

Radar Observation of Tropical Cyclones

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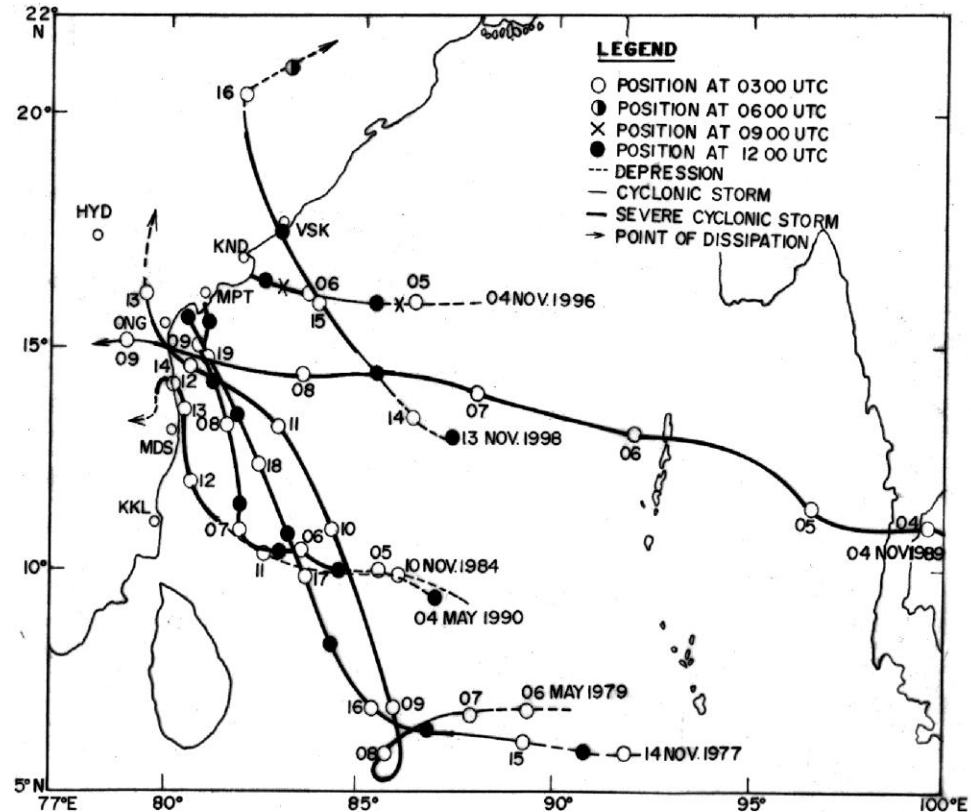
Presentation at DRaWS-2010, Chennai, 18-19 March 2010

Review of past work and projection of future prospects.

- Unlike the contributed papers at this session which may be reporting original work, I am presenting
- 1. a brief review on what has been done in the IMD so far on Observation and Study of Tropical Cyclones by radar.
- 2. the future prospects in India in this field.
- The references cited are listed in the last four slides for those who may wish to refer to them.
- I shall welcome a discussion at the end.

Why are Tropical Cyclones Important?

- Next to earthquakes tropical cyclones (TCs) are probably the most important natural hazards.
- With increasing development of coastal areas the **IMPACT** of TCs is increasing.



Typical tracks of severe cyclones hitting one state – Andhra Pradesh (From Raghavan and Rajesh, 2003)

Why are Tropical Cyclones Important? 2

- TCs are of **scientific** interest by themselves
 1. Their characteristic structure and dynamics
 2. Their role in the transfer of heat and momentum influencing the global circulation
 3. **TCs influence climate (and vice versa)**
 - a. There is *speculation* that “climate change” may lead to increase in intensity and frequency of cyclones.
 - b. El Niño has been linked to TC activity – not the same in all Basins
 - c. *Speculation* that TCs influence Climate. In the Pliocene era (5 to 3 million years ago) TC activity was part of a positive feedback mechanism that maintained permanent El Niño like conditions in the equatorial Pacific. (Fedorov et al., 2010).

IMD's Social initiative

- Around 1969 IMD took a new initiative on Outreach and Collaboration with the Public and the Disaster Management Community to try to mitigate Tropical Cyclone disasters besides its traditional role of Observation, Forecasting and Warning.
- As part of this initiative, establishment of ten S-band (10 cm wavelength) radars along the coasts was implemented in the next decade or so. Only this is relevant for the present talk.
- Radars involve heavy initial and recurring investment for maintenance, calibration, periodical upgradation, or replacement and induction of new technology and procedures.
- The benefit to Society especially in the area of TC warnings more than justifies the investment. **The greatest contribution of radars in India has been in TC tracking and forecasting.**
- Experience of 1972

