Utility of Doppler Weather Radar, an overview and
Its input for cyclone monitoring and prediction

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RADAR

An acronym for

Radio
detection
and
ranging
RADAR is an electromagnetic system for the detection and location of reflecting objects.

It has been employed to detect targets on or above the ground, in the air, in the space, under water etc.

Radar works on the principle of echo sounding principle.

When a radio wave emitted by a transmitter meets any object, a part of the energy contained in the radiation is reflected, a part is transmitted through, a part is scattered in all directions and apart is absorbed by the material of the object.
Weather Radars & DWR

- Radars used for the detection of clouds, precipitation, ice, snow, winds and other hydrometeors are termed as **Weather Radars**.

- The target is basically a water drop may be in the form of water, ice or snow which back scatters the electromagnetic waves after incidence.

- The Doppler principle for the measurement of the velocity of the object applied to the electromagnetic waves could lead to Doppler radars.

- In case of **Doppler Weather Radars (DWR)** the targets are the clouds which are the ensembles of the water droplets which back scatter the incident electromagnetic energy from a directional antenna.
Pulse radar transmits high-frequency impulsive signals of high power.

After this a longer break follows before a new transmitted signal is sent out during which echoes can be received.

Direction, distance and the altitude of the target can be determined from the antenna positions and propagation time of the pulse-signal.
Radar Diagram- Transmit/Receive Windows

- Transmitting
- Receiving

Out-going signal

Inter-pulse period

Range window

Time
Radar scans this entire volume by raising and lowering the beam as the antenna rotates.
Radar Beam Height versus Range
(standard refraction)

Fig 1
<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency</th>
<th>Wavelength</th>
<th>Applications</th>
</tr>
</thead>
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<tr>
<td>VHF</td>
<td>30-300 MHz</td>
<td>10-1 m</td>
<td>Wind Profilers</td>
</tr>
<tr>
<td>UHF</td>
<td>300-1000 MHz</td>
<td>1-0.3 m</td>
<td>Wind Profilers</td>
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<tr>
<td>L</td>
<td>1-2 GHz</td>
<td>30-15 cm</td>
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<tr>
<td>S</td>
<td>2-4 GHz</td>
<td>15-8 cm</td>
<td>Clouds study, heavy rainfall and Cyclone prediction</td>
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<tr>
<td>C</td>
<td>4-8 GHz</td>
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<tr>
<td>X</td>
<td>8-12 GHz</td>
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<td>Ku</td>
<td>12-18 GHz</td>
<td>2.5-1.7 cm</td>
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<td>K</td>
<td>18-27 GHz</td>
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</tr>
<tr>
<td>Ka</td>
<td>27-40 GHz</td>
<td>1.2-0.75 cm</td>
<td></td>
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<tr>
<td>mm</td>
<td>40-300 GHZ</td>
<td>0.75-1 mm</td>
<td>Microwave rain radars</td>
</tr>
</tbody>
</table>
Doppler Principle in Radar

- Doppler discovered that a moving object shifts the frequency of sound which is proportional to speed of movement.

- Exactly the same thing happens with electromagnetic radiation. The RADAR is stationary and CLOUD is moving. Thus the back scattered radiation from a moving droplet will have its frequency shifted in proportion to the speed of movement of droplets.

- Putting in term of phase, the phase of received signal will change from one pulse to next by an amount that is proportional to movement of the scatterer in that time.
Thus by measuring the phase difference between the transmitted and received signal, one can estimate the velocity of the scatterer towards or away from the radar.

The Doppler radar utilizes the phase property of electromagnetic radiation for estimation of speed of the scatterer.

The amplitude is utilized to detect and estimate the power received to detect and estimate the power received from the scatterers, as is done in conventional radar.
Principle of Doppler Weather radar

- Doppler Weather Radar is based on “Doppler Effect” in electromagnetic waves.
- If there is a relative motion between the source of the electromagnetic waves and the target then the reflected signal from the target gets a change in the frequency or phase as compared to the transmitted signal.
- This change in the frequency is known as Doppler Shift and is directly proportional to the relative velocity between target and the source of electromagnetic waves.
What is Doppler Weather Radar

- State of art weather radar based on Doppler principle.
- Capable of measuring strong wind speed and detection of severe weather phenomena such as thunderstorms, hailstorm, tornado & cyclone.
- High resolution data for precise estimation.
- Capable of working in the clear air environment.
- Measurement of vertical shear between any two levels.
- Detection of clear air turbulences.
- Vertical profile of winds available up to 7.5 km
What for Doppler Weather Radar?

- Direction and speed of the thunderstorms, hailstorm, tornado & cyclone.
- Rainfall rate & total rainfall associated to a weather system.
- Estimation of wind speed accompanied with a thunderstorm & cyclone.
- Expected storm surge height and potential of destruction by cyclone.
- Highly accurate short term forecast for severe weather and strong winds.
Typical Features of DWR

- Measurement of wind speed of the order of 64 m/s.
- Round the clock automatic collection of weather data at every 10 min interval.
- Surveillance range more than 300 km.
- Very good estimate for quantitative precipitation.
- Determines the location of a storm, its vertical extent associated heavy rainfall estimation.
- Automatic severe weather warning.
- Hailstorm warning.
Base Products of DWR

1. Radar Reflectivity Factor (Z) : A measure of size and number of droplets in sample volume.

2. Mean Radial Velocity (V) : A measure of mean wind towards or away from radar in sample volume.

3. Spectrum width (W) : A measure of variability of radial velocity i.e. turbulence in sample volume.
Radar Reflectivity Factor \( (Z) \)

- This product is a measure of the precipitation in the sample volume of a cloud system. The quantitative estimate of the precipitation contents, rainfall rate and other features of the system may be understood from this product.

