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REVIEW OF WEATHER RADARS - PAST, PRESENT AND THE SCOPE FOR FURTURE MODIFICATIONS WITH TECHNOLOGY INNOVATION

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ABSTRACT

Predicting the atmospheric changes has turned crucial today. Be it a travelling from one place to another or giving a timely weather report, everything relies on the prediction of the atmospheric changes. Radars are used for this purpose. Weather radar is considered as one of the most significant instruments developed for forecasting weather to meet the International safety standards. The high resolution data in lower layers of atmosphere, which is a crucial need for the aircraft operations is provided by Doppler radars. The current running NEXRAD, NEXT GENERATION WEATHER RADAR system has been proved to be of great value as of date. Also further modifications are under research with Indian Aircraft Industry, making it suitable for all weather conditions. Developing hardware and software technologies offer a promise for the manufacture of an efficient radar system. Approaches such as Adaptive waveform selection and volume scan patterns are helpful for optimizing the functioning of the radar in different weather conditions. All types of radars are not used in weather predictions. Known to all is that radar systems with phased-array antennae can support a broad range of applications. The design of weather radars have undergone various transformations due to rapid development in the technologies.

Key words: Adaptive Waveform Selection, High resolution, NEXRAD, Phased Array Antenna, Volume Scan Patterns.

I INTRODUCTION

To observe and predict the changes occurring in the weather is getting more and more important in today's world for different reasons. Weather forecasting is relying on unified observations from various systems that are non-synchronous in time. Weather radar is an instrument that provides an update regarding the climate and volumetric coverage of weather. In fact, radar alone works as sensor that yields real time and exact information regarding haphazard weather conditions such as mighty wind, storm and snow in a large scale area. Thus it warns the pilots of Aircrafts to take the necessary safety measures. In this paper, we discuss about the early developments in the field of weather radars and how the enhancements in technology has influenced it at various stages.

Figure-1 National Severe Storms Laboratory

1.1 Need for a Weather Radar

A question definitely arises regarding the adoption of weather radars. Current scenario demands encouraging weather for smooth flight travel and is the need of the hour for various other facilities. Several TV channels give weather predictions to make people aware of the weather conditions. Hence it is necessary to provide accurate weather observations from time to time which will be the input for weather forecasts and numerical weather prediction models.

Recently Hudh-Hudh cyclone had effected the Vishakapatnam City of Andhra Pradesh, destroying the beauty of the port City and causing tremendous loss to nature. The Ecological balance is damaged to a large extent. As it is predicted well before, the Government took the all the necessary measures to ensure that there is no loss of human lives though the incurred financial loss is huge. Hence it has become a necessity for having a weather warning system to give the required cautions. In places like US, Tornados are very frequent and pose a serious threat to mankind living there. The whirling winds move at hazardous velocity and there by destroying everything. Hence necessary precautions are to be taken to survive from such Natural Calamities.

1.2 A Basic Radar

RADAR-RAdio **D**etection **A**nd **R**anging is a system that uses Electromagnetic waves for the detection and location of objects and thus extending the capability of one's senses for observing the environment. An elementary Radar consists of a transmitter that generates the electromagnetic waves and these EM waves are then transmitted in to the space. When these waves meet an obstacle they get reflected in all directions. The energy that is reradiated in the back direction is collected by receiver antenna and passed on to the receiver.

Figure-2 A Weather Radar mounted on a ship

The operation of Weather radar is similar to that of a normal radar. In conventional radars the EM radiation is used for detecting the hostile warships and aircrafts. But in the case of weather radars, the radio waves are deployed to recognize rainfall, ice crystals and fog etc. The Electromagnetic waves that are being emitted by the transmitter after hitting the target get reflected back to the antenna. The weather radars are either stationary or mobile. The combination of the primary radar with subsidiary radars and with a network of other essential ground-based meteorological instruments has been shown to yield enhanced short-term forecasting capabilities. The development of weather radar came from an urgent need to enhance the ability of radars to extract information despite the presence of obstacles like radio-frequency interference.

II HISTORY

The idea of using a radar for observing the weather progressed as a result of the comprehensive study on Radars during World War II. The operators of military radar observed the noise in received echoes due to rain, snow and dry ice. Then the military scientists who realized that a radar can be further exploited for detecting the weather hazards, started working on those echoes for developing a use out of it. The radar usage was limited to military initially. Later, they were deployed in certain areas that are under Government supervision based up on its cost and complexity.

Following the World War-II, governments all over the world voluntarily extend their support for the development of weather radar. Initially, the Weather Bureau , now called as the National Weather Service utilized the leftover radars of World war-II from the military, for identifying the storms proceeding in a particular direction and their exact location. But the images formed on the radar screen told little about storm intensity. Beginning in July 1940, "a radar of wavelength 10cm was built at the General Electric Corporation Research Laboratory"[1] in Wembley, England. However, the first radar network used for weather surveillance was formed in Panama in April 1944. It started reporting weather changes to two harbor defense Cristobal installations at the Atlantic. In May 1944, this network was strengthened by setting up two higher power radars. These radars provided a report by encoding them in special radar reporting codes called as RAREPs. The second weather radar network was developed by various similar operations at individual stations. In the summer of 1944, APQ-13, a joint venture by Bell Telephone laboratories and MID Rad lab was developed. It was soon realized that the APQ-13, although originally designed as a bombing and navigation system, could also detect the sudden weather changes

Meanwhile, in 1946 the National Weather Service(NWS), bought 25 AN/APS- 2F aircraft radars from the navy, modified and released it. The development of the CPS-9, the WSR-57, the WSR-88D and a series of operational radar systems had marked the evolution of weather radars in United States. Each of these was a response to the new needs and opportunities and the deficiencies in the prior generation gave a need to develop a better radar than before. The "CPS-9 (X-band or 3-cm wavelength)"[2], introduced by the U.S. Air Force was the first radar precisely designed for meteorological purpose. The radar WSR-57 was used by NWS for its first weather related operation. From then these radars were customized to help guide the aircrafts that are stuck in harsh weather to places where they could land safely.