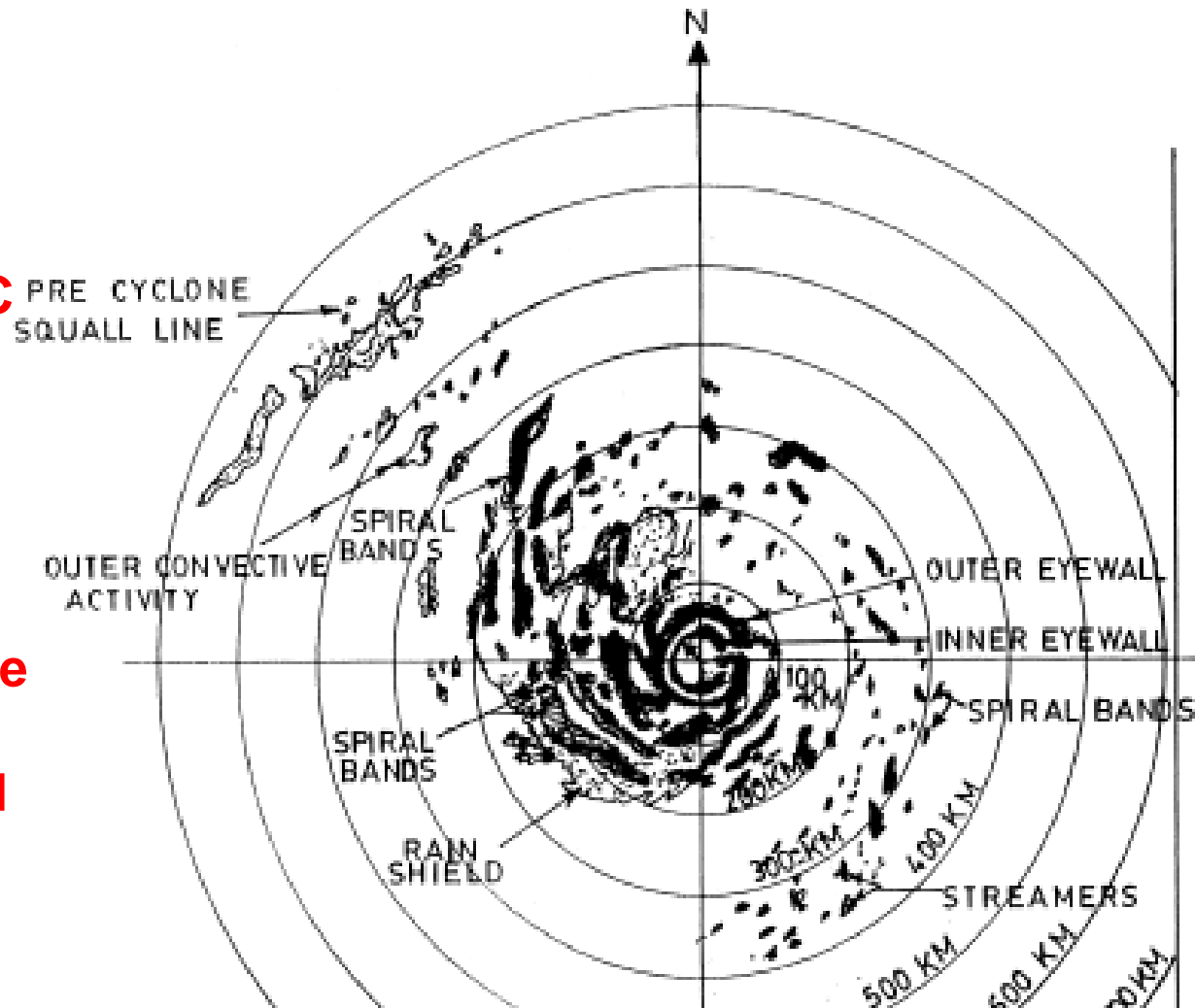
The tropical cyclone (TC) is particularly suited for observation and study by microwave radar.

Because of the spatial and temporal scale of the TC and the organised pattern of precipitation in it

First published (airborne) radar observation of a TC by Maynard (1945) of the US Navy.

Henry Piddington (1848) in India, formulated the concept of TC coiled up like a serpent. Coined the term "cyclone", spiral structure observed by radar (Simpson 1956).

Typical horizontal structure of a well-developed TC obtained by compositing radar echoes from a number of cyclones in the Bay of Bengal (Raghavan 1985) ↓



Radar - main tool for tracking of TC's

- Initially, only twice-a-day imagery from polar orbiting satellites of the USA was available for TC monitoring. From 1983 India has its own geostationary satellites continuously monitoring the region.
- Radars were the principal tools for operational tracking of TC's in the seventies and early eighties when relatively few satellite products were available.
- Radars in India up to year 2000 were analog radars giving “reflectivity factor” only as output,
- **Emphasis on finding techniques useful in the operational context**
 - cyclone position determination,
 - track prediction,
 - intensity determination,
 - mapping of rainfall distribution
 - storm surge prediction.
- Combined use of satellite and radar information has given good results leading to further improvement in TC forecasts and warnings.

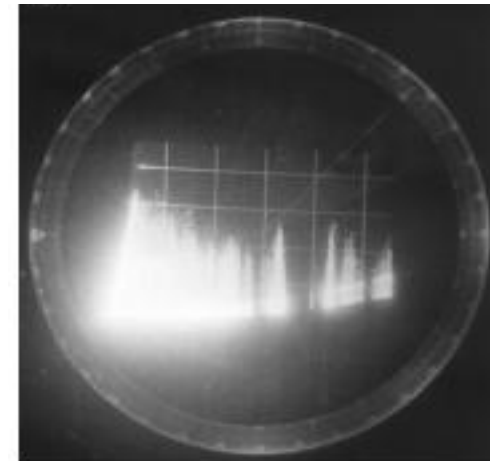
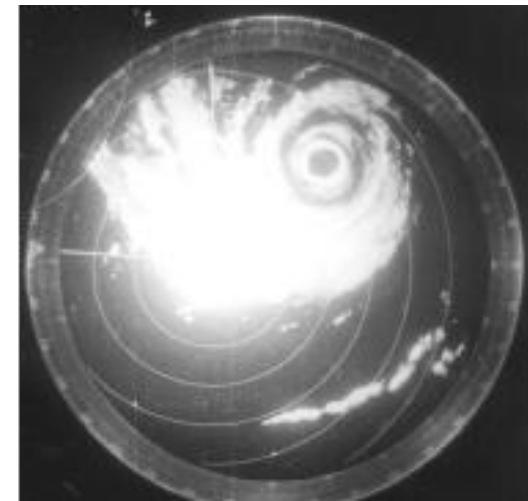
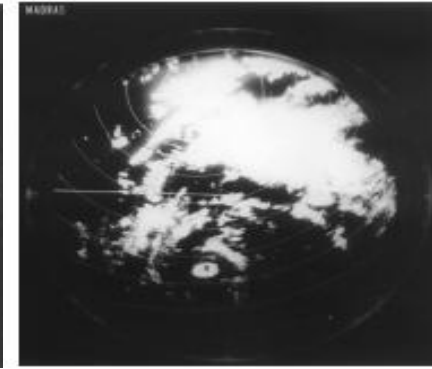
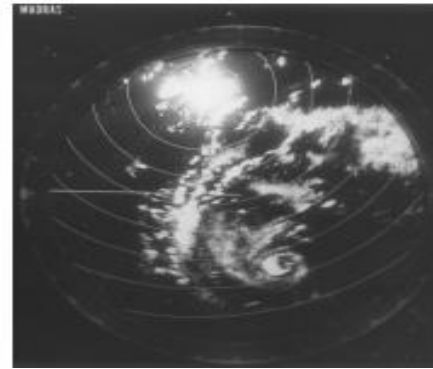
Considerable knowledge of TC evolution and behaviour and rainfall distribution and **Understanding of the core structure of TC's** has been obtained

Studies on

- Process of eyewall formation,
- changes in shape and size of eyewalls,
- their vertical and horizontal structure,
- eye geometry
- Double eyewalls
- asymmetries

Handicapped by non-availability of aircraft and other observations.

