METEOROLOGY KNOWLEDGE

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METEOROLOGY KNOWLEDGE

Introduction

The atmosphere is the densest part of the gaseous covering that envelops our planet. Due to its weight and to the property that gases have of being compressible, the whole atmosphere is in a state of hydrostatic equilibrium: this determines a horizontal stratification, in concentric 'strata', of the surfaces having not only a constant pressure (isobaric surfaces) and density, but also other magnitudes such as temperature, humidity or degree of ionization. The layers which are of greater interest to meteorology are the troposphere and the tropopause. Together they reach a width of about 26 km: it is here that all meteorological phenomena take place.

The main atmospheric parameters that must be known to study meteorological events are the amount of thermal energy that reaches the Earth (the temperature of the ground and of the air), atmospheric pressure and the humidity contained in the air.

What is meteorology

A great quantity of heat reaches the Earth from the Sun, through the layers of the atmosphere. Only a part of solar radiation reaches the Earth's surface: 34% of solar radiation is reflected into space by the atmosphere, by clouds and by the Earth's surface itself. Of the remaining 66%, 19% is absorbed by water vapour, by clouds and by the ozone layer and only 47% on average is absorbed by the Earth's surface. Solar energy reaches the ground largely in the form of ultraviolet rays, that pass through the atmosphere easily and are subsequently absorbed by the ground. On getting heated, the ground releases the energy in the form of infrared radiation which has a longer wavelength but is more calorific. Infrared radiation is in turn absorbed by the atmosphere, that gets heated: in practise, therefore, the atmosphere behaves like the glass of a greenhouse that allows ultraviolet rays to pass but detains the infrared ones.

Different behaviour. If the air is dry, the majority of solar radiation reaches the ground, which gets heated and which in turn, as a result of a conduction mechanism, heats the air it comes into contact with. The heated air in turn loses heat to the air surrounding it, by means of a convection mechanism, and in this way the heat of the Sun is redistributed through the entire atmosphere.

Things work out differently if the air is humid: the water vapour heats up, in fact, because it is capable of absorbing great amounts of solar radiation directly. In this way the atmosphere gets heated directly by the solar radiation and it, in turn, releases heat to the ground it comes into contact with. Atmospheric dust behaves in the same way, and so do carbon dioxide, methane and those that are commonly referred to as 'greenhouse gases'. In the same way as they absorb heat emanating from the Sun, these components of the atmosphere prevent the heat originating from the ground in the form of infrared radiation to move away, thus contributing to the heating of the lower levels of the atmosphere, a process that has become well-known as the "greenhouse effect".

This property can be easily verified during the night: we all know that, observing a winter sky bright with stars, we are bound to have a cold night with possible nocturnal frost, while an evening with a cloudy sky will definitely be warmer. The greenhouse effect is therefore a natural process: what is not natural is the great amount of 'greenhouse' gases that human activities release in to the atmosphere.

Unequal energy distribution. The amount of solar energy that reaches the Earth's surface depends on different factors, the most important of which is the magnitude of the angle formed between the direction of the Sun's rays and the surface itself: the greater the angle, the greater the amount of thermal energy that reaches the ground per unit of surface area. Theoretically, the angle of incidence of the Sun's rays should be greatest at the Equator, but due to the inclination of the Earth's axis, it varies during the year and is maximum in the belt that runs between the Tropics. The angle of incidence decreases at higher latitudes: for this reason, at low altitudes, the average temperature is greater than at higher altitudes.

The inclination of the Earth's orbital plane and the fact that it is elliptical, together with the inclination of the Earth's rotational axis, are therefore the cause of the differences between the various climatic zones of the Earth, of the alternation of the seasons and of the meteorological variations connected to them.

Atmospheric pressure

On Earth, atmospheric pressure is equal to the weight of the air column that 'weighs' on the Earth's surface. This is true at any altitude, but 99% of the atmosphere's mass is concentrated in the first 32 km. Pressure variations at sea level do not usually exceed 4% of the normal average value (that is 1013 millibar): lower values (up to 900 millibar) can be registered in the eye of tropical cyclones. With the exception of some small local variations, atmospheric pressure and density decrease with altitude following an exponential curve up to a level of about 100 km, where they reach a value equal to one millionth of the value at sea level.

Atmospheric pressure is not distributed uniformly in the atmosphere because it depends on different factors, among which temperature (warm air expands and is therefore lighter) and humidity (since water vapour is lighter than air, damp air is lighter than dry air). Hence, atmospheric pressure proves to be higher in polar regions, where the air is colder and dryer and lower in equatorial regions, where the temperature and the humidity of the air are greater. Moreover, atmospheric pressure undergoes daily variations that can be compared to the tide phenomenon.

Unit of measurement of atmospheric pressure. At sea level, the density of air is about 1.3 g/dm3 and decreases exponentially with altitude. Furthermore, at sea level, atmospheric pressure, and therefore the weight of the air above it, is equal to 1,033 g/cm^2. This weight is equivalent to the pressure of 1 atmosphere (atm), i.e. to the weight of a 760 mm high mercury column with a cross-section of 1 cm^2. In meteorology, this 'historical' unit of measurement is not used any more. The millibar (mb) is the unit that is generally utilized and it corresponds to a force of 1,000 dyne/cm^2: a dyne is the force required to impart an acceleration of 1cm/sec^2 to a mass of 1 gm. One million dynes/cm^2 correspond to one bar, and the millibar is a thousandth of the bar. Recently, with the adoption of the International System in 1974, pressure really ought to be expressed in Pascals (Pa). 1 Pa corresponds to 1 Newton/m^2, 1 atm is equal to 100,000 Pa, i.e. to 1,013 millibar: since the Pascal is a very small unit, in meteorology hectopascals are used (hPa), equal to 100 Pa.

