

Atmospheric circulation

Moving masses of air

It is difficult to construct a model of atmospheric circulation, because very many factors influence the displacement of masses of air through the atmosphere; however, the fundamental principle is that the gases that make up the atmosphere tend to seek a condition of equilibrium that implies a uniform distribution of energy, equalizing the temperature and the pressure on the entire planet. The 'motor' of atmospheric circulation is therefore given by the redistribution of the energy received from the Sun. Solar radiation, in fact, varies at different latitudes with the result that the equatorial regions are warmer than the polar ones. The atmosphere tends to re-balance this difference moving masses of warm air from the regions where there is an excess of heat towards colder regions, in an attempt to reduce the difference in temperature between the Equator and the Poles.

Differences in temperature bring about immediate differences in the pressure within the masses of air: it is these differences in pressure that cause air displacement. Low pressure areas attract air from areas where the pressure is higher. Vice versa, air tends to move away from high pressure areas towards areas with lower pressure. The speed at which this displacement takes place is directly proportional to the difference in pressure between the two points. In ideal conditions, if the Earth were motionless and if there were no friction or obstacles, air would flow perpendicularly to the isobars (the lines that join points with equal pressure), according to the so-called pressure gradient, following a path that makes the air travel along the shortest route from the high pressure area to the low pressure one. However, many factors contribute to deviating the flow of air from the ideal condition.

The Coriolis effect

The Coriolis effect, that gets its name from the physicist Gaspard Coriolis who postulated the theory in the 19th century, is an effect, caused by the Earth's rotation, that acts on moving bodies on the Earth's surface. It is also known as Coriolis force, but this definition is incorrect since it is not really a force, even though its effects may appear similar to those of a force to an observer within the system. As a consequence of the Earth's rotation, any object that travels in a straight line will undergo a deviation in its path that will take it far from the desired point unless it can carry out continuous changes in its course. In the Northern Hemisphere, every moving object will tend to drift towards the right, while in the southern hemisphere it is towards the left. To an observer within the system, it may seem that there is a mysterious 'force' that pushes objects off their course, but in actual fact, it is an effect caused by 'displacement' of the Earth's surface under the moving object.

The Coriolis effect is proportional to the angular velocity of the Earth (that is constant), to the speed of the moving object and to the latitude: it is null at the Equator and maximum at the Poles.

This effect can be observed in many daily situations: in the Northern Hemisphere aeroplanes have to change their course towards the left, the right railway track undergoes a greater wear, etc... Similarly, even winds undergo deviations: if the Earth were motionless, the winds would tend to move in a N-S direction, from the Equator to the Poles along the meridians, but as a result of the Coriolis effect, winds from the North tend to become winds from the NE and so on.

High and low pressure

If an isobar chart is observed, it can be seen that pressure is not distributed uniformly in the atmosphere around our planet: there are areas with a lower pressure than the surrounding areas and areas where the pressure is higher. Due to a characteristic of gases, air tends to move from high pressure areas towards those with low pressure in an attempt to balance the difference. The presence of high and low pressure areas is therefore the principal motor of all meteorological phenomena, in other words, of the 'weather'. Hence, it is important to understand how air circulates close to these areas (see graph) and how they are distributed in the atmosphere.

Anticyclones

In high pressure zones, air tends to sink towards the ground causing the air that is present to move away with a

divergent movement. The air gets compressed while descending and tends to disperse the clouds, and in fact high pressure conditions are associated with settled and calm weather. As a result of the Coriolis effect, air tends to move away from the high pressure system, clockwise in our hemisphere and anticlockwise in the Southern Hemisphere (anticyclonic circulation).

Cyclones

A low pressure area, instead, tends to attract air from the surrounding region where the pressure is higher. Near the centre of the cyclone, air tends to rise higher attracting a growing amount of air from the neighbouring areas. On rising, air expands and cools with the subsequent formation of clouds and precipitation: it is for this reason that low pressure areas are usually associated with bad weather. Air tends to converge towards the low pressure centre with an anticlockwise movement in our hemisphere and a clockwise movement in the Southern Hemisphere (cyclonic circulation).

