INTRODUCTION

Uses

The operational use of weather radars in many fields calls for automated forecast tools. Potential users are all who are interested in short-term forecasts of precipitation (rain, snow, hail) for a specific location or a specific region, e.g:

- Weather services,
- Media (Radio, TV, ...),
- Air services,
- Road services, Police,
- Agriculture,
- Construction companies (buildings, roads, ...),
- Water management services (municipalities, sewers, electricity ...),
- Sports and
- Private users.

Weather Detection by Radars:

- Precipitation measurements
- Severe storm detection and tracking
- Snow detection
- Cloud detection
- Weather modification programs
- Wind measurements

Nowcasting

Nowcasting methods based on satellite and radar data are a topic since more than 25 years. Radar measures rainfall and radial component of the wind over large areas in real-time. Furthermore, because it sees echo movement, it is also very useful for short term precipitation prediction.

Short-term Public Weather Forecasts: One of the primary applications of radar data is short-term (0-4 hr) weather forecasting, also known as **nowcasting**. Data collected at TSMS is sent in real-time to the Analysis and Forecasting Center. Since the range of the radar is limited to a few hundred kilometers and since weather generally moves at speeds averaging

50 km/hr (faster in winter, slower in summer), radar can only see precipitation a few hours ahead at most. It has hence limited applications for the usual longer term weather forecasts, but proves extremely useful to issue warnings when severe weather develops rapidly in the vicinity. In fact, if a severe thunderstorm warning is issued in your area, it is generally because it has been detected and tracked by radar.

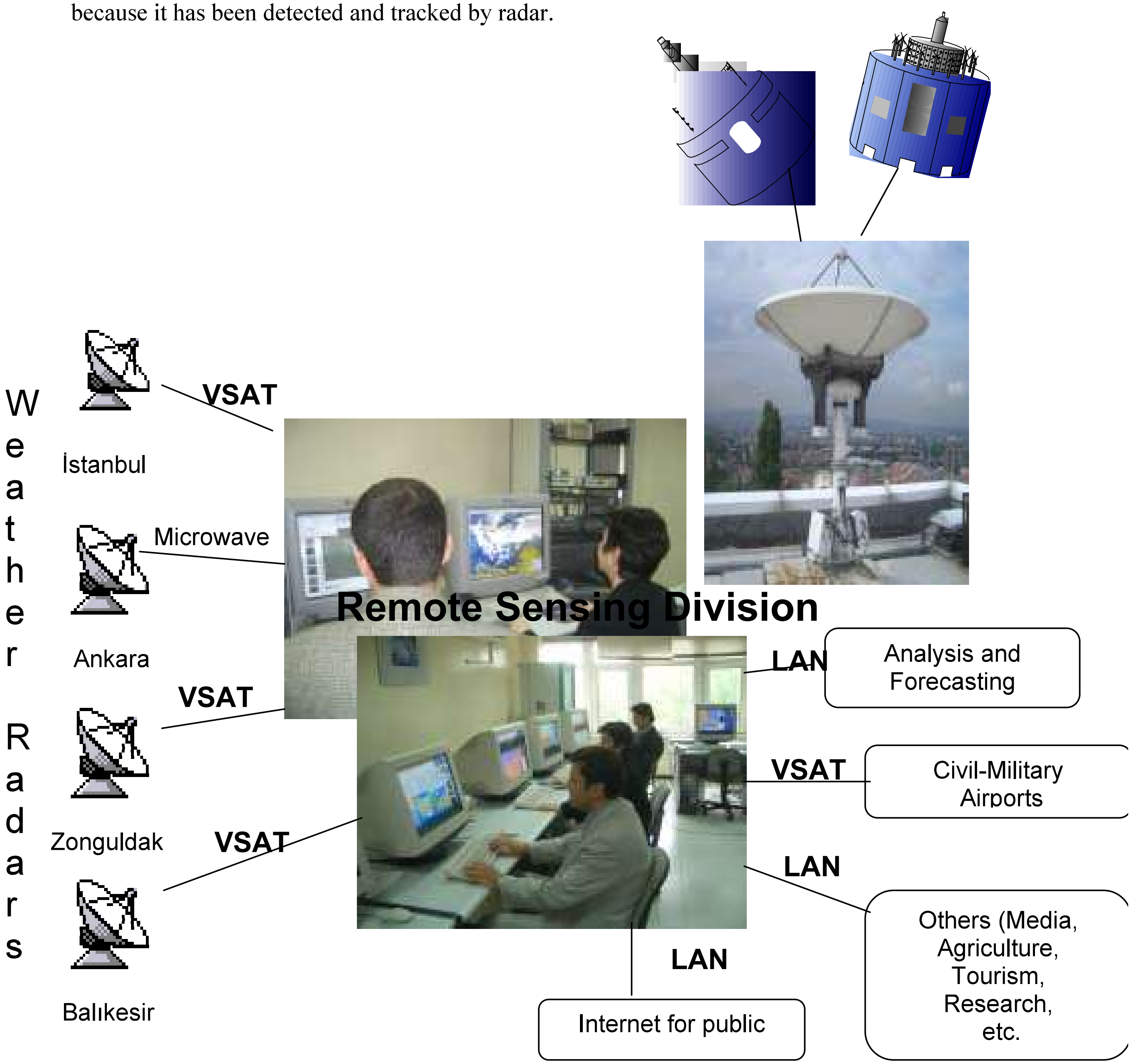


Figure 1: TSMS Radar and Satellite Data Acquisition.

Why is Radar Used in Meteorology?

Figure 2: Radar Image of a Squall Line.

This radar image shows a squall line (a line or narrow band of active thunderstorms). It affected a certain area during its movement. SL caused to heavy rain and also some hail over the many places that can be seen by using radar easily. When records of the 9 meteorological observing stations at the area were studied, heavy rain and thunderstorms were observed by all stations, but hail could be observed by only one station (Osmancık) at the time from 15:10 to 15:13.

Conclusion:

- In fact, SL caused thunderstorms with hail over the many places through its movement.
- Weather radars allow a wide point of view to the meteorologists.
- While satellite data gives a forecaster a sense of the "big picture", radar provides more detail on at smaller scales of weather.

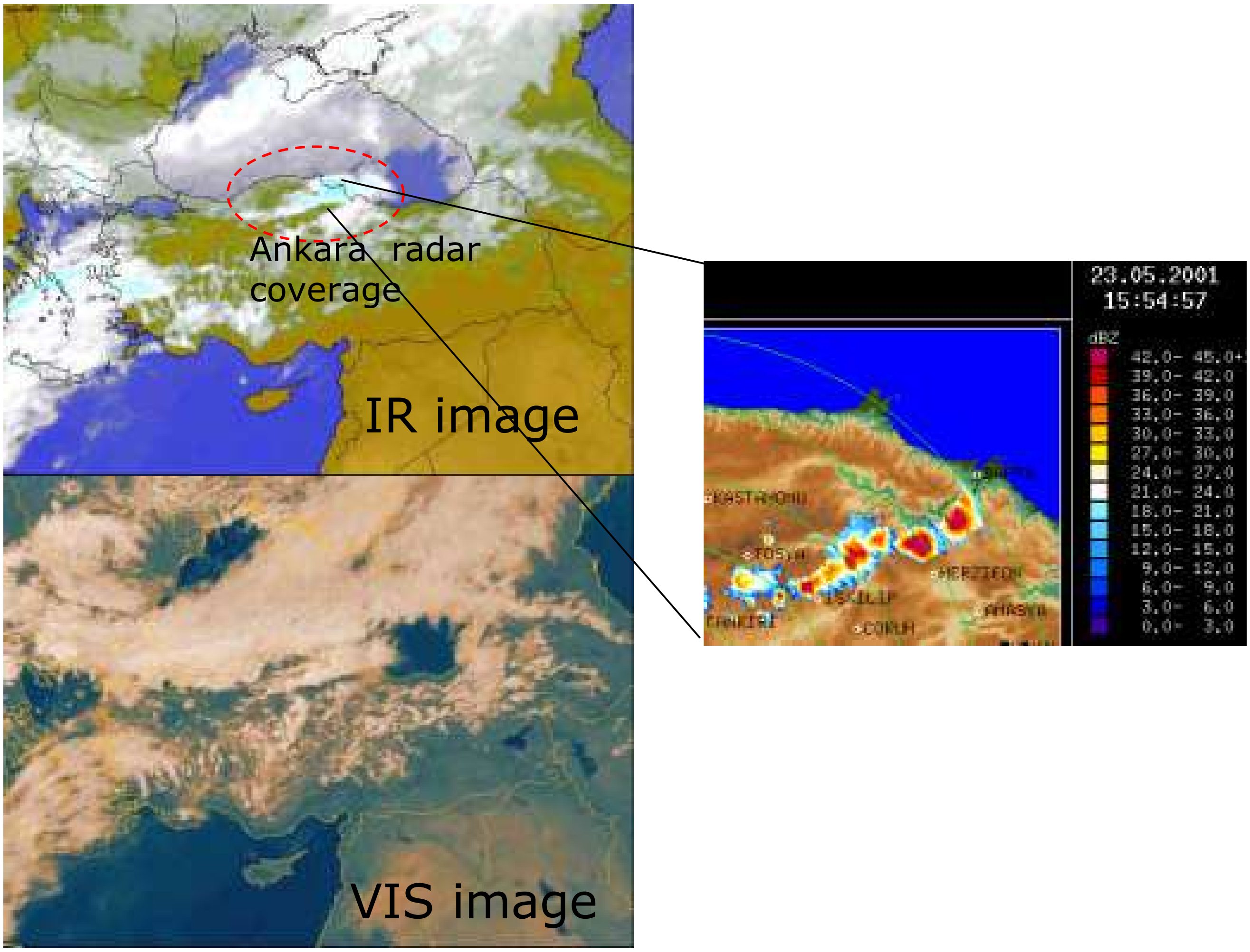


Figure 3: Satellite Images of the Squall Line.

Weather forecasters use radar to help determine:

- The movement and trend of thunderstorms
- Variability and concentration of precipitation

There are two important aspects of radar that we're concerned with:

- Amount of energy scattered back from a target to the radar

Estimate the intensity of storms and the amount of precipitation

- Velocity of a target relative to the radar

Estimate air motions and circulations within clouds

1. RADAR PRODUCTS

1.1. RPG (Radar Product Generation)

1.1.1. Signal Processing and Radar Product Generation

The processing of radar data generally involves two distinct steps. The first step, called **signal processing**, is the extraction of raw radar parameters like echo strength (reflectivity) or Doppler velocity from the radar signals coming out of the receiver. The second step, called **data processing** or **product generation**, is the further processing of raw radar parameters in order to obtain information that is useful for meteorological or hydrological purposes. In general, these two steps are done by different computers, signal processing being done at the radar site, while product generation can be done everywhere the data are sent to.

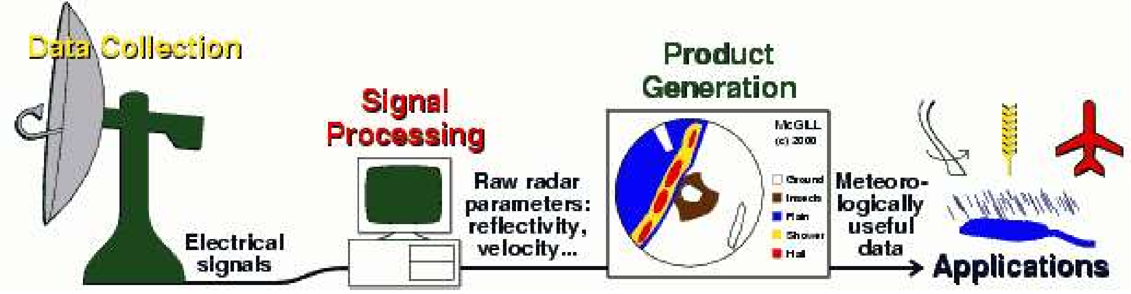
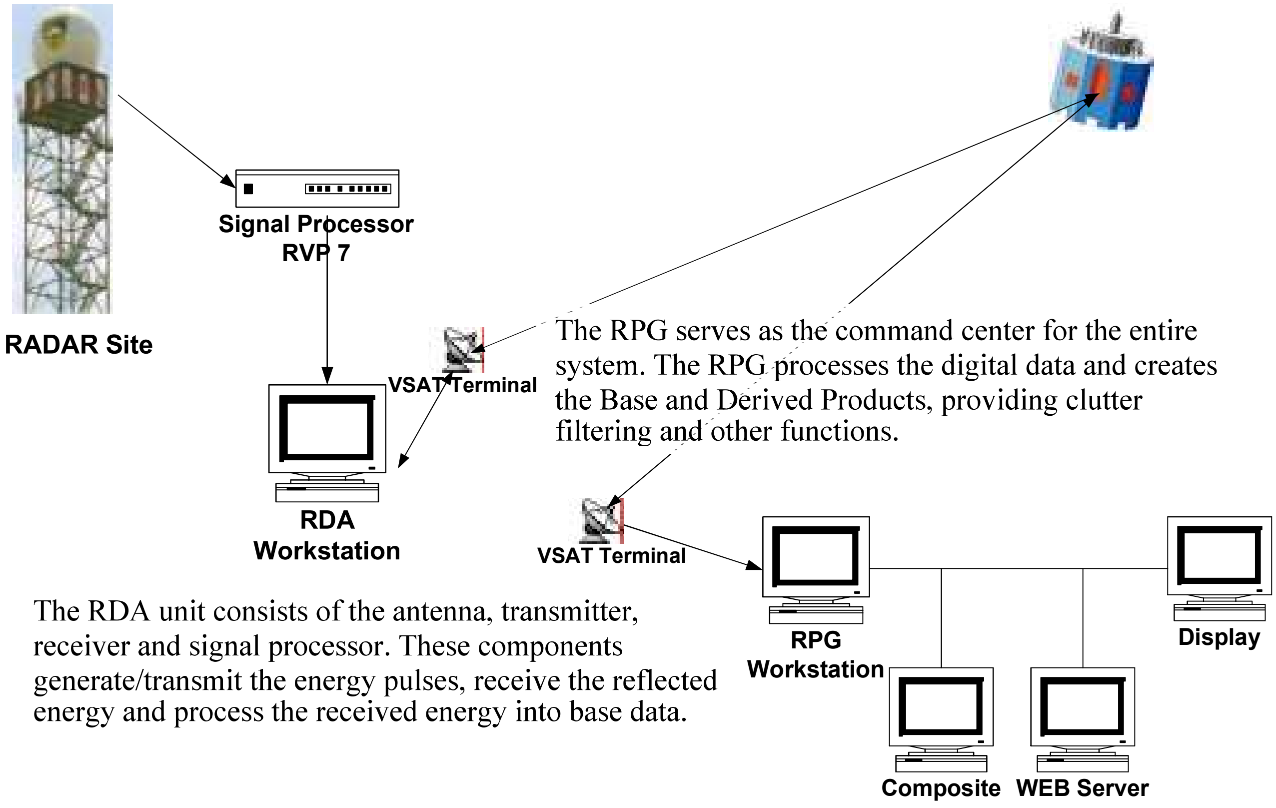


Figure 4: Signal Processing and Radar Product Generation.

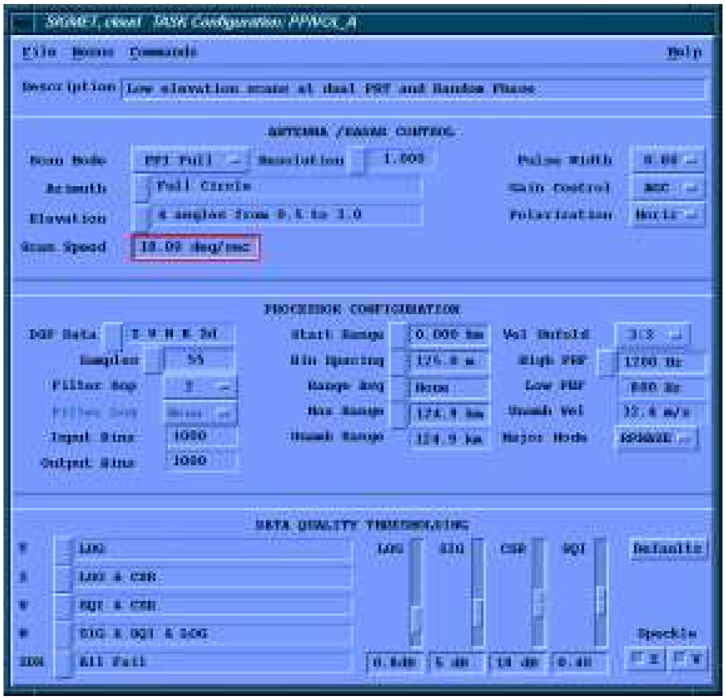


The RPG serves as the command center for the entire system. The RPG processes the digital data and creates the Base and Derived Products, providing clutter filtering and other functions.

The RDA unit consists of the antenna, transmitter, receiver and signal processor. These components generate/transmit the energy pulses, receive the reflected energy and process the received energy into base data.

Figure 5: Radar Data Flow Infrastructure.

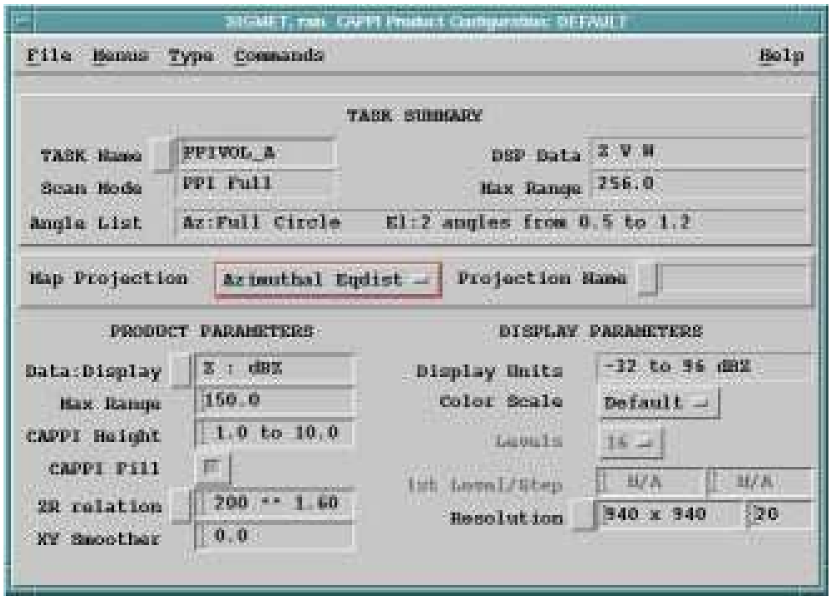
Every product is associated with a TASK, defines a radar TASK such as a volume scan, single PPI sweep or sector scan. Up to three TASKS can be linked together to form a hybrid TASK for complex scan strategies. There is no limit to the number of TASKS that can be defined.



Scan Mode: PPI Full
Resolution: 1.000
Azimuth: Full Circle
Elevation: 4 angles from 0.5 to 3.0
Scan Speed: 18.00 deg/sec
Start Range: 0.000 km
Input Bins: 1000
Output Bins: 1000
Vel Unfold: 3:2
High PRF: 1200 Hz

Figure 6: Task Configuration Tool.

