



Met Office



# Radar

National Meteorological Library and Archive  
Factsheet 15 — Weather radar

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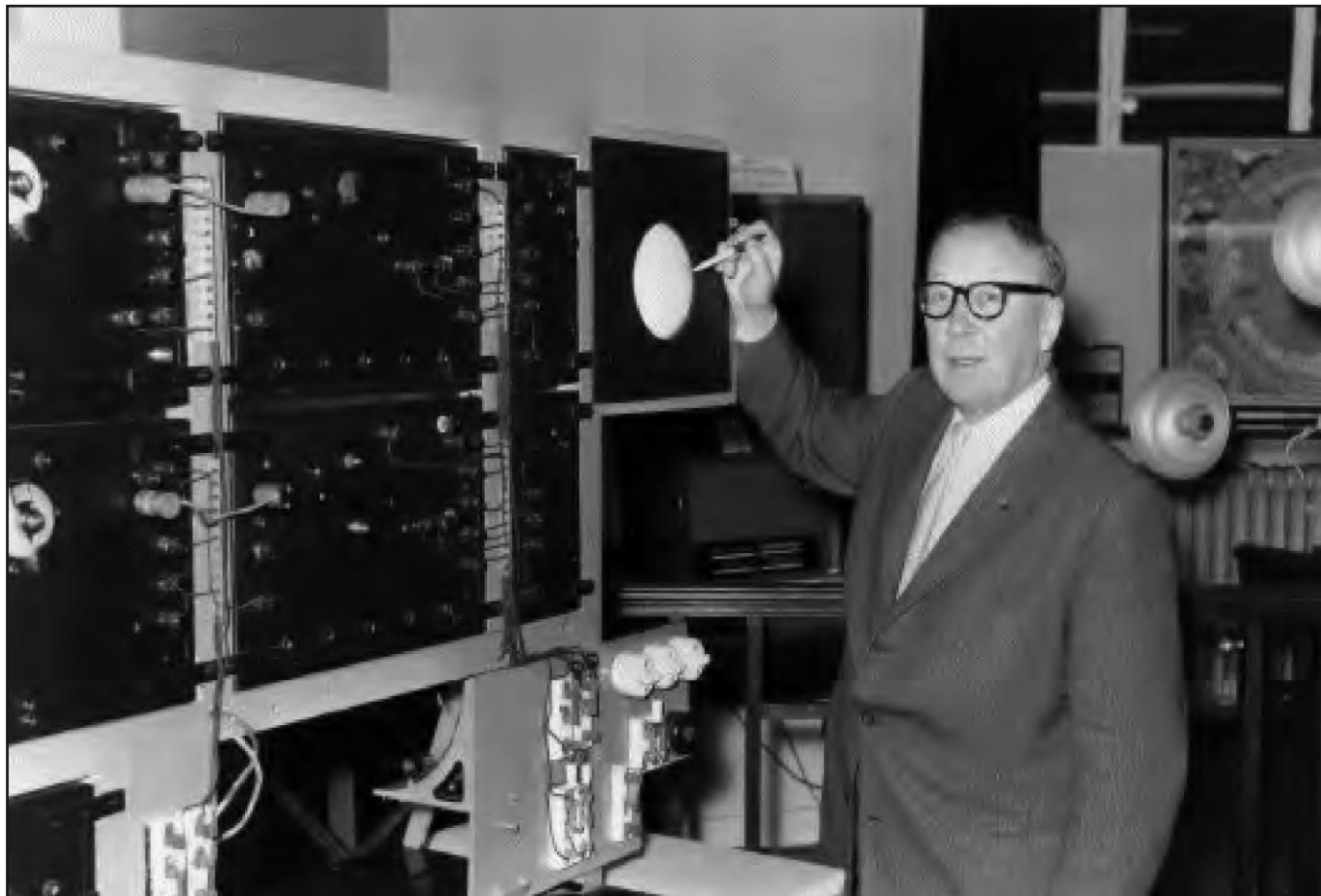
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## Radar – a brief history

The word RADAR is an acronym, for **RA**dio **D**etection **A**nd **R**anging.

Although some primitive work on radio location had been carried out in the United Kingdom as early as 1904, it wasn't until the mid 1930s before any serious development work on radar was instigated. In 1935, Robert Watson-Watt, a meteorologist by training and with an aim of applying his knowledge of radio to locate thunderstorms so as to provide warnings to airmen, patented the first practical radar system, not to look at rainfall echoes but, with war with Germany becoming a real possibility, to look for enemy aircraft, if and when war broke out.



*Figure 1: Robert Watson Watt*

When the first weather echoes were detected and recognised is not certain, but during the war weather echoes were regarded as a nuisance rather than of intrinsic value. Nevertheless, before the end of the war the Meteorological Office had established a radar research station at East Hill, some 30 miles north of London. For a time after the war, the Meteorological Office radar station at East Hill concentrated on the examination of turbulence, no doubt at the instigation of Sir Graham Sutton, who was the first Director of Telecommunication Research Establishment and then of the Meteorological Office, and whose major interest was in turbulence.

In the early 1950s the Meteorological Office began investigations examining the accuracy of precipitation forecasts based on the movement of radar echoes. Although it was found that the radar display could be of help to the forecaster, and subsequently in 1955 a radar was installed in London for the forecast office, the results were not sufficiently encouraging for much progress in this field.

In recent years, advances in data processing, communications and display technology have enabled the full potential of meteorological radar to be exploited. Various investigations have shown that the accuracy of rainfall estimates over large areas obtained from radar data, adjusted by a small number of check gauges, is better than that obtained from a dense network of rain gauges, and with the introduction of dual polarisation technology the opportunity for improvements is further enhanced. The Met Office Radar network was upgraded to be Doppler capable across the network in 2012, and the dual polarisation upgrade was completed in 2018. Some radars are owned by a consortium of agencies, such as the Environment Agency, with the Met Office providing the technical and operational support. This data provides valuable information for the immediate emergency response and the longer-term planning of future risk management and mitigation.

## How does radar work?

Radar is an echo-sounding system, which uses the same aerial for transmitting a signal and receiving the returned echo.

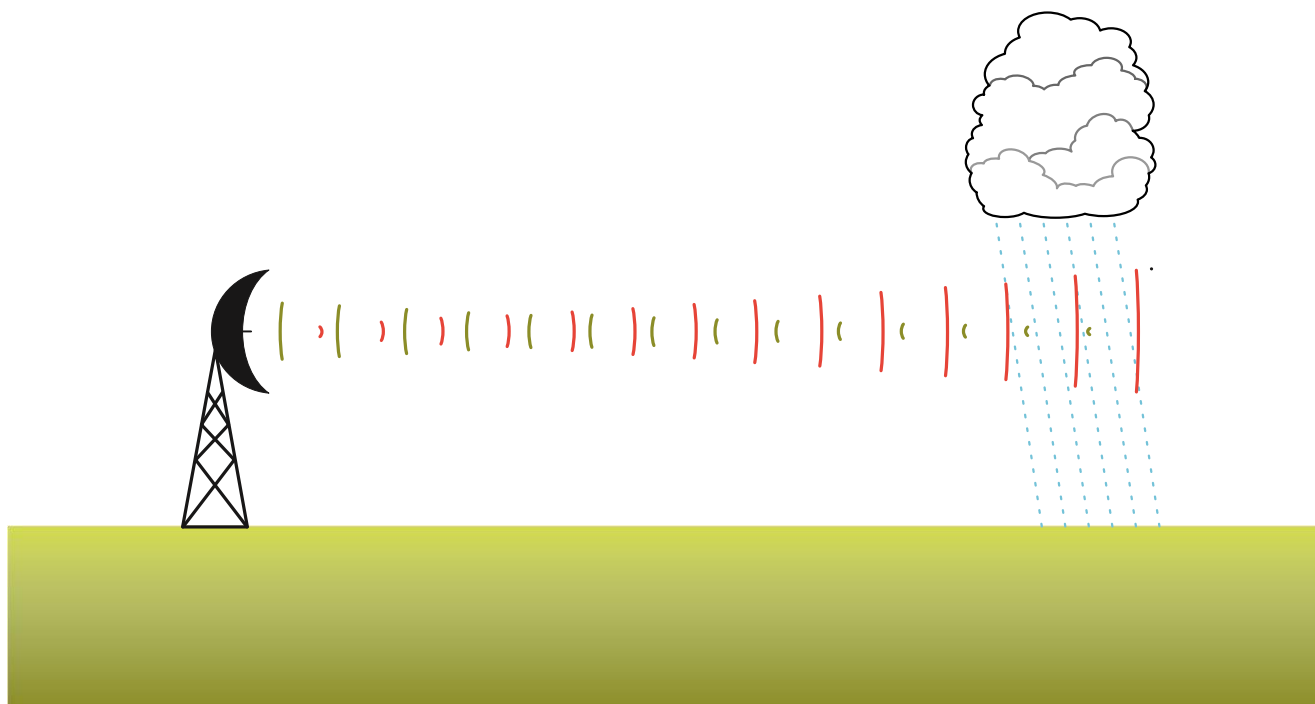


Figure 2: How radar works

Short pulses of electro-magnetic waves, which travel at the speed of light (approx. 186,000 miles per second), are transmitted in a narrow beam for a very short time (typically two microseconds).

