National Meteorological Library and Archive

Met Office

Fact sheet No. 3 – Water in the atmosphere

Introduction

Water is the only common and pure substance that appears naturally on Earth in all the three physical states of solid, liquid and gas at the same time. In typical usage, water refers only to its liquid form or state, but water can also appear in its solid state in the form of ice and its gaseous state as water vapour. Approximately 71% of the Earth's surface is covered by water and nearly all (about 96%) of the Earth's water is contained in the oceans. A tiny amount is locked away as ice sheets and glaciers. This leaves a very small amount (between 0 and 4%) as water vapour in the atmosphere. The meteorological importance of water vapour derives from the part it plays in forming clouds and precipitation elements. However, water in the atmosphere can appear in many other forms.

Dew

Dew is the condensation of water vapour on a surface whose temperature is at or below the dew-point of the air it is in contact with. Dew appears as innumerable small water droplets less than a millimetre in diameter. The most common natural surface upon which dew forms is vegetation, and in particular, grass.

'Dew point' is defined as the temperature at which the air, when cooled, will become saturated. Let us take as an example a day in which the air temperature reaches 18 °C with a dew point of 8 °C. Late in the afternoon, the air temperature begins to fall, but the dew point will still be around 8 °C. However, the air temperature is measured at 1 metre above the ground and, under a clear sky, the temperature of some objects may be significantly lower, due to loss of heat by radiation. Once the temperature of the object has fallen below the dew point, water vapour begins to condense on to it in the form of dew.

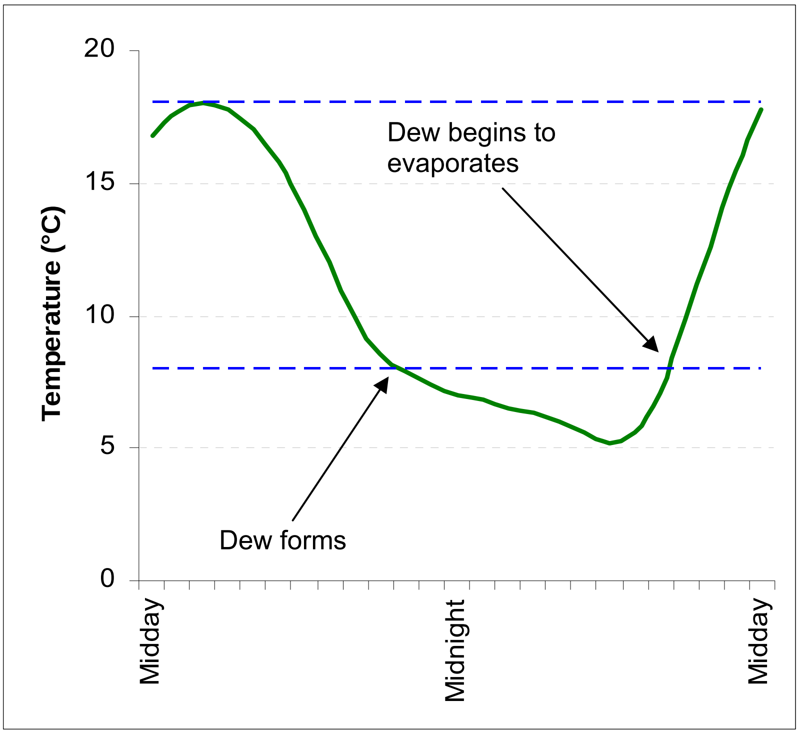

Figure 1. Graph showing the air temperature profile and the formation of dew.

Figure 2. Dew formation on grass.

Dew forms readily on grass because (a) the temperature falls more rapidly nearer to the grass and (b) the grass leaves produce water vapour, which raises the dew point of the air immediately in contact. Dew does not form as readily on other surfaces, such as soil, brick or stone. This is because these materials absorb heat from the sun which is then slowly emitted during the evening, causing the temperature of air immediately in contact to stay above the dew point for much longer than over grass.

