



Met Office



Radar

National Meteorological Library and Archive
Fact sheet 15 — Weather radar

(version 01)

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

Radar – a brief history

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.

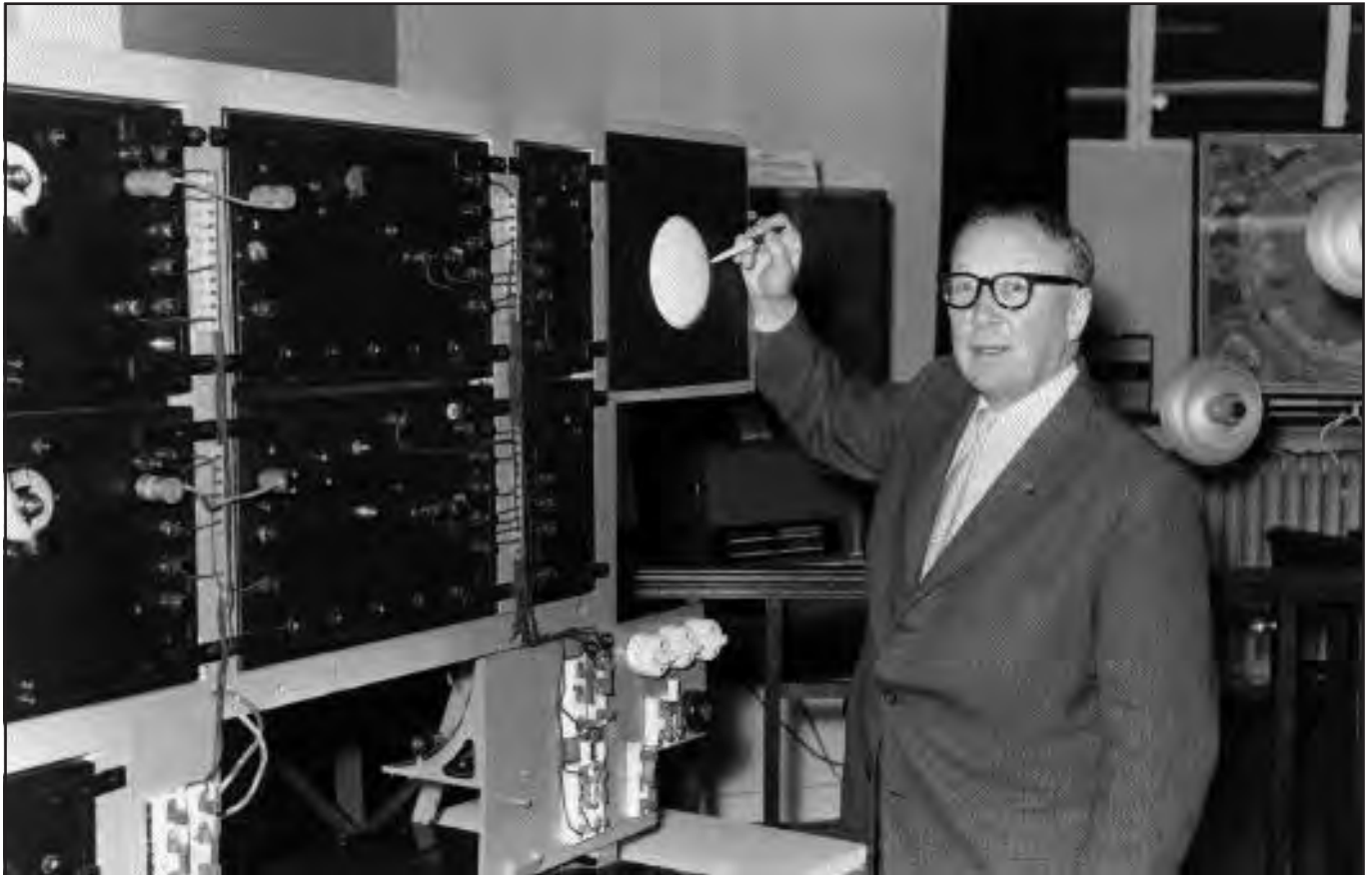


Figure 1. Robert Watson-Watt.

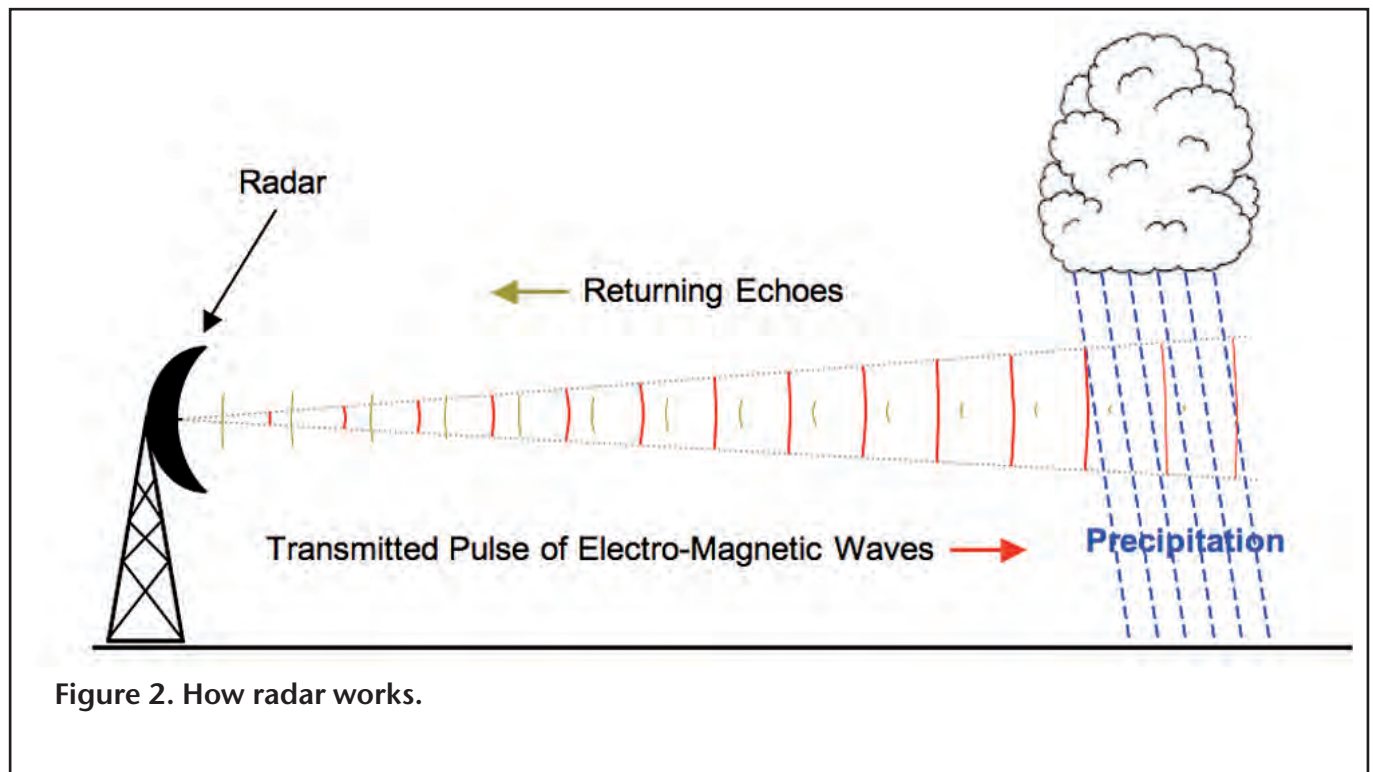
When the first weather echoes were detected and recognised is not certain, but during the war weather echoes were regarded as a nuisance rather than of intrinsic value. Nevertheless, before the end of the war the Meteorological Office had established a radar research station at East Hill, some 30 miles 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.

How does radar work?

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



Short pulses of electro-magnetic waves, which travel at the speed of light (approx. 186000 miles per second), are transmitted in a narrow beam for a very short time (typically 2 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 (3300 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 radars cannot send and receive at the same time, the transmitted pulse must be very short (or echoes from close range will be lost), and the listening time must be as long as possible, for detecting distant echoes. Increasingly the transmitted power is subject to engineering constraints and cost.

A longer transmission pulse would give more power and better long-range performance, but would reduce the close-range capability.

The returning echo is very much weaker than the transmitted pulse, and depends on several factors. There is attenuation, or absorption of energy, by particles of dust or cloud 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 many modern radars is approximately 1° and, as the target distance increases, only an increasingly small part of the transmitted beam is reflected back to the radar.

Location of radars across the British Isles

Site Name	National Grid Reference		Latitude	Longitude	Location
	Eastings	Northings			
Clee Hill	359485	277940	52°23'53"N	002°35'49"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 Stornaway, 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 Kinnesswood, Glenrothes, Fife
High Moorsley	433873	545572	54°48'20"N	001°28'32"W	Near Durham
Jersey	-	-	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 1. Current radar locations.

