# Precipitation

*Summary*

This section is about rain, and colder versions of it. People don't need rain. Well, not directly. That said, every drop of water out of the tap or lifted from the well once fell as rain. Plants of all kinds need rain, pretty regularly in this part of the world. A landscape with little rain is a dry, dusty desert. Absence of expected rain brings drought, famine and disease in its wake. Rain refreshes the flora of the world, germinates seeds and cleans the atmosphere. We may not need rain at first hand for personal survival but the world would be a pale brown shadow of its present self without it. Rain is the font of life for land living creatures – just compare Earth with the rain-free, lifeless worlds of the Moon and Mars. As Billie Holiday memorably sang more poetically, '*Every time if rains, it rains pennies from heaven. Don't you know each cloud contains pennies from heaven.*'

Rain comes from clouds and even in dry parts of the world clouds are not uncommon. Why is rain a lot less common than clouds? Why don't clouds fall out of the sky with greater frequency than they do? In the first instance, cloud droplets are generally too small and light to fall as rain. Why then does it ever rain, or hail, or snow? How, in brief, do raindrops and snowflakes form? That is the subject of this section. The topics here are covered in Ahrens' textbook in chapter 7 of the 8th edition.

*Size*

We have met condensation nuclei already. Those involved in cloud droplet formation are typically about 0.2 μm in diameter. Around these nuclei water droplets or ice crystals grow. It is quite a slow process. To form a rain droplet of say 2 mm in diameter, we must form a drop that is 100 times the diameter of average cloud droplet. A veritable Sun compared with our Earth. [fig. 7.1 shows a scale drawing, just like the Earth and Sun!].

*Growing a cloud droplet*

Favourable nuclei for growth of cloud droplets are **hygroscopic** (i.e. water absorbing chemicals). Water starts to condense on them at significantly less than 100% humidity. So far so good. However, a growing droplet reduces the humidity of the surrounding air, slowing growth. This particularly happens as its surface area increases, namely as it gets larger. There is therefore a built-in slowing down process. In air rich in nuclei, there is a tendency to form a great many tiny droplets, which clearly isn't helpful in producing rain. Compared with the size of these newly created droplets, each one is a huge distance from its neighbour. Our earlier figure for the density of condensation nuclei was 1 per cubic mm. To a droplet that is as small as 1 μm, 1 mm is 1000 times its size. Translated into everyday sizes, that's a bit like having the next person to you 1 km away. The fall speed of drops 1 μm in diameter is so small that they might as well be in treacle. Drops that do form and then fall into warmer, less humid air shrink by evaporation and so the process of forming larger drops is not that quick. In short, cloud droplets represent the size that water droplets grow to after a while by continuous condensation but their rate of growing larger by this process is very slow. The clouds just happily drift past.

*A Matter of Scale*

A raindrop typically contains a million cloud drops. A means is needed of growing large drops at the expense of small ones. One fact helps. Very tiny drops have a slightly larger vapour pressure due to the curvature of their surfaces. When the humidity in the cloud is barely 100%, these tend to evaporate whereas the larger drops continue to grow. This process favours larger drops. Nonetheless, most clouds don't produce rain because the process of building large drops is so very slow. One simple fact is that as a drop grows, its surface area/volume ratio decreases. Since drops grow at their surface only, this automatically slows their fractional growth rates.

## *Growing a Raindrop*

As far as falling is concerned, "size matters". The crucial forces involved are the frictional drag while falling, which is an upward force, and the weight of the drop, which is downward. As we've seen, the ratio of these forces (drag/weight) increases as the drop decreases in size so, for smaller drops the weight becomes less and less effective in making a drop fall.

The main way raindrops are formed is by *collision and coalescence*. Larger drops fall faster than smaller drops, overtaking them and quite often coalescing. A raindrop therefore increases its size, once it is on its way down. Smaller drops are easily moved in local updrafts within each cloud. Collision therefore takes place in upward motion as well. Even a droplet as large as 100 μm has a terminal velocity of only around 0.3 $ms^{-1}$. i.e. it takes 1 min to fall less than 20 m. Smaller droplets are therefore moved up and down in the local cloud currents, colliding and often increasing in size.

