

THE IN A HURRY SERIES

Weather *in a Hurry*

Fronts, storms, and reading the sky

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The Whole Thing in One Page

Weather usually arrives as a row of icons: sun, cloud, rain, lightning. The icons describe outcomes and hide the subject. Weather is motion in a thin, rotating, water-bearing atmosphere that is continually pushed out of balance because the Sun warms Earth unevenly.

Land heats and cools faster than sea. The tropics gain more solar energy than the poles. Day turns to night, slopes face different directions, clouds interrupt sunlight and wet ground spends energy on evaporation. These contrasts alter temperature, density and pressure. Pressure gradients begin air moving. Earth's rotation bends that motion. Friction, coastlines, mountains and cities reshape it near the surface. Wind is an imbalance becoming flow.

Water makes the flow more energetic. Evaporation transfers energy into invisible water vapour. Rising air expands and cools. When vapour condenses into droplets or ice, latent heat is released and can strengthen ascent. Relative humidity describes closeness to saturation; dew point is often the clearer guide to how much moisture is present. Cloud is visible phase change, not visible vapour.

The atmosphere also has a vertical disposition called stability. Lift air and compare it with its surroundings. If it becomes colder and denser, it tends to return. If it remains warmer and buoyant, it can keep rising. Stable air favours layers, fog and trapped pollution. Unstable air favours towers. Moisture, lift and wind shear decide whether a tower fades, becomes a brief thunderstorm or organises into something longer-lived.

Fronts are sloping transition zones between air with different histories. In the mid-latitudes, they often wrap around travelling lows. A warm front may announce itself through high ice cloud thickening and lowering before broad rain. A cold front is commonly narrower, with a sharper wind, temperature or humidity change. This is one important weather script, not the universal one. Tropical convergence, monsoon flows, sea breezes, mountains and warm-water streamers can organise rain without a textbook front.

Storm is a family name. Mid-latitude cyclones feed chiefly on horizontal temperature contrasts. Thunderstorms feed on buoyant moist air, with shear controlling their organisation. Tropical cyclones are warm-core vortices sustained over favourable tropical ocean and disrupted by land, dry air or strong shear. Similar cloud spirals can conceal different engines.

Reading the sky therefore means reading coordinated change. Pressure trend, wind shift, falling cloud base, growing towers, fading visibility and a shrinking temperature-dew-point gap reveal structure. One sign rarely settles the matter, and observation from the ground does not replace radar, satellite data or official warnings.

Forecasting begins by combining many incomplete observations into the best estimate of the present atmosphere. Physics-based and data-driven models calculate possible futures. Ensembles reveal how rapidly those futures separate. Forecasts work because atmospheric motion is lawful. Exact detail fails because the starting state and the models are imperfect, while nonlinear flow can amplify small errors.

Unequal heating creates motion; motion redistributes heat and moisture; that redistribution creates new contrasts, clouds and storms. The atmosphere never finishes balancing itself. Forecasting succeeds by following the process and remains limited by the process it follows. That is the book.

Why You Should Care

On the night of 25 October 1859, a severe storm crossed the Irish Sea. It destroyed 133 ships and killed about 800 people. The best-known loss was the steam clipper *Royal Charter*, driven onto the Anglesey coast with more than 450 deaths. Robert FitzRoy, head of the young Meteorological Office, argued that observations arriving by telegraph could have tracked the storm. On 5 February 1861 his office issued its first storm warning, using cones and drums raised along the coast.

That sequence contains the reason weather matters. The storm was not

prevented. The atmosphere did not become gentler. Information moved faster than the hazard, and that changed what people could do before it arrived.

The modern version surrounds you so completely that it has become easy to undervalue. Aviation routes around jet streams and thunderstorms. Ports, farms, electricity networks, construction sites and outdoor events make decisions from forecasts. A small temperature error at the wrong height can change whether rain freezes on contact. A small shift in a convergence line can move a cloudburst from one catchment to another. A front arriving three hours earlier can turn a safe crossing, harvest or mountain day into a dangerous one. Forecasting publishes fresh, falsifiable claims about the near future several times every day.

Yet most people receive the result without the model. A percentage appears beside a raindrop. A television chart shows blue triangles, red semicircles and white streamlines. Terms such as humidity, pressure and instability are familiar enough to sound understood, then collapse when asked to do explanatory work. Why does falling pressure often precede bad weather? Why can a winter high produce a week of grey fog? Why does a halo around the Moon sometimes arrive before rain? Why do some towering clouds die while another one becomes a supercell?

Understanding the machinery changes how the sky looks. A cloud stops being decoration and becomes evidence about vertical motion, moisture and stability. Wind direction becomes a history of where the air has travelled. Dew on grass becomes a measurement of surface cooling. A sharp visibility change across a hill becomes a boundary-layer problem. The weather map stops being a set of labels and becomes a compressed picture of forces acting in three dimensions.

The subject also trains a useful kind of judgement. Weather information is always incomplete, local and time-sensitive. You learn to distinguish a broad pattern from a precise outcome, a possibility from a warning, and a confident forecast from one in which plausible futures separate quickly. You learn that uncertainty can be measured and communicated rather than

hidden. A 30 per cent chance is not a failed promise if rain does or does not occur. It is a probability that should be judged across many comparable forecasts.

There are limits. Reading the sky cannot reveal every upper-level disturbance or detect rotation hidden inside a rain-wrapped storm. Folk rules often work only in the place and season that produced them. Weather knowledge does not confer immunity from lightning, flash floods, heat or wind. When official warnings conflict with your view from the window, the window is the smaller dataset.

Nor is weather the same as climate. Weather is the evolving atmospheric state over hours and days. Climate describes the statistical pattern of such states over longer periods. A single heatwave, snowstorm or wet afternoon cannot settle a climate argument by itself. This book explains the short-term machine: how the air moves, why clouds and storms organise, what the sky can tell you, and how a forecast turns scattered measurements into useful odds.

Once you see that machine, a change in the wind is no longer background. It is the atmosphere showing its working.

The Core Ideas

Weather Begins with Unequal Heating

The Sun supplies the energy, but weather begins with the fact that the energy does not arrive or remain evenly.

Most familiar weather occupies the troposphere, the lowest major atmospheric layer. It is deepest in the tropics, shallowest near the poles, and usually cools upwards to the tropopause.

Near the equator, sunlight strikes the surface more directly. Towards the poles, the same incoming energy is spread across a larger area and travels through more atmosphere. Earth is tilted, so the zone of strongest heating shifts with the seasons. Rotation gives every place day and night. Clouds

reflect sunlight. Snow and ice reflect more than dark soil or ocean. Land can warm sharply through an afternoon and cool quickly after sunset, while water mixes heat downward and changes temperature more slowly.

This patchwork matters because temperature changes density. Warm air usually becomes less dense than cooler air at the same pressure. Heating at the surface can make the lowest air buoyant. Cooling can make it dense enough to drain into valleys or spread as a shallow layer. Across larger distances, persistent temperature differences help create pressure differences aloft and the strong winds that circle the planet.

The phrase "warm air rises" is useful and incomplete. Warm air does not possess an urge to go upwards. It rises when it is buoyant relative to the surrounding air, or when something forces it up. A warm layer can sit beneath even warmer air and remain stable. Cold air can rise if a mountain, front or convergence zone lifts it. The comparison with the environment is what matters.

The atmosphere responds to unequal heating by moving energy. Trade winds converge towards a shifting tropical rain belt, where deep convection carries warm, moist air upward. Seasonal heating contrasts help reorganise winds and rainfall into monsoon circulations, though a monsoon is far more than one giant sea breeze. Farther poleward, travelling highs, lows and fronts exchange warm and cold air. The systems that interrupt a day or a week are pieces of planetary heat transport.

Daily weather begins closer to the ground. Sunlight passes through mostly transparent air and warms the surface, which then warms the air touching it. On a sunny afternoon, bubbles and plumes of warmer air rise from fields, roofs and roads. Sailplanes use these thermals. Small cumulus clouds can mark their tops if the rising air cools to saturation. After sunset the surface loses energy by infrared radiation. On clear, calm nights it can cool the adjacent air enough for dew, frost, fog or a temperature inversion.

Coasts create a compact demonstration. During a fair day, land often warms faster than nearby water. Air over land becomes warmer, expands and

contributes to a shallow pressure pattern that draws cooler marine air inland: a sea breeze. At night the contrast may weaken or reverse, producing a land breeze. The exact circulation depends on the larger wind, coastline, stability and terrain, but the engine is a difference in heating across a short distance.

Mountains complicate the same process. Sunlit slopes can warm air and drive upslope flow during the day. Night-time cooling creates denser air that drains downslope. A range can force moist air upwards, creating cloud and precipitation on the windward side. Descending air on the lee side compresses and warms, sometimes producing a dry, gusty foehn effect. The mountain did not create or destroy water. It changed the route, phase and temperature history of the air.

Cities alter the surface budget through stored heat, reduced vegetation, buildings and human energy use. The urban heat island is not a dome controlling every storm, but it can change near-surface temperature and stability. Soil moisture matters too: energy spent evaporating water is unavailable for direct surface warming. Neighbouring landscapes under the same Sun can feed different air into the afternoon boundary layer.

Weather begins wherever heating differs across space or time. Those differences do not dictate the outcome. Moisture, stability, rotation and the existing flow decide what the atmosphere can build. Without imbalance there is no reason for air to move, water to change phase or a forecast map to change.