Next morning, as the incoming solar radiation strengthens, the dew evaporates. Metal surfaces, such as car bodies, will dry relatively quickly whereas grass stays damp for considerably longer. In fact, from late autumn to early spring, in some places shaded from the sun, grass may remain damp all day after heavy dew.

The key meteorological factors suitable for the formation of dew are:

1. Night time (to eliminate incoming solar radiation).
2. Clear skies (to allow for maximum energy loss due to long wave radiation).
3. Calm winds (to prevent mixing with warmer air aloft).
4. A moisture source (best with high dew-point, or after daytime rain, to promote condensation).

These conditions are often satisfied under a high pressure area, particularly a high pressure formed in warm tropical maritime air such as an extension of the Azores sub-tropical pressure towards the United Kingdom.

Dew should not be confused with deposits from wet fogs or guttation (the exuding of liquid water from the tips of plants, usually under conditions of a warm, moist soil).

Hoar frost

Hoar frost is composed of tiny ice crystals and is formed by the same process as dew, but when the temperature of the surface falls below freezing point.

The 'feathery' variety forms when the surface temperature reaches freezing point before dew begins to form on it. A 'white' frost, composed of more globular ice, occurs when the dew forms first, then subsequently freezes.

A ground frost may occur when the air temperature does not get down to freezing point. Consequently, when the grass is covered in a white hoar frost at dawn it cannot be assumed that there is or has necessarily been an air frost.

The presence of fog tends to prevent the formation of hoar-frost as it checks the radiational cooling of surfaces.

Figure 3. The ‘feathery’ variety of hoar frost.

Figure 4. Hoar frost in the form of frozen dew.

Figure 5. Hoar frost on trees and shrubs.

Most frosts and dews are caused by radiative cooling of the ground followed by conduction between the ground and air which cools the air. However, it is possible to form dew and hoarfrost by advection of moist air over an already cold ground, such as might occur at the end of a particular cold spell of continental easterly weather in winter.

Frost must not be confused with glaze or rime. Glaze can only form when supercooled rain or drizzle comes into contact with the ground, or non-supercooled liquid may produce glaze if the ground is well below 0 °C. Glaze is a clear ice deposit that can be mistaken for a wet surface and is therefore highly dangerous to the unwary. Rime is a rough white ice deposit which forms on vertical surfaces exposed to the wind. It is formed by supercooled water droplets of fog freezing on contact with a surface it may drift past.

Figure 6. Glaze.

Figure 7. Rime.

Precipitation

By definition, precipitation is any liquid or solid weather phenomenon (rain, drizzle, snow, hail, etc.) falling from a cloud and reaching the Earth's surface.

Rain

Water drops larger than 0.5 mm in diameter are classed as rain, whereas smaller drops are described as drizzle. The difference is purely one of drop size rather than intensity of precipitation. Usually, drizzle comes from sheets of low, shallow cloud, whereas rain is more likely from deeper clouds. Drizzle, with its many small drops, will cut down the visibility more than the equivalent amount of water falling as rain. Also heavy drizzle is more wetting than slight rain.

When air rises, it cools and its water vapour condenses into tiny droplets of water to form a cloud. Condensation usually occurs around small particles called cloud condensation nuclei. The motion of air within the cloud causes the water drops to collide and larger drops tend to grow at the expense of the smaller ones (a process called coalescence).

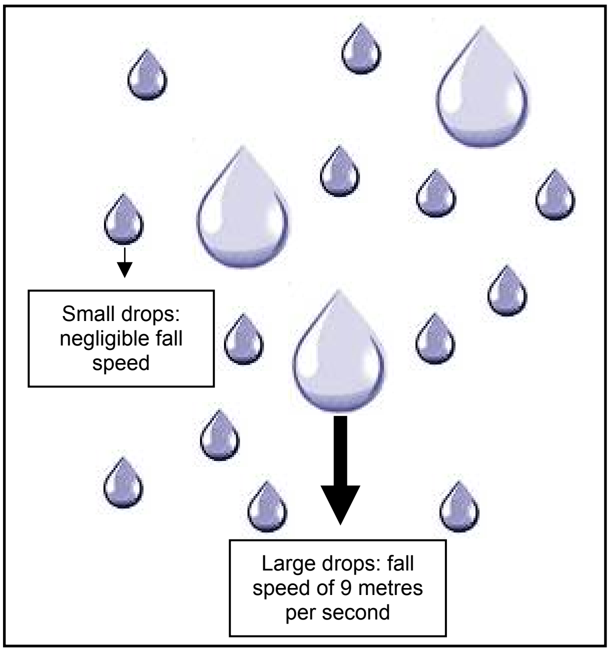

Figure 8. The process on coalescence.

