PRINCIPAL WEATHER SYSTEMS IN SUBTROPICAL AND TROPICAL ZONES

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Summary

The principal weather systems in the subtropical and tropical zones may be divided into two classes: 1) those comprising immutable links of the general atmospheric circulation (subtropical Highs as *centers of action* of the atmosphere, trade winds, the Intertropical convergence zone, monsoons) and 2) main perturbation systems in the tropics and subtropics (tropical cyclones, easterly and some other waves, monsoon depressions and Lows, the quasi-biennial oscillation and Madden-Julian oscillation, mesoscale rain and convective systems, cloud clusters and squall lines, small-scale vortices like tornadoes etc.). The information on their horizontal and vertical structure, characteristic wind and pressure parameters (where appropriate) as well as on the precipitation regime is given. Interactions between some of these elements are highlighted. Some examples of

national and international field programs directed on the study of various phenomena in lower latitudes are mentioned. Progress in understanding the many mechanisms involved in the maintenance of the above weather systems based on numerous satellite studies and numerical modeling using up-to-date computers is underlined. Significance for the Humankind of some potentially disastrous weather systems such as tropical cyclones with their strong winds, storm surges and floods, or abundant monsoon rains is especially signaled.

1. Introduction

The tropics (from the Greek *τροπικοζ*– "turning circle") may be (and are) defined in scientific literature in several different ways. Purely geographical definition locates the tropical zone between the Tropic of Cancer (23°27′ N) and the Tropic of Capricorn (23°27′ S). From the astronomic point of view, these are the latitudes where the Sun once a year is situated strictly in the zenith. This occurs on 22 June in the Northern Hemisphere and on 22 December in the Southern Hemisphere (the so-called *summer* and *winter solstices*). Meteorologically the apportionment of a «special» tropical zone is easily explained by the fact that the weather types all over that zone are homogeneous. The huge *subtropical Highs* (as the Azores and Honolulu Highs) are situated at its poleward sides, with the very steady (especially over the oceans) *trade winds* area in between. In former times sailors made good use of the trades to reach America from the Old World (hence the origin of the term). The above definition was introduced in the 1960s by Palmen and Newton. Alternative definitions of a line dividing the moderate and tropical latitudes include the median between mean altitudes of the poleward tropical tropopause and the equatorward tropopause of middle latitudes in the corresponding month and season (Petrossiants). The details of the atmospheric general circulation in the tropical and subtropical zones are given in Section 2.

Since the 1950s the Tropics have become a domain of permanently increasing interest among meteorologists. The reason why it is happening lays not only in the fact that they harbor the «nests» of devastating *tropical cyclones* (*hurricanes*, *typhoons*) – see Section 3.1 for them – but also in the belief of the many scientists that this part of the Earth represents, in its way, a «weather kitchen», supplying the rest of the world's atmosphere with energy, and so noticeably influences the weather over sometimes quite distant geographical areas. The monsoons, which mostly belong to the subtropical and tropical zones – see Section 2.4 – add greatly to that interest. The El Niño – Southern Oscillation phenomenon, quite newly discovered by the scientists, gives rise to headings of common newspapers quite often.

Quite logically, therefore, Humans have recently been witnesses of several large scientific undertakings connected with the study of tropical atmosphere and ocean. Among them are the GARP Atlantic Tropical Experiment – GATE (GARP stands here for the Global Atmospheric Research Program) of 1974, the Monsoon Experiment (MONEX) as a part of the Global Weather Experiment of 1979, the *Tropical Atmosphere – Global Ocean* (TOGA) Program and its Coupled Ocean - Atmosphere Response Experiment (COARE) fulfilled for 1992 – 1993 as well as numerous internationally coordinated (mostly by the World Meteorological Organization – WMO) field programs, conferences and symposia dedicated to the study of tropical cyclones both in global and regional scales. All these experiments and studies are finally aimed at the increase of quality of weather forecasts, both in the tropical zone itself and in the extratropics.

