CYCLONES, HURRICANES, TYPHOONS AND TORNADOES

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Contents

Summary

The article presents a general view on atmospheric whirls of different scales: tropical and extratropical cyclones (the former group includes also hurricanes and typhoons) and tornadoes. Their main features, both qualitative and quantitative, are described. The regions visited by thesekinds of atmospheric vortices, and the seasons of their activity are presented. The main physical mechanisms governing the whirls are briefly described. Extreme meteorological observations in the circulation systems (such as strongest wind speed, lowest air pressure, heaviest rainfalls and snowfalls, highest clouds and oceanic waves) are described. The role of circulation systems in the weather variations both in tropical and extratropical zones is analyzed. Record damage brought by the atmospheric whirls is described too, along with their biggest death tolls. A short historical review of studies of the circulation systems and their forecasting is presented. Contemporary and possible future trends in the frequency of atmospheric calamities and possible future damage, taking into account both natural and anthropogenic factors, are given.

1. Atmospheric whirls of different scales and origin

Everybody interested in weather or weather forecasts will have heard the words in the title of this article. Basically, all four of them refer to atmospheric whirlwinds of different scales, with minimum atmospheric pressure at the center and higher pressure on the periphery. Consequently, the rotating air movement around the low pressure core is the main characteristic feature of the quartet. The circulation around the axis of a whirl is also combined with the air flow along the axis of either a huge cyclone or a small-size tornado. In cyclones, hurricanes and typhoons the axis is located quasivertically, and the air moves upward. In tornadoes, the axis can be at any angle to the horizontal, from quasi-vertical to nearly horizontal, or it may be curved in a complicated manner, but in any case the along-axis air movement is mostly upward. All other characteristics of the four, including governing forces and physical mechanisms, size, regions of occurrence, and intensity of air flows (and thus ability to cause damage), vary greatly. Another common feature of the quartet is generally bad weather and, in many cases, calamities: the strongest winds, the heaviest rains and snowfalls, the highest oceanic waves and surges, the greatest damage from natural disasters, and so on.

1.1. Cyclones: large-scale whirls

Cyclone is the most common term among the four as it actually unites the first three. The term comes from the Greek word meaning "coil of a snake" and was used first by Henry Piddington for big storms in India in the 1830s. It means a large-scale (with a diameter of several hundred kilometers or more) atmospheric vortex with lower pressure in the center and circular air movement around it. The main forces and air motions in a cyclone are as follows. Once the lower pressure pattern appears in the atmosphere, the air tends to move to that region from the surrounding higher-pressure zone, pushed by the pressure gradient force. However, as the Earth rotates rather fast around its axis, the so-called Coriolis force comes into action. The direction and absolute value of this force can be obtained from vector equations, but for practical purposes it is enough to remember that it turns an air flow to the right in the Northern hemisphere and to the left in the Southern one, while its absolute value is proportional to the sine of latitude (hence, it is negligible in the near-equator zone and absent on the equator).

For large-scale air flows not influenced by the Earth surface friction, these two forces (plus centrifugal force pushing the air outside from the center) come into an equilibrium and generate the rotating air circulation around the low-pressure center—counterclockwise in the Northern hemisphere and clockwise in the Southern. Near the surface (usually, within the lowest 1 km layer), the friction force influences the air flow so that it turns (to some extent) to the center of the low pressure pattern, thus resulting in convergent circulation. The latter, in turn, provides conditions for upward air flow which is very typical feature of cyclones. Aloft the situation is nearly the opposite: the influx of lifting air provides higher pressure above the center of the cyclone. There the air tends to diverge, and the Coriolis force turns it to the right (to the left in the Southern hemisphere), thus generating an anticyclone with clockwise (counterclockwise in the Southern hemisphere) circulation.

Cyclones can be classified in a number of different ways. But the most general division is based on the latitude of their origin: depending on it, cyclones can be distinguished as tropical and extratropical. This division, being quite formal from the first viewpoint, is in fact rather substantial, reflecting the difference between two kinds of principal physical mechanisms governing the circulation systems.

1.1.1. Tropical cyclones, hurricanes and typhoons: hot beasts of the oceans

Tropical cyclones develop in the latitude belts from 5 to 30° both to the north and to the south from the equator, although they can travel as far as 42-45° from the equator. A necessary condition for their initial appearance is the presence of warm (no less than 26-28 °C) ocean surface; they cannot develop above cooler water or land. The regions most often affected by them are the Bay of Bengal and western parts of the Pacific and Atlantic oceans (north from the equator). Also, they occur to the west of the Pacific coast of Mexico, to the north-east and north-west of Australia, to the north-east of Madagascar island, and in the Arabian Sea. Tropical cyclones are relatively infrequent, on average about 50 of them develop each year. The main source of energy for a tropical cyclone is latent heat release due to condensation in tower-like cumulonimbus clouds located near its warm core. The typical spatial structure of a mature tropical cyclone includes a so-called storm eye in the center (an area with relatively weak wind and just thin clouds, or without any clouds at all), surrounded by giant walls of cumulonimbus clouds with the most powerful wind speed located near the surface and the heaviest rains in their vicinity. Spiral bands of relatively weak cumulonimbus clouds surround the main core of a tropical cyclone.

