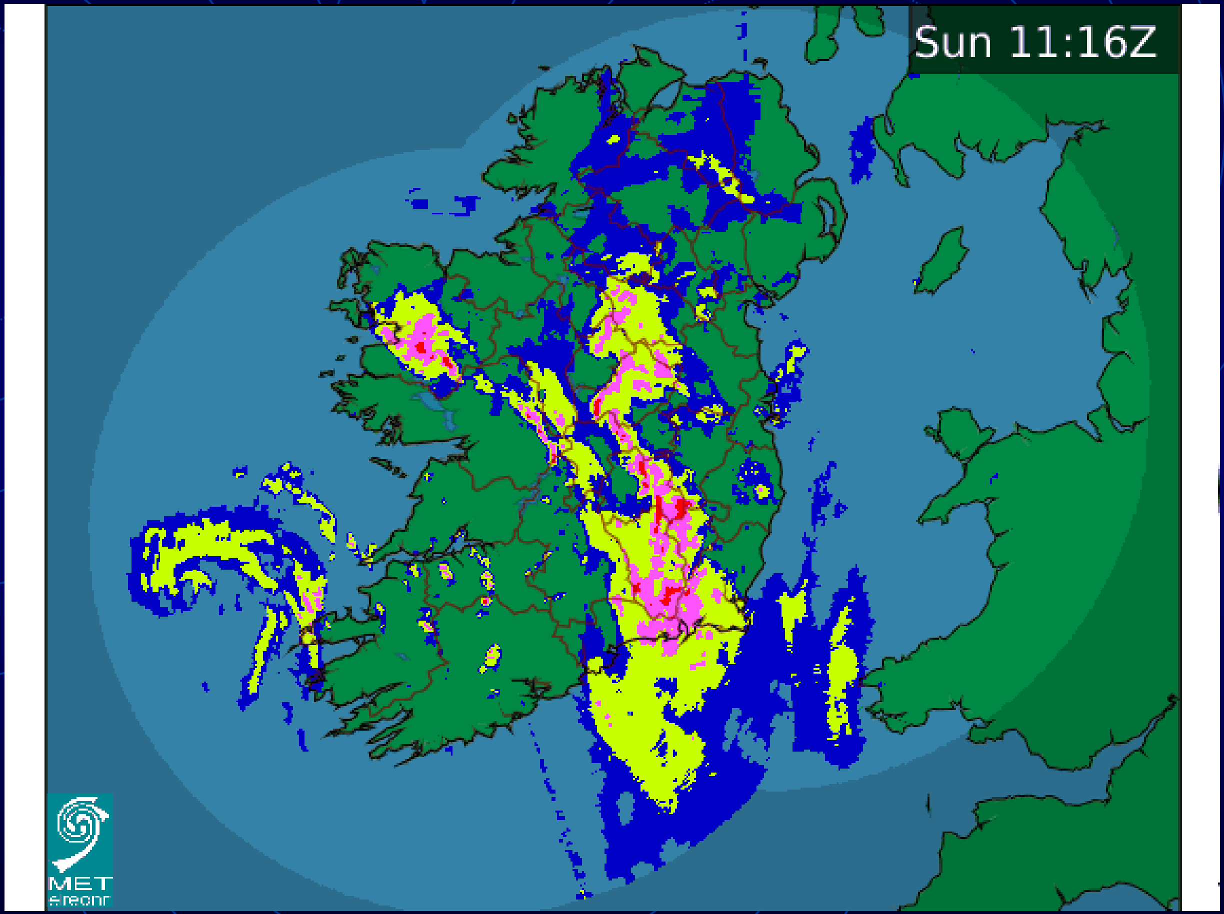
Weather Radar



Kieran Commins

Met Éireann

RADAR METEOROLOGY

- An introduction to the measurement of precipitation by Weather Radar.
- Presentation of the fundamentals involved in Radar Meteorology
- Understanding of the physical process involved
- Appreciation of the errors and problems involved.
- Interpretation of data

Radar Basics

- **RADAR** = RAdio Detection and Ranging
- Discovered in Britain
- Radio transmissions deflected by passing aircraft
- Lead to development of Radar during WW2

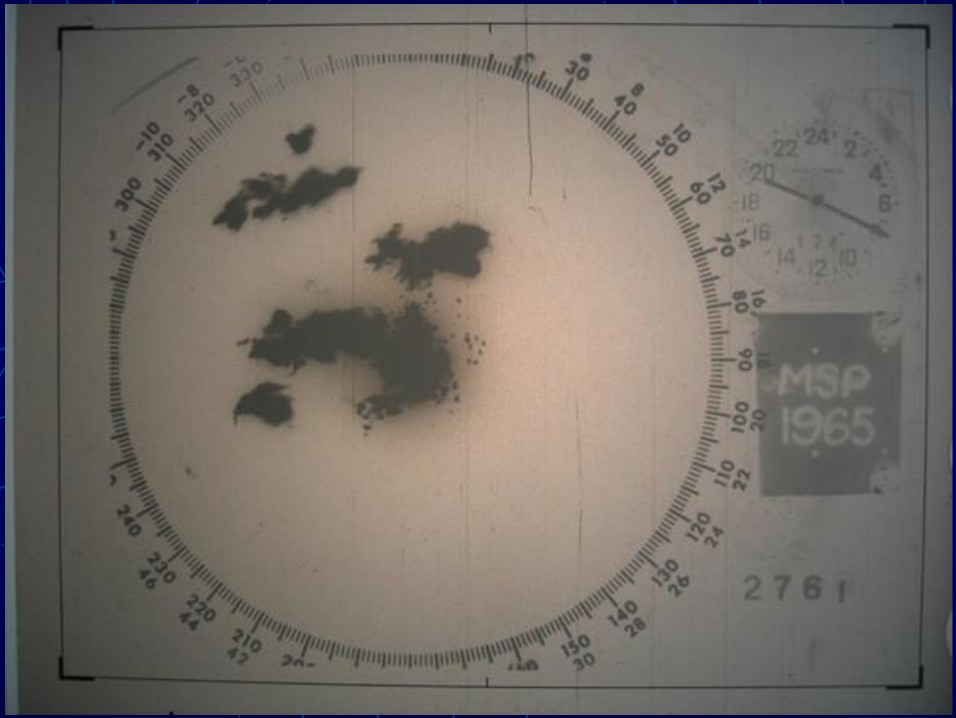
Radar and Weather

- Rainfall was seen by radar
- Regarded as 'contamination'
- Many radar have 'weather filters' to remove weather signals
- BUT some saw the potential is using radar for tracking precipitation

David Atlas
US Airforce & MIT

Weather Radar

- Early radar needed an operator and hand draw the results
- Major development was digitization and automation from early 80's
- Since then, resolution and quality and well as coverage has improved



Radar Components

- Steerable Antenna
- Transmitter
- Receiver
- Control Unit
- Signal processor
- Pre-processor

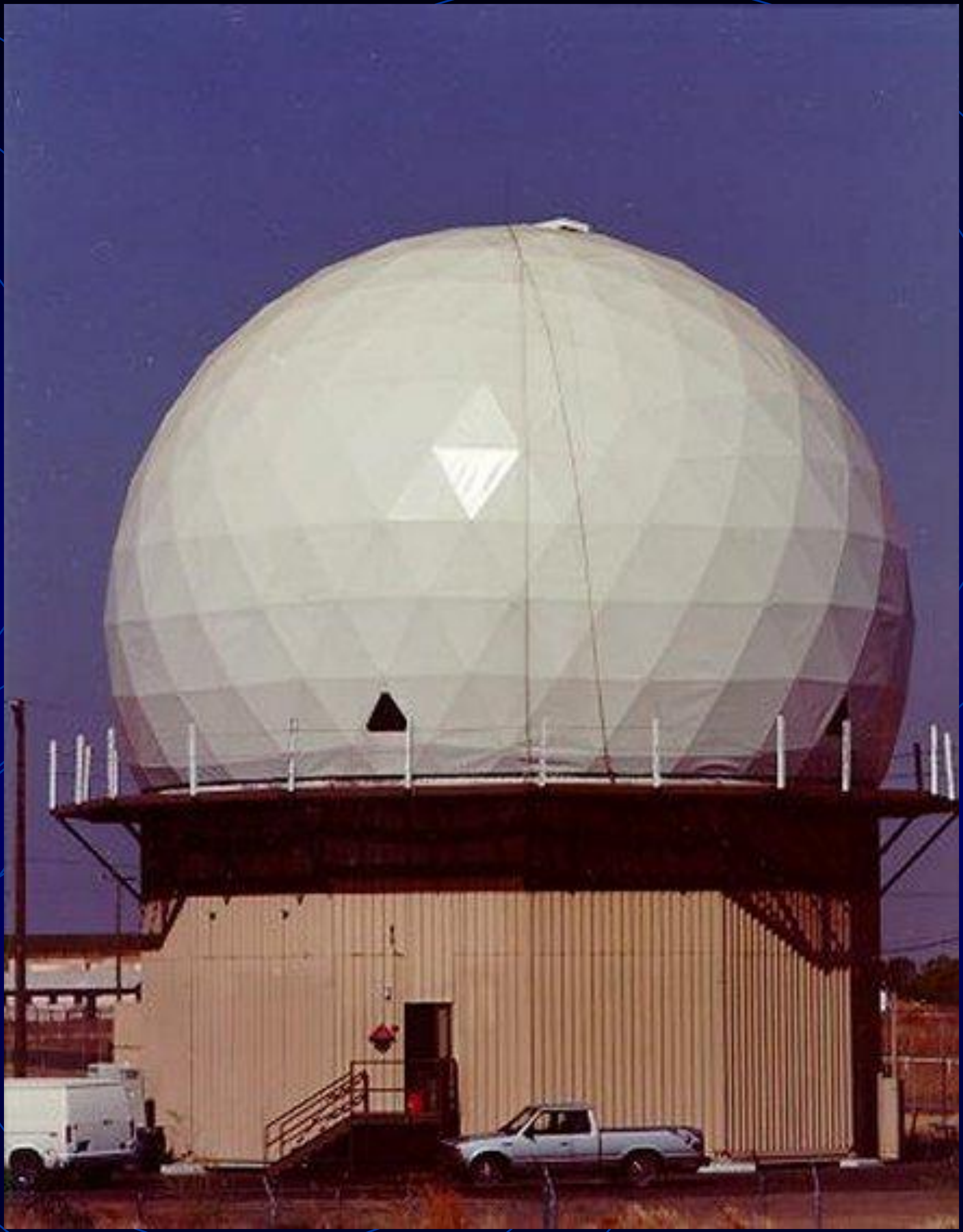
Antenna

- Directs the transmitted energy in a beam
- Collects the returned power
- Gain depends on the Diameter and wavelength
- A 4.2m antenna has a gain of 48,000 or 47dB
- Beam width of 0.82^{O} for the Dublin and Shannon Radars

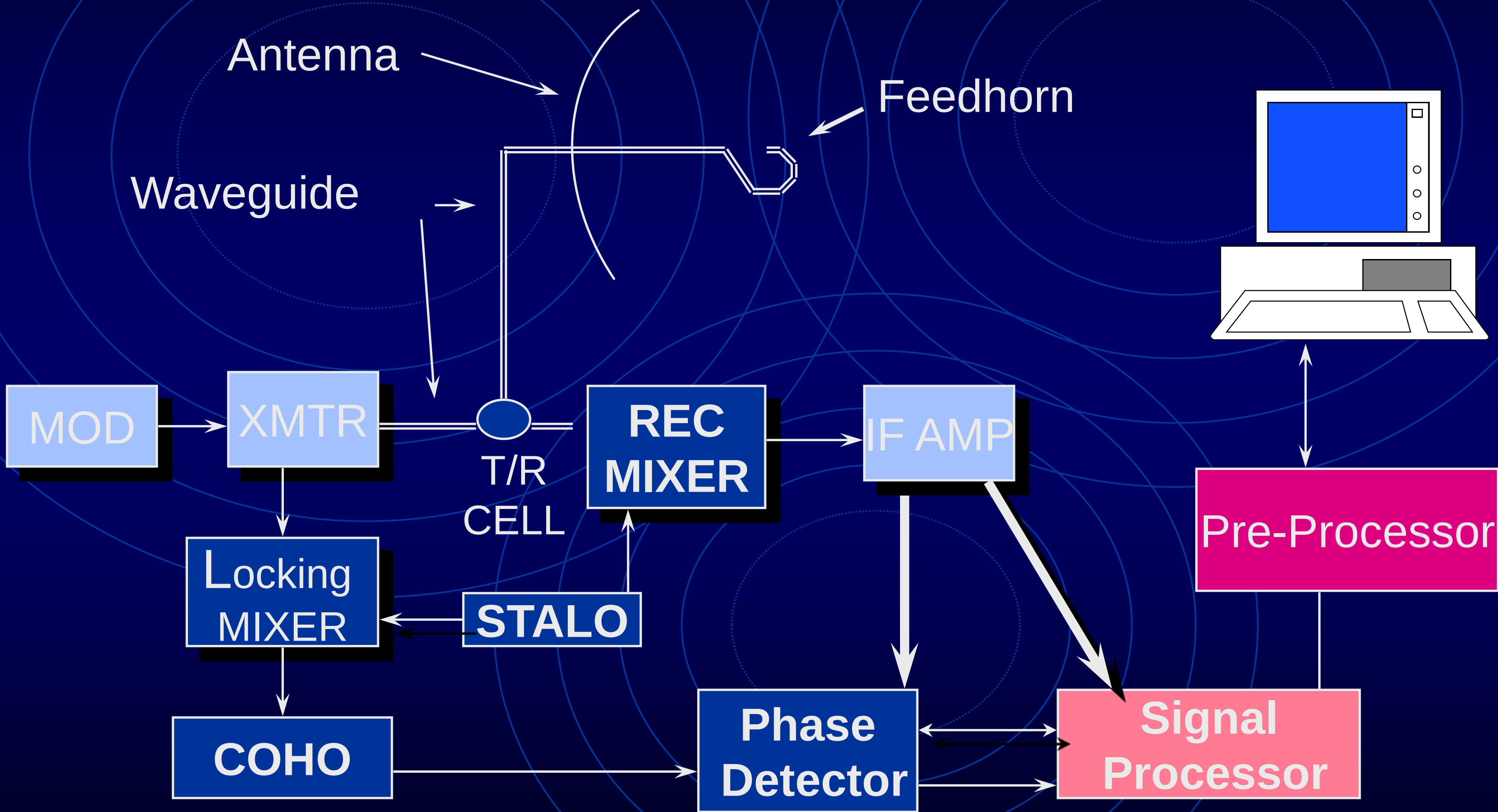
Chilbolton research radar, UK

Radome

- Protects antenna from wind and rain
- Less stress on antenna drives
- Shelter of personnel working on the antenna
- Sandwich construction ‘tuned’ to the radar wavelength



Radar ..Schematic Drawing

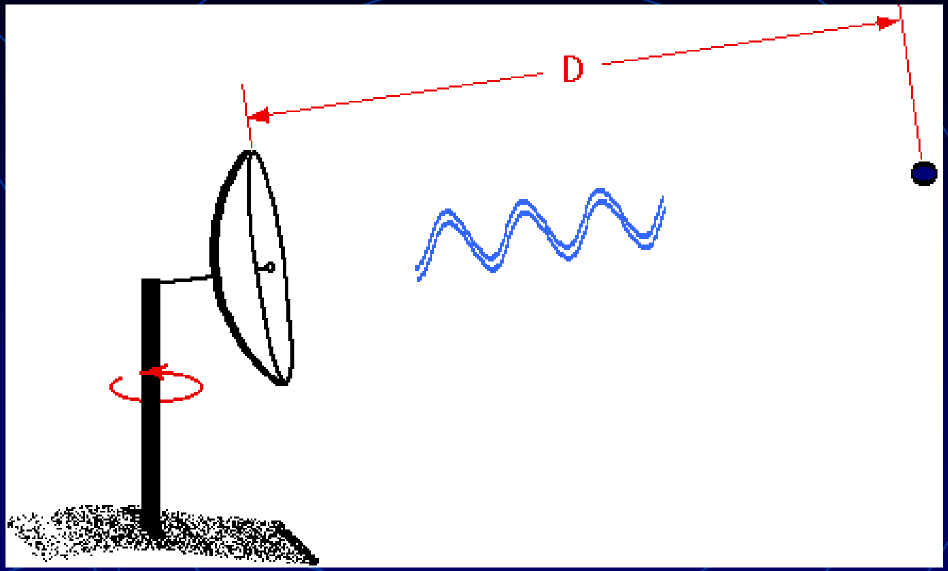


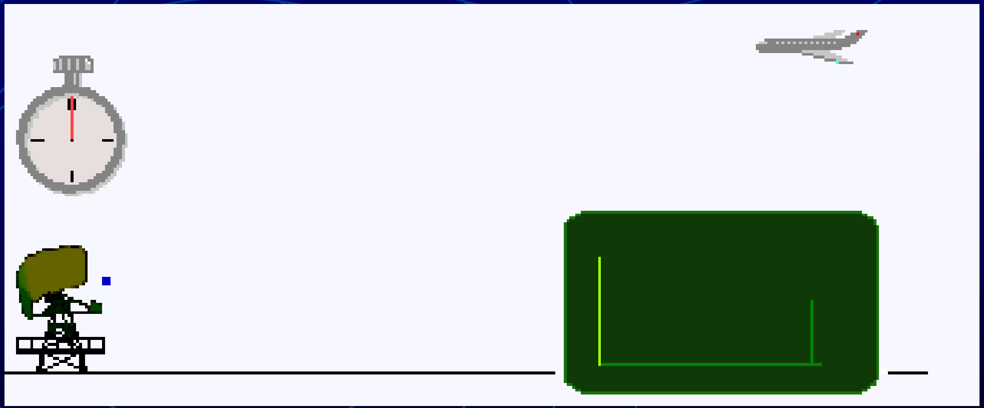
Radar Ranging

range = 1/2ct

c=speed of light

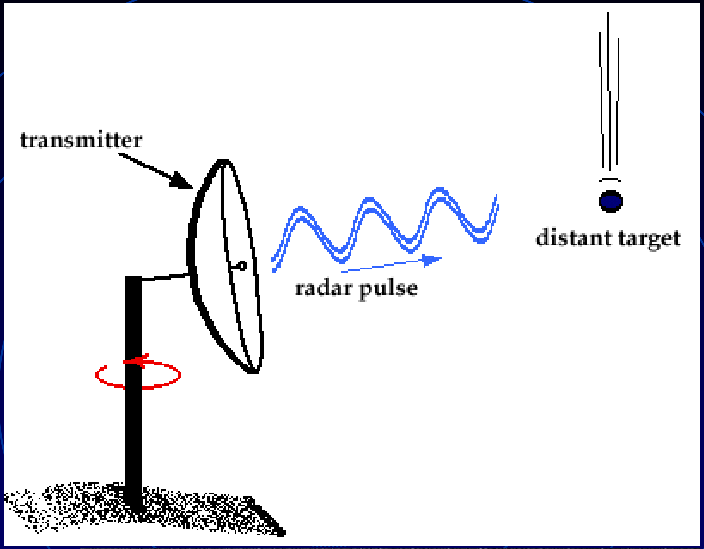
t=time taken for pulse to travel to target and back