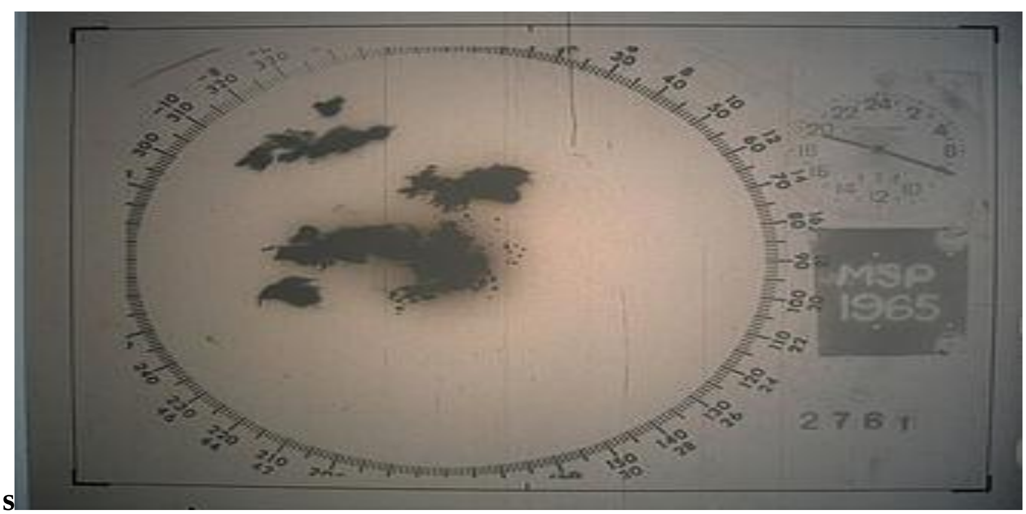
s 

Figure-3 Radar Technology detecting a Tornado

III STRUCTURE AND WORKING PRINCIPLE

3.1 Basic Structure of Weather Radar

The basic structure and fundamental elements of a weather radar are shown in the below figure. It consists of a transmitter, a feed-horn, a receiver and a Radome.

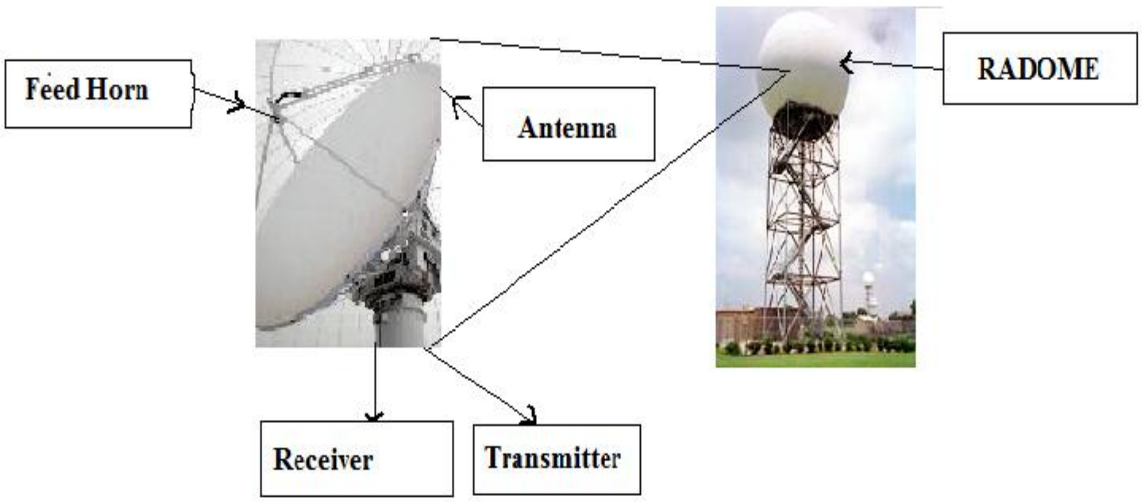


Figure-4 Basic Structure of Radar

The functioning of each of the blocks is explained below.

Transmitter: It generates the high frequency signal of the prescribed amplitude and phase that will be transmitted into the space. In the case of weather radar, the wavelength of a wave can be up to10cm approximately.

Antenna - The main goal of an antenna/dish is to concentrate the power transmitted into a beam of radiation and also to converge the retreated signal. There are many types of antennae available in various shapes.

Feed-horn - A antenna which used both at transmitter and receiver sections. It is used to feed the signal given by transmitter to transmitting antenna at the transmission section and at receiving section it collects the echo signal from the receiving antenna and gives it to the receiver. It also attenuates the unwanted signals from the other nearby channels by setting a specific polarization for the waves that are to be received.

Receiver - It track-downs the signal acquired from the target. In modern cases, the transmitter itself acts both as a transmitter and a receiver (called as Transceiver). Though in some cases, two different antennas are used for both Transmitter and Receiver, the use of Transceiver reduces the installation cost to large extent.

Radome - Known to all is that the antennae are placed at certain altitude from the Earth surface. The radome protects the antenna from high winds. Actually, the transmitter and the receiver lie inside the Radome, so that they can be protected from atmospheric disturbances and preserved on a long run.

3.2 Working Principle

As mentioned above, the weather radar works on the principle of reflectivity. The radio waves hit the target, get reflected back and the extent up to which it detects is banked upon the composition, size and number of droplets. For example, water particles are five times more reflective than ice particles of the same size.