Cloud droplets are well known to be charged and to move in the electrostatic field that always exists between Earth and upper atmosphere. Oppositely charged drop surfaces coming into contact will help secure coalescence, because opposite charges attract.

As I'm writing this note, it is raining outside, though not heavily. The two metre tall glass window in front of me is covered with individual raindrops clinging to the glass. Snaking their way down the window are half a dozen drops running from near the top to the bottom, each leaving an almost vertical wiggly track on the window. These running drops have sustained their downward path by collision and coalescence, the very process that created the rain. Once a drop near the top gets big enough for its weight to overcome the surface tension holding it static on the glass, then it starts to slide down. It soon meets a drop below it and the two coalesce, making an even larger drop that slips down more easily. So a sliding drop once started keeps going. Collision and coalescence of drops is made visible on a scale and in a timeframe that can easily be followed. If it keeps raining, the window will eventually be covered with water and few individual drops will be seen.

## *Rain*

Most important factor leading to rain is clearly a cloud's moisture content. For other factors, see page 195 (and the slide).

### *Drizzle, normal rain and heavy rain*

- small rain drops produce drizzle
- larger rain drops produce normal rain
- very large drops produce heavy rain

Heavy rain usually comes from cumulonimbus clouds that are tall and have a vigorous updraft associated with them, produced by unstable air. Raindrop growth is aided by updrafts and, of course, by thickness of cloud. Vigorous updrafts are driven by strong solar heating of the ground and so heavy rain showers are more common in the summer when the sunshine is hot and has had a chance to heat the ground when there is light cloud or no clouds earlier in the day. If the air mass coming across the country is already moist then heavy rain showers or even thunderstorms are more likely, for the atmosphere is pre-charged with moisture.

Rain from cumulonimbus clouds can be torrential. In fact it's unlikely to be light but it won't go on for hours. It's hard to predict where such rain will occur, for the clouds are localised and, as usual, clouds don't necessarily mean rain. However, for organisers of outdoor events such as Silverstone racing, Wimbledon tennis, the Open golf tournament, T in the Park and many more, the presence of torrential rain can make or break the enjoyment of tens of thousands so there is a lot of pressure on forecasters to improve their local forecasting of convective rain. It's not easy.

Prolonged rain comes from very thick stratus cloud, kilometres thick. The thickness supports extensive collision and coalescence. It also provides a huge store of droplets that allows the rain to continue for hours as fresh cloud slides across. Looked at another way, it usually stops raining not because the clouds above have emptied all their water on us but because they have moved on. Experience tells us that when there is almost no wind, rain can pour from a thick cloud for many hours.

The great floods in coastal Cumbria, West of the Lake District, in November 2009 were caused by a weather system bringing thick cloud laden with moisture and then coming to a halt over the region. As the system sat there, new moisture was fed into it from the sea to replenish the clouds. There was plenty of wind in this case from the active weather system but the system itself didn't move across the country as most low pressure systems do. The result was over 300 mm of rain in 24 hours in some places, the kind of figure that sets a record in the UK. 10 mm of rain would characterise a wet day in Aberdeen.

Thick extensive clouds are most often formed in cyclonic weather systems. A mass of moist air warmer than that in front of it is forced upwards as it as it meets side-on cooler air ahead. The net result is a 'warm front'. The details are taken up in a later part of the course.

*Ice Crystal Clouds*

Fig 7.6 (8th edition), *previous slide*, shows a tall Cb cloud. Below the 0°C level, all is water. Above that level, surprisingly enough most of the cloud is still water. Where the air temperature is -10°C, there is only one ice crystal for every million water droplets. These cold water droplets are **supercooled** - ready to freeze but not able to do so because a nucleus of an ice crystal needs to form first before the drop can crystallise. At 5500 m, about 500 mbar pressure, the temperature is -20°C and still water drops outnumber ice crystals. Such a cloud is called a **mixed cloud**.