Proposed new rainfall radar sites in the British Isles

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

Table 2. Proposed additional radar locations.

Current British Isles weather radar network

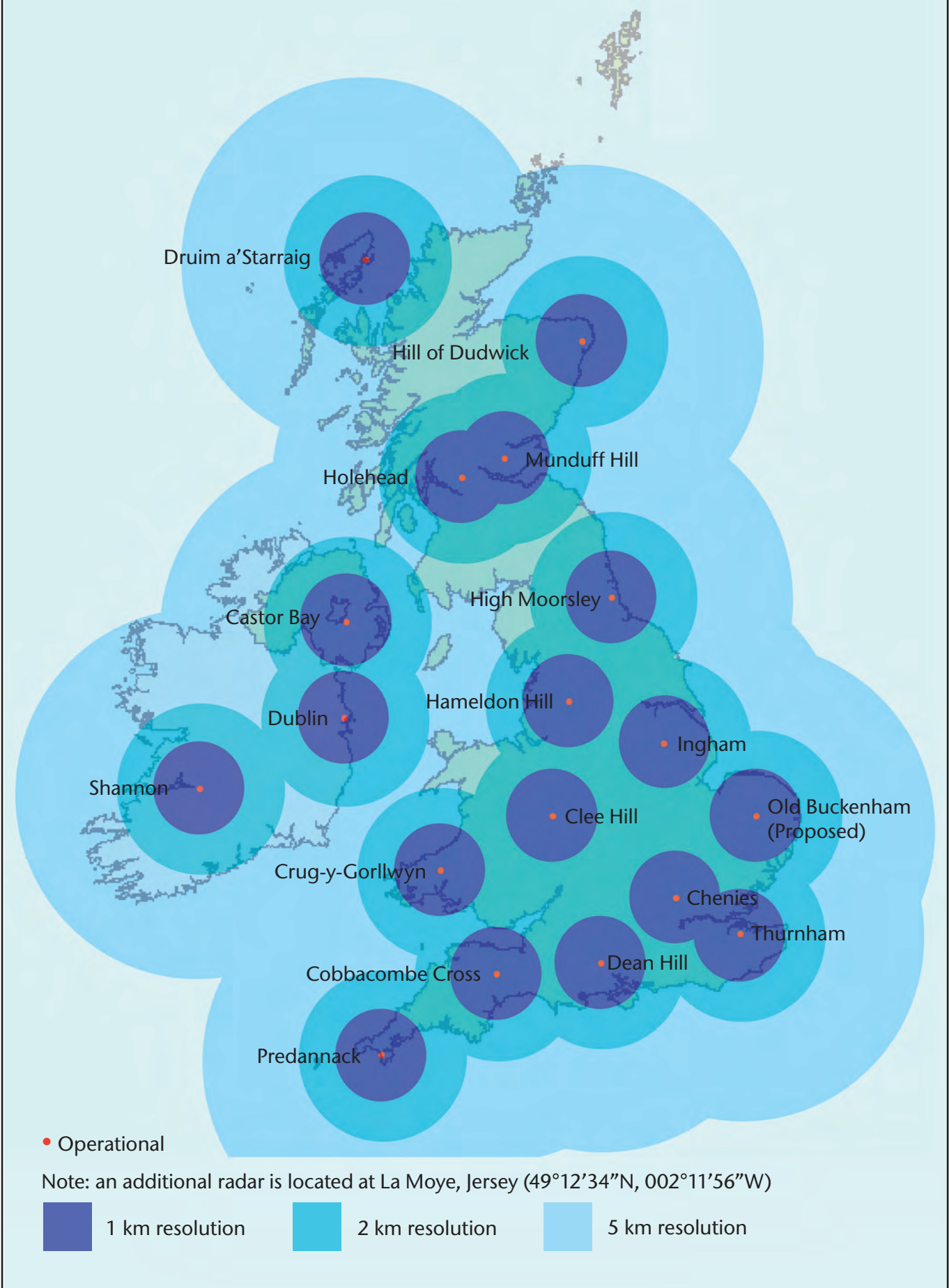


Figure 3. Current rainfall radar coverage across the British Isles.

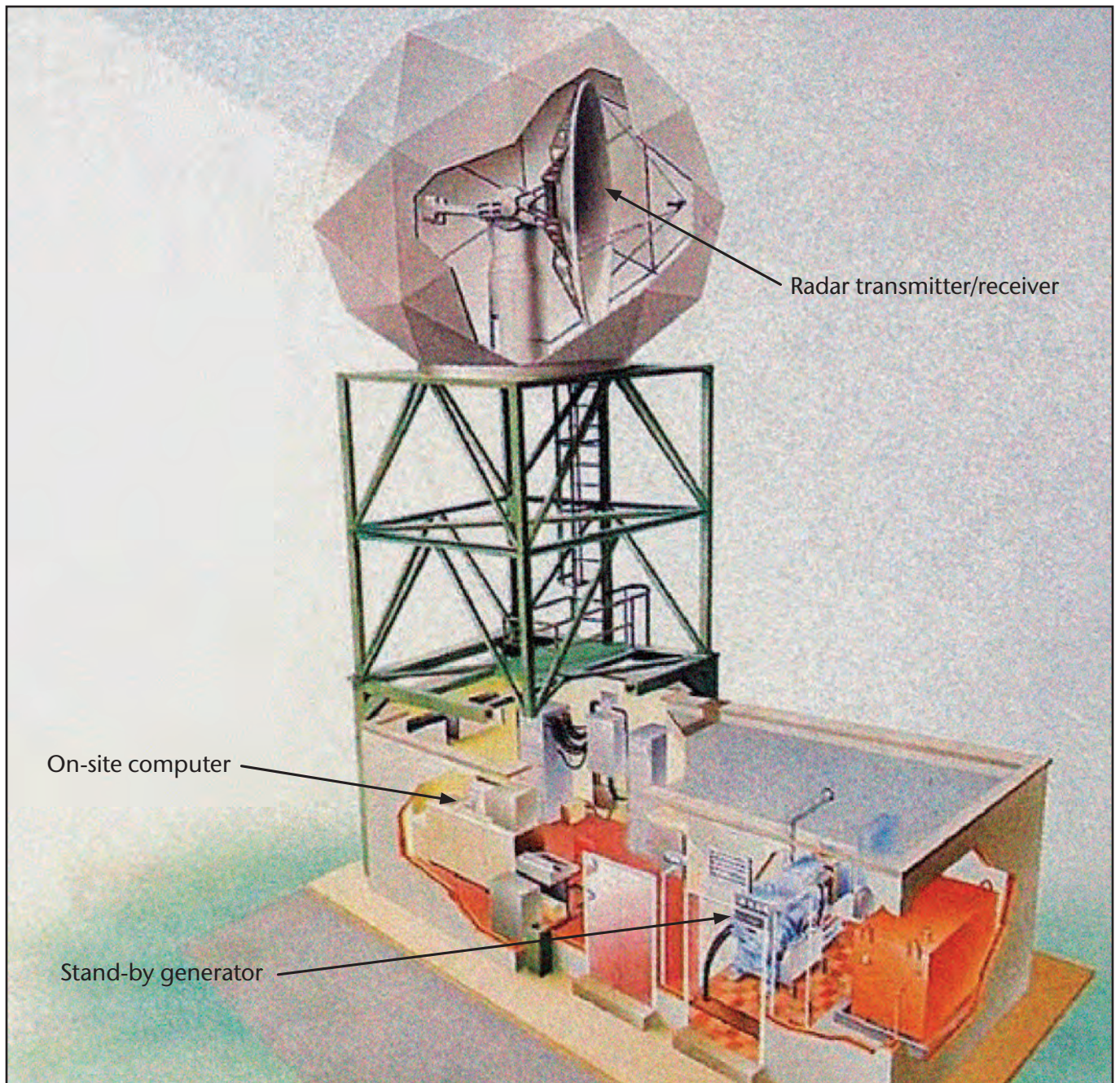


Figure 4. View of the internal workings of a weather radar.



Figure 5. Weather radar, Stornoway, Isle of Lewis.



Figure 6. Weather radar Chenies, Hertfordshire.



Figure 7. Weather radar, Dean Hill, Wiltshire.

At each radar location an on-site computer carries out aerial elevation control and digital signal processing. The raw data is then sent to the Radarnet IV Central Processing at Exeter where the following processing is carried out:

- Correction for attenuation by intervening rain
- Correction to range attenuation
- Elimination of ground clutter
- Conversion of radar reflectivity to rainfall rate
- Conversion from polar cells to National Grid Cartesian cells

The radar network is then linked to a central computer at the Met Office Headquarters in Exeter. Each radar is owned by a consortium of agencies, such as the Environment Agency, with the Met Office providing the technical and operational support.

