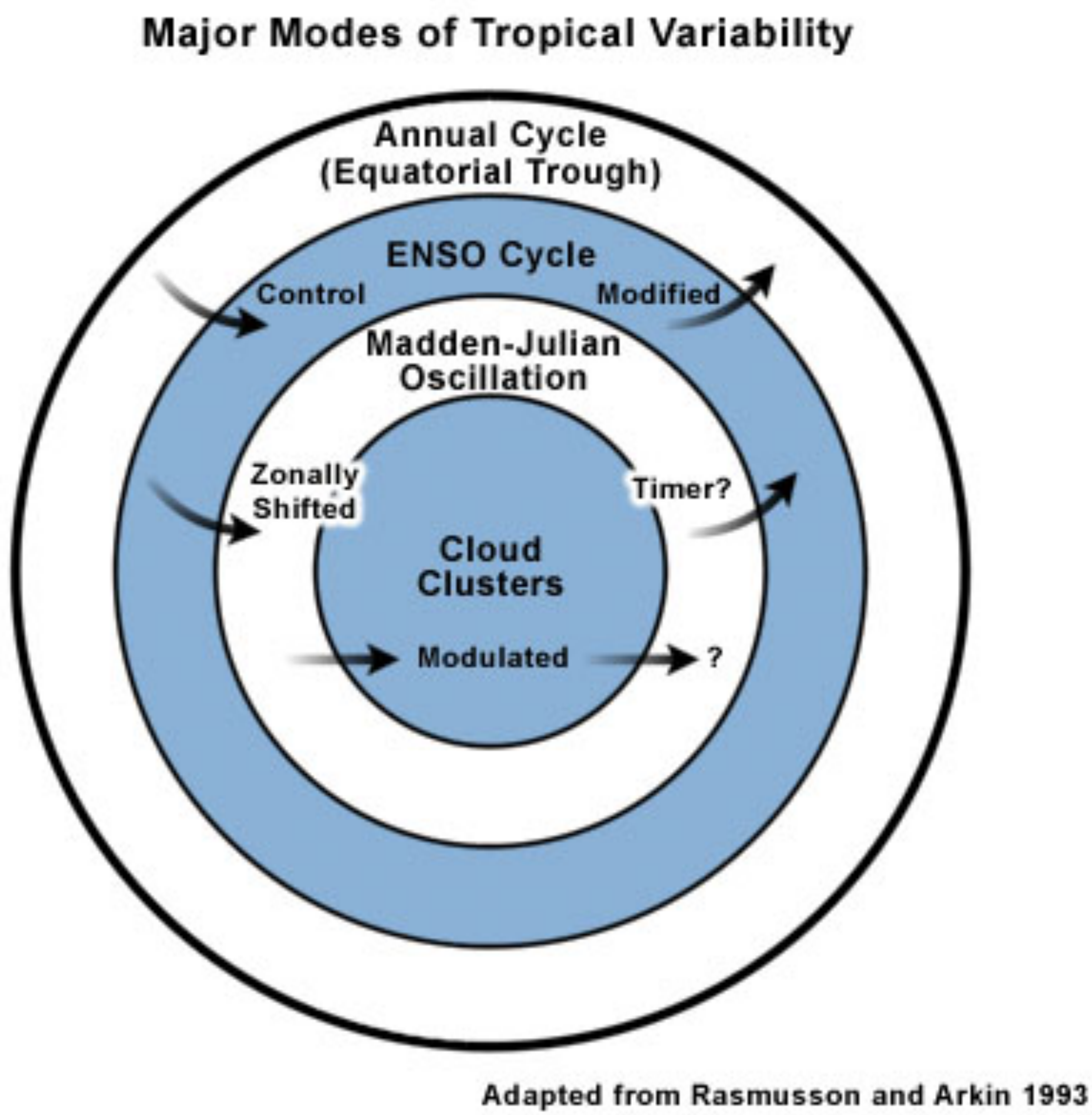
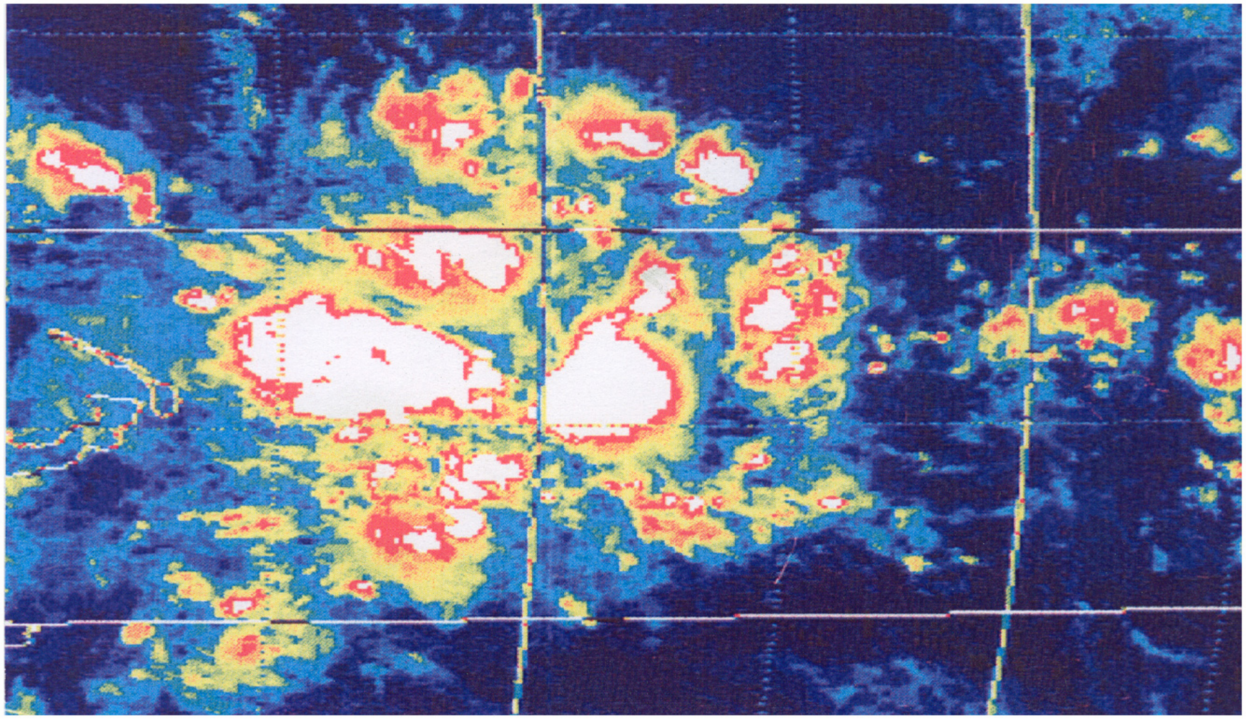
- Mesoscale convective systems (MCSs)
- Diurnal cycle of precipitation
- Issues with high-frequency simulation of convection