The temperature at which water can't resist freezing depends on the size of the drop. The smaller the drop, the lower the temperature. The smallest drops freeze at -40°C.

*Picture of water and ice clouds*

In this picture, taken while sailing up the West Coast in the summer of 2007, the lower cumulus clouds over the Knoydart peninsular are water droplet clouds that have formed over land (as the sun has generated instability in the lower atmosphere by increasing the lapse rate). The large anvil in the background has risen high enough to have an icy top and the ice has spread downward to the bulk of the cloud giving it the distinctive fuzzy appearance characteristic of icy cirrus.

*Growing ice crystals*

Ice crystals form best by condensation on 'ice nuclei'. Ice nuclei are solids whose surface crystal structure provides a significant match in inter-atomic spacing and shape to the crystal structure of ice. This match helps incipient ice crystals to get started. Ice nuclei are not particularly common. This is one reason why water droplets far outnumber ice-crystals.

At lower temperatures, the slight difference in vapour pressure between (solid) ice and liquid water becomes important. Ice has the lower vapour pressure, as you might guess, and hence less vapour surrounds small crystals. Vapour that would not condense onto a drop does onto an existing ice crystal. Nearby drops evaporate, feeding the growth of ice crystals. By this process, ice crystals once started in good numbers will grow quickly from the large reservoir of water droplets. Expanding the size of a small ice crystal to a big one is much easier than growing a tiny water droplet into a raindrop.

*Snow*

Snow crystals are elaborate ice crystals known as dendrites. These form well at temperatures -12°C to -16°C (Table 7.3). Large snowflakes are an aggregation of smaller ice crystals stuck together. This process works well at even warmer temperatures, when snowflakes fall through moist air slightly above freezing. A thin film of water can form on the edge of the flake which acts as glue when flakes come into contact. Snowflakes that have formed by coalescing, are asymmetric. Snowflakes that have grown from a tiny seed may have the hexagonal symmetry of crystalline ice.

Elsewhere in these notes I quote passages describing the experiences of severe wind and of freezing rain. I'll include here a few descriptions of snowstorms. Large snowflakes falling on a calm day in uncountable numbers as silently as a scene on a Christmas card create the impression that snow is a bringer of contentment. On some occasions it may be but often it is not. Imagine the extra ingredients of intense cold and biting wind and it's easier to appreciate the description of Miss Constance Gordon-Cumming, an independently minded woman born in NE Scotland who travelled the world and made a name for herself in the 19th century as travel writer and artist. "*In a true blizzard the blast sweeps on with irresistible velocity, so densely charged with pulverised snow and ice, as fine as flour, that it obscures the air with what is described as white darkness, rendering large objects totally invisible at a distance of two or three yards, and accompanied by such a roaring that the human voice can scarcely make itself heard within a few feet. The luckless traveller who is caught in such a blast runs every risk of suffocating, the action of the lungs being stopped by the swiftness as well as the intense cold of the wind, while the ice-dust – which penetrates the thickest clothing – is more choking than the sand of the simoon. … Moreover, in the anguish of suffocation, the victims of the blizzard seem occasionally to become insane before dying, in some cases tearing off* *their clothes as if to gain relief"*. Driving rain can be most unpleasant but it won't kill you. Driving snow, with accompanying cold, can do.

Even a century ago our ancestors said that winters were not as severe as people had experienced in earlier centuries. The following extract from another 19th century author, anonymous in this case, bears them out.

*"There is something eminently beautiful in the gentle descent of snow, as the features of the rural landscape, field, wood, homestead, and ivy tower are silently mantled with the pure and delicate material. But the scene becomes highly imposing in a mountainous country, when the gale blows tempestuously, and the flakes are driven along in clouds of irregular density, now obscuring the nearest objects, shutting out heaven and earth from sight, and then revealing for a moment between the flying volumes, patches of sky aloft with surrounding outlines of the landscape. The storm is enjoyable by the side of the hearth-stone; but is perilous enough and often fatal to the loan wayfaring stranger whose track is obliterated and to shepherds and their flocks in distant wilds. In 1719, an army of seven thousands Swedes perished in a snowstorm upon the mountains of Rudel, in their march to Drontheim* [modern Trondheim in Norway].