Each radar completes a series of scans about a vertical axis between four and eight low-elevation angles every 5 minutes (typically between 0.5 and 4.0 degrees, depending on the height of surrounding hills). Each scan gives good, quantitative data (1 and 2 km resolutions) out to a range of about 75 km and useful qualitative data (5 km resolution) to 255 km.

- 5 km resolution data provides a good overall picture of the extent of precipitation at a national/regional scale.
- 2 km data coverage extends over 85% of England and Wales and shows more detailed distribution of precipitation intensities. It is suitable for more demanding rainfall monitoring and hydrological applications.
- 1 km resolution provides the most detailed information, down to the scale of individual convective clouds. It is designed to assist real-time monitoring of small urban catchments and sewer systems.

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

Table 3. Rainfall intensity colour bands.

This data provides valuable information for the immediate emergency response and the longer term planning of future risk management and mitigation.

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.



Figure 8.
5 km resolution.

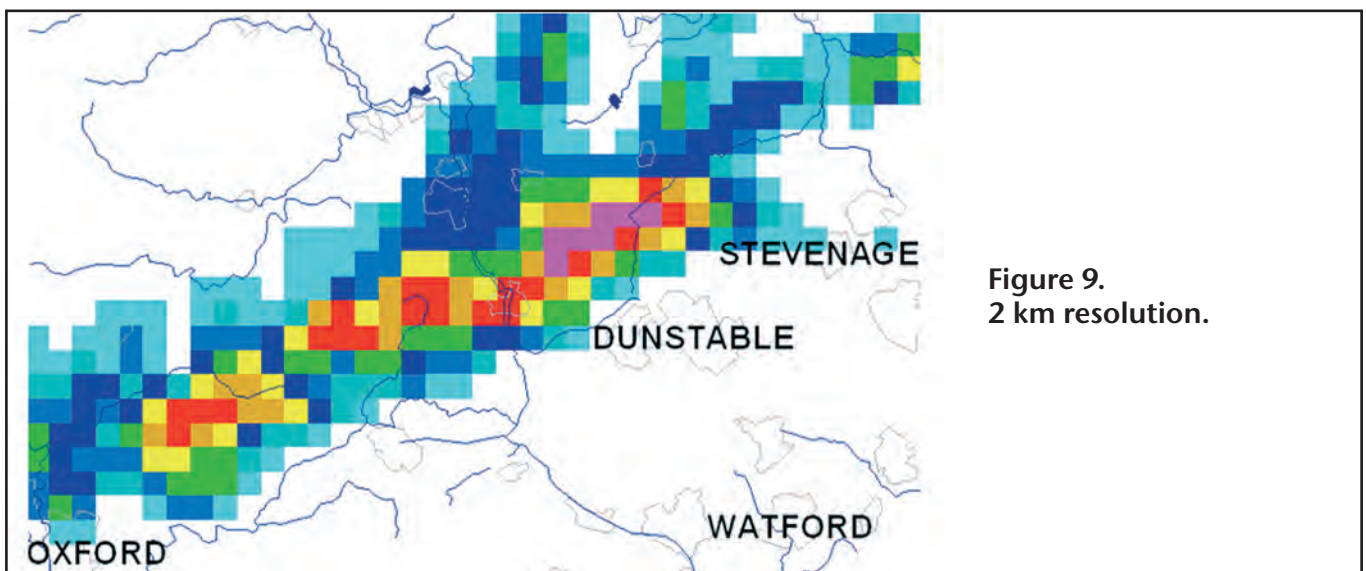


Figure 9.
2 km resolution.

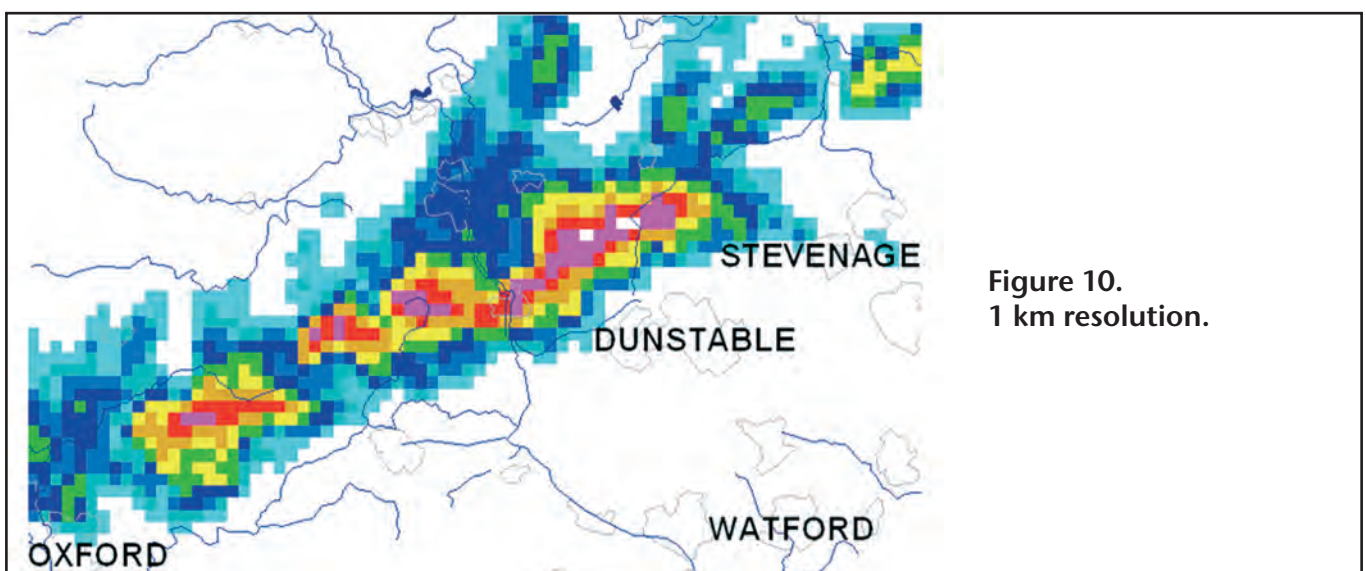


Figure 10.
1 km resolution.

Weather radar is very useful for forecasters in areas where there is little observable data. One recent 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.

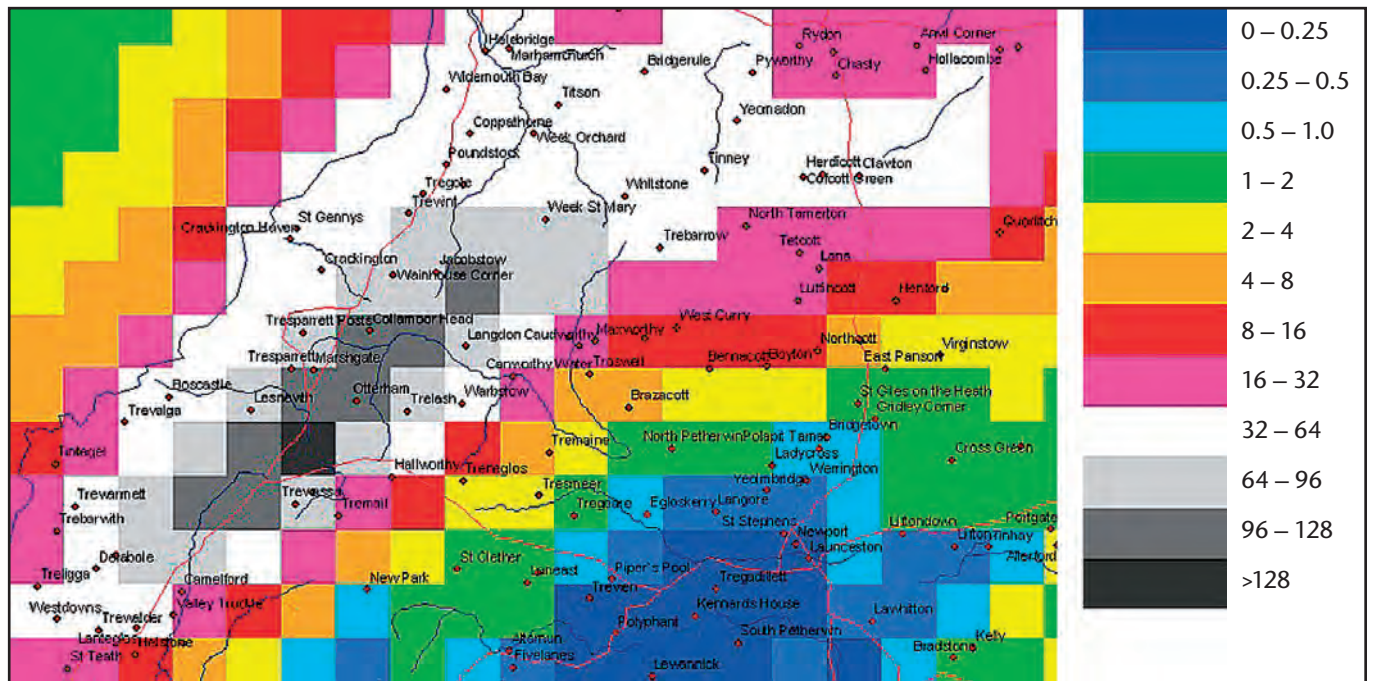


Figure 11. Radar rainfall accumulations from the Cobbacombe Cross radar (2 km resolution 1100 – 1800 UTC) during the Boscastle floods of 16 August 2004.