Goal: Understand high-frequency characteristics of tropical convection

Schematic overview of tropical variability



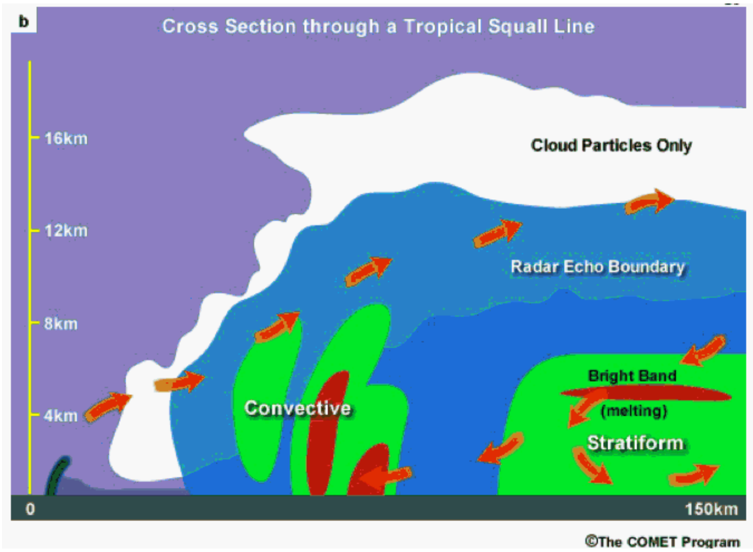
Mesoscale convective systems



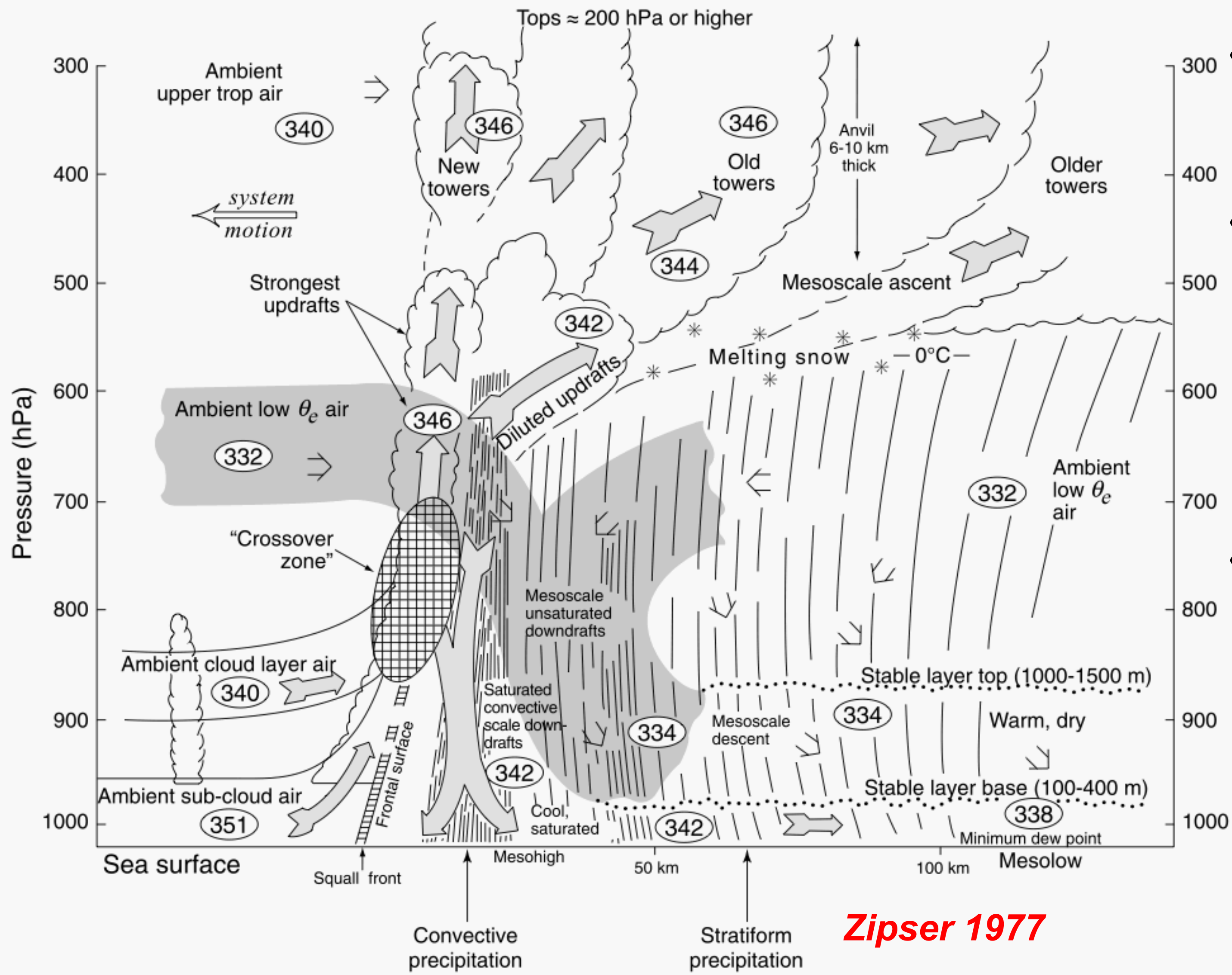
- Most tropical precipitation is produced by organized convective systems called *mesoscale convective systems* (MCSs)