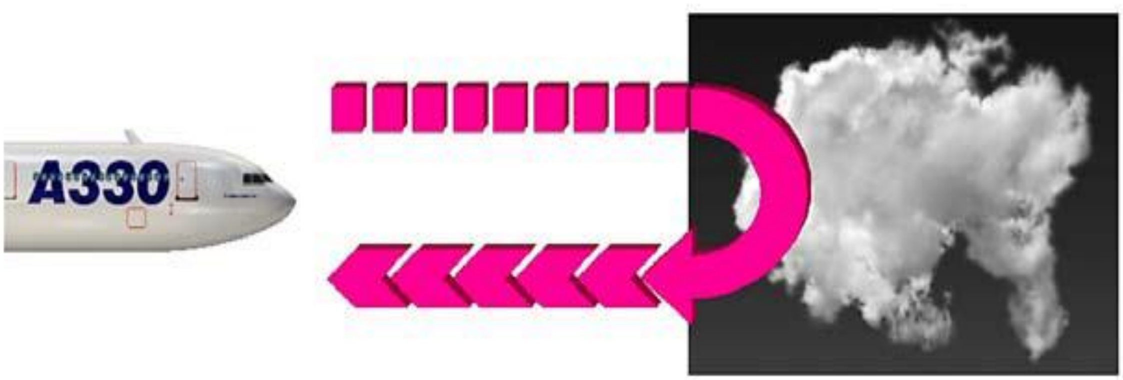


Figure-5 Weather Radar Working Principle

The radar can be used to identify the following due to their dense nature:

• Precipitation

• Commotion in the surrounding weather

• Ice crystals and dry hailstorm.

But there are certain elements that cannot be unmasked by a radar:

• Smog, clouds cannot be detected as the droplets are very small there

• "Clear air turbulence(no precipitation)"[3].

• Sandstorms also cannot be detected given that sand particles are very much trans to radar waves.

The radar echo that retreats back is found to be reporting about droplet size and severity of the precipitation. No echo will be returned from droplets of small size, whereas majority of radar waves will be coming back as echo from heavy droplets such as thunderstorm. The intensity and the type of precipitation are the dominant factors that effect the reflectivity of precipitation. Wet precipitation containing humidity can be easily detected than dry precipitation. Thus the reflectivity of wet hail is far better than dry hail.

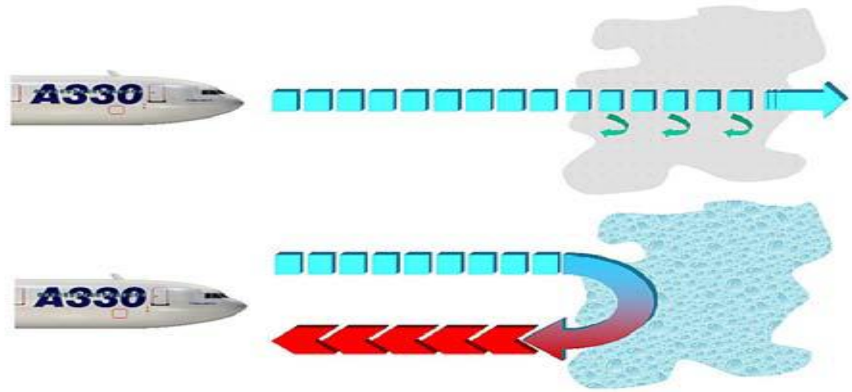


Figure-6 Reflectivity Variation according to droplet size

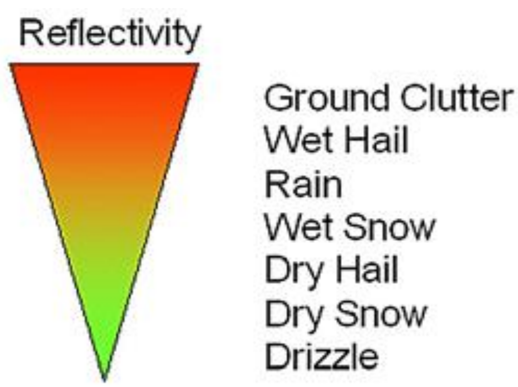


Figure-7 Reflectivity level according to Droplet type

IV THE EXISTING SYSTEM

As mentioned above, the idea of using a radar for weather predictions took birth during the period of World War-II. In recent years, the short range forecasting and integrated observing systems have been progressed in such a way that the data given by weather radars helped to extract entire information about the atmospheric conditions. Two such instances that are exclusively developed are

"Advanced Weather Interactive Processing System (AWIPS)"[4]- AWIPS helps the meteorologists gain access to the satellite imagery, gridded weather forecast and point measurements.

"Integrated Terminal Weather System (ITWS)"[5]- It provides a set of safety weather products to the pilot and ensures a safe travel for all the passengers. Also the controller here is free from excess workload.

WSR-57 radars served as standalone model for the surveillance of weather in USA for about 35 years. It was used by the National Weather Service for watching severe weather across the country. The below figure gives a view of WSR-57.

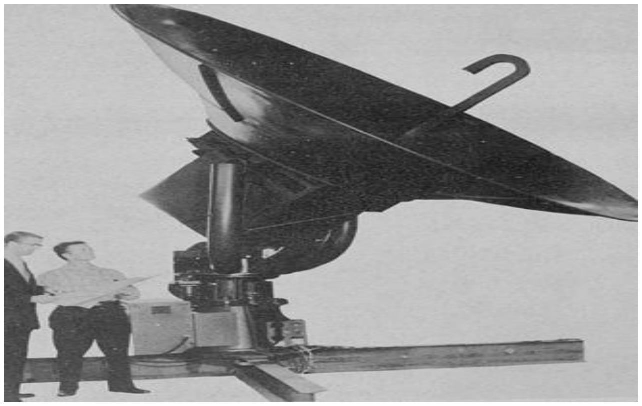


Figure-8 Weather Surveillance Radar-1957

The Weather Surveillance Radar - 1957(WSR-57) was the foremost weather radar network that was implemented in giving warning regarding weather. The WSR-57 took birth in 1957 with the help of World War-II technologies. It only given data about coarse reflectivity but there is no velocity data information and detecting of tornados had become remarkably tough. "Grease pencils were used for tracing weather systems across the radar screen"[6]. It was a manual work mostly and also commendable proficiency is required to gather information regarding the severity of storms exactly by tracing the green colored patches appearing on the scope of the radar.