Raingauge name	National grid reference	24-hour rainfall total (mm)	Event total (mm)
Otterham*	SX 169 916	200.4	–
Trevalac, Lesnewth	SX 134 900	184.9	181.0 (11:30 to 16:30 GMT)
Trevalac, 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 4. 24-hour rainfall amounts during the Boscastle floods of 16 August 2004.

By cycling the display forwards and/or backwards, both the motion and growth/decay of rainfall events can be observed.

Doppler radar

Depending on the equipment installed it is possible to obtain direction and speed information on the droplets observed. Using this data it is then possible to calculate wind speed and elevation data within the rain cloud, out to a range of 100 km from the radar. This data is then used, amongst others, by the Met Office's Numerical Weather Prediction 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.

Doppler radar used by the Met Office is still in its experimental stage but the sites currently equipped with Doppler radar are:

- Druim a'Starraig
- Hill of Dudwick
- Clee Hill
- Holehead
- Thurnham
- Cobbacombe Cross
- Dean Hill

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, then almost immediately, a second pulse is sent from the radar and again the returning echo is received. The computer then analyses these 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 wind speed within the cloud and the direction of the water droplets.

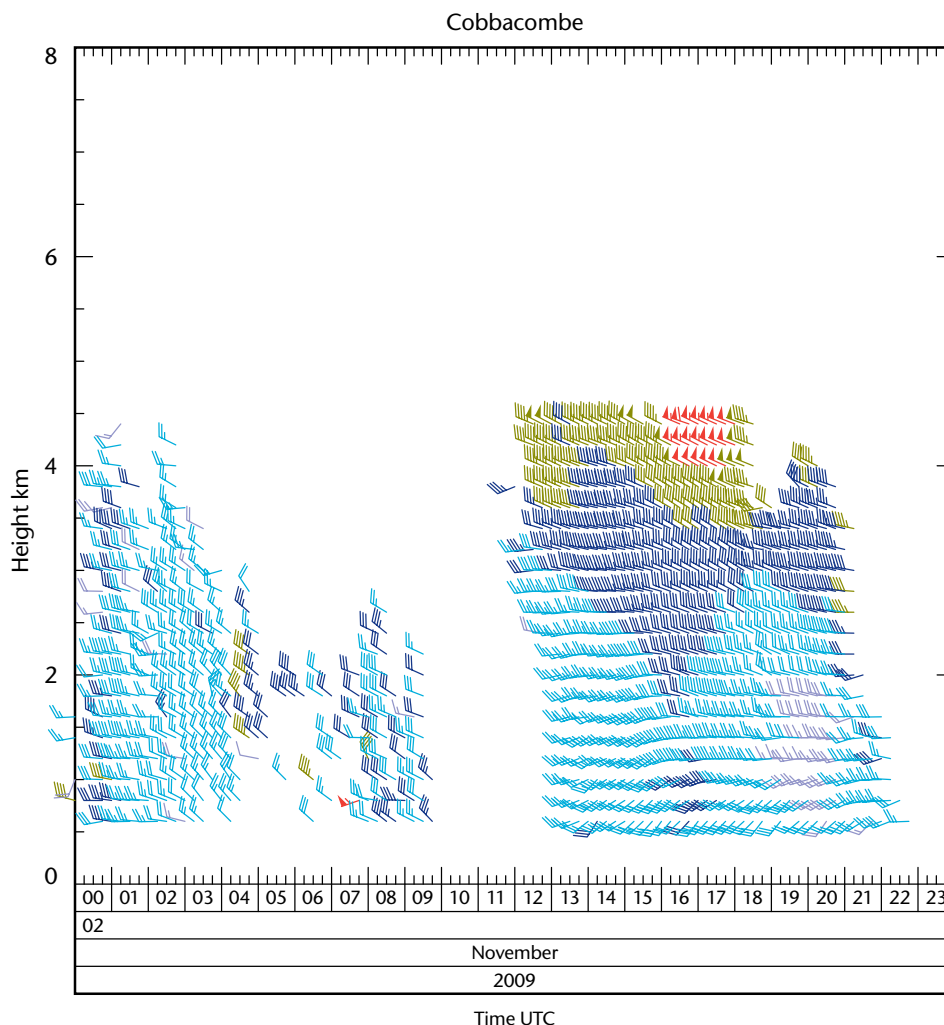


Figure 12. Wind profile generated by the Cobbacombe Cross Doppler radar.

Interpreting radar imagery

The radars do not receive echoes from tiny cloud particles, but only from the precipitation-sized droplets. 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 (occultation)

These are caused by hills or surface obstacles blocking the radar beam, and are often referred to as clutter. Clutter is rarely seen on radar imagery as it can be mapped on a cloudless day, and then taken out or subsequent pictures by the on-site computer.