Pressure Starts the Wind, Rotation Bends It

Atmospheric pressure is the weight of the air above a surface, expressed in weather reports in hectopascals. Standard sea-level pressure is about 1013 hPa, but the number alone tells you little. A reading of 1020 hPa can sit inside a falling pattern ahead of a storm, while 1000 hPa can be rising behind one. Weather responds to pressure relative to its surroundings and to how that pattern is changing.

A pressure gradient is a difference in pressure across distance. It exerts a

force from higher towards lower pressure. Closely packed isobars on a chart therefore signal a strong horizontal pressure gradient and, other things equal, stronger wind. Widely spaced isobars signal a weaker one. Air does not keep accelerating straight into every low because Earth is rotating.

Viewed from the rotating planet, moving air is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This Coriolis effect grows with speed and latitude and vanishes at the equator. It changes direction rather than supplying energy. Over large distances above the frictional boundary layer, the pressure-gradient force and Coriolis effect can approach balance, producing wind that runs roughly parallel to isobars. Meteorologists call this geostrophic balance.

Near the surface, friction slows the wind. A slower wind experiences a weaker Coriolis deflection, so the pressure-gradient force gains a component across the isobars. Surface wind therefore spirals somewhat inward towards low pressure and outward from high pressure. In the Northern Hemisphere, lows circulate anticlockwise and highs clockwise; the directions reverse south of the equator. The flow is rarely a perfect circle because pressure systems move, isobars curve, terrain intrudes and friction varies.

This explains a common puzzle. A low is not a hole sucking air into itself. It is a region whose pressure is lower than nearby regions at the same level. Air converges near the surface, rises somewhere in the system and diverges aloft. Rising air often cools and forms cloud, which is why lows are associated with unsettled weather. A high commonly contains sinking air and surface divergence. Descent warms and dries the air relative to saturation, often suppressing deep cloud. "Often" matters. A shallow moist layer can remain trapped beneath a high-pressure inversion, producing fog, low cloud and drizzle for days.

The pressure pattern also changes with height. Warm columns of air are thicker than cold columns because the air is less dense. Surfaces of equal pressure therefore sit higher over warm air and lower over cold air. Horizontal temperature contrasts create changes in wind with height, a

relationship central to the jet stream. The jet is a band of strong upper-level wind, commonly near the boundary between warm and cold air masses, that steers and helps develop weather systems below.

The jet does not drag every low along like a rope. Curvature, wind-speed changes and patterns of divergence aloft can support rising motion and falling surface pressure in some regions, while encouraging descent elsewhere. A small wave in the upper flow can amplify, helping a surface cyclone deepen. The surface system then moves heat and momentum, changing the environment that fed it.

At small scales, Coriolis becomes weak beside friction, container shape and the motion already present. It does not decide which way an ordinary sink or bath drains. At weather scale, with air moving for hours across hundreds of kilometres, the accumulated deflection is indispensable. It also helps explain why tropical cyclones do not form on the equator: too little planetary rotation exists there to organise a sustained vortex.

Pressure, then, begins the horizontal motion; rotation redirects it; friction lets it cross the contours; terrain and time deform the pattern. Wind is not a property attached to a place. It is the visible result of competing forces acting on moving air.

Water Is Weather's Energy Currency

Water vapour is invisible. The white material in a cloud is liquid droplets, ice crystals or both, large enough and numerous enough to scatter light. This distinction matters because weather is driven by water changing phase, not by vapour becoming visible through a change of name.

Evaporation requires energy. Molecules leaving liquid water carry energy into the atmosphere without necessarily raising the air temperature.

Meteorologists call this latent heat. When water vapour later condenses or freezes, that energy is released into the surrounding air. The cycle moves heat from the surface to the place where cloud and precipitation form. It is one reason a moist atmosphere can build stronger ascent than a dry one.

Air becomes saturated when it contains as much water vapour as can remain in equilibrium at its temperature and pressure. Relative humidity compares the current vapour amount with that saturation value. Because the saturation value rises steeply with temperature, relative humidity can change even when no water is added or removed. Warm the morning air and relative humidity falls. Cool it at night and relative humidity rises. This is why "cold air holds less water" is a rough shortcut that often produces bad reasoning. Air is not a bucket with a rigid capacity. Saturation is a thermodynamic balance, and condensation also needs surfaces on which droplets or ice can form.

Dew point is the temperature to which air would need to cool, at roughly constant pressure and water-vapour content, to reach saturation. A high dew point indicates moist air. A low dew point indicates dry air. The gap between air temperature and dew point gives a quick sense of how much cooling is required for saturation near the surface. A narrowing gap overnight can warn of dew, low cloud or fog, though wind, ground temperature, mixing and incoming cloud still matter.

Rising air usually encounters lower pressure. It expands and uses internal energy to do work, so its temperature falls even without exchanging heat with its surroundings. Unsaturated air cools at roughly the dry adiabatic rate. Once saturated, condensation releases latent heat and reduces the rate of cooling. This does not stop the air cooling; it changes the rate. The difference helps moist convection remain buoyant through a deeper layer.

Cloud formation therefore needs more than humid air. Air must reach saturation, commonly through ascent or surface cooling. Most droplets form as water vapour condenses onto tiny aerosol particles called cloud condensation nuclei; ice can form through related freezing and deposition processes. Lift can come from surface heating, a mountain, a front, convergence or turbulence. Fog forms when the saturation level reaches the ground. It is a cloud with its base at the surface, shaped by the same moisture and temperature rules as clouds above.

Precipitation requires cloud particles to grow large enough to fall and survive

the trip. In warm clouds, droplets collide and coalesce. In mixed-phase clouds, ice crystals can grow at the expense of supercooled droplets and then fall as snow, soft ice pellets called graupel, or rain after melting. A dark cloud does not guarantee rain at the surface. Drops can evaporate into dry air below, producing streaks called virga and sometimes cooling a descending downdraft.

Water also changes storm dynamics. Condensation heating can reinforce rising motion and lower pressure in developing systems. Evaporation and melting cool air, making it denser and helping create downdrafts, gust fronts and cold pools. A thunderstorm therefore contains linked engines: warm moist inflow and latent heating support ascent; precipitation loading and evaporation help drive descent. The storm survives when its organisation keeps the downdraft from cutting off the inflow too quickly.

The useful question is not "How humid is it?" in isolation. Ask where the moisture is, how close the air is to saturation, what could lift or cool it, and what phase changes will do to buoyancy. Water is weather's transportable energy account. Evaporation deposits energy into it. Condensation spends that energy higher in the atmosphere. Rain is the receipt.

Stability Decides Whether Air Spreads or Erupts

Two afternoons can begin equally warm and moist. One produces flat cumulus that fade before sunset. The other produces towers, hail and lightning. The difference often lies in the vertical temperature structure: how the environment changes with height, and what happens to an air parcel displaced through it.

Imagine lifting a small parcel without immediately mixing it with the surrounding air. As pressure falls, it expands and cools. Compare its temperature with the environment at the same height. If the parcel is colder and denser, gravity encourages it to return towards its starting level. The atmosphere is stable. If the parcel remains warmer and less dense, it continues rising. The atmosphere is unstable. If the temperatures stay close, small influences can decide the outcome.

This is why surface temperature alone is a poor thunderstorm forecast. Hot air beneath an even hotter layer aloft may be capped. Cooler surface air beneath rapidly cooling air aloft may become unstable after only modest heating. Forecasters use weather balloons, aircraft and remote sensing to measure temperature and moisture through depth because the atmosphere's profile matters more than one number at eye level.

A temperature inversion is a layer in which temperature rises with height. It is strongly stable because a lifted near-surface parcel enters warmer surroundings and loses buoyancy. Clear, calm nights can create a shallow inversion as the ground cools the air above it. High pressure can create an inversion aloft through sinking and compressional warming. Valleys can collect dense cold air beneath warmer air. Inversions suppress mixing, trapping fog, smoke and pollution near the surface. They can also act as a lid above moist air, storing potential energy until heating or large-scale lift weakens the cap.

Instability still needs a trigger. A buoyant parcel cannot rise if it never reaches the level where it becomes free to accelerate. Surface heating may provide the first push. A cold front can undercut warm air. Winds converging near the ground can force air upward. Mountains can lift an entire layer. Upper-level dynamics can remove mass aloft and encourage ascent below. Meteorologists separate ingredients because each answers a different question: is there moisture, is there instability, and is there lift?

Convective available potential energy, or CAPE, estimates the positive buoyant energy available to an idealised parcel under stated assumptions. A large value can support strong updraughts, but it is not a storm forecast or a direct speedometer for real clouds, which mix with surrounding air. The parcel may never break the cap. Moisture may be shallow. Dry air may strengthen downdraughts. The wind profile may fail to organise cells. CAPE is an ingredient and a diagnostic, not a promise.

Wind shear is a change of wind speed or direction with height. In weak shear, a thunderstorm's rain-cooled downdraught often falls back into or near the updraught, cutting off the warm moist supply. With stronger shear,

the updraught can tilt away from the precipitation. The cell may last longer, organise into a line or, under suitable directional and speed shear, develop a rotating updraught called a mesocyclone. A supercell is a storm built around such persistent rotation. It can produce severe hail, damaging winds and tornadoes, though many supercells do not produce tornadoes.

Stability also explains ordinary cloud shape. Stable ascent tends to spread, producing sheets such as stratus, altostratus and nimbostratus. Shallow instability produces small cumulus with flat bases and limited vertical reach. Deep instability produces cumulus congestus and cumulonimbus, with cauliflower towers and an anvil where the rising air reaches a stable layer near the tropopause. Lenticular clouds reveal waves in stable air flowing across mountains. Cloud streets reveal rolls of boundary-layer convection capped above.

