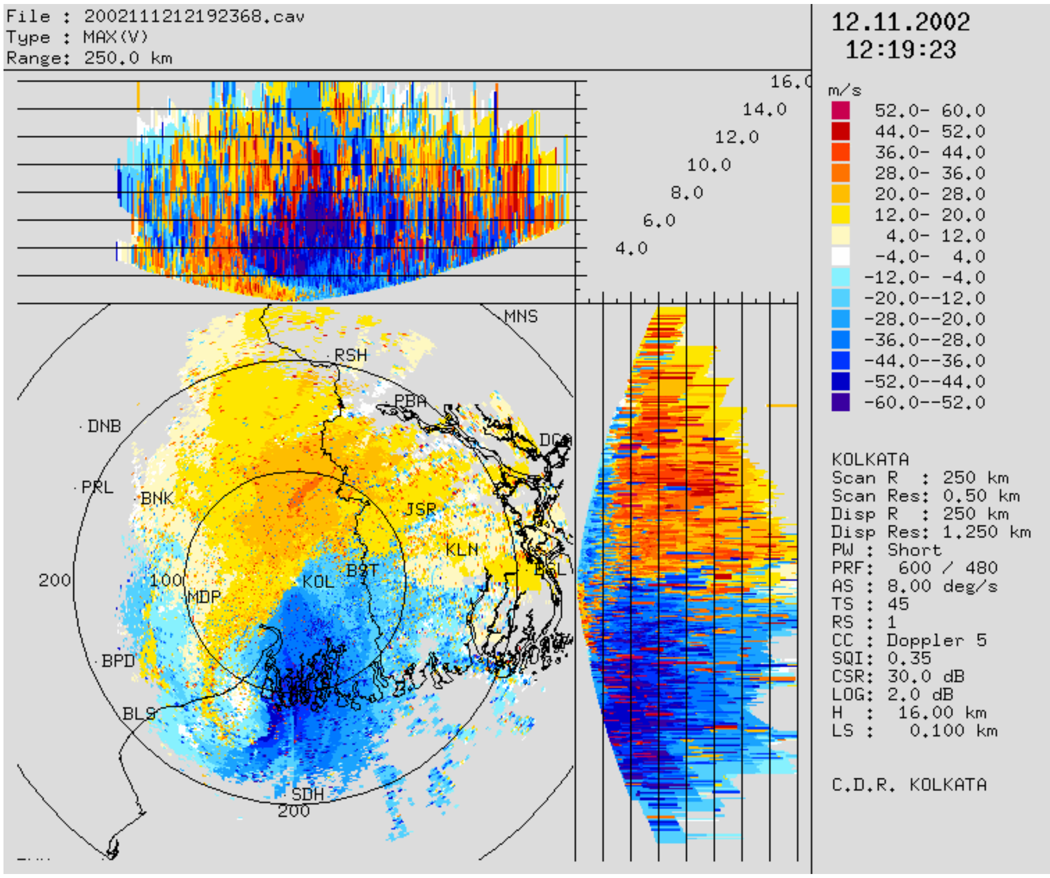

Fig. 17. Maximum velocity image

Using the Uniform Wind Technique (UWT), wherein the radar generates the UWT_2_250 km image. Here in this image the horizontal wind vectors, calculated from polar radial velocity data using Velocity Azimuth Display (VAD) like regression and are displayed with PPI_Z product as underlay. The horizontal wind is shown with wind barbs indicating the wind direction and speed in knots. The wind velocity and direction is derived for same altitude corresponding to the height defined by the range & elevation angle of underlay PPI product. In this image elevation angle of PPI _Z product has been selected as 0.5°. The UWT_2_250 km image of 1219 hr UTC (Fig. 16), 12th November 2002 indicated the general cyclonic wind circulation pattern over Bay and land. The incoming horizontal wind over Bay was between 45 & 70 knots near the storm centre and over the land the average horizontal wind velocity varied from 20 to 40 knots.

5. Results and discussions

It was observed that the eye configuration of the storm was changing continuously with respect to its shape and size. It was further noticed that at 1219 hr UTC the shape of the eye became dumble shaped as seen with 10 dBZ threshold value on PCAPPI_Z_250 km image (Fig. 8). The 10 dBZ threshold value was the normal default setting of the radar. However during offline processing of the archived data of the storm for 500 km range images, the threshold value was set to 22 dBZ for achieving better clarity of spiral band and eye of the storm. It was observed that in most of the cases clear eye could be observed when the storm was within the range of radar as weak returns around the storm centre were eliminated. The spiral bands though visible but could not be identified individually as they were still embedded in the cloud mass of the cyclone. The average height of the cloud cells were of 8 km, however some cloud cells could be seen upto a height of 10 to 14 km.