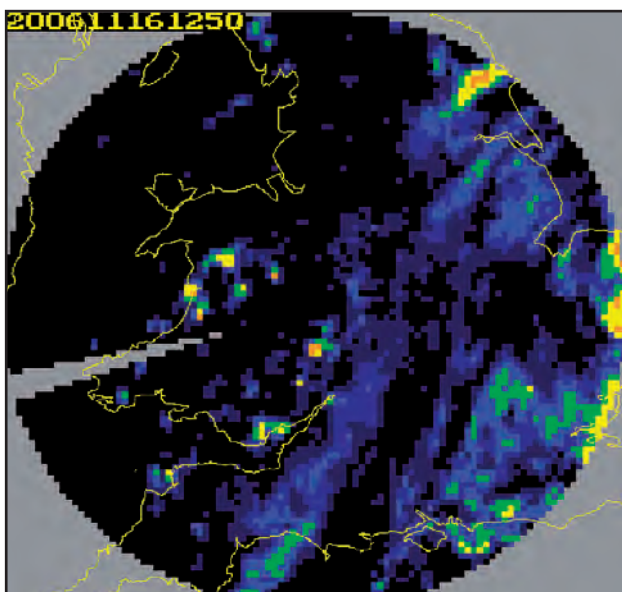
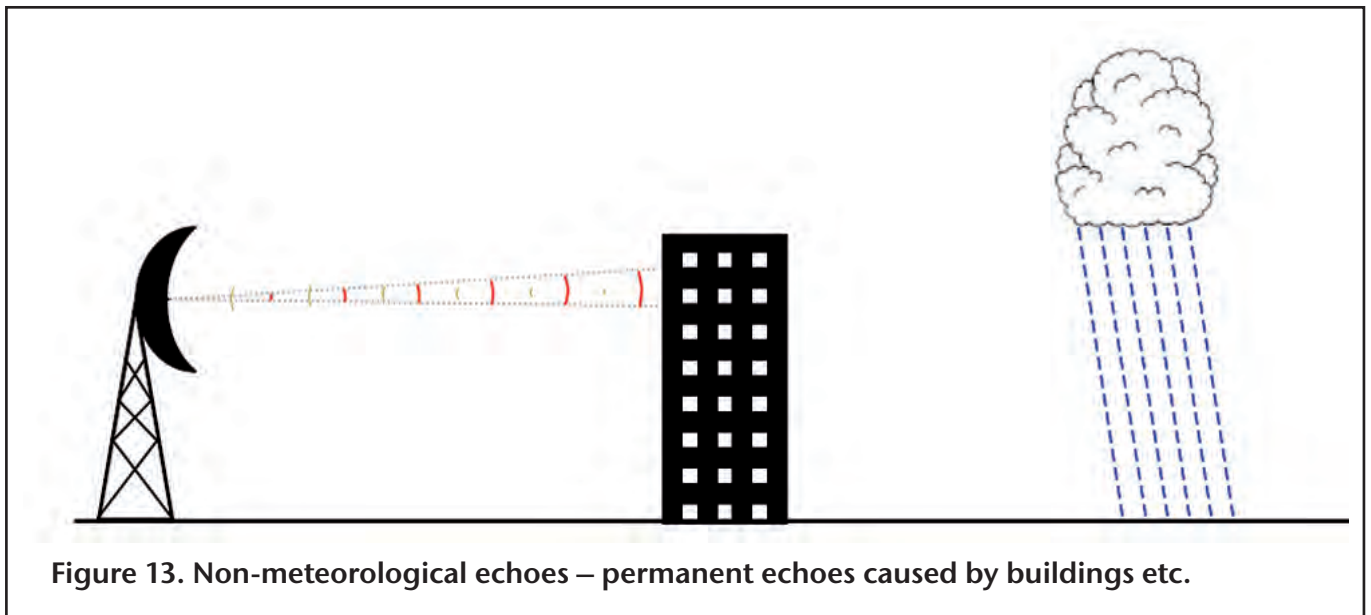
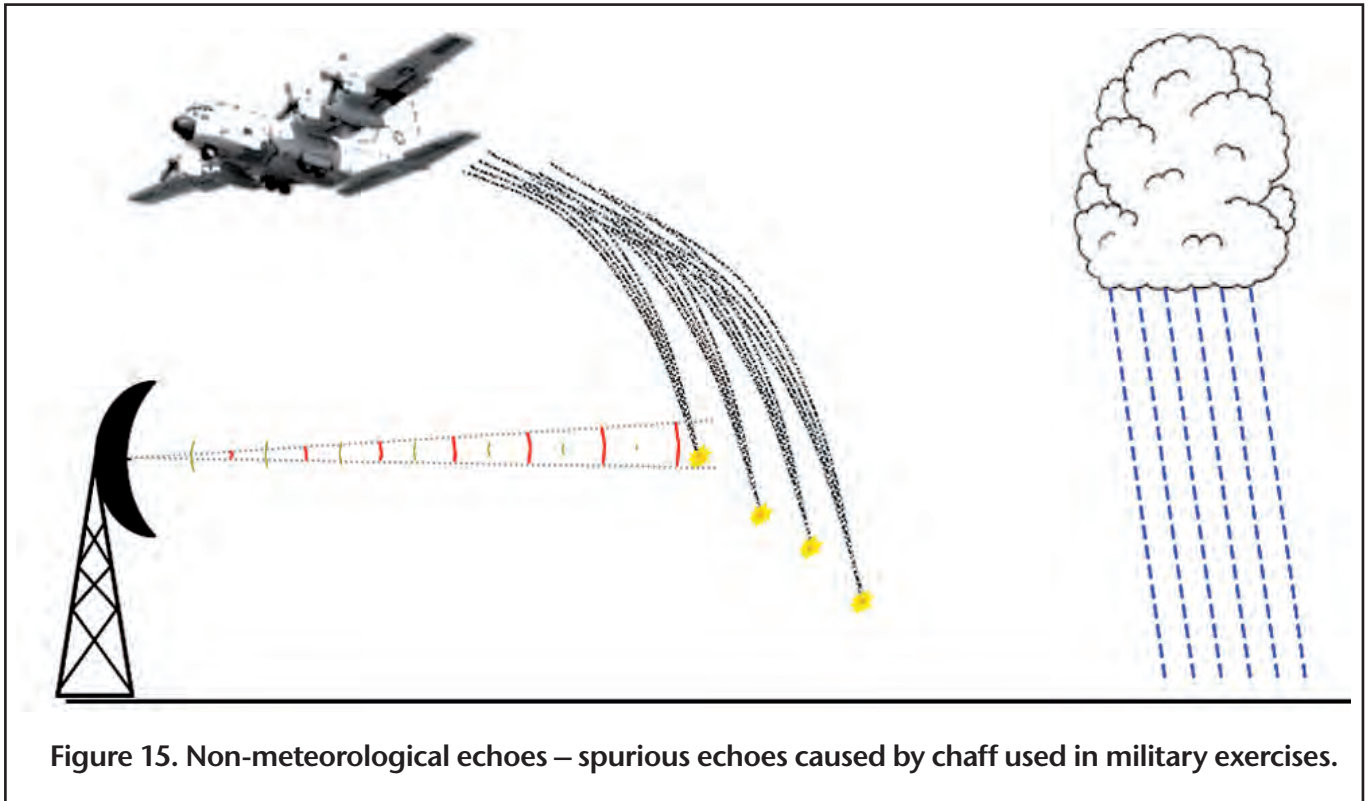


Figure 14. Clee hill radar display showing a break in the beam (occultation) caused by the Cambrian Mountain in Wales.

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

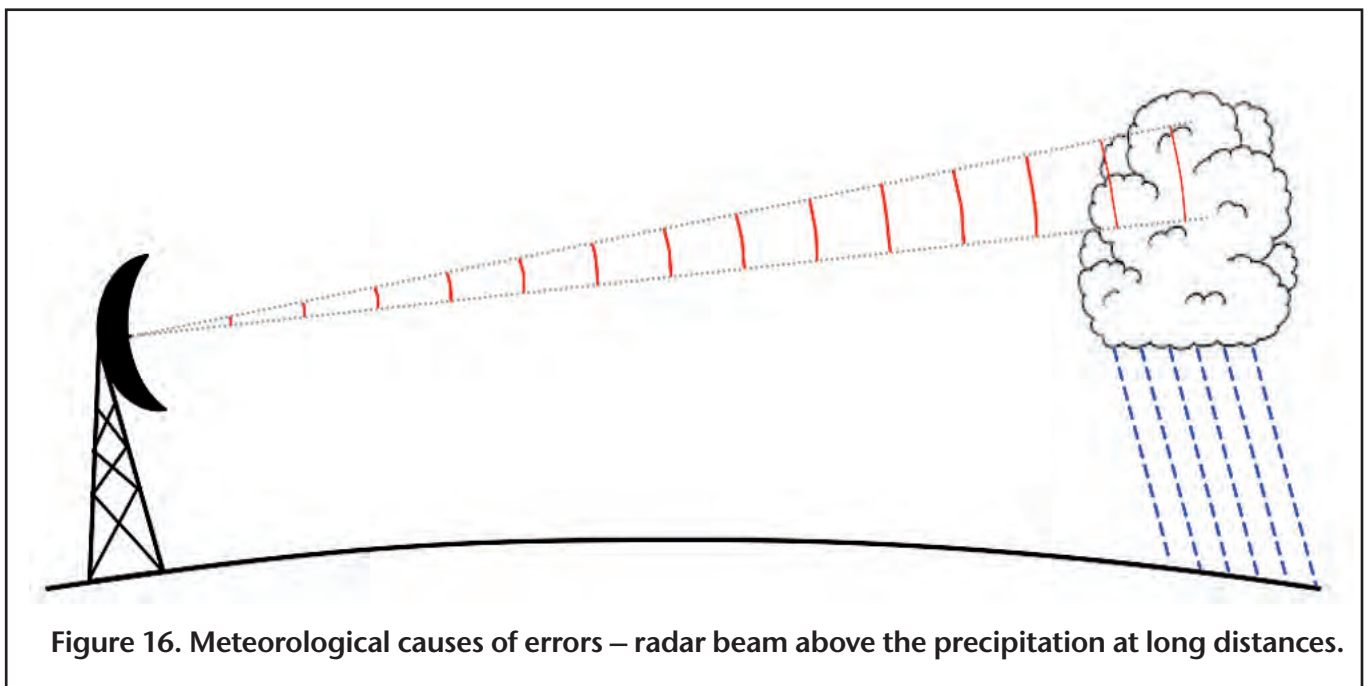
- Spurious echoes

These may be caused by ships, 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.



Meteorological causes of errors

- Radar beam above the precipitation at long ranges



Even with a beam elevation of only 1°, 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