- MCSs have characteristic spatial scales or order 10^2-10^3 km and lifetimes of several hours to a day

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



Zipser 1977

- Representative of a tropical oceanic MCS propagating from east to west
- Values in ovals are θ_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

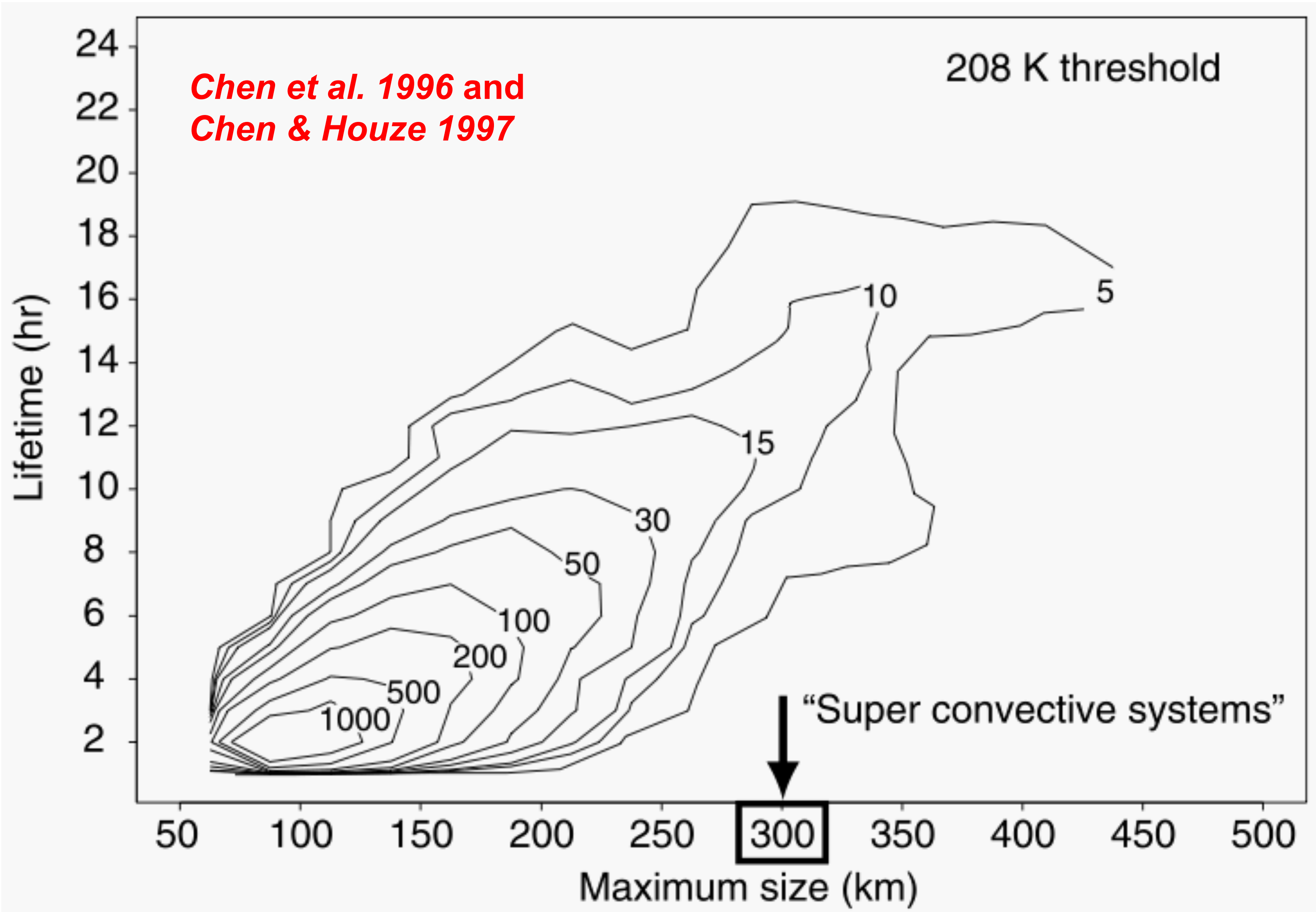
Precipitation in MCSs: Convective vs. Stratiform