2. The General Circulation: Tropics and Subtropics

2.1. Main Elements

The main function of the tropical circulation in the «heat engine» of the atmosphere is to transfer the excess of heat being accumulated in low latitudes because of the intensive absorption of solar radiation, to other parts of the atmosphere. Permanently maintained temperature difference between the equatorial area and the subtropics is thus the main driving force of air currents in the tropical circulation. This results in the large-scale circulation systems which are either very steady (trade winds) or exclusively periodical (monsoons). These systems form the basic flow of the tropical atmosphere. Equatorward flow near the ground spread from the subtropical Highs is deflected by the Coriolis force to the right in the Northern Hemisphere and to the left in the Southern Hemisphere making the trade winds, respectively, blow from the northeast and southeast. With moist and warm air rising at the equator (in the *equatorial trough*) and dry warm air sinking at about 30° N or S, it creates the so-called Hadley cell outlined already in 1735 by George Hadley, the simplified circulation model in the tropical zone. This cell explains why there is so much precipitation in the equatorial regions called the *doldrums*, meaning *much rain and light winds*. On the other hand, at latitude 30° north or south, the air sinking results in skies being clear most of the time. There is little organized motion near the ground here; sailors have often been becalmed in this area. As there is also almost no rain, most of the world's deserts are found here. This latitude band is often called the *horse latitudes* because sailors sometimes threw overboard (or perhaps ate) horses they could not feed.

Actually, the above picture is too idealized. The maximum rainfall often occurs just north and south of the equator. It is closely connected with the apparition of the *Intertropical convergence zone* (ITCZ) thoroughly studied, in particular, during GATE. As common in the tropical circulation system as trade winds and subtropical Highs are, the ITCZ migrates extensively from season to season (see Section 2.3).

The classical scheme is disturbed greatly in the regions where the land-sea contrasts evolve. There may be no trade winds in an area or they are substantially shifted; the ITCZ may be split into two. All this is the influence of *monsoons* which should be considered as not simply perturbations of tropical circulation but an integral part of its large-scale patterns.

2.2. Trade Winds

So the trade wind zone most of the time has the most persistent weather type of any in the world (with the 80 - 90% probability these wind systems may be found at any day of the year, i.e. not only on the time-mean maps), generally dry and sunny even over the oceans, though there are usually some cumulus clouds there. The weather may, however, be disturbed for a few days by an easterly wave (see Section 3.2.1 below) or the development and passage of a violent tropical cyclone. Over the land the trade winds spread the desert with its clear skies and scorching sunshine towards the equator – though how far they reach varies with the season as well as depending on the day-to-day variations in the subtropical high pressure belt as individual anticyclones intensify, pass by, decay or are rejuvenated. In the Northern Hemisphere the trade winds cover 11 % of the ocean surface, in the Southern Hemisphere as much as 20 %.

The trade winds are best developed over the eastern parts of the oceans. In the average the speed of trade winds near the ground surface is 5 to 6 (sometimes up to 8) m s^{-1}. Usually three well pronounced layers are singled out in a trade wind zone: 1) the lower layer with the height about 500 m near the subtropical Highs and increasing towards the equatorial trough up to 2500 m; 2) the *trade wind inversion* layer situated above the lower trade winds. As one moves towards the lower latitudes the thickness of the inversion layer increases from several hundred meters up to 1 km and its lower border's height again from several hundreds meters up to 2 km; 3) the layer of upper trade winds situated above the inversion. The trade wind inversion is often (Riehl) considered as, perhaps, the main link in the general circulation chain. It considerably prevents the upward cloud development so that the dry and clear weather dominates in the inversion areas. The typical trade wind cumuli (as a rule producing no precipitation) usually fade away in the inversion layer.

At the upper levels (above the inversion layer) within the trade wind zone a steady flow of *anti*-trade winds (as considered in the old classical Hadley theory) practically does not exist. Westerlies do prevail there but they are very often broken because of various wave perturbations. Seasonal changes different at different longitudes also take place. Perhaps, over the western parts of the oceans upper westerlies are most steady, especially in winter in the Southern Hemisphere. Still, averaging all over the world west components of the wind in the upper troposphere will prevail in the trade wind zone.

2.3. The Intertropical Convergence Zone

Somewhat idealized picture of the circulation systems in the tropical zone described in Section 2.1 has already brought to the concept of a zone where the trade winds of both hemispheres converge. It was named there the *Intertropical convergence zone* tacitly identified with the *equatorial trough*. The latter term, however, may be misleading since the ITCZ rarely lies over the equator. Historically this very important link in the tropical circulation system was otherwise called t*he trade wind convergence zone* (Palmen and Newton), *the intertropical front* (a product of the Norwegian meteorological school) and in some other ways. The active parts of the ITCZ are undoubtedly associated with the significant convergence (for the whole ITCZ it does not, however, happen always); a lower pressure is characteristic for this zone as well. The geographical locations of the ITCZ are quite different all over the tropical zone. In the Atlantic and eastern Pacific, within the trade wind zone, the ITCZ is usually very close to the equator. Its daily position relative to mean monthly latitude may, however, oscillate within 3 to 4°. Besides that, the ITCZ experiences the seasonal shift, as if moving following the Sun or, better to say, the latitude of the subtropical High. This latitudinal shift in the trade wind zone is usually no more than 5 to 7°. Such convergence zone is often called the *trade wind ITCZ.* Quite different situation is observed over the African and Asian continents, Indian and western Pacific oceans where the monsoon-type circulation may be as great as 25 to 30° along a meridian. Such convergence zone is labeled as a *monsoon ITCZ* (for details see below).