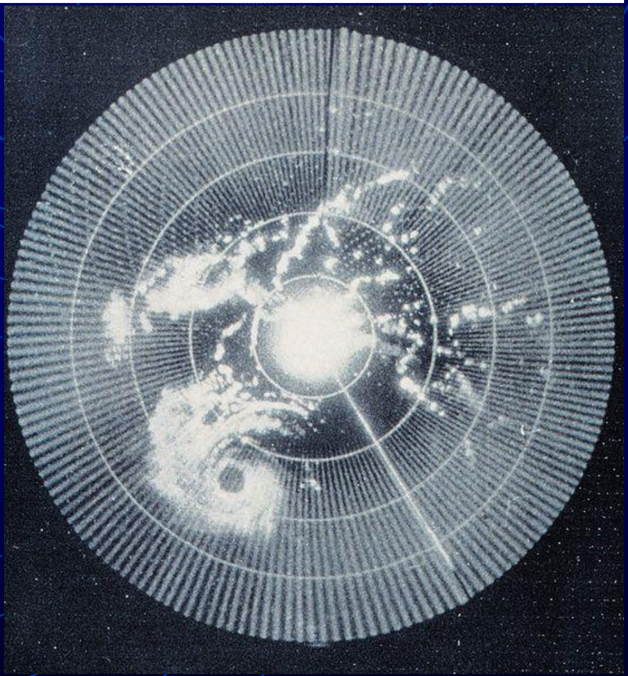




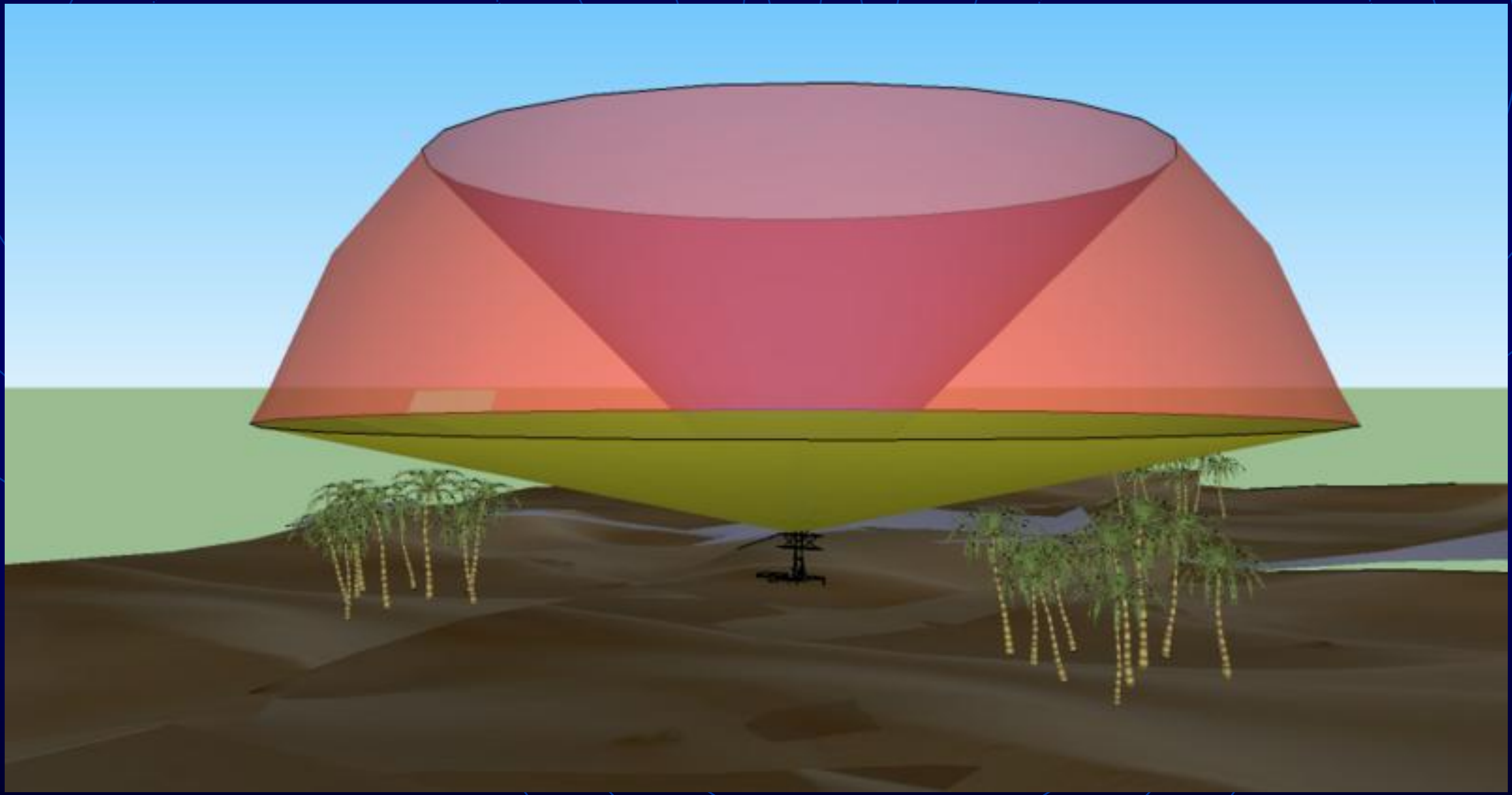
Radar Scanning

- Radar sends out a stream of pulses
- Antenna rotates
- Builds up a 'picture' of the echoes





Radar Polar Volume

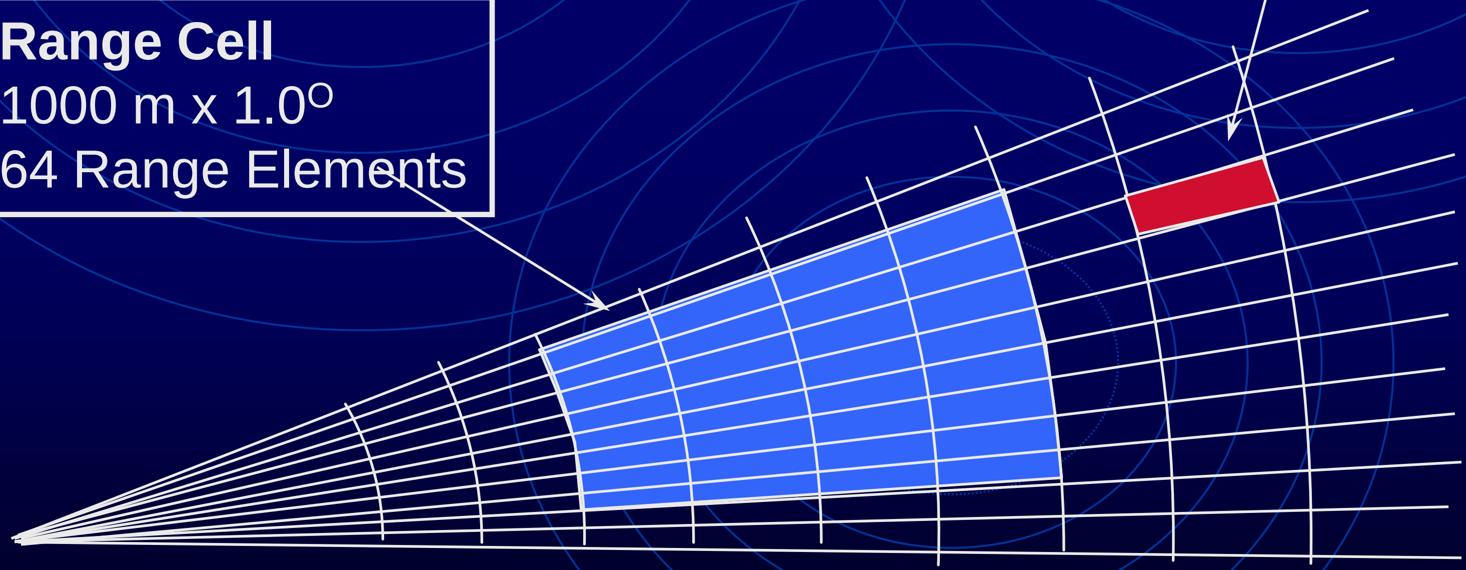


Data Collecting and Sampling

Shannon Radar

Range Element
250m x 1.0^{O}

Range Cell
1000 m x 1.0^{O}
64 Range Elements

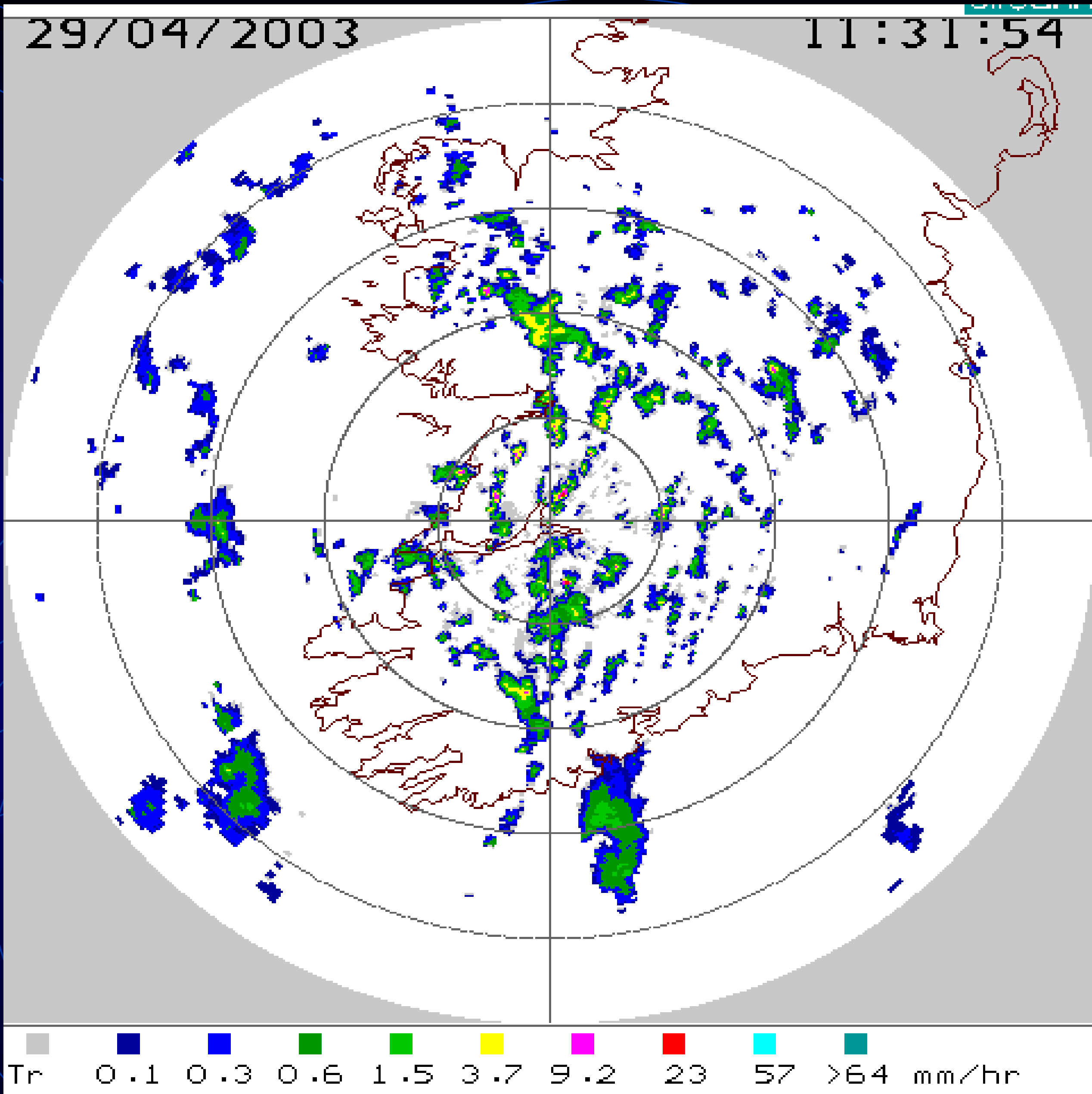


Shannon Radar

240 km

PPI

Plan-position Indicator



Radar Meteorology

A little Physics!

Some definitions

Antenna Gain:

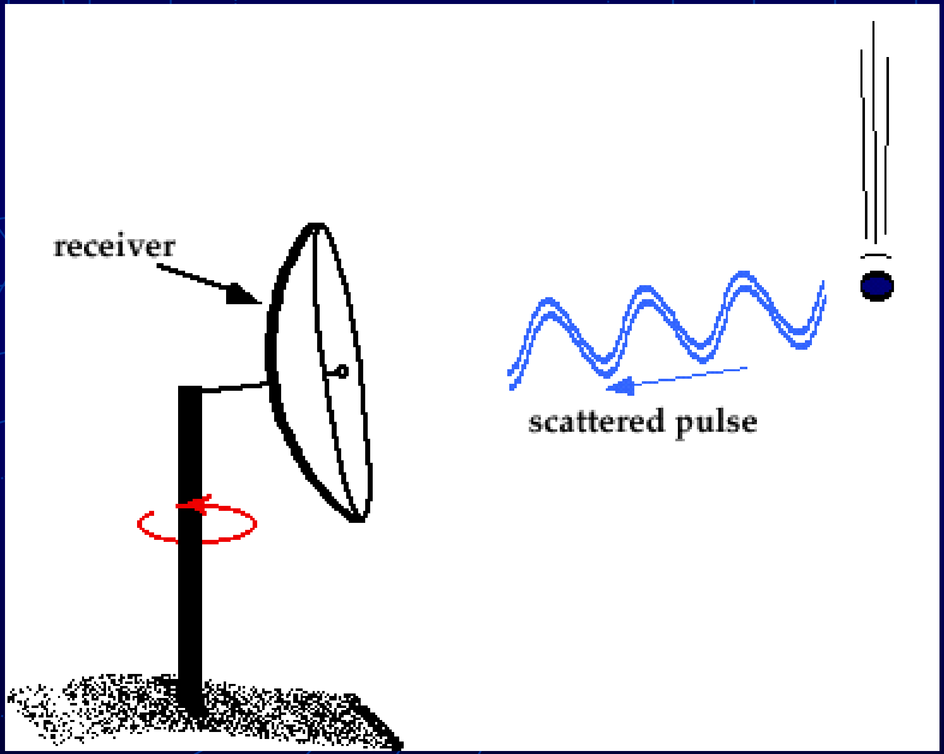
$$gain = \frac{power\ with\ antenna}{isotropic\ power}$$

or in terms of dB

$$g = 10\log_{10}\left[\frac{power\ with\ antenna}{isotropic\ power}\right] dB$$

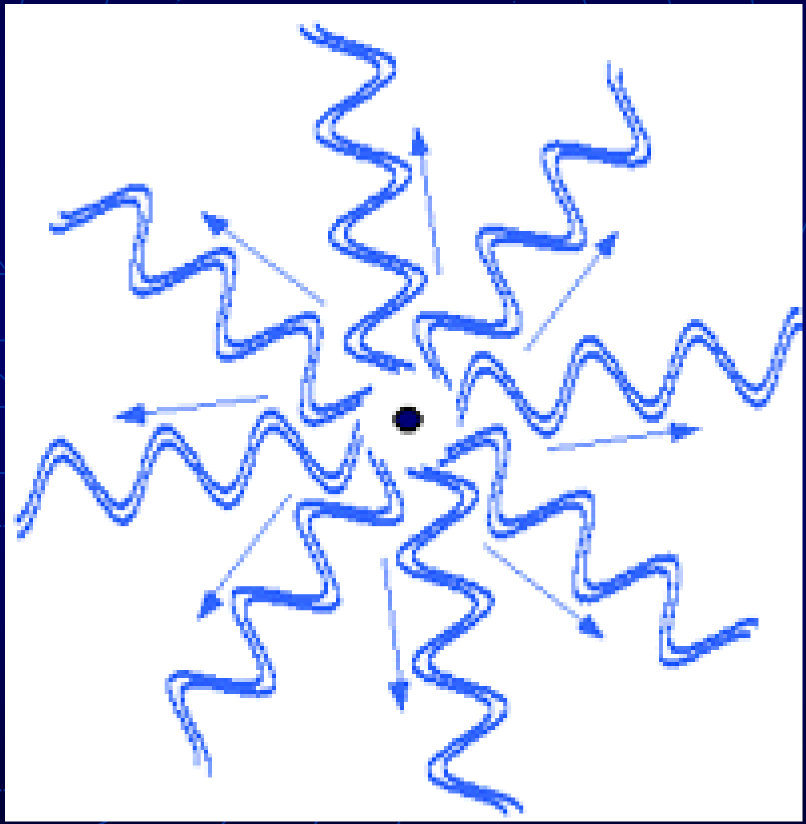
Point Target

- Radar sends out a pulse
- Scattered by the target
- Some power returns to the receiver



Scattering from a Point Target

- Radar Pulse is scattered by the target in all directions
- Only a small fraction of the power is returned to the receiver



Power received from a Point Target.

$$P_r = \frac{P_t\, g^2\, A_t\, A_e}{(4\pi)^2\, r^4}$$

where

P_r = Received Power

P_t = transmitted Power

g = antenna gain

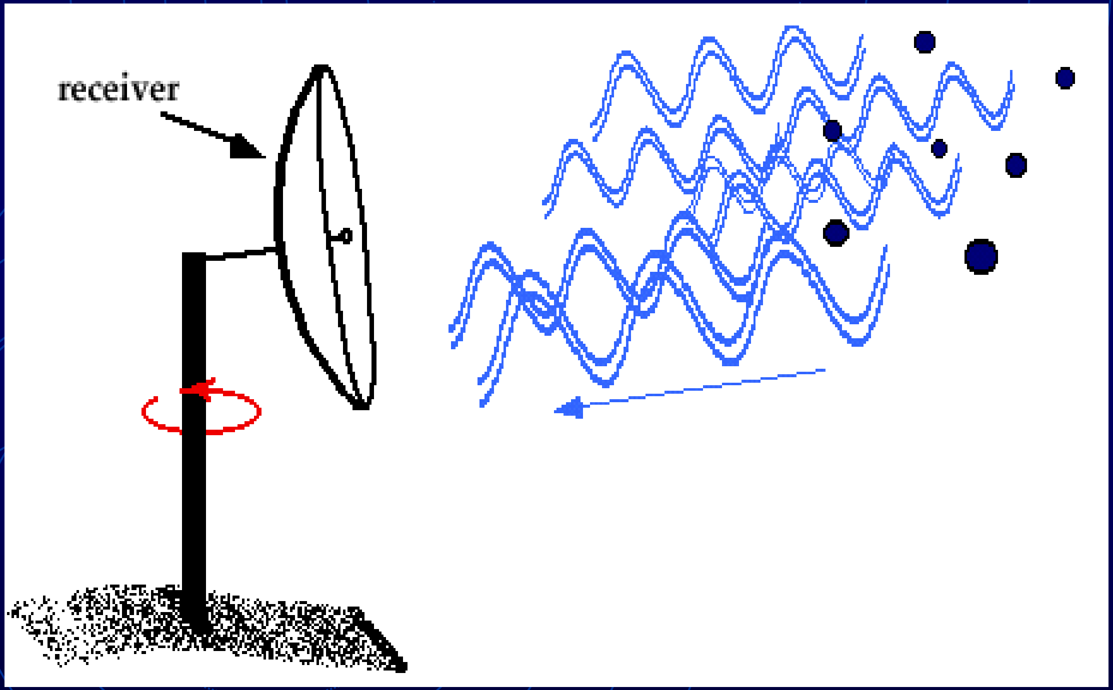
A_t = Target Area

A_e = Antenna effective area

r = range

Meteorological Targets

- Many targets – each raindrop!
- Power returned is the SUM of the powers from all the targets