Relationships between the radar-observed features and intensification, weakening, changes of track and damage swaths of the TC and rainfall distribution in TCs have been studied. (Summary in Raghavan 1997, 2003)



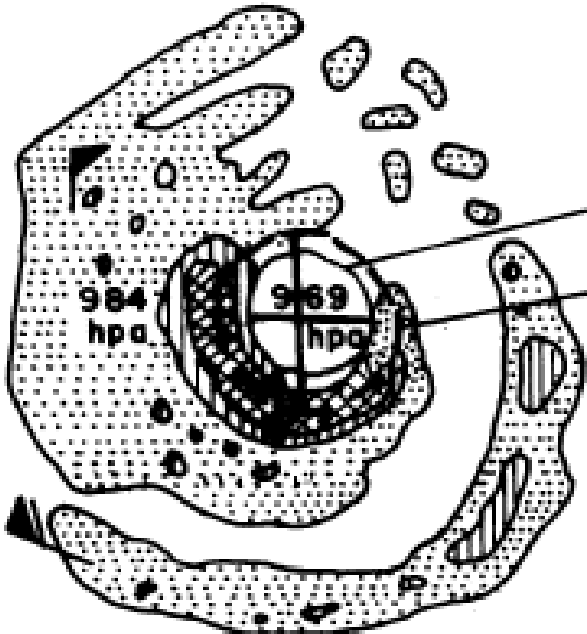
Concept of Radius of Maximum Reflectivity (RMR)

[Raghavan et al. (1989)] introduced operationally.

In the absence of Doppler capability RMR used as proxy for Radius of Maximum Winds (RMW) to compute Maximum Storm Surge and help assess intensity of TC

Other inputs of Radar to storm surge prediction a

- 1. Maximum Wind Velocity
- 2. Expected point and time of landfall, angle of track



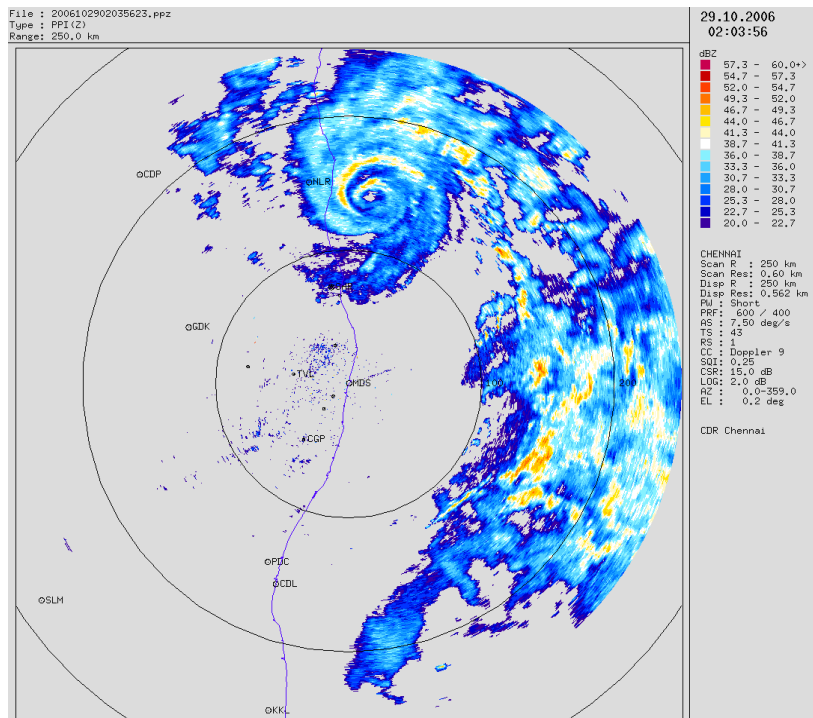
EYE
RING OF MAXIMUM REFLECTIVITY
RADIUS \sim 15 Km

Cross-hatched area reflectivity is 42 dBZ or more, vertical hatching 37 dBZ and stippled area 32 dBZ.

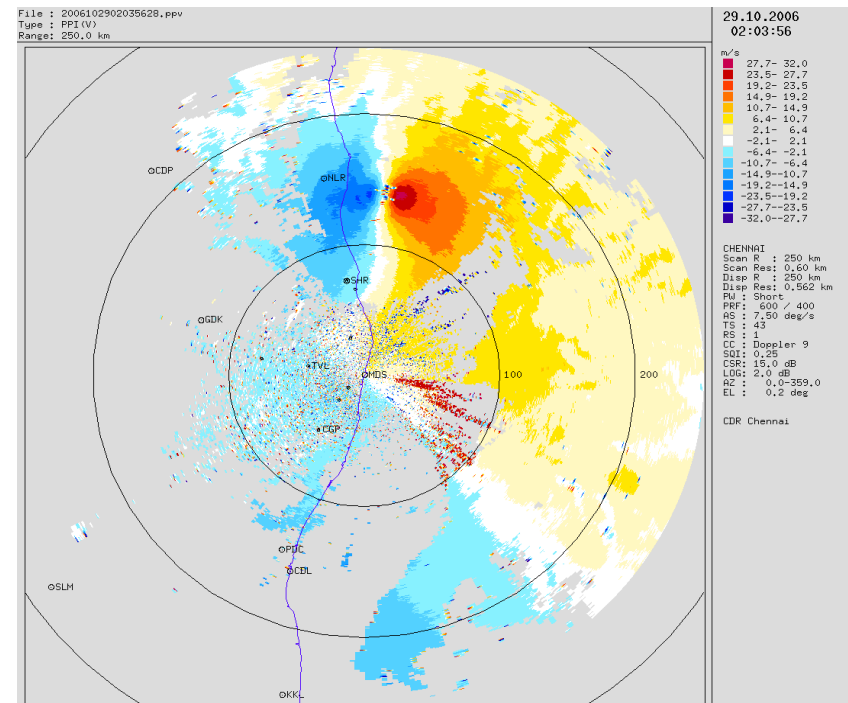
Radius of Maximum reflectivity coincides roughly with the Radius of Maximum Winds (RMW) [Jorgensen (1984), Marks and Houze (1987), Tabata et al. (1992), Raghavan and Veeraraghavan (1979) and Raghavan et al. (1984)]

DIGITAL DOPPLER RADAR - TC OGNI 2006

- With the introduction of digital Doppler radars with several derived output products, mapping winds in the core region and thereby a **direct estimate of TC intensity** is possible. This will also improve storm surge prediction.