- *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 if 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.

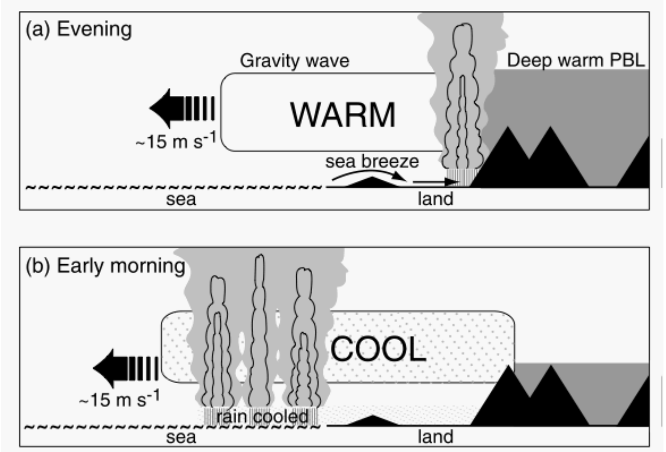
TOGA-COARE* MCS spacetime distribution



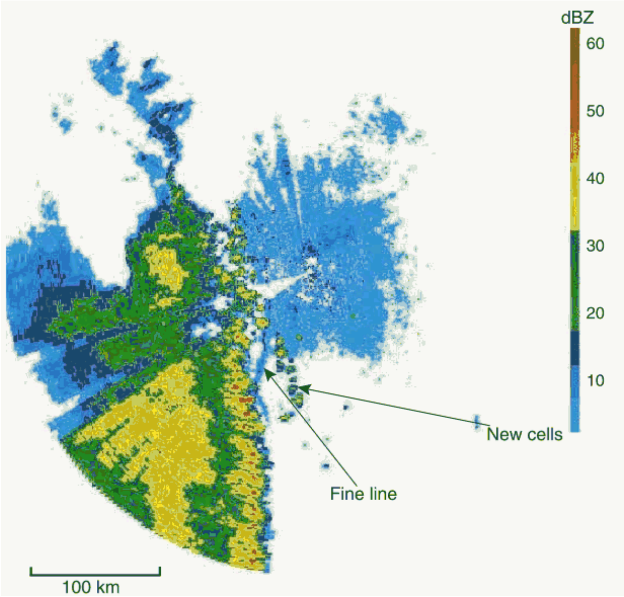
*TOGA-COARE: Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Experiment

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.