Meteorological Targets

Power received from Meteorological Targets

$$\overline{P_r} = \frac{P_t\, h\, A_e}{8\pi r^2} \cdot F K \sum \sigma_i$$

where

$\overline{P_r}$ = *mean power over several pulses.*

h = *pulse length*

A_e = *Effective Antenna Area*

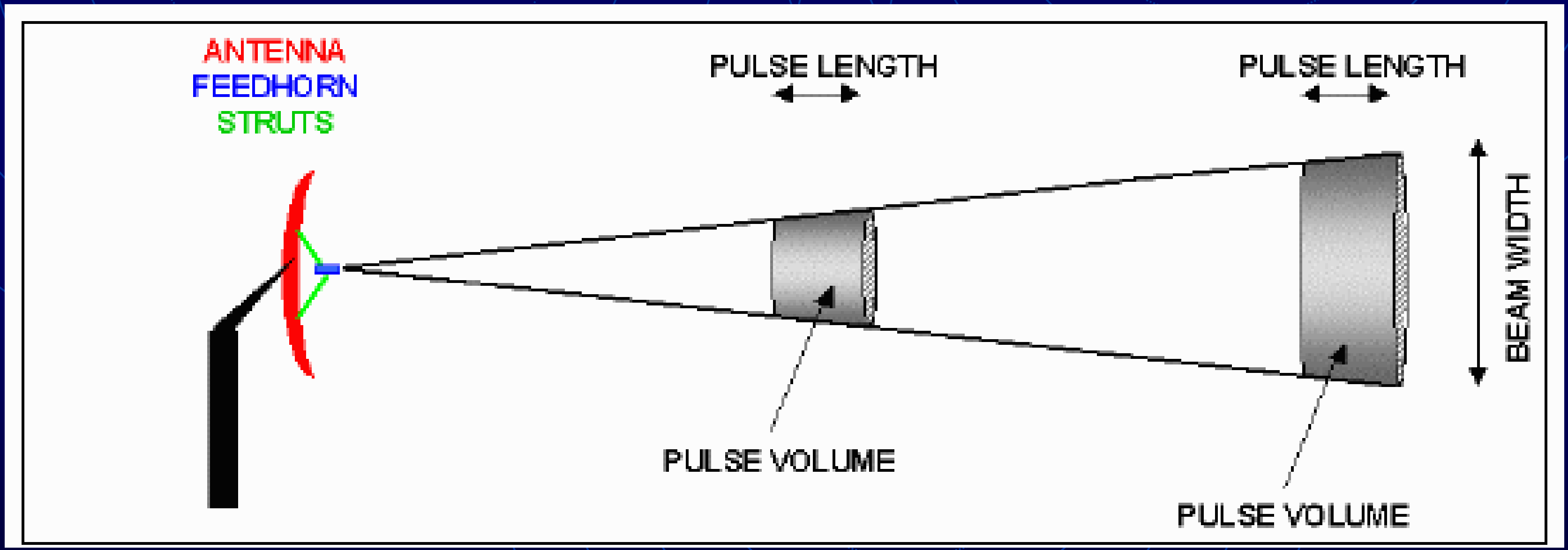
r = *range*

F = *fraction of the beam filled with targets*

K = *attenuation factor*

σ_i = *scattering cross section of each drop*

Pulse Volume



Pulse Volume

$$V_m = \frac{(r^2 \phi^2)}{4} \cdot \frac{h}{2}$$

ϕ is the beamwidth and h the pulse length

Note the r^2 above the line; this partly cancels the $1/r^4$ rule found in the Power from a Point Target.

Cross-section of Meteorological Targets

Cross-section:

$$\sigma_i = \frac{\pi^5}{\lambda^4} |K|^2 D_i^6$$

where

$$K = \frac{m^2 - 1}{m^2 + 2}$$

and m is a complex refractive index

$|K|^2$ = *0.93 for water and 0.197 for ice.*

D_i = *Diameter of a drop*

The Radar Equation

- Power Received from Precipitation

$$p_r = \frac{\pi^3 p_t g^2}{128} \cdot \frac{\theta\phi h}{8\ \ln(2)} \cdot \frac{|K|^2 l}{\lambda^2 r^2} . \Sigma D_i^6$$

$P_t = transmitted\ \ power$

$g = antenna\ gain$

$\theta\phi h = \ pulse\ volume$

$l\ =\ atmospheric\ attenuation\ factor$

$D_i =\ drop\ diameter$

$\lambda\ =\ wavelength$

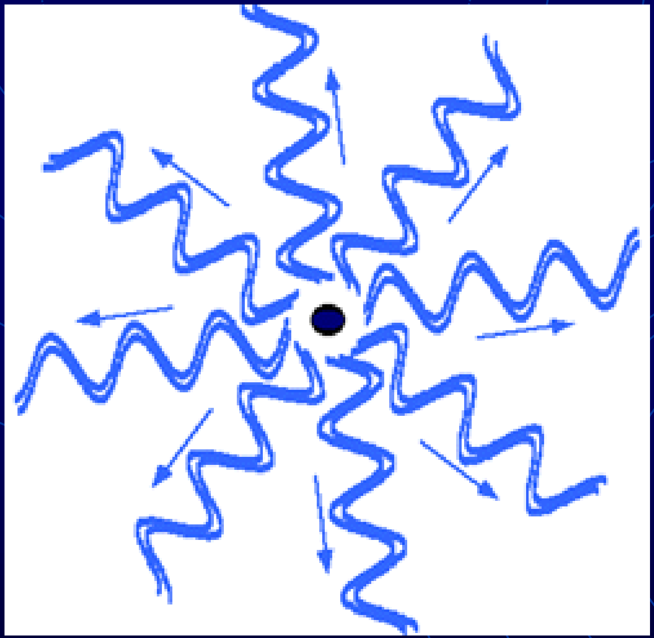
Radar Equation

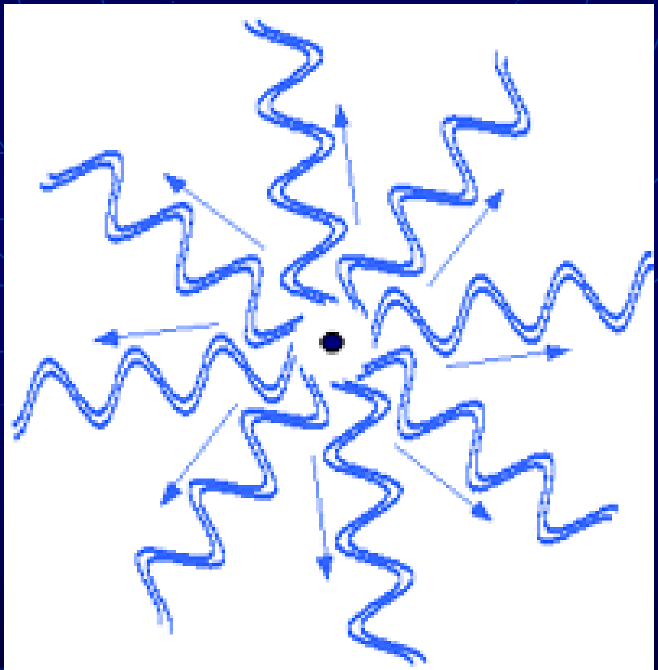
- For a given radar, most elements are constants
- Equation simplifies to:

$$p_r = C\frac{z}{r^2}$$

z = reflectivity
C = constant

Scattering from large and small targets





Reflectivity

- Radar measures the reflectivity of precipitation
- The reflectivity (z) is related to the size of drops

$$z \propto \sum D_i^6$$

Reflectivity and Rainfall..2
Effect of drop size.

- 1 Drop, 1mm diameter in 1 m^3:
  - $1^6 = 1$
  - z = 0 dBZ
- 1000 Drops, 0.1 mm diameter
  - $z = 1000 \times (0.1)^6 = 0.001$
  - z = -30dBz
- Same amount of liquid in both cases!

Reflectivity and Rainfall..3
Impossible Problem?

- NO!
  - Rainfall depends on drop size
    - large drops --> heavy rain
    - small drops -- > drizzle
  - large drops have higher vertical velocities
    - more water reached the surface
  - small drops low vertical velocities
    - remain suspended for much longer

Reflectivity and Rainfall..4
Z-R Relationship

- A definite relationship between Z and R has been found by empirical methods:
  - **$z = a\,R^{b}$**
- Standard relationship used in Ireland, UK and many other countries is:
  - **$z = 200\,R^{1.6}$**
- Marshall Palmer Relationship.
- Applies particularly to frontal rain.

Summary

- Radar measures **REFLECTIVITY** not rainfall
- Reflectivity is proportional to **SIXTH** power of the drop size
- Rainfall is deduced from reflectivity by an empirical relationship
- Heavy rainfall is over-estimated
- Light rainfall/drizzle is under-estimated

End of the Physics….

Radars in Met Éireann

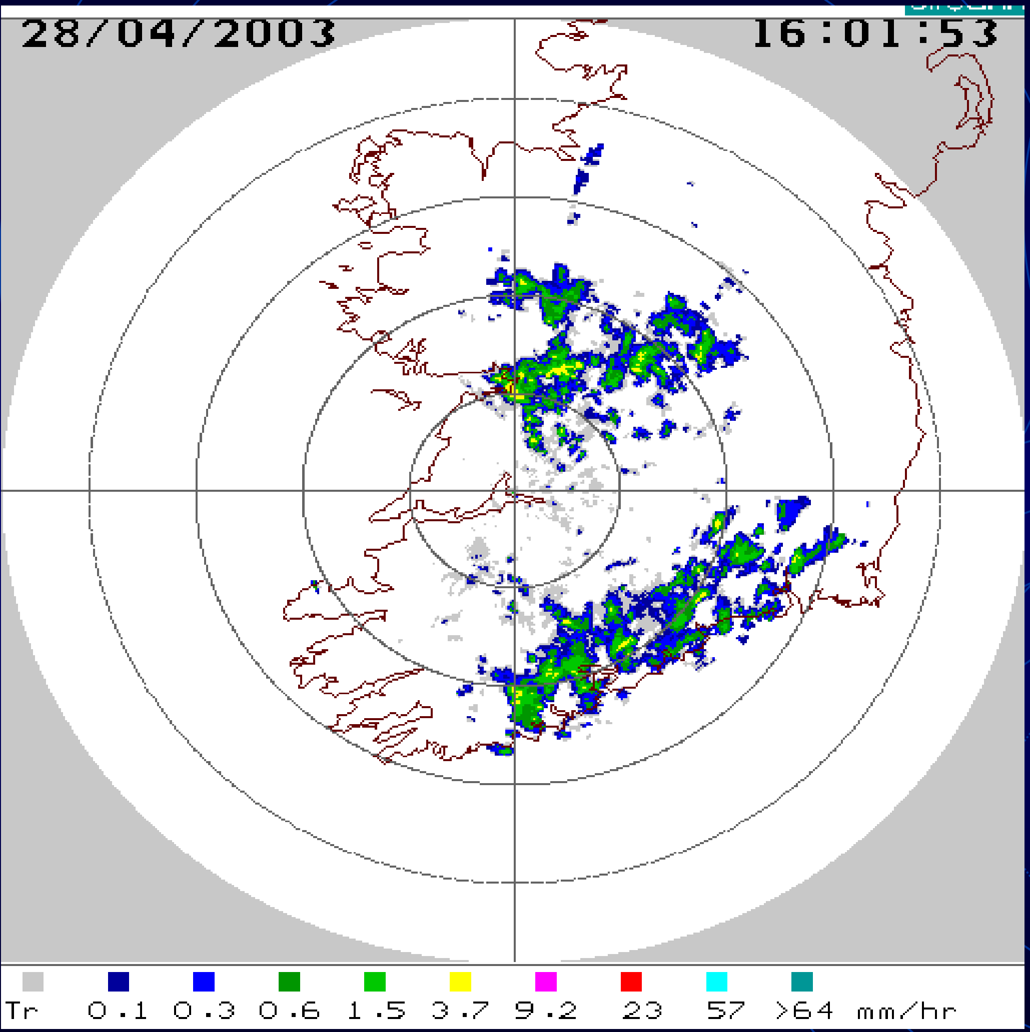
Radars in Met Éireann

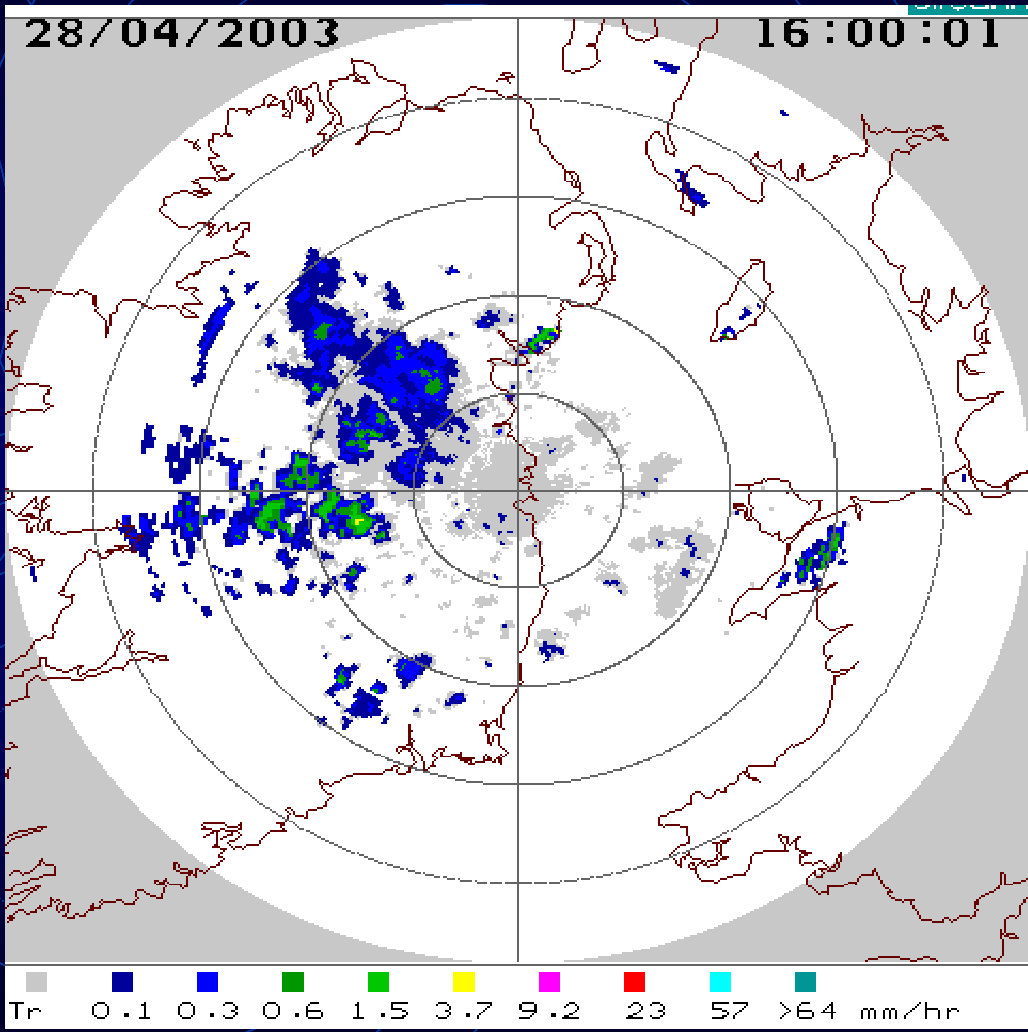
- Two radars: At Dublin and Shannon Airports
- Using radar since the 60's.
- First radar were manually operated and reports generated every 3 hours
- Shannon radar digitized in 1984, Dublin in 1991.
- Both upgraded in 2010-2011

Radar in Met Éireann

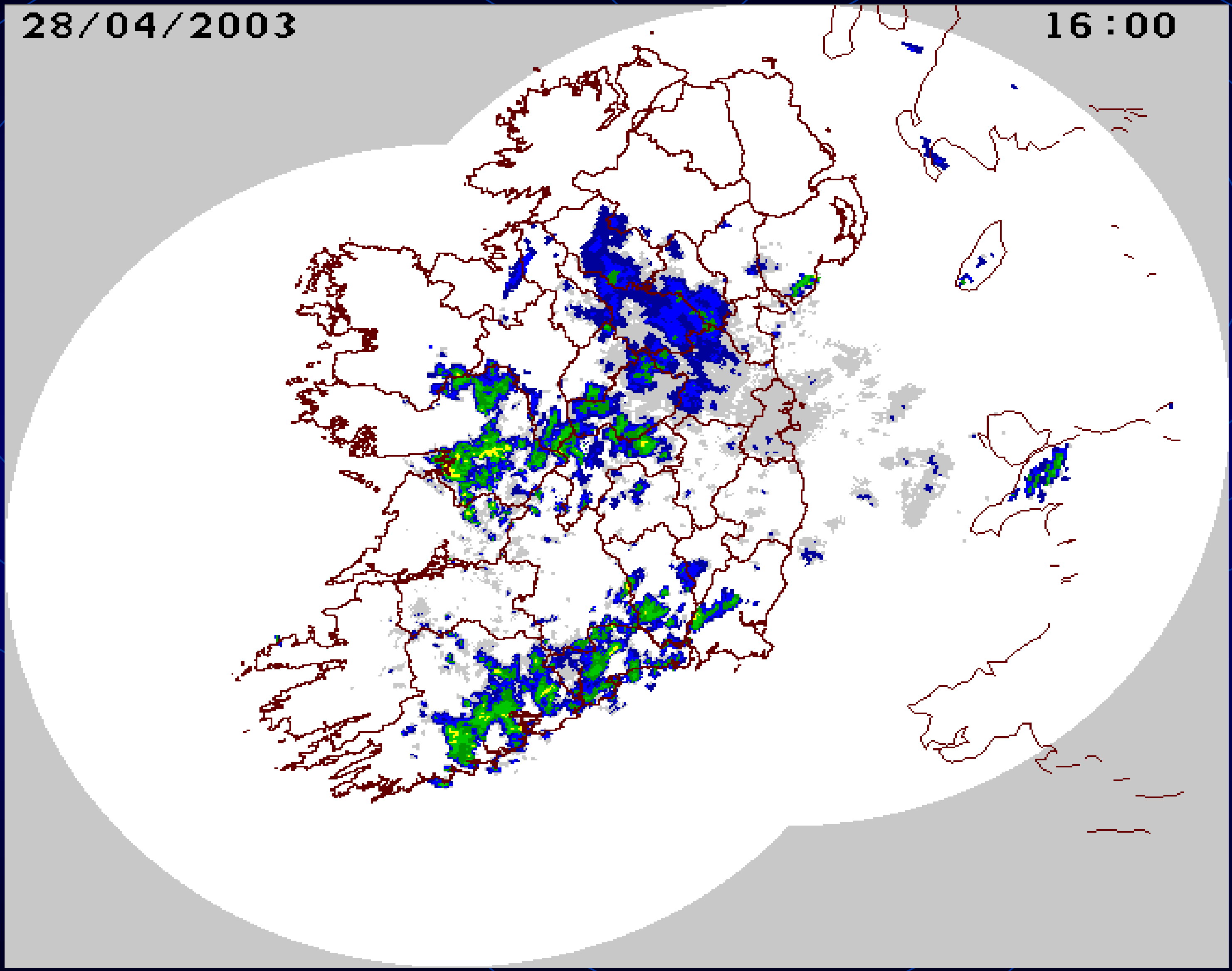
- Modern radars installed in the 90's
- Scan every 5 minutes to a range of 250 km with a 1km resolution.
- Archives dating from 1997.
- Accumulation data from 1998.
- Do not use telemetered raingauges or rain gauge corrections at present.