To configure the details of the product generation for each product type such as the range and resolution of the product as well as product-specific information such as the CAPPI heights.



TASK Name: PPIVOL_A
Scan Mode: PPI Full
Angle List: Az:Full Circle El:2 angles from 0.5 to 1.2
DSP Data: Z V W
Max Range: 256.0
Map Projection: Azimuthal Eqdist
Projection Name:
Data:Display: Z : dBZ
Max Range: 150.0
CAPPI Height: 1.0 to 10.0
CAPPI Fill: ☐
ZR relation: 200 ** 1.60
XY Smoother: 0.0
Display Units: -32 to 96 dBZ
Color Scale: Default
Levels: 16
1st Level/Step: N/A N/A
Resolution: 940 x 940 20

Figure.7: Product Configuration Tool.

1.2. Radar Parameters

The basic radar parameters are:

1. Reflectivity [Z]
2. Rainfall Rate [R]
3. Velocity [V]
4. Spectrum Width [W]
5. Differential Reflectivity [ZDR]

1.2.1. Reflectivity

Some degree of transmitted energy (power) is likely to be returned to the radar antenna (receiver) as a result of backscattering. Reflectivity is simply a measure of how much power was scattered back to the radar from any targets. Stronger targets have higher levels of reflectivity and return more energy. Thus, stronger targets have higher reflectivity values; that is, higher dBZ levels.

dBZ is also related to the number of drops per unit volume and the sixth power of their diameter (and also it can be related to rainfall rate through an empirical relationship called the **"Z-R relationship").**

$\mathbf{z=\sum D_i^6}$ (mm^6/m^3) → Linear Radar Reflectivity Factor

$\mathbf{dBZ=10\log_{10}z}$ → Logarithmic Radar Reflectivity Factor

Linear Value ***z(mm^6/m^3)***	***Logarithm*** ***$log_{10}z$***	***Decibels*** ***dBZ***
1000	3	30
100	2	20
10	1	10
1	0	0
0.1	-1	-10
0.01	-2	-20
0.001	-3	-30

No Precipitation

Table.1: The Range of Radar Reflectivity Factor.

Radar reflectivity factor can take on a tremendous range of values: 0.001(fog)–40,000,000 mm^6/m^3 (large hail) (-30 ~ +76 dBZ). Radar reflectivity factor of the clouds which do not produce rainfall or produce little rainfall is generally low. So, most of the meteorologists are not interested in very light precipitation.

Corresponding "dBZ" values of fog and hail:

$z=0.001\ mm^6/m^3$ (fog)
$dBZ=10\log_{10}z$
$=10\log_{10}(0.001)$
$=10x(-3)$
dBZ=-30

Definition of this fog:
Assume that there is a cloud in a radar scope which has 1,000,000,000 drops and average diameter of the drops is 0,01 mm in 1 m^3;
For each drops → $D_i^6=0{,}01^6\ mm^6=10^{-12}\ mm^6$
$z=1{,}000{,}000{,}000\ m^{-3}x10^{-12}\ mm^6$ → *$z=0.001\ mm^6/m^3$*

$z=156{,}250\ mm^6/m^3$ (heavy rain with some hail possible)
$dBZ=10\log_{10}z$
$=10\log_{10}(156{,}250)$
$=10x(5.19)$
dBZ=**51,9**

Definition of this hail:
Assume that there is a cloud in a radar scope which has
10 drops and average diameter of the drops is 5 mm in 1 m^3;
For each drops → $D_i^6=5^6\ mm^6=15625\ mm^6$
$z=10\ m^{-3}x15625\ mm^6$ → *$z=156{,}250\ mm^6/m^3$*

Energy backscattered from a target as seen on the radar display, i.e. echo intensities are displayed as on color figure below:

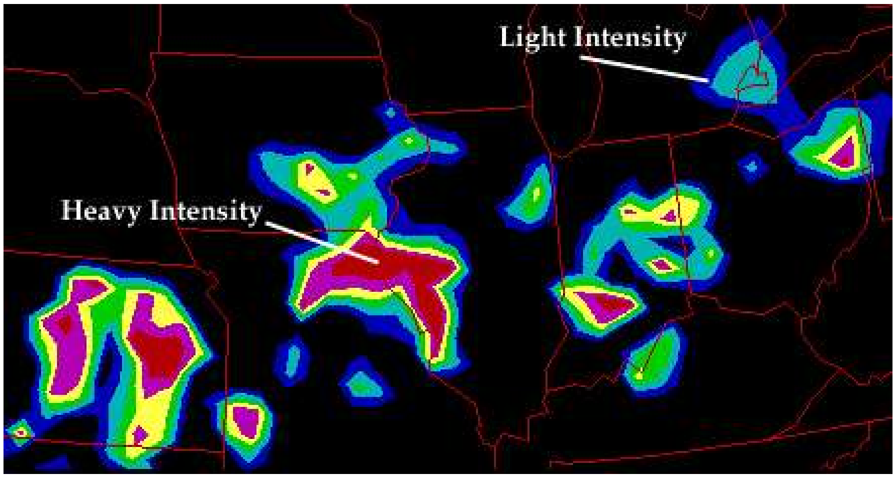


Figure 8: Echo Intensity.

Two different scales are generally utilized. A legend on the right side of the radar images show the relationship between the colours and the amount of reflected energy. Clear Air mode is more sensitive than Precipitation mode.

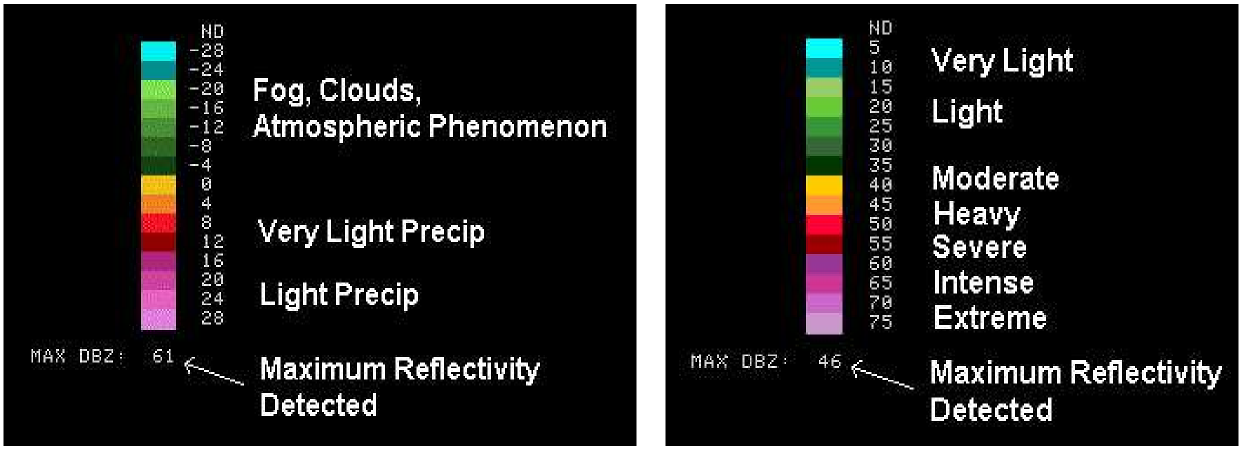


Figure 9: Echo Intensity Scales for Clear Air (on the Left) And Precipitation Mode (on the Right).

dBZ values are what you typically see on radar displays (e.g., on T.V.). In the table below a guideline on the interpretation of dBZ factors are given:

dBZ	Rain Rate	Comments
10	~0.2	Significant but mostly non-precipitating clouds
20	~1	Drizzle, very light rain
30	~3	Light rain
40	~10	Moderate rain, showers
50	~50	Heavy rain, thundershowers, some hail possible
60	~200	Extremely heavy rain, severe thunderstorm, hail likely

Table 2: The Interpretation of dBZ Factors.

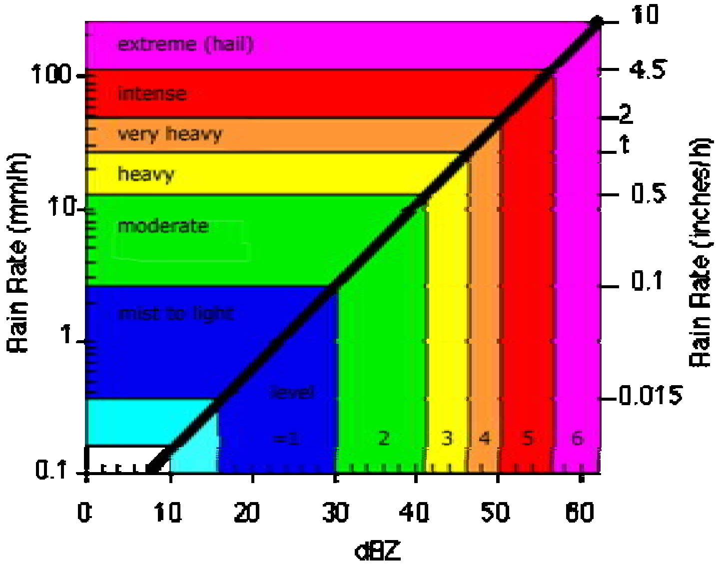


Figure 10: The Interpretation of dBZ Factors on Color Figure.

1.2.2. Rainfall Rate

One of the earliest quantitative uses of meteorological radar data was for the measurement of rainfall. Radar's ability to scan rain showers and thunderstorms over large areas very quickly made it obvious to the early users that much could be learned about rainfall through the use of radar.

Weather radars are not able to measure precipitation directly. We saw earlier that the reflectivity factor (z) is related to the size of precipitation particles in the radar echo. If we assume that our radar echo has known distribution of precipitation particles (i.e., number of drops of different size categories), we can relate the reflectivity factor (z) to the rainfall rate (R- mm/hr) in our echo feature:

$z=AR^b$ *(A and b are constants determined by the assumed drop size distribution)*

This kind of equation between reflectivity factor and rain rate is called "*Z-R relation*".

Precipitation measurement is done automatically by radar's softwares.
Since the value of A and b will be specific to each radar site configuration, many researchers have produced a large variety of values A and b. A and b depend on the distribution and character of precipitation. Most common Z-R relation is:

$z=200R^{1.6}$ by Marshall and Palmer (in 1948). This is used for stratiform rain.

Some other Z-R relations are:

$z=31R^{1.71}$ for orographic rain (Blanchard, 1953)
$z=500R^{1.5}$ for thunderstorm (Joss, 1970)
$z=350R^{1.4}$ for convective rain
$z=2000R^{2}$ for snow (Marshall and Gunn, 1958)
Scores more…

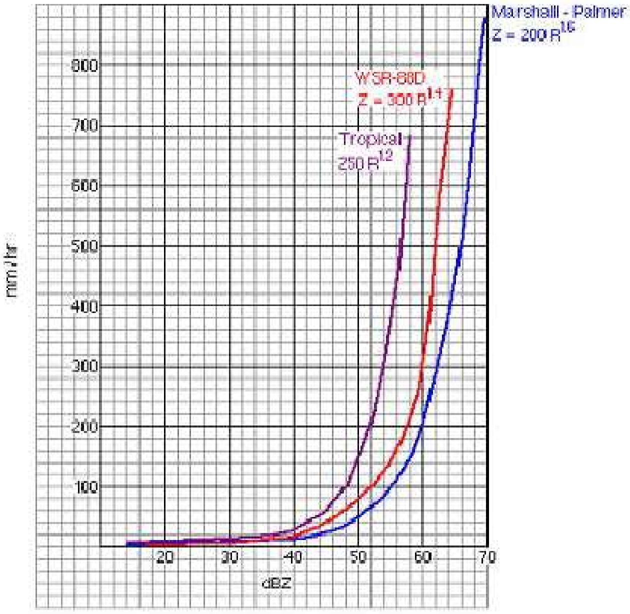


Figure 11: Some Z-R Relations as Graphically.

1.2.3. Velocity

Until now, we have only considered **power** measurements with radar. Most modern radars now easily measure **velocities** of targets. These are **Doppler radars**. Doppler is a means to measure motion. Doppler radars not only detect and measure the power received from a target, they also measure the motion of the target toward or away from the radar. This is called the "**Radial Velocity**". Radial velocity is determined from **Doppler frequency shift** of the target. Doppler frequency shift caused by a moving target. Moving targets change the frequency of the returned signal. This frequency shift is then used to determine wind speed. Doppler radars routunely measure velocities and used to detect wind speeds, tornadoes, mesocyclones.

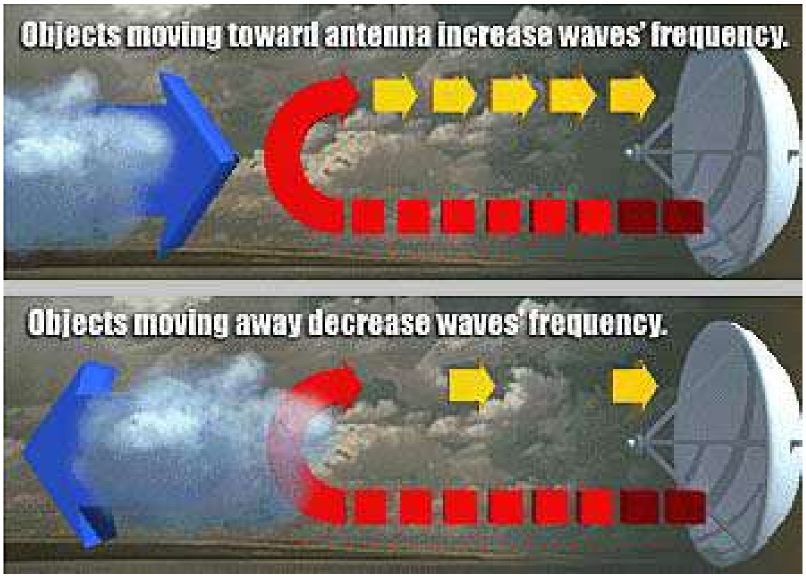


Figure 12: Doppler Frequency Shift by Moving Targets.

Motion towards a Doppler radar is expressed in negative values and green (cool) colours on a display screen. Motion away from a Doppler radar is expressed in positive values and red (warm) colours.

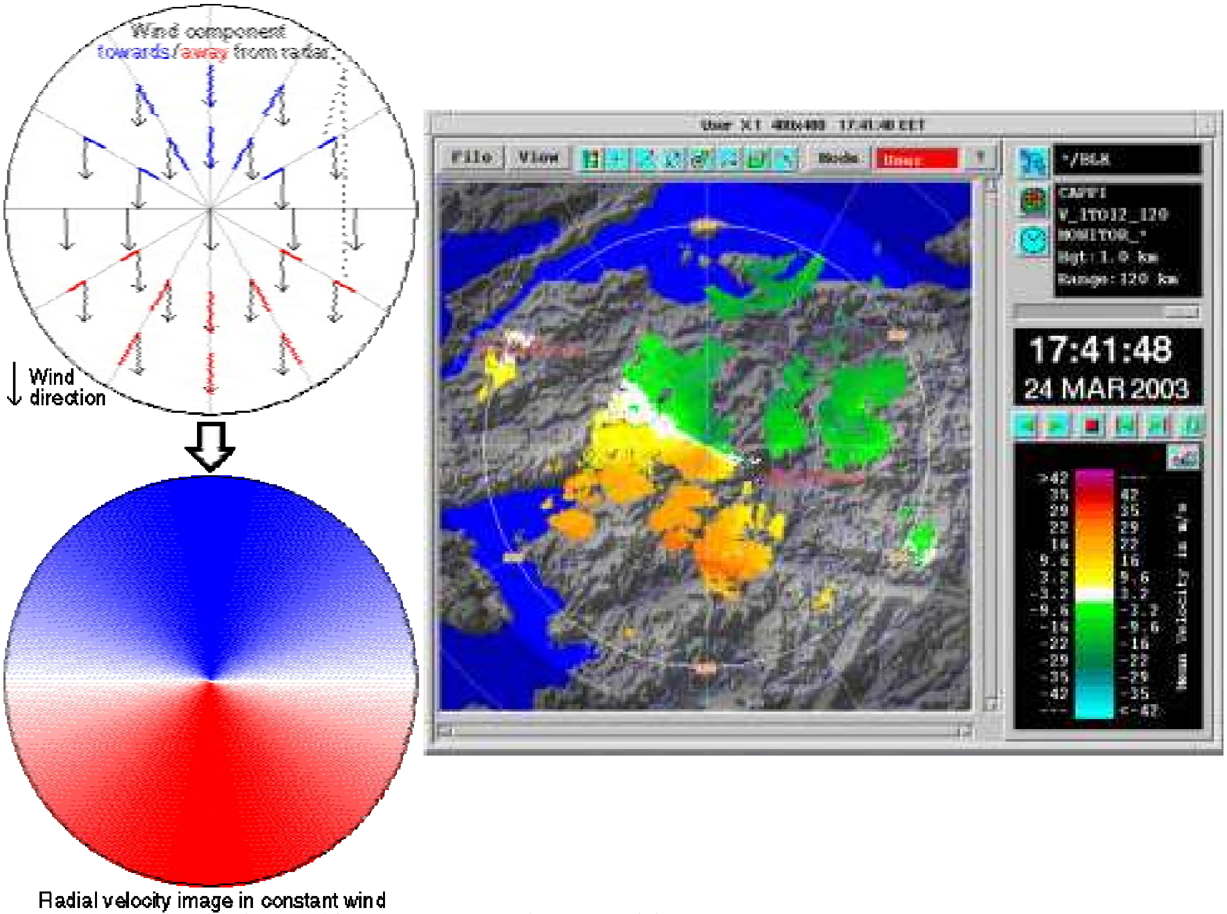


Figure 13: Doppler Radial Velocities and an Example Image.

If the target is moving sideways so that its distance relative to the radar does not change, the radar will record zero radial velocity for that target.

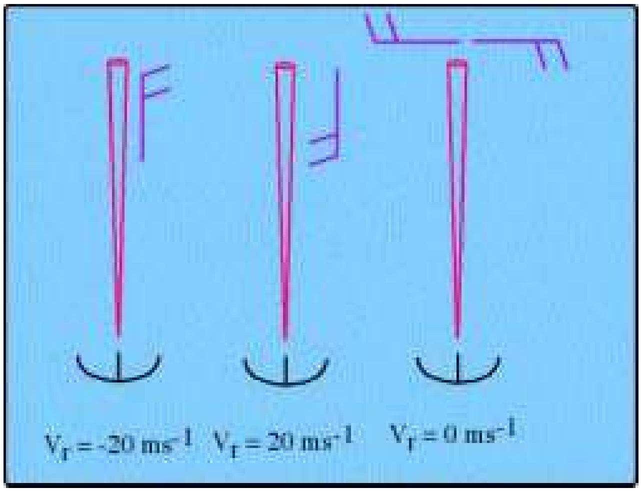
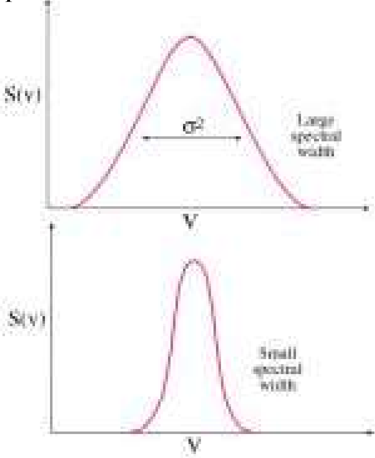


Figure 14: Another Schema of Doppler Radial Velocities.

