• Mesoscale convective systems (MCSs)
• Diurnal cycle of precipitation
• Issues with high-frequency simulation of convection

Goal: Understand high-frequency characteristics of tropical convection
Schematic overview of tropical variability

Major Modes of Tropical Variability

Annual Cycle (Equatorial Trough)

ENSO Cycle

Madden-Julian Oscillation

Cloud Clusters

Adapted from Rasmusson and Arkin 1993
Mesoscale convective systems

- Most tropical precipitation is produced by organized convective systems called *mesoscale convective systems* (MCSs)
- MCSs have characteristic spatial scales or order $10^2$-10$^3$ km and lifetimes of several hours to a day
Considerations for MCS structure

• We’ve described small scale convection in terms of buoyant parcels ascending from the ABL; however, organization of vertical MCS is characterized by a different process, namely *layer lifting*.

• In this process, an air layer, typically much deeper than the ABL and conditionally unstable, enters and rises coherently along a sloping path through the MCS.
  – The inflow layer enters at the “nose” of the MCS; aloft, it leads to the establishment of the broad stratiform region.

• Also important is environmental mid-level inflow.
  – This inflow enters the stratiform region in a direction determined by the prevailing environmental wind conditions at mid-levels; it contributes to downdrafts within the MCS.
More detailed anatomy of an MCS

- Representative of a tropical oceanic MCS propagating from east to west
- Values in ovals are $\theta_e$
  - Some "lucky" low-level air masses in the strongest updrafts reach the top of the MCS
- Note the flow structure is in 3D, so idealized updraft and downdraft trajectories do not generally overlap

Zipser 1977
Precipitation in MCSs: Convective vs. Stratiform

- **Convective**: precipitation falling from active convection
- **Stratiform**: precipitation falling in “older”, less active convection
  - Less intense than convective precipitation
  - Within an MCS, stratiform fraction increases as MCS matures
Factors determining MCS size

- It appears that the spatial scale of the MCS is determined by the development and regeneration of the stratiform region.
- Since the stratiform region forms from the remnants of active convection, the size of this region is set by the capacity of the MCS to generate new active convection.
- However, the maximum number of convective cells is limited: MCSs can attain this limit if conditions in the environment possess sufficient sustainability.
- Sustainability can be enhanced by favorable ABL conditions, e.g., warm and moist over long periods, such as the tropical ocean.
TOGA-COARE* MCS spacetime distribution

Chen et al. 1996 and Chen & Houze 1997

*TOGA-COARE: Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Experiment
MCS propagation

- Tropical MCSs do not simply sit in place but move:

- One mechanism for MCS propagation is layer lifting over an advancing cold pool, which forms new active convection along the leading edge of the MCS.

- Another mechanism involves wave dynamics.
  - Mass divergence creates waves. [Think about dropping a pebble into water.]
  - The waves may initiate convection away from the cold pool, as suggested by the radar echo (below right).
  - Wave mechanisms can be either internally generated (i.e., by the MCS itself) or externally.
  - More on wave dynamics in a future lecture.

Mapes et al. 2003
From R. Fovell (UCLA)
MCS Hovmoller

Propagating w/ wave velocity

“Bifurcation” into 2 MCSs?

Chen et al. 1996
Tropical squall line “lifecycle”

- Tropical squall lines with trailing stratiform are the most frequently studied MCSs.
“Hector”

- Named MCS occurring between Darwin Australia and the Tiwi Islands to the north during the local wet and transition seasons [70% of days have one.]
- Hector arises from interactions between island and marine boundary layers and breezes, which lead to the development of a squall line
West African squall lines

Images from Earle Williams and the MIT radar, in support of the African Monsoon Multidisciplinary Analysis (AMMA)
Distribution of convective vs. stratiform precipitation

- Convective precipitation rates are typically 3-6 x larger than stratiform rates [larger over land], while stratiform precipitation covers a larger fractional area.

- Within the tropics, stratiform rain fraction as a percentage of total accumulated precipitation is ~40%; this fraction increases beyond ~20° but only reaches 50% beyond 30°.

Schumacher & Houze 2003
Land versus ocean MCSs

- One category of MCS, mesoscale convective complexes (MCCs)—which are long-lasting, approximately circular MCSs with extremely high [cold] cloud tops—occur more commonly over land (dots in figure on the left)
  - MCC prevalence over land may be attributed to higher daytime low-level buoyancy [but these also appear to require compensation against nighttime stabilization as the land surface cools]
- Lightning strikes are more common over land than ocean, reflecting differences in ice particle characteristics.

Liang & Fritsch 1997

From S. Nesbitt (U. Illinois)
Shallow convective precipitation

- Another category of tropical rainfall which occurs in isolated cumulus clouds [i.e., not associated with MCSs]
- Shallow convective precipitation is generally weak and is largely confined to the ocean basins adjacent to stronger convection.
Diurnal cycle of precipitation

• Q: When does it rain in the Tropics?
• A zeroth-order answer is late afternoon, when solar heating and ABL height are maximized.
• However, other factors, such as surface effects, land-ocean contrasts, topogaphy, and MCSs may substantially modulate the diurnal cycle.
Mean tropical diurnal precipitation: land versus ocean

- Tropical land regions have a strong diurnal precipitation maximum in late afternoon (bottom).
- Tropical oceanic regions experience a weak but significant precipitation maximum around local sunrise (top).
  - Possible explanations include: interactions between convection and surrounding environment; absorption of incident solar at cloudtops leading to greater stability daytime stability; and higher relative humidity in the nighttime marine ABL.
Regional diurnal cycles: Maritime continent

1. Late evening: maximum precipitation near high topography
2. Midnight
3. Morning: max rainfall over ocean/ min over land
4. Early afternoon
Regional diurnal cycles: Africa

1. Late evening: maximum precipitation near high topography
2. Midnight: mature MCSs with broad region of stratiform rain
3. Early Morning: Diminishing land region/developing coastal rainfall
4. Late Morning: Minimum land region rainfall

Laing et al. 2007
Regional diurnal cycles:
South America

A. Amazon Basin: coupling to the land surface
B. Eastern flank of the Andes: mountain breeze circulations
C. Northern Patagonia: MCSs propagating eastward from the Andres
Challenges for modeling: MCSs

- MCSs represent a challenge in climate models since they require organization across scale.
- One specific aspect that is problematic is the partitioning of rainfall in convective vs stratiform: in general, current-generation climate models simulate too much convective precipitation (95% of the total, compared to 60% in obs).

Dai 2006
Challenges for modeling: diurnal cycle

- Over oceans, models tend to underestimate the amplitude of the diurnal cycle relative to observations.
- Over land, models tend to have the wrong phasing, with maxima occurring too early in the day.

Dai 2006