*In the remote Scottish highlands tales of destructive snowfalls, exciting adventures and narrow escapes are part of the lore of the ingle-nook. The 'thirteen drifty days' refers to a specially severe interval in 1620 during which the snow fell on the frosted ground day and night with little intermission. The cold was intense to a degree never before remembered; the wind was keen and biting; and through the whole period the sheep never broke their fast. About the fifth and sixth days the younger part of the flocks began to fall into a torpid state, and soon perished. On the ninth and tenth days, the shepherds commenced forming huge semicircular walls of the dead, in order to shelter the living; but the protection was of little or no avail, as want of food aided the havoc of the elements. Impelled by hunger the sheep were seen tearing at one another's wool with their teeth. On the fourteenth day at the close of the dismal period, many a high lying farm had not a survivor from their once extensive flocks. Misshapen walls of dead, surrounding small prostrate groups, alone met the gaze of the owners. Out of more than twenty thousand sheep, in the extensive pastoral district of Eskdalemuir, only forty remained alive on one farm and five on another.*

*A similarly bitter season, but briefer, occurred at the beginning of the year 1793. The snow fell in the night of January 24 and 25; and the storm visited with special violence the south of Scotland, from Crawfordmuir to the border. Seventeen shepherds perished, and upwards of thirty were carried home insensible, but afterwards recovered. So completely were the flocks overwhelmed that no-one knew where they were till the thaw exposed them. Numbers were driven by the violence of the gale into the streams, where they were then buried or frozen up, and finally carried out to sea by the subsequent floods. At the beds of Esk, in the Solway Firth, a place where the tide throws out and leaves whatever is borne into the estuary by the rivers, there were found the bodies of one thousand eight hundred and forty sheep, nine black cattle, three horses, two men, one woman, forty-five dogs, and a hundred and eighty hares, besides a large number of inferior animals."*

That's enough insanity and death for the moment. Accounts of disruption and destruction resulting from snowfall are easy to find too. Distinguishing fact from story-telling can be difficult in oral history but extreme weather is always likely to make a vivid impression on those who experience it and the descriptions relating to Scotland above are generally plausible in both years and extent. It was not the snow alone that had such a devastating effect but the snow in combination with cold and wind. In the 1600s, Britain was in the grip of ‘the little ice age’. Frost fairs on the frozen Thames can be read about. The little ice age (seriously unpleasant in some years but not of true ice-age intensity) continued irregularly into the 19th century, with some winters near the end of the 1700s being particularly severe and some summers then being dismal too. You certainly don’t need to look far to find accounts of severe snow and cold in years other than the ones mentioned above. Even in mid-twentieth century there were winters in Aberdeen when the snowfall was measured in feet and cars were buried in the suburbs at the side of the road. I remember them but there are photographs to prove it - no reminiscences are necessary to establish the fact. By the end of the century when my sons were growing up near Aberdeen, their simple plastic sledges spent all but a very few days every year hanging in the garage, waiting for snow that seldom came.

### *Generating precipitation*

This slide (fig. 7.13 in the 8th edition) outlines how ice-crystals grow and produce precipitation in clouds with a low water content (typically nimbostratus) on the left and clouds with a higher water content (typically cumulonimbus) on the right.

Nimbostratus clouds (like all stratus clouds) have less convection in them than cumulonimbus but because their tops are high ice-crystals form readily there and can grow larger and faster than water droplets. The larger ice crystals fall and aggregate into snowflakes quite readily. If the lower reaches of the cloud are above freezing, the falling snowflakes will melt into rain; if the lower reaches are cold, then snow will fall.