1.2.4. Spectrum Width

Spectrum Width data is a measure of dispersion of velocities within the radar sample volume. In other words, it is the distribution of velocities within a single radar pixel.One pixel on radar represents a volume within which there can be literally millions of individual hydrometeors. Each individual hydrometeor will have its own speed and direction of movement.

The radar averages the individual radial velocities with a volume sample to produce a single average radial velocity that is displayed for that pixel. In a situation, where shear and turbulence is **small** within a pixel, the spectrum width will be **small**. In a situation, where shear and radial velocity is **large** within a pixel, the spectrum width will be **large**. A technical way of defining spectrum width is the **standard deviation** of the velocity distribution within a single pixel.



→ Strong shear and turbulence, thunderstorm

Average Spectral Width (m/s)		
Turbulance		
Moderate	Severe	Extreme
4	7	≥ 8

Figure 15: Spectrum Width and Its Averages.

1.2.5. Differantial Reflectivity

Differantial reflectivity parameter is a kind of data produced by polarimetric radars. In general, weather radars send and receive microwaves at one polarization, usually horizontal, because raindrops are usually oblate. By transmitting and/or receiving radar waves at more than one polarization, additional information can be obtained on the nature of the targets. Differential Reflectivity is a ratio of the reflected horizontal and vertical power returns. Amongst other things, it is a good indicator of drop shape. In turn, the shape is a good estimate of average drop size.

The signals that are received from each polarization channel are averaged separately, and radar reflectivity factors are determined from each, giving z_H and z_V. The reflectivity depolarization ratio is defined as:

$$Z_{DR}=10\log_{10}(z_H/z_V)$$

where z_H and z_V are the linear radar reflectivity factors at horizontal and vertical polarization, respectively. Z_{DR} is measured in decibels.

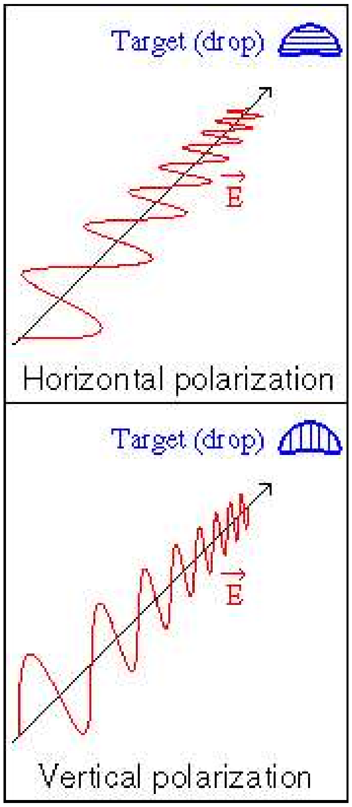


Figure 16: Dual Polarisation.

1.3. Product Descriptions

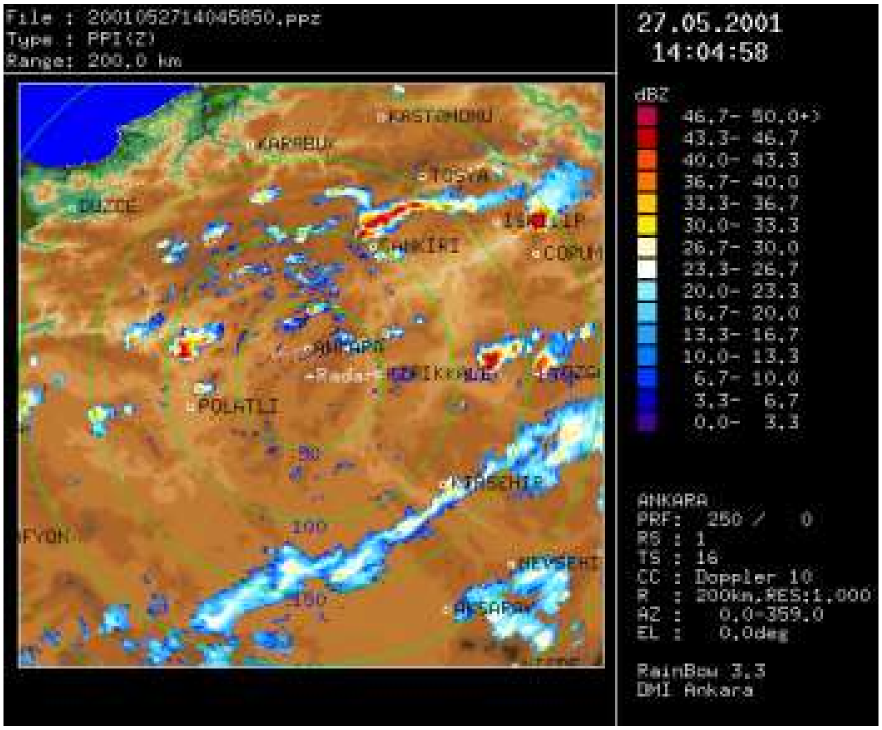
Radar data is displayed on three forms generally:

- **PPI** (*Plan Position Indicator*)
- **CAPPI** (*Constant Altitude Plan Position Indicator*)
- **RHI** (*Range Height Indicator*)

Radar scans for producing these basic products were explained in the Section of Scanning Strategies.

1.3.1. PPI (Plan Position Indicator)

PPI is the most common (classic) display of radar data and it is produced in much shorter time than volume scan. It shows the distribution of the selected data parameter (Z, R, V, W or ZDR) on a constant elevation angle surface (near to 0°).



```
File : 20010527140458S0.ppz
Type : PPI(Z)
Range: 200.0 km
```

```
27.05.2001
 14:04:58
```

```
ANKARA
PRF:  250 /   0
RS : 1
TS : 16
CC : Doppler 10
R  : 200km,RES:1.000
AZ :   0.0-359.0
EL :   0.0deg

RainBow 3.3
DMI Ankara
```

Figure 17: A PPI Reflectivity Product from Ankara Radar.

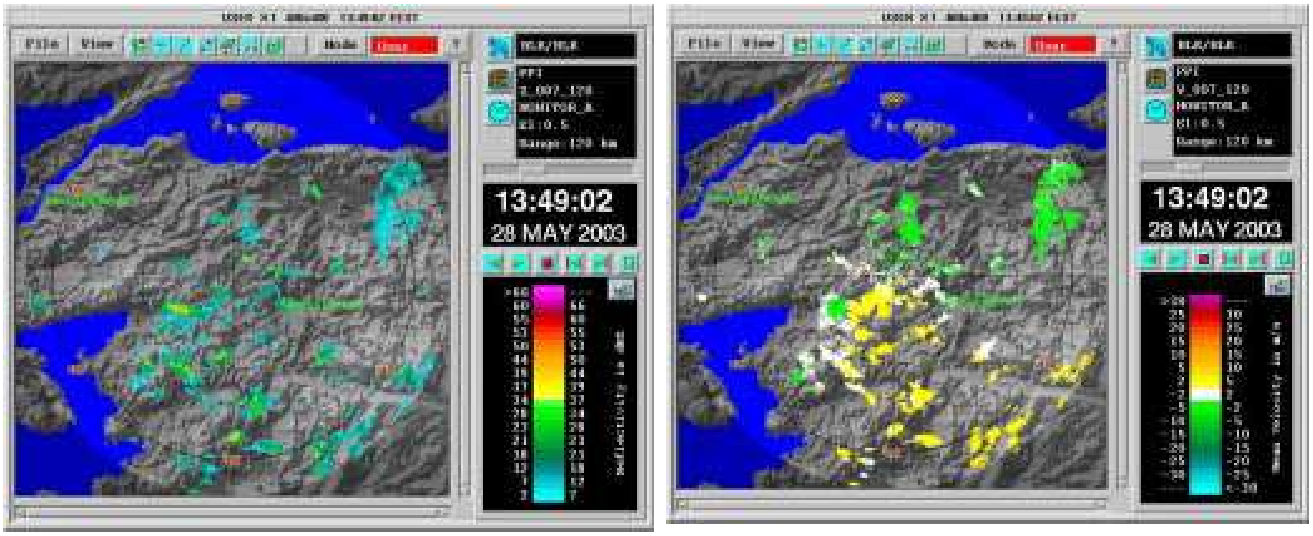


Figure 18: PPI Reflectivity and Velocity Products at the Same Time from Balikesir Radar.

1.3.2. CAPPI (Constant Altitude Plan Position Indicator)

CAPPI product is a horizontal cut through the atmosphere, therefore, it requeres a PPI volume scan at multiple elevation angles. The number of angles and their spacing depends on the range and height of the CAPPI you want to produce.

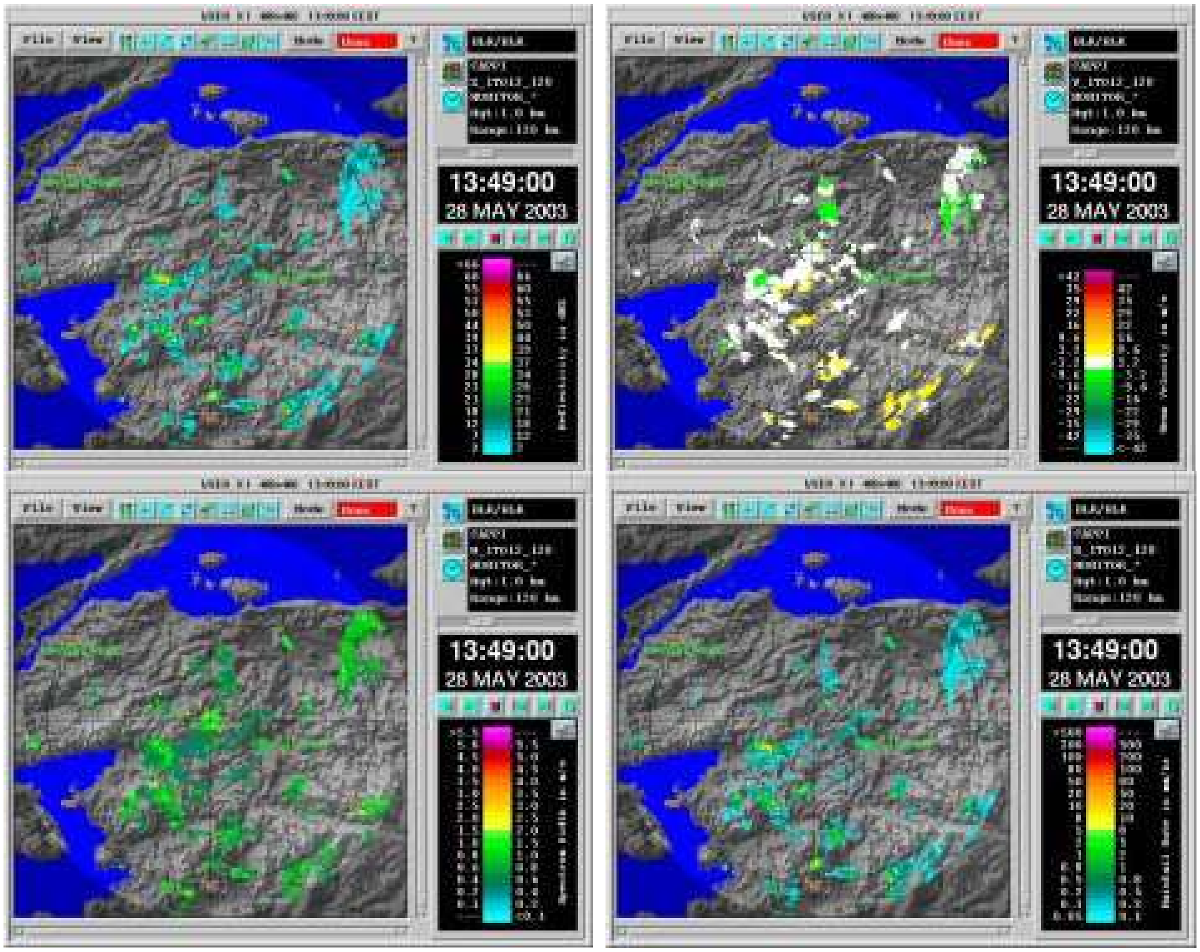


Figure 19: CAPPI Reflectivity, Velocity, Spectrum Width and Rainfall Rate Products at the Same Time from Balikesir Radar

1.3.3. RHI (Range Height Indicator)

RHI product is excellent for viewing the detailed vertical structure of a storm. In general, you should schedule a RHI TASK through a region of interest. During RHI scanning, the antenna azimuth is fixed and the elevation is swept, typically from near 0° to 90° to create a vertical cross-section effect.

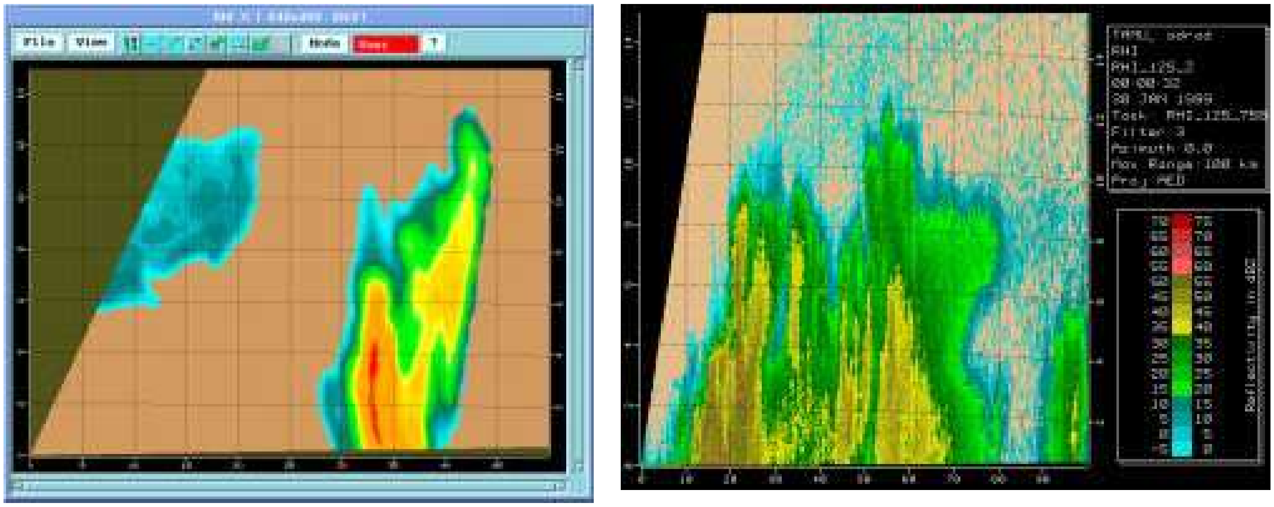


Figure 20: RHI Reflectivity Products.

1.3.4. Other Products

Some other important radar products are given below:

- MAX (Maximum Display)
- Echo Tops
- Wind Products
  - Horizontal Wind Vectors
  - VVP (*Velocity Volume Processing*) or VAD (*Velocity Azimuth Display*)
  - Wind Shear
- Rainfall Produts
  - SRI (*Surface Rainfall Intensity*)
  - Hourly and N-Hours Rainfall Accumulation
  - VIL (*Vertically Integrated Liquid)*
  - Rainfall Subcatchments
- Warning Products

1.3.4.1. MAX (Maximum Display)

MAX product shows the maximum echoes on each pixels between user selected heights (in this case 0 km and 15 km, below).

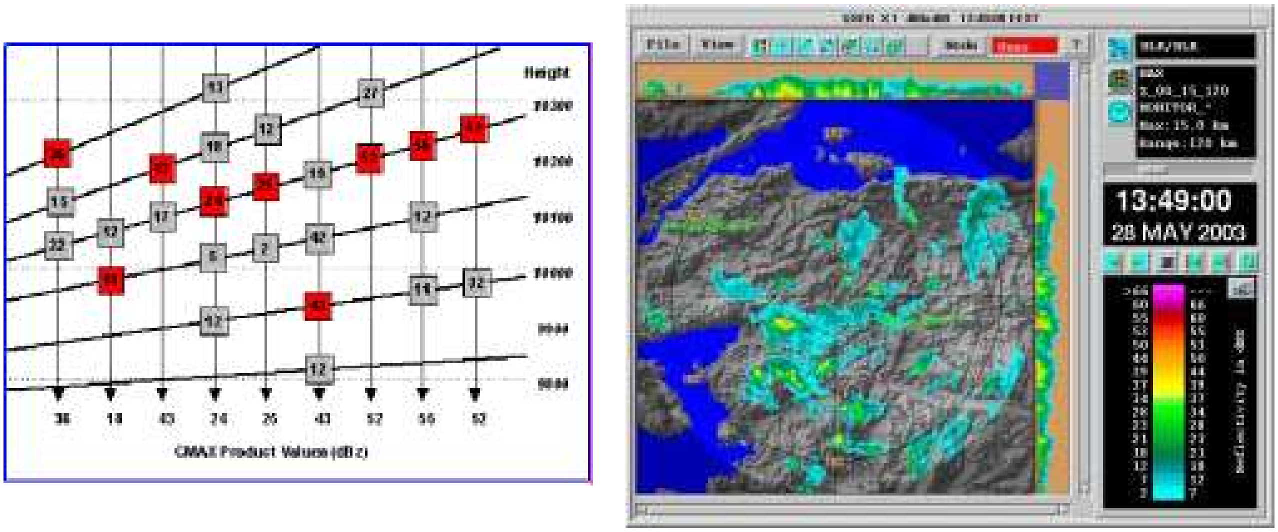


Figure 21: Schema of the MAX Product and a MAX Image from Balikesir Radar.