- Based on the precipitation contents in the cloud, the strength of the back scattered signal is presented in the form of “Z” expressed in the units of \( \text{mm}^6 / \text{m}^3 \). In logarithmic terms

\[
\text{dBZ} = 10 \log_{10} \left( \frac{Z}{(\text{mm}^6/\text{m}^3)} \right)
\]
Mean Radial Velocity (V)

- This product is an indirect measurement of mean wind velocity of the system towards or away from radar using Doppler Principle. As the radar is able to measure only the radial component of the wind velocity (along the radar beam), the velocity is referred as radial velocity.

- The radial velocity is taken as negative if it is measured towards the radar. When a system is approaching radar, its radial velocity will be taken as negative and represented in “Blue colours” or “cool colours” in the velocity pictures of DWR.

- The radial velocity is taken as positive if it is measured away from the radar in the outwards direction. When a system is moving away from radar, its radial velocity will be taken as positive and represented in “Red colours” or “warm colours” in the velocity pictures of DWR.
The radial velocity will be zero if the system is moving in the perpendicular direction of the radar beam.

The radial velocity of a system will be same as that of actual velocity when it is moving along the direction of radar beam.
Products useful in the prediction of Tropical Cyclones

- PPI (Plan Position Indicator) (Z,V)
- CAPPI (Constant Altitude Plan Position Indicator) (Z,V)
- PCAPPI (Pseudo Constant Altitude Plan Position Indicator) (Z,V)
- Max (Maximum Reflectivity) (Z)
- VVP_2 (Volume Velocity Product_2) (V)
- VVCUT (Vertical Cut) (Z)
- SRI (Surface Rainfall Intensity) (Z)
- VCS (Vertical Wind shear) (V)
This product is obtained at a fixed elevation by azimuth scanning of the antenna for a selected range of observation and shows all echoes received in the radar range.

The intensity of the echoes is expressed in dBz scale.

Depending upon the range of the target and the angle of elevation, the height of the echo is estimated.

The nearby echoes correspond to lower altitude where as the farther echoes correspond to higher altitude depending upon the range and angle of elevation.

The height of the radar beam increases with the range due to curvature of the earth.
CAPPI_Z (Constant Altitude Plan Position Indicator Reflectivity)

- This product displays echoes at user defined altitude (above mean sea level).
- The range and height of this product are user selectable and may extend up to 500 km and height from 1 to 18 km respectively.

CAPPI at 6 km altitude (SIDR)
PCAPPI_Z (Pseudo CAPPI)

- This product is similar to CAPPI except that areas where no data was available in the standard CAPPI, close to the radar site and at large ranges are filled with data of the corresponding elevation.

- At short ranges the data are taken from the highest elevation until this beam crosses the defined height and for large ranges, where the lowest beam is higher than the defined height, the data accumulations follow the lowest beam.
PCAPPI at 6 km altitude (SIDR)
Max_Z (Maximum Reflectivity)

- This is first level derived product from base reflectivity data. Each vertical column in all three directions (X, Y & Z) is searched for the maximum reflectivity and presented in the form of 2-dimensional image.
- The final image is composite of three partial images into a single imagery.
- Therefore, by combining all these partial images, an idea about the three dimensional reflectivity distribution may be obtained. Three partial images are:-
i) The central part of the Max_Z image shows the two dimensional presentation of the highest measured radar reflectivity values in Z-direction.

ii) This image shows the highest reflectivity value for each vertical column seen from the top of the cartesian volume.
➢ The top view appended above the central part is a North-South view of the highest measured reflectivity values in Y-direction.

➢ This image shows the highest measured reflectivity value for each horizontal line scan from North to South.
The right view appended to the central view is an East-West view of the highest measured values along X-direction. This image shows the highest measured reflectivity value for each horizontal line scan from East to West.
Importance of MAX Z image

- This image provides a wide distribution of the clouds associated with the cyclone in the cloud wall region and the estimated rainfall.
- The vertical extent of the clouds & the radar reflectivity distribution inside them, their development and dissipation as a thunderstorm & their radial distance from radar.
- The centre of the tropical storm, its spiral band structure, the eye and its diameter and the three dimensional structure may also be analyzed.
PPI_V (Plan position Indicator Velocity)

- This product is simply an azimuth scan at constant elevation for collecting the radial velocity data.
VVP_2 (Volume Velocity Processing 2)

- The name of this product itself shows that the volume velocity data has been processed to get this product.
- It shows a vertical profile of horizontal winds derived from the radial wind measurement after applying certain approximations and least square method to minimize the error.
- The winds are estimated at every 0.3 km interval from ground up to 7.5 km height and represented in the form of wind barbs.
- Therefore, this product is very suitable to know the wind fields at various levels on the DWR station and the surroundings.
VCUT_Z (Vertical Cross Section Reflectivity)

- This is a second level product derived from MAX_Z image.
- The vertical cross section of the reflectivity associated to cloud displayed in Max_Z image.
- Any two points A & B can be arbitrarily selected in the Max_Z image and vertical cross section can be derived.
- This product is similar to the RHI (Range Height Indicator) product in which the height of the cloud is displayed v/s range from the radar. One point was always at the radar and other point was in a particular direction. No two points can be selected arbitrarily in RHI what are available in VCUt_Z and therefore later one gains more advantage over earlier one.
Vertical Cross Section derived from a Max_z image for the tropical cyclone on 15th Nov 2007
Satellite & Doppler Weather radar Images of Phailin Cyclone
Satellite & Doppler Weather radar Images of Hudhud Cyclone
Severe Cyclone
Hudhud
During
06-12th Oct 2014
Thanks