Single Site Radar Images





Irish Radar Composite



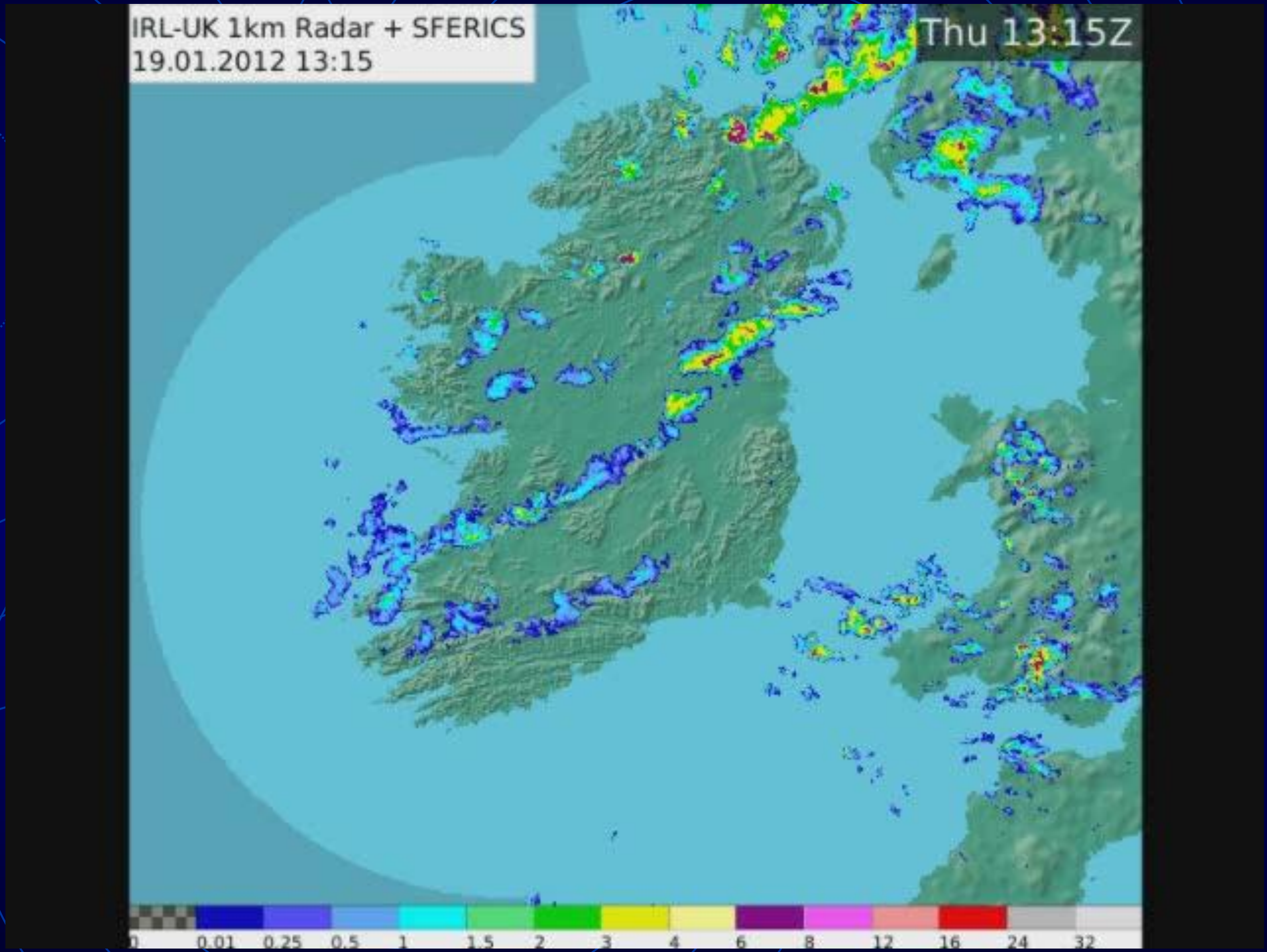
Animation -High Resolution Composite

- 2 radars
- Shannon
- Dublin
- Every 15 minutes
- Made in Dublin

Ireland Composite

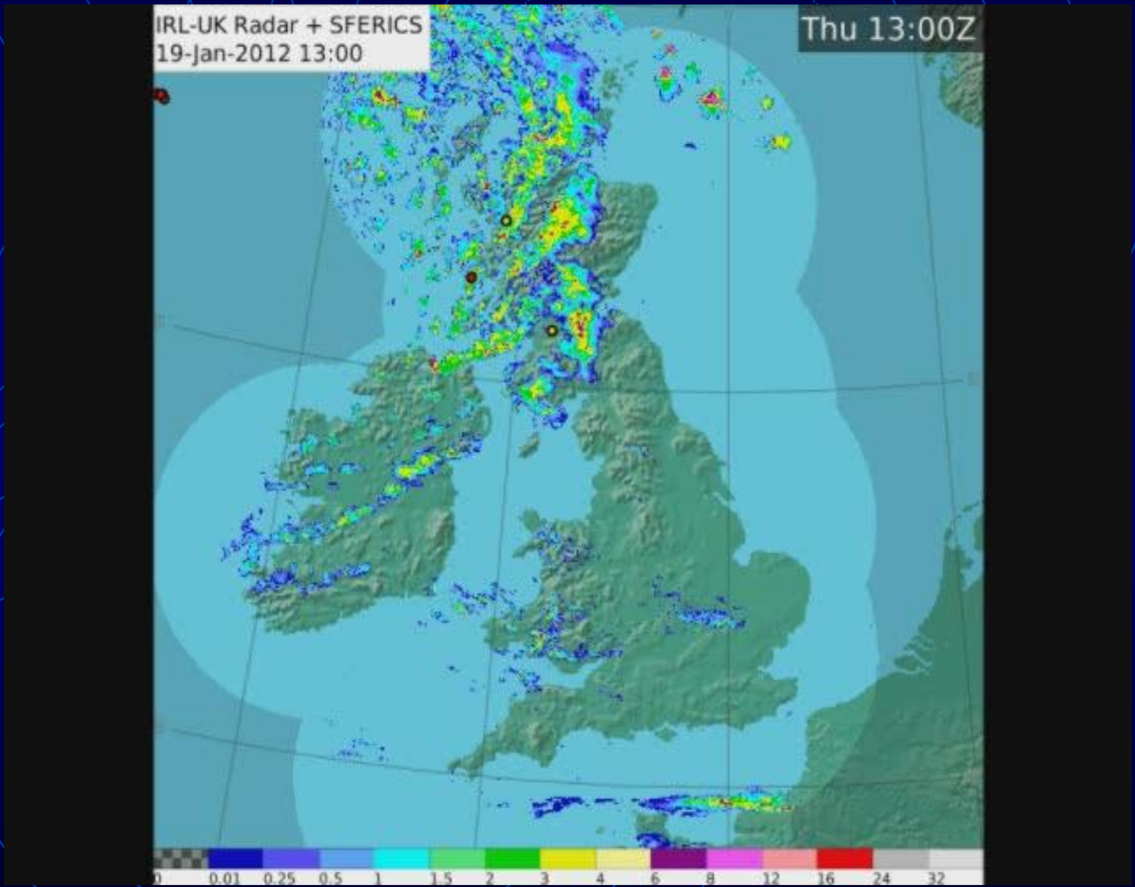
Radars Included:
Shannon
Dublin

Castor Bay
Crugygorllwyn
Cobbacombe Cross



UK-Ireland Composite

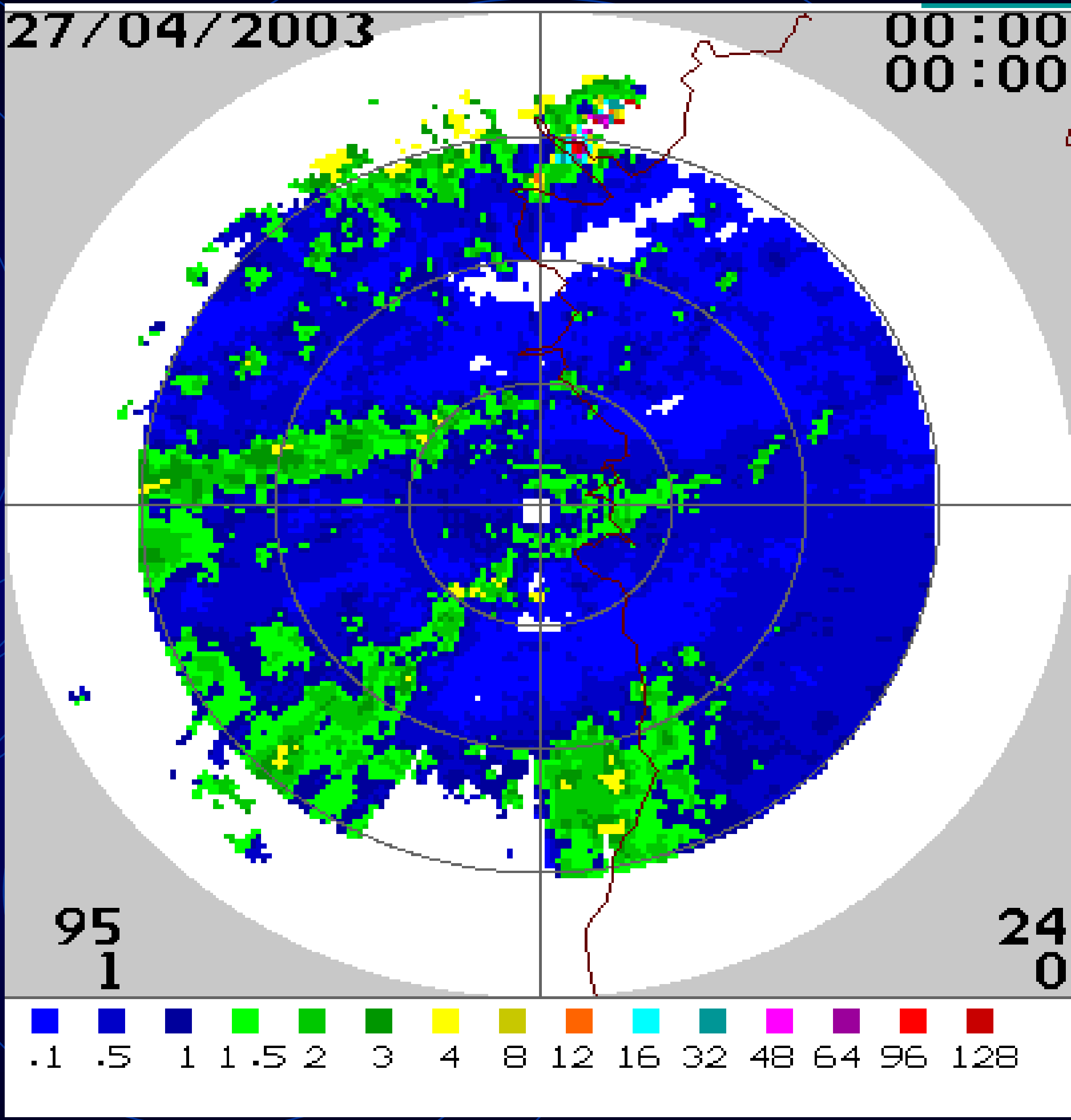
- 12 Radars in
- Ireland, Jersey and
- the UK