Temperature: hot zones, cold zones

The minimum temperature of the Earth's surface is registered at dawn, the maximum temperature between 3.00 p.m. and 4.00 p.m. The mathematical average of the two figures gives the average daily temperature. From the average of the daily temperatures in one month, the monthly average is obtained and from the average of these monthly averages, the average annual temperature is calculated. The annual average temperature of the Earth's surface is about 15°C, but local variations are considerable, with a wide range of daily and seasonal temperatures and significant differences from one point of the Earth to another. The lowest temperatures ever registered were taken at the Antarctic station of Vostok (- 91.5°C), while the highest were taken in Death Valley in California (+ 55.6°C).

The temperature of the atmosphere varies vertically too, decreasing from 15°C on the Earth's surface to -57 °C in the highest part of the tropopause. Atmospheric temperature depends firstly on the latitude, as a result of the different inclination with which the Sun's rays reach the ground. For this reason different thermal zones can be identified: the torrid zone, between the Tropics of Cancer and Capricorn, two temperate zones in the two hemispheres situated between the tropics and the polar circles, and two polar zones, found at latitudes beyond the Arctic and Antarctic Polar Circles.

Many factors

Temperature also depends on many other factors such as altitude, the position of the emersed land and of the surrounding seas, exposure to the sun, vegetation covering the soil, prevailing winds, the characteristics of the land etc. In particular, since it depends mainly on the irradiation of the earth, temperature diminishes with altitude, with an average vertical gradient of about 0.6°C every 100 m higher you climb: it is for this reason that the higher the altitude, the lower the temperature.

The proximity of large masses of water, such as seas or big lakes, is also important: due to the fact that water is characterized by a greater thermal inertia, close to vast bodies of water the climate is milder in winter and cooler in summer. Marine currents, moreover, can contribute directly, by carrying masses of warm water to cold places and vice versa, thus modifying the local temperatures: just one example suffices for all – the effects of the warm Gulf Stream on the cold Atlantic coasts of North Europe.

The distance away from the sea, instead, has the effect of increasing the temperature range between summer, that is very hot, and winter, that is very cold, typical of continental areas far from the sea: an example is the Verkhojansk locality in Siberia where the greatest seasonal temperature range can be observed, with a temperature of – 68°C in winter and of + 30°C in summer.
Even the kind of soil and the vegetation covering it influence local temperature variations, depending on the so-called albedo, i.e. the capacity to reflect the light of the Sun. The albedo varies from 5% on the surface of the sea, to 5-15% in forests, to 15-20% in cultivated fields, to 50-70% on glaciers and 80-90% on fresh snow. The vegetation contributes to determining local temperature even by producing water vapour that absorbs the radiation in the infrared band.
Even the transparency of the air is an important factor: a minor transparency can prevent infrared radiation irradiated from the ground from dispersing, which determines an increase in the temperature, or, on the contrary, it can prevent solar radiation from reaching the ground, determining a decrease in temperature. The transparency of the air depends on its content of gases such as CO_2, water vapour, polluting substances such as sulphur dioxide and sulphurous anhydride and on atmospheric dust.

The vertical thermal gradient

Air temperature decreases by about 0.6°C every 100 m you climb, a value that may be considered the normal thermal gradient in the lower strata of the atmosphere, but that can register local variations. In particular, when air masses move vertically, a new situation can arise in which there is imbalance with the surrounding air temperature, determining anomalous zones that are either colder or warmer.
At times situations of so-called thermal inversion can take place when the temperature, instead of decreasing, increases with altitude. This situation can take place when, for example, many days of good stable weather tend to make the air stratify according to its density, with the cold heavier air touching the ground and the warm lighter air at a higher altitude: this phenomenon occurs frequently in winter on the plain of the Po river resulting in persistent and widespread areas of fog. Thermal inversion can also occur in valleys that are not very windy as, for example, the Valtellina valley that is set out perpendicularly respect to the prevailing winds and where the air stratifies, with colder air on the valley floor. Yet another example of thermal inversion takes place when a mass of cold air wedges itself under a mass of warmer air as in the case of the cold front of a perturbation. In the air that covers large cities a situation of thermal inversion can prevent the dispersion of pollutants, giving rise to smog: it is not surprising that the alarm signals warning that the pollution levels have been exceeded in our big cities are more frequent in winter. The word smog derives from the words smoke and fog: it is in fact a mixture of drops of water and solid particles (generally made up of dusts and residual combustion products).

Isobars e isotherms

In order to indicate the pressures and temperatures of the atmosphere at ground level and at high altitudes in various parts of the Earth, special charts are created. The Isobar chart or Pressure chart, shows the pressure distribution. From the Greek words isos, equal and baros, weight, having an equal pressure, isobars are lines that join together points having an equal atmospheric pressure, analogously to the isohypse contour lines (to indicate equal altitudes) that are used to show the mountains on a topographical map. Since the pressure of an air mass depends on its altitude and the temperature, in order to compare the pressure values in different zones at different altitudes and different temperatures, it is necessary to make the data “uniform” before indicating them on a chart. With opportune conversion tables, the pressures are brought to sea level and to the same temperature, which has been agreed to be 0° C and only after this fundamental operation they are marked on the charts. Isobar charts are a basic instrument for meteorology, because they enable the identification of zones with greater or lesser pressure, which are very important in the determination of atmospheric circulation.

In order to represent the trend of the pressures at the higher altitudes better, isohypse charts are used instead. These charts show the trend at the high altitudes, compared to sea level, of the surface of a given pressure value (usually 500 mb), in a manner that is analogous to the topographical contours, where the isohypses refer to the Earth’s surface.

In the same way it is possible to draw isotherm charts, i.e. the lines joining points of equal temperature. Also in this case, before drawing the chart it is necessary to eliminate the effect of the altitude and convert the data to sea level values.

It is very useful, in order to analyze the climate and to make weather forecasts, to compare the isobar charts, (on ground level and at high altitudes) and the isotherms recorded at different hours of the day and in different periods of the year.