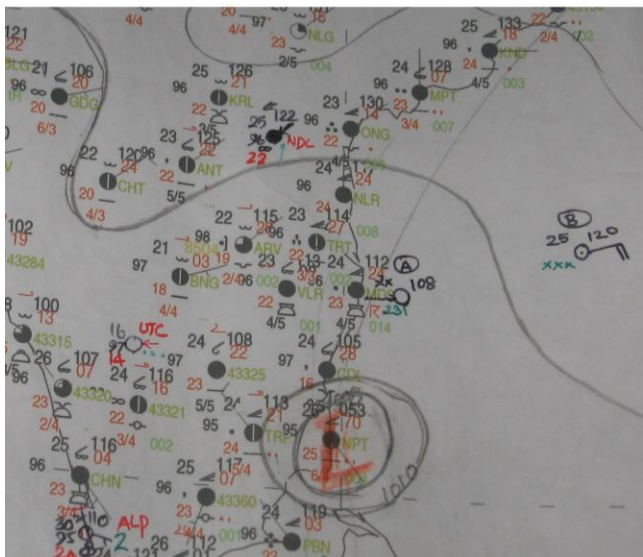


Reflectivity 02 UTC 29-10-06



Radial Velocity

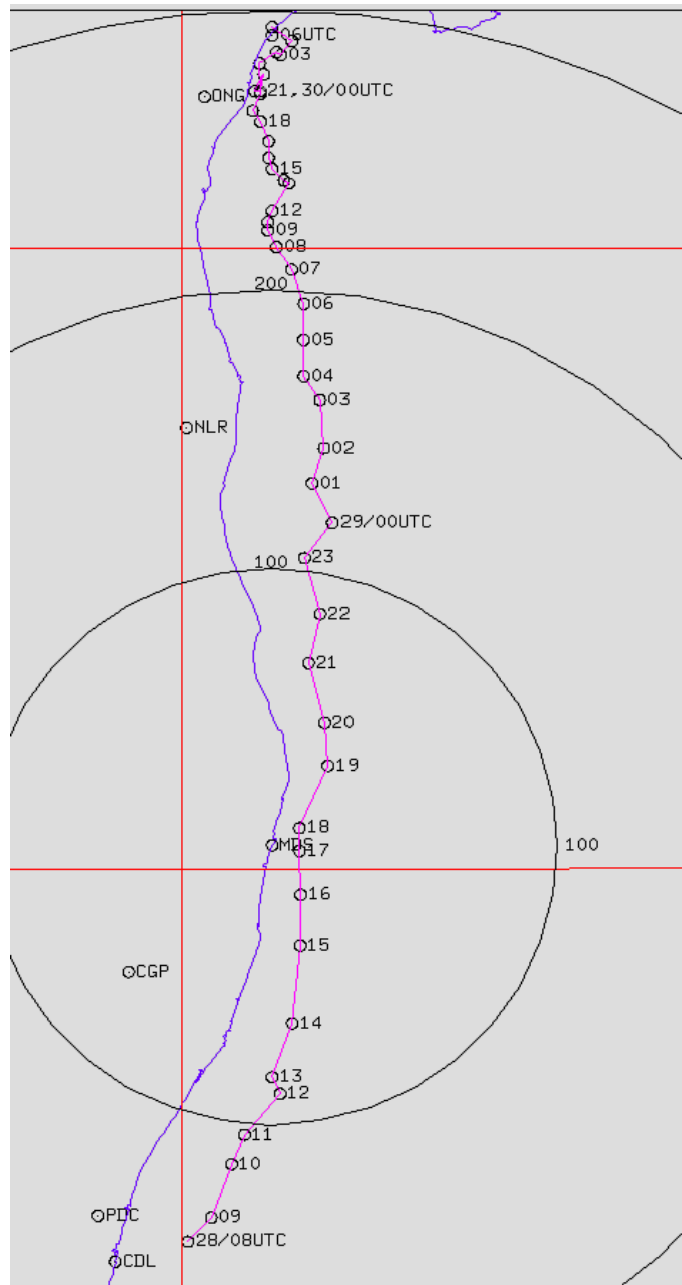
TC OGNI 2006 - contd.



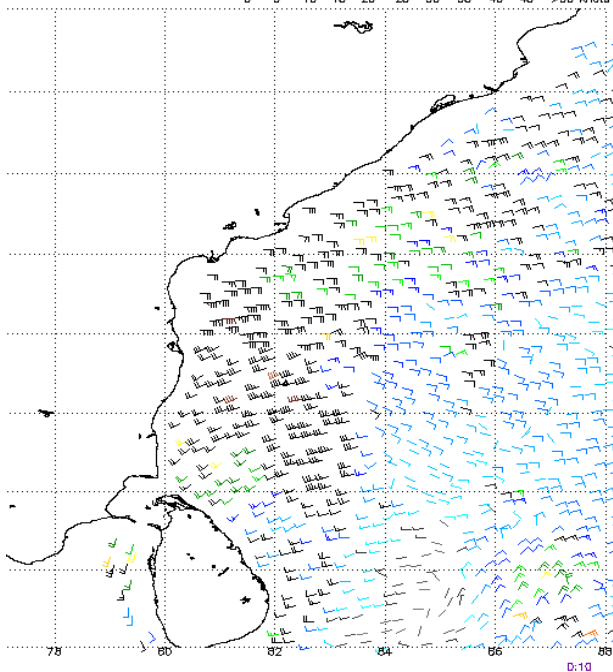
Surface chart 28 October (03Z)



Track (Thampi et al. 2007)