The sky is therefore a rough sounding. Flatness, layering, vertical growth and the speed of change reveal something about the temperature profile and lift. They do not reveal everything. A dangerous cap can sit above innocent low cloud, and strong upper winds can be invisible in clear air. But the governing question remains: when air is moved vertically, does the atmosphere resist, permit or amplify the displacement?

Fronts Are Sloping Boundaries

A front on a surface chart looks like a line. In the atmosphere it is a broad, sloping transition zone between air with different temperature, moisture and density. The line marks where that zone meets the ground, much as a coastline marks where a sloping shore meets sea level.

Air masses acquire characteristics by spending time over source regions. Air moving from a winter continent tends to be cold and dry. Air moving from a warm ocean tends to be mild and moist. These labels describe history, not purity. An air mass begins changing as soon as it crosses a different surface, and mixing blurs every boundary.

At a warm front, warmer air advances over a retreating wedge of denser cold air. The frontal surface commonly slopes gently, so ascent spreads

across a wide area. High cirrus may arrive first, followed by cirrostratus, altostratus and thicker nimbostratus as the cloud base lowers. Pressure usually falls ahead of the front, temperature and dew point rise as it passes, and steady precipitation may occur well before the surface boundary arrives. The sequence is useful because it reveals a sloping structure approaching above you before its lowest edge reaches the ground.

At a cold front, denser cold air advances beneath warmer air. The slope is usually steeper and the weather band narrower. Lift can produce a line of showers or thunderstorms, followed by a wind shift, rising pressure, lower temperature and often lower dew point. Some cold fronts pass with little rain because moisture or lift is weak. The symbol tells you the thermal movement, not a guaranteed weather package.

A stationary front forms when neither air mass advances decisively. Weather can persist near it because the boundary remains a focus for ascent. In the classic cyclone model, an occlusion develops as the faster cold front catches the warm front and lifts the warm sector near the low. Some ocean cyclones instead fracture their cold fronts and wrap a bent-back boundary around the centre. The neat spiral is a useful grammar, not a blueprint every storm obeys.

Why do fronts gather around lows? Mid-latitude cyclones grow where strong horizontal temperature contrasts and upper-level disturbances allow available potential energy to be converted into motion. Warm air moves poleward on one side, cold air equatorward on the other, and pressure falls as the three-dimensional circulation develops. The fronts sharpen some contrasts while the storm also mixes them. Mature systems eventually lose access to the strongest surface temperature difference and weaken, though upper-level forcing and latent heating can alter the sequence.

The jet stream is tied to the same contrast. Strong temperature gradients support strong changes of wind with height. Waves in the jet create regions favourable for ascent and cyclone development. A surface front is therefore part of a deep structure connecting temperature, pressure and wind from the ground towards the tropopause.

Reading a front means watching trends together. One cloud name proves little. A lowering cloud sequence, persistent pressure fall, strengthening wind and rising dew point tell a coherent story. The line on the chart is the shorthand. The weather occupies the volume around it.

Storms Organise Rising Air

Storms organise rising air, but they do so for different reasons. Ordinary tropical weather already proves the point: humid air can converge along trade-wind, sea-breeze or outflow boundaries and build deep towers without any cold or warm front. The larger storm families differ in energy source, scale, rotation and internal structure.

The mid-latitude cyclone is a travelling response to temperature contrast. It can span more than a thousand kilometres, carry warm and cold fronts, and produce broad areas of wind, cloud and precipitation. Its energy comes mainly from rearranging warm and cold air in a rotating system. Latent heating can strengthen it, but warm ocean water is not its sole fuel. Such cyclones can deepen rapidly over the North Atlantic or North Pacific because sharp contrasts, moisture and the upper flow align.

A thunderstorm is smaller and more vertical. It begins when moist, unstable air is lifted far enough to become buoyant. In the developing stage, an updraught builds cumulus towers. As precipitation forms, downdraughts begin. A short-lived cell weakens when its rain-cooled outflow cuts off the inflow. New cells can form along the gust front, creating clusters or lines that outlive any one tower.

Shear changes the architecture. It can separate updraught from downdraught, allowing repeated growth. In squall lines, cold outflow and environmental shear help maintain a long lifting boundary. In supercells, a persistent rotating updraught can support severe hail, intense winds and tornadoes. Tornado formation requires processes below the scale of the broad ingredient map, so a favourable environment raises risk without deciding which storm will produce one. Rivers, hills and city boundaries do not provide dependable protection.

Lightning is an electrical discharge produced after collisions among ice particles and supercooled water help separate charge within the cloud. Thunder is the pressure wave from air heated rapidly along the lightning channel. The useful safety rule is simpler than the microphysics: if thunder is audible, lightning is close enough to be a threat.

A tropical cyclone has another engine. Over sufficiently warm tropical ocean, evaporation supplies moisture and energy. Organised thunderstorms release latent heat, warming the core and lowering surface pressure. Air spirals inward, rises in the eyewall and flows outward aloft. Rotation must be strong enough to organise the vortex, which is why formation is rare close to the equator. Low vertical shear helps the warm core remain vertically aligned. Land, cold water, dry air or strong shear can weaken the system, though its rain and wind can remain dangerous after landfall.

Do not infer storm strength from central pressure alone across types. A broad mid-latitude low can produce damaging winds with a higher central pressure than a compact tropical cyclone. A severe thunderstorm may sit inside only a modest surface trough. Impact also depends on storm size, motion, duration, terrain and what lies in its path, material owned more fully by the disaster book.

What unites storms is organised vertical movement and a way to keep it going. What separates them is the energy source, scale, rotation and internal arrangement. Calling every spiral on a satellite image a hurricane is like calling every animal with wings a bird. Shape is a clue. Mechanism is the classification.

Forecasting Is an Initial-Condition Problem

A forecast begins before a model runs. It begins with a reconstruction of now.

Weather stations measure pressure, temperature, humidity, wind and precipitation near the surface. Balloons sample the vertical profile. Aircraft report conditions along flight paths. Ships, buoys and floats cover parts of the ocean. Radar detects precipitation and its motion. Satellites measure

radiation across many wavelengths, from which analysts infer clouds, temperature, moisture, winds and surface properties. Each observation is partial, unevenly distributed and imperfect.

Data assimilation combines these observations with a recent model forecast to produce an analysis: the best physically consistent estimate of the atmosphere and connected surface at a chosen time. The model then divides the Earth into a three-dimensional grid and advances equations describing motion, energy, moisture and other processes. Phenomena smaller than the grid, including parts of clouds, turbulence and surface exchange, must be represented through approximations called parameterisations.

The forecast can fail through two routes. The initial analysis is never exact, and the model is never exact. Weather is nonlinear, so a small initial difference can shrink, persist or grow rapidly depending on the flow. Edward Lorenz exposed this sensitivity in the 1960s. It is the source of the butterfly metaphor, though no forecast fails because one literal butterfly was omitted. Finite observation and calculation cannot specify every relevant detail.

Ensemble forecasting makes the uncertainty visible. Run many forecasts with slightly different initial states and model representations. If they remain close, the situation is relatively predictable. If they separate, confidence in a precise outcome should fall. The spread can be converted into probabilities, provided the system is tested and calibrated against past performance. A probability is therefore a summary of plausible modelled futures, not indecision disguised as mathematics.

Forecast skill depends on scale and lead time. A large, slow pressure pattern can be predictable while the exact location of an afternoon shower is not. Radar can provide excellent near-term information once precipitation exists, yet it cannot make an unformed cell appear in the correct field half an hour early. Fog, convective initiation, snowfall boundaries and local wind gusts remain difficult because small errors in temperature, moisture, terrain or timing can change the result sharply.

Human forecasters still add value by checking model biases, comparing systems, interpreting local effects, joining guidance to observations and communicating consequences. Machine-learning models have entered operations as well. As of September 2026, ECMWF was running version 2 of its deterministic and ensemble Artificial Intelligence Forecasting System beside its physics-based system. Data-driven models can produce skilful global forecasts quickly, but they still depend on analysed initial conditions, training data and verification. They do not abolish observation, uncertainty or physical constraint.

The causal loop closes here. Unequal heating keeps pushing the atmosphere into motion. Pressure, rotation, water and stability turn that imbalance into fronts and storms. Forecasting works by measuring those variables and calculating their evolution. Its limit comes from the same moving fluid: small uncertainty is stretched, folded and amplified by the flow.

A forecast is therefore neither a prophecy nor a guess. It is a conditional statement: given this estimated state, these equations or learned relationships, and these plausible uncertainties, here are the outcomes now judged most likely. Read it as a changing distribution, then update when new observations arrive.

How It Actually Works

Forty-eight hours upstream

Forty-eight hours before rain reaches western Britain, the weather may leave no local sign beyond an ordinary wind. The useful action is already happening over the Atlantic and high in the troposphere.

Cold air to the north lies beside milder air to the south. A wave develops in the upper flow and the jet stream curves around it. Where the flow removes mass from an atmospheric column faster than it is replaced, surface pressure falls. Air near the surface converges towards the developing low and rises. Warm air begins moving poleward ahead of the centre while colder air advances behind it.

Moisture alters the growth. Rising air cools and condenses, releasing latent heat that can reinforce ascent and reshape the pressure field. The cyclone still draws its main mid-latitude energy from horizontal temperature contrast, but dry dynamics and cloud physics are coupled. A forecast that moves the air correctly while mishandling cloud heating can misjudge how rapidly the low deepens.