Humidity

Atmospheric humidity is the amount of water vapour contained in the air. It represents a very small percentage of the water present on Earth (about 0.01%), but it is very important for the role it plays in the water cycle. It is in fact through atmospheric humidity that water moves, passing from oceans and seas to dry land: nearly all the water vapour that is present in the atmosphere originates from the evaporation of the ocean and sea waters and the contribution of continental sheets of water and evapotranspiration of the land and vegetation is very small.

Atmospheric humidity is not distributed uniformly, but varies greatly in the different regions of the Earth: both regions where the atmospheric humidity is very high and others in which the air is dry and devoid of water vapour, like in the desert regions, can be observed.

Absolute and relative humidity. Absolute humidity is measured weighing the water vapour (in grams) contained in 1 m3 of air. This, however, is not a very useful parameter in meteorology: it is

more important to know how much water it is potentially possible to obtain in the form of rain from a given quantity of air. For this, another parameter, relative humidity, is utilized.
At a certain temperature and pressure, air can contain a fixed quantity of water vapour: when this amount is reached, the air becomes saturated with vapour and any small variation of pressure or temperature or any addition of vapour make the air over-saturated: the excess water vapour condenses in the form of small drops of liquid water. For a determined amount of water vapour contained in air at a fixed pressure, the temperature at which condensation takes place is called condensation temperature or dew point temperature. Relative humidity is the percentage ratio between the quantity of water vapour present in the air and the quantity of vapour required to make the air saturated with moisture, at the same temperature. A relative humidity of 100% indicates that the air is saturated with vapour and about to condense the water vapour in the form of drops of water: from a meteorological point of view, it is a condition that is potentially favourable to bringing about precipitations. On the contrary, a low relative humidity indicates dry air that is not favourable to precipitations.

Humidity and temperature

The amount of vapour that the air can contain depends greatly on its temperature: the hotter the air is, the greater the amount of water vapour that it can contain. On cooling a mass of air, it becomes over-saturated and the vapour condenses in the form of microscopic droplets of water. We can appreciate this phenomenon observing the behaviour of the air that we exhale: our breath contains a certain percentage of water vapour, that, at 37°C (our body temperature) is far from saturation point. If we breathe in cold surroundings, the exhaled air cools, becomes over-saturated and the excess vapour condenses in the form of little droplets of water (that we incorrectly call 'vapour', but which in actual fact is liquid water: water vapour is a transparent, colourless, invisible gas). If we exhale in warm surroundings, instead, this phenomenon does not occur, even though the quantity of vapour contained in the exhaled air is always more or less constant.

Precipitations

Precipitation includes all forms of additional water, in the liquid or solid state, that fall or form on the Earth's surface. They can be subdivided into direct precipitation, such as rain, snow and hail and occult precipitation, such as dew and frost, that do not derive from clouds but form directly on contact with the Earth's surface. Liquid precipitation, or rain, takes place when drops of water present in a cloud grow bigger and bigger until they are too heavy to remain in the cloud and therefore fall to the ground.
The mechanisms by which the cloud drops grow bigger are several: by absorbing water in an over-saturated atmosphere or, specially by coalescence, that occurs when drops collide against each

other on falling. The limit that separates cloud drops from rain drops is around 100 micron, but generally rain drops are much bigger, at times greater than 2000 micron.

Snow

Snowflakes are an aggregation of ice crystals formed from vapour condensing within clouds at a temperature below 0°C. Contrary to what you might think, water vapour and low temperatures are not the only conditions needed to form ice crystals. Dust particles are crucial for this process, as water vapour molecules form around them aggregating to create crystals. A newly-formed ice crystal arranges into a column-shaped hexagonal structure. Then, aggregating with other water molecules, it changes an infinite number of times gaining an incredible array of different natural shapes. In some cases, ice crystal are higher rather than larger and create needle shapes. Other crystals are larger and create wide hexagonal plates. Arms sprout from the six corners of the initial hexagonal prism and further branches develop on them creating spectacular shapes (dendritic growth).

Each ice crystal has a unique story: from its origin to the moment it falls to the ground, it passes through different atmospheric areas which vary in terms of temperature and humidity, the main factors influencing ice crystal shaping. Moreover, every ice crystal is formed by billions of water molecules aggregating unpredictably. For this reason, it's impossible for two ice crystals to be alike!

Snowflakes: the air-cleaners. Many scientists have focused their research on ice crystals and snowflake formation. One of the first to study this phenomenon was Descartes who published a treaty on their morphology. To this day the formation mechanisms of ice crystal aren't completely known. Scientists haven't found out yet why water vapour aggregates to existing crystals favouring either the prism walls, bases or corners according to temperature and humidity. Scientists' main goal is understanding why snow is the best "air-cleaner". Among all pollutant substances depositing on the ground, as much as 90% are incorporated in ice crystals and snowflakes. These substances are snow aggregation nuclei: particles are incorporated in the ice crystals during formation and deposited on the ground when snow falls. Some scientists believe that understanding the mechanisms of their formation could be useful to create more effective anti-pollution filters.

Hail

Connected to thunder clouds, hail is made up of practically spherical masses of ice. Each hailstone is made up of hundreds of ice crystals, in alternate transparent and translucent layers due to the presence of air bubbles. The transparent crystals form slowly in the inferior portion of a cumulonimbus, that is characterized by higher temperatures, while the opaque crystals are typical of the superior portion, where the lower temperatures cause the rapid formation of crystals that trap air bubbles as they grow. The alternate layers of each hail stone indicate that the strong vertical currents and the turbulence present within a cumulonimbus can transport the hailstones from one portion to the other of the cloud before they fall to the ground. In Italy, the dimensions of the hailstones generally do not exceed a couple of cm, but in tropical countries hailstones can reach sizes greater than 10 cm, up to a maximum of 20 cm!