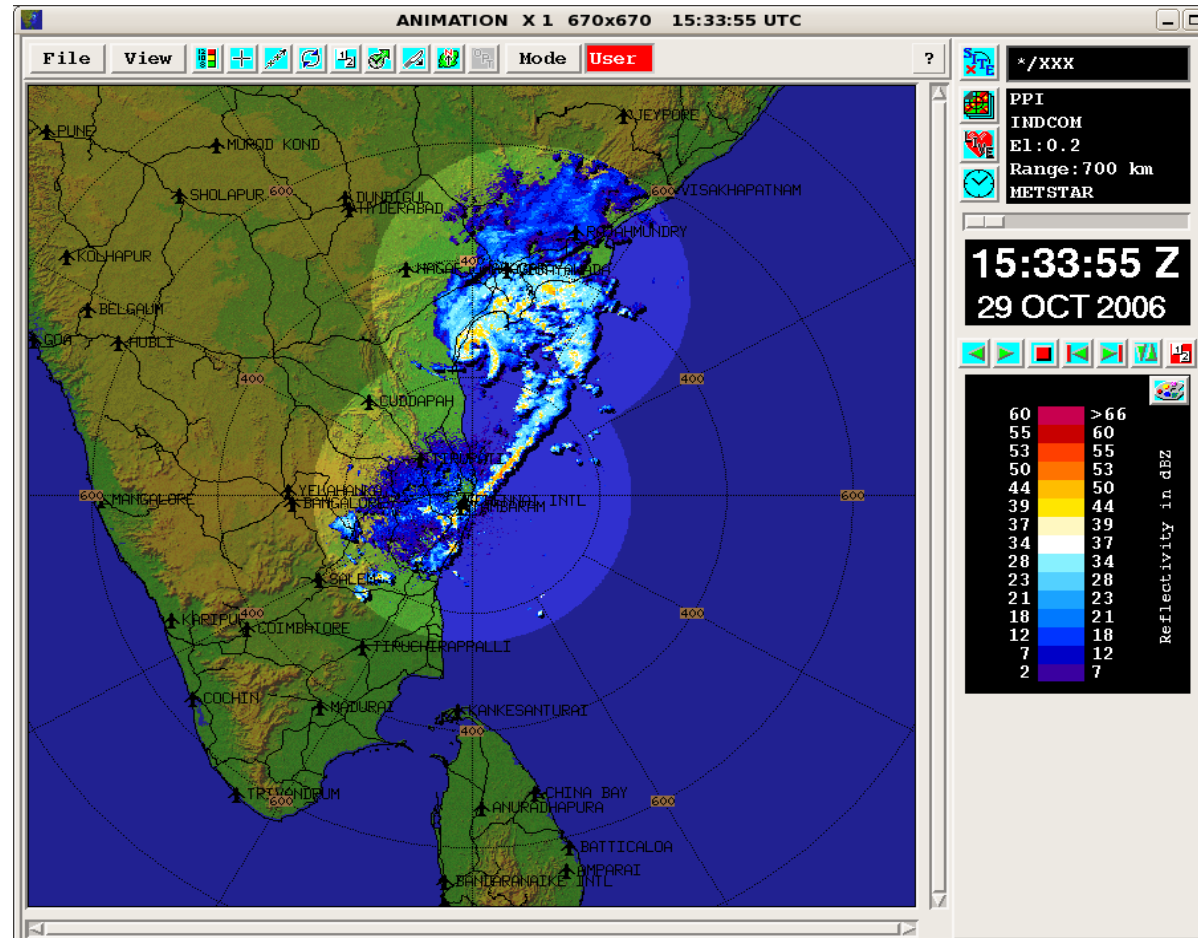
07:42 UTC 2006 ascending



Qscat picture
←29 October
does not show a
vortex
though a shear
is shown
prominently

Integrating inputs from multiple sources.

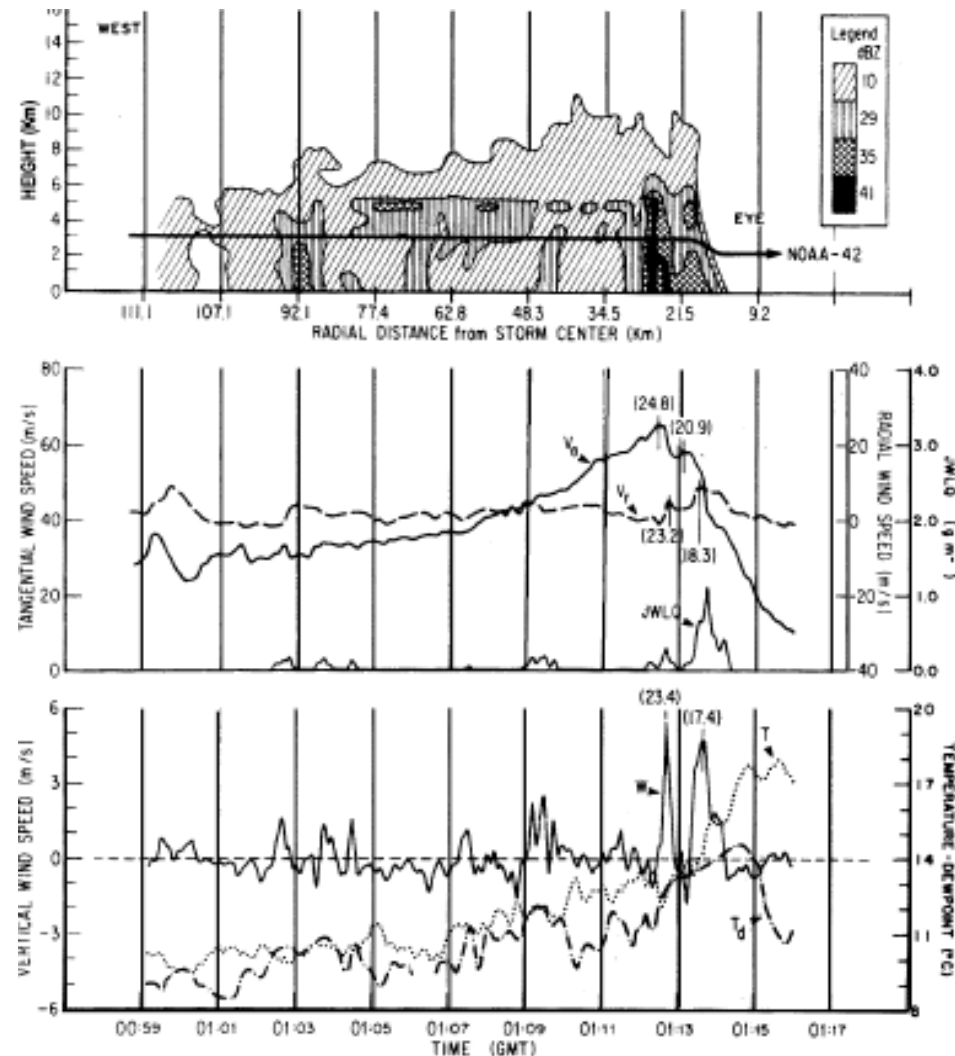
- We have seen cases before of TCs appearing on the Radar scope without being detected earlier by satellite or synoptic charts.
- This shows the capability of the radar. At the same time it points to the need of integrating inputs from multiple sources, the first step being the **networking** of radars.
- Digital technology enables this as well as processing of data to yield many more outputs