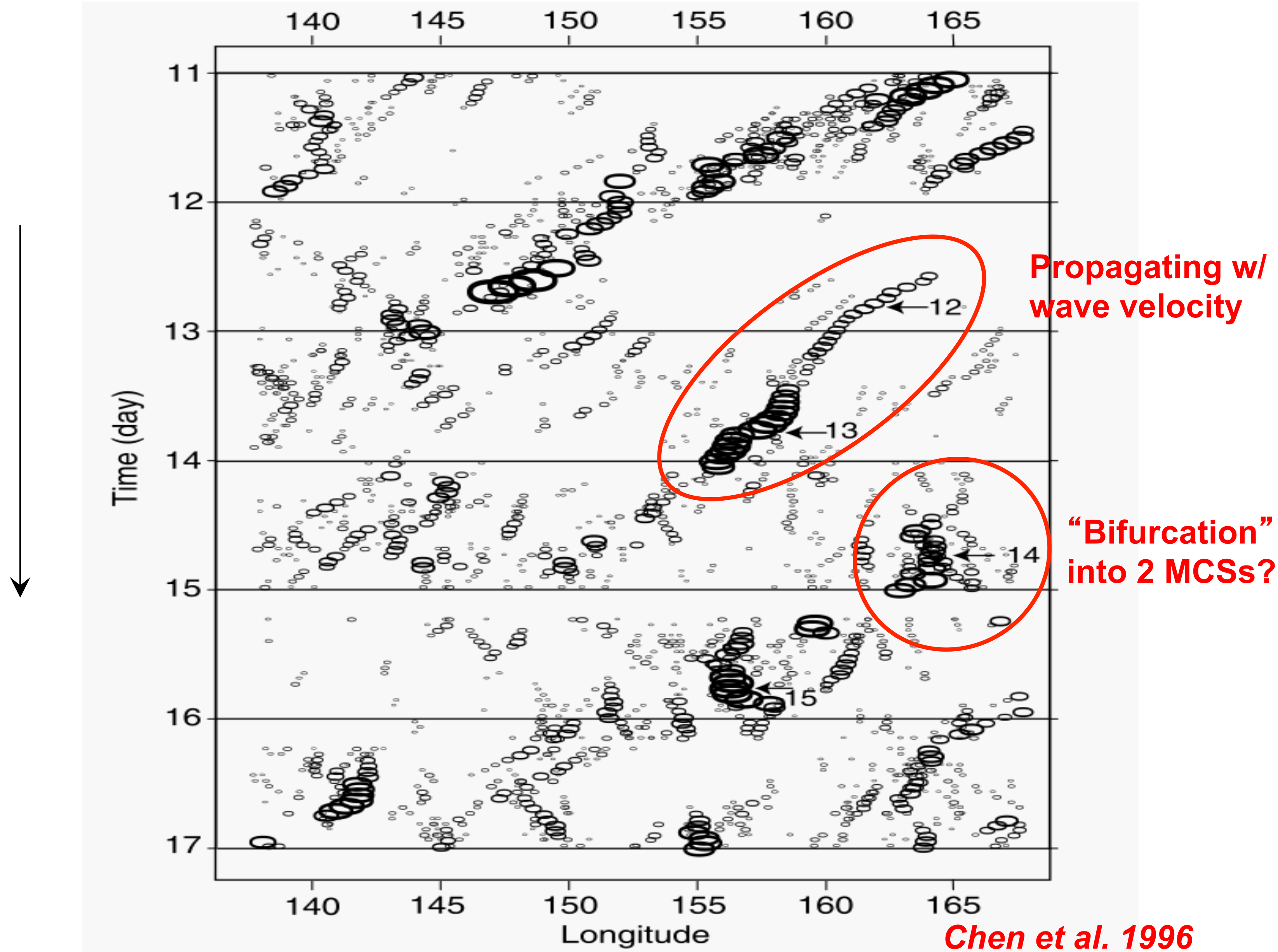


Mapes et al. 2003



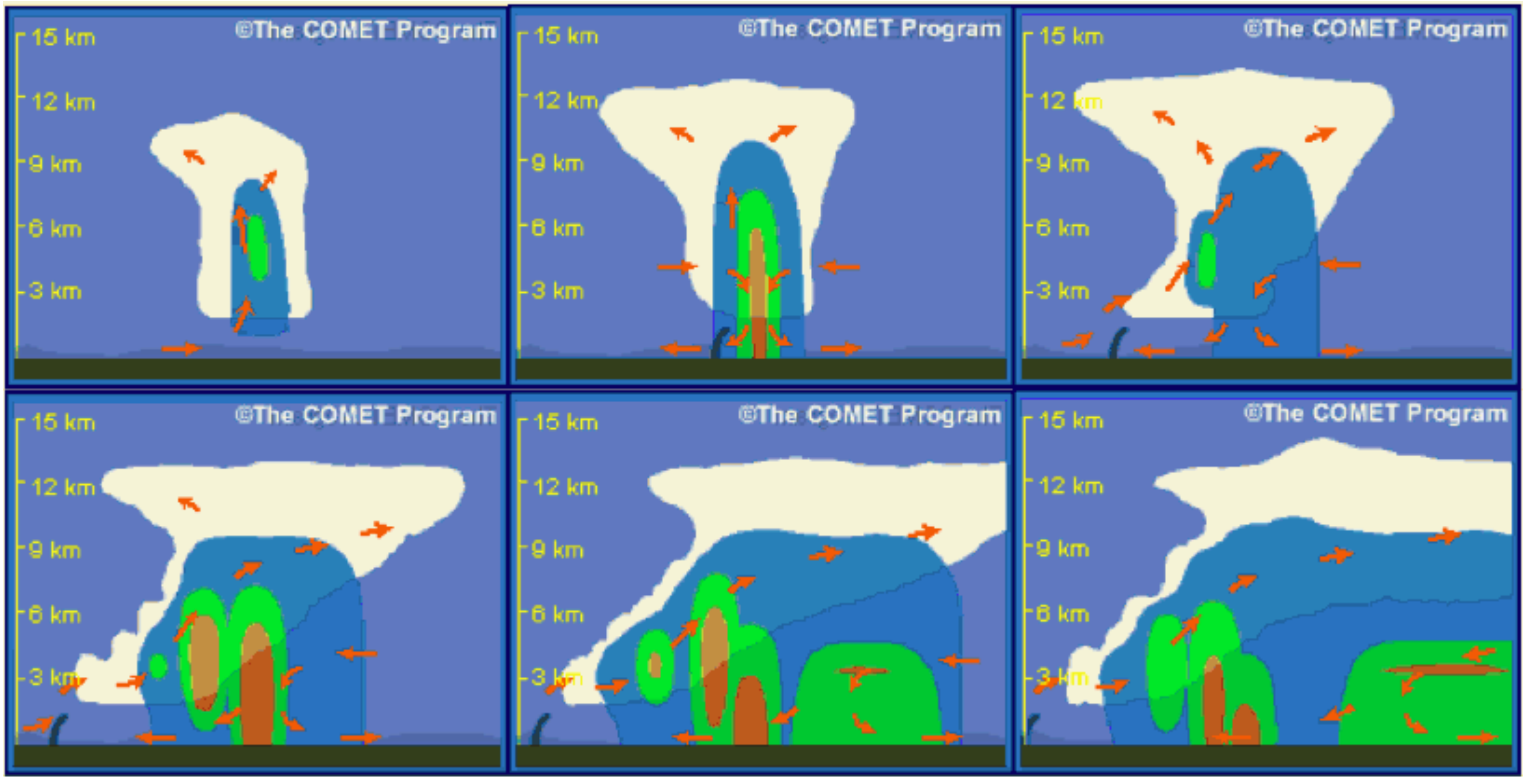
From R. Fovell (UCLA)