Fog

Fog is a sparsely dense not very thick layer of cloud that forms on contact with the ground in particular meteorological conditions. Generally the drops of water in a fog are smaller and less numerous than in a cloud, for this reason fogs are less dense and more transparent than clouds.
Fogs form when there is a difference in temperature between the ground and the air above it. Radiation fog forms after sunset, when the temperature of the ground decreases, provoking a slow cooling also of the air above. If the temperature drops below dew point, a fog forms. Generally the formation of fogs is favoured by the presence of stretches of water that provide water vapour to the air, thus making it more humid.
Advection fog, instead, forms when the wind brings humid warm air over colder stretches of land, or on the contrary, when cold air rests above a warmer stretch of water, such as the fogs that form over the North Sea , where warm humid air, that moves following the Gulf Stream, comes into contact with the cold waters of the North Sea, or along the coasts of Peru and Ecuador, where, on the contrary, the fog forms due to the contact of the cold waters of the Humboldt current and the hot humid equatorial air. With a similar mechanism also coast (sea) fogs form, these can be seen in the morning along the coasts and dissolve rapidly during the course of the morning.
Persistent fogs, that are typical in the winter season in the Po valley, instead, are due to cold air that descends into an anticyclone area: if there is humid air near the ground, due to the presence of sheets of water or due to the humidity in the soil (for example the humid soil in the paddy fields), the humidity in the atmosphere condenses giving rise to heavy fog that persists as long as the high pressure conditions continue.

Dew and frost

When the ground, dispersing heat by radiation, reaches dew point, the air that is directly in contact with it, condenses and deposits drops of water directly on the ground, and on all the surfaces the air comes into contact with, thus forming dew.
Dew supplies a quantity of water that can be important in some particular situations: where there is no direct precipitation, the vegetation however receives an amount of water that is sufficient for its vital processes. For this reason these are known as occult precipitations, i.e. they are not directly visible. It is not easy to evaluate their quantity, but these precipitations must be taken into account when calculating the ideological balance of the water cycle. In fact dew is partly absorbed by the ground, and a part of it evaporates during the day, and thus becomes part of the water-cycle once again. This type of water supply is fundamental for the survival of plants and animals in arid, semi-

desert zones. **Frost** forms at temperatures below 0°C, due to the dew that freezes or due to direct precipitation of small ice needles. **Rime**, which is known as *galaverna* in a dialect of Northern Italy, is a particular form of frost, characterized by large needle-shaped ice crystals which may be transported by the wind, and cover all the surfaces following their contours in their finest detail, as for example blades of grass, twigs, electric wires and antennas. Frost too, belongs to the category of occult precipitations. It can melt and evaporate during the course of the day, or it may remain on the ground for various days, depending on the temperatures. If frost deposits on snow and is then covered by snowfall, a level of ice crystals may form within the layer of snow that is not very coherent, and may cause the release of slab avalanches.

The weather

Weather, from a meteorological point of view, indicates the set of atmospheric phenomena that take place at a particular moment in a part of the Earth. Some phenomena have a strictly local influence, limited to extremely restricted areas, while others involve entire regions. Atmospheric phenomena are characterized by great variability and small local variations can contribute in making the weather evolve into situations completely different from those foreseen.

Air masses. Air masses, in a meteorological sense, are volumes of atmosphere with uniform temperature, pressure and humidity. Air masses can be subdivided into six big categories: Arctic air (very cold and very dry), Continental Polar air (cold and dry), Maritime Polar air (cold and humid), Continental tropical air (hot and dry), Maritime tropical air (hot and humid), Equatorial air (hot and very humid).

Perturbations. Perturbations are all climatic and meteorological events that, in some way, disturb the state of equilibrium the atmosphere is in. Since it is a dynamic equilibrium, that varies continuously, it is difficult to establish what exactly a perturbation is when the atmosphere is in a ‘normal’ state, hence the term perturbation today is synonymous with events that bring on bad weather, precipitation or atmospheric events that are in some way unpleasant or threatening for man. In general, from a meteorological point of view, a perturbation is created every time there is interaction between air masses at different temperatures and pressure, even though this does not necessarily mean bad weather and precipitations.

Fronts

A front in a meteorological sense is the zone of contact between air masses with different density, temperature and humidity. The frontal band is the area in which two air masses come into direct contact, the area in which energy exchanges take place and where the more intense atmospheric phenomena are produced. Generally, a front appears as a more or less regular surface, with a low angle, slightly inclined, and it generally forms a curved line on the horizontal plane. Meteorologists identify three types of fronts: cold, hot and occluded.

When hot or cold fronts form, the condensation processes free thermal energy and this contributes to creating areas at different temperatures, triggering off local circulation and mixing and contributing to a further increase in the instability of the air masses.
The front of a perturbation, in the initial phases of its formation, is generally related to the so-called wind front, that is associated to the progress of cold masses of air that descend from the perturbation. At times the wind front is made visible by dust clouds that rise from the ground (as in dust storms) or by the condensation front that gives rise to the formation of spectacular arc-shaped clouds on the same level of the perturbation front.
The presence of mountains along the course of the front can bring about variations and deformations of various kinds that can make the perturbation evolve in an unpredictable way.

Storms

Perturbations that bring storms are formed when there is a collision between two air masses at different temperatures or when the excessive heating of the ground, along with a high level of humidity, brings about the formation of masses of warm, humid air. The mechanism is the same as that which leads to the formation of fronts and cloud systems (ascent, cooling and condensation), but owing to the great differences in temperature, the phenomenon is more intense and 'energetic'. Storms are therefore typical of warm, humid regions, such as tropical and subtropical zones, or our latitudes during the summer months. The mechanisms that lead to the formation and evolution of storms were studied at the end of the Forties at the University of Chicago in a research programme called Thunderstorm Project, that brought to the construction of a clear picture regarding these atmospheric phenomena. The indicators connected to a storm cloud (winds, precipitation even including hail, lightning) can be very violent and destructive and in particular conditions storms can evolve into tornadoes or whirlwinds.