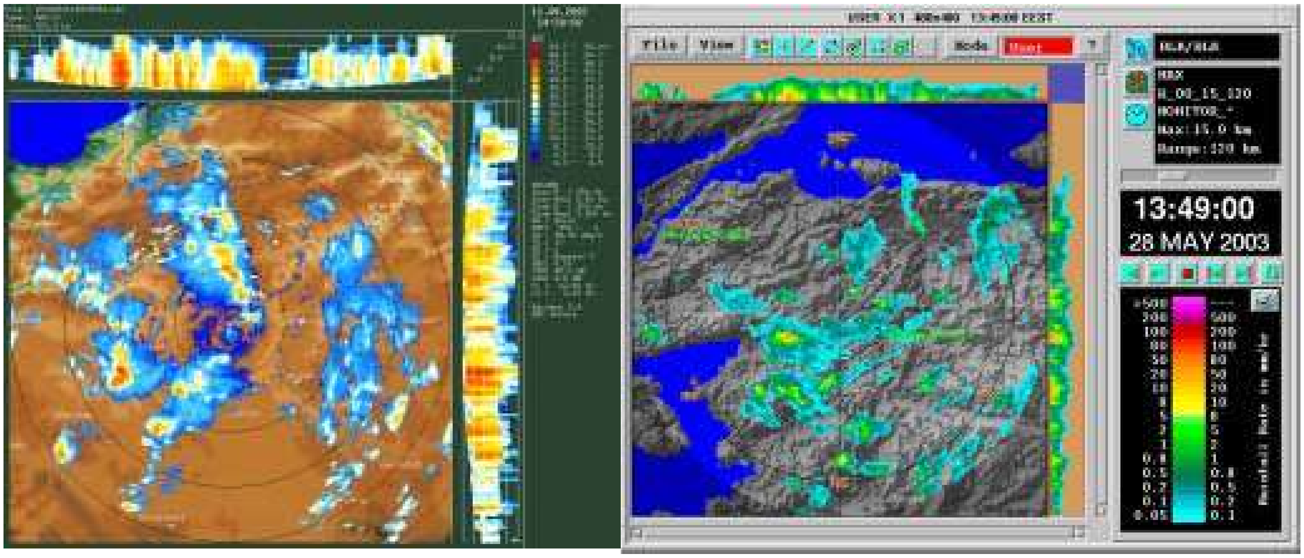


Figure 22: Other Some MAX Products (Reflectivity from Ankara, Rainfall Rate from Balikesir Radar).

1.3.4.2. Echo Tops

Echo Tops product shows tops heights (in kilometers) at the user selected thresholded (in this case at 30 dBZ, below). It is an excellent indicator severe weather and hail.

Figure 23: An Echo Tops Product.

1.3.4.3. Wind Products

1.3.4.3.1. Horizontal Wind Vectors

Horizontal wind vectors are displayed as wind speed and direction with either wind barbs or wind strings.

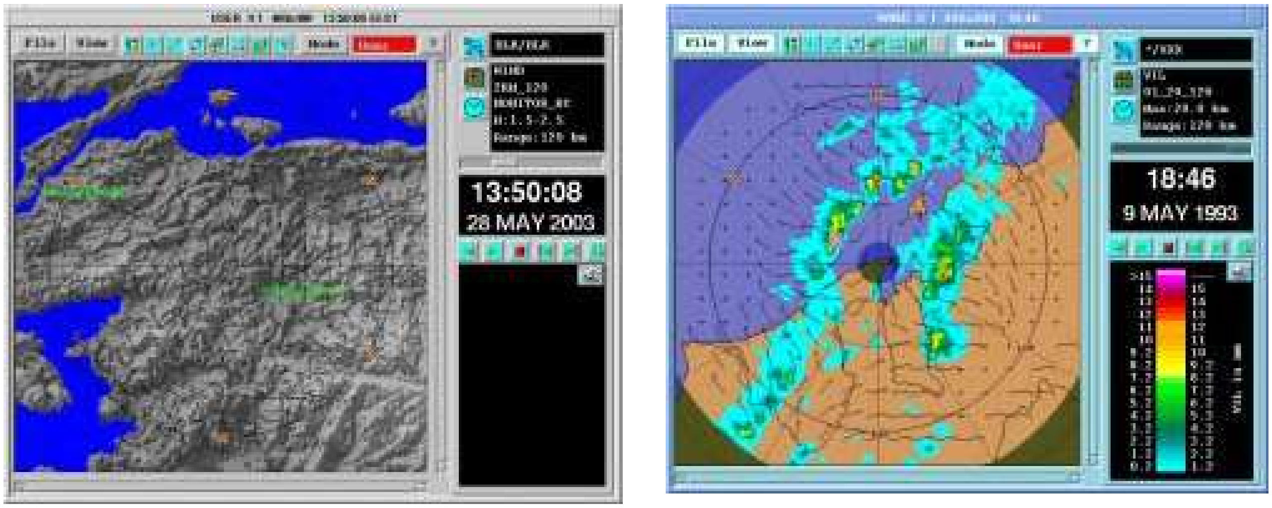


Figure 24: Horizontal Wind Vectors.

1.3.4.3.2. VVP (Velocity Volume Processing) or VAD (Velocity Azimuth Display)

In the VVP product, wind speed and direction (windbarbs) is plotted as a function of height an time. Also, the background is color coded with reflectivity levels.

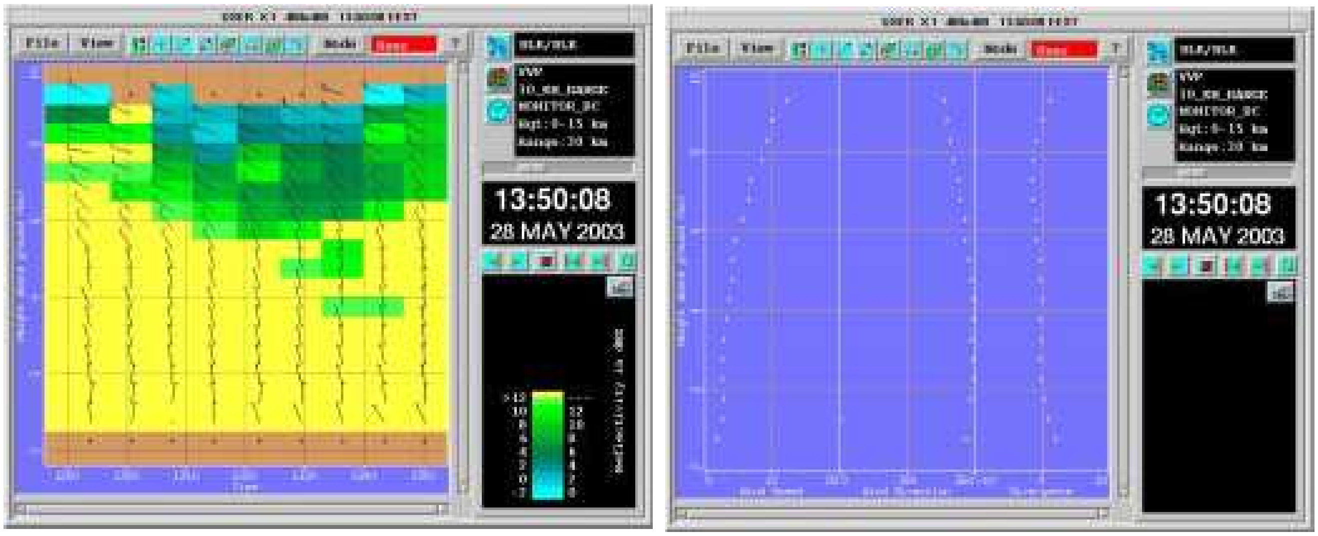


Figure 25: Some Types of VVP Product.

1.3.4.3.3. Wind Shear

Wind shear in the atmosphere can be detected by Doppler radars. Wind shear product is used for microburst and gust front detection. An important point that mountain radars are not able to observe to sufficiantly low altitudes immediately above the airports to reliably detect microburst.

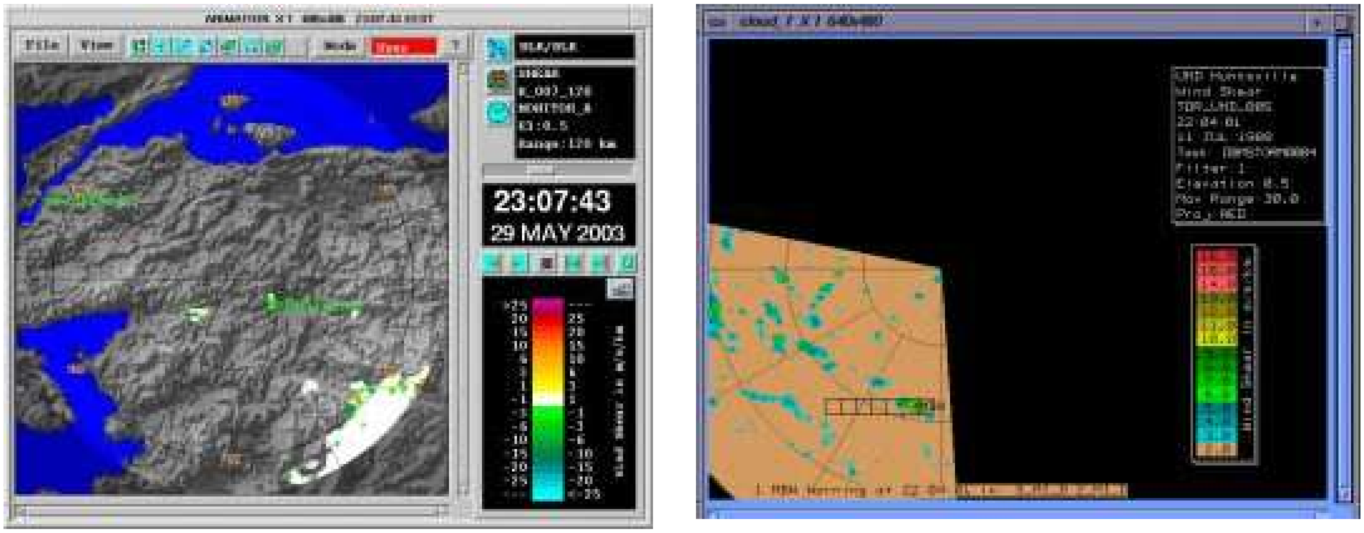


Figure 26: Some Wind Shear Products and Microburst Warning on the Right.

1.3.4.4. Rainfall Products

1.3.4.4.1. SRI (Surface Rainfall Intensity)

The SRI product shows the rainfall intensities based on Z-R relation.

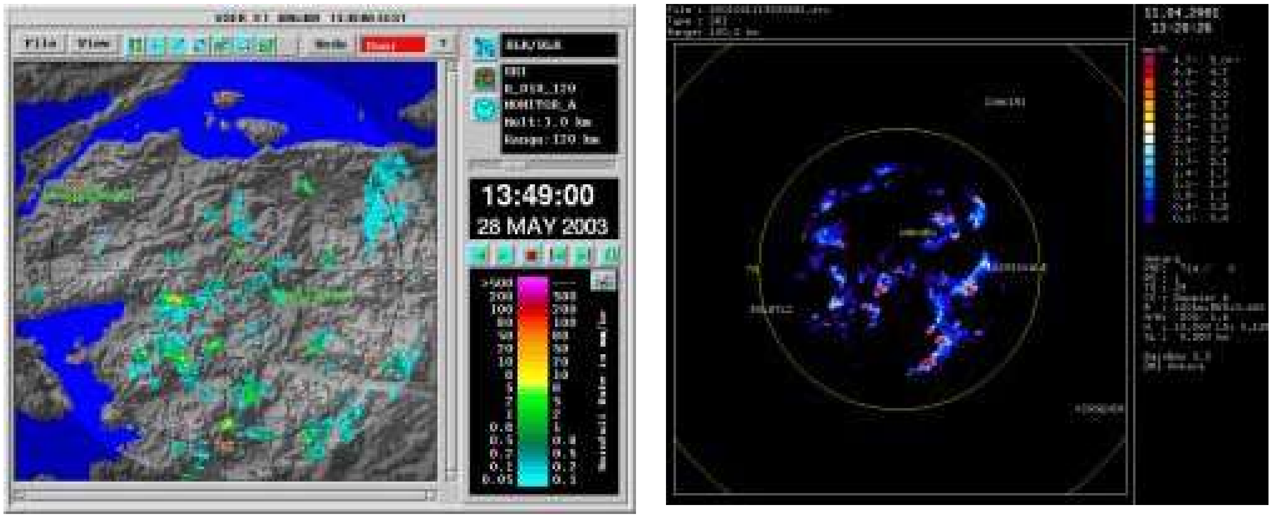


Figure 27: Some SRI Products.

1.3.4.4.2. Hourly and N-Hours Rainfall Accumulation

Hourly and last 6-Hours rainfall accumulation example products are below.

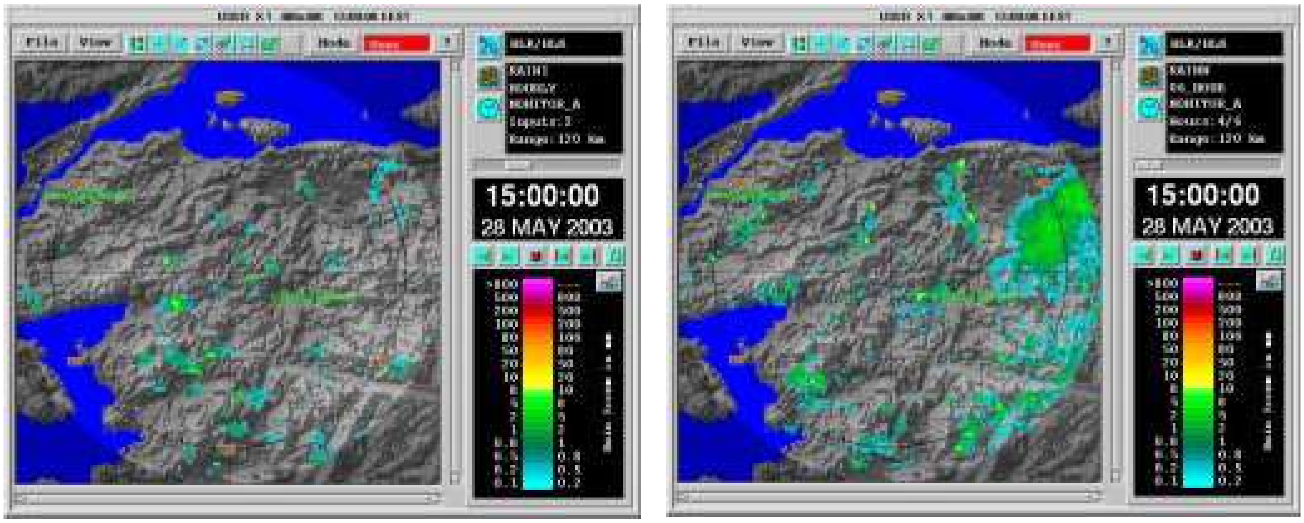


Figure 28: Hourly and 6-Hours Rainfall Accumulation Products.

1.3.4.4.3. VIL (Vertically Integrated Liquid)

VIL product is an excellent indicator of severe storm activity, especially with regard to the rainfall potential of a storm. The output shows the estimated precipitation (in milimeters) contained within a user-defined layer. If the layer height is above the freezing level, high VIL values are an excellent indicator of severe storm and hail. If the layer height extends from the surface up to 3 km, then the VIL values serve as a forecasting guide as to how much precipitation is likely to fall during the next few minutes.

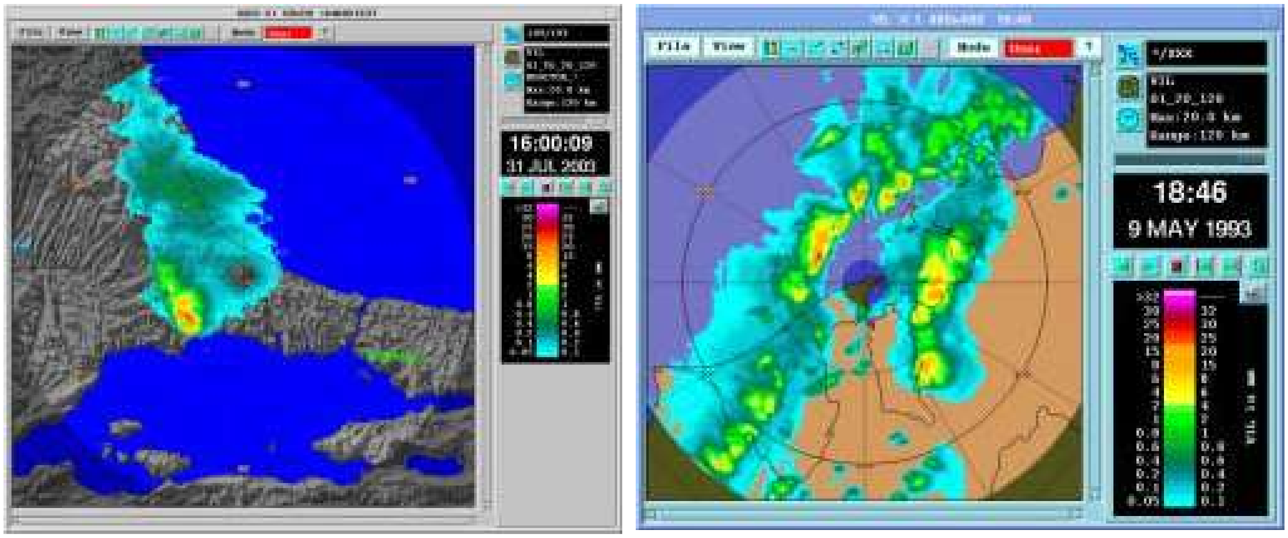


Figure 29: Some VIL Products.

1.3.4.4.4. Rainfall Subcatchments

The precipitation accumulation in subcatchment regions such as watershed areas can be calculated by radars. It is used for hydrometeorological applications such as estimating the total rainfall in a river basin for the purpose of flood forecasting. This product can also issue warnings if the precipitation in a subcatchment region exceeds a treshold value.

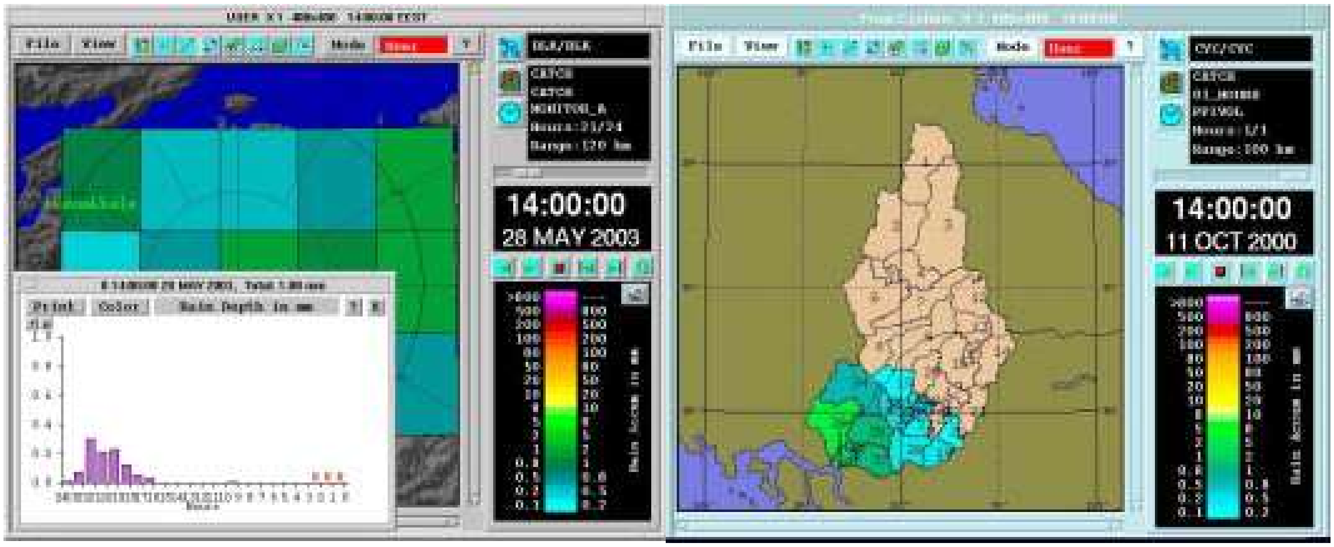


Figure 30: Some Rainfall Subcatchments Products.