24 hour accumulation

Short range 75km
1000m height

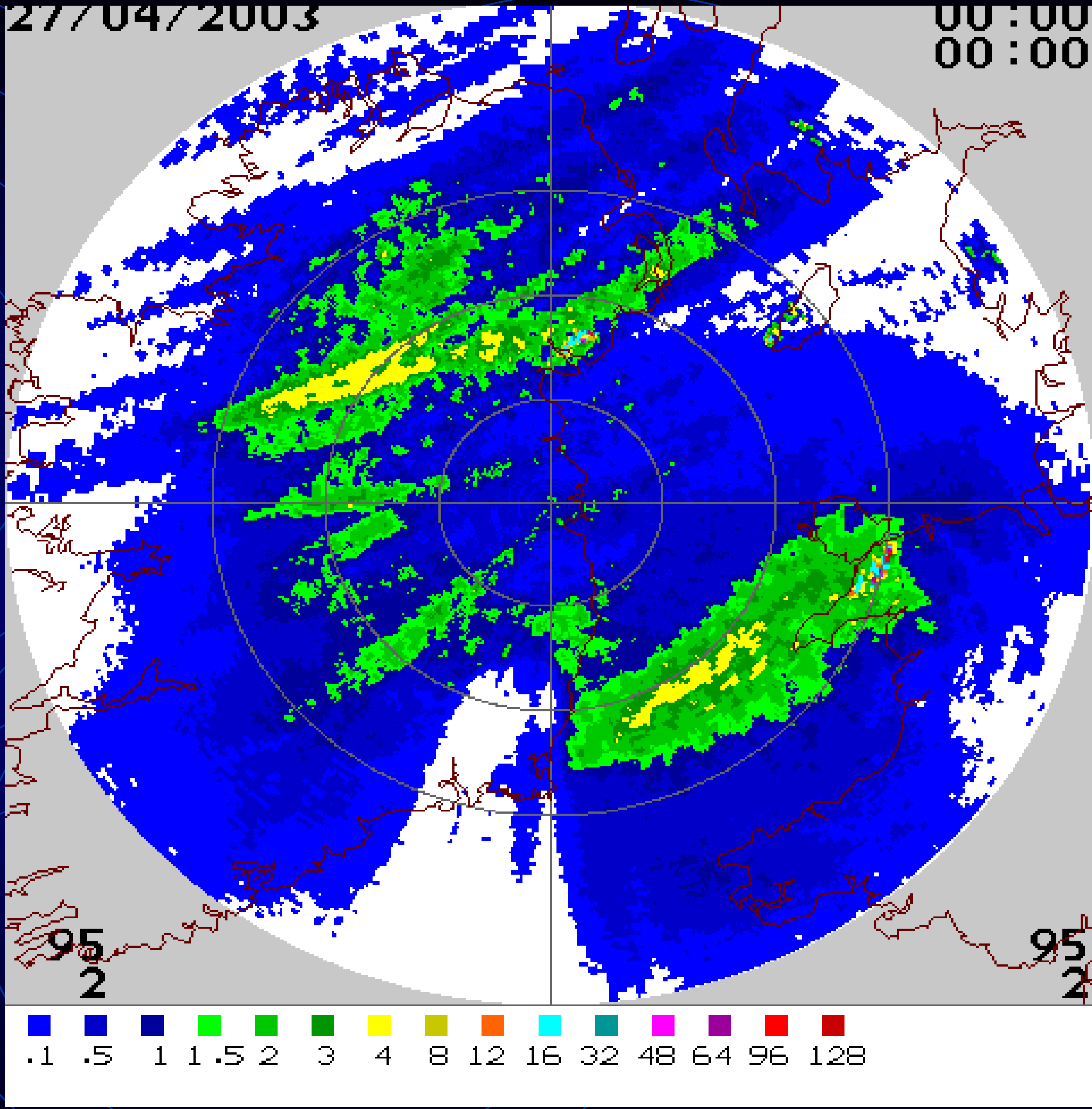
Distribution is even



24 hour accumulation

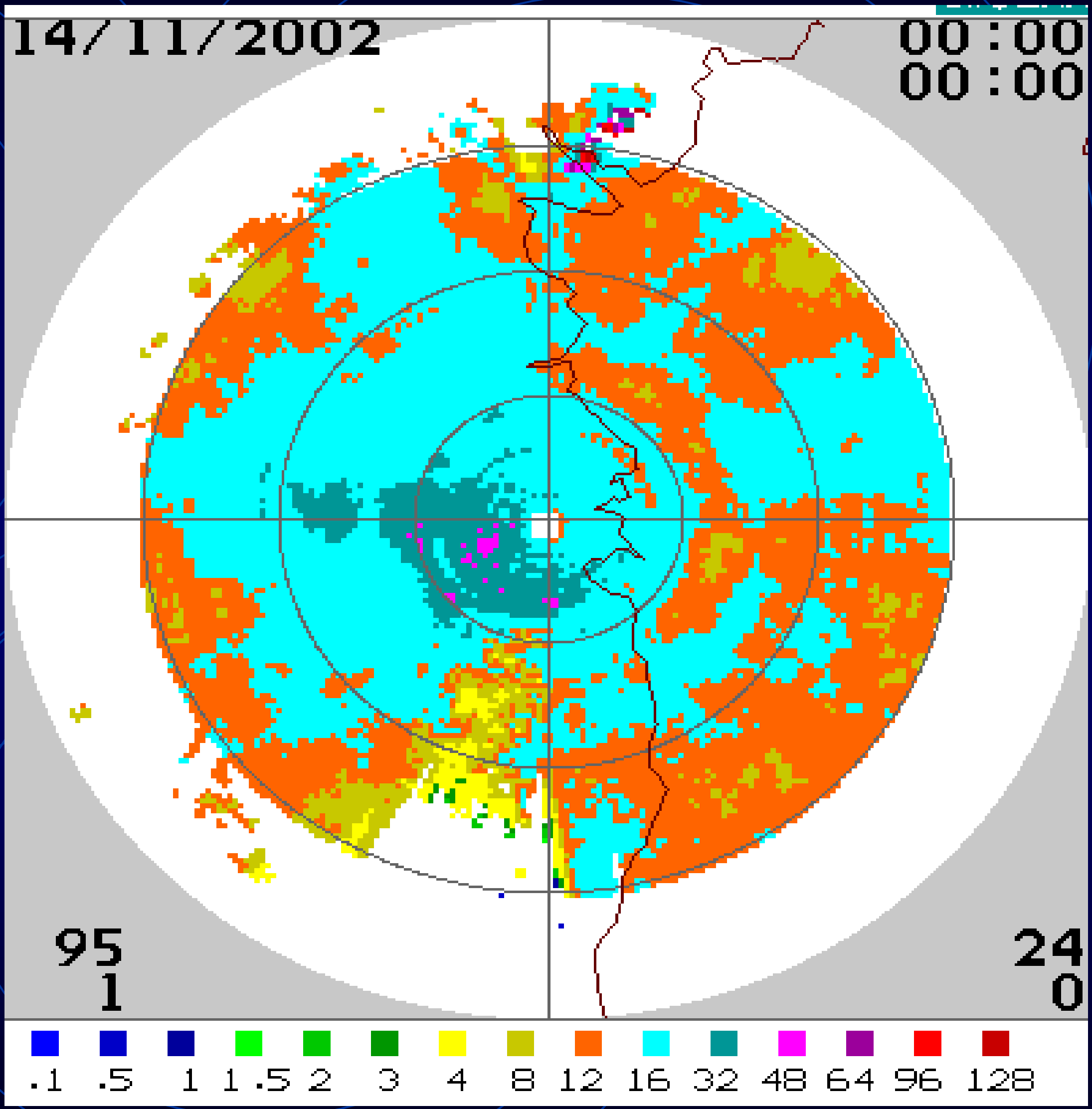
240km range

Intensities fall off at long ranges



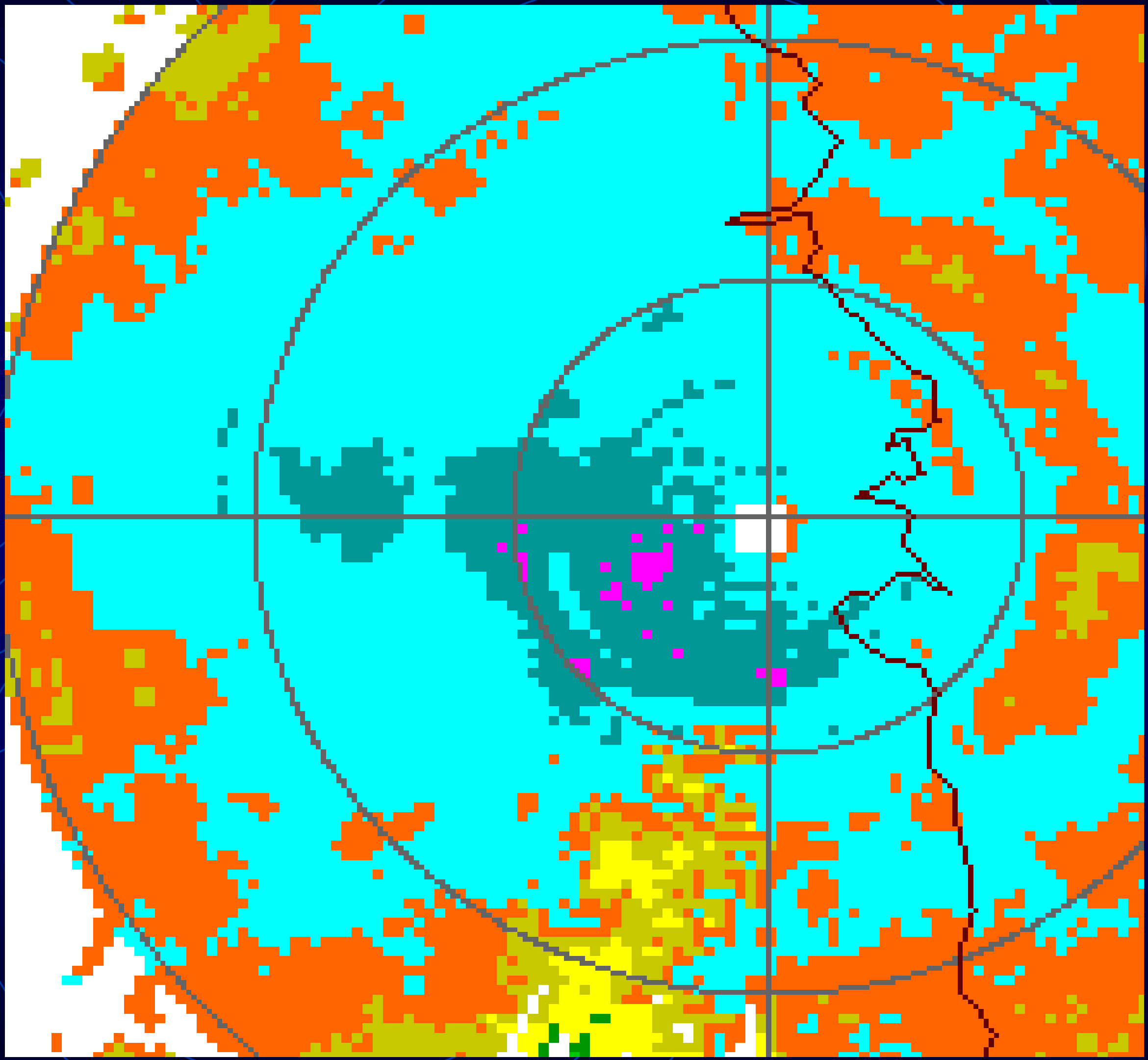
14 Nov 2002

- Major rainfall event
- Flooding of Tolka and Liffey.
- 24 Hour accumulation



14^{th} Nov 2002

- Close up of Dublin Area
- Intense areas to the West of Dublin



Future

- Much research is being carried out on improving radar rainfall measurements.
- New techniques involve dual-polarisation or even dual frequency radars but these are much more expensive.
- The next 10 years should see some major improvements.

Differences between Meteorological and ATC Radars

- Elliptical Antenna giving a “fan” beam.
- High rotation speeds - 15 rpm
- Wide beam width
- Suppression of all slowing moving targets especially weather.
- No vertical information - rely on transponders for height information
- Some have a “Weather Channel” especially in USA

Radar Problems!

Radar problems

- Earth’s curvature
- Ground Clutter
- Permanent Echoes
- Occultation by High Ground
- Bright Band
- ANAPROP

The Earth is Curved

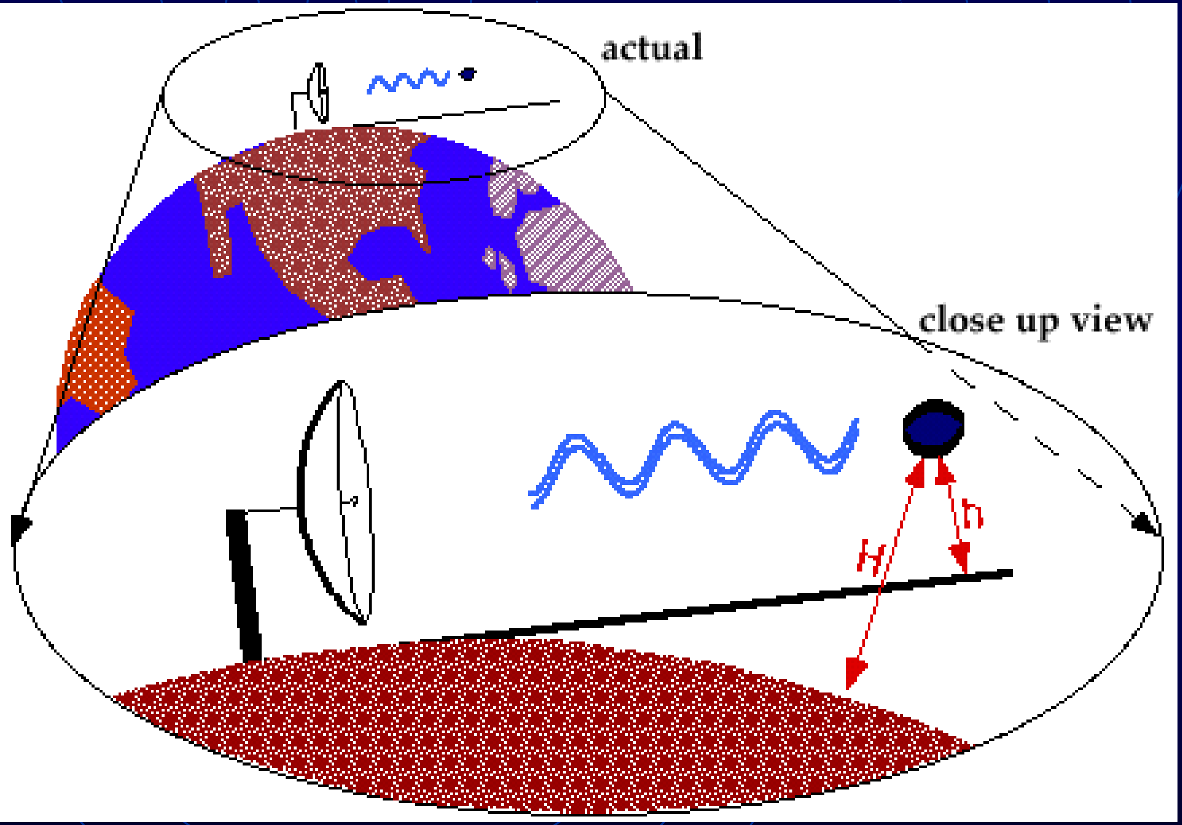
The following does not apply if the Earth is flat!!!

Curved Earth

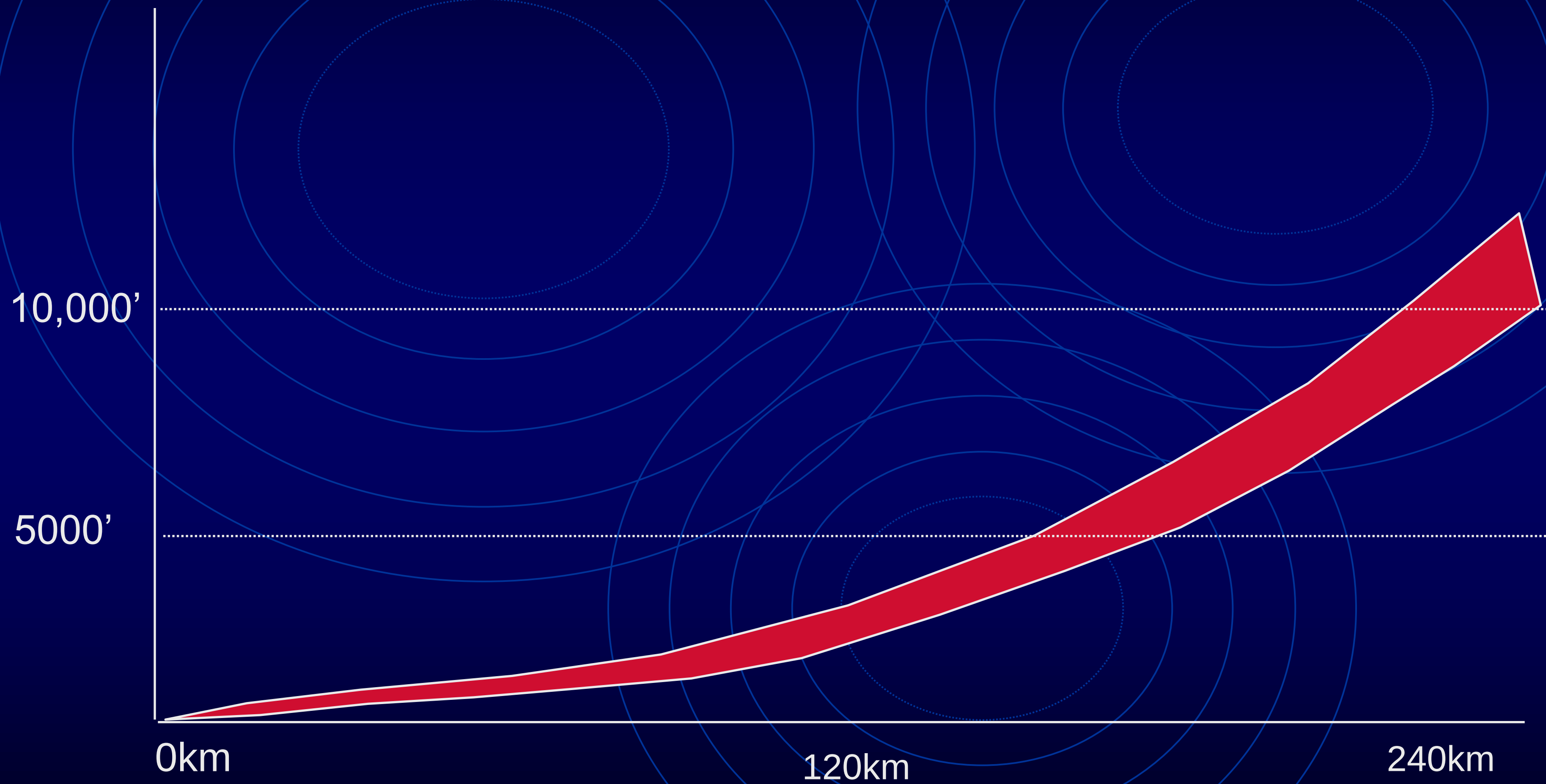
- The Earth is curved!
- This curvature is very significant for radars.
- At a distance of 250km, the lowest point visible to the radar is 12,000 – 14,000 ft above the surface.
- An entire rain system can exist below this level and may not be seen.

Earth’sCurvature

- Even though the beam is horizontal, it still rises above the Earth’s surface



Lowest Radar beam
Height Vs Distance



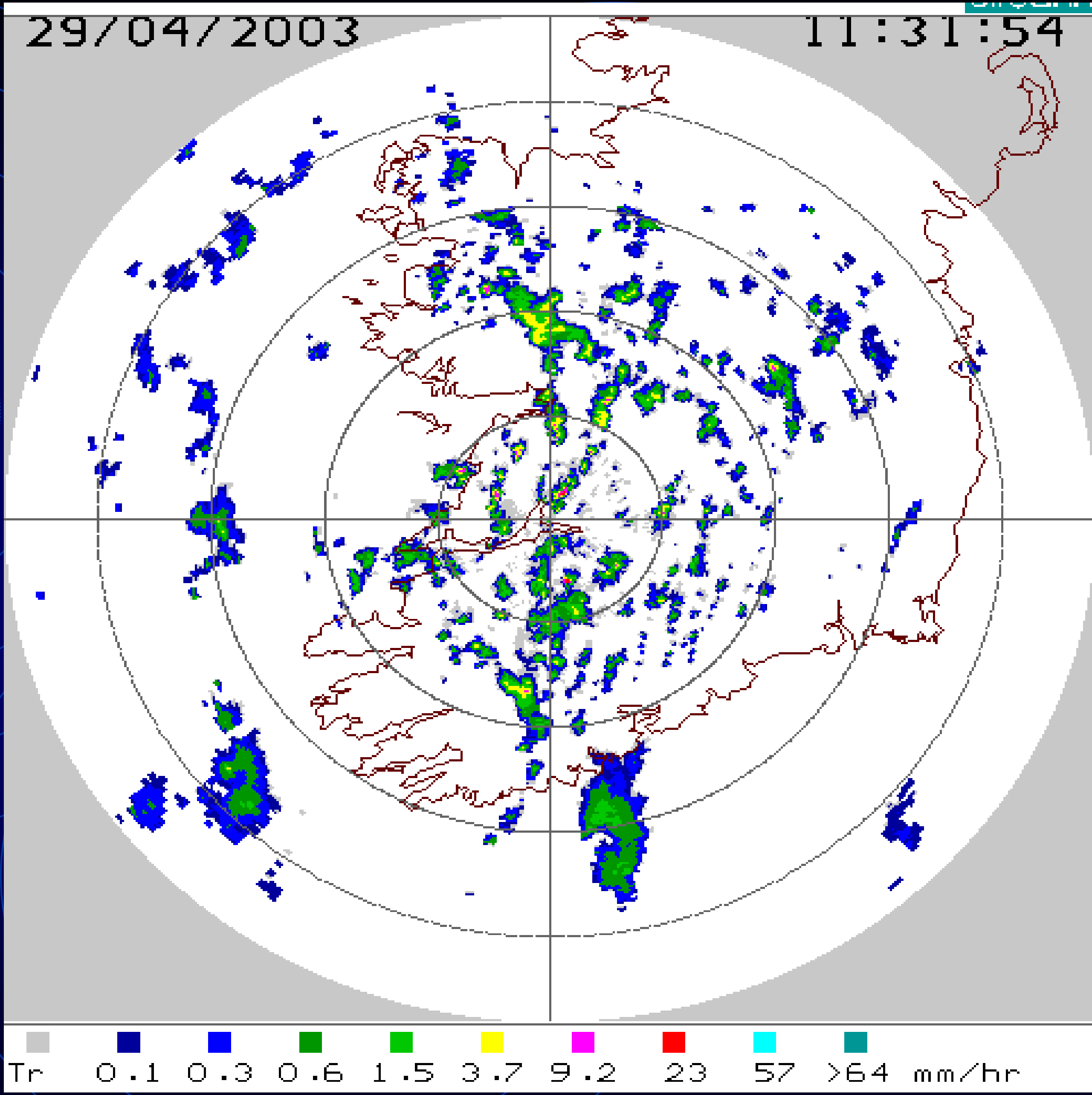
Shannon Radar

240 km

Weaker intensities at the longer ranges.

Radar only "sees" Tops of clouds.