Cyclones and hurricanes

Around low pressure areas, air circulation generates a depression vortex called a cyclone. The circumstances that lead to the onset of a cyclonic circulation are always the same: the low pressure centre attracts air from the surrounding areas with an anticlockwise movement in the Northern Hemisphere and a clockwise movement in the Southern Hemisphere.
But cyclones are not all the same. Why are some violent and unexpected, real catastrophes? Why do some last for months? Why are others relatively 'calm' and do not cause damage?
In theory, the greater the difference in pressure, the greater the violence and speed of the winds and therefore the more destructive the cyclone will be. However, generally, the differences in pressure are relatively small and similar in each vortex (normally, a couple of tens of mb). It all depends on the size of the low pressure area. Considering that the difference in pressure is constant, if the low pressure area is extended, the pressure gradient will be low and the winds relatively 'slow';

if, on the other hand, the area is restricted, the high pressure gradient will provoke violent, very fast-moving winds which in some cases can exceed 250 km/hr, reaching up to 400 km/hr like in tornadoes or whirlwinds.

Therefore there will be considerable differences between the power of a so-called extratropical cyclone, like those that occur in our latitudes and that are extended over areas with a diameter of thousands of km, and that of a tropical cyclone, or of a hurrican, that rarely has an extension that exceeds hundred kilometres. Even more destructive, but on a strictly local scale, are whirlwinds and tornadoes (from the Spanish word for ‘vortex’), or their marine equivalent, the waterspouts, that generally have dimensions of a couple of hundreds of metres: these are the most violent meteorological phenomena even though they are not the most destructive because fortunately they are small and they last a very short time.

Tornadoes

Tornadoes form evolving from cumulonimbus storm clouds when the atmospheric conditions are particularly humid. They begin with the downward shear of a part of the cloud, thus forming a funnel-shaped cloud that is the first sign of the birth of a tornado. The funnel cloud descends gradually towards the ground: if it reaches the Earth’s surface, it becomes a tornado. The dimensions of the funnel cloud are indicators of the strength of the tornado, and range from 15 m to a couple of kilometres in diameter. Along the surface of the funnel, air is rotating rapidly, with a spinning ascending motion. Tornadoes move over the Earth’s surface at a speed that can reach 120 km/hr, but the speed of the rotating winds within a tornado can reach 450 km/hr with ascending wind speeds of 290 km/hr. The pressure inside the vortex can be practically reduced to zero, and it is for this reason that tornadoes behave like enormous ‘vacuum cleaners’, that collect whatever they find along their path: houses, cars, trees, livestock, whatever happens to be on the course of a tornado gets uprooted and flung upwards. Just like in tropical cyclones, inside the vortex instead, the air is calm and practically motionless. There are several accounts of people who found themselves miraculously safe and unharmed inside the vortex of a tornado, or of livestock that was lifted up and then deposited unhurt on the roofs of buildings, or of electric and telephone cables completely coated with hay and of other ‘curious’ facts. As the destructive energy gets depleted, the funnel of the tornado slows down its run, the winds inside decrease in speed and the funnel changes shape taking on a flexuous, snake-like form, a clear indication that the energy of the tornado is running out. Tornadoes are surely the most destructive meteorological events, but generally the devastations take place on a reduced scale, in other words they bring about an almost total trail of destruction in their wake but over relatively restricted areas, unlike hurricanes. Generally, tornado damage paths range from 90 to 1,500 m. On average, a tornado dissipates within 15 minutes and covers around 15 kilometres, but some of the bigger clouds can travel even 400 km and last for several hours.

Whirlwinds

Whirlwinds are similar to tornadoes, but are decidedly smaller and with less energy. When they evolve from storm clouds, they behave like small tornadoes and can be quite destructive. Whirlwinds, also called dust devils, with smaller dimensions and minor energy, usually form in very warm and dry air conditions in desert regions or in the plains and are not associated with clouds or precipitation. These vortices are triggered off by convective phenomena caused by intense heating of the ground. 'Dry' whirlwinds of this kind are very frequent in the SW of the United States, where generally their size is limited, and they cause no damage. A game that American children living in this area often play, is to try and chase the whirlwind and enter inside the vortex: when they succeed in doing this the convective process gets interrupted and the whirlwind vanishes.

Waterspouts. When a tornado or whirlwind passes over a body of water (the sea, but also a lake), it is called a waterspout. Usually, they dissipate as soon as they touch land, but in some cases they can travel several kilometres inland. The vortex sucks in air and water as it passes, so that its walls are made up of rapidly rotating water. In this case, a curious phenomenon may occur whereby fish, frogs, and other aquatic animals that the whirlpool has collected along its path appear to rain from the sky when they are abruptly released after the waterspout ceases.

A thunderstorm breaks

The main atmospheric phenomenon associated with a thunderstorm is surely the rain, that often arrives in the form a sudden violent downpour. It has been calculated that only 20% of the humidity accumulated in the thundercloud is actually returned in the form of rain. Often precipitation may take the form of hail, that forms when the temperatures inside the cloud allow the formation of ice crystals.

Also the wind is a phenomenon that can have a particularly violent nature during a storm, and it can evolve, at times, into a tornado or hurricane. Surely the most impressive phenomenon of a thunderstorm is the lightning, electric discharges that are produced within the cloud, between different clouds, and between the clouds and the ground. Thunder is the "noise" produced by the movement of air provoked by the electric discharge and therefore is only a "collateral" manifestation.

Lightning

Lightning is one of the most typical and characteristic manifestations of thunderstorms. Lightning is visible in the form of electric discharges that originate from the thundercloud and hit the ground, however the phenomenon is much more complex, and since it takes place at the speed of light, it is so rapid that we are unable to understand it immediately.