As the network of WSR-57 radars aged, WSR-74S were developed. These are models with similar performance but with greater reliability. Mostly WSR-57 in the National Weather Surveillance Network are replaced with WSR-74S radars. In this network of radars, if one radar turns defective, then the adjacent radar will have to do the job of giving the updates. The WSR-88D(Weather Surveillance Radar-1988, Doppler) are considered as the successors for the WSR-74Cs model. For two decades, WSR-74 assisted the US National Weather Surveillance. Still twelve of such models were not demilitarized, and out of these, seven are functioning even today. The last WSR-74C, set up by the NWS in Williston, was demilitarized in 2012.

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Figure-9 Weather Surveillance Radar-1974

V THE CURRENT SYSTEM

The current technology WSR-88D (NEXRAD) system is the successor of the existing WSR-74 series radars. The word NEXRAD stands for NEXT GENERATION WEATHER RADAR. These radars are spread out all over the United States and some overseas nations in 1990's. It is technically called as WSR-88D, which stands for Weather Surveillance Radar, 1988, Doppler. In addition to the normal operations like prediction of weather, this radar system can also be used as crucial appliance that allows various other aerial applications.

Figure-10 Test bed of Weather Surveillance Radar-1988 Doppler

NEXRAD tracks down condensation and changes occurring in the atmosphere. The data rebounded is processed and the results are displayed in a mosaic map. This aids the meteorologists to know about the precipitation, fog, wind movements and accordingly report the same. Basically, a radar system can be operated in two modes and the operator selects any one of it at a time.

1. "A slow-scanning clear-air mode"[7] for examining the movement of breeze when there is less or no exertion in the area.

2. "A precipitation mode, with a faster scan for tracking active weather"[8].

NEXRAD has drawn appended significance regarding automation of the radar functioning, in addition to the use of algorithms and computerized volume scans. Volume coverage patterns (VCPs) are generated serves the purpose of the surveillance of atmospheric volume surrounding the NEXRAD. The "clear air patterns"[9] cover the lowest layers of the atmosphere and provide information about status of wind, sea breeze fronts or storm outflow boundaries. This new technology has higher attenuation, and therefore a decreased ability to determine if there are weather cells with high levels of precipitations.

5.1 Deployment of NEXRAD

The NEXRAD systems are being used widely since they have replaced the WSR-74 series in 1970's. The National Weather Service and the Air Weather Service agency of the U.S. Air Force have conducted tests for next three years and concluded that Doppler radar rendered more enhanced and quick revelation about hazardous thunderstorms. On 12th June 1992, the first WSR-88D for operational use was installed in Sterling, Virginia.

The current generation NEXRAD radars are equipped with much more upgraded features than the previous radars in use. It has given data regarding Doppler velocity and also extended the tornado detection capability by noticing changes in the rotation within the storm from different angles. It offers enhanced resolution and sensitivity, favoring the operators to notice features such as cold waves, cloudburst breeze, and "mesoscale to even storm scale features of thunderstorms that are hardly seen on radar"[10]. The Volumetric scans of the atmosphere performed by the NEXRAD systems allowed the operators to study the behavior of storms. Additionally, the NEXRAD systems when operated as wind profilers, give information about wind movements for several miles ahead of the location of radar.

Figure-11 Weather Surveillance Radar-1988 Doppler Installation Sites

5.2 Augmentation

There are certain developments in the present radar which are really useful for it's effective functioning. They are mentioned below.

5.2.1Super resolution

By enhancing the level of super resolution of the radar, data of much higher resolution is yielded. Initially, WSR-88D used to offer "reflectivity data at 1km by 1 degree to 460 km range and velocity data at 0.25 km by 1 degree to a range of 230km"[11]. After upgrading the resolution factor, the reflectivity greatly increased "with a sample size of 0.25 km by 0.5 degree, and increase the range of Doppler velocity data to 300 km"[12]. In addition to the reliable detection information, super resolution improved the range of velocity, speed of provision of data and faster analysis of potential tornado detection.

5.2.2 Dual polarization

All the WSR-88D radars throughout the country are boosted to function as polarimetric radar, which offers vertical polarization to the horizontal waves in order to figure out the target exactly. This polarization done in two directions is called Dual Polarization. "This dual polarization helps the radar to distinguish between rain, hail and snow, something the horizontally polarized radars cannot do"[13]. During early days, different impressions are given by rain, snow, insects and birds by dual polarization. This marked a convincing improvement in predicting the winter storms and heavy thunderstorms. The implementation of dual polarization ability to NEZRAD started in the year 2010 and it was finished by 2013 summer.

5.2.3 Antenna Tilt

Tilt means change in the direction. The antenna needs to change it's direction as per requirement. To shake off the effect of both over and under scanning, effective management of the antenna tilt, along with adequate selection of ND range is necessary. It assures flawless tracking and anticipation of the current weather condition on the display.

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The displayed data on the ND are of the target cells that are hit by radar beam. For understanding the weather radar it is necessary to consider the factor of antenna tilt.