The convection in cumulonimbus is more likely to form hailstones in the upper cold regions of the cloud. Hailstones aggregating with supercooled water in the convection will increase in size. When the hailstones are large enough to fall to the bottom of the cloud, they may precipitate as hail or rain, depending on the low-level temperatures

### *Sleet, freezing rain and hail*

Sleet and freezing rain are formed by precipitation falling through layers of air at different temperature.

*Sleet* hits us as rain with an icy component. It is formed by rain falling through a thick layer of freezing air near the ground.

*Freezing rain* is less common in this part of the world. Freezing rain is essentially super-cooled rain, drops cooled below freezing point put unable to freeze due to a lack of ice nuclei in them. Upon hitting the ground, or buildings, cars, etc. the contact surface provides the necessary ice-forming nucleus and freezing takes place in an instant. Freezing rain is unpleasant and dangerous.

*Hail* was mentioned with the previous slide. Tremendous updrafts and downdrafts sweep drops up and down inside the freezing cloud. What starts as a raindrop freezes and gets added to within the cloud, often in layers. Finally, its weight overcomes the strongest updraft and the hailstone plummets to the ground. Even though the air at ground level may not be freezing, there is little time for a large layered hailstone to thaw as it falls. You can get caught in a hailstorm when it is several degrees above freezing.

Knowing what's going on is one thing but following my theme of describing what the experience can be like I'll quote from an account by James Glaisher, one of the pioneering meteorologists of the 19th century whom I introduce in the supplementary piece on 'ballooning' on the web page. He wrote that during one hailstorm "a*n extraordinary darkness of the atmosphere with clouds hanging so low as to almost rest upon the house-tops, dazzling flashes of lightning, and one long continuous roar of thunder, were enough in themselves to be impressive; but to them were added a deluge of hailstones, which lasted more than twenty minutes. The scene was positively terrific, and the fright of many of the inhabitants of the town* [Cambridge] *was in no small degree increased by the crash of broken windows and the inundation of their houses. During the whole of this time it was impossible for the eye to penetrate many yards through the storm; the hail fell with such wonderful closeness, and there was such a peculiar mistiness rising from the earth, that a complete barrier was opposed to the power of vision. We are almost afraid to speak of the size of the hailstones, or rather blocks of ice, but we are certainly not exaggerating in the least degree when we say that many of them were as large as ordinary walnuts; some indeed far exceeded this size; one that was picked up measured three and a half inches* [~90 mm] *in circumference, and several have been described as being the size of a pullet's egg….. Glass was shivered; window-frames dashed in; fruit was cut up; birds were killed; crops were utterly destroyed. In a single half hour the standing corn was stripped, laid flat, and literally cut up into little pieces.* Glaisher's description is completely believable. A few years ago a relative sent me a picture of her car and garden that had been caught in a hailstorm in Texas. The car had been stripped of almost all its paint and was dented all over, the garden was awash with foliage stripped from trees and bushes. Fortunately, hail isn't often as bad as this but it's worth knowing how serious it can get.

*Effect of vertical temperature profile on precipitation*

This slide from the textbook, fig. 7.23 (8th ed'n), shows how the kind of precipitation is influenced by the temperature profile in the atmosphere.

This is a suitable place to continue my theme of 'the experience', with an account of a serious incident of freezing rain. It happened a long time ago in Philipsburg, Pennsylvania. The story is extracted from a description in my library published in 1836. It is not fiction. Let the eye-witness tell his tale. "*This morning a heavy rain set in after the thaw, and increased in violence throughout the day and night. …. Immediately on the descent of the rain it froze so as to envelope the trees and the earth with a thick coating of transparent ice, and to render walking no easy process.*" On the next day the account continues "*Such an accumulation of ice had now formed upon the branches of the forest trees as presented a beautiful and extraordinary spectacle. The small underwood or 'brush' was bowed to the earth, while the noblest timbers were everywhere to be seen bending beneath the enormous load of ice with which their branches were encrusted, and the icicles which thickly depended from every point. The heavy foliage of the hemlock and spruce was literally encased, or rather formed solid masses of ice, the smallest twig or blade of grass being surrounded by more than an inch of ice, and resembled the vegetable substances sometimes occurring in masses of crystal. Rain fell in torrents all day, and the chief part of the ensuing night, until there were about four inches of clear ice overspreading the surface of the ground.*