If water droplets continue being developed within the cloud, such as in moist air rising over a hill, they eventually start falling out as drizzle. In deeper clouds, where updraughts are more vigorous, water droplets become larger before entering a region of the cloud where there is a compensating downdraught and fall as rain.

This explains precipitation from cloud that is composed entirely of water, but another process is at work when a cloud contains ice crystals. In 1933 Tor Bergeron demonstrated that these ice crystals are important in the formation of raindrops.

The water inside a cloud does not start to freeze at 0 °C, but at a much lower temperature. In the meantime, it exists as supercooled water. When the temperature falls to -40 °C, all water turns to ice, but between about -10 °C and -40 °C, the cloud consists of a mixture of supercooled water and ice crystals. Bergeron demonstrated that water vapour condenses more readily (a process known as sublimation) on to ice crystals than on to supercooled water.

Aggregation of the ice crystals occurs as they move into areas of cloud where the temperature is above -25 °C. Accretion also occurs as water droplets crystallize on coming into contact with the ice crystals. These snowflakes eventually begin to fall, being precipitated out as rain when the air temperature is above about 3 °C.

For synoptic purposes, rain (other than in showers) is classified as ‘slight’, ‘moderate’, or ‘heavy’, for rates of accumulation less the 0.5 mm h^{-1}, 0.5 to 4 mm h^{-1}, and greater than 4 mm h^{-1}, respectively.

Figure 9. Heavy rain.

In weather reports, liquid precipitation from a convective cloud (cumulus or cumulonimbus) is designated as a shower and is distinguished in such reports from the precipitation, intermittent or continuous, from layer clouds. Showers are often characterized by short duration and rapid fluctuations of intensity.

For synoptic purposes, rain showers are classified as ‘slight’, ‘moderate’, ‘heavy’, or ‘violent’ for rates of accumulation of about 0 to 2 mm h^{-1}, 2 to 10 mm $h^{-1,}$ 10 to 50 mm h^{-1}, or greater than 50 mm h^{-1}, respectively.

Figure 10. Heavy rain shower.

Drizzle

Drizzle is liquid precipitation in the form of water drops of very small size (by convention, with diameters between about 200 and 500 μm).

Drizzle forms by the collision (coalescence) of water droplets of stratus cloud. Larger droplets have faster fall speeds than smaller droplets and it is this difference in fall speeds that allows collisions to take place. If all the droplets within the cloud were the same size they would all be falling at the same speed and so collisions would be rare. The turbulent motions of air within clouds also leads to collisions between different sized drops as small drops are carried upwards within rising air currents more quickly than large droplets. High relative humidity values below the cloud are also required to prevent the drops from evaporating before they reach the earth’s surface.

For synoptic purposes, drizzle is classified as ‘slight’, ‘moderate’, or ‘heavy’: slight drizzle corresponds to negligible runoff from roofs, heavy drizzle to a rate of accumulations greater than 1 mm h^{-1}.

Snow

Snow is defined as solid precipitation which occurs in a variety of minute ice crystals at temperatures well below 0 °C but as larger snowflakes at temperatures near 0 °C. Snowflakes are the formed by the process of aggregation, i.e. the collision of ice crystals. This usually accounts for the larger snowflakes that are seen to fall.

Precipitation falls as snow when the air temperature is below 2 °C. One would expect the falling snow to melt as soon as the temperature rises above freezing, but this is not so. As the melting process begins, the air around the snowflake is cooled. At temperatures above 2 °C the snowflake will melt to become 'sleet' or rain. In this country, the heaviest falls of snow tend to occur when the air temperature is between zero and 2 °C. Individual ice crystals and snowflakes can be the shape of prisms, plates or stars - but all have six sides.

