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WORKSHOP ON PHYSICS OF MESOSPHERE-STRATOSPHERE-TROPOSPHERE INTERACTIONS WITH SPECIAL EMPHASIS ON MST RADAR TECHNIQUES

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WEATHER AND CLIMATE OF THE TROPICAL ATMOSPHERE

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Weather and Climate of the Tropical Atmosphere.

Lecture Notes:
This lecture is intended to provide a background for later lectures on MST/ST radar observations of the lower tropical atmosphere. The lecture begins with an overview of the large-scale circulations of the tropical atmosphere. This is followed by an introduction to tropical convection and its relation to the large scale circulation systems of the tropical atmosphere. The concept of the tropical tropopause is introduced and its climatology is presented. Equatorial waves and the Madden-Julian Oscillation is introduced. The lecture ends with some comments on the global observing system of today and tomorrow.

1. Hadley and Walker Circulations:
The large-scale circulation that takes place in the meridional-vertical plane is known as the Hadley Circulation. Often the circulation is described as a zonal mean circulation. The Hadley Circulation is driven by latent heating from active convection that takes place in the tropical atmosphere. Ascending motion occurs in the tropical troposphere and in the upper troposphere horizontal motions diverge and are poleward. Subsidence or descending motion occurs in the subtropical latitudes with equatorward flow in the lower troposphere completing the circulation.

The circulation is anchored and fueled by the regions of active convection which are located over the continents of South America and Africa and the so-called maritime continent of Indonesia and the western Pacific warm pool. A convergence zone where most of the tropical convection and rainfall occurs separates the two hemispheres. This region tends to move with the sun being farthest north in northern summer and farthest south in southern summer.

The Walker circulation takes place in a zonal-vertical plane. The Walker Circulation is also driven by active convection. Over the Indonesian maritime continent and western Pacific warm pool region convection reaches its peak during northern winter and the Walker circulation is responsible for upper tropospheric westerlies over the equatorial Pacific which relax during northern summer when the circulation is less pronounced.

2. Monsoon Circulations:
Monsoon circulations develop when heated land masses are adjacent to relatively cold oceans. During the summer months convection develops over the land masses as the surface is heated and there is a circulation that develops that gives rise to upward motion over the heated land mass and sinking motion over the adjacent ocean. The configuration of land masses leads to a progression of monsoon circulations through the year. The most developed monsoons occur over China and Tibet and India although other monsoon circulations occur over the Americas.

3. Convection in the Tropical Atmosphere:

Convection occurs when parcels of air are heated near the surface and become hydrostatically unstable to vertical displacement. In the dry atmosphere these convective motions are usually limited to 1-2 km and seldom exceed 1-2 m s^{-1}. However ascending parcels are cooled by expansion and if condensation occurs clouds form. The formation of clouds leads to the release of latent heat which further fuels convection and upward vertical motion. Cumulus clouds often form over heated regions of the atmosphere during daytime. Convective showers of warm rain often result. Deeper convection occurs in regions of especially warm humid air especially when accompanied by low level convergence. Deep convective cloud systems penetrate the freezing level which in the tropical atmosphere is around 5 km. The release of latent heat during freezing leads to additional buoyancy of air parcels. These parcels will rise past the level of neutral buoyancy where the equivalent potential temperature of the environment equals the equivalent potential temperature of the parcel. Parcels with vertical motion often penetrate this level and continue to ascend to the tropopause and occasionally the lower stratosphere.

The equivalent potential temperature is the temperature that is attained by a parcel when the latent heat is released due to condensation and freezing. It provides a convenient but rough measure of the depth of penetration that may be anticipated by a parcel.

4. Inter-Tropical Convergence Zone:

Convection is not uniformly distributed in the tropics. It tends to occur over the warmest and most humid land and sea surfaces. It also is concentrated in convergence zones. A prominent feature of the tropical atmosphere is the Inter-Tropical Convergence zone or ITCZ. The ITCZ forms the meteorological equator. Meridional motion tends to change direction across the ITCZ, converging at the lowest levels and diverging in the upper troposphere. Over much of the global oceans the ITCZ is displaced north of the equator. Over the eastern Pacific it is typically 6 - 10 degrees north of the equator. Both the intensity and position of the ITCZ varies through the year. In some locations there is evidence of a double ITCZ. Where this occurs there is usually a cold tongue of water separating the two branches of the ITCZ.

4. Convection and the Tropical Tropopause:

To a first approximation convection is responsible for the vertical mixing in the troposphere. Convection is a common feature of the lower troposphere even in dry regions. However, deep mixing of the troposphere requires deep convection which is always associated with deep precipitating cloud systems. The Tropical tropopause can be thought of as the deepest level to which active convection penetrates in the tropical atmosphere.

The tropical tropopause varies systematically through the year and from year to year. The tropopause is highest in northern winter when convection is most pronounced over the western Pacific warm pool region. This is also the time of the year when the convection is closest to the equator. The tropical tropopause is lowest during northern summer when convection in the equatorial zone is minimum and is displaced well north of the equator.

There is an inverse relationship between tropopause height and lower stratospheric temperature. Lower stratospheric temperatures are coldest when the tropopause is high. Interannual tropopause variations occur in relation to the El Nino and the QBO.

5. Equatorial Waves and the Madden-Julian Oscillation.
An important part of the dynamics of the equatorial zone is the occurrence of equatorial waves. Several types of equatorial waves have been identified and can be observed in the tropical atmosphere. Mixed-Rossby gravity waves are seen in the meridional winds and tend to have a period of 3-6 days. They propagate from east to west. Kelvin waves are manifest in the zonal winds and have periods 5-20 days. They propagate from west to east. An important intraseasonal oscillation is associated with the Madden-Julian Oscillation. This oscillation tends to migrate from west to east and tends to be associated with 30-60 day time periods.

6. El-Niño and the Southern Oscillation.
Convection is usually most active over the western Pacific warm pool region and the Indonesian maritime continent. However, during El Nino the warmest waters move eastward toward the dateline and the convection moves with it. Under these circumstances the Walker circulation is diminished and the contrast between the western and eastern Pacific is minimal. The westward trade wind circulation in the lower troposphere relaxes and equatorial upwelling is greatly reduced so that the cold tongue that normally extends from the South American coast to the dateline disappears and leaves abnormally warm waters in the eastern equatorial Pacific and off the coast of South America.

The Southern Oscillation refers to the temporal variability of the Walker Circulation. The Southern Oscillation Index (SOI) is formed by the difference of surface pressure between Tahiti and Darwin. Under normal conditions Darwin surface pressure is lower than Tahiti surface pressure so that the SOI is positive. During El Nino the surface pressure at Darwin is increased and the surface pressure at Tahiti decreases so that the SOI is negative. Since there are records of surface pressure at both Darwin and Tahiti for over a century there is a century long record of SOI.

7. The Global Climate Observing System (GCOS)
Our understanding of the global climate system is limited by our global observing system. Observations over the populated regions of the northern hemisphere are generally adequate but observations over the Southern Hemisphere and vast tropical oceans are too sparse. Under the auspices of the World Meteorological Organization efforts are underway to improve the Global Climate Observing System. A Global Ocean Observing System is already in an advanced concept design stage. An atmospheric observing system is also being planned through the member states of the World Meteorological Organization but is not as far along as the ocean observing system.