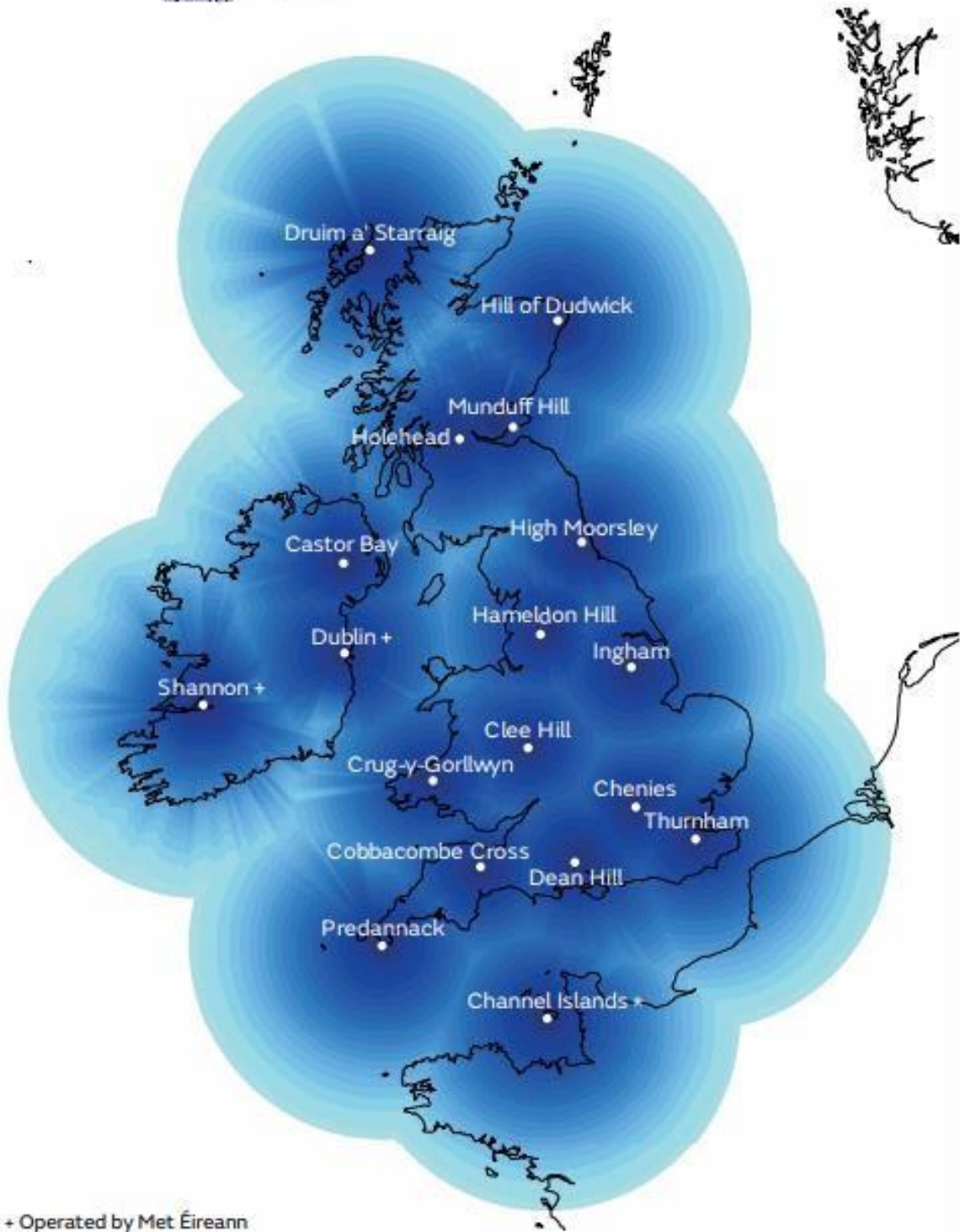
When the beam hits a suitable target, some of the energy is reflected back to the radar, which 'listens' out for it for a much longer period (typically 3,333 microseconds in the case of Met Office radars) before transmitting a new pulse. The distance of the target from the transmitter can be worked out from the time taken by a pulse to travel there and back.

## The range and power of a radar

Since these radars cannot send and receive at the same time, the transmitted pulse must be very short – usually microseconds (or echoes from close range will be lost), and the listening time must be relatively long, for detecting distant echoes. Another motivation for transmitting a short pulse is that the ability to resolve targets in range is related to the pulse length. E.g. A longer transmission pulse would give higher average power and better long-range sensitivity but would reduce the close-range capability and resolution.

The returning echo is very much weaker than the transmitted pulse, and depends on several factors: There is attenuation, or absorption of energy, by rain droplets in the atmosphere. There is also an inverse square relationship with range (i.e. doubling the range cuts the return power to one quarter) due to the increasing spread of the radar beam.

The beam width of typical modern radars is approximately  $1^\circ$  and, as the target distance increases, only an increasingly small part of the transmitted beam is reflected back to the radar.



+ Operated by Met Éireann  
\* Operated by Jersey Met



→ Improving quality

The radar network covers over 99% of the UK

Figure 3: Current rainfall radar coverage across the British Isles.

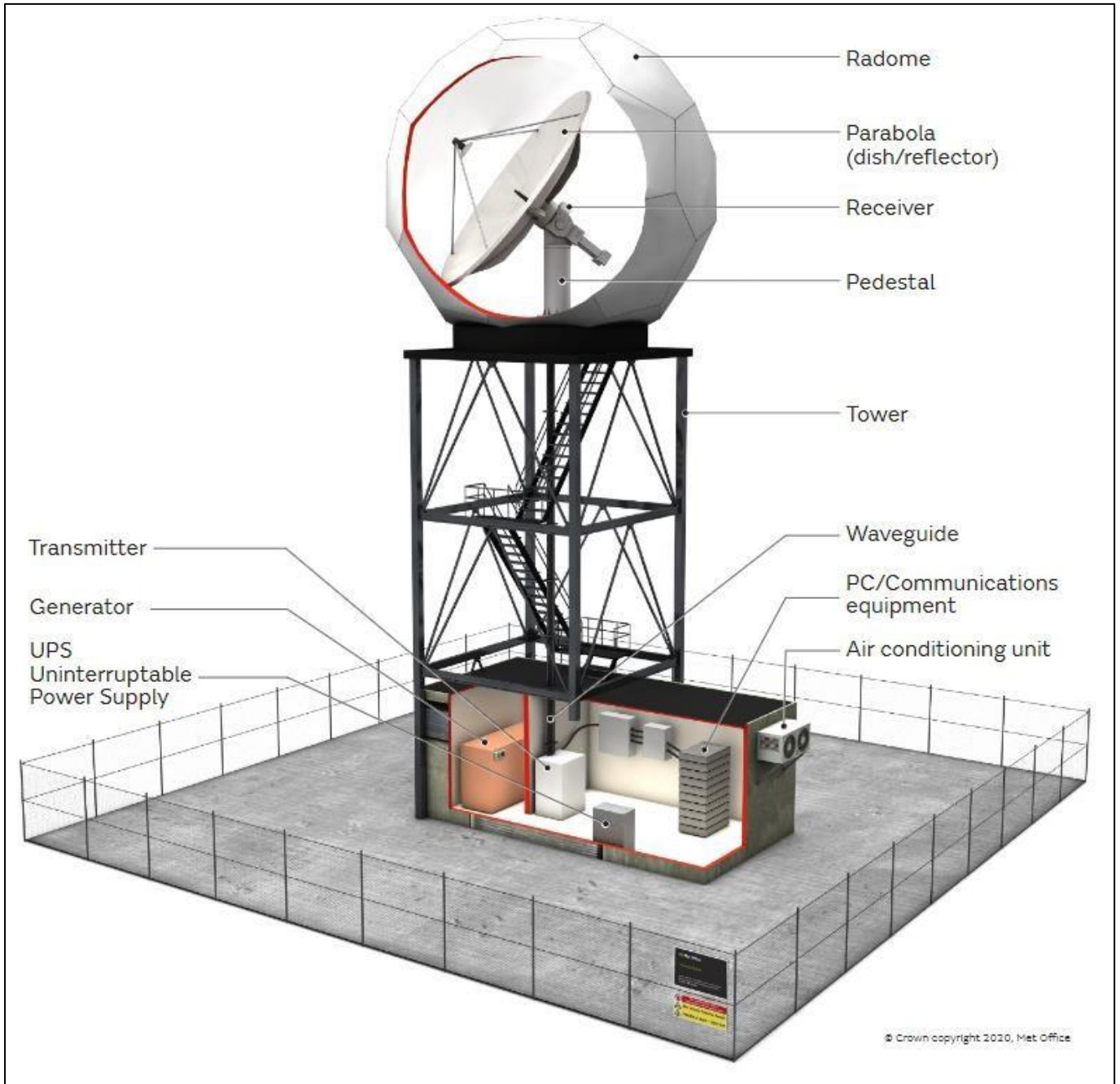


Figure 4: View of the internal workings of a weather radar



Figure 5 - High Moorsley Radar, County Durham



Ingham Radar, Lincolnshire



Clee Hill Radar, Shropshire

At each radar location an on-site computer carries out aerial position, transmitter, receiver control and digital signal processing. The Met Office develop this software in-house and it is known as “Cyclops”. The raw data is then sent to the Radarnet Processing at Exeter where the following processing is carried out:

- Elimination of ground clutter
- Correction for attenuation by intervening rain and atmosphere
- Correction for blocking of the beam by hills etc.
- Correction for the changes in the measurement with height
- Conversion of radar reflectivity to rainfall rate
- Conversion from polar cells to National Grid Cartesian cells

Each radar completes a series of scans about a vertical axis between five and ten low-elevation angles every 5 minutes (typically between 0.5 and 9.0 degrees). Each scan typically gives good, quantitative data out to a range of about 75 km and useful qualitative data to 255 km. The reduction in accuracy with range is largely due to the beam increasing in altitude requiring greater corrections to approximate conditions at the ground.

The radar image displayed gives the rainfall rate in nine colour intensity bands.

	0 – 0.25 mm per hour
	0.25 – 0.5 mm per hour
	0.5 – 1.0 mm per hour
	1 – 2 mm per hour
	2 – 4 mm per hour
	4 – 8 mm per hour
	8 – 16 mm per hour
	16 – 32 mm per hour
	>32 mm per hour

Figure 6 Rainfall Intensity colour bands

Below is a set of radar images from the Chenies Rainfall Radar, all from the same time and for the same area, but at 5, 2 and 1 km horizontal resolutions. They show instantaneous rainfall rates, but with increasing horizontal resolution, and this shows some intense rainfall cells between Dunstable and Stevenage that only become identifiable in the higher resolution image. Nowadays all the Met Office data is presented at 1km resolution, however resolution of the underlying data from the sites will vary with range.