The storm was asymmetrical both with respect to reflectivity and radial wind velocity. It was also observed that wind convergence on the front right quadrant was more and close to the centre of storm as compared to the left front quadrant of the storm. This aspect is clearly

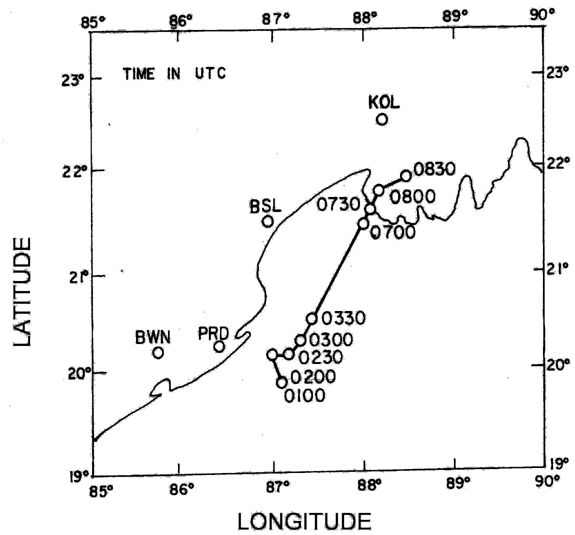

Fig. 18. Track of cyclonic storm based on DWR, Kolkata observations, 12 November 2002

observed in the maximum velocity image MAX_V (Fig. 17) and also in the PCAPPI_V image (Fig. 9). In the right quadrant the highest radial wind velocity measured was 44 to 52 m/s when the storm was over the sea. Whereas in the left quadrant the receding wind was of the value 12 to 20 m/s and was located away from the storm centre. The maximum reflectivity was observed both on the northeast and southwest sectors of the storm and the height of the rear eye wall cloud echo (southwest) was taller than the front (northeast) eye wall cloud echo as seen from the VCUT image of 1219 hr UTC (Fig. 15), which appeared to be unusual for the storm.

Tropical cyclone's intensity and its movement are two important elements for any weather forecasting. An important theoretical concept of tropical cyclone motion is the steering principle, which states that small scale tropical cyclones tend to follow the large scale currents in which they are embedded. Because of the fact that tropical cyclone movement is sensitive to the large scale flow which is not sensed by DWR. Hence, there is always some uncertainty in the prediction of the movement of the tropical cyclone. Since DWR is an equipment/instrument which gives *in-situ* status of cyclonic storm by measuring the radial velocity around centre of storm and mapping the wind field pattern and reflectivity which could be used to issue forecast for warning using knowledge of the atmospheric physics. In the past forecast for cyclone movement and its intensification were solely based on radar reflectivity and spiral pattern. So far radar based cyclone warning is concerned, DWR provides additional information on radial velocity and its derived product. In the case cyclone of 12th November 2002, it was found that zone of convergence with high wind gradient on right front quadrant gives fair prediction of storm movement which was in the north-east direction with respect to cyclone centre. Radar track of cyclone is depicted in Fig. 18.

It is well known that tropical cyclones have tendency to move towards the region of high isallobars. Also, it is known that rainfall is maximum in the region where maximum vorticity occurs, *i.e.*, zone of convergence. Air being continuum, hence, strong convergence of wind for the asymmetric storm under study in right quadrant will push the air up causing more rainfall as indicated by maximum reflectivity in this case. Further, due to this release of more latent heat will push cyclone to move in the direction where strong convergence zone with high wind gradient exists. Similar result was observed for the case of 12 November 2002 cyclonic storm of Bay of Bengal crossing near Sagar Island. Anthes (1982) stated that as the air pulled closer to storm centre by the strong radial pressure gradient, its rotational velocity increases rapidly. This increase is a consequence of the partial angular momentum. As the radial and tangential wind speeds increase so does the magnitude of the low level moisture convergence and rainfall. That is indicative of intensity. From DWR Kolkata, it was possible to identify weakening of cyclone intensity in term of wind speeds as indicated over a series of observations, of shorter interval and in an objective manner.

6. Conclusions

(*i*) This is the first study of cyclonic storm over Bay of Bengal using Doppler Weather Radar.

(*ii*) The reflectivity images of cyclonic storm displayed neither the typical spiral bands nor a well developed tall eye walls generally associated with cyclones. It was observed that for this storm the threshold settings of 22 dBZ for reflectivity images gave a better fixing of the storm centre as eye became more prominent due to elimination of nearby weak cells. However it was still not possible to identify individual spiral bands. The eye configuration with regard to shape and size was changing continuously during the movement of the storm over the Bay.

(*iii*) The cyclonic storm of 12th November 2002 was having a small core with a radial wind velocity of 44 to 52 m/s which could be detected with the Doppler radar. However the radial wind velocity value decreased to 28 to 36 m/s at the time of landfall. From the velocity images it was seen that the convergence was more on the right front sector of the storm with four consecutive velocity gradient arcs spanning radial wind values from 52 - 44 m/s, 44 - 36 m/s, 36 - 28 m/s and 28 - 20 m/s respectively. This was indicative of the direction in which the storm was moving (Figs. 1 and 18).

(*iv*) In general cyclonic storm moves with an average speed of 20 to 25 km/hr. On comparing PCAPPI_Z_ 250 km images of 1219 hr UTC (Fig. 8) and 1319 hr UTC (Fig. 11), the estimated speed of the storm was of the order of 40 to 45 km/hr, during the above period which was considerably higher. From track of the cyclone as observed in DWR (Fig. 18), these values were calculated and verified.

(*v*) The intensity of cyclonic storm so long it was over the sea was found to be more severe and it weakened gradually before the landfall.

Acknowledgements

The authors are thankful to Dr. R. R. Kelkar, DGM, for his constant encouragement to carryout this study.

References

Anthes, R. A., 1982, "Tropical Cyclones - their evolution, structure effects", Meteorological Monographs, **19**, 41, *American Meteorological Society*.

Bhattacharjee, P. and De, A. C., 1965, "Radar study of the cyclonic storm of 21 September 1962 in the Bay of Bengal", *Indian J. Met. & Geophys.*, **16**, 1, 81-84.

Raghavan, S., 1977, "Structure of an immature cyclonic storm in the Bay of Bengal as revealed by radar", *Indian J. Met. Hydrol. & Geophys.*, **28**, 2, 223-232.