Circulation cells

Temperature and pressure differences are not distributed casually in the atmosphere but permanent and stable low and high pressure areas can be identified, which are organized so as to form big circulation cells around the world. This situation, obviously, is not static and unchangeable. During the year the circulation cells move towards the North or the South, depending on the unequal amount of solar energy that the different regions of the Earth receive in each season: in our hemisphere, they move towards the Equator in winter and towards the Poles in summer.

Three main circulation cells can be identified in each hemisphere that are placed symmetrically respect to the Equator.

When air masses meet

When a moving cold air mass meets a warm air mass, that is lighter, it tends to wedge below the latter, thus giving origin to a cold front. The warm air is forced upwards and its ascent causes the formation of clouds. Since the surface of contact between the two masses is quite steep and ascent is rapid, the clouds will be prevalently of the cumuliform type. The passage of a cold front is accompanied by widespread cloud systems and precipitations, with a sharp drop in the temperature, an increase in the pressure and precipitations often characterized by thunderstorms.

On the weather charts, cold fronts are indicated using a black line with triangles. Cold fronts form typically at our latitudes, when the cold dry air from the Polar regions meets the humid air coming from the tropical regions.

Warm fronts

If, on the contrary the warm air mass is moving towards the cold air mass, the warm air mass slowly slips over the cold one, and rises along a vast gently sloping surface: in this case we can speak of a warm front which also brings clouds and perturbation systems. The margins of a warm front are less marked than those of a cold front, changes are more gradual and the perturbations arrive less rapidly. The passage of a warm front is marked by a rise in the temperatures, a decrease in pressure and persistent rains, which are however of a moderate intensity. Since the clouds rise slowly, the cloud system that forms generally consists of stratified clouds. On the weather charts, warm fronts are indicated with a black line with semicircles.

Occluded fronts

An occluded front forms when a cold front reaches a warm front, forcing all the warm air to rise to higher altitudes and the cold air is stratified near the ground. At our latitudes, over the Atlantic, cyclonic areas form continuously, these are fed by the Azores anticyclone and the Polar anticyclone. Here, the tropical warm and humid air and the cold dry polar air meet, and generally a depression vortex is formed in which a warm front and a cold front are active. The cold front is generally more active and advances more rapidly than the warm front. When the cold front reaches the warm front an occluded front is originated. After having discharged the remaining humidity on to the occluded front, the weather generally returns to good weather, the air on the ground starts to warm again: and the perturbation is exhausted.

On the weather charts occluded fronts are indicated with a black line with alternating triangles and semicircles.

Perturbation front

The presence of mountain ranges on the course of a front can provoke variations and deformations of various types, that can lead to evolutions in a perturbation that are difficult to forecast.

Circulation cells

Between the Equator up to 30° latitude (N or S), we find the Hadley cell.

In the Equatorial region, air is heated and rises, creating a low pressure area. Air would tend to shift towards the N along the meridians, but in the northern hemisphere, due to the Coriolis effect, the flow is deviated towards NE and descends toward the 30° parallel, bringing warm humid air. Once it descends, the air is again drawn towards the Equator due to the low pressure of the area, and this time the air travels from NE to SW, again as a result of the Coriolis effect. This movement gives origin to the NE trade winds. The same occurs in the southern hemisphere where the trade winds blow from the SE. The area where the NE trade winds clash and converge with the SE trade winds creates an equatorial low pressure area characterized by precipitations and violent perturbations, the so-called area of equatorial calm, that gets its name due to the low pressures and low wind speeds. Between the 30° and 60° latitudes, instead, in both hemispheres the Ferrel cell is active. It rotates in the opposite direction to the Hadley cell. Converging with the margin of Hadley's Cell, a tropical high pressure area is created, around 30°, the so-called horse latitudes area, where the winds blow from the SW on ground, the westerlies which however have a more irregular trend than the trade winds. In this belt there are a series of anti-cyclonic nuclei, among which the Azores anticyclone whose seasonal movements determine the weather in our regions. The masses of air from the Ferrel cell move back to the higher altitudes around the 60° latitude, where the area of sub-Polar low pressure is formed.

In the higher latitudes the Polar cell forms, which has the same trend as the Hadley cell with easterlies at ground level and westerlies at higher altitudes. The Polar cells are the least extended, but thanks to the Polar high pressures, these have the important task of transferring the freezing polar air to the middle latitudes in the Ferrel cell.