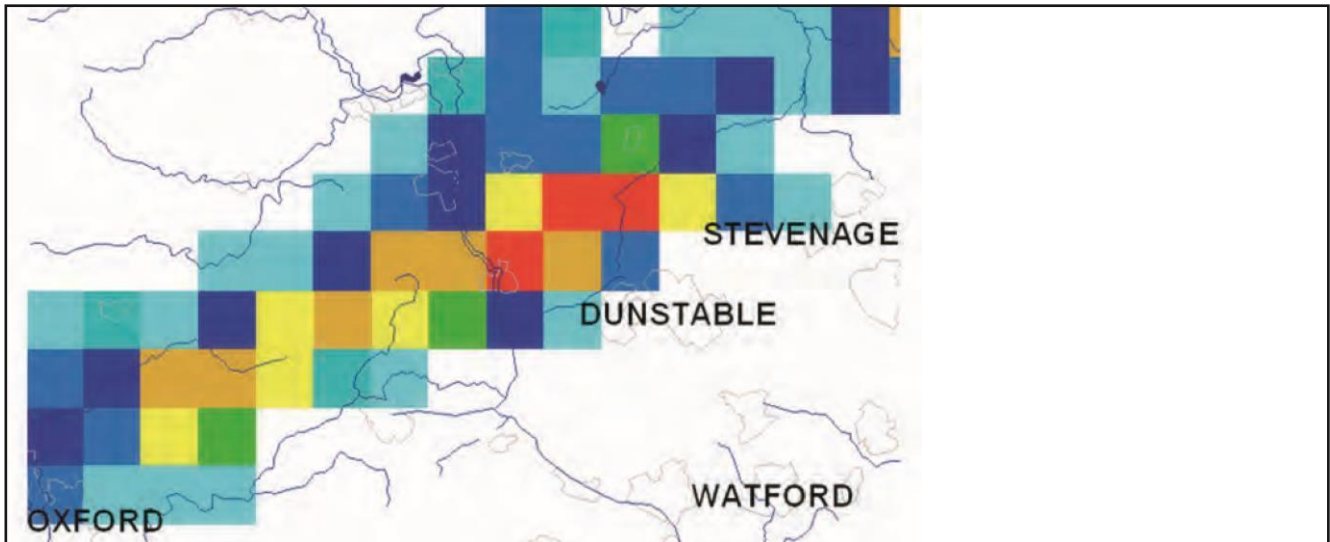


Figure 7 - 5km resolution

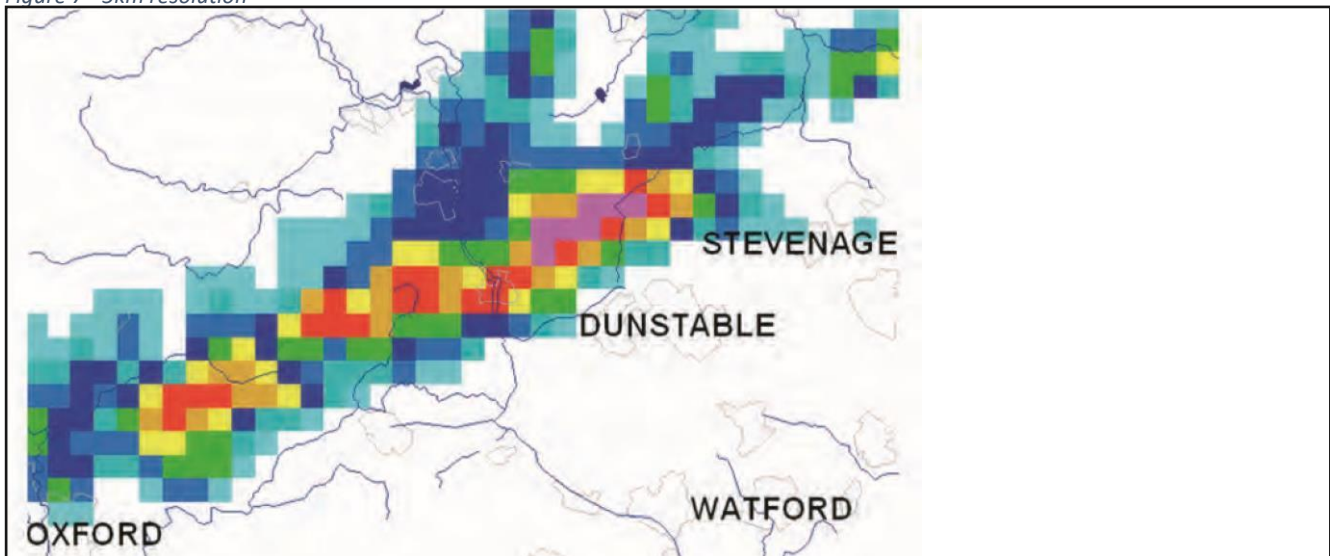


Figure 8 - 2km resolution

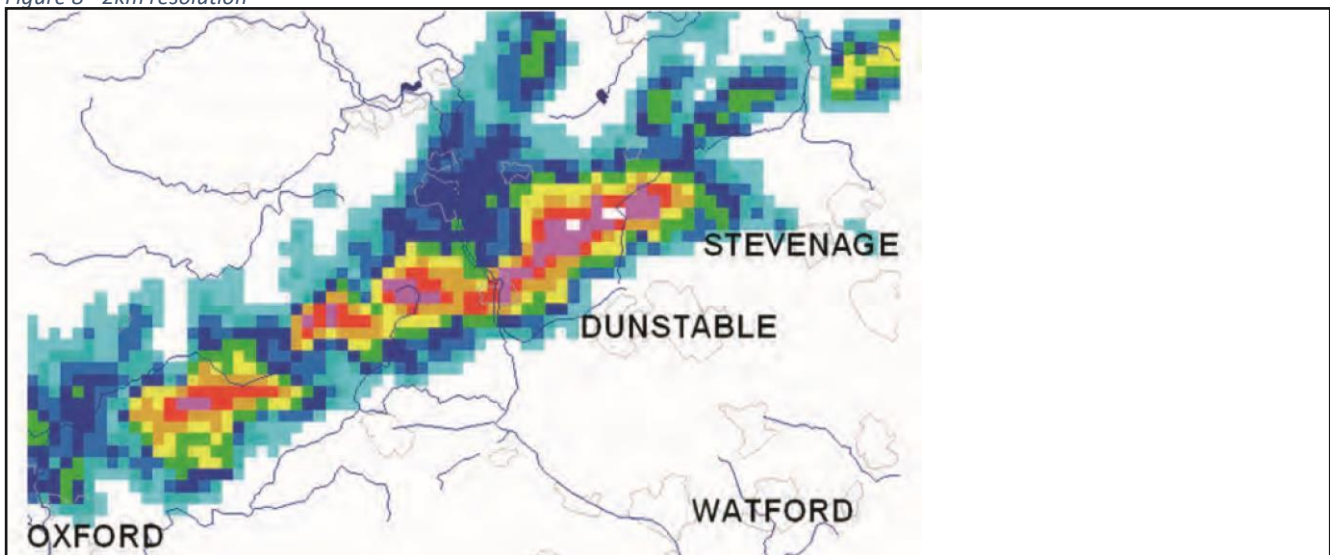


Figure 9 - 1km resolution

Weather radar is very useful for forecasters in areas where there is little observable data. One example was during the floods at Boscastle in Cornwall on 16 August 2004. With no real-time observations from that area, the nearest observing site is at St. Mawgan, approximately 20 miles away. Weather radar provided vital information about the rainfall intensities in that local area and allowed the Met Office to provide valuable information to the emergency services.



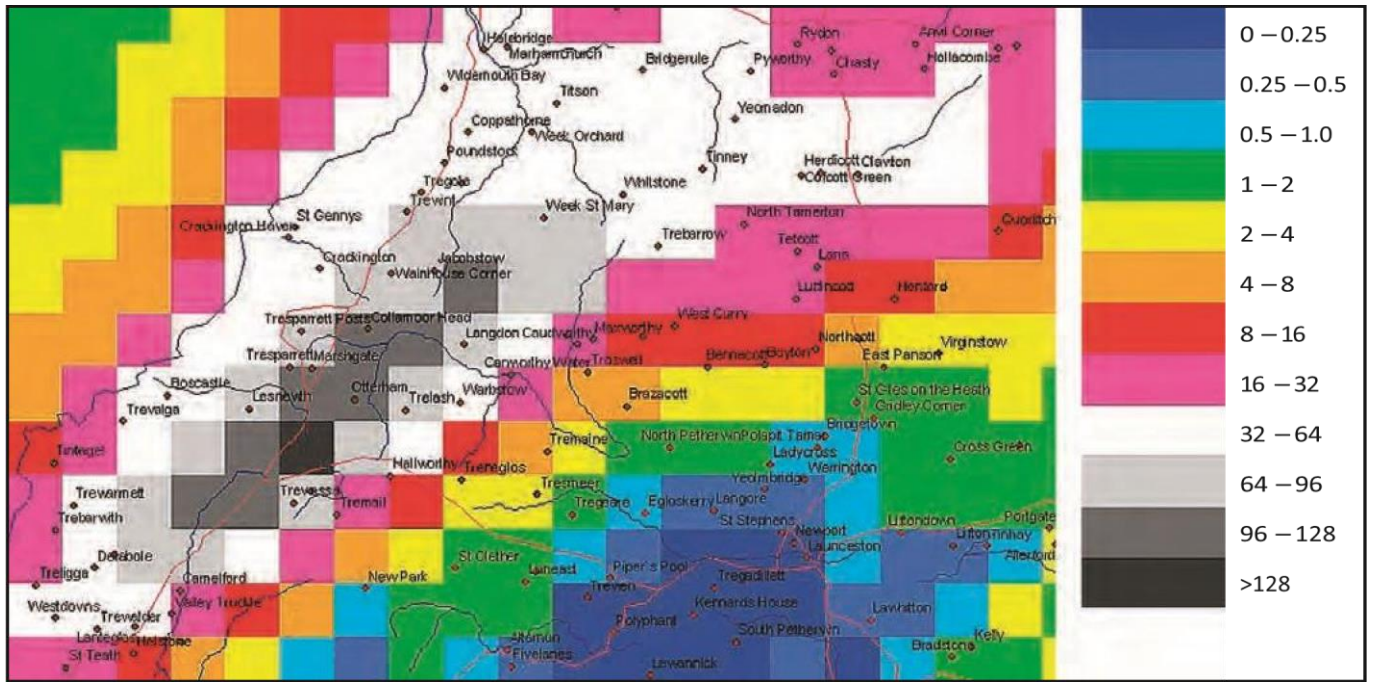


Figure 10 Radar rainfall accumulations from the Cobbacombe Cross radar (2 km resolution 1100 – 1800 UTC) during the Boscastle floods of 16 August 2004)

Raingauge name	National grid reference	24-hour rainfall total (mm)	Event total (mm)
Otterham*	SX 169 916	200.4	–
Trevallec, Lesnewth	SX 134 900	184.9	181.0 (11:30 to 16:30 GMT)
Trevallec, Lesnewth	SX 134 900	155.8	152.8 (12:15 to 16:19 GMT)
Creddacott	SX 231 956	123.0	–
Slaughterbridge TBR	SX 109 857	76.5	–
Bude	SX 208 063	46.7	–
Canworthy Water TBR	SX 228 916	15.0	–
Lower Tregellist (St Kew)	SX 006 775	5.9	–
Lower Moor	SX 128 833	2.0	–

\*The 24 hour value from Otterham would give a return period in excess of 200 years (using the Flood Estimation Handbook method).

Table above: 24-hour rainfall amounts during the Boscastle floods of 16 August 2004.

## Doppler radar

Using radar it is also possible to obtain direction and speed information on the droplets observed. From this data the wind speed of the precipitation can be calculated out to a range of 100 km. This data is then used, in conjunction with a large number of other data sources, by the experienced Met Office's Numerical Weather Prediction meteorological team with the ultimate aim of improving the numerical model that is used to forecast the weather. This in turn increases the accuracy of the forecasts that are issued.

The way Doppler radar works is that two pulses of electromagnetic radiation are transmitted. The first pulse is sent from the radar and the returning echoes are received and its phase measured; then a second pulse is sent from the radar and again the returning echo is received. The computer then analyses the difference between the two returned echoes and the movement of the droplets of water is calculated. This movement is only very slight but it is enough to calculate the direction of the water droplets and so the wind speed within the cloud.