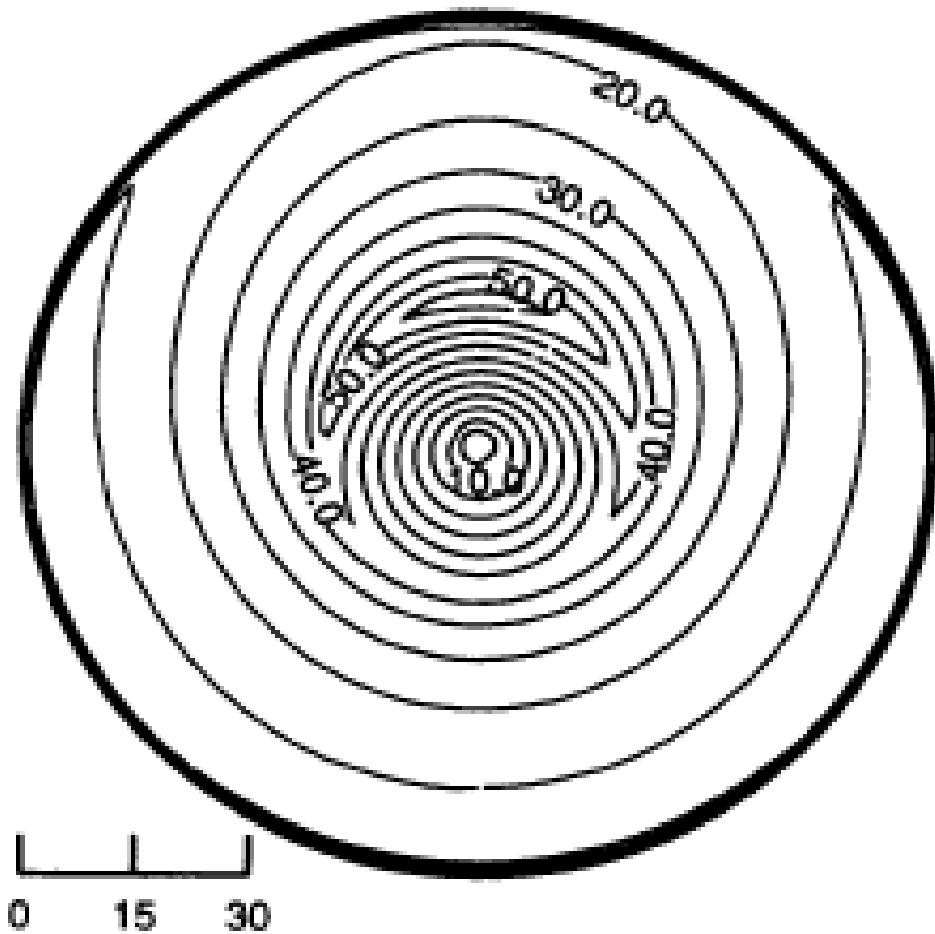
Composite image of Reflectivity of TC OGNI from Chennai and Machilipatnam radars.
(Figure: Courtesy Mr. S.B. Thampi)

Airborne Radar

To digress a little, much of the knowledge of TC structure has come from **airborne** radar. IMD's plans to have aircraft reconnaissance of TCs has so far not materialised. I should particularly mention the **Velocity-Track Display (VTD;** Carbone and Marks 1989, Lee et al. 1994) algorithm which decomposes, by harmonic analysis, Doppler velocities on cylindrical rings into tangential, radial and mean cross-track components of the wind velocity.



A Ground-Based version of Velocity Track Display (GBVTD) [Lee et al. (1993, 1999, 2000), Lee and Marks (2000)] maps winds around circles centred on the TC centre with a radar located away from the circle.



← The GBVTD-retrieved tangential winds for a vortex. (from Lee et al. 1999; courtesy AMS).

Tested on a real TC. technique can be used even when the radar does not directly see points of maximum velocity in the vortex.

Multi-radar and multi-sensor integration

- The Warning Decision Support System–Integrated Information (WDSS-II) developed at the US National Severe Storm Laboratory (Lakshmanan et al., 2007) is a system of tools for the analysis, diagnosis, and visualization of remotely sensed weather data.
- WDSS-II provides a number of automated algorithms that operate on data from **multiple radars** to provide information with a high temporal resolution and better spatial coverage.
- With our new 55 Doppler radar network IMD is in a position to plan networking all the radars and integrate them with other data and present composite realtime displays for short-period forecasting (not only for TCs but for thunderstorm nowcasting, aviation and hydrology).