The word "cyclone" is also commonly used as a local term for tropical cyclones in the Indian Ocean and adjacent countries, as well as near northern Australia. In that part of the world, people just do not face other kinds of cyclones (for instance, extratropical). In other regions, long-established local terms are used for tropical cyclones: "hurricane" in North America and the West Indies (from Spanish or Portuguese words of native American origin meaning "strong wind"), "typhoon" in South-Eastern Asia (from the Japanese word of Chinese origin meaning "great wind"), and other less common words such as "willy-willy" in Australia and Oceania, "baguio" in Philippines, and some others. Usually these terms are used for rather powerful tropical cyclones only, while weaker ones are called just "tropical storms". For example, the word "hurricane" refers to a storm with a wind speed higher than 33 m s^{-1} and air pressure at the center lower than 980 hPa.

Tropical cyclones are among the most devastating natural phenomena in the world, as they bring the greatest amounts of rains and extremely strong winds over huge territories, combined with the severest surge waves on the oceanic coasts.

1.1.2. Cyclones beyond tropics: temperature jump

Extratropical cyclones develop at latitudes more than 30° north and south from the equator, both above oceans and land; sometimes they are called "depressions". They occur much more often than tropical cyclones: normally, no less than 30 of them occur every day throughout both hemispheres. Basically, extratropical cyclones affect almost all regions of our planet beyond the tropics, although their appearance varies very much from one place to another: for example, in the vicinity of Iceland cyclones are observed nearly daily, while near the center of the Sahara desert one might wait for several years to see just a weak dissipating cyclone.

Extratropical cyclones develop in all seasons, being most frequent in the winter of each hemisphere. Unlike tropical cyclones, the energy in extratropical cyclones mostly comes from releasing latent heat in the areas where strong contrast of air temperature leads to intensive horizontal and vertical air motions (so-called baroclinity conditions). So, extratropical cyclones develop on an atmospheric front—a border between two air masses with quite different temperature and, often, humidity. The cyclone, in turn, makes the front more active and pushes warm and cold air masses to areas which it passes, thus causing considerable weather changes and being responsible for most atmospheric calamities in middle and high latitudes. In particular, extratropical cyclones contribute immensely to snowfalls and ice storms. They have no storm eye, but dense multi-layered clouds and intense precipitation occupy the central part of a cyclone, as well as near-front zones. Unlike in a tropical cyclone, the central core of an extratropical one is colder than the surrounding air, and the maximum wind speed occurs at elevations about 2.5-3 km above the surface.

1.2. Tornadoes: small, but terrifying

Tornadoes, known as the most violent atmospheric calamity, in some sense are the *enfant terribles* of the cyclones: they cannot develop without powerful tower-like cumulonimbus clouds formed either in a tropical cyclone or on a cold front in an extratropical cyclone. (A tornado can potentially develop from a cumulonimbus cloud not connected with any cyclone or front, but it would never become very powerful.) And a bit like with children, their number can vary significantly from one "parent" to another: most cyclones do not have tornadoes at all, while some cyclones (both tropical and extratropical) generate more than 100 of them. Furthermore, sometimes one can observe "twins": several (up to 5 or even more) tornadoes generated by one cloud. One would expect that more powerful "parents" (i.e. tropical cyclones) would also cause stronger tornadoes, but in fact, the most powerful and destructive tornadoes are those generated on cold fronts of extratropical cyclones.

The word "tornado" has a Spanish origin: "tornada" - "thunderstorm", or "tornar" - "to turn". While this term is the most widespread (probably due to the most powerful tornadoes occurring in the mid-west of USA—a region first explored by Spanish-speaking people), there are also other words depicting this destructive phenomenon. These include "tromb" in France and Sweden, and "smerch" in Russia, eastern Europe and the former Soviet Union (the word is very similar to the Slav "smert'", meaning "death"). Sometimes a tornado sucking water from a sea or lake is called a "waterspout". In arid regions of Africa and Asia, one can meet rather weak analogues of tornadoes called "dust whirl", “dust devil” or simply "sandstorm". These weaker whirls usually occur in dry air, sometimes even without cumulonimbus cloud aloft, but their nature is very similar to that of a real tornado.

From this list of names, one can see that tornadoes occur in many parts of the world, but they don't take place in polar regions where cumulonimbus clouds cannot develop. Also, they practically cannot develop near the equator as there are no cyclones and atmospheric fronts there, and the local cumulonimbus clouds don't have the necessary features for tornado development. The region most often visited by tornadoes (mid-western states in the US from northern Texas to Iowa) is sometimes called "Tornado Alley": every year no less than several dozen of them occur there. Quite often they take place also in other regions of USA (e.g. Georgia, Ohio), and in Australia. The frequency of tornadoes is higher in seasons with stronger temperature contrasts between air masses, i.e. at the end of spring and the beginning of summer, as well as during autumn.

In regions where powerful cumulonimbus clouds only develop during warm season e.g. in eastern Europe, tornadoes do not take place in other seasons. Of course, they usually occur in the afternoon when the cumulonimbus clouds are most powerful.

From the first viewpoint, the forces and air motions in a tornado are the same as in a cyclone: lower pressure in the middle and air circulation around its axis, combined with along-axis flow. But there are also important differences. First, the low pressure in the middle of a tornado is not the reason for its formation, but rather a result of extremely intensive upward air flow generated by a cumulonimbus cloud aloft (such clouds have extremely intensive vertical air motions, both upward and downward, caused by both thermohydrostatic conditions and dynamics of air flows). Moreover, due to the much smaller size of these whirls, the Coriolis force doesn't play a significant role in their formation, and unlike cyclones, some tornadoes (about 5% of them) have clockwise circulation in the Northern hemisphere and counterclockwise in the Southern. And the rotating circulation itself results mostly from inclination of pre-existing vortices with horizontal axes due to intensive vertical air motions in cumulonimbus clouds. The vortices appear usually in the areas with significant vertical wind shear, i.e. large contrast in wind direction and speed at different levels.

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