MCS Hovmoller



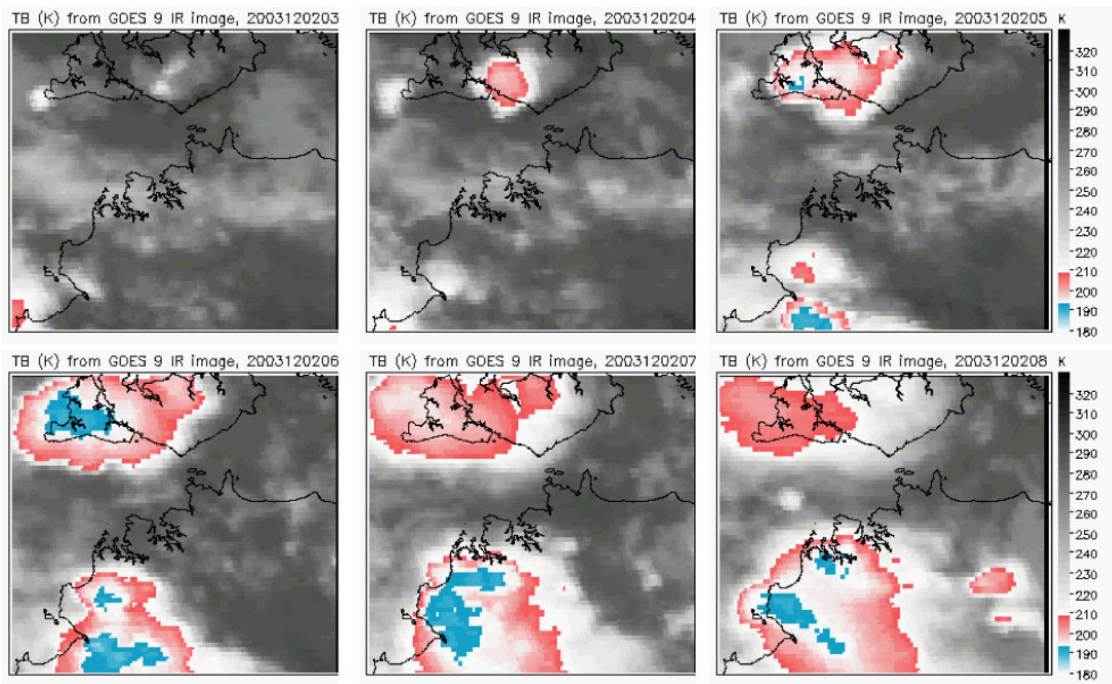
Chen et al. 1996

Tropical squall line "lifecycle"