1.3.4.5. Warning Products

Warning products are used for detecting significant weather. For example, the occurrence of 45 dBZ at 1.5 km above the freezing level is a good indicator of hail in many mid-latitude locations. Suppose the freezing level is at 4 km, and you run an Echo Tops product for the 45 dBZ contour. If the Echo Tops product shows 45 dBZ tops at heights greater than 5.5 km, there is a high probability of hail. Because of this general approach, the automatic warning feature can provide alerts for a wide variety of weather phenomena.

Some examples of warning criteria are summarized below:

Hail Detection: [45 dBZ Echo Tops > 1.5 km above freezing level] over an area of 10 km^2

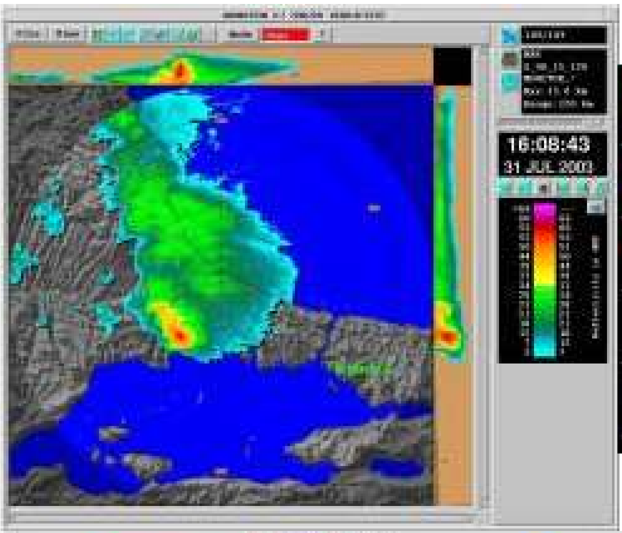
Wind Shear Detection: [Wind Shear > 10 m/s/km at 0.5° EL] .AND. [... at 0.7° EL] over an area of 3 km^2

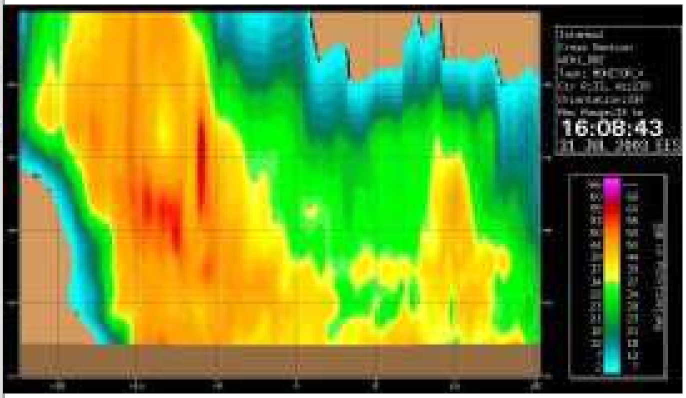
Storm Turbulence Detection: [Spectrum Width > 6 m/s] .AND. [Reflectivity > 20 dBZ] over an area of 10 km^2

Precipitation Surveillance Detection: [1.5 to 14 km VIL > 1mm] over an area of 10 km^2

Severe Storm Detection or Lightning Hazard: [1.5 to 15 km VIL > 10 mm] .AND. [10 dBZ TOPS > 8 km] over an area of 10 km^2

Flash Flood Warning: [Hourly Rainfall or N-Hour Rainfall > 5 mm] over an area of 25 km^2


16:08:43
31 JUL 2003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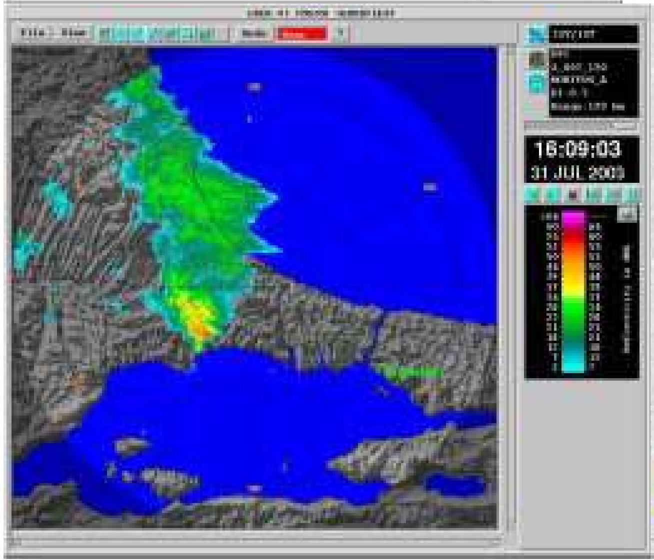
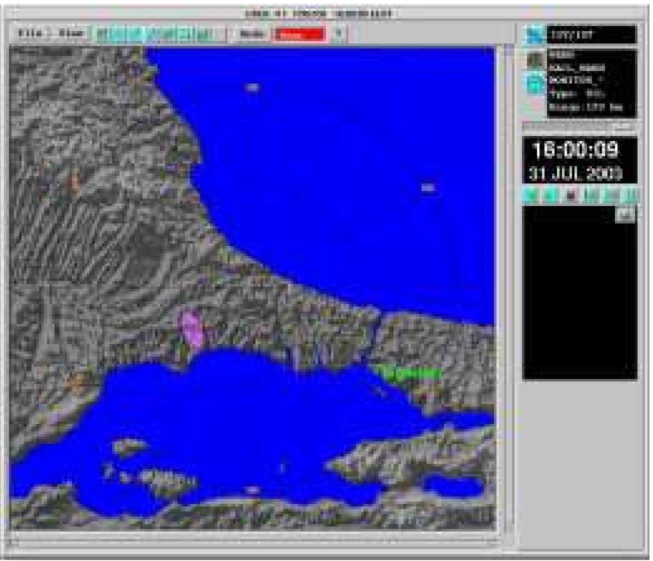
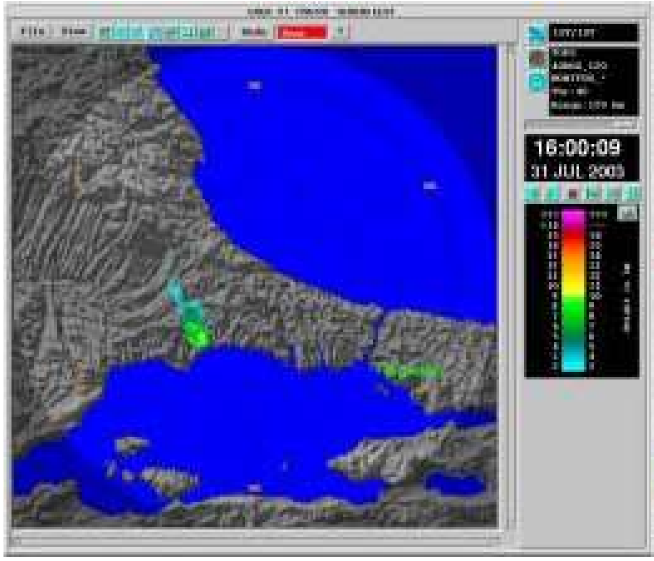

16:09:03
31 JUL 2003


16:00:09
31 JUL 2003


16:00:09
31 JUL 2003

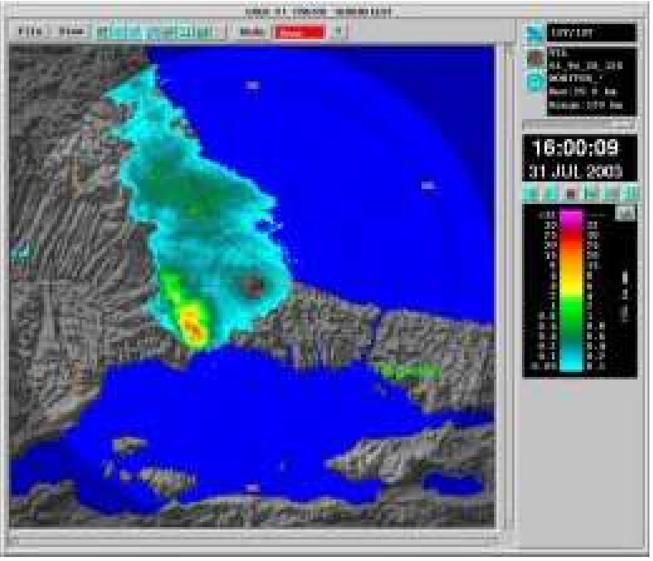

16:00:09
31 JUL 2003

Figure 31: Hail Warning And Related Other Products.

The images below show a fairly typical microburst signature on the radar display. The left image (a) shows the radar reflectivity (dBZ) and the right image (b) shows the corresponding radial velocity (m/s) relative to the CSU-CHILL radar. In a microburst, the spreading out of the air near the ground surface is similar to turning a garden hose on and aiming the end toward the pavement.

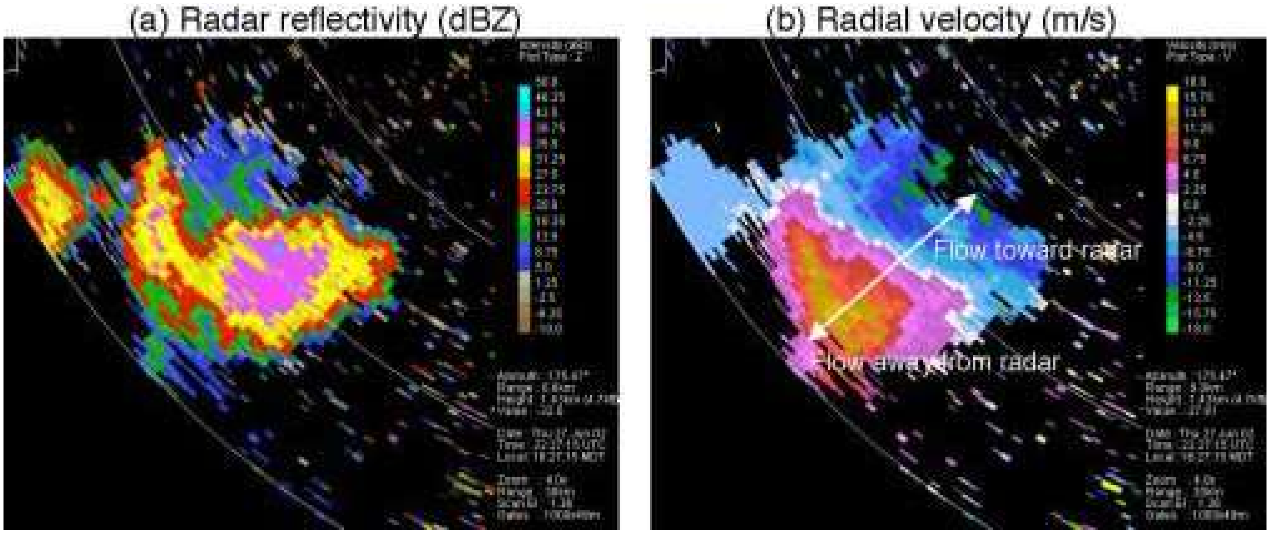
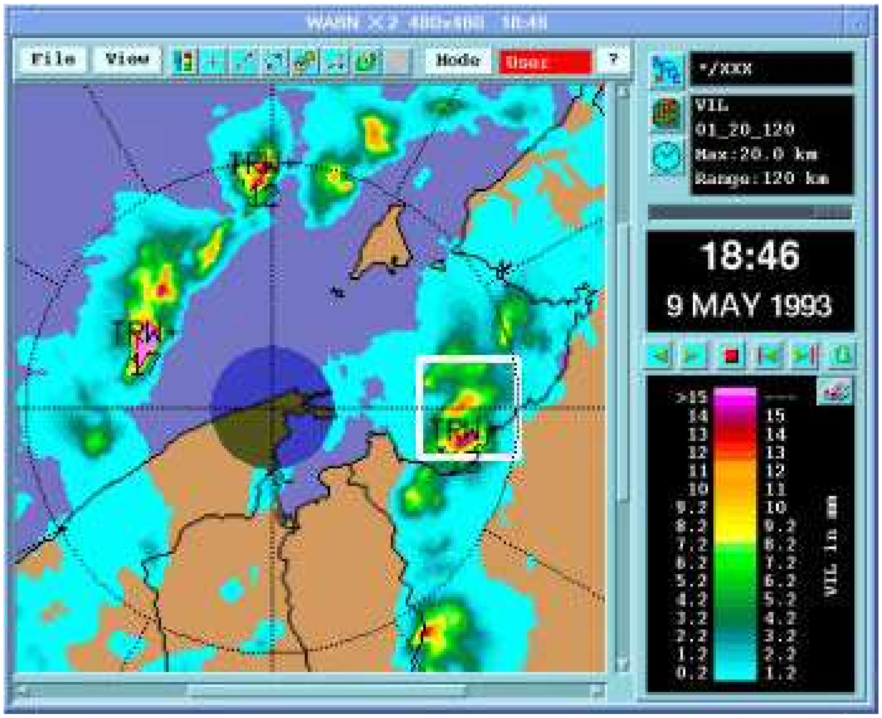


Figure 32: Detection and Warning Microburst on Radar Images.



*/XXX
VIL
01_20_120
Max:20.0 km
Range:120 km

Figure 33: A Thunderstorm Warning Product

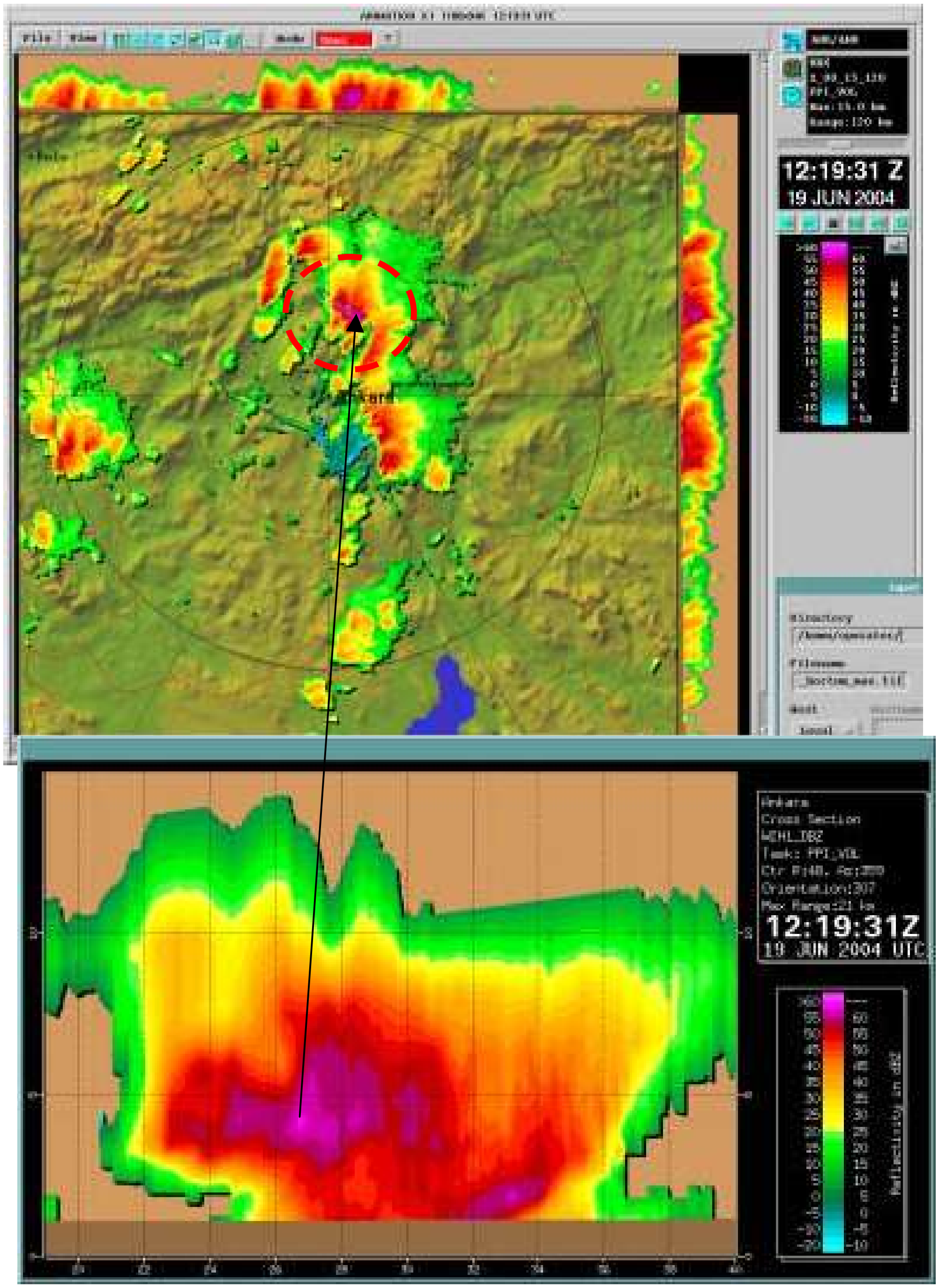
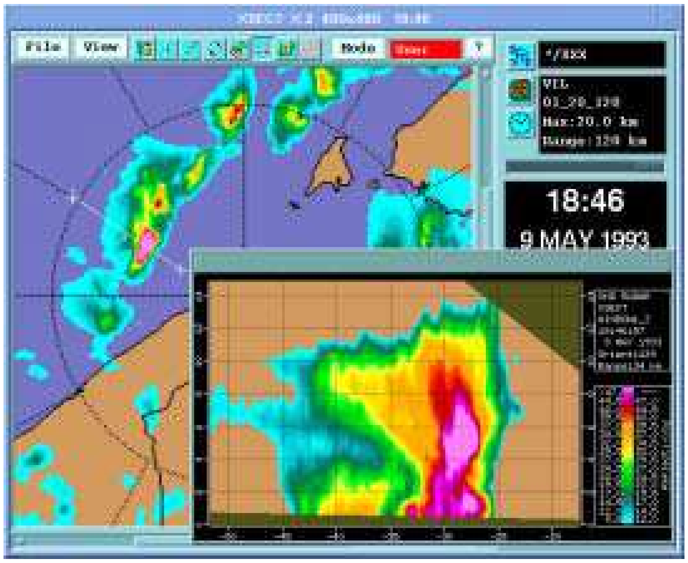
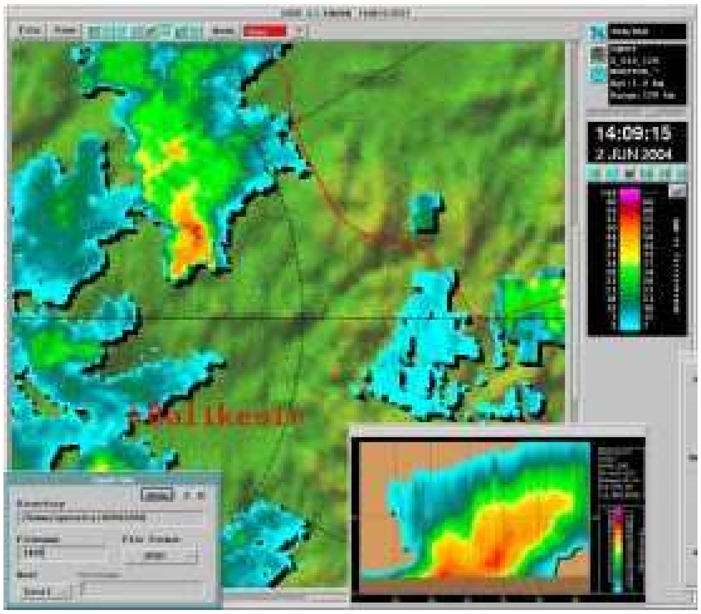


Figure 34: MAX Reflelectivity and its Cross Section Indicate a Tornado in a Small Area


File
View
Mode
*/XXX
VIL
01_20_120
Max:20.0 km
Range:120 km
18:46
9 MAY 1993


14:09:15
2 JUN 2004
Balikesir

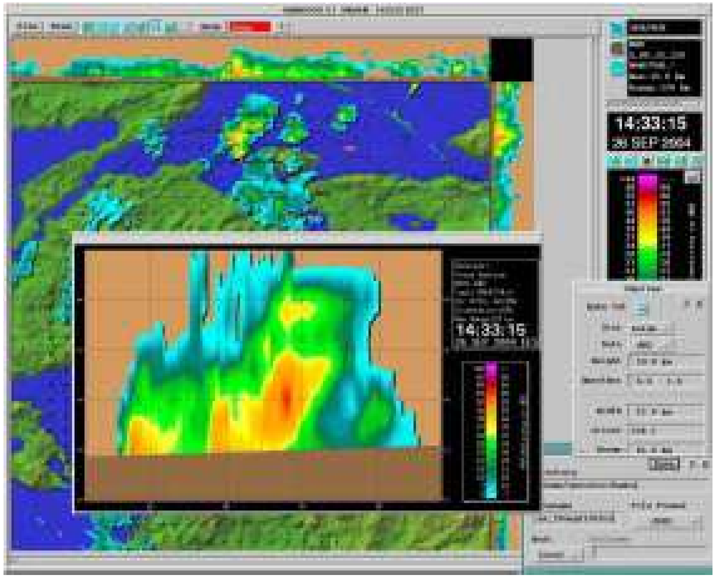

14:33:15
28 SEP 2004
14:33:15

Figure 35: Some Cross Section Images From Supercells.