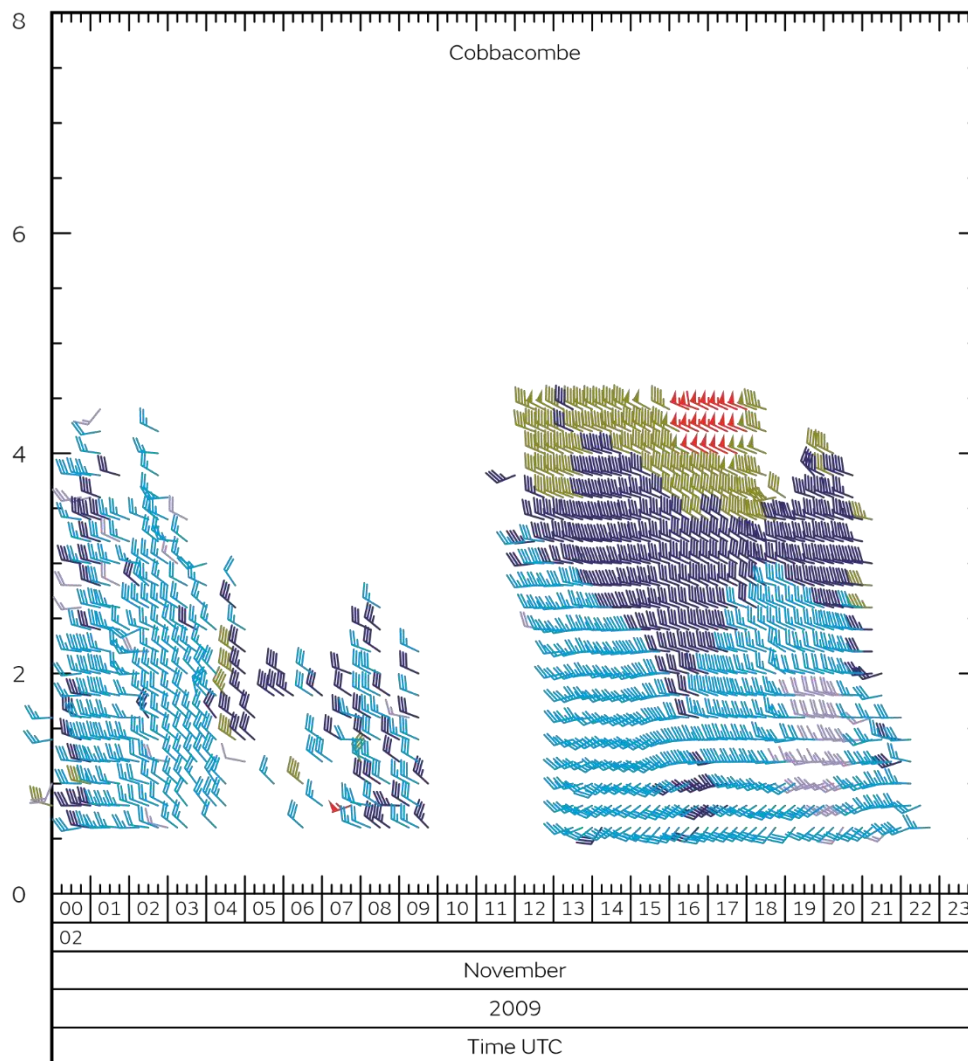


Figure 11 Wind profile generated by the Cobbacombe Cross Doppler radar data

## Dual Polarisation

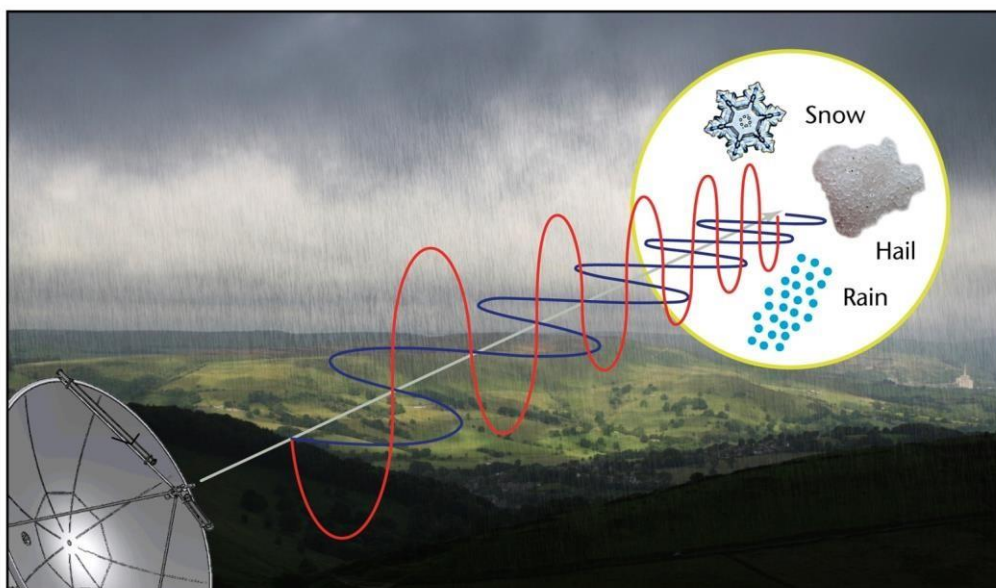


Figure 12 Schematic of dual polarisation measurement

A dual polarisation radar can retrieve more information about the nature of the target being observed. It does this by transmitting a pulse which is polarised both horizontally and vertically and then receiving the signal reflected by the target in the horizontal and vertical. From this, information about how the target has affected the two different components can be used, giving additional information about the shape of the targets being illuminated.

Dual polarisation provides information on:

- The average axis ratio of the particles in the sample volume as a power-based measure
- A measure of the diversity of particle sizes in the sample volume
- The average axis ratio of the particles in the sample volume as a phase-based measure
- The average canting angle of particles

The additional information from dual polarisation measurements can be used to:

- Determine the type of precipitation being observed (rain, snow, hail)
- Improve the removal of non-meteorological echoes, such as ground returns.
- Give improved estimates of rain rates
- Improve the correction for attenuation by heavy storms.

Additional information about the benefits of dual polarisation can be found here:

[https://digital.nmla.metoffice.gov.uk/IO\\_da92368b-0348-4659-82c4-535220600d15/](https://digital.nmla.metoffice.gov.uk/IO_da92368b-0348-4659-82c4-535220600d15/)

## Interpreting radar imagery

The radars receive echoes from typical precipitation-sized droplets i.e. rain but not fog or clouds. Drizzle is generally too small to be reliably observed, unless close to the radar, but rain, snow and hail are all observed without difficulty.

It is important to interpret the radar imagery in terms of the beam's elevation and 'width' and the earth's curvature. The latter, for example, means that echoes come from an increasingly higher level the further away precipitation is from the radar. Thus, at a range of 100 km, the radar beam is being reflected from the raindrops in a cloud at a height of 1.5 km, but beneath that level rain may be falling from the cloud which the radar misses.

For this and other reasons (listed below), the radar rainfall display may not fully represent the rainfall observed at the ground.

## Non-meteorological echoes

### Permanent echoes (ground clutter)

These are caused by hills or surface obstacles reflecting the radar beam and are often referred to as ground clutter. Ground clutter is rarely seen on radar imagery as it can be identified by its dual polarisation characteristics and then removed by Radarnet.

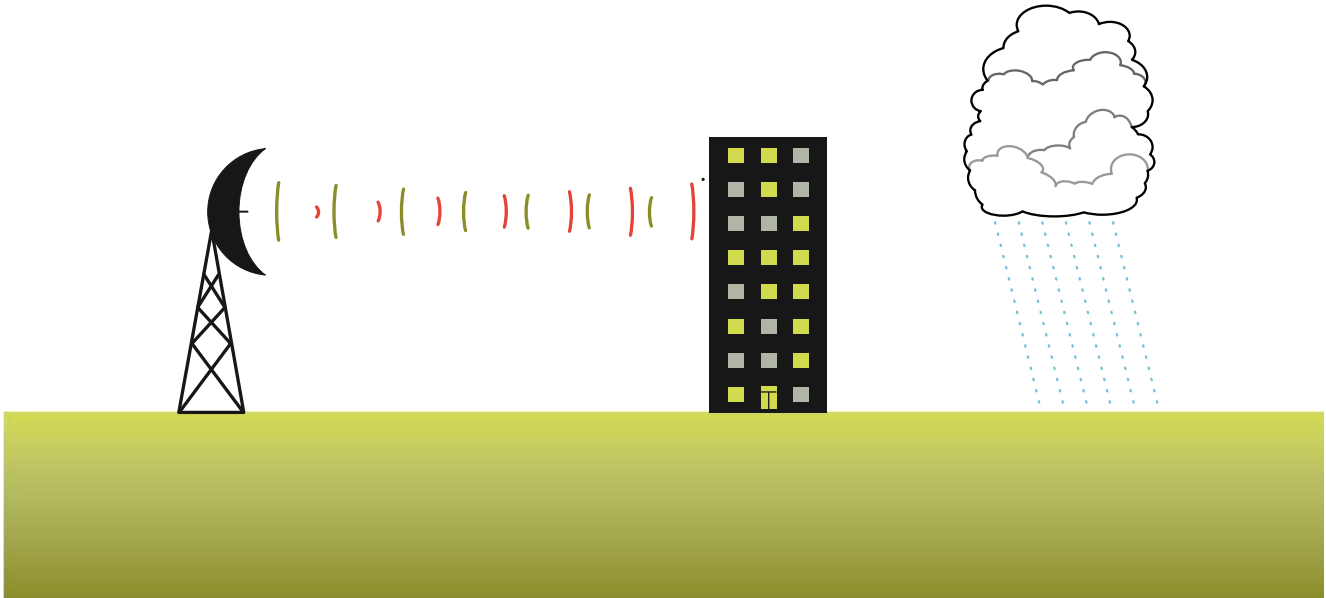


Figure 13 Non-meteorological echoes – permanent echoes caused by buildings etc.

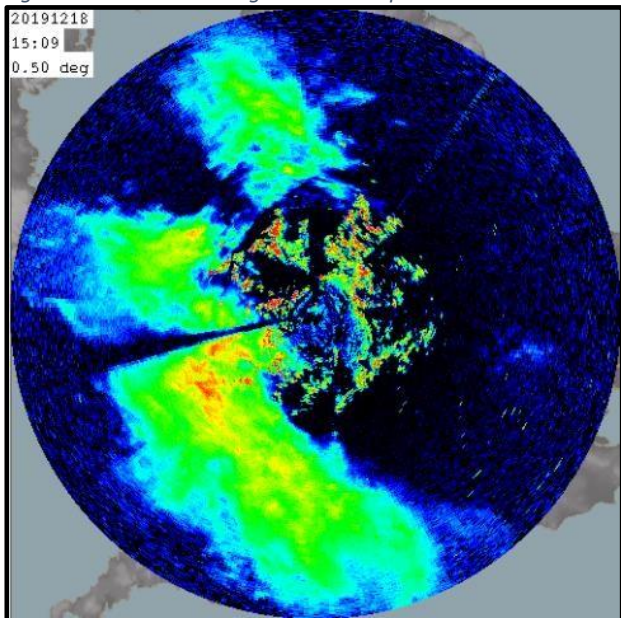


Figure 14 Clee Hill Radar display showing a break in the beam (occultation) caused by the Cambrian Mountains in Wales

Occultation is caused by the radar beam being obstructed by a tree, hill or building. A network of overlapping radars helps to minimise this problem.