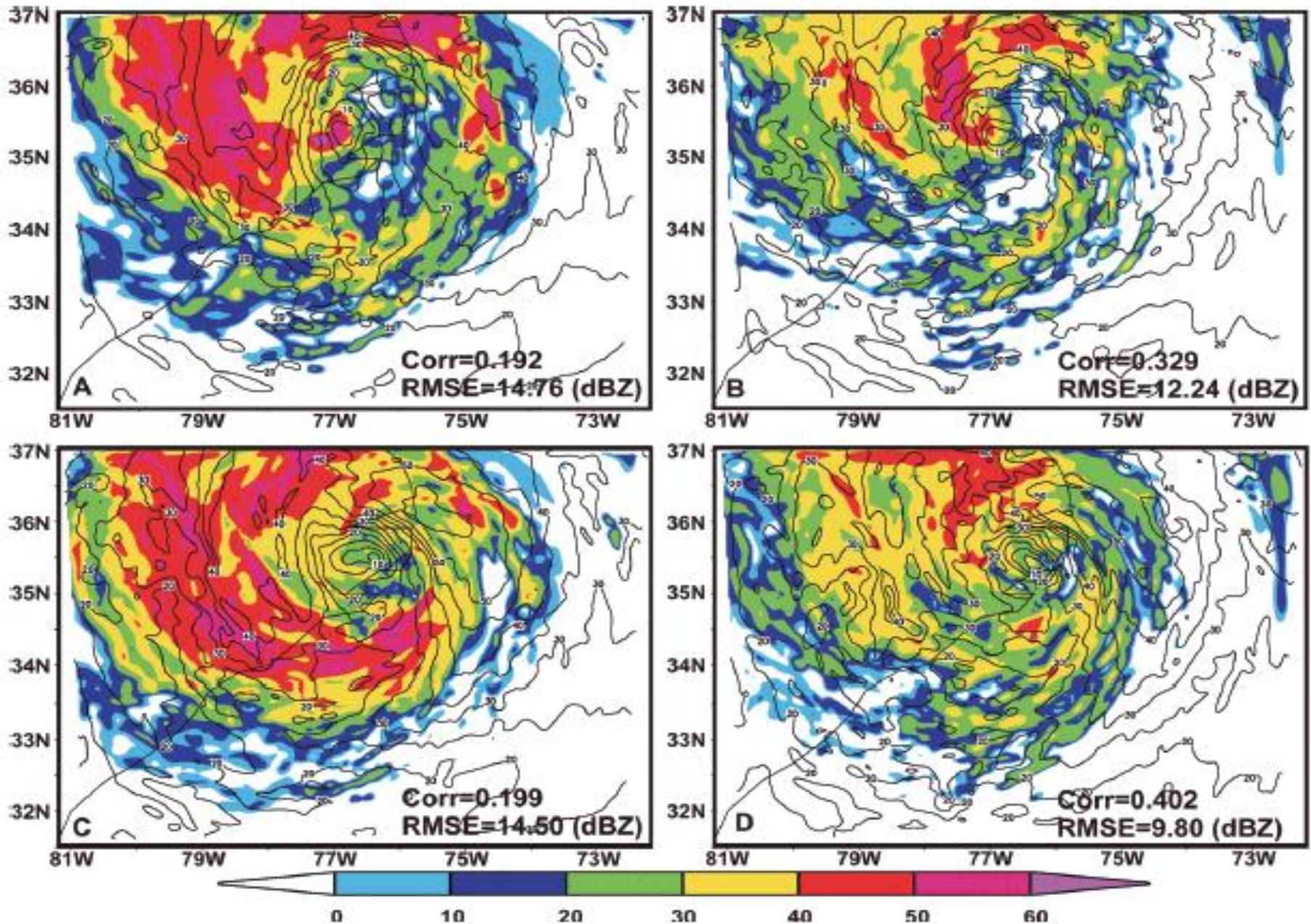
Numerical models

- **The most important recent advance is the direct assimilation of Doppler radar data in numerical models which has been taken up by several institutions in India.**
- It has been demonstrated (Zhao and Jin, 2008) in the Atlantic hurricane Isabel (2004) that **assimilation of reflectivity factor and Doppler radial velocity** from 5 radars into a mesoscale Numerical Weather Prediction (NWP) model [US Navy's Coupled Ocean–Atmosphere Mesoscale Prediction System (COAMPS)] improves TC intensity and structure analyses and forecasts significantly.

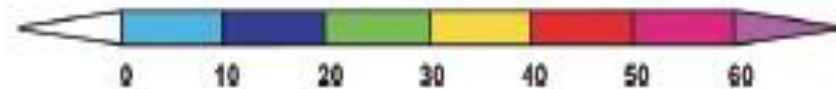
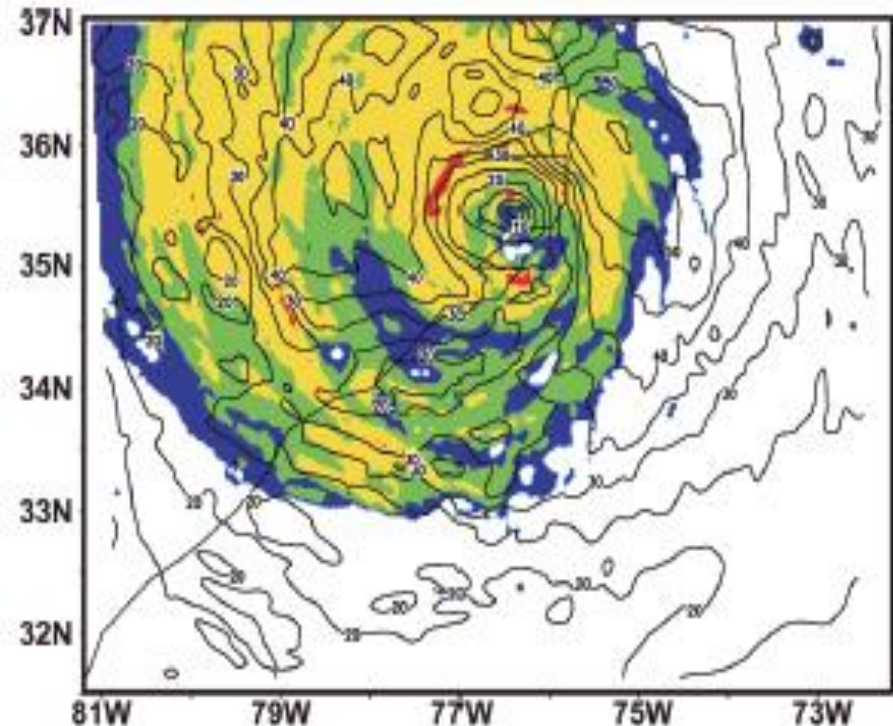
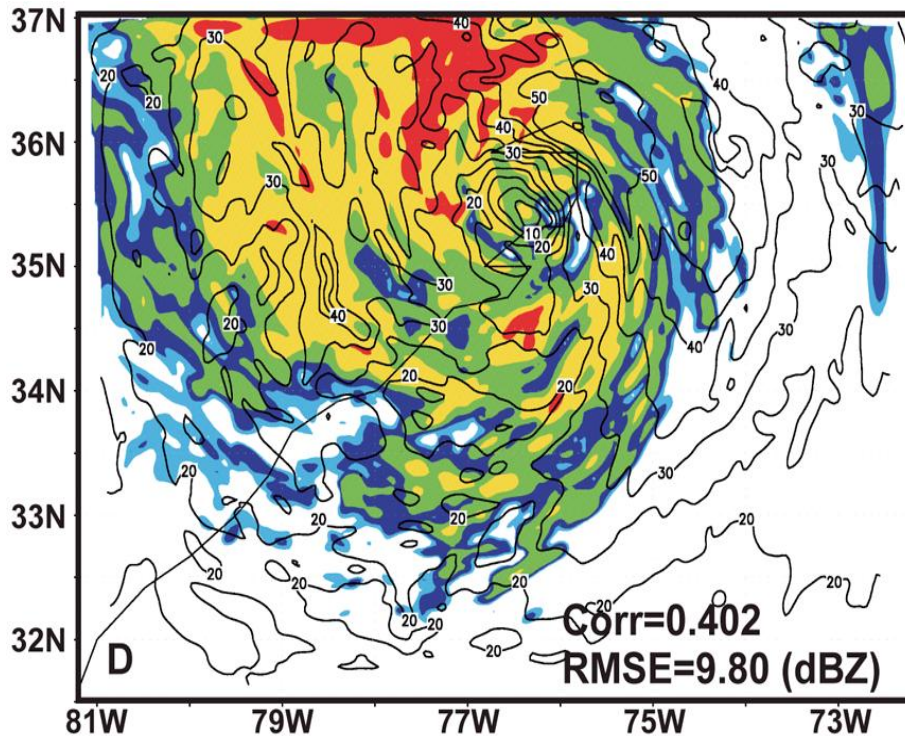
Next slide shows