*The change which this phenomenon effected in the usual appearance of the woods was striking. The bushes and smaller trees, extending to those of fifty feet in height, were now* *bent to the ground, and pressed upon each other beneath their unwanted burden, resembling, in some respects, fields of corn beaten down by a tempest. Above, the tall trees drooped and swung heavily; their branches glittering, as if formed of solid crystal, and, on the slightest movement of the air, striking against each other, sending down an avalanche of ice. During the previous night, and on the succeeding morning, the limbs of the trees began to give way under the unusual load. Everywhere around was seen and heard the crashing of the topmost branches, which fell to the earth with a noise like the breaking of glass, yet so loud as to make the woods resound. As the day advanced, instead of branches, whole trees began to fall; and during the twenty-four hours, the scene which took place was as sublime as can well be conceived. There was no wind perceptible, yet, notwithstanding the calmness of the day, the whole forest seemed in motion; falling, wasting, or crumbling, as it were, piecemeal. Crash succeeded crash until, at length, these became so rapidly continuous, as to resemble the incessant discharges of artillery, gradually increasing, as from the irregular firing at intervals of the outposts, to the uninterrupted roar of a heavy cannonade. Pines of one hundred and fifty and one hundred and eighty feet in height, came thundering to the ground, carrying others before them; groves of hemlocks were bent to the earth like reeds; and the spreading oaks and towering sugar maples were uprooted like stubble, and often without giving a moment's warning. Under every tree was a rapidly accumulating mass of displaced limbs and branches; their weight increased more than tenfold by the ice, and crushing everything in their fall with sudden and terrible violence……..".*

Freezing rain isn't a once-in-a-century phenomenon. When there was a manned meteorological station at the top of Ben Nevis (whose remnant walls you can still see there) they reported it as a common occurrence between November and March. They called it the 'silver thaw'. One of their observers reported: "*Outside objects became covered with several inches of solid uncrystallized ice, through which their original outline could be but faintly distinguished. The chimneys of the Observatory became choked with ice, and, as the ladder leading to them was in these circumstances impassable, the whole being frozen into a solid mass, the observers had to endure the discomfort of back draught till a thaw came, when the ladder could be cleared without destroying the wood-work".* They had at the observatory (in the 1880s) one of the pioneering atmospheric dust particle counters of the Scottish meteorologist John Aitken and they deduced that the two conditions that tended to bring on the silver thaw were very small concentrations of dust particles in the atmosphere and a temperature inversion above them, with below freezing at ground level.

These descriptions are a reminder that nature has no sense of the appropriate or inappropriate. A little freezing rain is an inconvenience, a lot is an unmitigated disaster; moderate snowfall brings on the winter sports of skiing, sledging or simply building snowmen, excessive snow buries animals, cripples transport and isolates communities; modest rain waters the plants and keeps the burns and rivers flowing, excess rain brings flooding and disaster; a fresh breeze powers sailing boats through the waves or runs the generators of wind turbines, a howling gale sinks vessels, uproots trees, strips tiles or whole roofs from houses and topples stoutly rooted pylons; a sunny spell dries the washing, ripens crops and brightens the countryside, continuous sunshine parches the landscape, withers the crops and kills off livestock. When someone complains about the daily weather, tell them it could get seriously worse. The account of the freezing rain in Philipsburg is one example of how seriously worse just one aspect of the weather can become.

### *Measuring precipitation*

Precipitation is measured in **mm of water.** If the precipitation falls as snow, hail or ice of any kind, then what is recorded by meteorologists for the purposes of precipitation records is the depth of water formed by the melted ice. Gauges that measure precipitation therefore only have to measure liquid water.