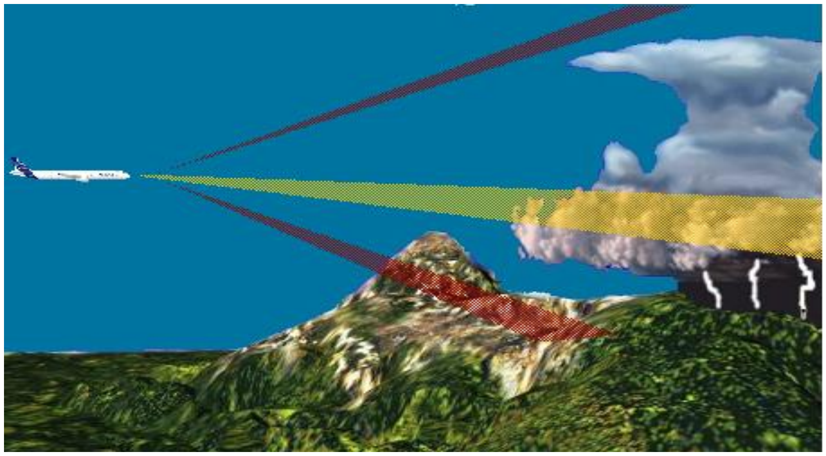

Figure-12 Auto Tilt Function

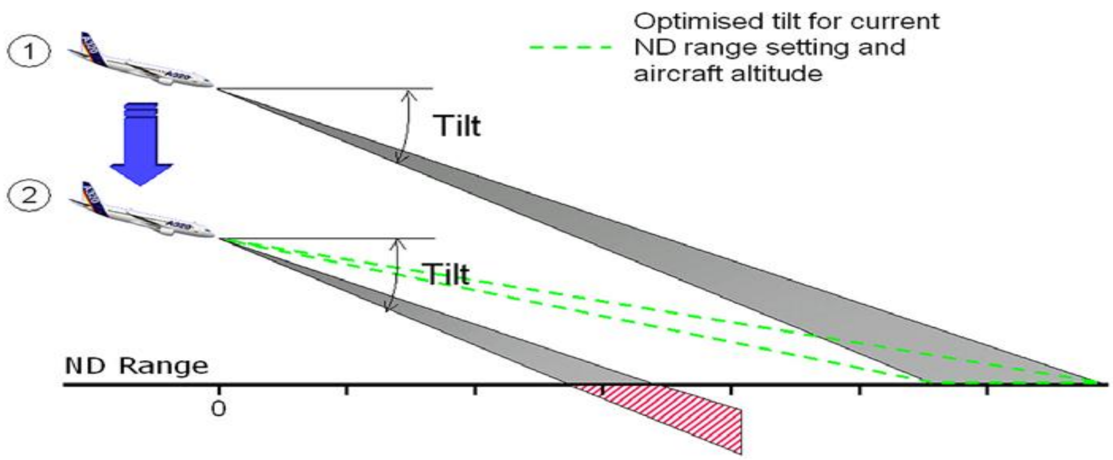

Figure-13 Tilt Adjustment

"Antenna tilt should be adapted to the ND range selection and it must be adjusted as the flight progresses based up on the altitude at which plane is flying."[14]. This depends up on the height at which an aircraft flies, current weather condition and ND range selection. The above three factors effect the antenna tilt. So for averting the issues of over/under scanning, the tilting of the antenna should be monitored and adjusted accordingly with every change in altitude of the flight, except in the auto tilt condition. In an auto tilt condition, the tilt automatically occurs sensing the changes in the altitude and the surroundings.

VI IMPROVED SCANNING STRATEGIES AND DISPLAY

6.1 Scanning Strategies

The scanning is done in two ways depending up on the altitude the flight is flying and the type of target. Unlike its predecessor, where the radar has to be controlled by the user, WSR-88D can automatically refresh it's databases with the help of any one of the predefined patterns. The scanning here is done in three dimensional fashion. At present, the NWS meteorologists have nine number of "Volume Coverage Patterns (VCP)"[15] available to them. A VCP consists of pre-designed instruction set that supervise the factors like rotational speed of antenna, pulse width, elevation angle and transmitter pulse repetition. Significant advancements in scanning techniques were initiated in 2014. "AVSET (Automated Volume Scan Evaluation and Termination) and SAILS (Supplemental Adaptive Intra-Volume Low-Level Scan)"[16] are such progressive and adaptive scanning techniques and these two are known for increasing the temporal resolution of the scans.

(1) In the case of AVSET, the radar unpreventably detects the precipitation level at certain altitude and when it is dropped below a preset threshold, it stops scanning further higher altitudes.

(2) SAILS, on the other hand checks the lower most tilt by volume scanning.

The scanning by the antenna depends up on the antenna tilt and its angle. As far as radar is concerned, three types of information that are required for detecting the target are "Azimuth angle, Distance to the target of interest and Elevation angle"[17].

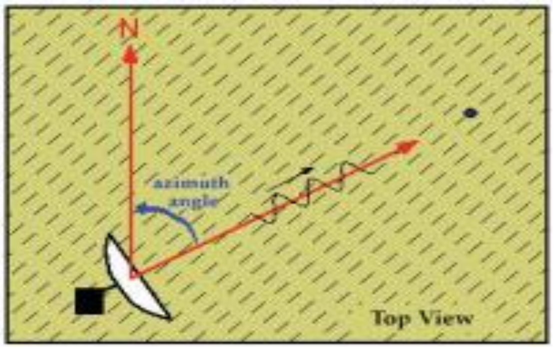

Figure-14 Azimuth Angle

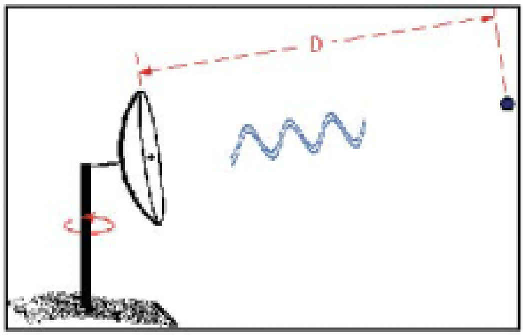

Figure-15 Distance of the target of interest

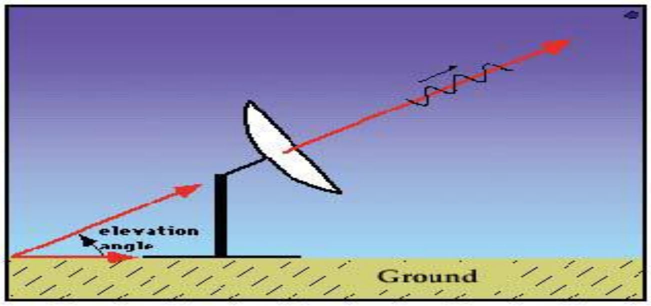

Figure-16 Elevation Angle

In meteorology, radars are supposed to follow these two scanning techniques:

1. PPI Technique
2. RHI Technique

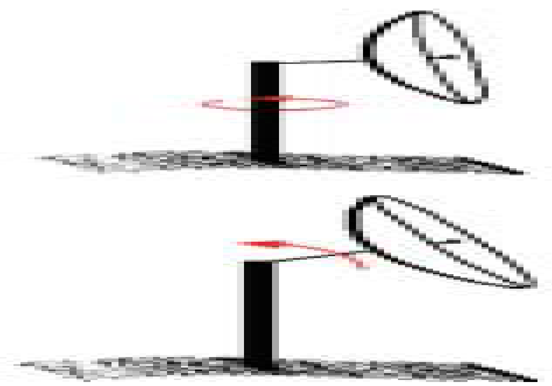

Figure-17 Plan Position Indicator and Range height Indicator techniques

1. Plan Position Indicator (PPI): Here azimuth angle is varied by keeping the elevation angle unchanged. In the case of surveillance scan, the radar will have to rotate 360 degrees around. But in the case of sector scan the radar rotates less than 360 degrees around. PPI indicator ensures great surveillance scanning and has got perfect operational set up too.