The convectively active part of the ITCZ is usually rather narrow, of the order of 100 km. The vertical currents in the ITCZ destroy the trade wind inversion and, as a consequence, not just trade wind cumuli but towering cumuli and then cumulonimbus appear and rains (even showers) may be as intensive as 90 mm per hour (according to Falkovich: GATE experience). The rainy periods may last 2 to 3 days followed by another 2 to 3 days of dry weather. The ITCZ sometimes breaks up into cloud clusters with closed circulations, and precipitation concentrates locally in these areas.
In the monsoon ITCZ the southwest (at the eastern coast of China southeast) flow of the summer monsoon over Africa or Asia meets continental flows of tropical air masses having the north component. So, the summer monsoon ITCZ forms in higher latitudes to be compared with the trade wind ITCZ, especially over Asia. That is why in the monsoon ITCZ not only active convection but also monsoon Lows and monsoon depressions form. As a result monsoon showers are produced leading sometimes to catastrophic floods in India. In summer over the eastern Indian and western Pacific, in addition to the monsoon ITCZ, a second ITCZ shows; it represents the merger of the southeast trade wind of the Southern Hemisphere and the equatorial outlying regions of the southwest monsoon flow. During the translation seasons the *equatorial zone of westerlies* over the Indian Ocean is very narrow (several latitude degrees) and is situated symmetrically to the equator. In summer of the given hemisphere this zone is widened while joining with the summer monsoon. One of the two (see above) ITCZs, herewith, continues to stay near the equator but the other moves to the north together with the advancing monsoon. This is the third example (along with the trade winds and monsoons) of flow types forming an ITCZ (Khromov and Petrossiants).

The ITCZ plays a very important role in the energetics of the tropical atmosphere. Approximately one half of solar energy obtained by the Earth is concentrated in the tropics, which is the only region of the globe receiving more solar energy than it radiates into the space. The main part of surplus radiation energy is accumulated in the oceans. About one third of it is carried to middle latitudes by oceanic currents, the remaining two thirds being transported to the atmosphere mainly by evaporation. Almost all this energy passes through the ITCZ. This zone performs as a *distributor*: when it is well developed it transforms all the latent heat energy gathered in the tropics into sensible heat (which is accompanied by heavy precipitation), to the subtropical regions; when the ITCZ is depressed, moist air flux in the lower half of the troposphere rushes to the subtropics. It should be noted that such a role is played not only by the ITCZ but by any tropical disturbance (Falkovich). Another important aspect when discussing the ITCZ «mission» lays in the fact that it stimulates actively the formation of tropical cyclones. Certainly, it happens only if the ITCZ is situated in higher latitudes (not near the equator). In this case the Coriolis force is great enough to create the torque which is necessary for the formation of a tropical depression. If, consequently, the environmental conditions are favorable such a depression may develop into a hurricane or typhoon (see Section 3.1).

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Biographical Sketch

Prof Sitnikov Igor Georgievich (1935 – 2002) graduated from the Moscow State University. He worked in Central Hydrometeorological Research Center of the Russian Federation as Head of the Laboratory of Dynamics and Numerical Forecast in Tropical Zone and the Laboratory of Atmospheric Dynamics in Tropical Zone.

In 1967 – 1968, as a senior researcher, he worked in the Joint Soviet-Cuban Research Laboratory dealing with study of hurricanes. In 1977-1981 he worked in Geneva for World Meteorological Organization (WMO) as a scientific coordinator of the GARP Atlantic Tropical Experiment (GATE), and the First GARP Global Experiment (FGGE).

He is the author of several numerical forecasting models including a barotropic model for the prediction of geopotential in middle latitudes and several models for the prediction of tropical cyclone tracks and development. Prof. Sitnikov is an author of more than 90 scientific papers and monographs.