At this range, the forecast is a family of tracks. One ensemble cluster may take the centre across Ireland, another through Scotland, another farther south. A windy unsettled spell can be likely while the location of the strongest gusts and rain remains uncertain. Useful forecasting preserves that distinction instead of forcing every level of confidence into one icon.

Reconstructing the present

Before any future can be calculated, the present must be assembled from measurements made at different times, heights and places.

Surface stations report pressure, temperature, dew point, wind, visibility, cloud and precipitation. Radiosondes rise beneath balloons and sample the vertical profile. Commercial aircraft contribute wind and temperature along busy routes. Ships and buoys cover parts of the ocean. Radar repeatedly scans precipitation near land. Satellites measure radiation across the globe, including regions with few instruments at the surface.

Each view is partial. A satellite does not place a thermometer at every altitude; it measures radiation influenced by layers of atmosphere and surface. A station can describe its field and miss a sharp boundary five kilometres away. A balloon is detailed and temporary. Radar can overshoot shallow rain at distance, encounter clutter and reveal less about clear air.

Data assimilation combines the observations with a short model forecast. The previous forecast supplies a physically organised first estimate. New measurements pull that estimate according to their uncertainty and representativeness. The resulting analysis fills the three-dimensional grid with a balanced estimate of wind, pressure, temperature, moisture and surface conditions. It is an evidence-constrained reconstruction, not a

photograph.

Building the forecast machine

FitzRoy's nineteenth-century office used the telegraph to gather coastal observations on the same morning. That created a synoptic view: conditions seen together across a region rather than remembered in sequence at one point. Pressure patterns and wind shifts could be mapped before a storm reached the next coast. Standard instruments, shared observing times and common codes later allowed countries to combine reports.

Lewis Fry Richardson published a gridded, equation-based forecasting scheme in 1922. His hand calculation was too slow, and its starting data too poorly balanced, to make an operational prediction. The architecture was recognisable. In 1950, Jule Charney, Ragnar Fjørtoft and John von Neumann published results from ENIAC calculations of simplified large-scale pressure change. Electronic computation turned Richardson's impossible timetable into a practical programme.

The view from orbit removed another blindness. TIROS-1, launched in 1960, was the first successful experimental weather satellite. Its images exposed organised cloud systems across regions that surface networks sampled sparsely. Later satellites added infrared and microwave measurements, supplying information about temperature, moisture, wind, cloud, sea and land as well as pictures.

Radar filled a different gap by scanning precipitation frequently near populated land. Balloons remained valuable because a direct vertical profile can expose an inversion, moist layer or wind shear invisible at the surface. Aircraft, ships and buoys became part of the network. The modern forecast is a cooperative measurement system before it is a computer product. No instrument sees weather whole.

Reading the approach

Hours before the surface warm front arrives, high cloud may spread across the western sky. Cirrus thickens into cirrostratus, sometimes producing a halo as sunlight or moonlight passes through ice crystals. The sheet lowers towards altostratus. Pressure falls more steadily. Wind may strengthen and change direction. The sequence appears because warm air is already ascending the frontal slope far above the observer.

It is not a countdown clock. High cloud can come from a jet-stream plume without a surface front. A front can arrive with its upper sequence broken, hidden or displaced. The sign gains force when independent changes agree: cloud thickening and lowering, sustained pressure fall, rising dew point and a wind consistent with the approaching system.

The trend often matters more than the number. A barometer falling several hectopascals in a few hours says the atmospheric column is changing quickly. It cannot reveal the low's track or decide the hazard alone, but it can show that the local atmosphere is evolving with the larger pattern.

Through the frontal system

The warm front's surface line lies behind much of its cloud and precipitation because warmer air ascends a shallow slope over colder air near the ground. Cloud bases lower. Nimbostratus may produce persistent rain across a broad area. Moist flow into the cold layer can reduce visibility. In winter, precipitation type depends on the whole temperature profile. Snow may melt in a warm layer aloft, refreeze into ice pellets, or remain liquid below 0°C and freeze on contact. A small error at the wrong height can change the hazard.

As the surface boundary passes, temperature and dew point commonly rise, the pressure fall eases and the wind shifts. The change may be muted. Dense cold air can remain pooled in valleys while milder air crosses above, and marine influence can narrow the contrast at a coast. A front is a moving three-dimensional zone; an observer samples one path through it.

Between the fronts lies the warm sector. The name is relative. At the surface it may be mild, windy and damp beneath stratus and drizzle, or broken by brighter intervals and showers. The strongest wind need not coincide with either front. It depends on the pressure gradient and on whether turbulence, daytime heating or precipitation mixes faster air from aloft downwards.

The cold front is commonly steeper and faster. Denser air advances beneath the warm sector, concentrating ascent into a narrower band. The visible result may be ragged low cloud, heavy rain and a sudden gust. Where moist instability is present, cumulonimbus can bring lightning, hail or severe wind. At passage, wind often veers in the Northern Hemisphere, pressure bottoms out or begins rising, and temperature and dew point fall. Some fronts pass dry; others carry much of their rain behind the surface boundary.

Thunderstorm outflow can arrive before the rain. Evaporation and falling precipitation cool and drag air downwards, creating a dense current that spreads across the surface. A shelf cloud may mark its leading gust front. That cloud is attached to outflow rather than a tornado, although straight-line winds behind it can still be destructive. Strong shear can organise cells along the front, while small bows, breaks and embedded rotations concentrate risk below the scale of the line on a national chart.

The textbook sequence remains a model. A wave can delay clearance, fronts can split or weaken, and some marine cyclones wrap a bent-back boundary around the low rather than performing a tidy occlusion. The symbols help organise evidence. They do not compel the atmosphere to draw neatly.

Behind the front

Pressure rises after the cold front and visibility often improves. The incoming air is colder and drier by history, but over a comparatively warm ocean its lowest layers gain heat and moisture. Sunshine alternates with cumulus, showers and sharp gusts. A rainbow beneath a retreating shower can mark the broken post-frontal sky.

Geography sorts the showers. Western hills force repeated ascent while eastern valleys sit in a rain shadow. Rows of convection can align downwind of warm water, placing snow or rain in one narrow corridor while a nearby place stays dry. Near the low, cloud and precipitation may wrap around an occlusion. Farther along a trailing boundary, a secondary low can begin the process again.

Weather without fronts

The Atlantic sequence makes three-dimensional structure visible, but much of the world's daily weather does not arrive on a warm-front, warm-sector, cold-front timetable.

Take a humid tropical coast. Overnight, land cools while the nearby sea changes little. Morning may begin with shallow cloud or a land breeze. After sunrise, the ground warms, the boundary layer deepens and cumulus forms over preferred patches of heated land. A sea breeze then moves inland. Where it meets the background trade wind, another sea-breeze front or air flowing off hills, convergence forces moist air upward. If a cap holds, towers flatten. If lift breaks the cap and the air remains buoyant through depth, one tower becomes a thunderstorm.

Its downdraught spreads a cold pool. The leading outflow boundary can trigger the next cell, so a storm generated by daytime heating survives by creating fresh lift after the original thermal has gone. The rain may miss the coast and flood an inland strip, or form late enough to persist after sunset. No polar air mass or classic front is required. The same four questions still work: where heating differs, where air converges, how much moisture is present, and whether vertical displacement grows.

A monsoon is a broader seasonal reorganisation of winds and moisture, not a single storm and not uninterrupted rain. Land-ocean heating contrasts, migration of tropical convergence, pressure fields, topography and disturbances combine to draw moist flow over a region. Within an active spell, embedded lows, convergence zones and mountain lift can produce repeated heavy rain. During a break, the large monsoon circulation can

remain while convection shifts elsewhere. Calling every downpour a monsoon confuses the seasonal regime with one weather event.

Across the tropical oceans, the trade winds carry shallow cumulus through broad belts of subsiding air. Farther equatorward, converging flow supports deeper cloud and recurrent rain. Westward-moving disturbances can organise thunderstorms across hundreds of kilometres without resembling a mid-latitude front. Most pass as clusters of squalls and showers. A small minority encounter warm water, moist air, low enough shear and pre-existing rotation, allowing a tropical cyclone to form. The sequence is conditional: warm ocean is a source of energy, not a guarantee that a vortex will close.

Weather can also organise after dark. Thunderstorm cold pools and winds a kilometre above the ground may keep feeding a line or cluster after surface heating fades, while the ground beneath becomes stable. The observer feels cool outflow and sees lightning on the horizon; the storm's inflow can be arriving from another direction and height. This is why a surface thermometer can describe the air at your feet while saying little about a storm's remaining supply.

Other scripts are smaller. Cold air crossing a warm lake or sea can build narrow convective streamers. A mountain can create cloud and rain on one side while descending air clears and warms on the other. A valley can fill with fog while slopes remain clear. Desert heating can mix dry air deeply, then produce damaging downdraughts from rain that partly evaporates before reaching the ground. The front is one organiser among several; lift, moisture, stability and flow remain the common grammar. One icon can conceal every one of these scripts.

The ground edits the pattern

A large-scale forecast describes the approaching air and pressure field. The surface decides how that pattern is experienced.

Mountains force ascent, create waves and channel wind. Coastlines generate temperature contrasts and convergence. Valleys collect dense

night-time air. Cities store heat, roughen the flow and alter the balance between heating and evaporation. Wet soil uses more incoming energy to evaporate water; dry soil can warm the near-surface air more strongly. Islands, headlands and gaps bend or accelerate wind.