2. Range Height Indicator (RHI): Unlike PPI, here the elevation angle is changed while keeping azimuth angle unvaried. As the rotation here is from its horizon to zenith(the point in the sky overhead), the vertical storm structure can be detected easily.

It is challenging task to extricate between ground returns and weather echoes. The ground returns immediately change their color and shape with every change in the antenna tilt. For the detection of weather echoes in a better way, the direction of antenna is to be adjusted towards lower altitude where traces of moisture can be detected. If any red patterns are detected at a lower level, then the area should be scanned in vertical fashion by reducing the antenna tilt.

6.2 Display Range

The display and scanning are related to each other. The decisions and safety measures are needed to be taken when the storm is at least 40 NM away from the flight. For accomplishing this task, the display range should be really appreciable and encouraging. To prevent the bad weather conditions, the course changes should be done at both higher and lower range levels. It helps in avoiding the Blind alley effect which is a change in course that looks perfectly alright when a low range ND is used, but reveals blockages when scanned at higher range.

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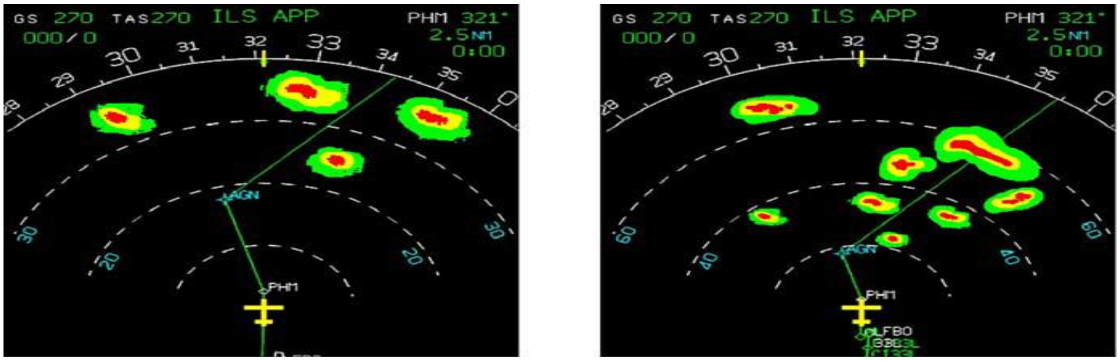


Figure-18 Blind Alley Effect

The antenna tilt should be flexible enough to be adjusted as per the selected range. To avoid over scanning, the antenna boarded on the radar need to have marginal negative tilt. If it is perfectly set, then a few of ground returns are visible at the top edge of ND.

VII. FUTURE ENHANCEMENT

Many solutions have come up regarding weather radars, proposing enhanced methodologies for a better weather warning systems. In this paper we discuss about two such latest technologies. They are

1. Rockwell Collins Multi-Scan Threat Track Weather Radar.

2. Honeywell's IntuVue RDR-4000 3D Weather Radar.

7.1 Rockwell Collins Multi-Scan Threat Track Weather Radar

Beyond the dual polarization and MESO-SAILS, the further step in the weather radar will probably be the advent of the phased array antennae. It has the ability to scan large areas rapidly and thus provides the much needed advantage to the radar meteorologists. Also Multi-Scan Threat Track weather radar put forward a contemporary approach for identifying and studying the severe weather conditions. This radar is manufactured by Rockwell Collins Company. The radar provided by Rockwell Collins is found reliable and is currently mounted on nearly 7,000 aircrafts all around the world today. This system provided a safe and comfortable journey to the passengers by aiding the pilots in decussating unsafe weather in every way possible. After numerous tests, the results showed significant improvement than the prevailing "Enhanced Flight Vision Systems(EFVS)"[18] in many aspects.
Today's vision systems adopted Infrared(IR) for detecting the clutters on the ground as they get near to the runway. Moreover the IR sensor should be able to work in any weather condition and it's waves should be able to penetrate through all kinds of weather. Rockwell Collins' Multi-Scan weather radar functions at a comparatively low

frequency range than the IR sensors and permits it to provide "ground imaging in all weather"[19]. Unlike other radars like millimeter wave radar, Multi-scan radar will not require any other hardware installations that in turn add weight to the aircraft.

Figure-19: Rockwell Collins Weather Radar

This Multi-scan threat track by Rockwell Collins has got a package of new features that help in enhancing the performance of the radar. Some of those are mentioned below.

- The Patented track-while-scan technology helps to prioritize the threats out of 320nm. It is achieved by performing a dedicated number of both horizontal and vertical scans.
- It has got a special feature of Two-level enhanced turbulence detection which helps in detecting a high level and severe commotion nearly 40nm in front of the aircraft.
- The Core threat assessment helps in examining the "thunderstorm cells and also increases colors to represent the actual thunderstorm threat"[20] in a better way.
- It has got a database consisting of the variations in the geographic and seasonal conditions which helps the Multi-Scan Threat Track's algorithms in yielding exact information about the threat.
- The advanced ground clutter suppression feature helps in eliminating the shuffle/rummage on the ground at all possible ranges on the display. It also helps the pilots to fully concentrate on the true weather threats.