Lightning is an electric discharge inside a storm system. Lightning can occur within a cloud, between adjacent clouds, or between the clouds and the ground. Generally about 80% of the electric activity

of a storm cell is discharged within the cloud or between two clouds and only 20% of the discharges take place between the clouds and the ground. Notwithstanding this, it has been calculated that streaks of lightning hit the ground at a rate of over 100 per second!
Above the 0°C thermocline, water in the cloud takes the form of ice crystals which have a positive charge on the surface. Instead, under the thermocline the drops of water have a negative charge. In this way within the clouds that extend vertically beyond the 0° C isotherm, strong differences in potential form between zones with opposite electric charges. Thus electric discharges are produced between the zone with the positive charge and the negative charge zone. This occurs within the cloud, but also between two clouds when zones with different electric charges come into contact.
It is slightly more complicated to explain how lightning is discharged to the ground. The Earth's surface generally has a negative charge, as also the base of the storm clouds. Electric discharges of the same sign tend to repel each other therefore, during a storm, on the Earth's surface, where the negative charges have been pushed away by the negative charges of the base of the cloud, areas with a positive charge are formed.
When charges of opposite signs accumulate, due to their reciprocal attraction, a channel of ionized air forms, which propagate from the cloud to the ground, and that is known as the stepped leader. As the stepped leader reaches the ground, from the Earth's crust a second stroke is triggered, that reaches the stepped leader before it connects to the ground: this is what we see as the main lightning stroke. Obviously this all takes place at the speed of light in only a few milliseconds, therefore it gives us the illusion that the lightning stroke travels from the cloud towards the ground. If on the ground there are concentrations of positive charges that are close to each other, a number of return strokes may leave the ground simultaneously toward the same leader, and the lightning appears in the typical shape branching downwards.

Thunder

When lightning is generated, the electric discharge produces a great quantity of heat that ionizes the surrounding air, transforming it into a plasma (gas consisting of only electrons and nuclei) at an extremely high temperature (10-15,000° C). The air all around expands violently, in a few millionths of a second, provoking the propagation of a compression wave though the air, which we hear as an acoustic wave that produces thunder. Thunder propagates at the speed of sound (350 m/s), while lightning travels at the speed of light (300,000 km/s), therefore the sound produced by the lightning is heard with a slight delay. We can enjoy calculating the distance of a storm cloud by measuring the time-interval from when we see the lightning to when we hear the thunder. With a rather approximate calculation, dividing the number of seconds that have passed by three, we obtain the distance in kilometres.

The rainbow

The rainbow is a phenomenon that has always fascinated man, on one hand because generally it indicates that the end of a storm is near, on the other because of the sight offered by its colours. Who hasn't been charmed by the display of a rainbow, perhaps against a sky darkened by threatening stormy clouds? About rainbows there are a number of myths and legends. For the Greeks it was a visible manifestation of a messenger of the Gods, according to Northern legends, at the far end of a rainbow is a pot containing a fabulous treasure.

In reality, a rainbow is a simple optical phenomenon, caused by the refraction of white light as it passes through the drops of water: analogously to the light that passes through a prism, the sun's light that passes through a drop of water is refracted and separated into its different wavelengths. Diversely from the prism, through which we are able to see all the visible wavelengths of the spectrum at the same time, we are able to see one colour only, only one wavelength for each drop, depending on the height of the drop compared to our position, and the angle of light refraction from the drop to our eyes. Sunlight that simultaneously hits millions of microscopic drops of water is therefore refracted through each one of these (actually light is refracted twice, on entering the drop and when it passes outside). The result is that we see a series of concentric bands of coloured arcs drawn across the sky. The colours derive from the decomposition of the spectrum, that are visible at the different wavelengths, and are always in a precise order (depending on the wavelength) starting from the innermost arc with violet, indigo, blue, green, yellow, orange and red in the outermost arc.

A rainbow can be observed immediately after a downpour, when the sun breaks out between the clouds and it can be seen when the sun is behind our shoulders. A rainbow can form a complete arc from one point on the horizon to another, or only a part may be visible. At times double rainbows can also form, where one is always less brilliant and the sequence of colours is inverted, due to a complicated play of refraction and reflection inside and on the surface of the drops.

Iridescent halos and more faded rainbows with less brilliant colours may also form around the sun or the moon when these are veiled by cloud formations composed of ice needles, like the cirrus clouds. This type of rainbow can easily be seen in high mountain areas.

How it works…

The weather station

The weather station is a small construction in which all the instruments used to measure the principal atmospheric parameters are set up. It is a wood cabin, painted white in order to reflect the Sun's rays in the best possible manner, the sides are louvered shutters in order to guarantee air circulation. The cabin must be placed 1 m above ground so that it is not affected by direct heating from the ground. Many instruments are lodged in the cabin: a thermometer to measure the

temperature, usually the maximum and minimum temperature type, a barograph and, on the outside, an anemometer and an anemoscope and a pluviograph are the minimum standard instrumentation.
The weather station must operate even if an operator is not present on the site, therefore all the instruments must be able to record data. Once, recordings were made on paper supports, and the operators periodically replaced the rolls of paper and collected the data, but now most of the instruments are electronic and are able to record data continuously, transfer them to a computer, and transmit them in real time to the recording stations, usually by means of radio signals.

The barometer

The most precise and accurate instrument to measure pressure is the mercury barometer, on the model of E. Torricelli's barometer invented in 1643. The aneroid barometer is less precise, however it is smaller and easier to use. It consists of a metal container in which a forced vacuum is created and sealed with a light flexible metal cover that rises and falls with variations in the external pressure. The movements of the cover are transformed by a mechanism into movements of a needle along a measuring scale that indicates the value of the atmospheric pressure.
By changing the values on the reference scale, aneroid barometers can be used as altimeters, to measure the height above sea level.
In a weather station, barographs are utilized. These are barometers coupled with a system to indicate the variations in the pressure graphically on a strip of paper. At present electronic instruments are able to transmit data directly to the processing stations and to record them on a computer.

The thermometer

The most commonly used thermometer is the mercury thermometer in which the temperature is measured on the basis of the expansion of liquid mercury in a bulb, however also ethyl alcohol thermometers are used. The thermograph that enables the recording of temperatures over a period of time is more complex: generally it consists of a bimetallic lamina, in which two different metals, that are welded together expand differently with the same variation in temperature.