These effects interact with the wider pattern rather than replacing it. Strong offshore flow can prevent a sea breeze from moving inland. A rain shadow shifts when the wind turns. An inversion can keep a valley cold while the ridge above warms. Two places ten kilometres apart can therefore experience different cloud, wind or precipitation under the same analysed system. The atmosphere does not issue weather by postcode, and a national map cannot display every boundary-layer edit.

From model output to a forecast

From the analysis, a numerical model advances winds, pressure, temperature, moisture and exchanges with land and ocean through time. Its grid cannot resolve every turbulent eddy, droplet, ridge or street canyon. Smaller or more complex processes are represented through parameterisations or learned relationships. Higher resolution can expose more structure without removing model error.

Forecasters compare models and ensembles, seek agreement in the broad pattern and identify differences that matter to decisions. If most members take a front through London during the afternoon while a minority delay it until evening, the forecast can state a likely wet afternoon and retain timing uncertainty. If the tracks divide into wet and dry clusters, one average may describe a future that no member produced.

Rain probability needs a defined place, period and threshold. For a Met Office point product, a displayed 30 per cent assigns that location a three-in-ten probability of measurable precipitation during the stated interval. It does not mean rain for 30 per cent of the hour or across exactly 30 per cent of the town. Amount, duration and impact need separate information.

As lead time shortens, observations take more weight. Satellite imagery shows the cloud shield and cyclone structure. Radar reveals existing

precipitation and Doppler motion towards or away from the instrument. Surface reports confirm pressure trends, wind shifts and precipitation type. Nowcasting extrapolates observed features and blends them with short-range guidance. It is strongest once a feature exists and moves coherently, weaker when the central question is where new convection will ignite.

Warnings answer a different question from ordinary icons. They combine likelihood with expected impact and may cover a broad area while track or timing remains uncertain. A warned location can avoid the worst outcome without the warning having been irrational. The decision was made while several futures remained possible.

The horizon of useful detail

Three days ahead, the large-scale low may be well predicted while the frontal rain band remains uncertain by tens of kilometres. A week ahead, ensembles may agree on an unsettled regime and disagree on the timing or depth of individual lows. Farther out, the forecast can retain information about broad patterns after losing useful detail for one afternoon in one town.

There is no universal day on which every forecast becomes worthless. Predictability varies with flow, scale and variable. A blocked high can persist yet remain difficult at its edges. A rapidly developing cyclone can have modest track uncertainty with large practical consequences. Convective initiation can be uncertain within hours because small boundaries decide where the first tower forms. Temperature may be easier than rain in one situation and harder in another when cloud timing is wrong.

Machine-learning models change the computational route, not the logic. They learn from large archives of analysed weather and can produce skilful global forecasts at low running cost. Physics-based models calculate approximations to governing equations. Operational centres compare both. Each starts from an estimated state, each can smooth or miss small features, and each must earn trust through verification.

Once the weather happens, the forecast becomes evidence. Thousands of

such comparisons reveal whether probabilities are calibrated, rain is displaced or certain regimes defeat the system. Forecasting improves through this repeated encounter between model and outcome, not one celebrated hit or miss.

How we know

Weather science joins direct measurement, laboratory physics, field campaigns and repeated forecast tests. Pressure, temperature, humidity and wind are observed at the surface and aloft. Radar measures returned radio energy and Doppler shift. Satellites measure radiation from which atmospheric and surface properties are inferred. Balloons, aircraft, ships and buoys provide vertical detail and independent checks.

The governing relationships come from fluid dynamics, thermodynamics, radiation and phase change. Their atmospheric use is tested against observed fronts, storms and long records. Reanalysis applies one forecast system consistently to historical observations, producing a physically organised reconstruction while retaining greater uncertainty where measurements were sparse.

The largest gaps sit at small scales and inside clouds. Turbulence, droplet and ice processes, convective initiation, fog and terrain effects can remain unresolved or poorly sampled. Radar and satellites infer many quantities rather than touching them directly. Verification establishes average skill, not certainty for one future.

Confidence is strongest where mechanisms, observations and independent guidance agree. It weakens where the initial state is sparse, small processes control the outcome or ensemble futures separate rapidly.

What People Get Wrong

“High pressure always means blue skies”

High pressure encourages sinking air, and descent commonly warms the air away from saturation. That is why anticyclones often bring settled, dry conditions.

The shortcut fails near the ground. Sinking air can create an inversion that traps a shallow moist layer beneath it. In winter, weak sunlight and light wind may be unable to mix that layer out. Fog or low stratus then persists under a strong high, sometimes with drizzle. The Met Office's phrase "anticyclonic gloom" describes the result plainly: pressure is high, the weather is quiet, and the sky remains grey.

Clear skies under a high can also produce frost or radiation fog overnight because the surface loses heat efficiently. In summer, the same pressure pattern may give hot sunshine and poor air quality. Wind direction can import cold continental air or cool marine cloud.

Pressure describes a mass distribution and circulation, not a sky colour. Ask whether the air is rising or sinking, how deep the moist layer is, where the inversion sits, and whether heating or wind can break it. The correction matters because "settled" means weakly changing, not necessarily bright, warm or harmless.

“Clouds are made of water vapour”

Water vapour is a gas and is invisible. The visible cloud consists of tiny liquid droplets, ice crystals or a mixture of both. The white plume above a kettle is not steam in the strict sense at the point you see it; it is condensed droplets after invisible vapour has cooled.

The mistake survives because cloud appears when humid air cools, so the visible material is treated as vapour itself. The missing step is saturation and condensation onto aerosol particles. Temperature, pressure and the availability of nuclei determine when and how that transition occurs.

This distinction explains several observations. Air can contain abundant water vapour under a clear sky. A cloud can evaporate without its water disappearing from the atmosphere. Ice can exist in a cloud when the ground is above freezing. Dark cloud is often optically thick rather than dirty or filled with a different kind of vapour.

The correction matters because phase change carries energy. Evaporation stores latent heat, condensation releases it, and freezing or melting changes the energy budget again. Calling the cloud "vapour" erases the machinery that helps build rain, downdraughts and storms.

“Cold air holds less water”

This phrase can predict that cooling promotes condensation, but it gives air the wrong job. Air is not a container with a fixed water capacity. Saturation vapour pressure depends strongly on temperature, and liquid water or ice can coexist with vapour in a temperature-dependent equilibrium.

Relative humidity measures how close the vapour pressure is to saturation. Cool air without removing moisture and the relative humidity rises. Warm it and relative humidity falls. The water-vapour amount may be unchanged. That is why cold outdoor air brought indoors and heated can feel dry: its low absolute moisture remains, while the saturation value increases.

Dew point is usually the better everyday measure of how much moisture is present near the surface. Two afternoons at the same relative humidity can feel different if their temperatures and dew points differ sharply.

The shorthand becomes dangerous when people infer that warm air automatically contains more water or that cold air cannot be humid. Warm air has a higher saturation value, but it may still be dry. Cold fog can be saturated. The correction separates moisture content from closeness to saturation, which is essential for understanding cloud, frost, heat stress and precipitation.

“A front is a wall of air”

The symbols encourage the mistake. A cold front becomes a blue line with triangles, as though a vertical sheet of cold air were sweeping across the map.

A front is a transition zone with horizontal width and vertical slope. The surface line records only where that zone meets the ground. At a warm front, cloud and precipitation can extend far ahead because the warm air ascends over the cold wedge aloft. At a cold front, the slope is usually steeper, but the boundary is still neither vertical nor infinitely thin.

Real fronts also contain waves, dry gaps, multiple wind shifts and local modifications. Mountains slow or split the lowest air. Evaporation changes temperature. A surface boundary can weaken while a strong contrast remains aloft. Forecasters sometimes disagree on the exact line because nature has supplied a gradient rather than a painted edge.

The wall model makes people expect all weather at one instant. The sloping-zone model explains why high cloud arrives early, why rain can precede a warm front by hours, and why the temperature change may lag the first precipitation. The chart is a projection of a volume.

“The Coriolis effect makes water spin down the plughole”

Earth's rotation deflects moving air and ocean currents over long distances. In the Northern Hemisphere the deflection is to the right; in the Southern Hemisphere it is to the left. This helps organise large weather systems.

A sink or bath is too small and drains too quickly for Coriolis to dominate. The basin's shape, the position of the outlet and tiny motions already in the water are much stronger. Carefully controlled laboratory experiments can reveal rotational effects, but an ordinary plughole is not a hemisphere detector.

The myth feels persuasive because cyclones rotate in opposite directions across the equator, and a familiar household vortex looks similar. Similar

shape does not establish similar controlling force. Tornadoes can even rotate anticyclonically in some cases because storm-scale dynamics can overpower the planetary preference.

The correction matters beyond trivia. Coriolis does not start the wind or pull air into lows. It deflects motion created by other forces, and its importance increases with duration, speed and scale. Weather systems are large enough to feel it. Your bath is not.

“A 30 per cent chance of rain means rain for 30 per cent of the day”

It can also be misread as rain over 30 per cent of the forecast area, or as forecasters being 30 per cent confident in a private guess. None is a safe general interpretation.

A precipitation probability must be tied to a location, time interval and measurable threshold. On a Met Office point forecast, 30 per cent means an assessed three-in-ten chance that precipitation will fall at that location during the stated period. It says nothing by itself about whether the rain would last two minutes or two hours, or whether it would be drizzle or a downpour.

Probabilities can come from ensembles, statistical calibration, forecaster judgement and combinations of evidence. They should be tested across many forecasts. If events assigned 30 per cent occur roughly three times in ten comparable cases, the forecast is calibrated even though every individual case ends as rain or no rain.