A simple raingauge is a funnel of standard design that feeds into a measuring cylinder, or perhaps simply a reservoir that can be poured out into a measuring cylinder later. Rainguages can 'get it wrong' due to effects such as splashing up from the ground below, splashing up from within the gauge funnel, swirling wind. All these factors can't be eliminated at every site and hence there are rules governing the siting of gauges designed to make sure that like is being compared with like, not only from one place to another but over a timespan of decades. The design of meteorological instruments therefore isn't something that changes much. You have to be able to compare the readings taken this year with those taken 50 years ago to get sensible measures of climate change. Even the size and shape of the funnel in raingauges is more or less fixed to a standard pattern, though you might have thought that any old funnel would do so long as its size was measured.

The simple raingauge has the disadvantage in today's world that it must be read by a person on-the-spot. This is considered a waste of human resource in these times of automation. Someone has to be available to do it, 365 days a year. The record is only available when the person is available, not necessarily when the rain falls. If there is a long delay in taking a reading after the rain, then some of the stored rain may evaporate, reducing the reading that should have been made.

An electronically recording raingauge makes the record when the rain falls, and provides a time, too. Two common types are based upon the traditional funnel but have an electronic means of measuring the amount of water collected. The first passes the water through a narrow bore pipe and counts the drops emerging. The second, the more widely used, collects the water in one side of a small double bucket that sits on a central rocker. This is the kind we have on the Fraser Noble building. When one side of the little bucket fills up, it tips over and activates an electrical switch that closes a circuit. Distant electronics records the closing of the circuit and is able to count the number of bucket tilts in a fixed amount of time. The action of tilting empties the bucket but brings up the other side to be filled. You can see the detail on the slide. Our tilting bucket measures in units of 0.2 mm of rainfall. You can work out that there are still some reasons why such a device will 'get-it-wrong' sometimes, but the errors are considered acceptably small.

These automatic systems still need manual intervention to keep them clean. Leaves get into the funnel, accumulated dust and grit can almost block the funnel if it is not cleaned out. The rocker mechanism can wear or get off balance, wiring and electrical contacts can corrode. Vandals can pour beer into it or kick it over. It is for this reason that we don't put our rainguage at ground level on an open site, which is the recommended place. All automatic systems need calibrating to make sure that when a known amount of water is poured into the funnel, the electronic reading gives the correct answer.

*Rain radar*

Rain radar is a neat development that capitalises on an effect that interferes with the use of radar to locate planes. Rain reflects radar pulses. Rain radars are specially developed for the job. The wavelength chosen is in the cm range of the electromagnetic spectrum, a lot shorter than that used for broadcast transmissions in the FM or AM wavebands of either radio or TV signals. Quite a powerful transmitter sends out a coded signal of short pulses from a directional aerial and listens for the return echo. The directional response of the aerial means that operators know which direction the echo comes from. The timing of the echo tells them how far away the rain is. The strength of the echo is related to how much rain is falling.

Radar pulses travel at close to the speed of light, $3.0\times10^8$ $ms^{-1}$. Hence to travel 50 km to the rain and 50 km back again takes $10^5/3.0\times10^8$ seconds, namely ~0.33 ms. This is a long time electronically, and hence easily measured, but a short time mechanically. In this time a rotating aerial hasn't moved much so the aerial is still pointing in the right direction to receive the return pulse.

The Met Office used to be very reluctant to make their radar pictures available to the public over the web, having invested many millions of pounds establishing a network of rain radars that covers most of the country. I argued then that it is public money they had spent and therefore the public were entitled to see some direct return for it. With satellite imagery now freely available world-wide, the rain over the UK was hardly a state secret, or even a commercial secret. In 2001 they relented a bit and made low resolution rain radar pictures available through the BBC weather web site. Since then, low resolution pictures have been made available directly by the Met Office and their URL is highlighted on our 'Links' web page. By clicking on the UK map, more detailed pictures can be seen now for each region.

**End of Precipitation**

*JSR*