## Spurious echoes

These may be caused by ships, wind turbines, aircraft, sea waves, chaff in use on military exercises, technical problems or interference from other radars. The pattern formed by spurious echoes are short-lived and can usually be identified as they look very different from genuine precipitation echoes and have a distinct polarisation signature.

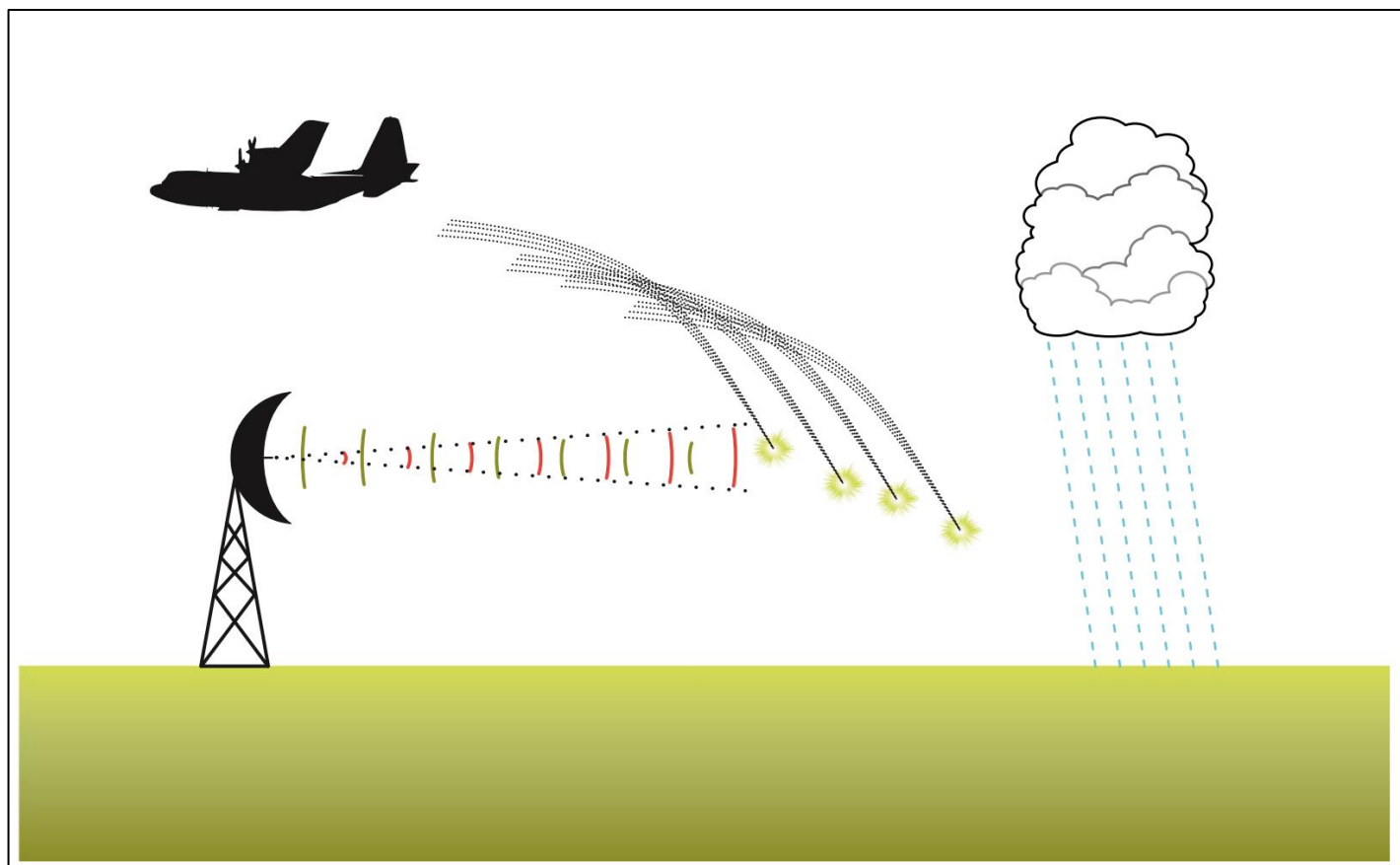


Figure 15 Non-meteorological echoes – spurious echoes caused by chaff used in military exercises

## Meteorological causes of errors

### Radar beam above the precipitation at long ranges

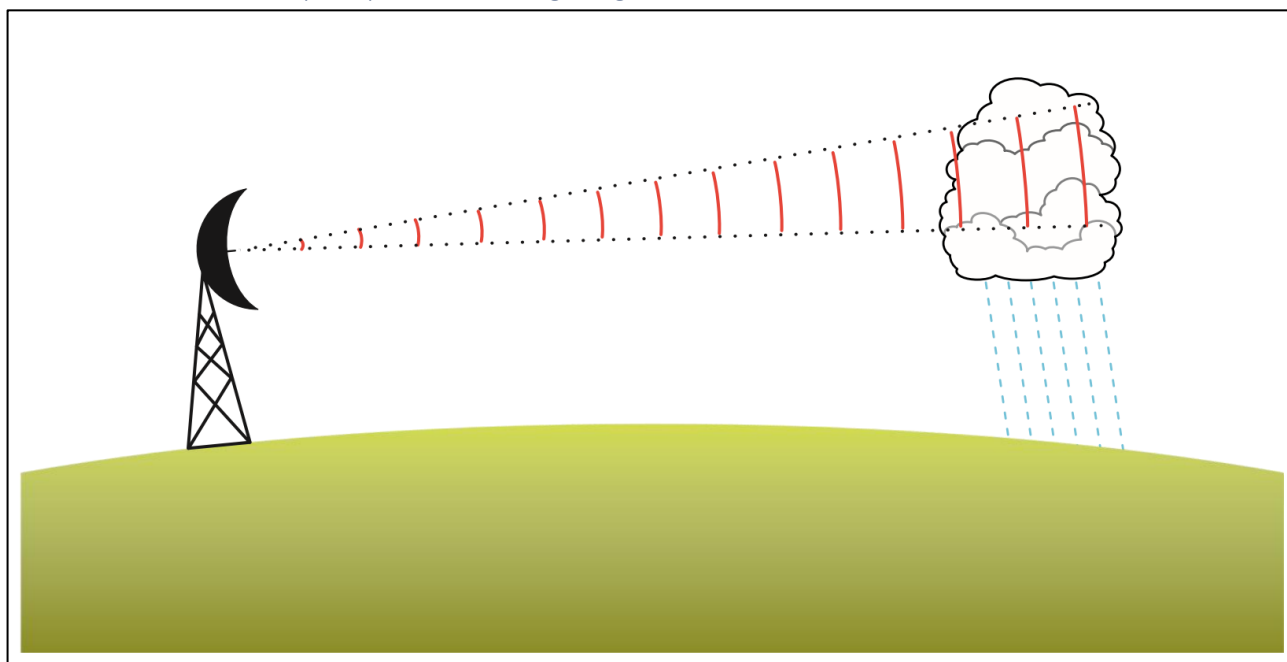


Figure 16 Meteorological causes of errors – radar beam above the precipitation at long distances.

Even with a beam elevation of only  $0.5^\circ$ , an individual radar may not detect low-level rain clouds at long distances. A network of overlapping radars helps to minimise this problem.

### Evaporation of rainfall at lower levels beneath the beam

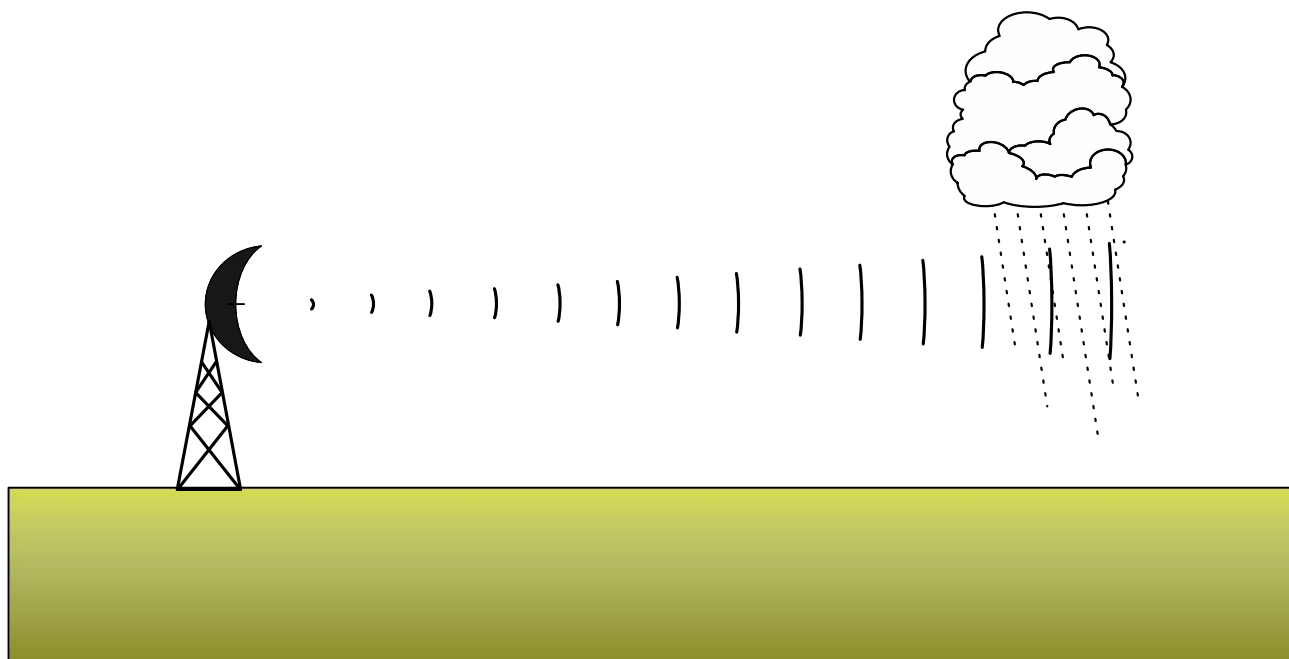


Figure 17 Meteorological causes of errors – evaporation of rainfall at lower levels beneath the beam

Precipitation detected by the radar at high levels may evaporate if it falls through drier air nearer the ground. The radar rainfall display will then give an over-estimate of the actual rainfall.