- Thirty centimetres of fresh fallen snow has about the same water equivalent as 25 mm of rainfall.
- If rain falls continuously through air with a temperature as high as 6 °C, it may cause the air temperature to fall low enough for the rain to turn to snow. This is due to latent heat being absorbed by the evaporation of water vapour from the raindrops as they fall, leading to the reduction in temperature.

Figure 11. Fields of snow in early February.

For synoptic purposes, snow (or a snow shower) is classed as ‘slight’, ‘moderate’, or ‘heavy’ for a rate of accumulation of snow (in the absence of drifting or melting) less than 0.5 cmh^{-1}, 0.5-4 cm h^{-1}, and greater than 4 cmh^{-1}, respectively.

Hail

There are three different phenomena which affect the British Isles that could loosely be described as hail.

These are:

- Snow pellets
- Ice pellets
- Hailstones

Snow pellets

Snow pellets are beautifully white but are easily crushable between the fingers. They are occasionally called 'soft hail'.

Figure 12. Snow pellets.

Ice pellets

Ice pellets are quite moderate in size and are composed of clear ice, sometimes conical in shape.

Hailstones

Hailstones are whitish in appearance and vary greatly in size. If a hailstone is cut open, a layered structure like an onion is sometimes apparent. A large hailstone may consist of several layers of clear and opaque ice.

Figure 13. Hail.

Figure 14. Cross section through hailstones.

Large hailstones fall from deep cumulonimbus clouds. The cloud base may be 3,000 feet (900 m) above the ground with tops as high as 60,000 feet (18,000 m). Much of the cloud will be composed of supercooled water droplets. As the hailstone falls it will collect water droplets which instantly freeze and form a layer of ice. It may then be caught in a vigorous updraught and, as it is carried back higher into the cloud, it collects more water droplets or ice particles to form another layer of ice. Thus layers build up on the hailstone (made of alternate layers of clear and opaque ice) and the cycle may be repeated until the stone is so big that it falls to earth.

Hail showers are quite common over the British Isles in westerly and northerly airstreams during the spring, but really large hailstones originate in hot, continental air and are very much a feature of summer months.

The largest hailstone recorded in the British Isles weighed 141 grams (5 oz) and occurred at Horsham, West Sussex on 5 September 1958. Certainly anything approaching golf-ball size is remarkable, but hailstones can grow large enough to dent cars, shatter greenhouses, injure, and perhaps even kill people.

Figure 15. 3.5 inch hailstone which fell on Cardiff, South Wales, during a thunderstorm on 1 July 1968.

The USA, Canada, central Europe, the southern parts of the CIS, India and China all experience large hail. So too do land areas in the southern hemisphere. The heaviest hailstone (as quoted in the Guinness Book of Records) occurred in a hailstorm in the Gopalanj district of Bangladesh on 14 April 1986. The hailstones weighed up to 1 kg (2 lb 3 oz) and were reported to have killed 92 people.

Fog

The official definition of fog is a visibility of less than 1,000 m. This limit is appropriate for aviation purposes, but for the general public and motorists an upper limit of 200 m is more realistic. Severe disruption to transport occurs when the visibility falls below 50 m. Useful labels for these three categories are aviation fog, thick fog and dense fog. The reduction in visibility is due to tiny water droplets suspended in the air. The thickest fogs tend to occur in industrial areas where there are many pollution particles on which water droplets can grow.

Freezing fog is composed of supercooled water droplets (i.e. ones which remain liquid even though the temperature is below freezing-point). One of the characteristics of freezing fog is that rime - composed of feathery ice crystals - is deposited on the windward side of vertical surfaces such as lamp-posts, fence posts, overhead wires, pylons and transmitting masts.