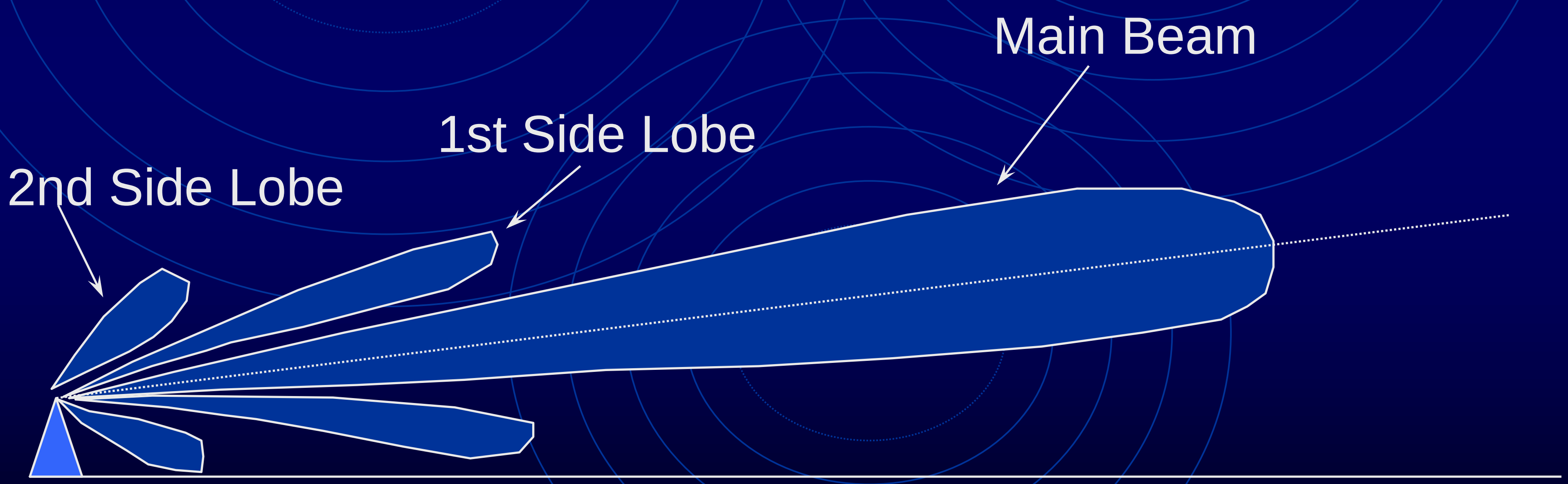
Best signals near the radar.



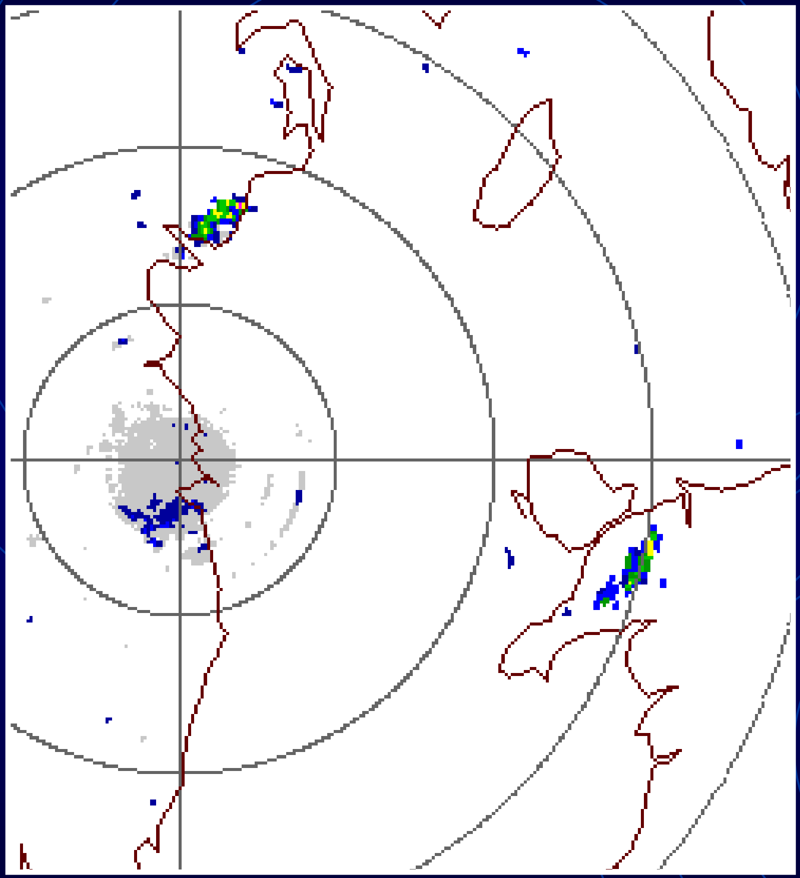
Radar problems
Ground Clutter

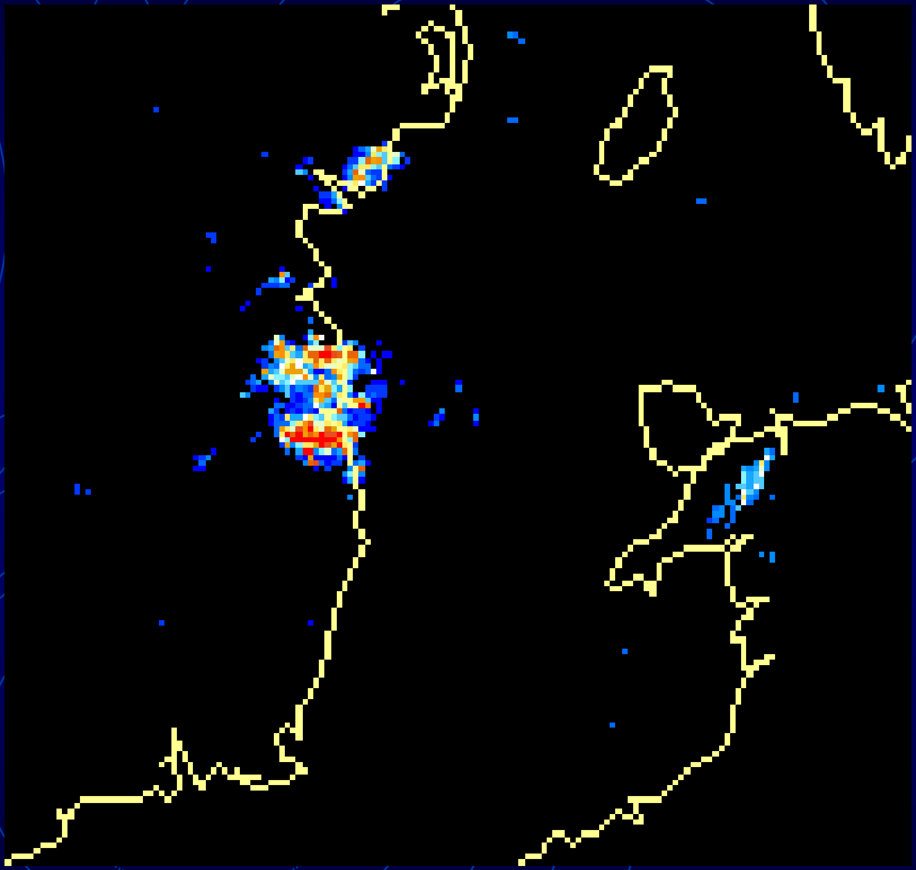
- caused by power in the antenna **side lobes**
- about 5% total power is in side lobes
- signal reflected by the ground and buildings
- worst within 10km of radar
- Permanent echoes from hills mountains or tall buildings
- Very evident on Dublin Radar display

Side Lobes



Permanent Echoes





Radar problems
Ground Clutter Solutions

- Radar site
  - low flat site : good
  - hill top good for permanent echoes but clutter more of a problem
- Clutter Maps
  - subtract clutter recorder on a fine day
  - can be used at Dublin and Shannon
  - not very effective

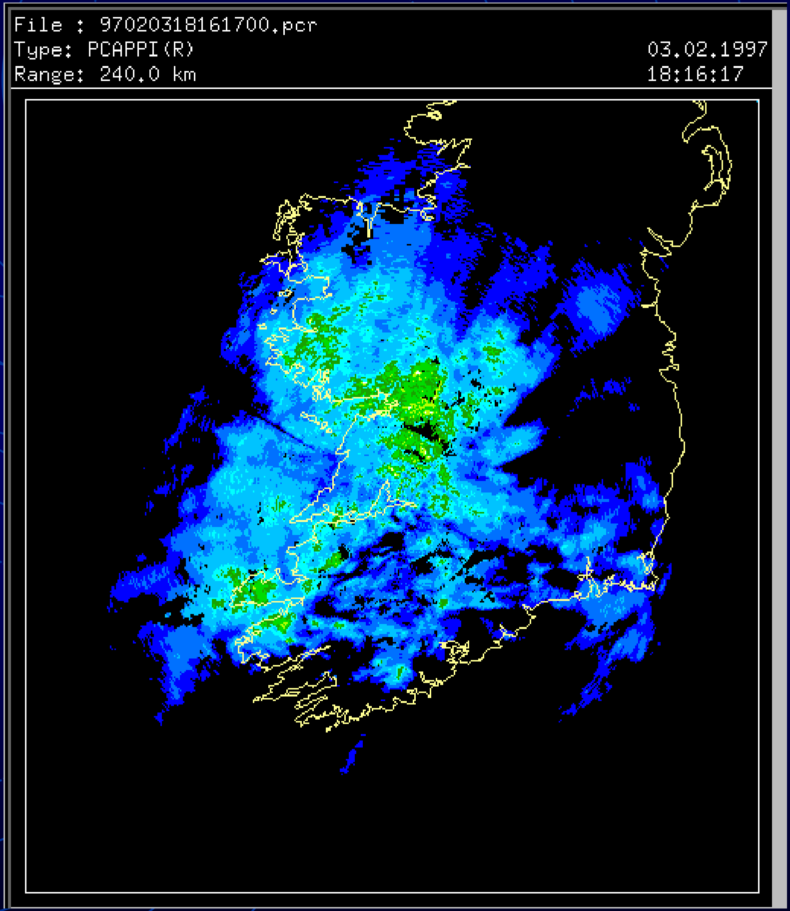
Radar problems
Ground Clutter Solutions

- Doppler Suppression
  - remove echoes with a velocity near zero
  - loose some real data!
- Statistical MTI
  - examine a large number of echoes in each range cell
  - clutter has smaller spread that echoes from hydrometeors

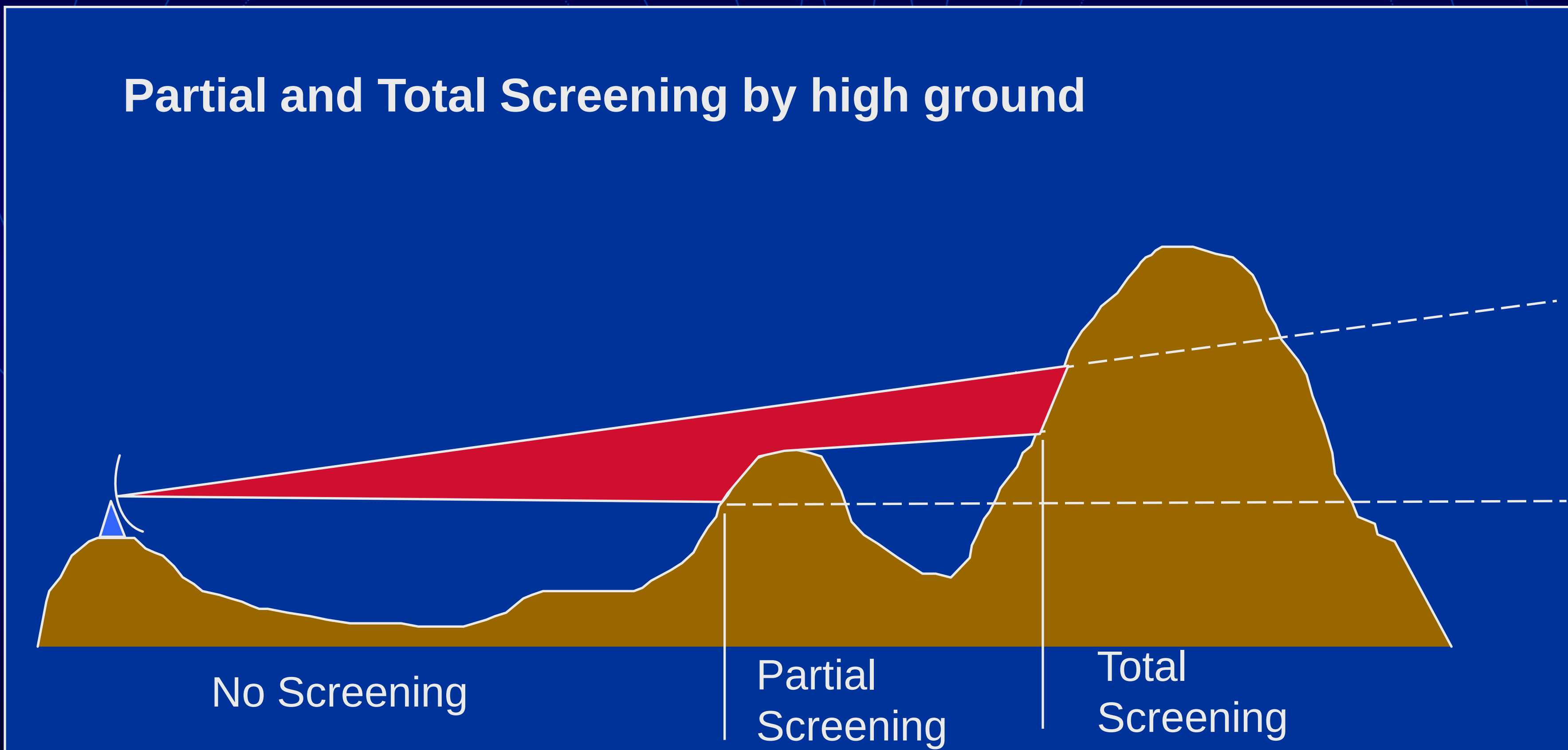
Radar problems

Occultation by High Ground

- Radar beam is partially or Totally blocked by hills.
- Get “shadows” in the rainfall patterns especially in Accumulation products



Occultation



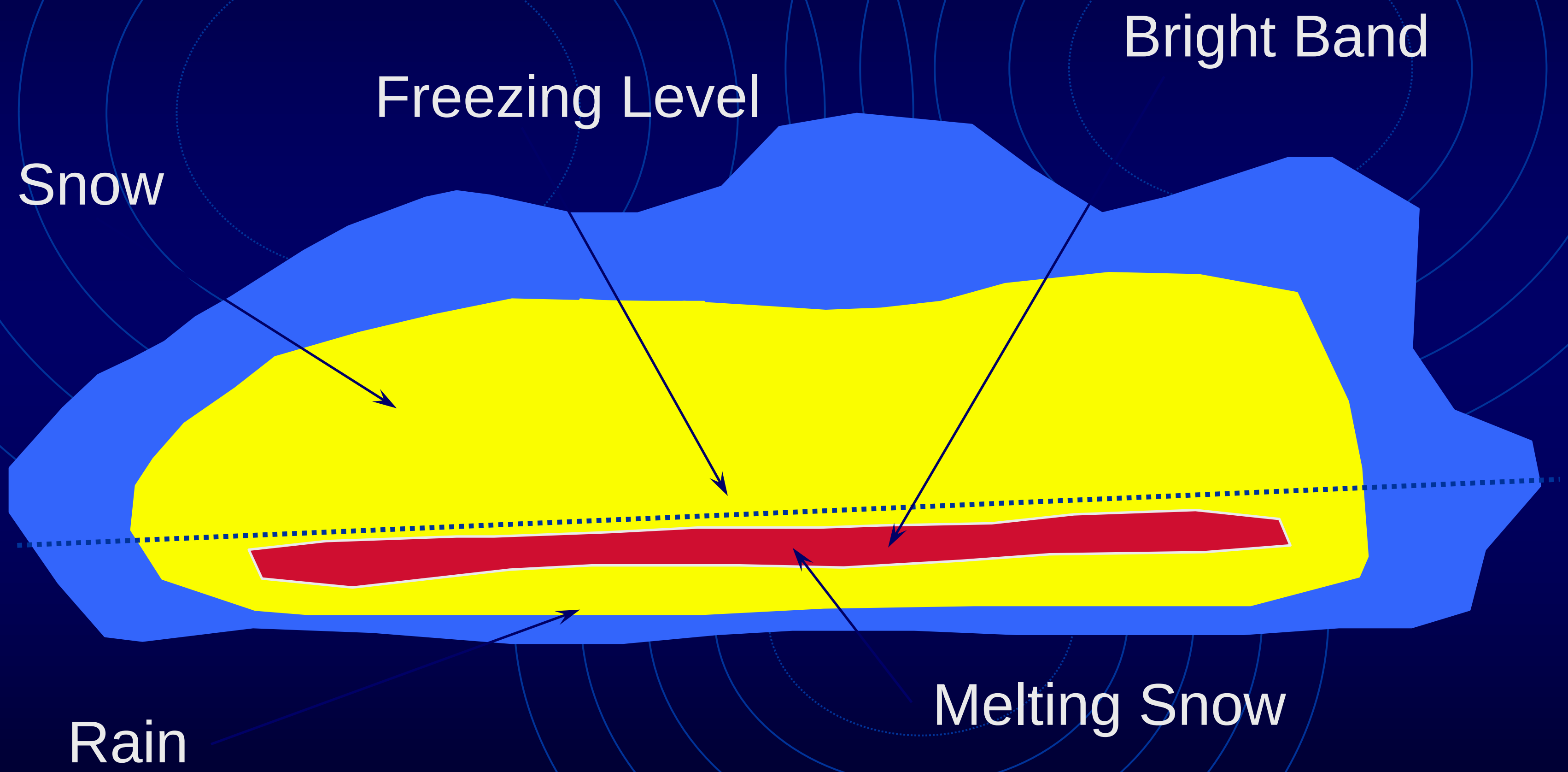
Radar problems
Occultation by High Ground

- Partially Blocked Beam:
  - correct affected cells by a % correction
  - effective up to 50% blockage
- Totally Blocked Beam:
  - use nearest unblocked cells
  - use weighted mean of nearest neighbours
  - mark as blocked
- 3D Clutter and Occultation Scheme

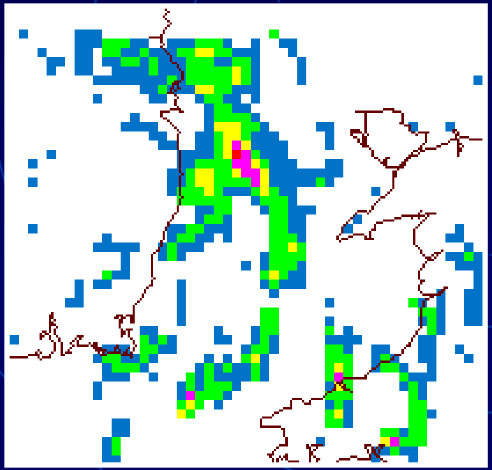
Radar problems
Bright Band

- Caused by melting snow
- Wet snow has higher reflectivity than either snow or rain
- Can be seen in vertical cross-sections
- Can lead to over-estimation of rainfall
- Solutions
  - visual examination
  - computer algorithms (experimental)