The hygrometer

Relative humidity is measured with instruments called hygrometers. The most widespread are the hair type hygrometer, that exploit the unique property of human hair to stretch proportionally with the relative humidity (as those who have curly hair well know, when the air is humid, hair becomes more curly and knotted).
In meteorology more precise instruments called psychrometers (from the Greek word psycros, cold) are used. These consist of a couple of thermometers positioned side by side, one of which has a

bulb covered with a cloth soaked with water. So long as the relative humidity is less than 100%, the thermometer with the wet bulb shows a lower temperature than the dry one, and the difference increases when the relative humidity decreases. By means of special tables it is therefore possible to calculate the relative humidity from the difference in the temperatures measured by the two thermometers. In fact, in order to make the water of the wet bulb evaporate, energy is necessary, which is subtracted from the bulb, which cools. The speed of evaporation, and therefore of the bulb cooling, is greater when the relative humidity is lower (i.e. when the air is dryer). When relative humidity is equal to 100% and the air is saturated with water vapour, instead, evaporation on the wet bulb stops and the two thermometers show the same temperature.

The rain gauge

The amount of water that falls on the ground is expressed in millimetres, i.e. the height the water would have reached had it fallen on a horizontal impermeable surface. One millimetre of rain that falls on a surface of 1 m2 is equivalent to one litre of water collected. The amount of rain that falls is measured with pluviographs. These consist of a cylinder shaped container, positioned in a special weather cabin, above which is a collection funnel that has standard characteristics. The water that is collected is weighed and the data are recorded automatically and forwarded to a processing unit. Snowfall is collected on special tables, and the height is measured with measuring rods. Electric heating elements positioned on the funnel of the rain gauge melt the snow and thus the millimetres of rain, equivalent to the snowfall are obtained.

The anemometer

Wind speed is expressed in km/h or knots (1 knot = 1.852 km/h), or, more rarely in meteorology, with the Beaufort scale (proposed in 1805 by the English Admiral Francis Beaufort, to classify the winds according to their intensity).

Anemoscopes measure the direction of the wind and consist of simple metal vanes that rotate on a pivot and align with the direction of the wind (like the weathercocks on the roofs of houses or windsocks in the airports, that also provide an estimate of the speed of the wind depending on how the sock expands). A special instrumentation allows automatic recording of the data. Anemometers instead enable measurement of the wind speed with a small “pinwheel” that spins at a speed that is proportional to the speed of the wind. Generally, anemoscopes and anemometers are coupled in the same instrument. The more modern models are electric and special transmitters enable the transmission of data in real time to the processing station.

The heliograph

Insolation is when the Sun shines above the horizon on a given point of the Earth. This is measured by means of a helio-phano-graph, which consists of a spherical lens that concentrates the Sun’s rays

on to a strip of special thermal paper that blackens when hit by the Sun's rays that have been concentrated by the lens.
The energy received from a given surface, instead, is called global radiation, and is measured with an instrument called pyranometer or solarimeter, and is expressed in calories per unit of time per surface unit.

The weather forecasts

The capacity of making weather forecasts has always been one of Man's requirements, in order to be able to manage and plan all his activities, from his leisure time to sports, to agricultural activities and industrial activities in the open air.
Nowadays our knowledge about the weather and meteorological phenomena has greatly improved, even though we are far from totally comprehending them, and consequently, weather forecasts are increasingly reliable. In Italy the official body in charge of formulating the weather forecasts is Servizio Meteorologico dell'Aeronautica Militare, the Meteorology Service of the Military Aeronautic Service, in collaboration with the European and World Meteorological Organization.
The Meteorology service publishes the official Meteorology Bulletin daily, making use of the data collected in the stations on ground (positioned in all the airports and integrated by other stations scattered around the national territory). Some of these are equipped with instruments for radar monitoring and for launching probe balloons. The data are then integrated with the recordings carried out by the world network of meteorology satellites, in particular by the European METEOSAT satellites.
For short term forecasts, with indications that are valid up to 12-24 hours, ground level and high altitude synoptic weather charts are used. For this type of forecasts, the experience and personal capacity of the meteorologist are still fundamental. Therefore these are very subjective forecasts, and their reliability depends greatly on the meteorologist's ability. For mid-term forecasts, valid up to a maximum of 3-5 days, mathematical-numerical methods are prevalently used. In this case the forecasts are based on a mathematical model of the atmosphere, that represents a state of the weather with a series of equations in which the unknown values are the temperature, pressure, air density and wind-speed. These methods require the use of very powerful and rapid calculators because simulation requires an enormous number of calculations. The evolution of high power computers for civil purposes has taken place, as a result of the research to satisfy the need to carry out calculations in the meteorological field.
For long term forecasts, that are valid from a week to a month, instead, statistical analyses are used, based on series of meteorological data over a period of time. In practice the mean conditions of the weather in the past are studied in order to foresee the possible behaviour of the weather in

analogous meteorological conditions. This type of study is more suited to study the climate than to solve the problems of weather forecasts.

Global network

On ground level, meteorological observations are carried out by a network of over 10,000 stations distributed all over the Earth's surface, to which we must also add the numerous mobile stations on ships and aircraft that are equipped for the purpose.

The main observations are pressure, temperature, air humidity, direction and speed of the wind, precipitation, clouds. The more important stations also measure insolation, the sun's radiation, evaporation and ground temperature. The data that are collected enable the reconstruction of the weather charts on ground. In Italy, the stations are managed by the meteorology service of the Military Aeronautics, and are connected to the international network, coordinated by the World Meteorological Organization. All observations and transmission of data are carried out according to a precise international code.

The ground stations' data are integrated with the data recorded by the satellites, that are connected to each other through the worldwide network of meteorological satellites. The World Meteorological Organization carries out the task of collecting the data, coordinating and codifying the exchange of information of various Countries, so that it is possible to work at the problems connected with the weather and climate on a global scale.

At present, thanks to the Internet network, it is possible to access numerous sites that are concerned with meteorology, including the national services, where it is possible to consult weather charts and have access to forecasts and satellite images.

What is a weather chart?