It also got a set of additional features such as

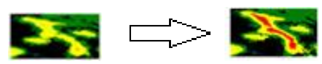
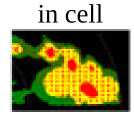
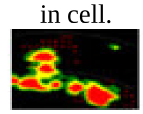
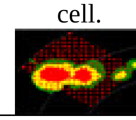
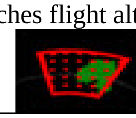
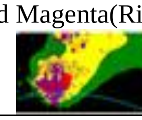
- Fully automatic operation.
- Smart scan real time weather during turns.
- It supports the split functionality of antenna when required.
- True Zero antenna compensation.
- Anticipating wind shear striking with the help of pre-enabled event data recording and retrieval system.
- Simultaneous display of the received updates in any mode of operation.
- Various temperature based gain.

- Over flight protection and also prevents the thunderstorm top penetration.

This Multi-scan threat track system operates in various modes based up on the requirement of a certain functionality like:

- Self starting/automatic multi-scan
- Providing a ground map
- Detection of turbulence
- "Manual operations– independent; mode, gain, tilt, range for each pilot"[21].

TABLE-1 Table showing various Threats and their displays

Threat Track Feature	Annunciated Threat	Cockpit HMI
Core threat analysis	Active convection, turbulence and Lightning probability in Medium threat cells	Colors are adjusted to more accurately reflect the cell threat 
Associated Threat assessment Scheme	Mid-altitude Associated Threat Probability of lightning near the Freezing level	Red speckled pattern in Green or Yellow regions inferring the probability of lightning in cell 
	Mature cell associated Threat High level of warning for potential hail, Lightning and Convection outside of reflectivity areas	Red speckled pattern outside the cell boundary inferring the probability of threat in cell. 
	Anvil Top Associated Threat Highest potential hail and lightning outside of reflectivity area	Extended Red speckled pattern in Direction of wind inferring the probability of threat in cell. 
Predictive Over flight (POF) Protection	Rapidly building cell below the Aircraft flight path	Red Outline with Red speckled Interior, Replaced by actual weather when cell reaches flight altitude. 
Two level Enhanced turbulence	MOPS 0.3g-rms Turbulence Ride quality 0.2g-rms Turbulence	Solid Magenta(Severe) Speckled Magenta(Ride quality) 

7.2 IntuVue RDR-4000 3D Weather Radar

Another enhancement in the field of weather radars is IntuVue RDR-4000 3D weather radar, designed by Honeywell Aerospace, India. It is a low weight and high intensity radar that has improved the weather prediction capabilities by introducing 3-dimensional Volume scanning and pulse compression techniques. The pilots of the aircrafts should have "better communication with on-the-ground air traffic control and flight operators"[22] in order to provide exact and immediate information about the weather. It issues predictive hazard warnings regarding snow, wind shears and storms. It also provides automatic operation and visceral displays and thereby decreasing the workload for the pilot on board. Conventional 2D radars(tilt based radars), be it manually operated ones or auto-tilt controlled, can only issue very less information about the weather. Due to this, the pilot cannot have a clear picture of the weather and have to change the tilt manually for knowing the status of storm tops & weather condition below the level of the aircraft. This manual operation requires lot of skill and efficiency on the part of the pilot. Also in situations where the workload of the pilot is heavy, there may be chances of mishandling of the radar or misinterpretation of data.

As mentioned above, the two factors that make RDR-4000 radar unique are Volumetric 3D scanning and Pulse Compression. These two are termed as the IntuVue's game changing technologies.

7.2.1 Volumetric 3D scanning

The enhanced 3D scanning continuously covers the entire space in front of the aircraft from about -80 to +80 degrees ahead of the aircraft, 0 to 60,000 ft and up to 320nm ahead. While other 2D radars need to change the antenna tilt either manually by the pilot or automatically by the radar itself. The RDR-4000 radar is known to be the only radar that scans all the weather constantly without any fail and collects all the data in a 3D buffer. This helps in providing 3-dimensional image of the weather and terrain. The 3D buffer is revised with the latest reflectivity data obtained from latest scans.

7.2.2 Pulse Compression Technique

Commercially RDR-4000 is the first radar to associate with the pulse compression technique. Pulse compression technique helps in increasing the detection range and resolution of the radar simultaneously. Many current technologies are forced to give up on higher resolution data for achieving long range detection. Pulse Compression technique helps in delivering both at a time.

The following are the limitations in the current 2D weather radar and these very reasons encouraged the development of RDR-4000 radar.

TABLE-2 Comparison between 2D and RDR-4000 3D radars

Limitations of the 2D radar	The IntuVue/RDR-4000 Solution
Radar scans only a portion of airspace in front of it by using one or two tilt modes.	The 3D volumetric scanner captures all the weather ahead of the radar from -80 to +80 degrees in front of the aircraft, from 0 to 320nm ahead, and from 0 to 60000 ft height.
No information regarding vertical development of storm is provided	The Volumetric 3D scanning in RDR-4000 enables the surveying of the vertical development and movement of storm with flight level slices in 1000ft increments.
Does not correct/adjust for the Earth's curvatures and the pilots have to perform geometrical calculations based on tilt angle and Earth's curvature to identify weather altitude at a specific range.	It is equipped with a 3D buffer which automatically gets adjusted for the Earth's curvature. This enables the weather to be accessed with respect to that particular aircraft's altitude.
The hazard detection capabilities are limited here	RDR-4000 was the first radar to give predictive hail and lightening displays, enabling more effective re-routing decisions. It also gives distinct displays for hail and lightning.
There will be signal losses due to the presence of wave guide	The innovative design of RDR-4000 radar eliminates the waveguide runs that reduce the power and sensitivity of the radar.

VIII APPLICATIONS

Weather radar has got a wide range of applications. It is used in aircrafts for predicting the weather conditions, in military to give warnings regarding changes in atmosphere. Of all the special features it has got, it's ability to unmask the risky weather conditions and detecting of harsh storms stands out. Often large systems like hurricanes are also monitored by weather radars which can be extended over large area.