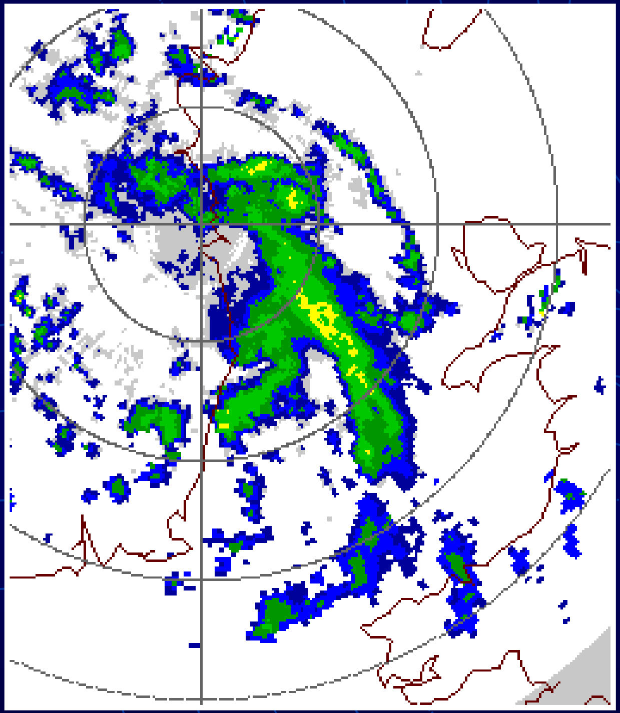
Bright Band



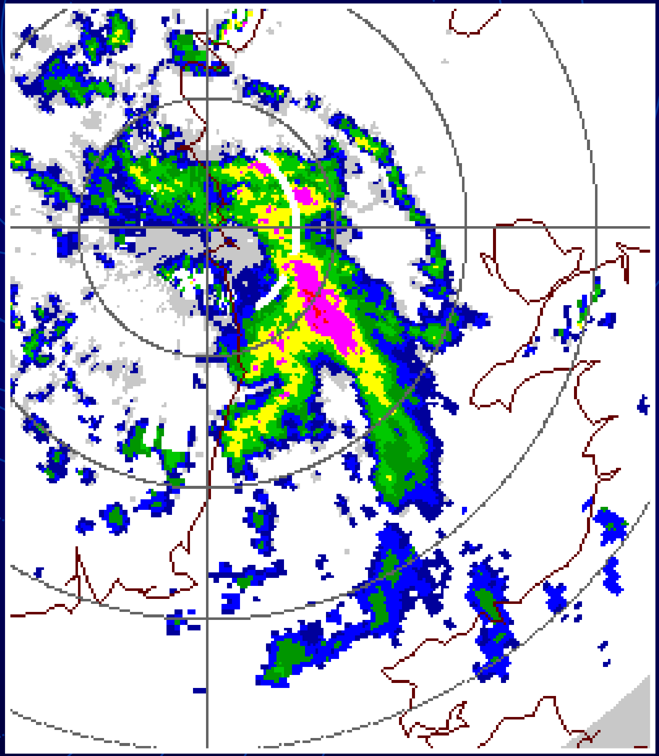
Bright Band Example
24th April 1998



UK Composite



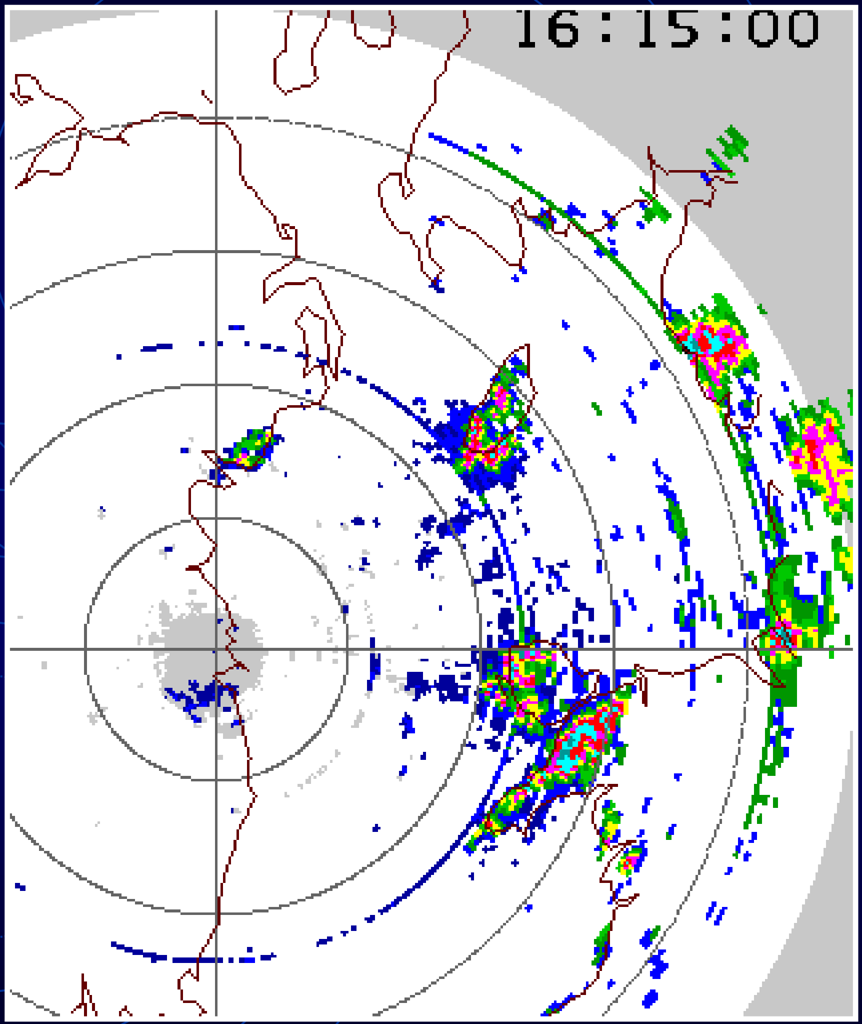
Dublin CAPPI



Dublin MAX CAPPI

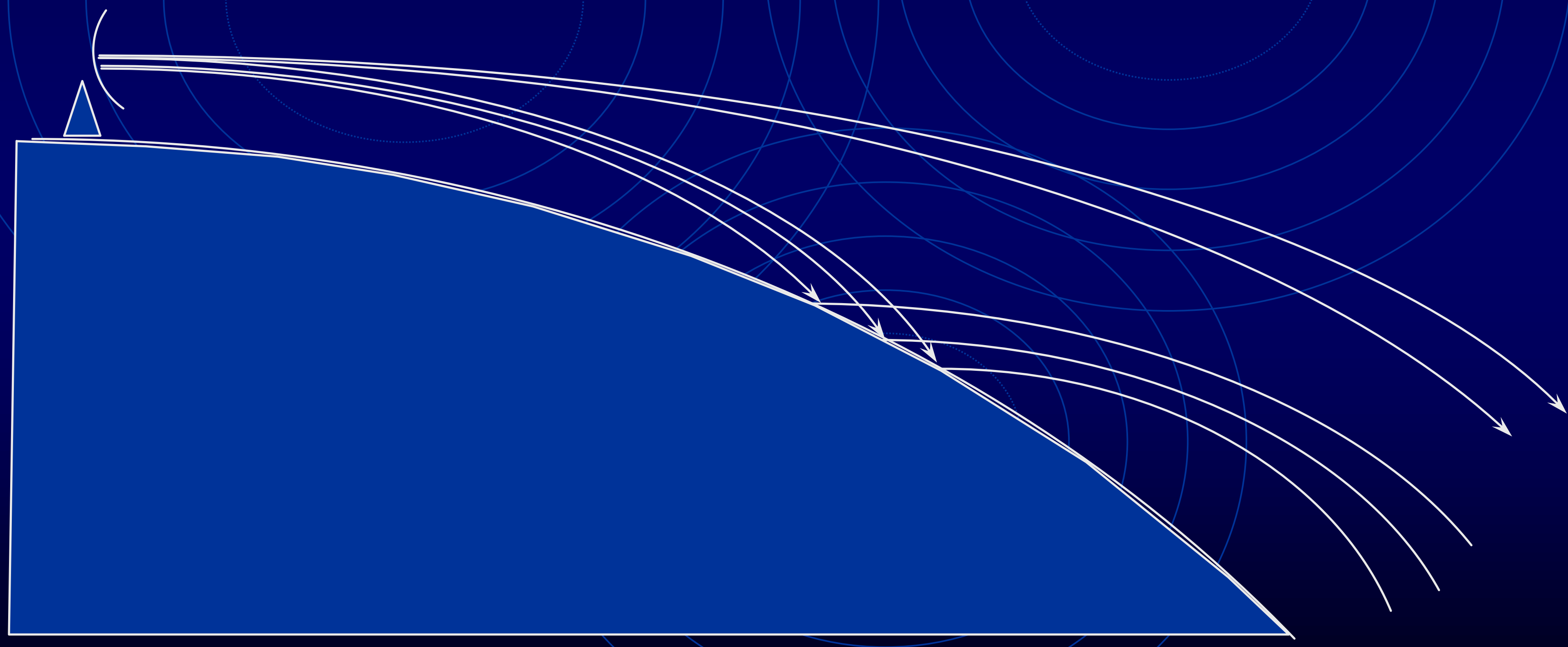
Radar problems
ANAPROP

- Anomalous Propagation
- Normally refractive index decreases with height and bends beam down
- In ANAPROP refractive index changes and the beam can:
  - bend back to the ground OR
  - away from the ground



Anaprop

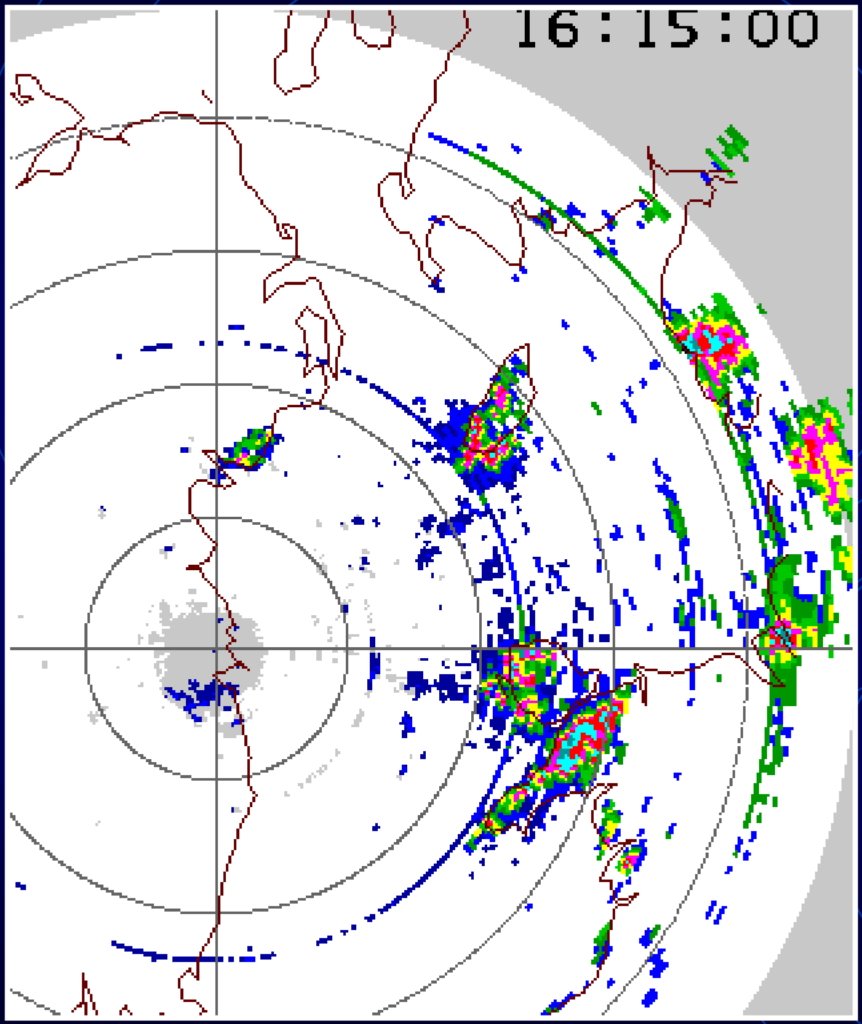
Anomalous Propagation; reflection of the radar beam from the Earth's Surface

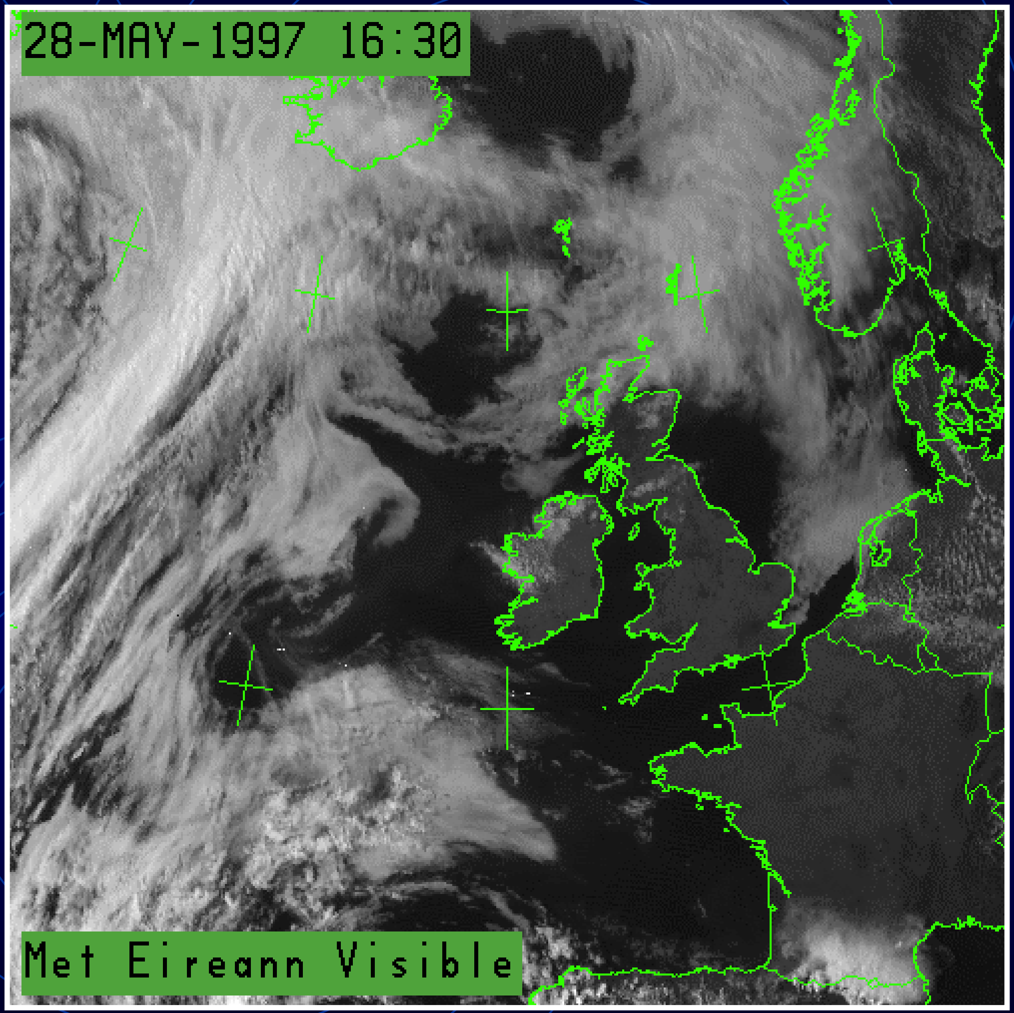


Radar problems ANAPROP

- Sometimes distant coasts can be seen - Welsh coast
- Solutions:
  - Doppler and Statistical suppression helps
  - usually visually identifiable