Fogs which are composed entirely or mainly of water droplets are generally classified according to the physical process which produces saturation or near-saturation of the air. The classifications are:

- Radiation fog
- Advection fog
- Upslope fog
- Evaporation fog

Radiation fog

Away from coasts, the most common type of fog is 'radiation fog'. It forms overnight when the ground loses heat by radiation, and cools. The ground, in turn, cools the nearby air to saturation point, thus forming fog. Often the fog remains patchy and is confined to low ground, but sometimes it becomes more dense and widespread through the night. Ideal conditions for the formation of this type of fog are light winds, clear skies and long nights. Consequently, the months of November, December and January are most prone to foggy conditions, particularly inland areas of England and the lowlands of Scotland in high pressure conditions.

Figure 16. Radiation fog.

Advection fog

Advection fog is formed by the passage of relatively warm, moist and stable air over a cool surface. It is associated mainly with cool sea areas, particularly in spring and summer, and may affect adjacent coasts. It may occur also over land in winter, particularly when the surface is frozen or snow-covered. The term is also used to describe pre-existing fog transferred from a distant source which may not necessarily be cooler, e.g. the inland spread of sea fog due to a developing sea-breeze circulation.

Figure 17. Advection fog over Dover harbour.

Upslope fog

Upslope fog is formed on the windward slopes of high ground by the forced uplift of stable, moist air until saturation is reached.

Figure 18. Upslope fog over St Oswald's Bay, Dorset.

Evaporation fog

Evaporation fog is formed by evaporation of relatively warm water into cool air. Examples are:

- ► Arctic Sea Smoke – when cold air moves over warm water. This phenomenon occurs, for example, over inlets of the sea in high latitudes; over newly formed openings in pack ice; over lakes and streams on calm, clear nights; and over damp ground heated by bright sunshine in cool conditions. Alternative names are ‘frost smoke’, ‘sea smoke’, ‘warm-water fog’, ‘water smoke’, ‘steam fog’ and ‘the barber’.
- ► Frontal Fog – fog which forms at and near a front. Such fog forms when raindrops falling from relatively warm air above a frontal surface, evaporate into cooler air close to the Earth’s surface and cause it to become saturated.

Figure 19. Arctic sea smoke.

Figure 20. Steam fog.

Mist

Mist is a state of atmospheric obscurity produced by suspended microscopic water droplets or wet hygroscopic particles. The term is used for synoptic purposes when there is such obscurity and the associated visibility is equal to or exceeds 1 km; the corresponding relative humidity is greater than about 95 per cent.

Figure 21. Mist over the Grand Union Canal, Braunston, Northamptonshire.

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

Tel: 0870 900 0100
Fax: 0870 900 5050
Email: enquiries@metoffice.gov.uk

If you are outside the UK:

Tel: +44 (0)1392 885680
Fax: +44 (0)1392 885681

All of the images used in this fact sheet along with many others covering all aspects of meteorology can be obtained from the National Meteorological Library.

For more information about what images are available, please contact the Library Information Officer at:

Tel: 01392 884845
Email: metlib@metoffice.gov.uk

Other titles in this series still available are:

- Number 1 Clouds
- Number 2 Thunderstorms
- Number 4 Climate of the British Isles
- Number 5 White Christmases
- Number 6 Beaufort Scale
- Number 7 Climate of Southwest England
- Number 8 The Shipping Forecast
- Number 9 Weather Extremes
- Number 10 Air Masses and Weather Fronts
- Number 11 Interpreting Weather Charts
- Number 12 National Meteorological Archive
- Number 13 Upper Air Observations and the Tephigram
- Number 14 Microclimates
- Number 15 Weather Radar
- Number 16 World Climates
- Number 17 Weather observations

Our unique collection of weather images is now available via the National Meteorological Library and Archive's online catalogue.

The collection illustrates all aspects of meteorology, from clouds and weather phenomena, to instruments and the work of the Met Office. Our online catalogue can be found at:
http://library.metoffice.gov.uk/

All of the fact sheets in this series are available to download from our website

The full list can be found at:
http://www.metoffice.gov.uk/learning/library/factsheets

Met Office
FitzRoy Road Exeter
Devon EX1 3PB
United Kingdom

Tel: 0870 0900 0100
Fax: 0870 0900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk