What is meteorology?

Some physics of the atmosphere

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.

Energy from the Sun

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/cm2. 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 cm2. 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/cm2: a dyne is the force required to impart an acceleration of 1cm/sec2 to a mass of 1 gm. One million dynes/cm2 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/m2, 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.

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℃, 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℃), while the highest were taken in Death Vall ey in California (+ 55.6℃).
The temperature of the atmosphere varies vertically too, decreasing from 15℃ on the Earth’s surface to -57 ℃ 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℃ 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℃ in winter and of + 30℃ 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℃ 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 th ey 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 (vedi sezione aria e acqua). 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℃ (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.