The correction changes decisions. A low chance of a severe outcome can matter more than a high chance of harmless drizzle. Read probability beside amount, timing, uncertainty and impact, not as a fractional description of the day.

“One dramatic event proves or disproves climate change”

A record heatwave does not establish the full climate case by itself. A cold snap does not refute it. Both are weather events produced by an evolving atmospheric state.

Climate concerns the distributions, averages, variability and extremes of weather over longer periods. Human influence can shift the probability or intensity of some events without creating them from nothing.

Event-attribution studies compare the observed world with modelled counterfactual climates and ask how the odds or magnitude changed. Confidence varies by hazard, region and metric.

The misconception is persuasive because events are concrete and climate statistics are abstract. A flood on screen feels more evidential than a changed probability distribution. Political argument then recruits whichever day suits it.

The correction cuts both ways. Do not use one storm as a substitute for climate analysis, and do not use ordinary weather variability to deny a measured long-term shift. Weather explains the event's immediate dynamics. Climate explains the changing background distribution. *Climate in a Hurry* owns that wider account. This book keeps the boundary because getting the timescale wrong corrupts both subjects and encourages certainty from evidence that cannot carry it.

Use It

Read change before category

Pressure of 1005 hPa does not tell you whether a storm is approaching or leaving. Pressure falling steadily, cloud thickening and wind strengthening tells a direction of travel. Temperature of 12°C means something different if the dew point is rising rapidly than if dry air is arriving. A south-westerly wind can be mild and damp ahead of a front or cold and showery behind one, depending on the air's origin and the upper pattern.

Build a short sequence. Note pressure at the same instrument, wind direction, visibility, cloud height and whether temperature and dew point are converging or separating. Look again an hour later. The atmosphere often reveals itself through coordinated change before any one value becomes remarkable.

A forecast updated from dry to wet, or from a compact probability range to a broad one, contains information about the evolving analysis. Do not preserve yesterday's forecast as though it were a promise. New observations change the estimate of now and therefore the calculation of next.

Use dew point to read moisture

Relative humidity is easy to quote and easy to misread because it changes with temperature. Dew point is more useful for many everyday questions.

A high dew point means the near-surface air contains substantial water vapour. If temperature falls close to it overnight, dew, fog or low cloud becomes more plausible. If temperature rises while dew point stays steady, relative humidity falls without the air losing water. If dew point drops sharply behind a front, drier air has arrived even if rain has only just stopped.

The temperature-dew point spread is not a fog formula. Wind can mix drier air downward. Cloud can slow surface cooling. Wet ground can add moisture. Valleys and coastlines alter the result. But the spread tells you

whether saturation is near, while relative humidity alone can hide the reason it changed.

For comfort and heat stress, dew point also separates a merely hot dry day from a hot humid one. For storms, it indicates the moisture available near the surface, though the depth of that moist layer still matters. Use it as a clue, not a forecast.

Read cloud behaviour, not a cloud checklist

The ten basic cloud genera give the sky a useful vocabulary. The larger skill is to read height, shape and change.

High, thin ice cloud that thickens and lowers suggests broad ascent increasing above you. A halo within cirrostratus can precede a warm front, especially when pressure is falling. Layered cloud points towards stable lift. Small cumulus with flat bases shows shallow convection. Towers growing rapidly through the afternoon show that instability and lift are overcoming inhibition. An anvil reveals a cumulonimbus reaching a stable upper layer. Virga shows precipitation entering dry air and evaporating before the ground.

Watch movement at more than one level. Low cloud travelling one way beneath high cloud moving another reveals wind shear. Lenticular cloud near mountains marks wave motion and strong flow aloft even when the cloud appears fixed. A shelf cloud marks thunderstorm outflow and can precede damaging straight-line wind.

Do not turn every sky into a prophecy. Cloud names identify forms, not guaranteed outcomes. The useful inference comes from cloud evolution, pressure, wind, moisture and the known larger pattern.

Separate storm ingredients from storm outcome

When severe weather is possible, ask four questions: is there moisture, instability, lift and organising wind shear?

Moisture supplies condensate and latent energy. Instability allows lifted air

to accelerate upward. Lift starts the displacement through heating, fronts, convergence, terrain or upper dynamics. Shear shapes the storm by separating updraught and downdraught and, in some environments, supporting rotation.

The ingredients describe an environment, not a schedule. A cap can prevent initiation. Cloud cover can reduce surface heating. Moisture may be too shallow. Storms may form but remain isolated from the strongest shear. A supercell may develop without producing a tornado. This is why risk maps cover areas and probabilities rather than tracing a certain path days ahead.

As the event nears, change tools. Broad model guidance is most useful for the environment. Radar, satellite, surface observations and official warnings become more useful once storms form. If thunder is audible, stop conducting your own sky analysis from an exposed place. Observation is not a reason to delay shelter.

Let the ground rewrite the broad forecast

A national forecast can be correct while your hill, beach or valley differs.

Onshore wind can bring a low cloud bank inland while a place farther from the sea stays sunny. A sea-breeze boundary can turn a light regional wind into a sharp local change. Mountains force ascent on the windward side and create drying descent in the lee. Valleys collect cold air and fog. Urban surfaces store heat and roughen flow. Forest, dry soil and wet fields divide incoming energy differently between warming and evaporation.

Learn your local modifiers. Which wind direction brings the cleanest visibility? Which valley fog persists after nearby slopes clear? Which ridge accelerates the flow? Which coast gets showers when cold air crosses warm water? Local knowledge has value because the same mechanisms repeat over fixed terrain.

Keep the knowledge conditional. A mountain rain shadow weakens if the wind changes direction. A sea breeze can be suppressed by strong offshore flow. An urban heat island does not repel storms. Local rules are the final

edit applied to the larger pattern, not an alternative to it.

Treat forecasts as decision ranges

A deterministic forecast gives one best trajectory. An ensemble shows a set of plausible trajectories. Use both.

For a routine walk, the likeliest outcome may be enough. For a flight, race, outdoor event or mountain route, the tail matters. Ask what the reasonable worst outcome is, how much the ensemble members disagree, and whether the decision can be delayed until new observations reduce uncertainty.

Read probability with its definition. A 30 per cent rain chance is a location-and-period probability, not a fraction of the afternoon. Read amount separately. A 70 per cent chance of light rain and a 20 per cent chance of a violent thunderstorm are different decisions. Warnings add impact to likelihood and may remain broad because the atmosphere has not yet selected a track.

Update as lead time shrinks. Several days out, focus on the regime and range. The day before, focus on timing windows and local modifiers. In the final hours, use radar, satellite, observations and warnings. A forecast is information for action, not a score to be defended after the weather has changed.

The limits

You cannot reconstruct the full atmosphere from the ground. Clear air can contain strong turbulence and upper-level forcing. Night hides cloud structure. Rain can conceal rotation. A barometer cannot locate a low. A halo can occur without an approaching warm front, and a warm front can arrive without a visible halo.

Sky rules are geographically biased. "Red sky at night" has some value in mid-latitudes where weather often moves west to east and cloud near the horizon interacts with low sunlight. It performs poorly where flow, season or tropical convection differs. Animal behaviour, aching joints and folklore can coincide with weather without providing a stable forecast method.

Forecast systems also have limits. Convection, fog, precipitation type and terrain effects can change over short distances. Model agreement can be false confidence if systems share data or biases. Ensemble spread can be too narrow. Machine-learning models can reproduce learned patterns skilfully, but rare or changing situations require especially careful testing. Verification is the defence, not branding.

Use official warnings for hazards. Understanding weather helps you interpret information, not outvote radar, instruments and trained forecasters from a garden chair.

The one thing to keep

Keep the motion.

The sky is not a sequence of pictures placed above you. It is the visible surface of a three-dimensional fluid carrying heat, water and momentum. Pressure gradients start movement. Rotation bends it. Friction and terrain reshape it. Rising air cools; sinking air warms. Water changes phase and moves energy. Stability decides whether displacement fades or grows. Fronts organise contrast. Storms organise ascent.

Once you keep that chain, weather signs stop being charms. Falling pressure matters because the column is changing. Cirrostratus matters because ice cloud is spreading through ascent aloft. A falling dew point matters because a different air history has arrived. A tower matters because buoyancy is winning through depth. An ensemble matters because several nearby starting states have begun to separate.

The permanent change is not that you can predict tomorrow from one cloud. It is that you know what kind of evidence a cloud is. You look for a mechanism, a trend and a scale. You ask what is moving, what force is acting, where the water is, how stable the air is and how certain the starting state can be.

Weather is the atmosphere exposing part of its calculation in public. Read the working, then respect what remains out of sight.

Terms

Adiabatic. A change in a parcel's temperature caused by expansion or compression without heat being exchanged with its surroundings. Rising air expands and cools; sinking air compresses and warms.

Air mass. A large body of air with a recognisable temperature and moisture history acquired over a source region. It changes as it crosses new surfaces and mixes with other air.

Analysis and data assimilation. The best physically consistent estimate of the current atmosphere, created by combining observations with a recent model forecast. It supplies the initial state for numerical prediction and is updated as new observations arrive.

Anticyclone. A high-pressure circulation, clockwise in the Northern Hemisphere and anticlockwise in the Southern. It commonly brings descent and settled conditions, but can trap fog or low cloud.

Atmospheric pressure. Force per unit area exerted by the air above. Weather reports usually reduce measurements to mean sea level so stations at different elevations can be compared.

Boundary layer. The lowest part of the atmosphere, directly influenced by the surface through friction, heating, cooling and evaporation. Its depth and turbulence change strongly through the day and across different surfaces.