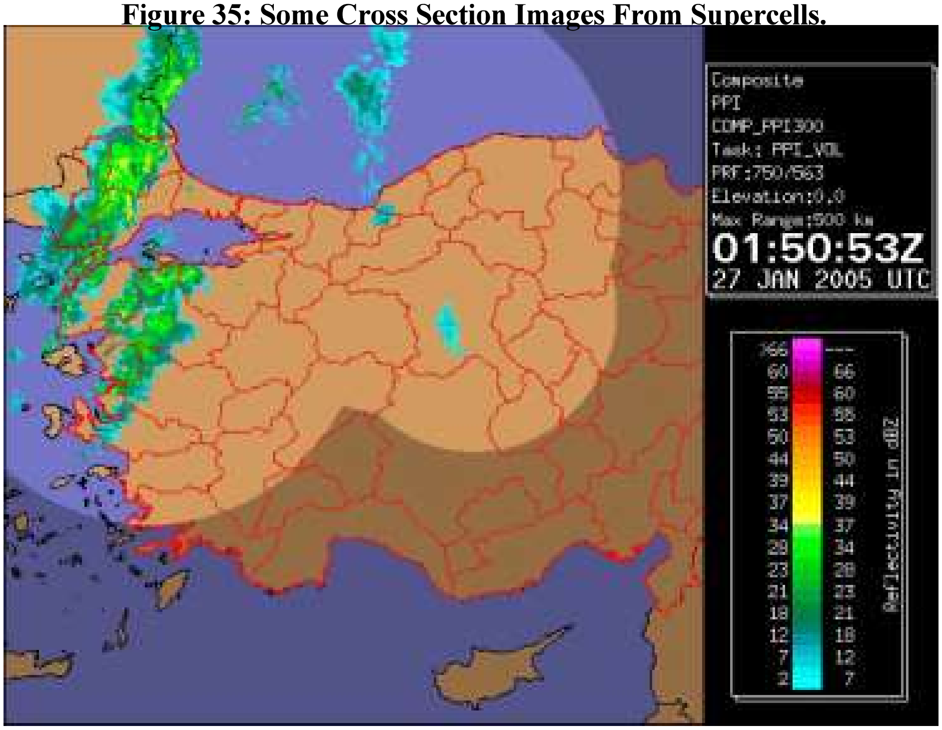


Figure 36: A PPI Reflectivity Mosaic Image Of Turkey Radar Network.

2. SCANNING STRATEGIES

For radar to find a target of interest (e.g., a cloud), three pieces of information are needed:

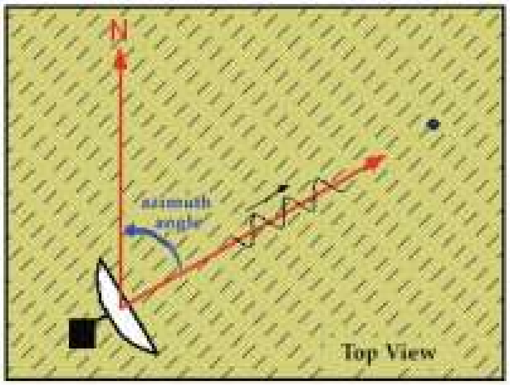


Figure 37: Azimuth Angle

1. Azimuth angle (direction relative to north)

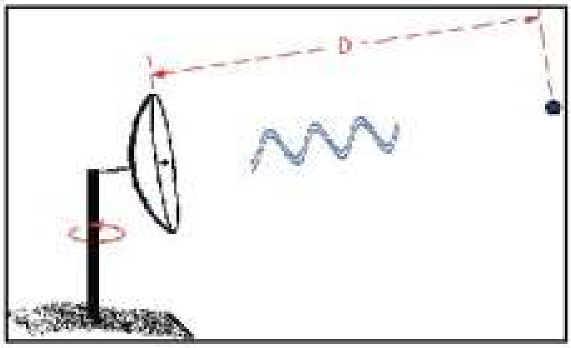


Figure 38: Distance to the Target.

2. Distance to the target of interest

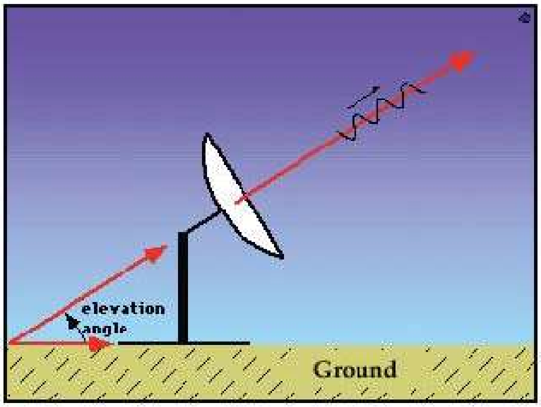


Figure 39: Elevation Angle.

3. Elevation angle (angle above the ground)

Scan Mode	PPI Full	PPI Sector	RHI
Azimuth	Full Circle: antenna scans 0° to 359° in azimuth continuously	Antenna scans between two azimuthal angles	Antenna is fixed in an azimuthal angle
Elevation	Single angle in elevation or different elevation angles from -2° to 90° in elevation can be chosen for volume scan	Single angle in elevation or different elevation angles from -2° to 90° in elevation can be chosen for volume scan	Antenna scans between two elevtion angle

Table 3: PPI and RHI Scanning Types.

In meteorology, radars usually employ one of two scanning techniques:

Plan Position Indicator (PPI): The radar holds its elevation angle constant but varies its azimuth angle. If the radar rotates through 360 degrees, the scan is called a "*surveillance scan*". If the radar rotates through less than 360 degrees, the scan is called a "*sector scan*". It's good surveillance scan and good in operational setting.

Range Height Indicator (RHI): The radar holds its azimuth angle constant but varies its elevation angle. The elevation angle normally is rotated from near the horizon to near the zenith (the point in the sky directly overhead). It's good for determining the vertical structure of the storm.

Figure 40: PPI and RHI Scanning.

We are most concerned with the PPI scan. The TSMS radars operate by collecting a series of surveillance scans at increasing elevation angles. It takes a radar ~ 8 minutes to collect the data, depending on how many elevation angles are used. The radar then repeats the cycle.

2.1. Winter Task

Precipitation Mode is the standard mode of operation whenever precipitation is first detected. When rain is occurring, the radar does not need to be as sensitive as in clear air mode as rain provides plenty of returning signals. When the weather conditions turn severe, the Precipitation Mode can be activated. The Precipitation Mode provides a **faster scan rate** to monitor a larger volume of space in a shorter time. This permits the tracking of rapidly moving meteorological phenomena found in convective weather patterns. This mode is characterized by the use of **a short pulse width** at both **high and low PRFs**. It consists of the

Surveillance Task with Monitor Task. In addition, a RHI task can be scheduled for observing storm structure in detail, especially for storms close to the radar (max range 120 km). In precipitation mode, the radar products update every 6 minutes.

Elevation Angles (°)	0.5-45.0 (16 angles)
Resolution (°)	1.0
Pulse Width (usec)	1.00
Scan Speed (°/sec)	12.00, 24.00, 24.00
Data	T, Z, V, W
Samples	64, 32, 32
Number of Bins	1200
Bin Spacing (m)	250.0
Max Range (km)	120.0
PRF (Hz)	1200-900
Unambiguous Velocity (m/s)	48 (4:3)
Processing	RPHASE
Data Quality Thresholding	T: LOG, Z: LOG&CSR, V:SQI&CSR, W: SIG&SQI&LOG
LOG (dB)	0.8
SIG (dB)	10
CSR (dB)	18
SQI	0.4
Speckle	Z on, V on

Table 4: Precipitation Task Configuration.

2.2. Convective (Summer) Task

2.2.1. Clear Air Mode

Clear Air Mode task is preferred when significant precipitation is not estimated in the radar coverage. In this mode, the radar is in its most sensitive operation. This mode has the slowest antenna rotation rate which permits the radar to sample a given volume of the atmosphere longer. This increased sampling increases the radar's sensitivity and ability to detect smaller objects in the atmosphere than in precipitation mode. This mode allow to meteorologists, detecting clear air phenomena, such as dry lines, dry microbursts, and wind shift lines. In clear air mode, the radar products update every 10 minutes. It uses **a long pulse** and the radar is operated at a relatively **slow scan** rate that allows the sampling of **five** contiguous elevation angles (0.5° to 4.5°) in a period of 10 minutes. When a radar system detects precipitation of a specified intensity and extent (30 dBZ), it automatically switches from Clear Air to the Precipitation Mode by using Automatic Mode Switch Menu for two plans.

Elevation Angles (°)	0.5, 1.5, 2.5, 3.5, 4.5
Resolution (°)	1.0
Pulse Width (usec)	2.00
Scan Speed (°/sec)	12.00
Data	T, Z, V, W
Samples	55
Number of Bins	1200
Bin Spacing (m)	250.0
Max Range (km)	300.0
PRF (Hz)	500-375
Unambiguous Velocity (m/s)	20 (4:3)
Processing	PPP
Data Quality Thresholding	T: LOG, Z: LOG&CSR, V: SQI&CSR, W: SIG&SQI&LOG
LOG (dB)	0.8
SIG (dB)	10
CSR (dB)	18
SQI	0.4
Speckle	Z on, V on

Table 5: Clear Air Task Configuration.

2.2.2. Surveillance Task

Surveillance Task Configuration is used to generate PPI at a single elevation close to zero for **long range** weather monitoring (Elevation Angle:0.5°, Max Range:300 km, Pulse Width:2). It can be used for winter and summer conditions.

PPI is the fastest of all radar products and therefore suitable for studying the fast-developing mesoscale storms.

2.3. Negative Scanning and Cone of Silence

Mountainous terrain provides particularly challenging circumstances for weather radars. Radar scans are severely blocked at valley bottom locations and commonly overshoot important low-elevation phenomena (especially precipitation) for mountaintop locations. For mountaintop radars in Turkey the operational scanning strategy includes a Doppler scan taken at negative elevation angles. The lowest elevation angle Doppler scan of –0.5° corresponds to the lowest observable local application angle. Doppler scans are taken at the first elevation angle of -0.5° during an 8 minutes cycle with a maximum range of 120 km.

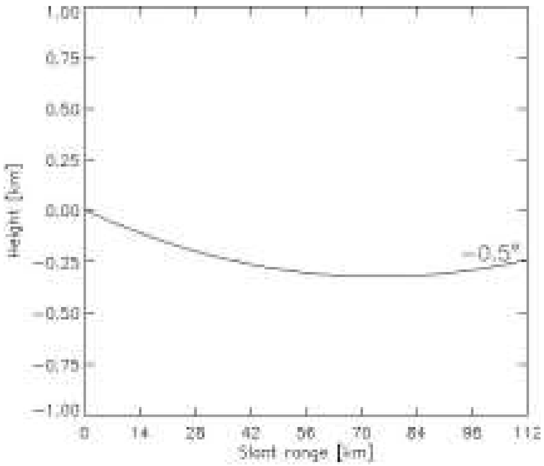


Figure 41 Slant Range-Height Diagram for an Elevation Angle of -0.5°.

Close to the radar, data are not available due to the radar's maximum tilt elevation. This area is commonly referred to as the radar's "**Cone of Silence**".

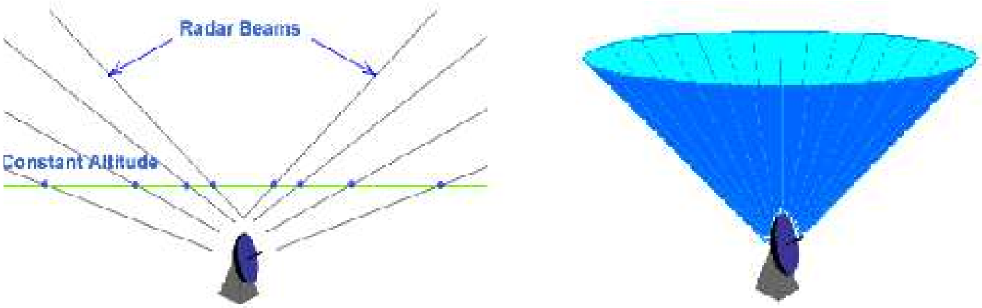


Figure 42: Cone of Silence.

2.4. Scanning Strategy Plan

Recall, when a radar system detects precipitation of a specified intensity and extent (30 dBZ), it automatically switches from Clear Air to the Precipitation Mode by using Automatic Mode Switch Menu for two plans. This is shown in figure below:

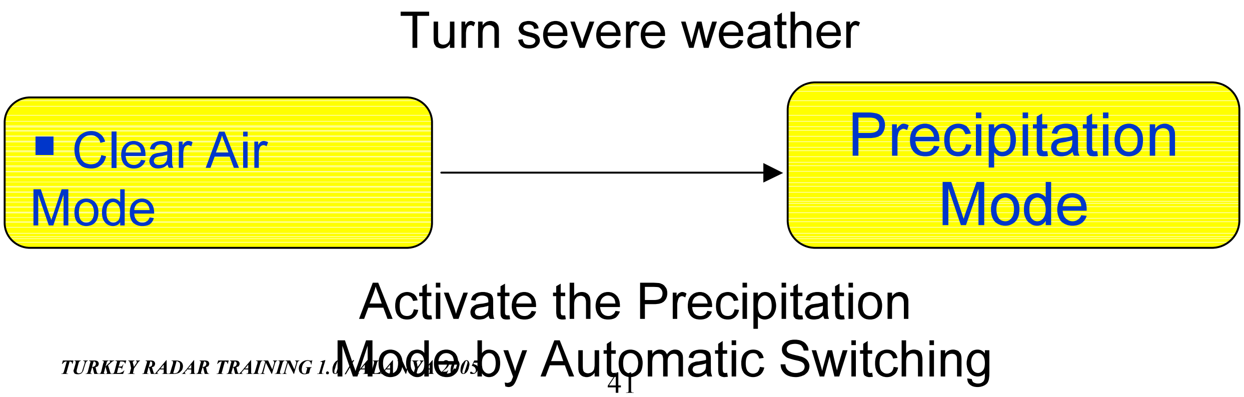


Figure 43: A Scanning Strategy Plan.

3. RADAR PRODUCT APPLICATIONS

3.1. Z-R Relation, Gauge Adjustment

Z-R relation was explained in Section 1.2.2. In practice, real-time adjustments to the Z-R conversion are sometimes made using readings from a number of raingauges or distrometers in radar's coverage automatically. As you have probably noticed, the precipitation estimates from radar data don't always agree with rain gauges! Meteorologists have been working on this problem for over 50 years now.

Question:

Why is it so difficult to compare rain gauge and radar measurements?

Besides assumptions in the Z-R relation, there are a number of other complications:

- The radar samples precipitation in the cloud some distance above the ground. Particles may evaporate or otherwise be modified before they hit the surface.
- Clouds and precipitation frequently consist of a variety of particle types (e.g., ice and rain). Each particle interacts with the radar's energy in its own unique way.
- Rain that is further away from the radar returns a weaker signal than rain close by.

Other factors complicating the comparison of radar and rain gauge estimates of precipitation:

- The region sampled by the radar increases with distance. The wider the beam, the greater the likelihood of sampling a mixture of precipitation types, or the greater the likelihood of sampled both inside and outside of a cloud.

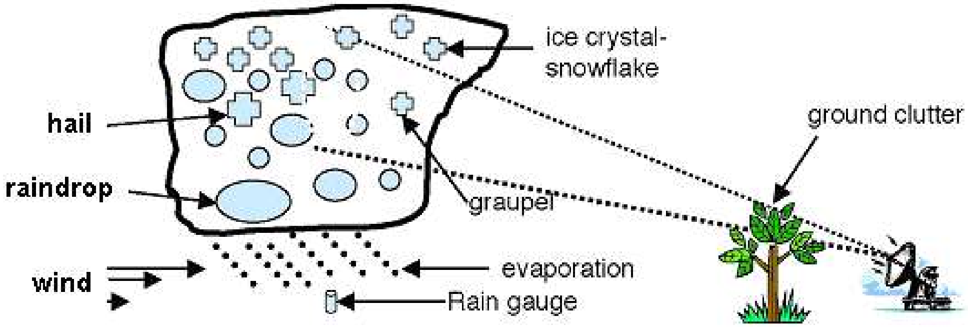
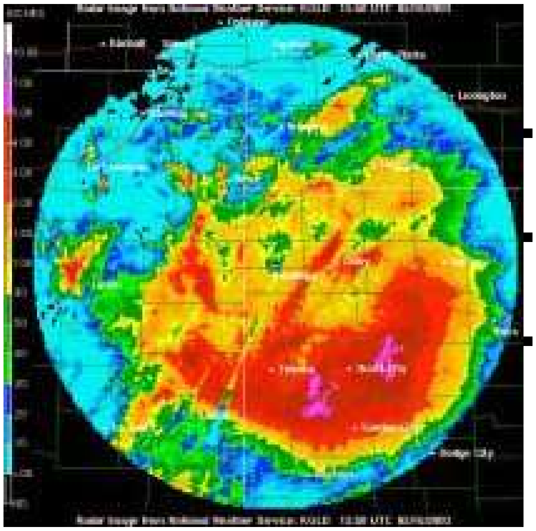


Figure 44: Radar and Rain Gauge Precipitation Estimating.