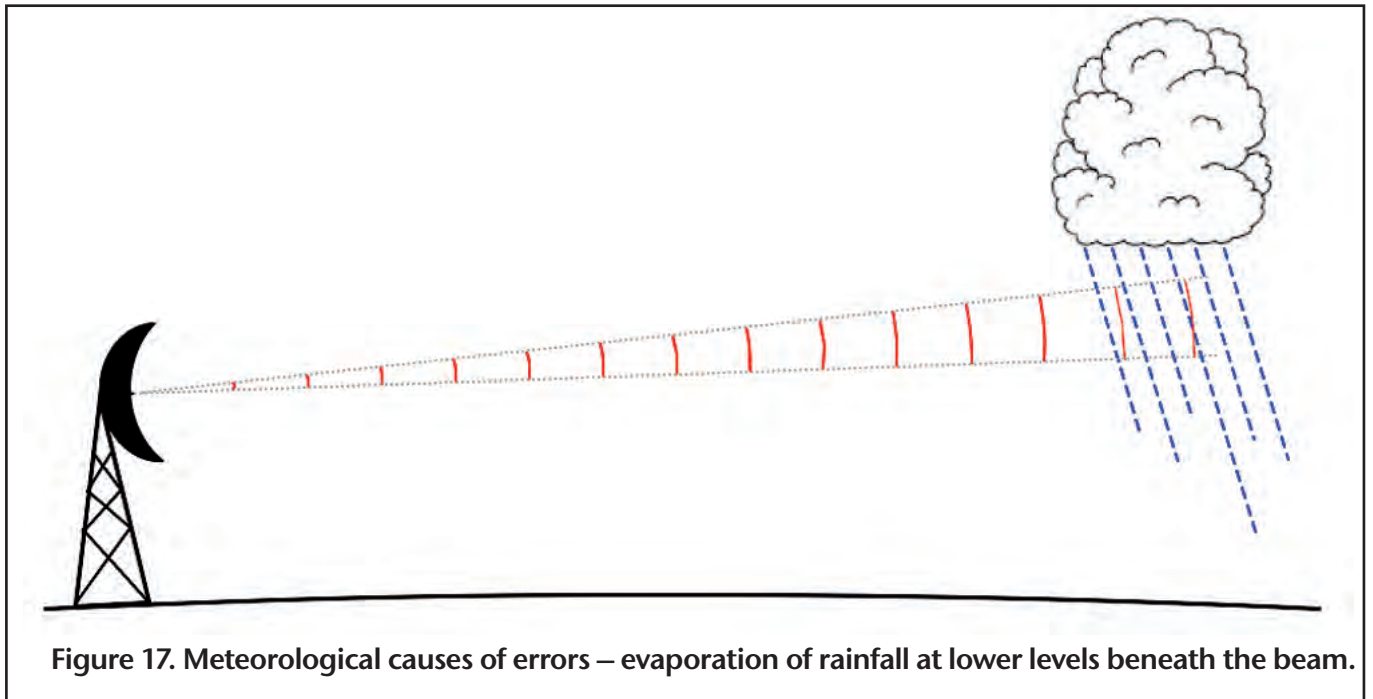


Figure 17. Meteorological causes of errors – evaporation of rainfall at lower levels beneath the beam.

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

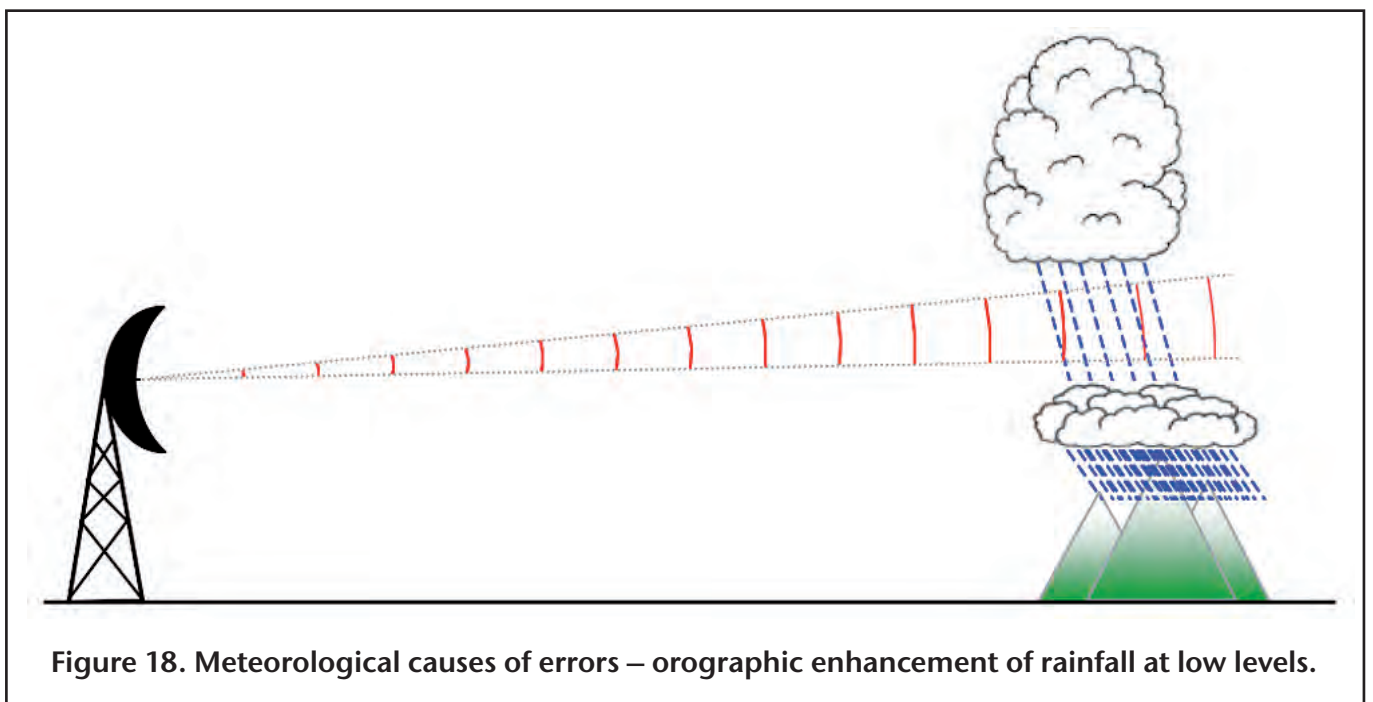


Figure 18. Meteorological causes of errors – orographic enhancement of rainfall at low levels.

accumulations. 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.

- 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.

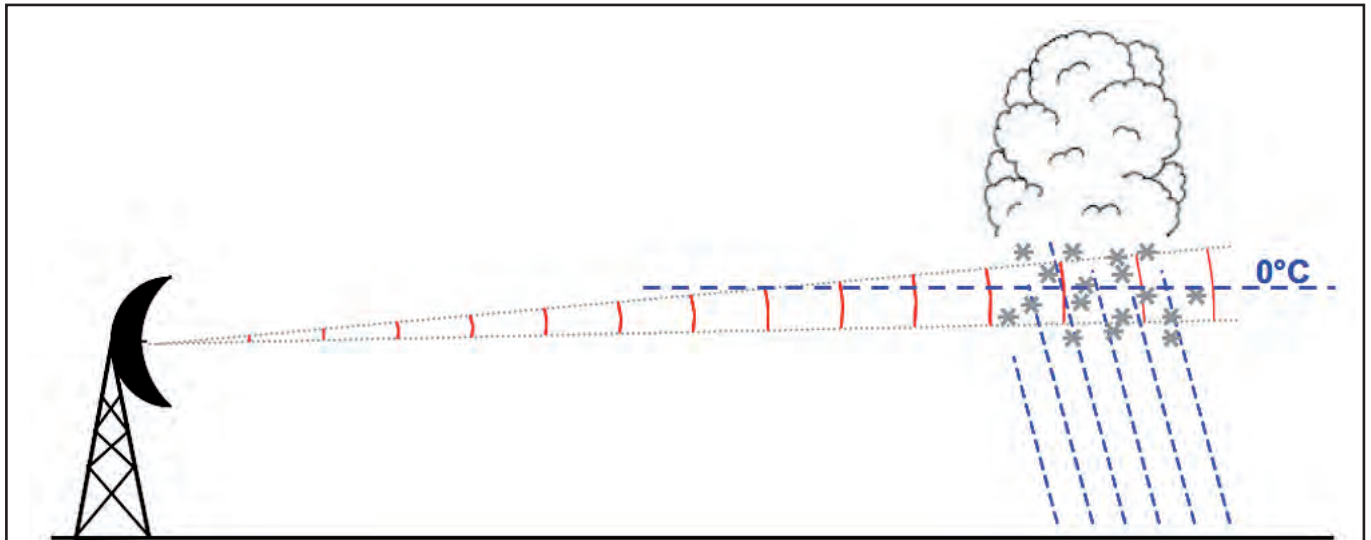


Figure 19. Meteorological causes of errors – bright band.

- 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 over estimate the rain falling from clouds with very large drops (e.g. showers).