- Composite reflectivity (dBZ, shaded) and horizontal wind speed (m s^{-1} , contoured at 5 m s^{-1} intervals) at 2 km above the surface, from the model forecasts at 2 h after the data assimilation (valid for 1800 UTC) from (a) Control, (b) Z assimilation, (c) V_r assimilation, and (d) Z and V_r assimilation. The hurricane symbol indicates the approximate location of the observed hurricane centre. Corr and rmse of composite reflectivity forecasts verified against the observations (shown in the slide after that) are also calculated and shown for each experiment. (Slides Courtesy American Meteorological Society)

Radar data assimilation in Hurricane Isabel



Hurricane Isabel - Verification



Left: Z and Vr assimilation repeated from last slide Right: Observed composite reflectivity (dBZ, shaded) at 1800 UTC and retrieved horizontal wind speed (m s^{-1} , contoured at 5 m s^{-1} intervals) retrieved from the radar observations at 2 km above the surface.

Technology and calibration issues

- The development of an Indian-designed Doppler radar has led to insights in technology and many of the future radars are expected to be Indian.
- The development of the Indian MST radar in the 1980's and the ongoing development of UHF wind profilers, may also be expected to contribute to greater understanding of TC structure and behaviour. Profilers can be used for calibration of Radars.
- Since there will be large network of radars of IMD and other Agencies, there is a proposal to set up a **National Weather Radar Operation Centre (NWROC)**. This will be a national agency with sufficient knowledge base on weather radars and wind-profilers specific to network planning, operation, maintenance, upgradation, software development, calibration, validation and induction of new technologies.

Future Technologies

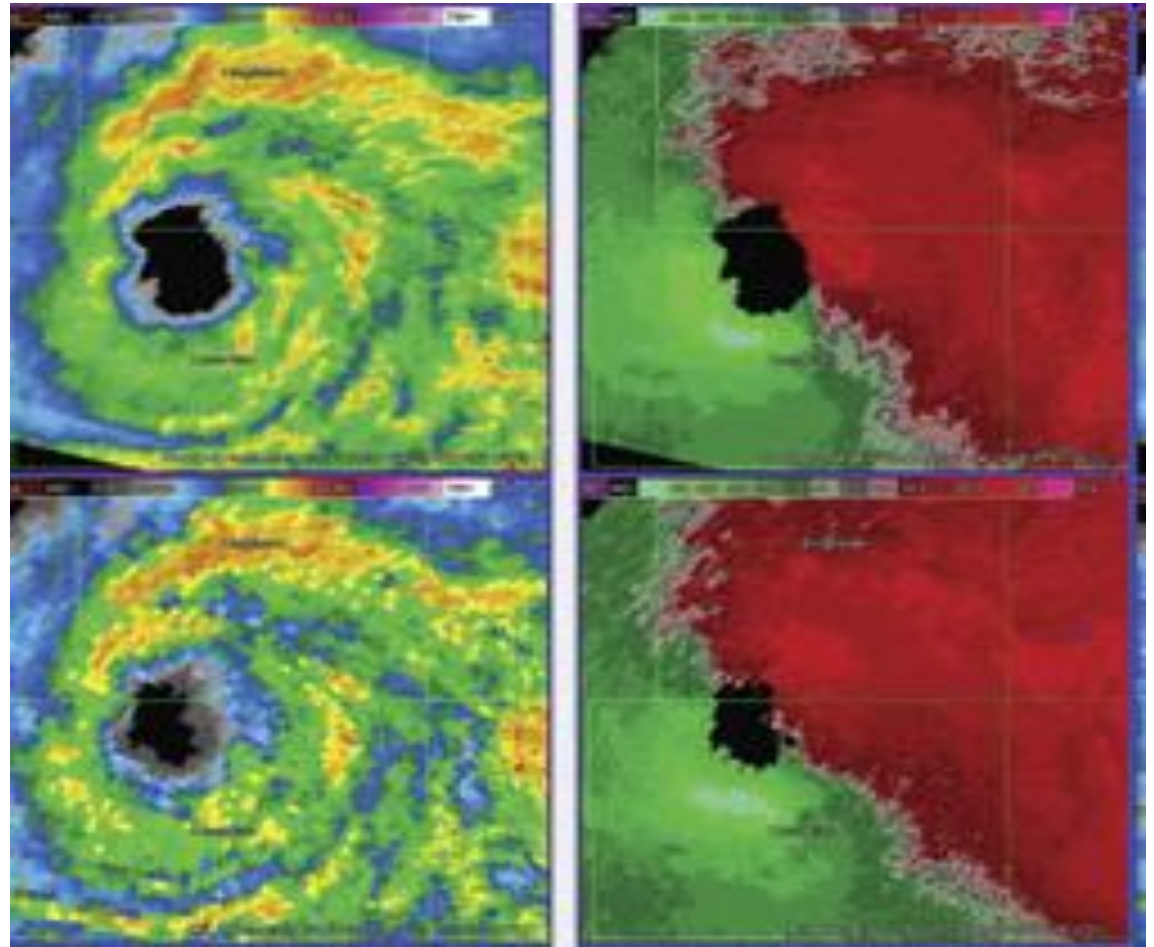
- The near-term plan of the IMD is to have **polarimetric** capability which will enhance the accuracy of rainfall-mapping besides a better understanding of the structure and physics of the TC.
- While the S-band radars perform well over the sea, the addition in future of **a denser network of higher frequency radars** (such as CASA) will help to observe land-falling systems better and detect and document **tornadoes** developing in the TC on landfall. So far there is no documentation of tornadoes in cyclones in India though we have observed other landfall effects such as reintensification after landfall.
- The introduction of **mobile** radars (for which an initiative has been taken) which can be moved to the expected area of landfall and the proposed plan for **radar-equipped aircraft reconnaissance** will greatly expand forecasting and warning capabilities.

Phased Array Radar

The deployment of phased array radars (PAR) at a later stage may make the radars more versatile in continuous monitoring of tropical cyclones as very fast scan speeds and targeted observations (to locate the most severe weather) will be possible.

A Tropical Storm Erin re-intensified over land in Oklahoma near the National Weather Radar Testbed

T.S. Erin rain bands and "eye" as captured by PAR.
(Photograph courtesy NSSL, NOAA. USA)



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