- Obstacles frequently block a portion of the radar beam, resulting in an artificially high power return.

Given all the issues, why use radar to measure precipitation?



- Radar is the only way to map the spatial distribution of precipitation over large areas
- Topography or other logistics may prevent locating gauges in many areas
- Radar can be used as a forecasting tool for flash flooding and severe thunderstorms

Figure 45: NWS NEXRAD (KGLD) Storm Total Precipitation 16 May 2003 15:58 UTC.

A Gauge Adjustment Method:

Recall, real-time adjustments to the Z-R conversion are sometimes made using readings from a number of raingauges or distrometers in radar's coverage automatically. The rainfall data of automated weather observation stations can be used for reproduced Z-R relation. A method called **Bulk Adjustment** is explained below:

The new constant of a:

$$a=A(\sum R/\sum G)^b$$

a=radar estimate of rainfall (R) / raingauge total (G)

An example:
For a raingaue station, raingauge's rainfall rate is 23.6 mm. Radar estimate of rainfall is 27.5 mm (A=200 and b=1.6).

$a=200(27.5/23.6)^{1.6}=255.4$

Error rate of radar estimate of rainfall is *3.9 mm.*

$$z=aR^b$$

$40,175.6=255.4*R^{1.6}$

$\ln(40{,}175.6)=\ln(255.4)+1.6*\ln R \rightarrow$ **R=23.6 mm** (The rainfall rate of the raingauge is obtained)

What is the dBZ value?
$z=AR^b$
$\ln z=\ln A+b*\ln R=\ln 200+1.6*\ln(27.5)=10{,}601$
$z=40{,}175.6\ \mathrm{mm^6/m^3}$
$\mathrm{dBZ}=10\log10z=10\log_{10}(40{,}175.6) \rightarrow$ **dBZ=46**

The new Z-R relation is determined as $\boldsymbol{z=255R^{1.6}}$

3.2. Hydrometeor Classification

Perhaps a more significant result of polarisation measurements is the ability to perform hydrometeor identification, to differentiate liquid water from ice using their different dielectric properties and to identify various form of ice (snow, hail, crystals).

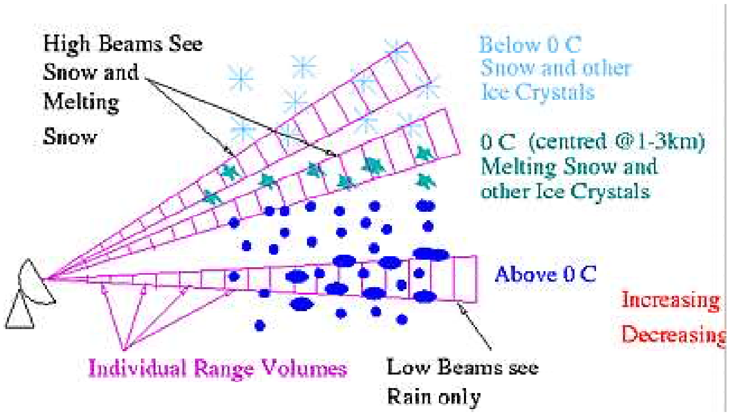


Figure 46: Hydrometeors in the Atmosphere.

The shape of raindrops falling in the atmosphere varies from nearly perfect spheres for small droplets up to a couple of millimeters in diameter to more flattened drops up to 5 or 6 mm across. These flattened drops give stronger returns at horizontal polarization than at vertical. Thus, Z_{DR} varies from near zero for spherical droplets to values as large as +5 dB for echoes from large water drops. This added information is useful for refining rainfall measurements made by radar.

Target	*Z_{DR} (dB)*
Drizzle	0
Rain	0.5 - 4
Snow, Graupel	(-1) – (+1)
Hail	~0

Table 6: Z_{DR} Values of Hydrometeors.

Z_{DR} is also useful for indicating the presence of hail. When hail is present, Z_{DR} often goes to near zero.

In moderate to heavy rain, the rain drops are large and as they fall they flatten to become oblate spheroids, giving a stronger echo for horizontal polarisation. Raindrop diagram:

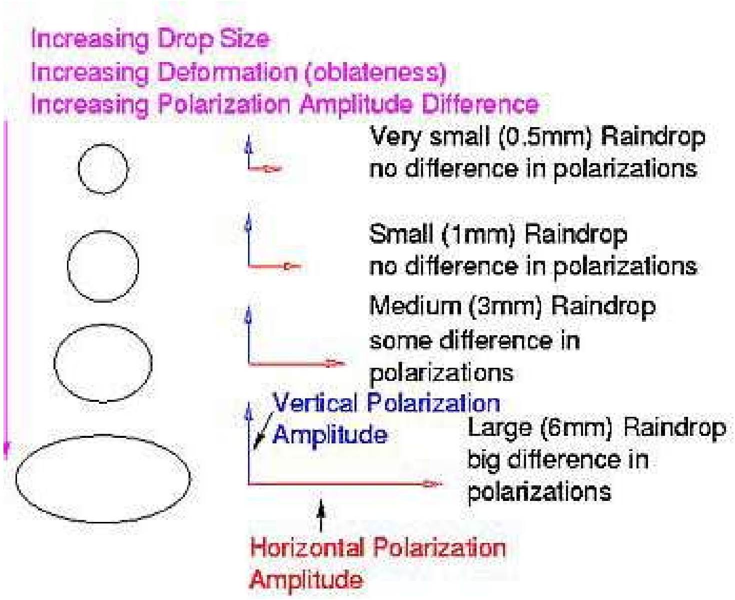


Figure 47: Raindrop Diagram.

3.3. Radar Data Quality Algorithms

- Radar reflectivity data is subject to many contaminants. Not all reflectivity corresponds to "true" weather.
- Radar reflectivity data must be corrected to account for anomalous propagation (AP), ground clutter and returns from non-weather echoes.
- Doppler clutter filter for clutter cancellation needs to remove clutter without destroying rain data.
- Quality control softwares can be produced.
- Real time quality control of reflectivity data using satellite infrared channel and surface observations.

These limitations are explained below:

3.3.1. Limitations of Doppler Radar

There are limitations in the velocities and ranges that a radar can resolve unambiguously. PRF is the pulse repetition frequency (PRF) of the radar. Maximum unambiguous velocity detectable by a doppler radar is:

$$V_{max} = PRF\,\lambda / 4$$

This is an important result. It ways that if we want to be able to detect high velocities, we must use long wavelengths, large PRF's or both.

The maximum unambiguous range is:

$$R_{max} = c / 2PRF$$

c=speed of light

Unfortunately, the PRF appears in both expressions, but in the denominator of one and the numerator of the other. This forms what has been called the "*Doppler Dilemma*".

$$V_{max}R_{max} = c\lambda / 8$$

If we want to have a large V_{max}, we must have a small r_{max} since the right side of the equation is a constant for a given radar. Conversely, if we want to detect echoes at long ranges, we can only detect small velocities.

An example:

If we use large PRF=1200

$R_{max} = c / 2PRF$ = 300.000 km/s / 2x1200 s^{-1}

$= 125\ km$

If our radar's wavelength is λ=5.35 cm;

$V_{max} = PRF\,\lambda / 4$ = 1200 s^{-1}x0.0535 m / 4 = $16.05\ m/s$

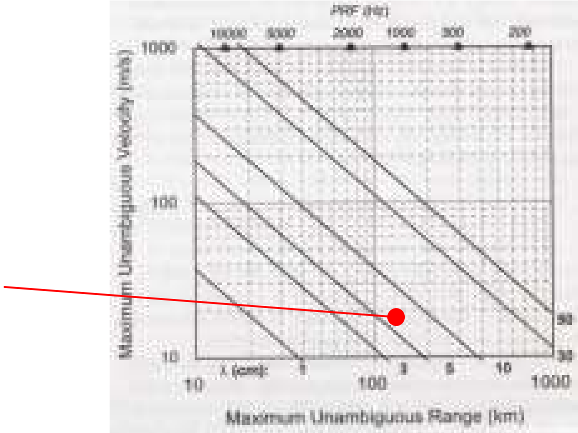


Figure 48: Doppler Dilemma Diagram.

PRF (Hz)	R_{max} (km)
1200	125
1000	150
750	200
500	300
300	500

Table 7: Values Of PRF-R_{max} Relation.

- One partial solution to the Doppler dilemma is in our choice of wavelength. We can increase both Vmax and rmax by using a longer wavelength radar. Unfortunately, longer wavelength radars are more expensive and bigger, and they don't detect weather targets as well as shorter wavelength radars, so using a longer wavelength is not necessarily a solution to the problem.

- The result is that most Doppler weather radars usually suffer significant range or velocityambiguities or both.
- **for defeating doppler dilemma,** the volume coverage pattern are organized in a way of the lowest elevation scans are sampled twice in low and high PRF, the middle scans are performed in alternating low and high PRF and the upper elevation in high PRF

3.3.2. Spurious Echoes

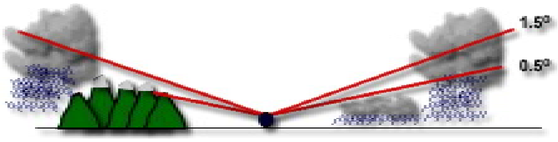
Not all echoes on weather radar are due to rain or snow. Non-meteorological returns may be caused by:

- The Earth's surface and stationary objects on it
- Transient objects (ships, aircraft, birds, insects)
- Technical problems with the radar equipment
- Interference from other sources, such as nearby radars

The most common of the non-meteorological echoes are ground echoes or "***clutter***". These occur when a radar beam intersects any surface feature, such as high ground, buildings and trees. The echoes mainly occur close to the radar site.

3.3.2.1. Beam Blockage

Beam blockage occurs due to ground clutters especially regions close to the radar. Data can not obtained from these regions. Screening or occultation of precipitation by hills results in a reduction of the rainfall that is estimated by a radar at places beyond the high ground.



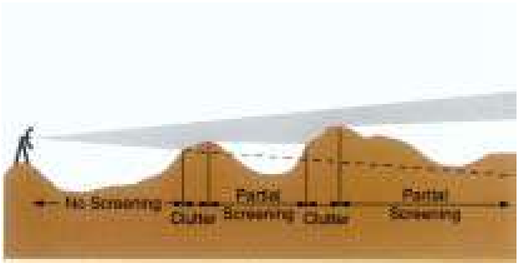


Figure 49: Beam Blockage.

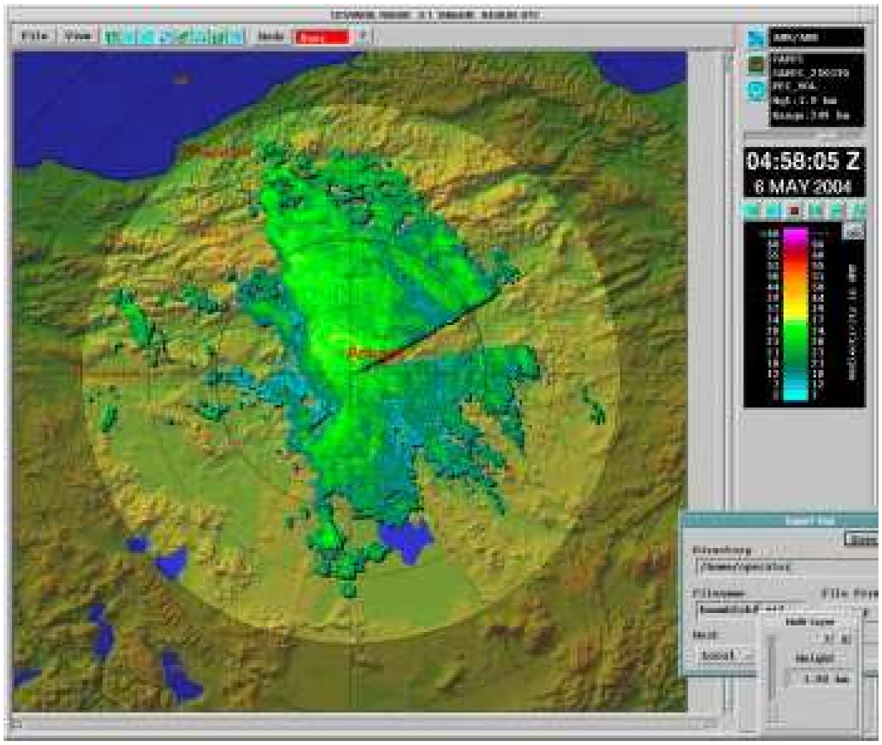


Figure 50: Beam Blockage Image.

3.3.2.2. Side Lobe

Radars transmit energy along a main beam having a typical beam-width of 1°. There are also secondary power transmissions along side lobes located a few degrees degrees from the main beam centre. Normally the side lobe returns are too weak to be significant. An exception may occur with very highly reflective targets, such as columns of heavy rain or hail within a Cb cloud.

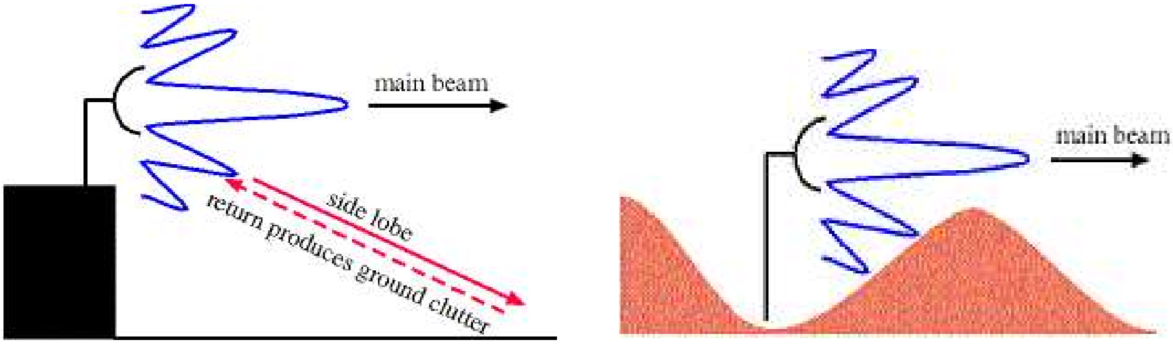


Figure 51: Side Lobe.

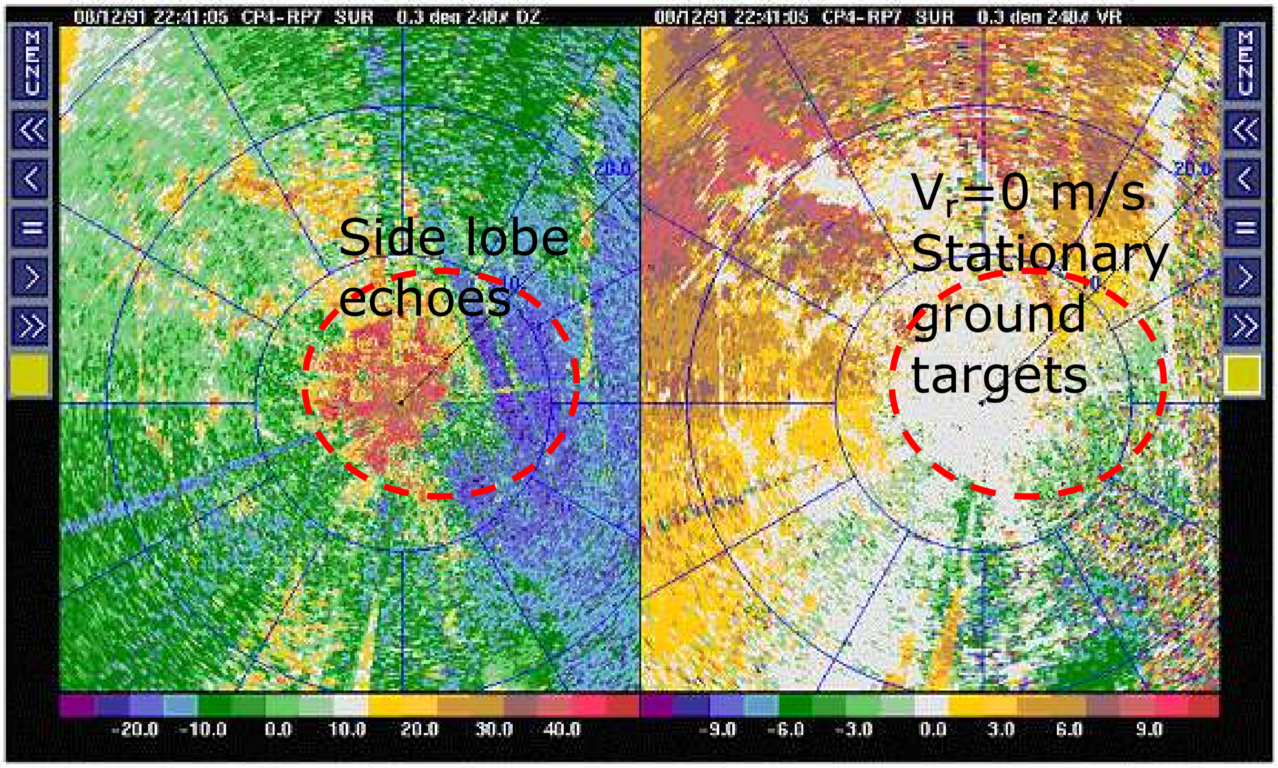


Figure 52: Side Lobe Images (Reflectivity Image on the Left and Velocity Image on the Right.

3.3.2.3. Attenuation

Attenuation is the weakening of a radar beam as it moves downstream due to some of the energy being lost to scattering and absorption. At short wavelengths, especially X- and C-band, the radar signal is attenuated by the precipitation along its path. So, attenuation is a severe problem at C-band.

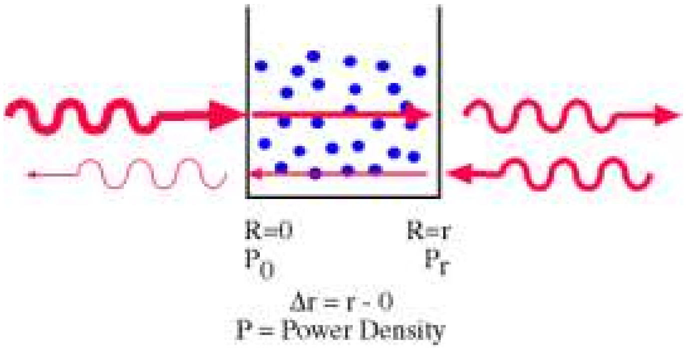


Figure 53: Attenuation.