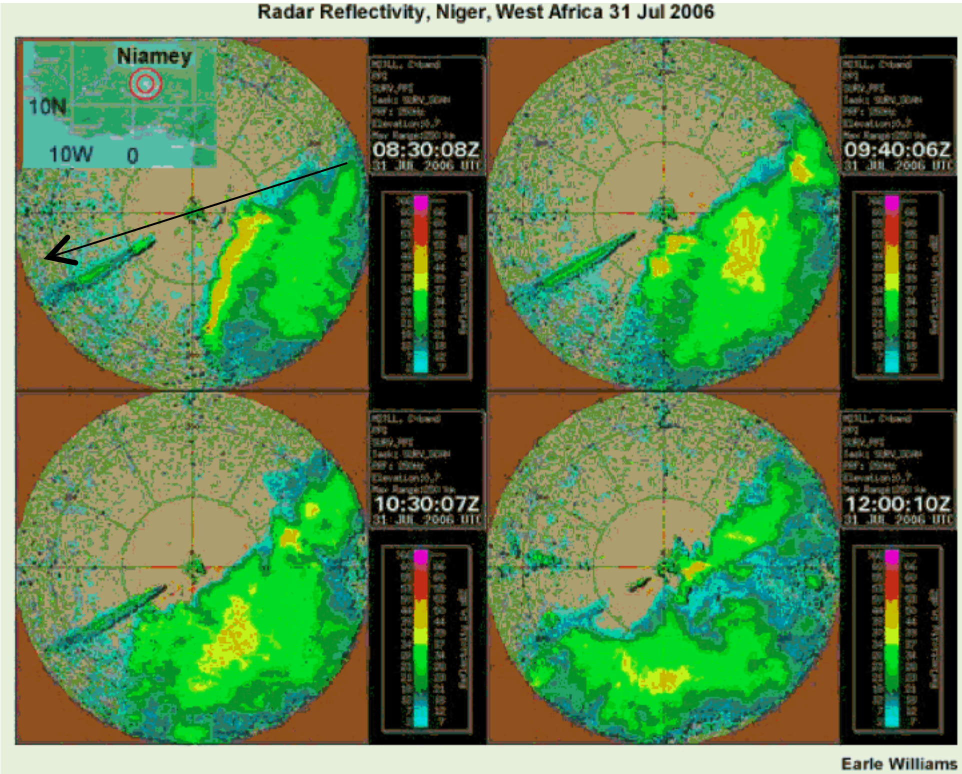
- Tropical squall lines with trailing stratiform are the most frequently studied MCSs.

"Hector"

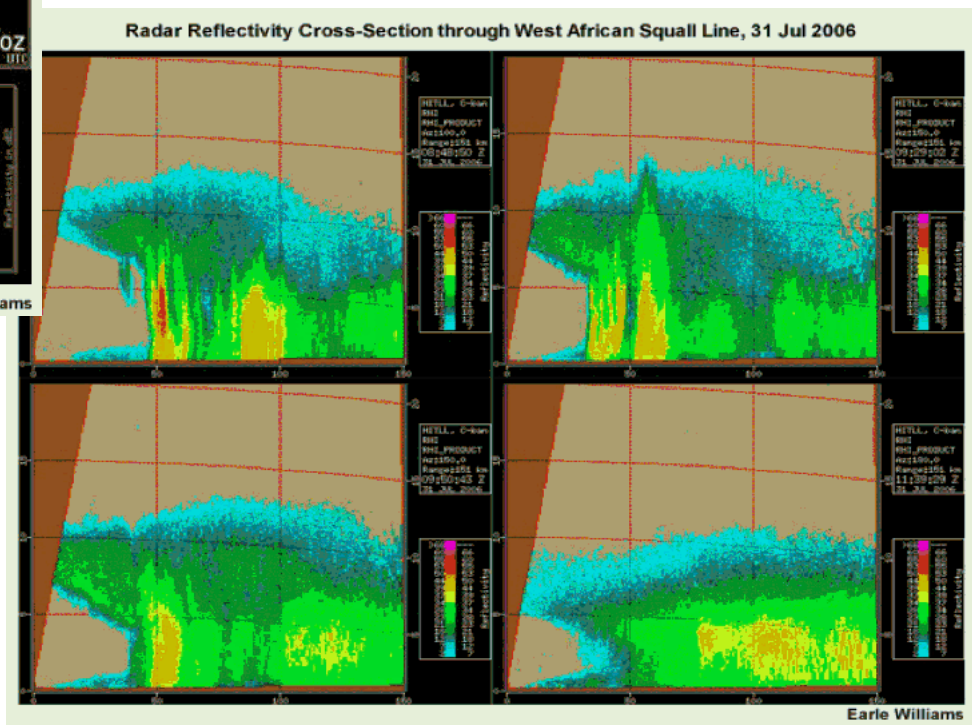


- Named MCS occurring between Darwin Australia and the Tiwi Islands to the north during the local wet and transition seasons [70% of days have one.]
- Hector arises from interactions between island and marine boundary layers and breezes, which lead to the development of a squall line