8.1 Civil applications

Since the time of it's first generation itself, weather radar was being used extensively in civil applications. "In early 1960's, the meteorologists used to take and transmit RAREP for every hour"[1]. The RFCs couldn't give any warning regarding flash floods and hence the meteorologist of that area did the job of detecting the flash floods and their intensity. Current WSR-88D precipitation handling system in spite of the system's relative immaturity, is able to reveal data about flash floods. "The radar scope photographs were taken routinely at all WSR-57 site, other network stations"[1] and sent to NCDC for further study and observations.

8.2 Military applications

Data from weather radar is used to provide weather warnings more accurately so that protective measures can be planned more efficiently. In military, the radar is used not only to forecast the thunderstorms and their severity but also to enlighten the meteorologists regarding wind-speed and it's direction so that precise warnings can be issued. Also success rate of some military operations which are sensitive to radar can be improved.

SUMMARY

A weather radar is a device used for detecting and warning about severe weather conditions so that safety measures can be taken in time. With any other tool this work cannot be done with much efficiency. Each radar has some specifications and there is no guarantee that two radars display a given weather condition in a similar way. User guide of a weather radar gives all the specifications regarding that particular radar. So for achieving best results one should have complete knowledge about the specifications of a radar. Also enhancement of the radar technology cannot be achieved unless the capabilities and limitations of that particular type of radar are analyzed fully.

REFERENCES

[1] Whiton, R.C., Smith, P.L., Bigler, S.G., Wilk, K.E. and Harbuck, A.C., 1998. History of operational use of weather radar by US weather services. Part I: The pre-NEXRAD era. *Weather and Forecasting, 13(2), pp.219-243*

[2] Hardy, K.R. and Katz, I., 1969. Probing the clear atmosphere with high power, high resolution radars. *Proceedings of the IEEE, 57(4), pp.468-480*

[3] Gossard, E.E., 1988. Measuring drop-size distributions in clouds with a clear-air-sensing Doppler radar. *Journal of Atmospheric and Oceanic Technology, 5(5), pp.640-649*

[4] Glahn, H.R. and Ruth, D.P., 2003. The new digital forecast database of the National Weather Service. *Bulletin of the American Meteorological Society, 84(2), pp.195-20.*

[5] Evans, J.E. and Ducot, E.R., 1994. The integrated terminal weather system (ITWS). *The Lincoln Laboratory Journal, 7(2), pp.449-474*

[6] Nohara, T.J., Eng, B., Eng, M., Weber, P., Ukrainec, A., Premji, A. and Jones, G., 2007. An overview of avian radar developments–past, present and future.

[7] Grund, C.J., Banta, R.M., George, J.L., Howell, J.N., Post, M.J., Richter, R.A. and Weickmann, A.M., 2001. High-resolution Doppler lidar for boundary layer and cloud research. *Journal of Atmospheric and Oceanic Technology, 18(3), pp.376-393*

[8] Zrnic, D.S., Kimpel, J.F., Forsyth, D.E., Shapiro, A., Crain, G., Ferek, R., Heimmer, J., Benner, W., McNellis, T.J. and Vogt, R.J., 2007. Agile-beam phased array radar for weather observations. *Bulletin of the American Meteorological Society, 88(11), pp.1753-1766*

[9] Hardy, K.R. and Ottersten, H., 1969. Radar investigations of convective patterns in the clear atmosphere. *Journal of the Atmospheric Sciences, 26(4), pp.666-672*

[10] Mukhopadhyay, P., Mahakur, M. and Singh, H.A.K., 2009. The interaction of large scale and mesoscale environment leading to formation of intense thunderstorms over Kolkata Part I: Doppler radar and satellite observations. *Journal of Earth System Science, 118(5), p.441*

[11] Crum, T.D. and Alberty, R.L., 1993. The WSR-88D and the WSR-88D operational support facility. *Bulletin of the American Meteorological Society, 74(9), pp.1669-1687*

[12] Smythe, G.R. and Zrnic, D.S., 1983. Correlation analysis of Doppler radar data and retrieval of the horizontal wind. *Journal of Climate and applied Meteorology, 22(2), pp.297-311*

[13] Cao, Q., Yeary, M.B. and Zhang, G., 2012. Efficient ways to learn weather radar polarimetry. *IEEE Transactions on Education, 55(1), pp.58-68*

[14] Hellemann, K. and Zachai, R., 1999, July. Recent progress in millimeter-wave sensor system capabilities for enhanced (synthetic) vision. In *Enhanced and Synthetic Vision 1999*(Vol. 3691, pp. 21-29). International Society for Optics and Photonics

[15] Lakshmanan, V., Rabin, R. and DeBrunner, V., 2003. Multiscale storm identification and forecast. Atmospheric research, 67, pp.367-380.

[16] Daniel, A.E., Miller, M.W. and Center, R.O., 2014. 5.2 NEW WSR-88D OPERATIONAL TECHNIQUES: RESPONDING TO RECENT WEATHER EVENTS.

[17] Chen, V.C., Li, F., Ho, S.S. and Wechsler, H., 2006. Micro-Doppler effect in radar: phenomenon, model, and simulation study. *IEEE Transactions on Aerospace and electronic systems, 42(1), pp.2-21*

[18] Shelton, K.J., Kramer, L.J., Ellis, K. and Rehfeld, S.A., 2012, October. Synthetic and Enhanced Vision Systems (SEVS) for NextGen simulation and flight test performance evaluation. *In Digital Avionics Systems Conference (DASC), 2012 IEEE/AIAA 31st (pp. 2D5-1). IEEE*

[19] Yujiri, L., Shoucri, M. and Moffa, P., 2003. Passive millimeter wave imaging. *IEEE microwave magazine, 4(3), pp.39-50*

[20] Kohn, M., Galanti, E., Price, C., Lagouvardos, K. and Kotroni, V., 2011. Nowcasting thunderstorms in the Mediterranean region using lightning data. *Atmospheric Research, 100(4), pp.489-502*

[21] Collins, R., 2003. Collins WXR-2100 MultiScan™ Radar Fully Automatic Weather Radar. Internet Citation, Jan, 1, p.1OPP.

[22] National Research Council, 1998. The future of air traffic control: Human operators and automation. National Academies Press.