- Attenuation is produced by clouds, rain, snow, hail, water vapor and other gases in the atmosphere.
- Attenuation at C-band radars can be serious especially during the heavy precipitation, so it can affect estimating precipitation.
- Attenuation by rain is even stronger than it is from clouds, in addition to this, attenuation by hail is strongest.
- Modern radar systems have capability to recognize and correction algorithms for attenuation.

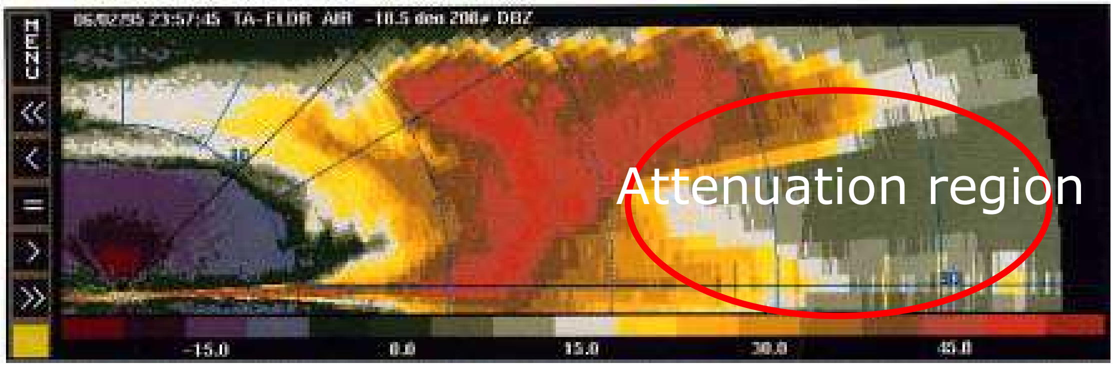


Figure 54: Attenuation Image.

3.3.2.4. Clear-Air Echo

Meteorological information can come from nonmeteorological as well as meteorological targets. We usually think that the radar is detecting echoes from weather. Some important wind phenomena are detectable largely because of clear-air echo.

Two general categories of radar echo in the cear air:

1. Insects, dust, chaff and other particulates in the atmosphere that are large enough to return some power to the radar.

2. Refractive-index gradiends. When it chganges significantly (lower atmosphere is unstable), the wind increases rapidly with height just above the ground. This indicates the mechanical turbulence.

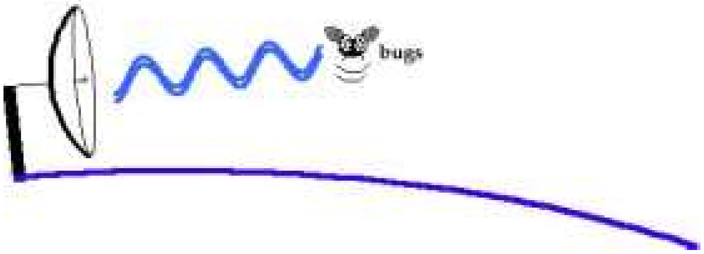


Figure 55: Clear-Air Targets.

- Clear-air returns are most common closer to the radar.
- They are always present during the warmer seasons

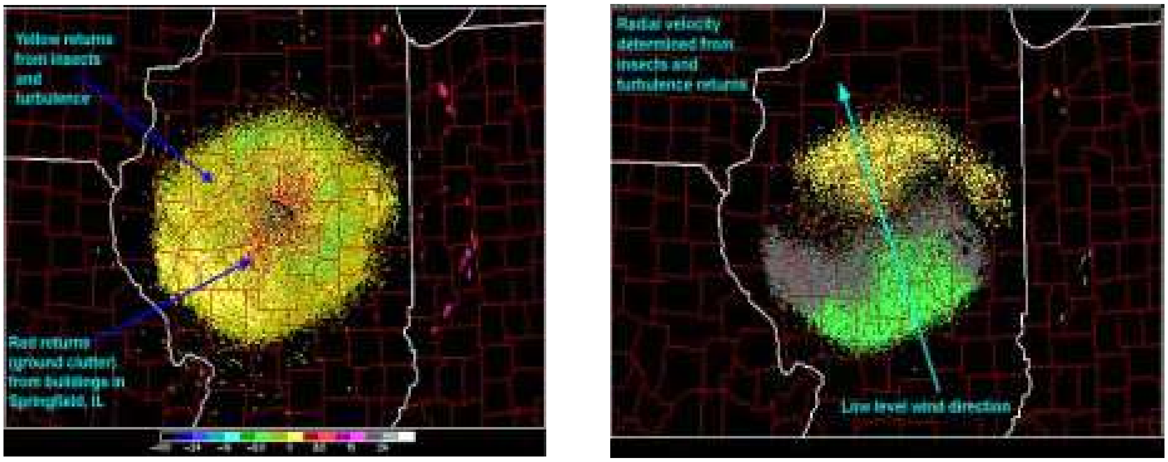


Figure 56: Clear-Air Echoes.

3.3.2.5. Bright Band

Occasionally a band of very high reflectivities will appear on the radar. This is called **"bright banding"** and is related to an area in the clouds where snow is melting into rain. The melting/wet snow has a much higher reflectivity than snow and a higher reflectivity than rain. It occurs at the altitude where the temperature is around 0 °C, i.e. temperature in the upper reaches of the cloud is below freezing and temperature of the cloud closer to ground is above freezing. The weather forecaster must be aware of this process so as not to confuse the bright band with an intense area of precipitation.

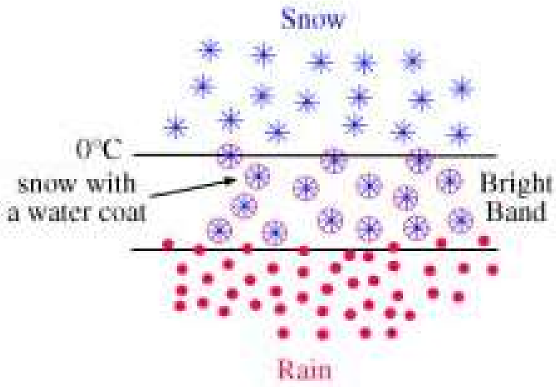


Figure 57: Bright Band.

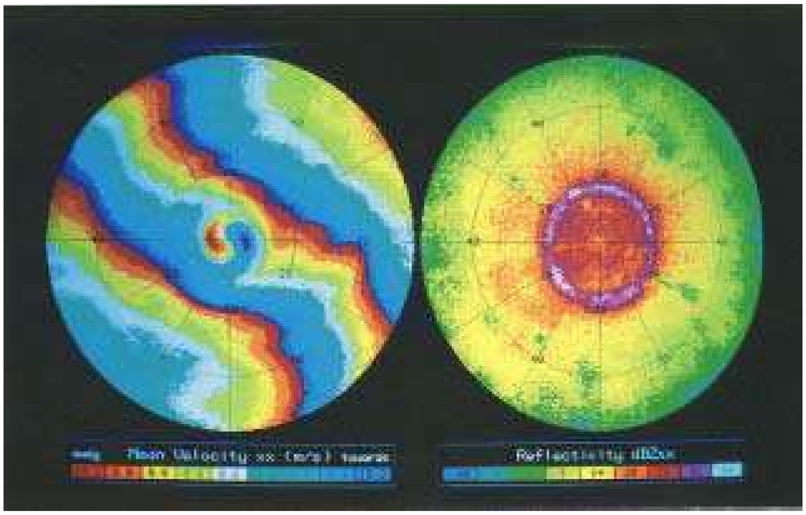


Figure 58: Bright Band Echoes.

3.3.3. Effects of the Earth's Curvature and Atmospheric Refraction

3.3.3.1. Effects of the Earth's Curvature

Earth is spherical. Microwaves do not follow the surface. In the picture on the next slide is shown the height of some radar beams as function of distance from radar at different elevations.

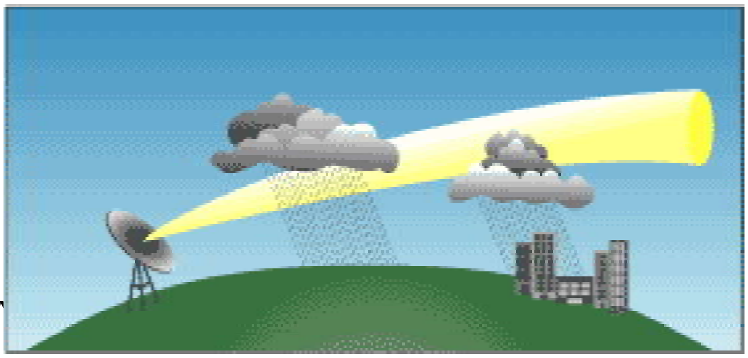
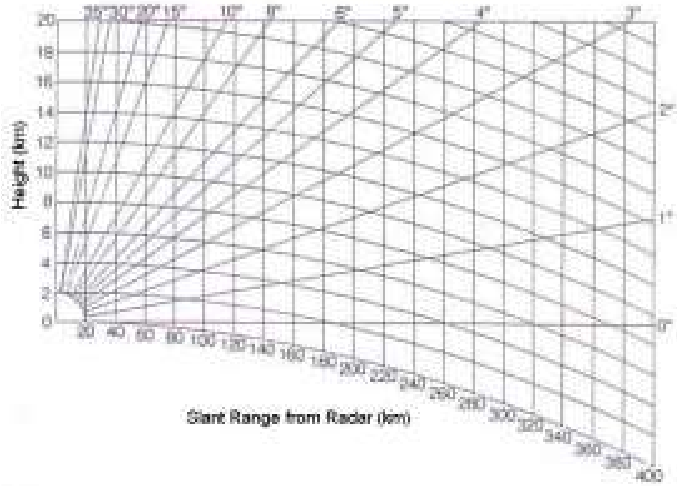


Figure 59: Earth's Curvature.

For standard refraction conditions, when a radar sends a signal into the atmosphere, signal will spread out of the above ground at the far away from radar. Therefore radar echoes can not be seen at long range.



If for a 0.8° elevation angle of signal is sent into the atmosphere, height of the radar beam will be at the distance of:

50 km → 0.8 km,
100 km → 2.0 km,
150 km → 3.4 km,
200 km → 5.1 km,
250 km → 7.1 km.

Figure 60: Radar Range-Height Diagram.

3.3.3.2. Atmospheric Refraction

Radar assumes the beam is undergoing standard refraction. The beam height will be misrepresented under super/subrefractive conditions.

Bending of light, or refraction, is a result of a density gradient in our atmosphere. The density gradient will depend on the temperature, pressure and humidity profile of the atmosphere.

Snells Law: Electromagnetic waves may be refracted in the atmosphere due to density variations. The bending of light as it passes from one medium to another is called **refraction**.

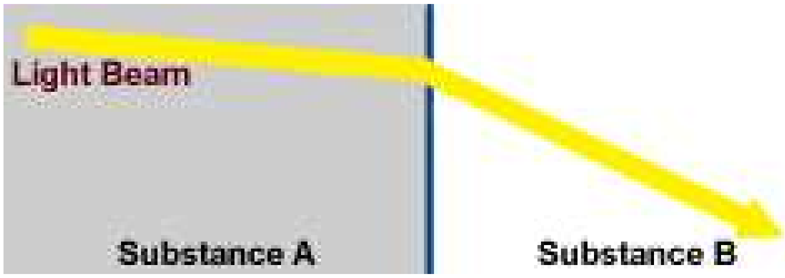


Figure 61: Refraction.

3.3.3.2.1. Standard Refraction

This figure gives height as a function of range and elevation angle for standard refraction conditions and is a useful way to determine the height of a radar beam. Note that, if the radar located above sea level, its height must be added to the height determined from the graph to give heights above mean sea level (See Figure 59).

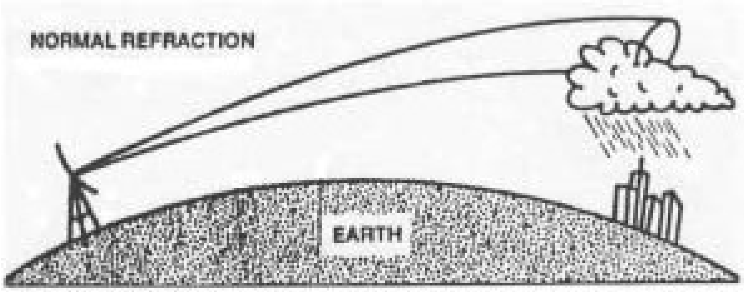


Figure 62: Standard Refraction.

3.3.3.2.2. Subrefraction

The beam refracts less than standard. The beam height is higher than the radar indicates. Beam can overshoot developing storms. This occurs when the beam propagates through a layer where:

- Temperature lapse rate is ~ dry-adiabatic (The dry adiabatic rate is 1.0°C/100 meters)
- Unstable atmosphere
- Moisture content increases with height
  - ✓ Will help eliminate ground clutter

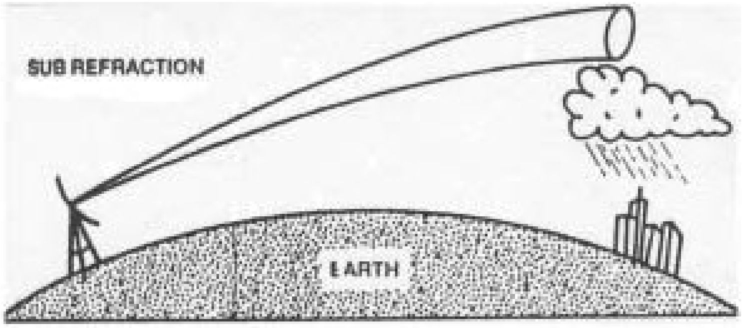


Figure 63: Subrefraction.

3.3.3.2.3. Superrefraction and Ducting

The beam refracts more than standard. The beam height is lower than the radar indicates. This occurs when the beam propagates through a layer where:

- Temperature increases with height (inversion)
- Stable atmosphere
- Moisture decreases sharply with height
  - ✓ Will likely produce ground clutter

If the refraction of the radiation is strong enough, the radar waves can be trapped in a layer of the atmosphere (Ducting).

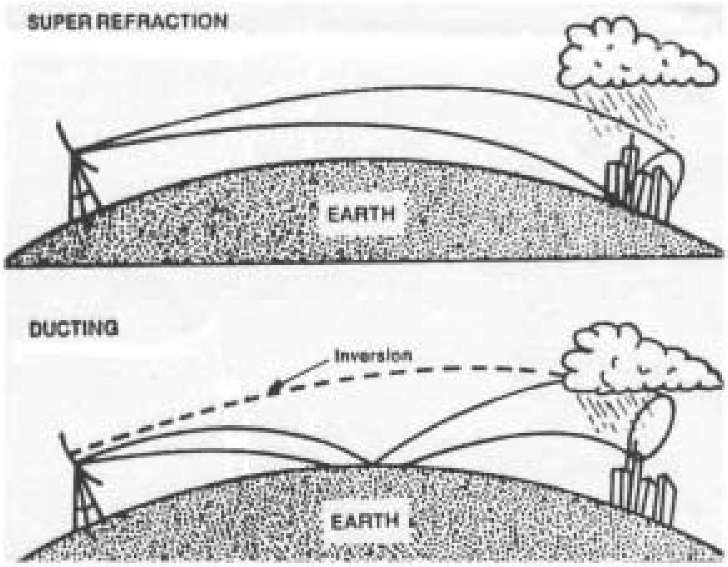


Figure 64: Superrefraction and Ducting.

The condition of extended range of detection of ground targets is called **anomalous propagation or anaprop (AP).**

3.3.4. Reducing Ground Clutter

- The main way to reduce substantially ground clutter is generating a ground clutter map from the echoes received on a cloudless day. Echoes from the clutter regions on subsequent rainy days can then be ignored, and interpolated data from surrounding areas can be used.
- A higher beam elevation at close range.
- Used to Doppler radar for distinguish stationary clutter from moving rain.

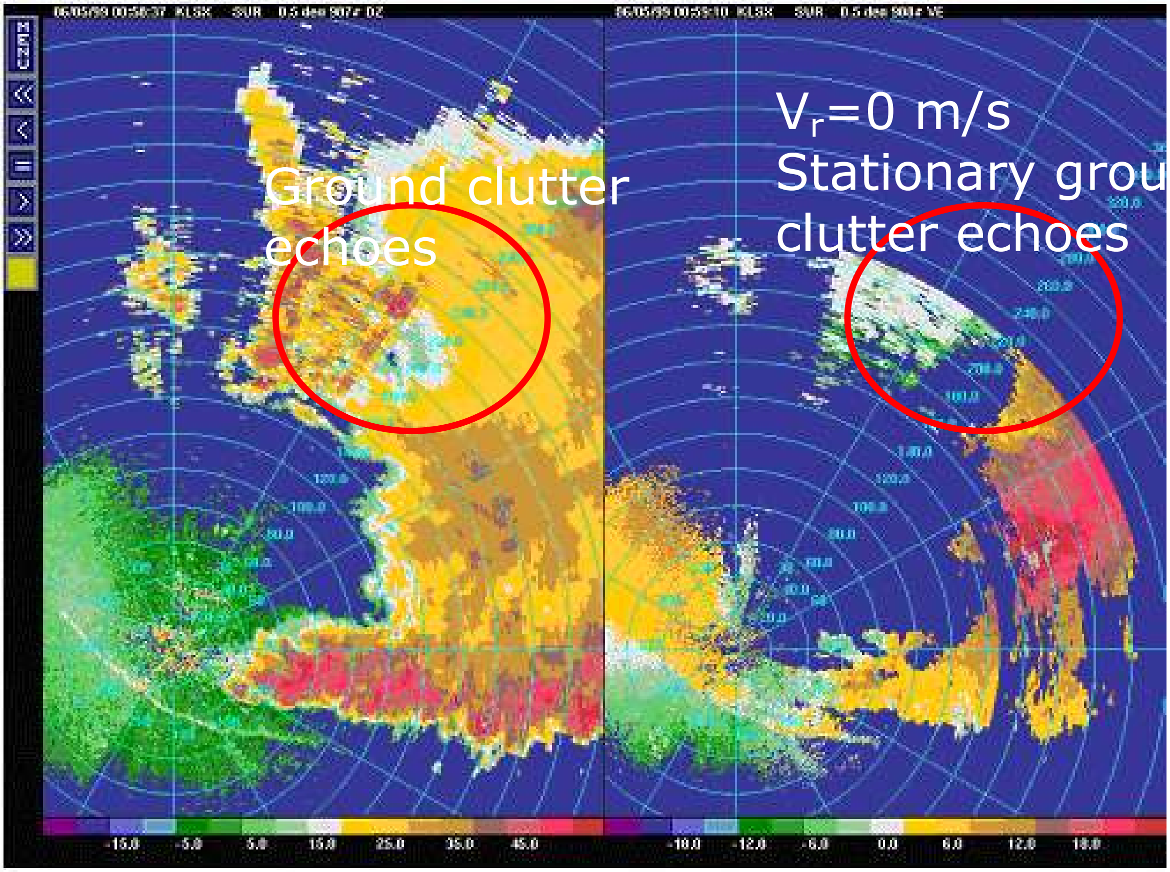


Figure 65: Ground Clutter Echoes.