### Orographic enhancement of rainfall at low levels

The rather light precipitation which is generated in layers of medium-level frontal cloud can increase in intensity by sweeping up other small droplets as it falls through moist, cloudy layers at low levels. This seeder-feeder mechanism is very common over hills, resulting in very high rainfall rates and accumulations.

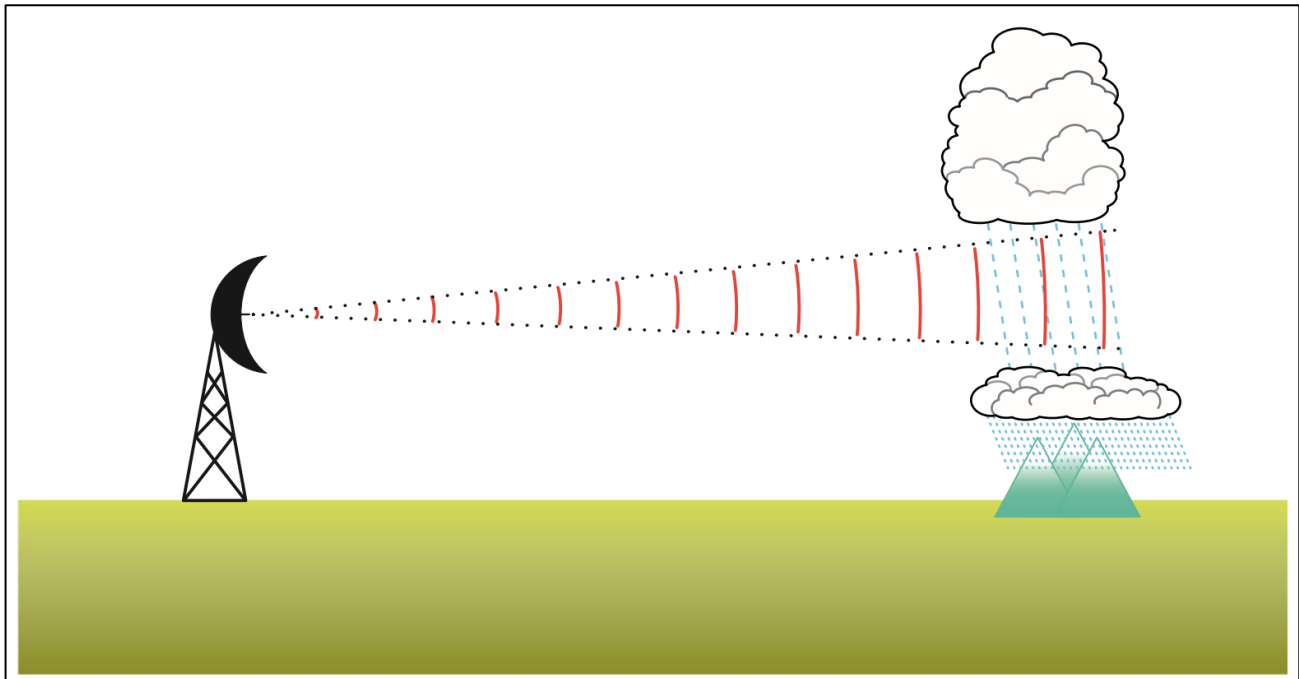


Figure 18 Meteorological causes of errors – orographic enhancement of rainfall at low levels

Even with a network of radars, the screening effect of hills can make the detection of this orographic enhancement difficult, resulting in an under-estimate of the actual rainfall. In the Radarnet processing system a correction based on numerical weather prediction model outputs is applied which attempts to correct for this effect.

### Bright band

Radar echoes from both raindrops and snowflakes are calibrated to give correct intensities on the rainfall display. But at the level where the temperature is near 0° C, melting snowflakes with large, wet, reflective surfaces give strong echoes. These produce a false band of heavier rain, or bright band, on the radar picture. The Radarnet processing system makes a correction to the data to try to account for this enhancement.

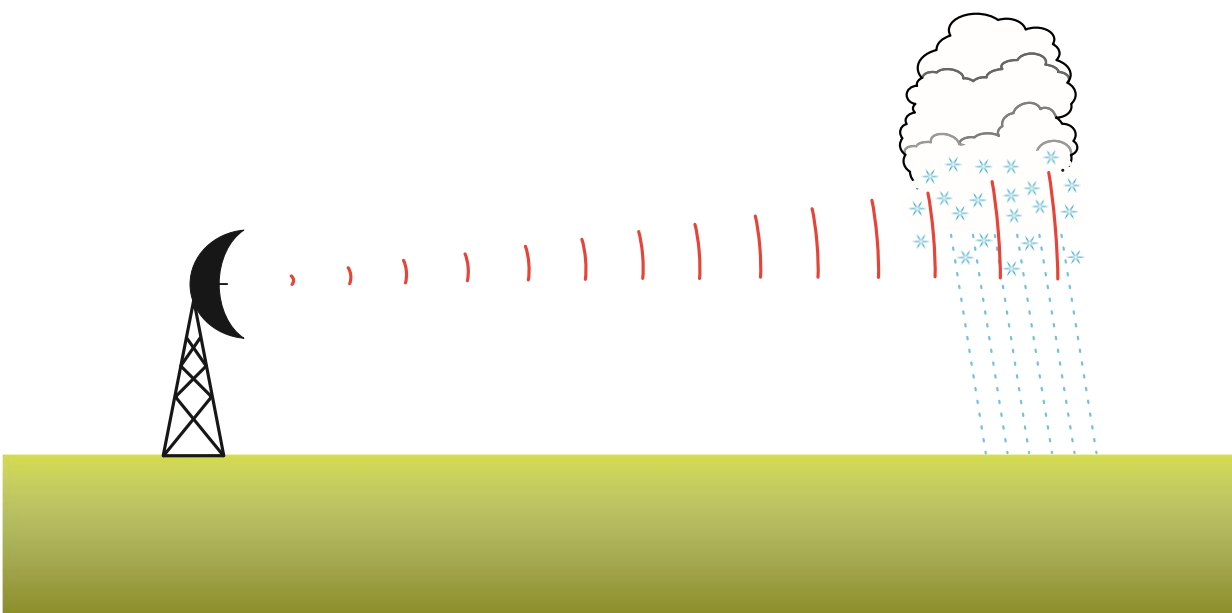


Figure 19 Meteorological causes of errors – bright band

### Drop sizes of precipitation within a cloud

Every cloud has a different composition of droplets; in particular, frontal rainfall clouds differ from convective shower clouds. In deriving rainfall rates from radar echo intensities, average values for cloud compositions are used. Radars under-estimate the rain from clouds composed of smaller-than-average drops (e.g. drizzle), and overestimate the rain falling from clouds with very large drops (e.g. showers).

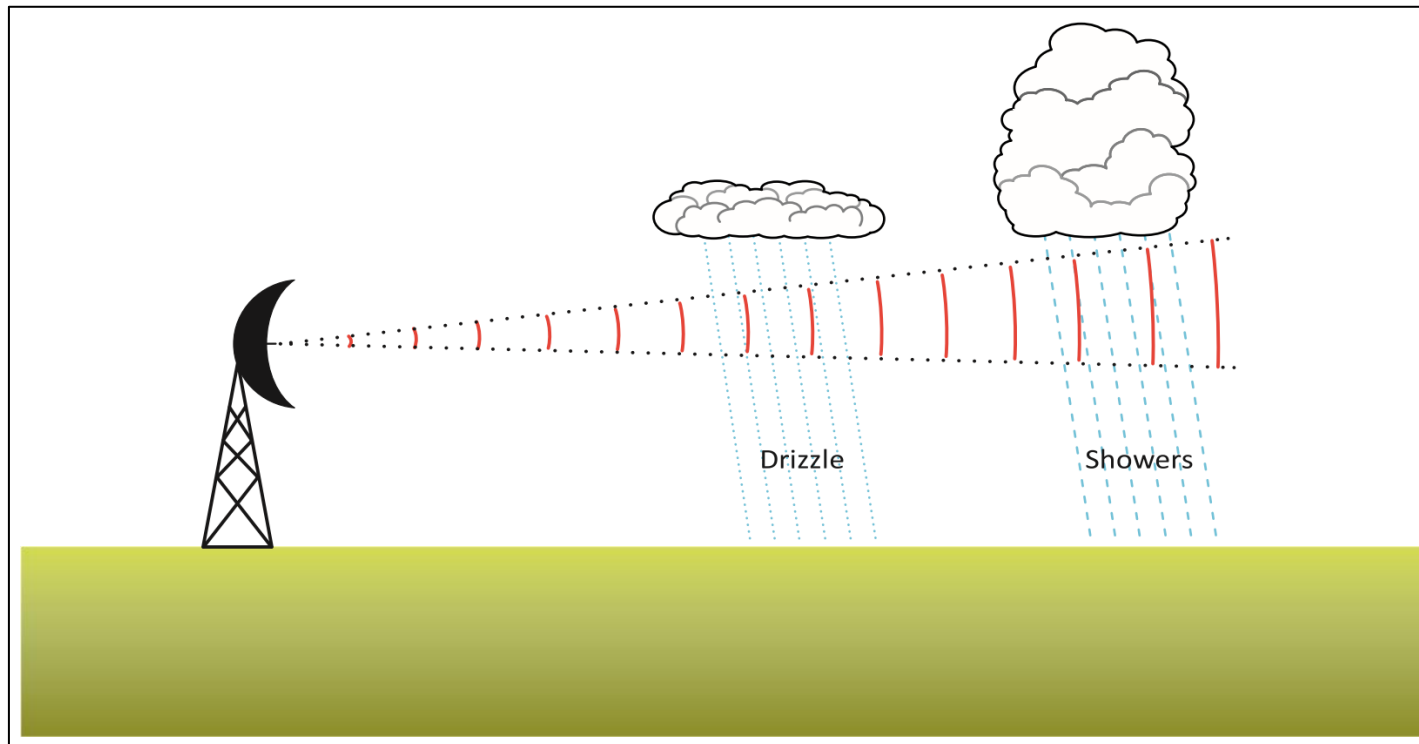


Figure 20 Meteorological causes of errors – drop size of precipitation.



## Anomalous propagation (anaprop)

Radar beams are like light beams, in that they travel in straight lines through a uniform medium but will be bent (refracted) when passing through air of varying density. When a low-level temperature inversion exists (see fact sheet number 13 – Upper Air Observations and The Tephigram), the radar beam is bent downwards and strong echoes are returned from the ground, in a manner akin to the formation of mirages. This usually occurs in anticyclones, where rain is unlikely and so anaprop is normally recognised without difficulty.