Weather charts are the fundamental basis for weather analysis and forecasts. They are based on the data collected by weather stations on the ground and on the data recorded at high altitudes by probes and satellites. Most modern instruments are able to guarantee a continuous recording of atmospheric data, but the weather charts are created using the data recorded at preset conventional timings, so that they may be comparable with one another in different locations around the world. The timings set by the World Meteorological Organization are called synoptic hours and are at 00:00-06:00-12:00-18:00 hrs.

The related charts are known as synoptic weather charts. All the world stations are connected by networks managed by the World Meteorological Organization and for Europe, by The International Network of European Meteorological Services and the charts are created using standard criteria and symbols, so that they can be compared with each other. A weather chart includes an isobar chart and the representation, with opportune symbols, of the principal atmospheric parameters, such as

wind direction and speed, types of clouds and extension of the cloud formations, the position of warm, cold and occluded fronts and the high and low pressure centres.
Weather charts can describe the weather conditions on ground, or at high altitudes, and are the basis for the creation of weather forecast maps.

Interaction with the oceans

The atmosphere, with its movements and the phenomena that take place, is not an isolated and independent system but it is affected by the interaction and exchange of energy with the hydrosphere, the lithosphere and the biosphere. In particular it is not possible to understand the mechanisms governing the behaviour of the atmosphere without studying its relation with the oceans.
The oceans with their enormous volumes of water, form an immense "heat container" that stores very large quantities of thermal energy absorbed from solar radiation. Unlike the ground that returns most of the energy it receives immediately, water has a great thermal inertia, therefore it is able to store large quantities of heat that are then released slowly and returned to the atmosphere. Through the sea and ocean currents, thermal energy is redistributed from the Equatorial zones where there is an excess of heat, to the Polar regions where , on the contrary, there is a "deficit" of energy. Ocean circulation therefore has a very large influence on the distribution of atmospheric circulation cells on a planetary scale, besides, naturally, on the exchanges on a local level. The position of the high and low pressure cells also depends on the large ocean currents system. The transfer of thermal energy carried out by these, in fact, can modify the climate of entire regions. An example is the already mentioned case of the Gulf Current on the climate in Northern Europe, or the contrary case of the cold Humboldt current that touches the coasts of Ecuador and Peru.
Observing the circuits of the principal ocean currents and the atmospheric circulation cells, it can be noted that there is a certain similitude, as if the first mirrors the second or vice versa.
The role of oceans is also important in the carbon dioxide cycle, of which oceans are a large "depot", that subtract it from the atmosphere.

Cities and local climate

Anyone who lives in suburban areas and works in the city has surely experienced the differences in the climate of large urban conglomerations compared to the climate in zones that are far from the city. Cities are generally much warmer than the surrounding areas, besides being more polluted, and in the winter months the conditions for thermal inversion are often present. In other words, large cities seem to modify local climatic conditions. What is this phenomenon due to?
The progressive replacement of land and vegetation by tar, asphalt and cement is the first cause. These materials absorb large quantities of heat, that they then release slowly, behaving as "heat wells". In this manner, the temperatures in the cities are sensibly higher than in the surrounding

areas. Secondly the fact that the buildings that are grouped together, close to one another, hinders air circulation, which also favours the heating process. The progressive increase of cement surfaces prevents infiltration of water in the ground, therefore the land that is built up with cement and covered with asphalt is less humid than natural soil. The air in the cities, therefore is generally dryer. Since the evaporation of atmospheric humidity contributes to cooling the air itself, in this case this characteristic favours heating of the air and also a slower cooling after sunset. For this reason the inhabitants in the cities do not experience the night's cooling effect on warm summer nights.

In summer, most of the heat released by the large cities favours convectional phenomena and the formation of storms. Apparently the presence of very high buildings seems to favour the formation of cumulonimbus clouds. Also the greater emission of polluting substances in the form of gases and dusts, that are typical of industrialized areas with a high population density, contribute to modifying the characteristics of the atmosphere, in particular the capacity to absorb and radiate heat. Statistical studies show that the increase in the temperatures in the cities is proportional to the density of the population.

A global climatic model

Man has always tried to understand the climate and make forecasts on the weather. For agricultural activities, for travel, for transportation, weather forecasts are indispensable in order to plan human activities, but also for the realization of housing, roads, bridges that must resist against the most adverse weather conditions. It is difficult for us to understand a complex system such as the climate on a planetary scale. In fact in order to understand how the climate functions and in order to build a valid and realistic model, it is necessary to understand that the climate is a complex system, a chaotic system made up of a set of orderly sub-systems. In other words, while we are able to understand the single events that take place (a thunderstorm, a snow storm, a cyclone) and to write about the physical laws governing them, we are unable to describe the behaviour of a system, where single events can be summed, using mathematical formulas. In order to describe the climate, therefore, it is necessary to elaborate models that are as similar as possible to reality, however we must be aware that any model will only be a schematic and incomplete representation of the real climatic system.

In the current climatic model it is postulated that the atmospheric circulation, and therefore the climate on a planetary scale, depends on the differences in solar radiation due to both orbital parameters and the Earth's inclination on its axis during rotation. These parameters are responsible for the alternating seasons and the difference in energy between the Equator and at the Poles, and therefore atmospheric circulation is organized in six large high and low pressure cells that are also influenced by the interaction with the ocean currents. The present distribution of the climates on the Earth and their variability during the course of the year, derive from this model. Until significant variations in these parameters and in the physical and chemical characteristics of the atmosphere arise, the present climatic model should theoretically remain valid without any major modifications. However many parameters that are taken into consideration in the climatic model that is currently proposed, are difficult to control and to foresee: and therefore, for example, small variations in solar radiation or small modifications in the oceanic circulation may produce big changes in the climatic model. The problem is to succeed in understanding whether the climatic variability that can be observed every year in different parts of the Earth, the “exceptions” to the current climatic model, are only natural and casual fluctuations, or if, instead, these are precursors of a possible change in the global climatic model.

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