CAPE. Convective available potential energy, an estimate of positive buoyant energy available to a lifted parcel. It indicates potential updraught strength under assumptions, not whether a storm will form.

Cloud condensation nucleus. A tiny aerosol particle on which water vapour condenses to form a droplet. Most cloud droplets depend on these surfaces as well as cooling, sufficient moisture and the particle-size distribution.

Cold front. The leading transition zone of advancing colder air at the surface. It is commonly steeper than a warm front and may bring a narrow

band of rain, showers or thunderstorms.

Convection. Vertical transport produced when buoyant air rises and denser air sinks. It ranges from small daytime thermals to deep thunderstorm updraughts and tropical cloud towers.

Coriolis effect. The apparent deflection of motion on a rotating Earth, towards the right in the Northern Hemisphere and left in the Southern. It matters increasingly with scale, speed, latitude and duration of motion.

Cumulonimbus. A deep convective cloud capable of lightning, heavy precipitation, hail and strong downdraughts. Its anvil forms where the updraught reaches a stable upper layer.

Cyclone. A closed low-pressure circulation. Mid-latitude and tropical cyclones can look similar on satellite images but obtain energy through different combinations of temperature contrast, moisture and rotation.

Dew point. The temperature to which air must cool, at roughly constant pressure and vapour content, to reach saturation. It helps indicate near-surface moisture, fog potential and how muggy the air may feel.

Ensemble forecast. A set of forecasts run with slightly different initial states or model representations. Their agreement and spread help estimate predictability and express outcomes as probabilities.

Front. A sloping transition zone between air masses with contrasting properties. The line on a surface chart marks only where that three-dimensional zone meets the ground.

Geostrophic wind. An idealised flow parallel to straight isobars when pressure-gradient force balances Coriolis deflection. Real winds depart from it through friction, curvature, acceleration and vertical motion.

Inversion. A layer in which temperature increases with height. It is stable, suppresses vertical mixing and can trap cold air, fog, smoke or pollution near the surface.

Isobar. A line joining equal atmospheric pressure on a map. Close spacing

usually indicates a strong pressure gradient and supports stronger wind, though friction and system motion still matter.

Jet stream. A narrow band of strong upper-level wind associated with horizontal temperature contrasts. Its waves help steer and develop mid-latitude weather systems.

Latent heat. Energy absorbed or released when water changes phase without the energy appearing immediately as a temperature change. Evaporation absorbs it; condensation releases it.

Lapse rate. The rate at which temperature changes with height. Comparing the environmental lapse rate with a lifted parcel's cooling rate helps diagnose atmospheric stability.

Occlusion. A front formed when a cold front catches a warm front in a mature cyclone, lifting the warm sector away from the surface near the low. Real occlusions vary in structure.

Parameterisation. A model representation of processes too small, complex or costly to calculate explicitly on the grid, such as parts of cloud physics, turbulence and surface exchange.

Pressure gradient. A pressure difference across distance. It creates the force that begins horizontal air motion; a stronger gradient generally supports stronger wind.

Radar. A system that sends radio pulses and measures returned energy from targets. Weather radar maps precipitation, while Doppler shifts reveal motion towards or away from the instrument.

Relative humidity. The ratio of current water-vapour pressure to saturation vapour pressure at the same temperature. It can change through warming or cooling without moisture being added or removed.

Stability. The tendency of the atmosphere to resist or amplify vertical displacement. Stable air suppresses ascent and spreads layers; unstable air can support deep convection.

Warm front. The leading transition where warmer air replaces colder air at the surface, usually by ascending a gentle slope. High cloud and broad precipitation can arrive well ahead of it.

Wind shear. A change of wind speed or direction with height or distance. Vertical shear can organise thunderstorms, support rotation, create turbulence and change how momentum reaches the surface.

Go Deeper

The accessible overview

Peter Inness, *Understand the Weather: Teach Yourself* (John Murray Press, 2010). This is the natural next step for a reader who wants the mechanisms in this book expanded without moving straight into equations. Inness covers fronts, clouds, pressure systems and forecasting with enough practical structure to connect a weather chart to the sky outside. It is broad rather than current on every forecasting technology, which is an acceptable trade for a stable introduction. The examples often assume British weather, making it especially good on Atlantic lows, changing air masses and the everyday ambiguity between cloud, drizzle and rain.

The sky

Gavin Pretor-Pinney, *The Cloudspotter's Guide* (Sceptre, 2006). Read this to keep looking upwards. It combines cloud identification with physics, history and close observation, making the ten basic genera memorable without turning them into a test. Its tone is more companionable than systematic, and it ranges beyond operational forecasting. Its names align with the international classification used by professional observers, but the book remains a companion rather than a manual. Keep a small observation log while reading it: cloud height, growth, movement, pressure and the weather that followed. That turns recognition into evidence rather than collecting names.

The forecast machine

Andrew Blum, *The Weather Machine: How We See Into the Future* (The Bodley Head, 2019). Blum follows the institutions, observations, models, standards and people that make a modern global forecast possible. The book is strongest on the hidden international infrastructure behind an ordinary app icon. Read it after the physics because it explains how the scattered measurements and calculations became a working public system. Machine learning has advanced since publication, but the network it describes still matters. The book also corrects the idea that a forecast comes from one supercomputer. It comes from international standards, shared observations, communications, public institutions and repeated verification as much as raw calculation.

The technical route

James R. Holton and Gregory J. Hakim, *An Introduction to Dynamic Meteorology*, 5th edition (Academic Press, 2012). This is the route from verbal model to equations: rotating fluids, vorticity, waves, instability, fronts and large-scale circulation. It is a university text and expects calculus and physics. Do not begin here merely to prove seriousness. Use it when phrases such as geostrophic balance and baroclinic development have become questions you want to derive rather than accept. Read selectively: the early chapters on rotating flow and vorticity establish the grammar, while later chapters explain waves, fronts and instability. Work problems on paper; this material cannot be absorbed by recognition alone.

Notes and Sources

The scientific account in this book was checked against standard atmospheric-science texts and current material from national and international forecasting bodies. Operational details and definitions were reverified on 2 September 2026. Weather processes vary by latitude, season, terrain and scale, so a stated tendency should not be read as a universal local rule.

The Whole Thing in One Page and Why You Should Care

Nearly all familiar weather occurs in the troposphere, the lowest major atmospheric layer. The basic energy, circulation, moisture and stability account follows John M. Wallace and Peter V. Hobbs, *Atmospheric Science: An Introductory Survey*, and James R. Holton and Gregory J. Hakim, *An Introduction to Dynamic Meteorology*, checked against NOAA's JetStream material on the atmosphere, winds and clouds.

The Royal Charter Gale account follows the Met Office history pages, especially “The storm that shaped the Shipping Forecast” and “Tragedy and warnings: the origins of the Shipping Forecast”. The storm struck the Irish Sea on the night of 25 October 1859. The Met Office records about 800 deaths, 133 ships destroyed and more than 450 deaths from the *Royal Charter*. FitzRoy's national gale-warning service issued its first storm warning on 5 February 1861. The service showed how timely regional observation could alter decisions even when the storm itself could not be controlled.

The distinction between weather and climate follows standard WMO and IPCC usage. Weather concerns the evolving state and events; climate concerns statistical distributions over longer periods. The final misconception is limited to that boundary because *Climate in a Hurry* owns climate mechanisms, attribution and long-term change.

Core Idea 1: unequal heating

The treatment of solar geometry, surface energy, land-sea contrast, thermals and the atmospheric boundary layer follows Wallace and Hobbs and NOAA JetStream's atmosphere and wind modules. “Warm air rises” is narrowed to buoyancy relative to the environment. Forced ascent can lift air that is cold in an everyday sense, while an inversion can keep warm air below warmer air.

The global-circulation passage follows Wallace and Hobbs, Holton and Hakim, and NOAA material on trade winds, tropical convergence and

monsoons. The text treats a monsoon as a seasonal circulation and rainfall regime shaped by land-ocean heating contrast, moisture transport, topography and the migrating tropical rain belt, not as one enormous sea breeze or one prolonged storm.

Sea and land breezes arise from differential heating and the resulting local pressure circulation, modified by the background wind and stability. The mountain discussion follows the WMO International Cloud Atlas material on orographic cloud and the Met Office account of the foehn effect. Air descending the lee slope warms through compression and becomes drier relative to saturation; rainfall on the windward side and loss of condensate can intensify the contrast.

Urban heat islands, soil moisture and local surface effects are retained only as modifiers of the surface energy balance and boundary layer. The text avoids claiming that cities routinely split or repel storms, a popular model unsupported as a general rule.

Core Idea 2: pressure, wind and rotation

Standard sea-level pressure is conventionally about 1013 hPa. The value is a reference, not a boundary between good and bad weather. The distinction between absolute pressure and pressure tendency follows Met Office guidance on high and low pressure.

The force account follows Holton and Hakim and NOAA JetStream's "Forces and Winds": pressure-gradient force accelerates air, Coriolis deflects moving air, and friction alters the near-surface balance.

Geostrophic wind is an idealisation most useful away from strong friction, curvature and acceleration. Surface flow generally crosses isobars towards lows and away from highs because friction weakens the Coriolis term.

The direction of cyclonic circulation is stated by hemisphere. The Coriolis effect approaches zero at the equator, one reason tropical cyclone formation is rare there. The plughole correction follows the scale argument: container geometry and pre-existing motion dominate an ordinary drain, while planetary rotation accumulates over weather-system distances and times.