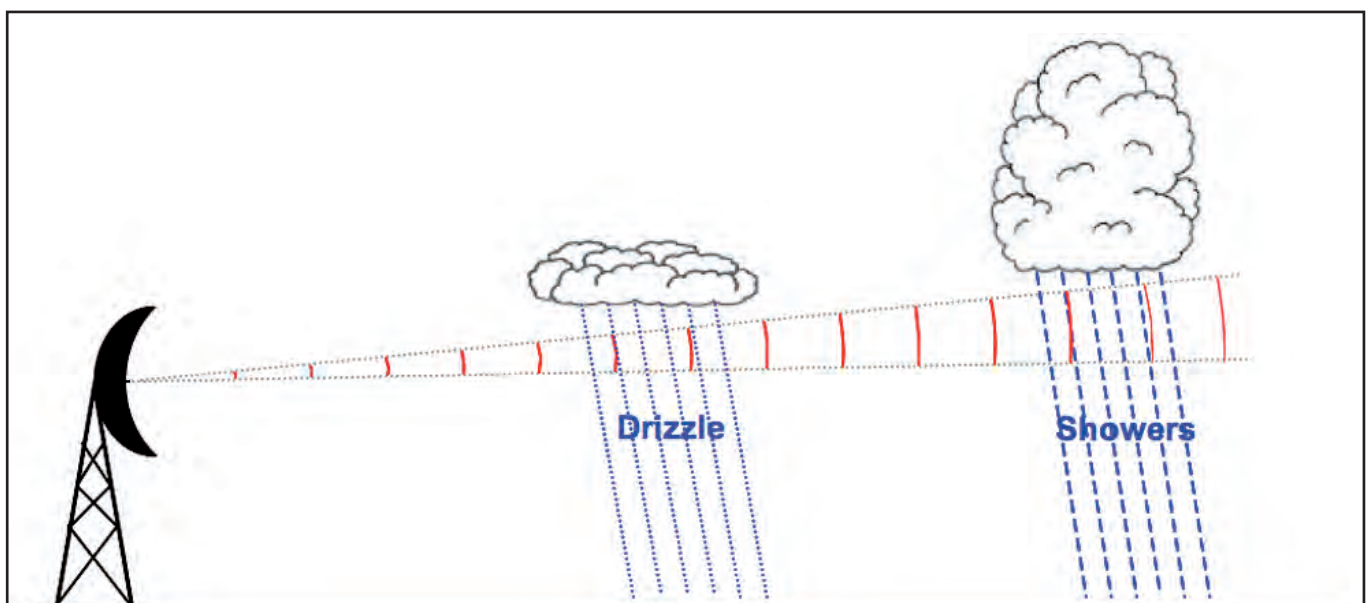
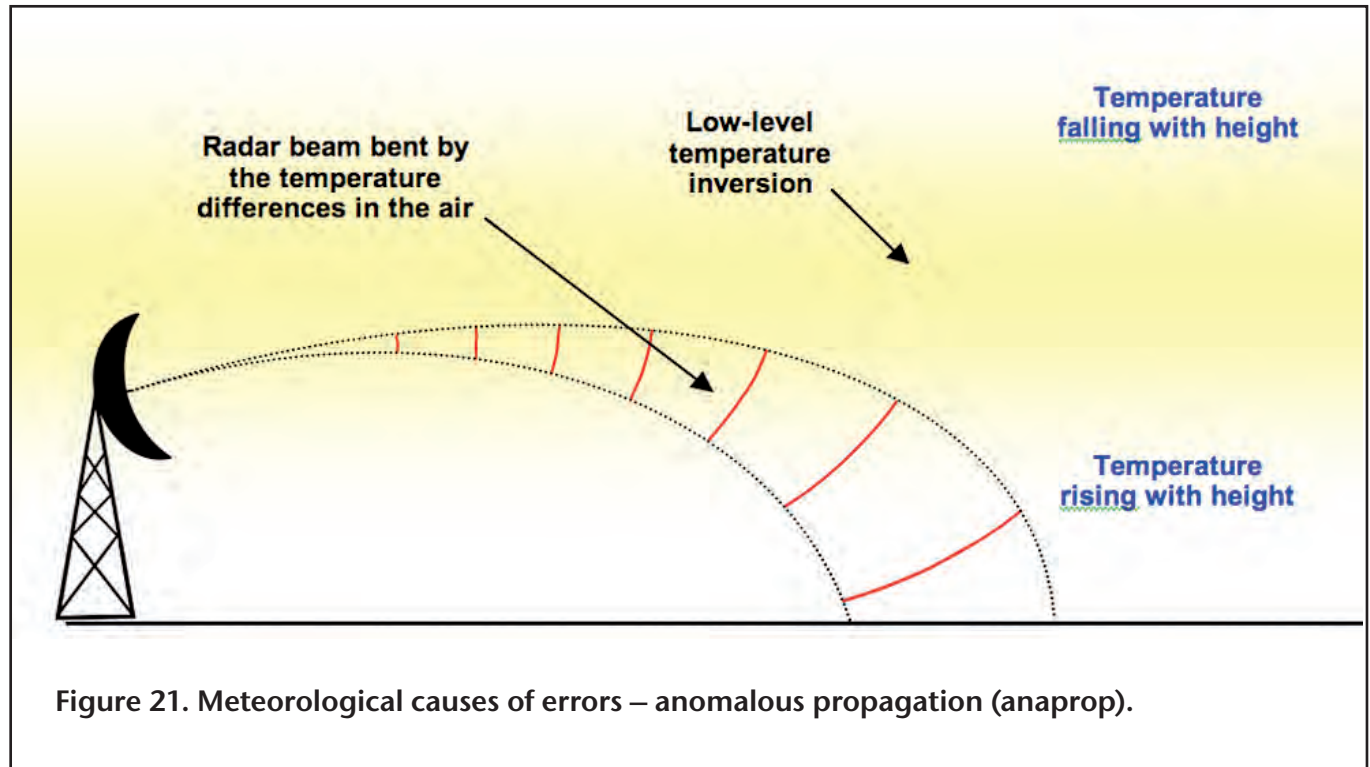


Figure 20. Meteorological causes of errors – drop size of precipitation.

However, averaging the rain over 5 km squares on the radar rainfall display reduces the peak intensities in convective cells.

- 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.



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 show rainfall actually at the surface
- Display also shows 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.

