Course Introduction

Most generally, tropical meteorology refers to the meteorology of the tropics. More specifically, tropical meteorology can refer to the study of the physics and dynamics associated with meteorological phenomena occurring in the tropics. Even this definition requires further clarification, however. What defines the tropics? And, what are the meteorological phenomena commonly associated with the tropics?

Herein, we define the tropics most generally as the latitudes at which the Coriolis force (i.e., air parcel acceleration due to the rotation of the Earth), horizontal temperature gradients, and horizontal pressure gradients are all relatively weak compared to their mid-latitude counterparts. In Section 1.3 of *An Introduction to Tropical Meteorology, 2nd Edition*, several more specific definitions for the tropics are given. These include:

- The range of latitudes where the angle of solar declination can be 90° (i.e., the sun is directly overhead) at any point during the year. This encompasses the latitudinal band between the Tropic of Capricorn (23.5°S) and Tropic of Cancer (23.5°N).
- The range of latitudes where the net annual incoming (shortwave) solar radiation is greater than the net annual outgoing (longwave) terrestrial radiation. This encompasses the latitudinal band between ±35-40° latitude.
- The latitudinal region of net ascent, easterly boundary layer flow, and lower surface pressures associated with a meridional overturning circulation (the Hadley cell) that arises as a consequence of the aforementioned net positive radiation at lower latitudes. In the mean, this encompasses the latitudinal band between ±30° latitude.
- The range of latitudes where the temperature change between the warmest and coldest months is smaller than the temperature change between day and night and/or where rainfall variability is best characterized by wet and dry seasons (rather than the four seasons of the higher latitudes).

Arising from each of the above definitions are the concepts of radiative balance and radiative-convective equilibrium. These concepts are discussed in detail in a subsequent section. Of the definitions presented above, however, it is the third definition above that best exemplifies these concepts and is thus used to define the tropics throughout the remainder of this course.

There exist a large number of meteorological phenomena with origins in the tropics. In the first half of this course, salient features of the tropics will be discussed. These include the climatology of the tropics; characteristics of the tropical meridional and zonal circulations; the El Niño Southern Oscillation; equatorial waves; monsoons; concepts of stability; tropical disturbances and jets; and subtropical ridges and their accompanying trade wind inversions. Important questions to be addressed in association with each of these topics include, but are not necessarily limited to:

- **Climatology of the tropics:** What are the climatological air masses and weather features of the tropics? What is the structure of the tropical mean vertical profile of temperature and moisture and what is the nature of the variability in this profile? What are heat sources and heat sinks and what role(s) do they play in modulating the meteorology of the tropics?

- **Tropical meridional and zonal circulations:** What are the concepts of radiative balance and radiative-convective equilibrium and why do they matter? What is the Hadley cell and why does

it exist? What is meant by the conservation of absolute angular momentum and why is it important? Why is the Earth's meridional overturning circulation best represented by a "three cell" (rather than "one cell") model? What is the nature of the variability of the Hadley cell? What is the zonal Walker circulation? What drives the Walker circulation?

- **El Niño Southern Oscillation:** What is meant by "El Niño Southern Oscillation" (ENSO)? How is ENSO analyzed? How does ENSO impact the zonal Walker circulation in the tropics? How does ENSO impact large-scale mid-latitude weather patterns? What physical processes lead to El Niño and/or La Niña events? How is ENSO forecast?

- **Equatorial waves and oscillatory modes:** What is the Madden-Julian Oscillation (MJO)? How does it impact sensible weather across the globe? What is the Quasi-Biennial Oscillation (QBO)? What are Kelvin waves and why are they important? What is an equatorial Rossby wave and why is it important? What are inertia-gravity and mixed Rossby-gravity waves and why are they important? How do these equatorial waves modulate deep, moist convective activity and large-scale tropical phenomena?

- **Monsoons:** What is a monsoon? Where do monsoons typically occur? Why are they important to both the climatology of the tropics and billions of people worldwide? What drives a monsoon and how is this modified by phenomena on intraseasonal to interseasonal time scales?

- **Subtropical ridge and trade wind inversion:** What are the typical structure and climatology of subtropical ridges? How and why do vertical profiles of temperature and moisture vary with increasing distance from the center of a subtropical ridge? What are the concepts of dry and moist static stability?

- **Tropical disturbances and jets:** What is an African easterly wave? How do easterly waves form, grow, and decay? What role(s) do barotropic and baroclinic instabilities play in the life cycle of an easterly wave? What are the African and tropical easterly jets and how do they influence easterly waves and the meteorology of Africa? What is the Saharan air layer and what are its characteristics?

In the second half of this course, characteristics of tropical cyclones (or TCs) will be discussed in detail. Topics of study include TC climatology; variability in TC occurrence within and between seasons; TC formation; mature TC structure; TC motion; factors influencing the intensity and intensification of tropical cyclones; tools used to monitor and forecast TCs; and the concepts of extratropical and tropical transition. Important questions to be addressed in association with each of these topics include, but are not necessarily limited to:

- **Tropical cyclone climatology:** Where and when do tropical cyclones form? What are the necessary conditions for tropical cyclone formation to occur? Conversely, why do tropical cyclones not form in other locations and/or times of the year? Once formed, what are the climatologically favored tracks for tropical cyclones to follow?

- **Tropical cyclone formation:** What are the necessary conditions for tropical cyclone formation to occur? Is tropical cyclone formation a "top-down" or "bottom-up" process, a hybrid between the

two, or something else altogether? What is wind-induced surface heat exchange and how does it relate to tropical cyclone formation? What insight into tropical cyclone formation is provided by the so-called "pouch paradigm"?

- **Tropical cyclone intensity change:** What are positive and negative contributors to tropical cyclone intensity and how do they act to influence intensity? What is the Maximum Potential Intensity (MPI) of a tropical cyclone, what are its underlying physical principles, and what keeps a tropical cyclone from reaching its MPI? What is the Carnot heat engine approximation for a tropical cyclone and why is it important?

- **Mature tropical cyclone structure:** What are the salient characteristics and dynamics of the primary circulation of a tropical cyclone? Similarly, what are the salient characteristics and dynamics of a tropical cyclone's secondary circulation? What is the typical structure of a tropical cyclone rain band? What are secondary eyewalls and what impact do they have on tropical cyclone intensity?

- **Tropical cyclone motion:** To zeroth, first, and second orders, what are the factors controlling the movement of tropical cyclones? How do these vary as a function of tropical cyclone intensity?

- **Tropical cyclone monitoring and forecasting:** What are the in situ and remotely-sensing tools that forecasters routinely use to monitor tropical cyclones? What are the capabilities of these tools? What are the different types of guidance used by forecasters to make forecasts of tropical cyclone track and intensity?

- **Extratropical and tropical transition:** What is extratropical transition (ET)? What factors influence the post-ET evolution of a tropical cyclone? What influences do extratropically transitioning tropical cyclones exert on downstream weather patterns? What is tropical transition (TT)? Under what conditions is TT possible and/or favored?

We will tackle each of these topics throughout the remainder of the semester. This course has been designed blend *breadth* and *depth* such that a wide range of topics can be covered in a fair amount of depth. However, as we cannot go into great depth on any given topic, suggestions for further reading are included where applicable. I encourage you to take advantage of these suggestions in areas of particular interest to you. Please do not hesitate to ask for additional information and/or references on any given topic, whether during a regularly-scheduled class meeting or during office hours.

For Further Reading

- Chapter 1, *An Introduction to Tropical Meteorology, 2nd Edition*, A. Laing and J.-L. Evans, 2011.