The jet-stream discussion follows Holton and Hakim, the Met Office's jet-stream material and NOAA's upper-air modules. Strong horizontal temperature contrasts support strong vertical wind shear. Jet curvature and speed changes can create patterns of upper-level convergence and divergence that favour descent or ascent below. The book avoids treating the jet as a solid current that mechanically tows every surface low.

Core Idea 3: water, humidity and cloud

The phase-change account follows Wallace and Hobbs, NOAA cloud-formation material and the WMO International Cloud Atlas. Water vapour is invisible. Visible clouds consist of liquid droplets, ice crystals or both. Condensation normally occurs on aerosol particles rather than in perfectly clean air.

Evaporation absorbs latent heat; condensation releases it. This is transfer and conversion of energy, not creation of energy. Rising unsaturated air cools through expansion at close to the dry adiabatic rate. Once saturation and condensation begin, released latent heat reduces the cooling rate. The exact moist rate varies with temperature and pressure, so no single value is used in the body.

Relative humidity is a ratio to saturation at the current temperature. It can change through temperature change alone. Dew point is used as a practical indicator of near-surface water-vapour content, with the warning that it does not describe the full vertical moisture profile or guarantee fog.

Cloud-particle growth is compressed into warm-cloud collision and coalescence and mixed-phase ice growth. Virga and evaporatively cooled downdraughts follow NOAA and Met Office cloud and thunderstorm material. Precipitation type is described as a depth-of-atmosphere problem because melting and refreezing layers aloft can matter more than a single surface temperature.

Core Idea 4: stability and shear

The parcel method, lapse rates, inversions and CAPE follow Wallace and Hobbs, NOAA JetStream's "Parcel Theory", and Markowski and Richardson's *Mesoscale Meteorology in Midlatitudes*. A parcel is an analytical approximation. Real air mixes with its surroundings, and different parcel choices can give different instability estimates.

CAPE estimates positive buoyant energy under stated assumptions. Large CAPE can support strong updraughts but does not ensure that convection initiates. The three basic thunderstorm ingredients, moisture, instability and lift, follow NOAA National Weather Service teaching. Wind shear is added as the main organiser rather than treated as a fourth guarantee.

The supercell description follows Markowski and Richardson and NOAA National Severe Storms Laboratory material. A supercell contains a persistent rotating updraught, or mesocyclone. It raises the risk of severe hail, damaging wind and tornadoes, but many supercells do not produce tornadoes. The text does not claim that CAPE, shear or rotation alone predicts tornado formation.

Cloud-form clues follow the WMO International Cloud Atlas. Layered cloud is associated with stable or gently forced ascent; vigorous vertical growth signals convection. Lenticular cloud marks waves in stable flow across terrain. These are diagnostic clues, not deterministic forecasts.

Core Idea 5: fronts and mid-latitude cyclones

The three-dimensional front model follows NOAA's air-mass and frontal cross-section material, Met Office guidance on warm, cold and occluded fronts, and the standard dynamical texts. A front is a transition zone and sloping surface. The line on a chart marks its intersection with the ground.

Warm fronts commonly slope gently and can produce high cloud and broad precipitation before the surface boundary arrives. Cold fronts are commonly steeper and narrower, with more abrupt wind, temperature and dew-point changes. The wording stays probabilistic because moisture, stability, front

orientation, terrain and cyclone structure alter the weather.

The life-cycle discussion uses the Norwegian cyclone model as a teaching model, while stating that real occlusions and cyclones vary. The revision adds the alternative bent-back-front structure common in some ocean cyclones and avoids treating occlusion as one universal thermal arrangement. The energy account follows baroclinic-development theory: mid-latitude cyclones convert available potential energy associated with horizontal temperature contrasts, while latent heating and upper-level dynamics can strengthen and reshape them.

Core Idea 6: storms

The book separates mid-latitude cyclones, thunderstorms and tropical cyclones by energy source, scale and structure. NOAA and Met Office sources support the thunderstorm life cycle, gust fronts, lightning and tropical-cyclone ingredients. Markowski and Richardson support the treatment of lines, supercells, shear and tornado environments.

The no-front weather sequence follows standard tropical and boundary-layer meteorology. Convergence, diurnal heating, sea-breeze boundaries, tropical waves and cold-pool outflows can organise deep convection without a mid-latitude front. The examples are deliberately distributed across a tropical coast, a monsoon regime, warm-water streamers, mountains and desert terrain so the Atlantic frontal sequence is not treated as weather's universal script.

Lightning results from charge separation within storm clouds and electrical discharge. The safety sentence follows National Weather Service guidance: audible thunder means lightning is close enough to threaten. The book does not attempt a full lightning-physics account.

Tropical cyclones obtain energy through warm-ocean heat and moisture, deep convection and latent heating within a rotating warm-core vortex. Adequate Coriolis influence and relatively low vertical shear favour organisation. Sea-surface temperature is not presented as a sufficient threshold by itself. Ocean heat content, atmospheric moisture, stability,

shear, pre-existing rotation and internal storm processes all matter.

Statements about impact are kept proportionate because *Disasters in a Hurry* owns exposure, vulnerability, warning response and recovery. Here, size, motion and terrain appear only to prevent central pressure or category from being mistaken for total impact.

Core Idea 7 and the forecasting sequence

The analysis and data-assimilation account follows Eugenia Kalnay, *Atmospheric Modeling, Data Assimilation and Predictability*, and ECMWF's current "Data assimilation" and Integrated Forecasting System documentation. Observations are blended with a short model forecast to create a physically coherent analysis. No instrument provides a complete atmospheric state.

The observation network description follows ECMWF, Met Office, NOAA and NASA material. Surface stations, radiosondes, aircraft, ships, buoys, radar and satellites sample different variables and scales. Satellite retrievals infer atmospheric properties from measured radiation; radar reflectivity and Doppler velocity infer precipitation structure and motion. Limitations such as beam height, ground clutter and sparse ocean sampling are retained because they affect the mental model.

The historical sequence follows the Met Office archive, Richardson's 1922 *Weather Prediction by Numerical Process*, Charney, Fjørtoft and von Neumann's 1950 *Tellus* paper, NOAA histories of numerical prediction, and NASA's TIROS-1 records. Richardson established a calculational scheme before electronic computers could make it operational. The 1950 ENIAC work produced successful simplified large-scale integrations. TIROS-1, launched in 1960, was the first successful experimental weather satellite.

The forecast model description follows Holton and Hakim, Wallace and Hobbs, Kalnay and ECMWF. Grids cannot calculate all cloud, turbulence and surface processes explicitly, so parameterisations remain necessary. Higher resolution narrows some gaps but does not remove model error or initial-state uncertainty.

Lorenz's sensitivity result is grounded in “Deterministic Nonperiodic Flow” and ECMWF training on chaos and ensemble forecasting. The body avoids a fixed universal forecast horizon. Predictability varies with atmospheric flow, scale, variable and decision. Ensemble forecasts sample plausible initial states and model uncertainty, and their usefulness depends on calibration and verification.

The statement on machine learning was current as of 2 September 2026. ECMWF's AIFS Single had been operational since 25 February 2025, AIFS ENS since 1 July 2025, and both were upgraded to version 2 on 12 May 2026. The body states the operational status directly and says these systems run beside physics-based models. It does not imply that one model family has replaced the other or that data-driven forecasting removes dependence on observations, analysed initial conditions and verification.

Reading the sky and local effects

The cloud sequence ahead of a warm front follows Met Office cloud guidance and the WMO International Cloud Atlas. Cirrostratus can produce a halo and may precede a warm front, but neither sign is guaranteed. The Use It section therefore requires trends in cloud, pressure, wind and moisture to agree.

The account of windward cloud, rain shadow, foehn warming, lenticular cloud and mountain waves follows Met Office and WMO sources. Sea-breeze and valley-flow explanations follow NOAA's local-wind material and standard boundary-layer texts. These examples are mechanisms, not promises about one location.

The statement that a national forecast can be correct while local outcomes differ reflects scale rather than excuse. Terrain, coastlines and boundary-layer structure can alter lift, mixing and precipitation below the resolution or communication scale of a national chart.

Forecast probabilities and warnings

The precipitation-probability interpretation follows the Met Office's current "What does this forecast mean?" guidance, verified 2 September 2026. A point probability refers to the assessed chance of measurable precipitation at that location during the specified interval. Thresholds depend on interval and product, so the narrative avoids presenting one global definition.

Probability calibration is a repeated-frequency test across comparable forecasts. One outcome cannot validate or invalidate a 30 per cent forecast. The book separates probability from amount, duration and impact because each answers a different decision question.

Warnings are described as products combining likelihood and impact across an area. A warned location can avoid the worst outcome because the decision was made under uncertainty before the track was known. Detailed warning practice varies by national service and hazard, so no universal threshold is given.

Misconceptions and corrections

"High pressure always means blue skies" is corrected with Met Office material on high pressure, winter inversions and anticyclonic gloom. "Clouds are made of water vapour" follows NOAA and WMO cloud physics. "Cold air holds less water" is corrected through saturation vapour pressure, relative humidity and dew point.

"A front is a wall of air" follows the three-dimensional frontal model. "The Coriolis effect makes water spin down the plughole" is corrected through scale analysis and NOAA's description of Coriolis. "A 30 per cent chance of rain means rain for 30 per cent of the day" follows the Met Office definition above.

"One dramatic event proves or disproves climate change" follows the IPCC Sixth Assessment, Working Group I, Chapter 11, which assesses observed changes and event attribution in terms of changed likelihood or intensity with confidence that varies by event type and region. The passage neither

denies event attribution nor treats a single event as the whole climate case.

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