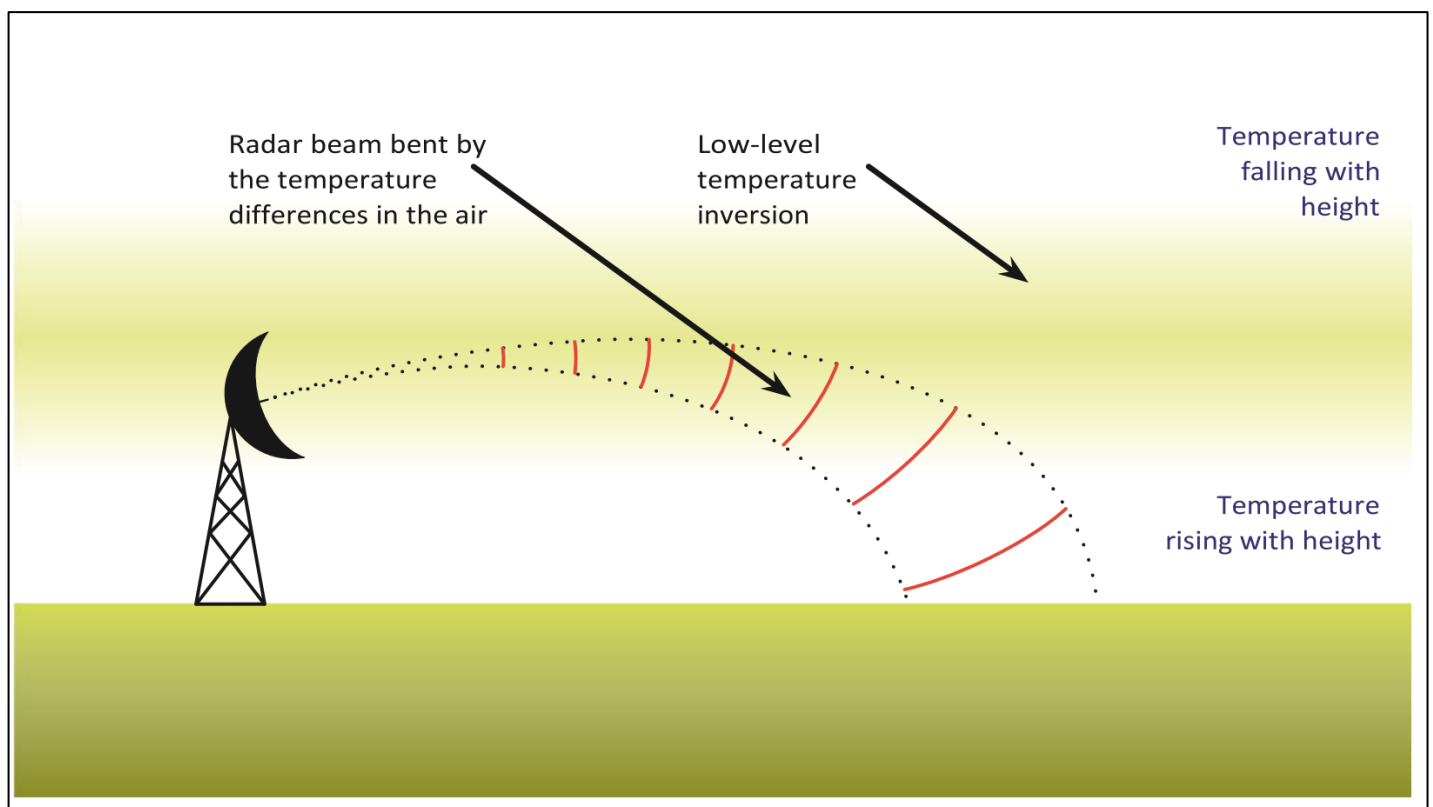


Figure 21 Meteorological causes of errors – anomalous propagation (anaprop)

## Advantages and disadvantages of weather radar

### Advantages:

Detailed, instantaneous and integrated rainfall rates

- Areal rainfall estimates over a wide area
- Information in near-real time
- Information in remote land areas and over adjacent seas
- Location of frontal and convective (shower) precipitation
- Monitoring movement and development of precipitation areas
- Short-range forecasts made by extrapolation
- Data can be assimilated into numerical weather prediction models

### Disadvantages:

- Display does not measure rainfall actually at the surface
- Can also show non-meteorological echoes
- Estimates liable to error due to technical and meteorological related causes

## Radar imagery used in real-life weather forecasting

Radar imagery is just one of the tools that a forecaster has at their disposal when analysing weather patterns in order to issue a forecast. For example, on the 2 December 2005 a vigorous depression approached the far southwest of England. Using satellite imagery, it was possible to follow the cloud patterns associated with this depression but only when the rainfall radar was used was it possible to see exactly where the heaviest rain was falling and issue warnings as appropriate.

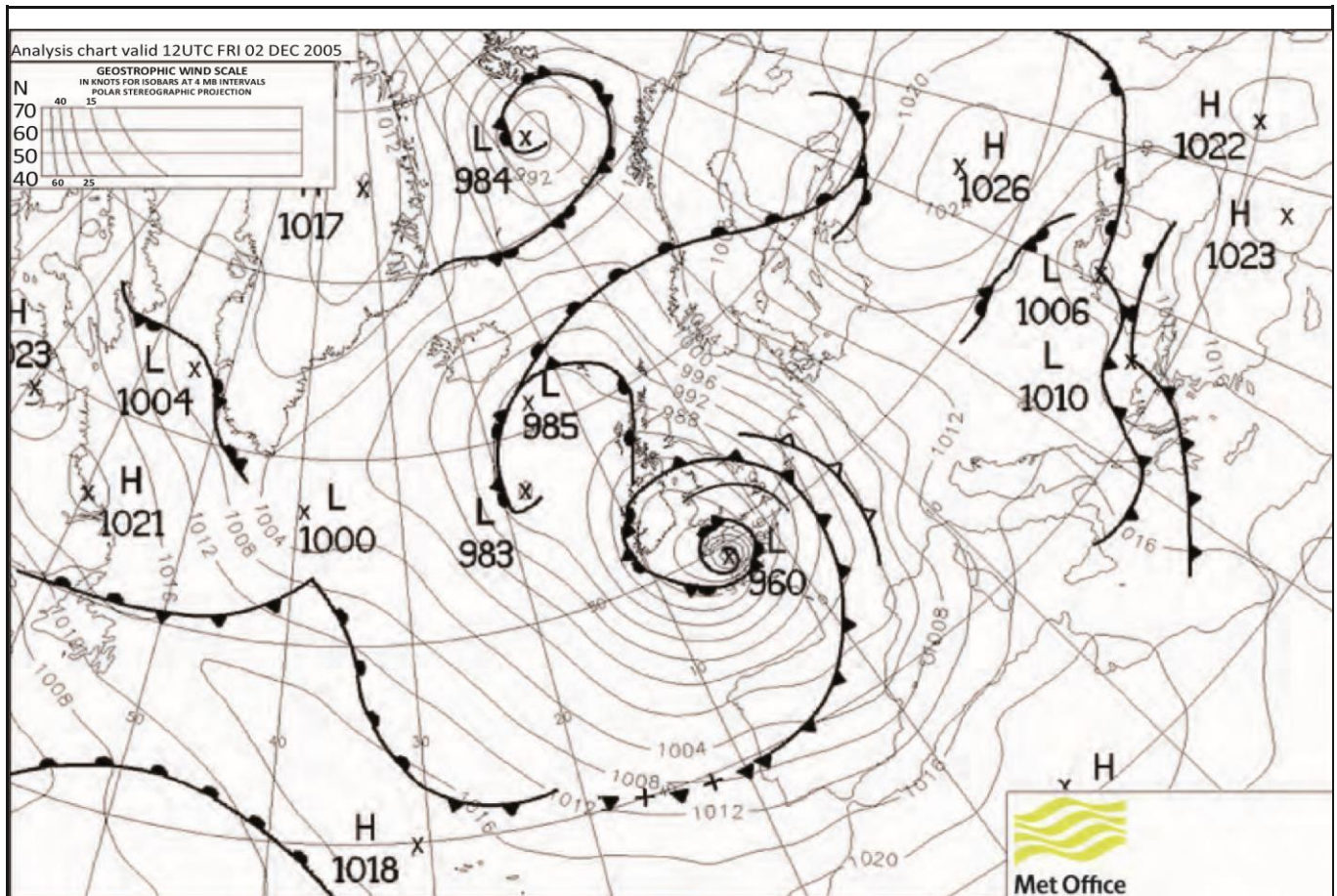


Figure 22 North Atlantic surface synoptic chart for 1200Z on 2 December 2005

metoffice.gov.uk

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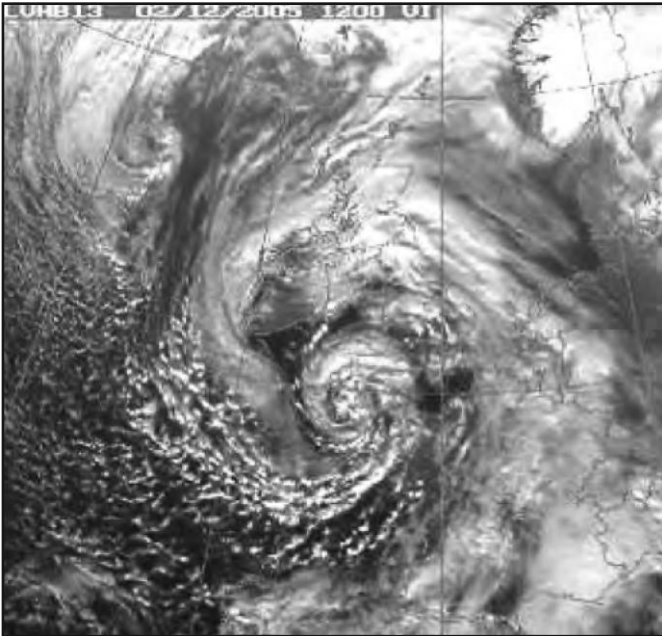
## Summary of United Kingdom weather for 2 December 2005

Much of the UK had a cloudy, mild and wet night with outbreaks of rain. The rain was heavy in places and there were gales along the exposed coasts of south Wales, the English Channel and East Anglia. The rain turned showery over southwest England. It remained dry across central and northwest Scotland with air frost in Highland.