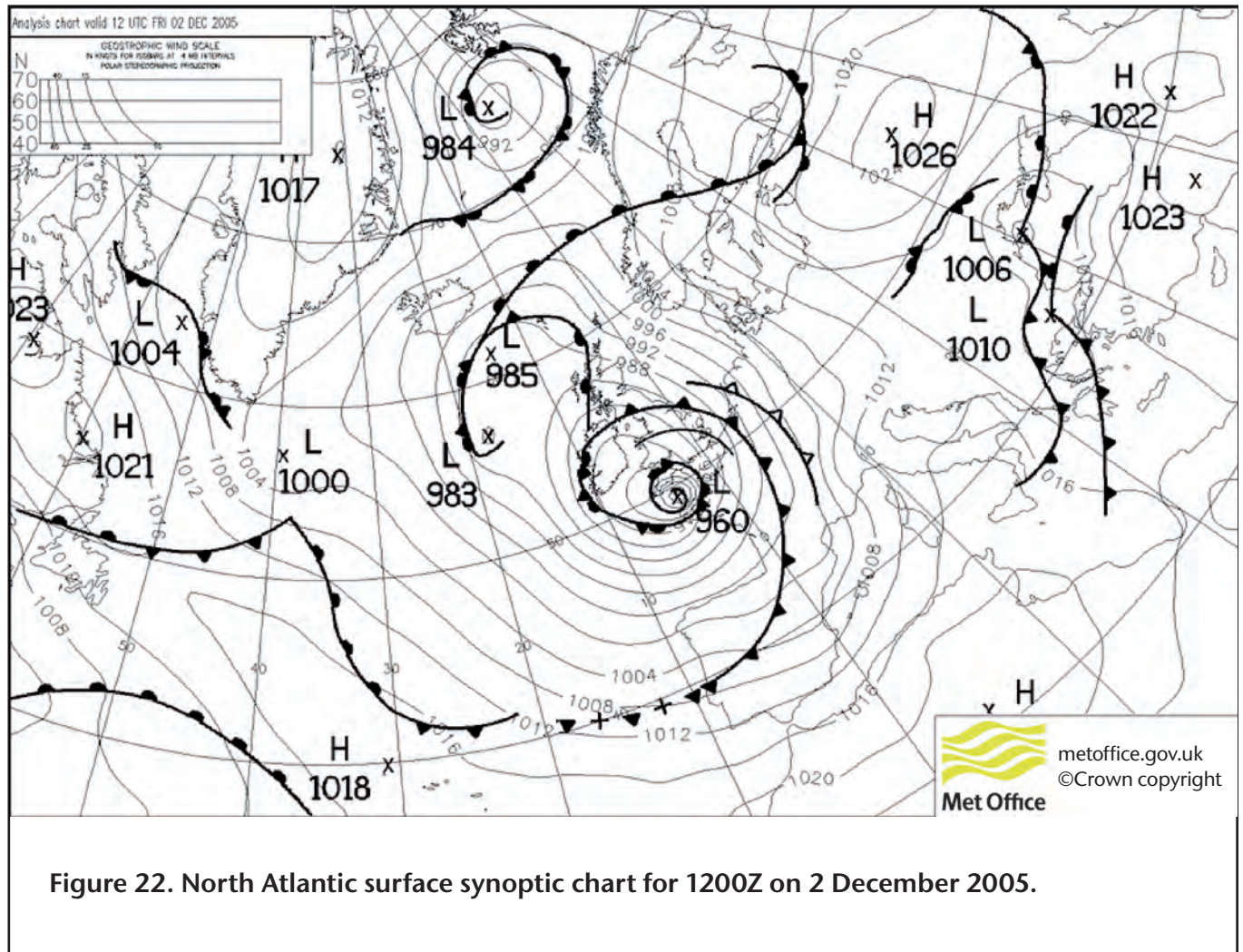


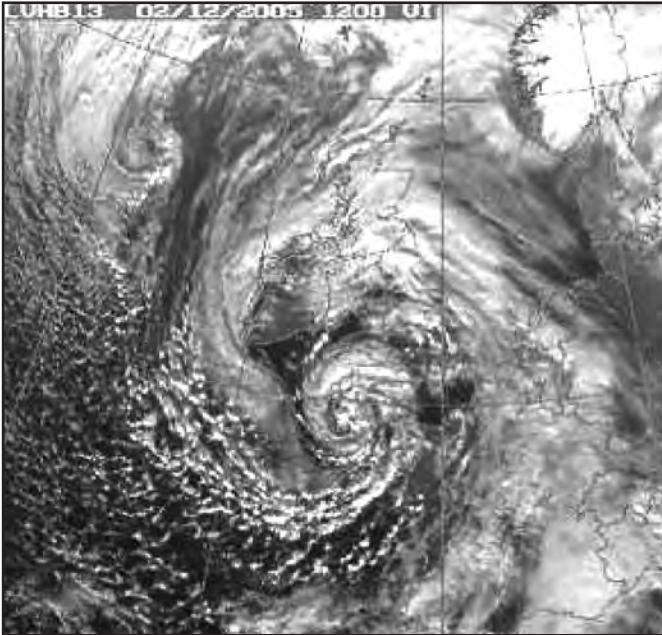
Figure 22. North Atlantic surface synoptic chart for 1200Z on 2 December 2005.

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.

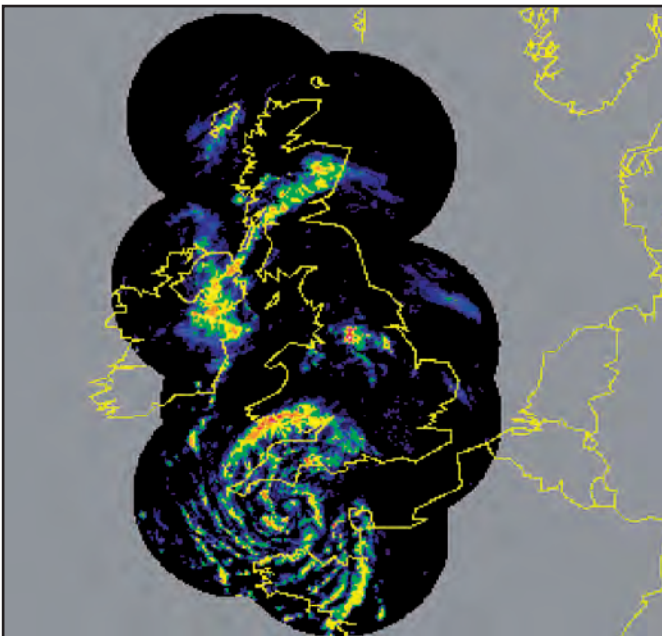
Areas of rain tended to fragment as they continued to move north or northwest across the UK during the morning. However, the rain became persistent across Northern Ireland and eastern Scotland during the afternoon. At the same time, heavy showery rain developed across southwest England and south Wales.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



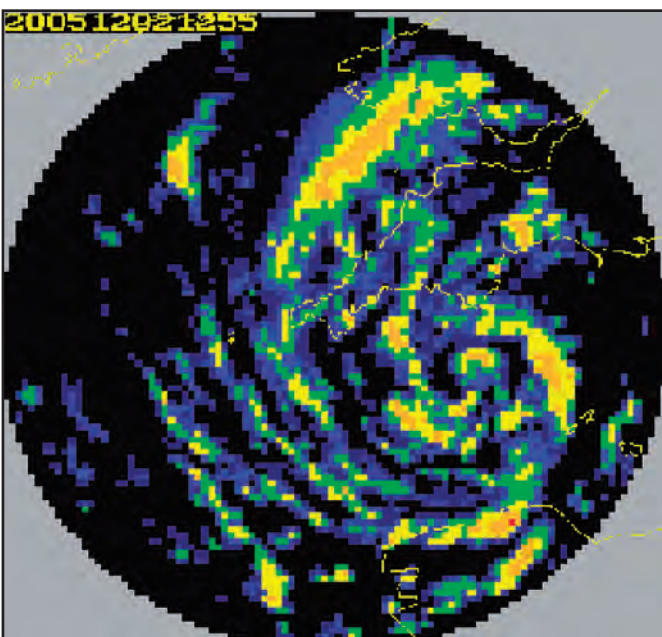
The midday satellite image shows a deep and well developed area of low pressure centred in the western English Channel between Brest and Plymouth. The image shows clearly the cloud structure swirling around the centre with bands of rain and also some quite heavy and blustery showers. The main frontal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

Figure 23. 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.

Figure 24. 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.

Figure 25. 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.

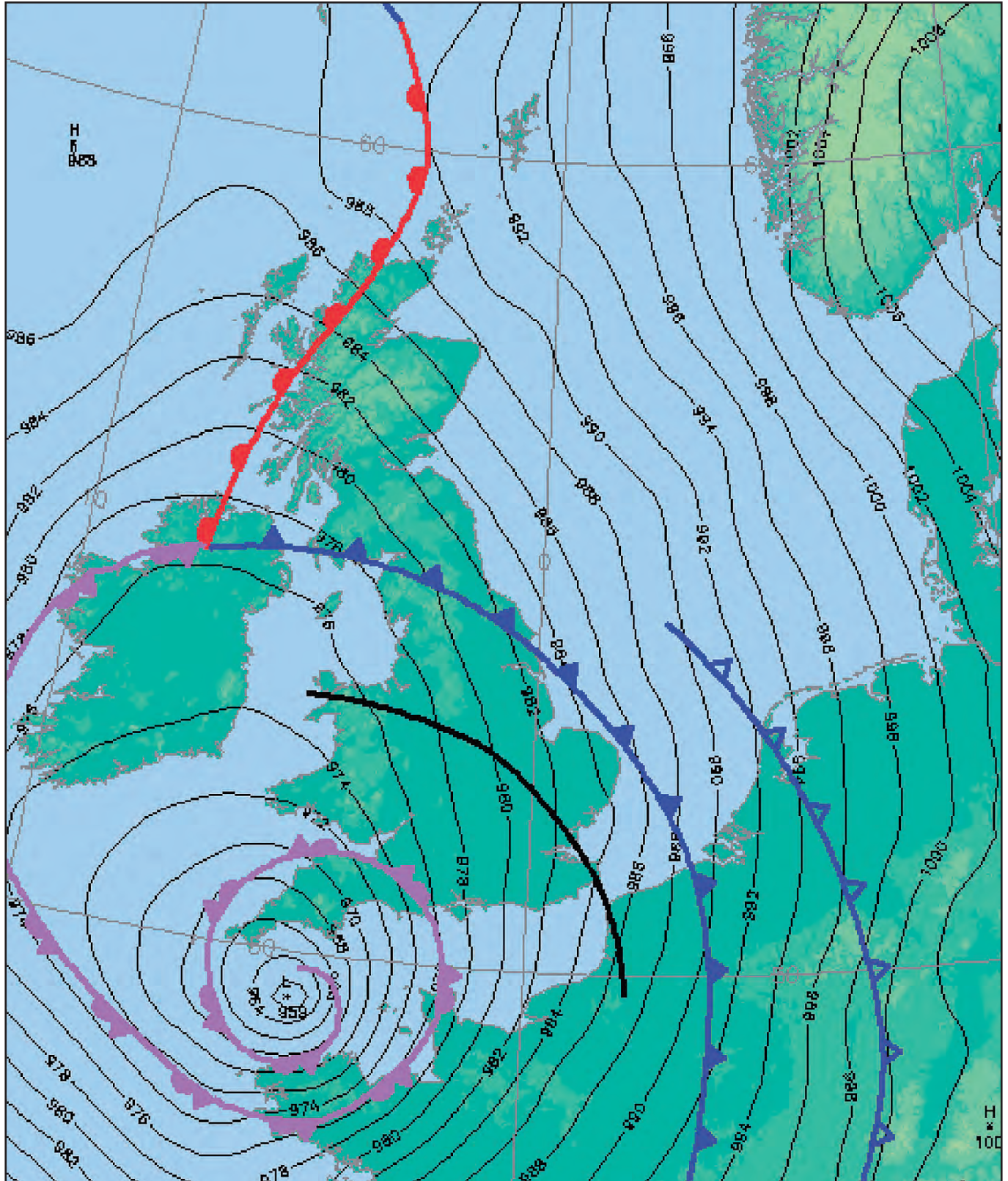


Figure 26. Met Office's Operations Centre analysis chart for 1200Z on 2 December 2005.

This fact sheet has been produced in conjunction with the Met Office's Observation Networks remote sensing section.

For more information about Remote Sensing, please contact the Met Office Customer Centre on:

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- Number 9 Weather Extremes
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