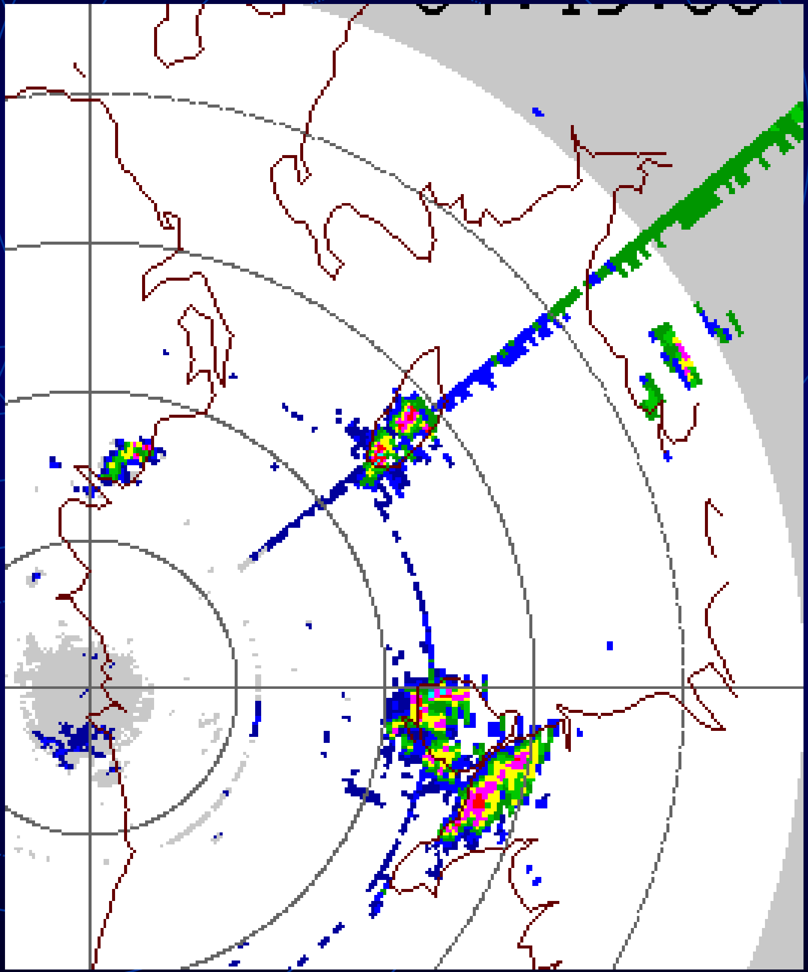
ANAPROP Example





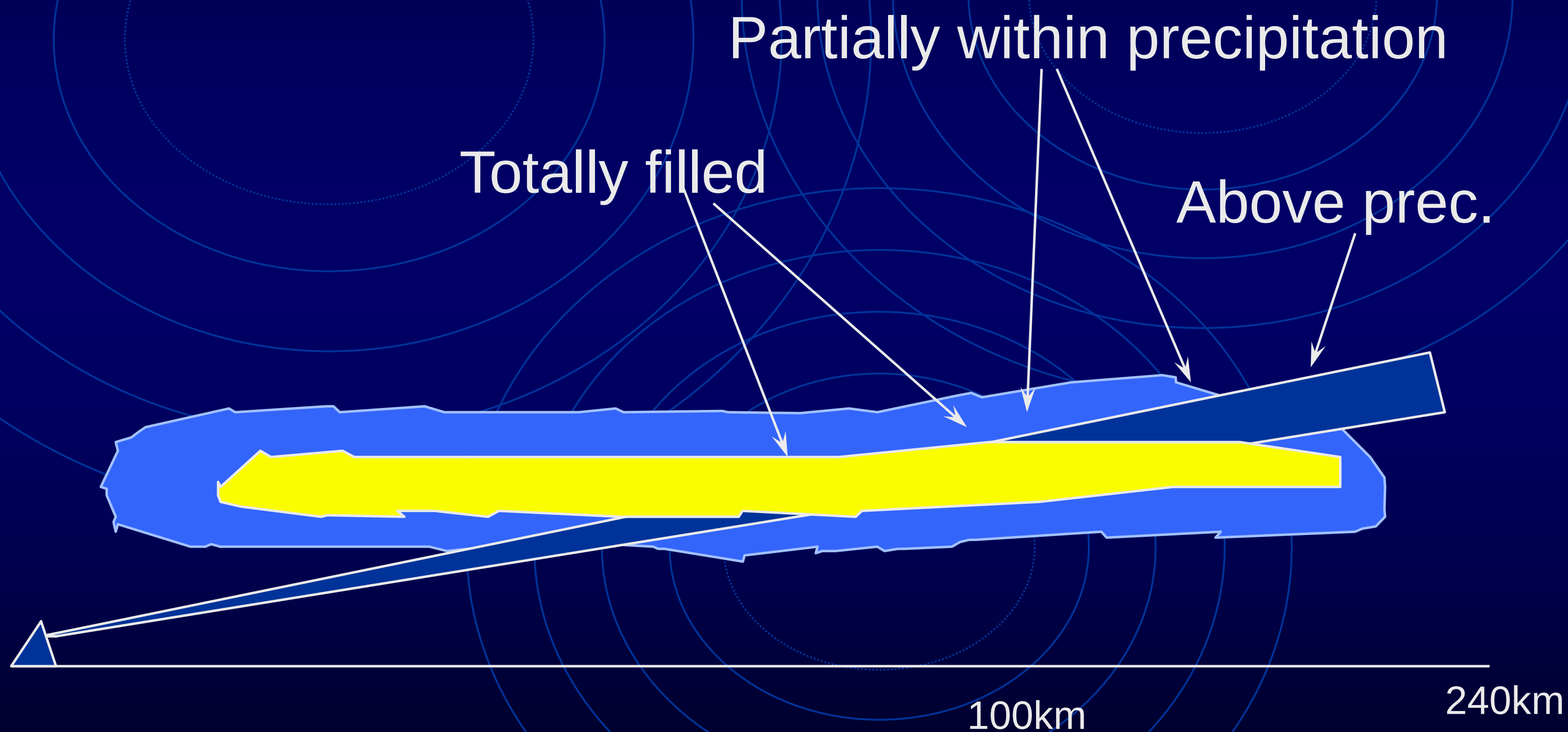
Effect of the Sun

- Radar Receiver detects noise from the sun.
- Shows as a beam
- Sun is used to align the antenna
- *Also strong ANAPROP on image*

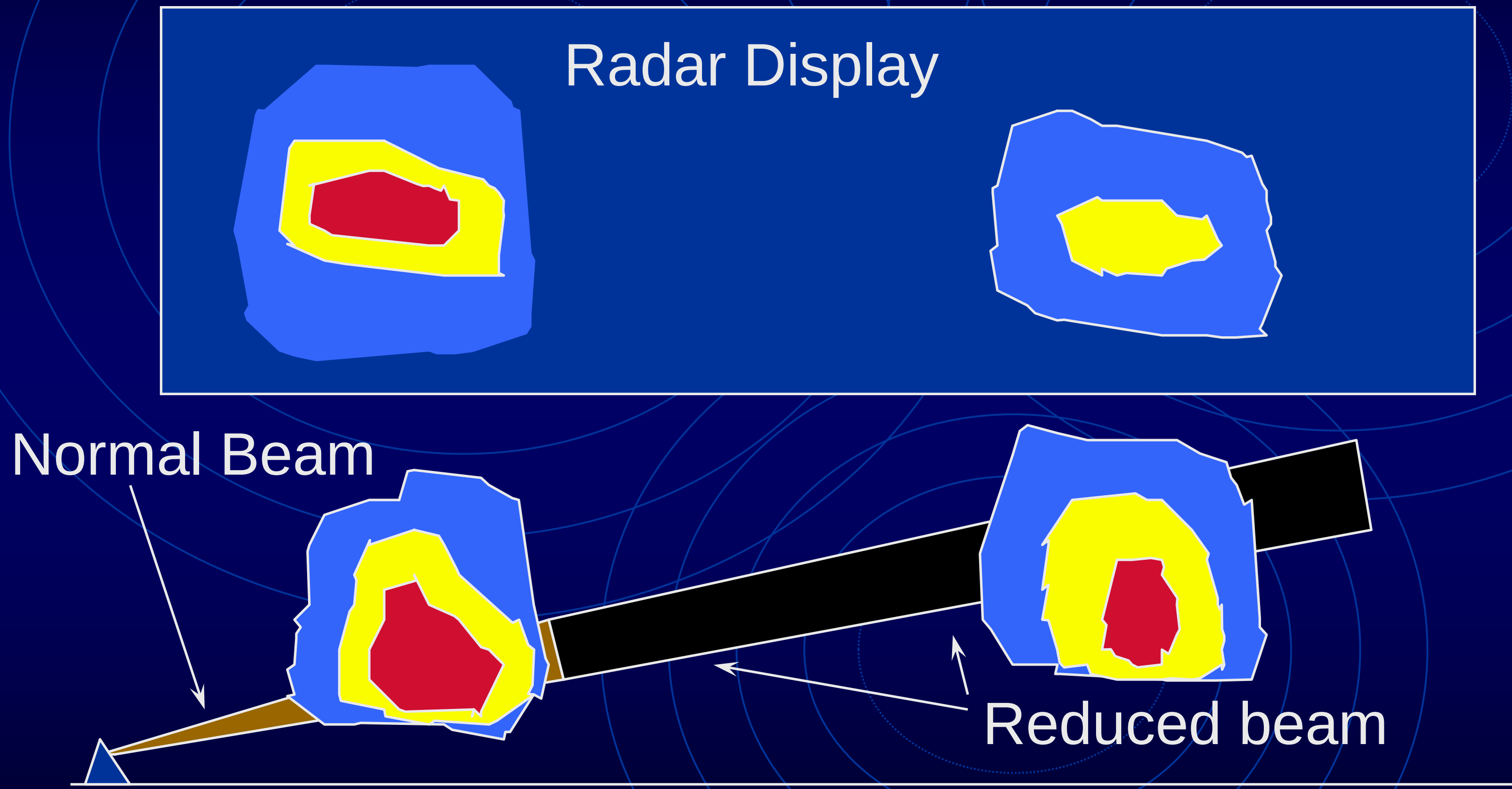


Radar Problems

Incomplete Beam Filling

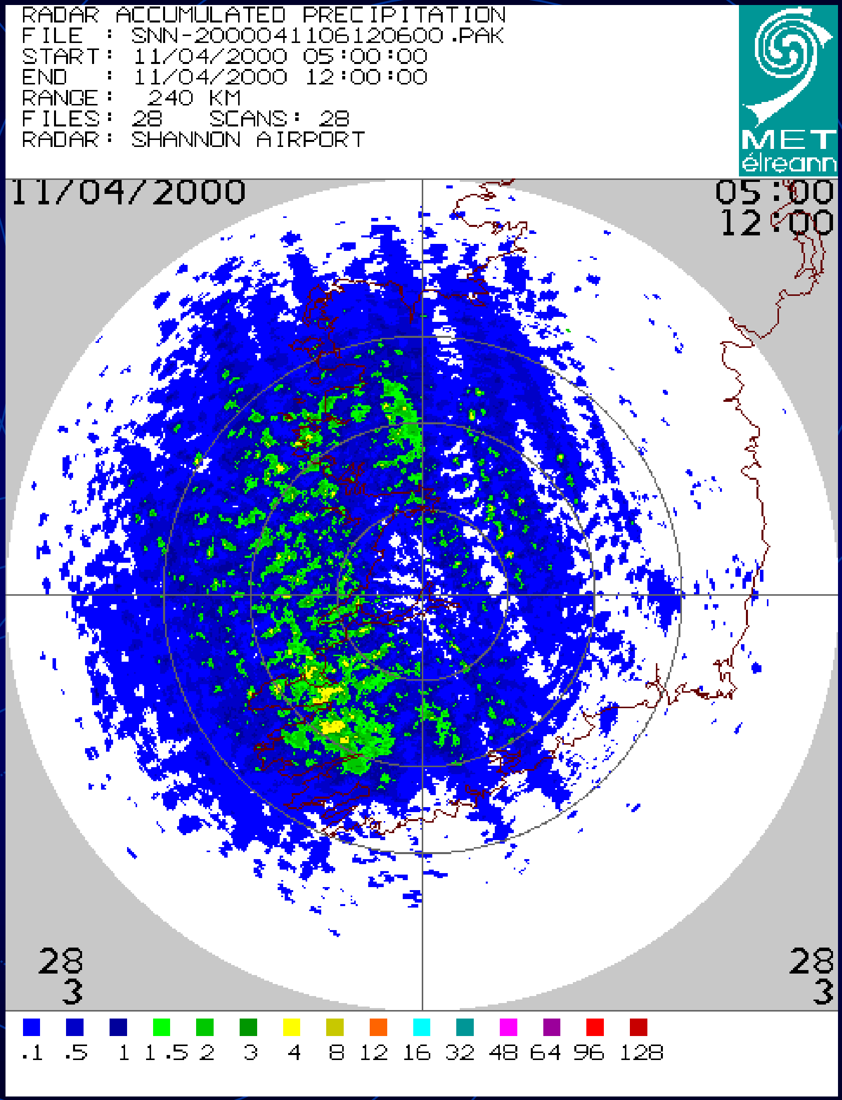


Radar Problems
Rainfall Attenuation



Accumulation problems

- Instant values every 15 minutes
- Accuracy reduced with fast moving showers
- Some areas may be missed!



Accuracy

- Due to high dependence on the drop size distribution, accuracy in limited
- Best for frontal rainfall - 50% accuracy
- Over estimates showers - 50 - 200%
- Under estimates drizzle - 50 - 100%
- Accuracy falls off badly at longer ranges, perhaps 5 - 10% > 200km
- Subject to contamination/occultation

Radar

Vs

Raingauges

Raingauges

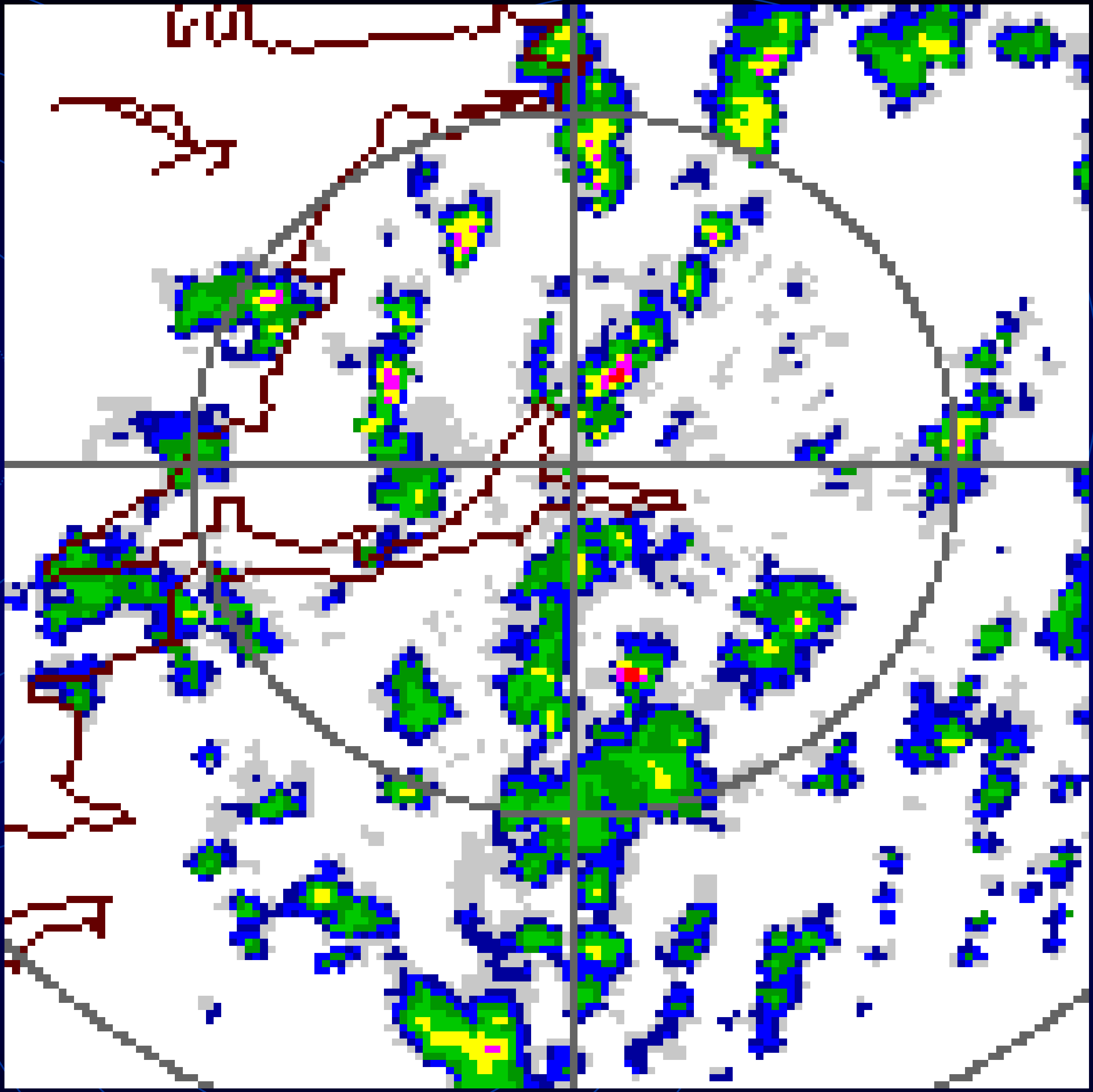
- These measure surface rainfall at a point.
- They are subject to errors – wind causes loss of rainfall.
- But they much more accurate than radar.
- Modern raingauges can be telemetered automatically reporting data.

Raingauges

- Rainfall varies widely even over short distances.
- Even 600+ rainfall stations in Ireland cannot fully measure rainfall variations.
- “Hot spots” or areas of intense rainfall can be missed by gauges.

Shannon Radar

Close-up



Small scale but extreme variations in intensity.

Raingauges can easily miss these.

Radar and Raingauges

- The combination of Radar and Raingauges can significantly improve the accuracy of radar rainfall measurements.
- Radar data can be corrected by ground truth and the corrections interpolated to the rest of the data.
- Get a map with high spatial resolution with reasonable accuracy.

And finally

Summary

Some Pros and Cons of Radar

- Advantages
  - Good spatial resolution - 1km x 1km
  - Good temporal resolution - 15 minute
  - Good for surveillance esp. when networked
- Disadvantages
  - Poor rainfall rate accuracy
  - Poor rainfall accumulation accuracy
  - Interference from ground and other problems

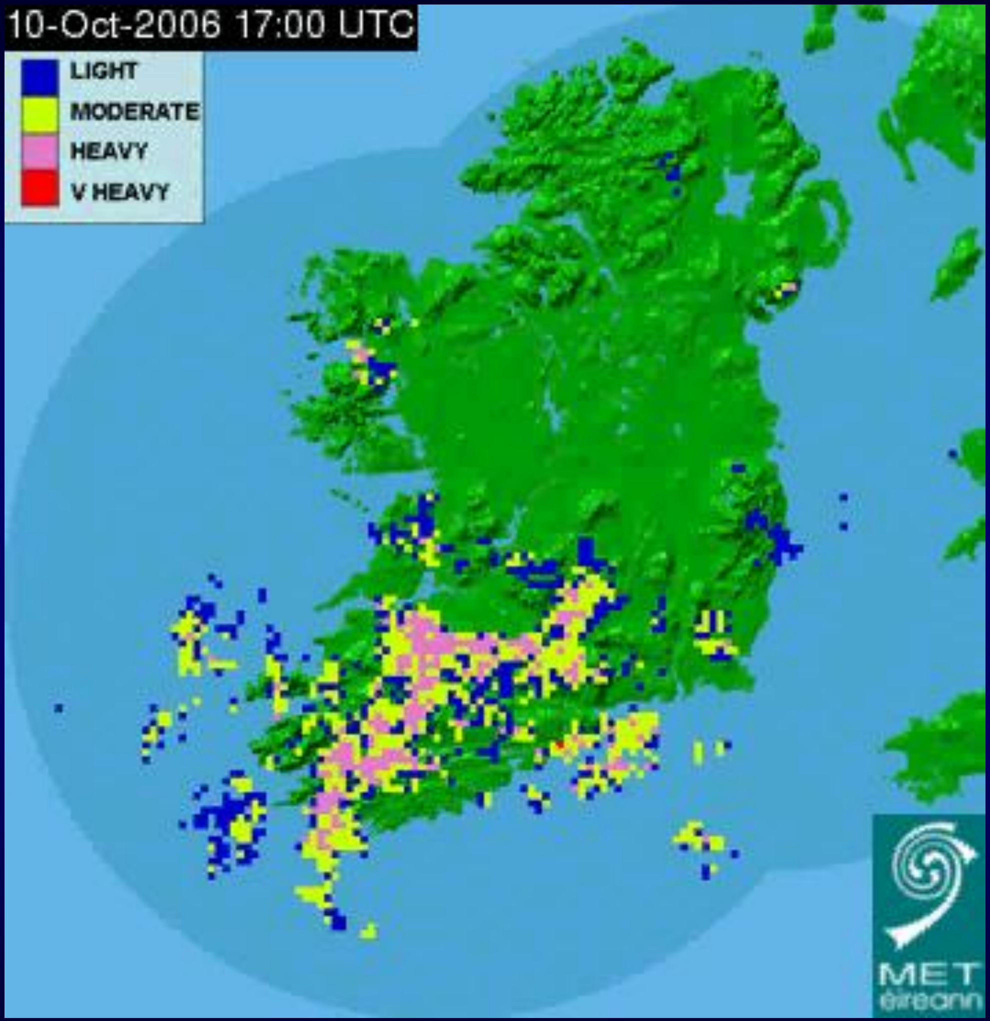
Advantages of Radar

- Good spatial coverage – wide area at good resolution
- Good temporal coverage – typically 5 to 15 minutes intervals
- Possible to make accumulation maps
- Combine several radars to form regional composites

Uses of radar data

- Nowcasting
- River managment in conjunction with flow and hydrometric gauges. Well developed in the UK (Environment Agency and Met Office).
- Flood warnings.
- Hydrological studies.
- Climatological enquiries – did it rain at a particular place?

Thank you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