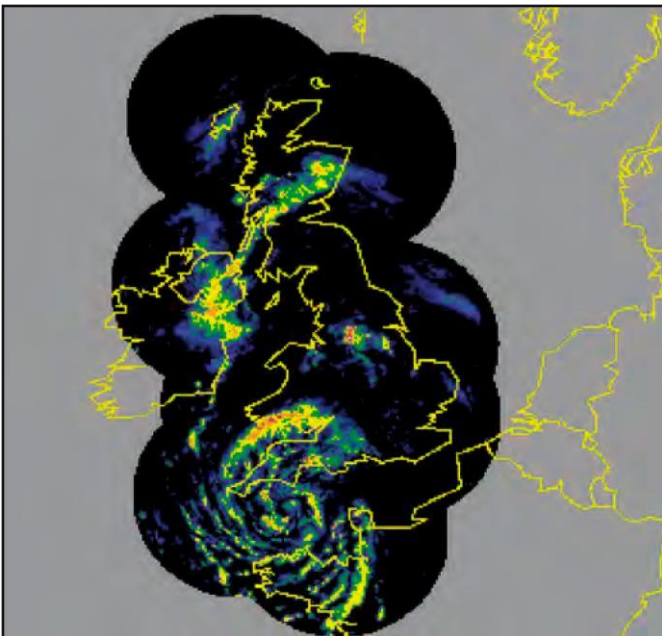
Areas of rain tended to fragment as they continued to move north or northwest across the UK during the morning. However, the rain became persistent across Northern Ireland and eastern Scotland during the afternoon. At the same time, heavy showery rain developed across southwest England and south Wales.

Frequent heavy showers then developed over much of England and Wales, with local hail and thunder across south and southeast England. It was a windy day with gales in places. Maximum gusts included 69 knots at the Isle of Portland (Dorset), 67 knots at Alderney (Channel Islands), 63 knots at Brixham (Devon) and 62 knots at Guernsey airport (Channel Islands).

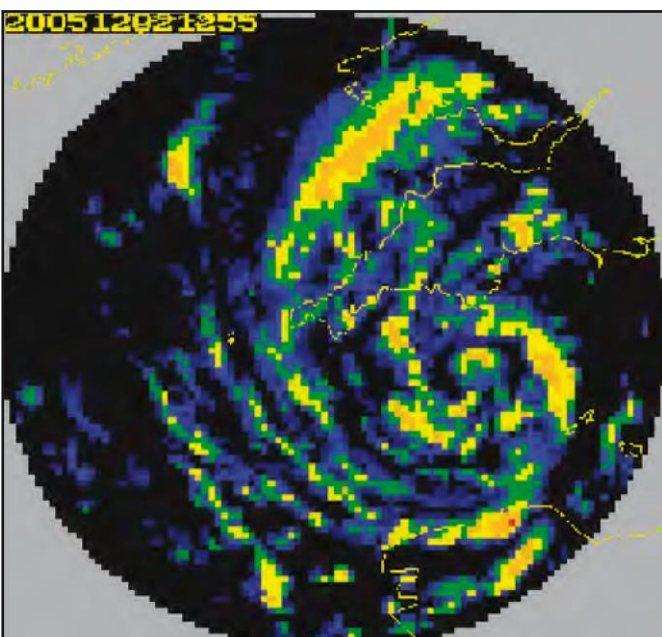
The afternoon temperatures were in the normal or mild categories.



The midday satellite image shows a deep and well developed area of low pressure centred in the western English Channel between Brest and Plymouth. The image shows clearly the cloud structure swirling around the centre with bands of rain and also some quite heavy and blustery showers. The main frontal zone can be seen from south of Ireland extending across Scotland to the North Sea then across the continent to the western Mediterranean. *Visible satellite image for 1200Z on 2 December 2005.*



The 1255z radar image shows the swirl of precipitation associated with a deep depression centred in the western English Channel between Brest and Plymouth. This image shows clearly the frontal rain across Scotland and Ireland as well as the showery activity swirling around the centre of the depression. *United Kingdom 5 km radar imagery composite for 1255Z on 2 December 2005.*



The 1255z Predannack radar image shows the swirl of precipitation associated with a deep and a well developed area of low pressure centred in the western English Channel between Brest and Plymouth. *Predannack 5 km radar imagery for 1255Z on 2 December 2005.*

The midday surface chart of the British Isles shows a deep area of low pressure in the western English Channel with its associated occluded frontal system wrapped around it. Also depicted on this chart is a warm front across the western part of

Scotland and into Northern Ireland and a trailing cold front lying from Northern Ireland, through Dumfries and Galloway, Cumbria, across the Pennines and down through East Yorkshire and away into the North Sea and onwards into the near continent. Following on behind this cold front is a trough running from North Wales, across the Midlands and Southeast England then away into Northern France.

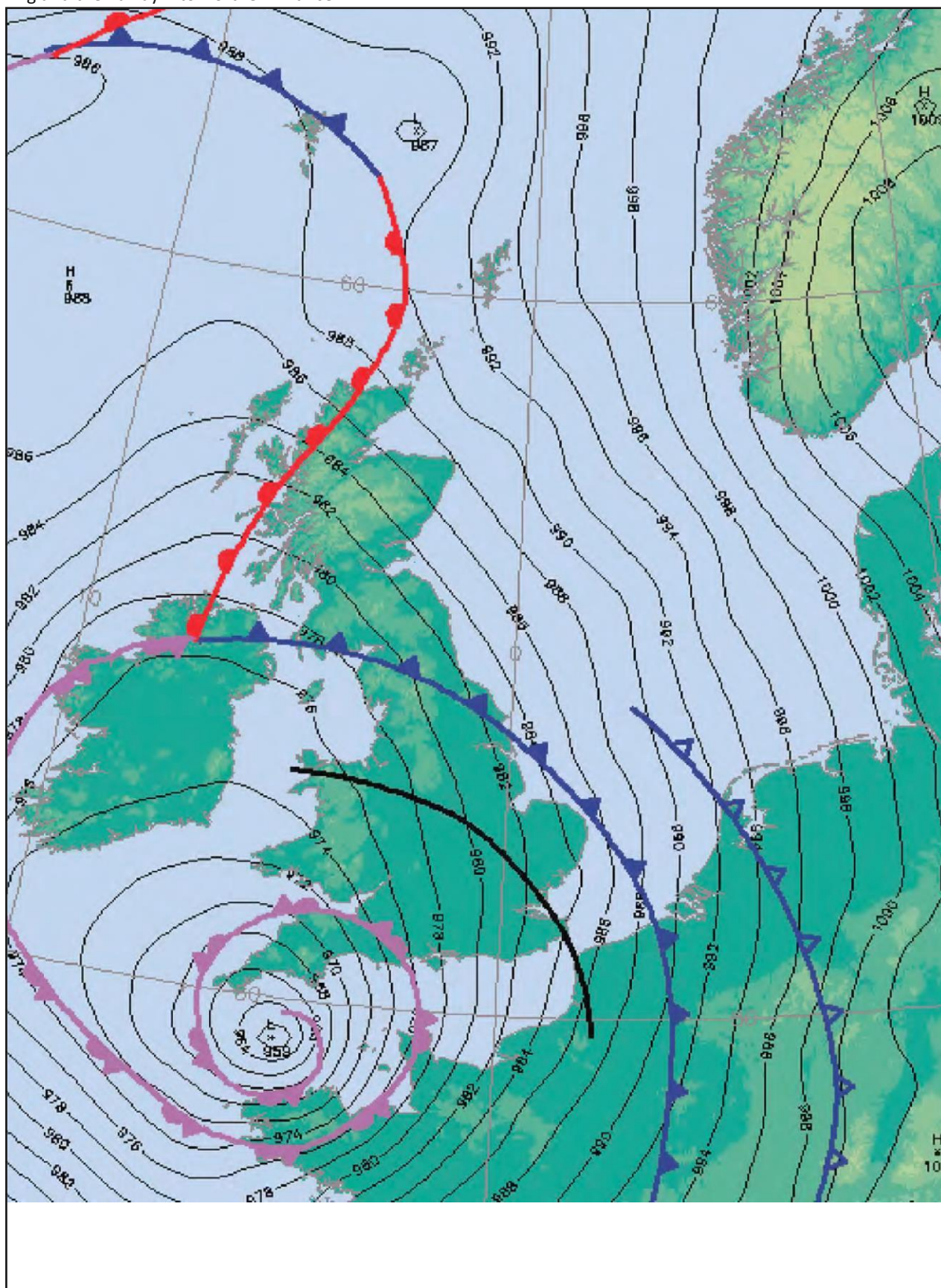


Figure 23 Met Office's Operations Centre analysis chart for 1200Z on 2 December 2005

Location of radars across the British Isles

Site Name	National Grid Reference		Latitude (WGS84)	Longitude (WGS84)	Location
	Eastings	Northings			
Clee Hill	359585	278006	52°23'55"N	002°35'43"W	Titterstone Clee, near Ludlow, Shropshire
Hameldon Hill	381060	428740	53°45'17"N	002°17'19"W	Dunnockshaw, near Burnley, Lancashire
Chenies	501642	199959	51°41'21"N	000°31'50"W	Flauden, near Amersham, Hertfordshire
Castor Bay	119112	520302	54°30'00"N	006°20'24"W	Near Lurgan, Belfast, Northern Ireland
Predannack	169185	016440	50°00'12"N	005°13'21"W	Near Ruan Major, The Lizard, Cornwall
Ingham	496045	382975	53°20'06"N	000°33'33"W	Ingham, near Lincoln, Lincolnshire
Crug-y-Gorllwyn	232190	234085	51°58'47"N	004°26'41"W	Near Capel Iwan, Carmarthen, Carmarthenshire
Hill of Dudwick	397925	837835	57°25'51"N	002°02'10"W	Near Ellon, Aberdeenshire
Druim a'Starraig	154395	932345	58°12'40"N	006°10'59"W	Near Stornoway, Isle of Lewis
Cobbacombe Cross	298080	119230	50°57'48"N	003°27'10"W	Huntsham, near Tiverton, Devon
Thurnham	581670	158290	51°17'41"N	000°36'15"E	Near Maidstone, Kent
Dean Hill	424335	125730	51°01'50"N	001°39'16"W	Near West Dean, Salisbury, Wiltshire
Holehead	261790	682835	56°01'06"N	004°13'08"W	Holehead, near Fintry, Stirling
Munduff Hill	318820	703225	56°12'53"N	003°18'38"W	Near Kinneswood, Kinross
High Moorsley	433873	545572	54°48'20"N	001°28'32"W	Near Durham
R&D (not operational)					
Wardon Hill	360907	102337	54°49'09"N	002°33'23"W	Wardon Hill, Long Ash Lane, Frome St Quintin, Dorset
Included in UK Composite (not Met Office owned)					

Channel Islands	-	-	49°12'34"N	002°11'56"W	La Moye, Jersey Channel Islands
Dublin	117207	400906	53°25'44"N	006°15'31"W	Dublin Airport, Ireland
Shannon	-	-	52°42'01"N	008°55'24"W	Shannon Airport, County Clare, Ireland

**Table above: Current radar locations.**

### Proposed new rainfall radar sites in the British Isles

Site Name	National Grid Reference		Latitude (WGS84)	Longitude (WGS84)	Location
	Eastings	Northings			
Old Buckenham	608500	293500	52°29'58"N	001°04'13"E	Near Carleton Rode, Attleborough, Norfolk

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