West African squall lines



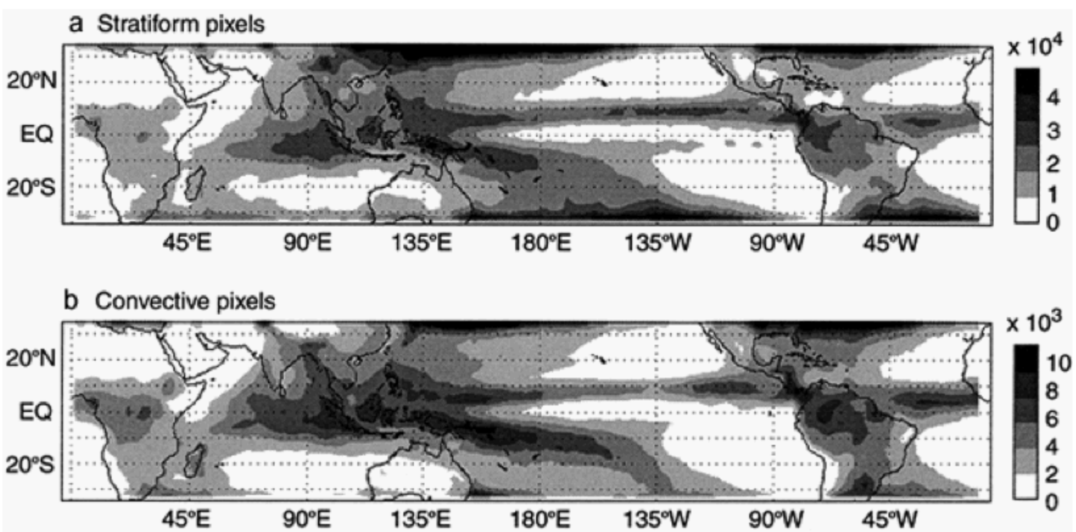
Images from Earle Williams and the MIT radar, in support of the African Monsoon Multidisciplinary Analaysis (AMMA)



Distribution of convective vs. stratiform precipitation

Table 1. Mean tropical convective and stratiform rain statistics for 1998-2000

	Stratiform rain fraction (%)	Stratiform area fraction (%)	Convective rain rate (mmh^{-1})	Stratiform rain rate (mmh^{-1})	Ratio of convective-stratiform rain-rate
All	40	73	7.3	1.8	4.1
Land	35	75	10.2	1.8	5.5
Ocean	43	72	5.8	1.8	3.3

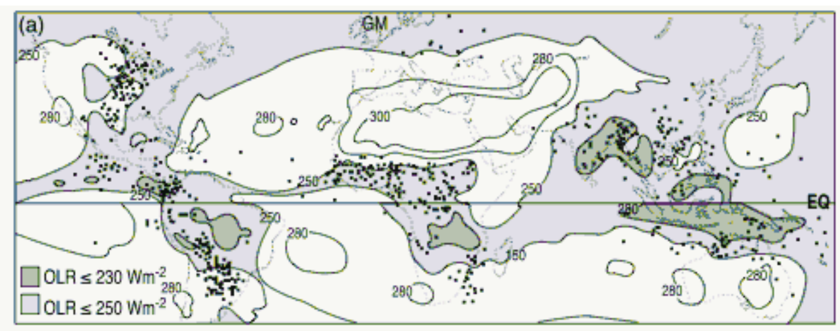


Schumacher & Houze 2003

- 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°.

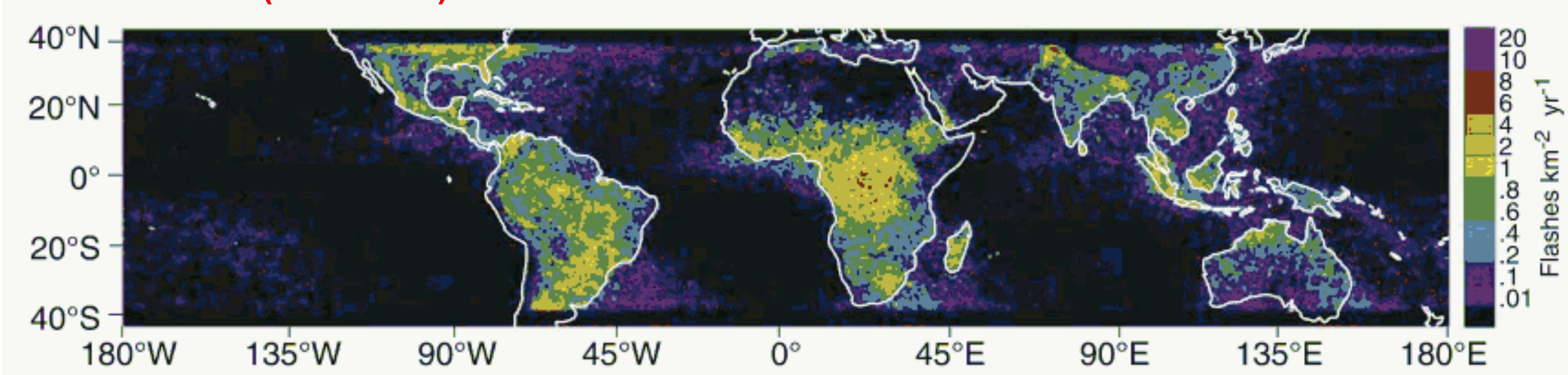
Land versus ocean MCSs

- 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.



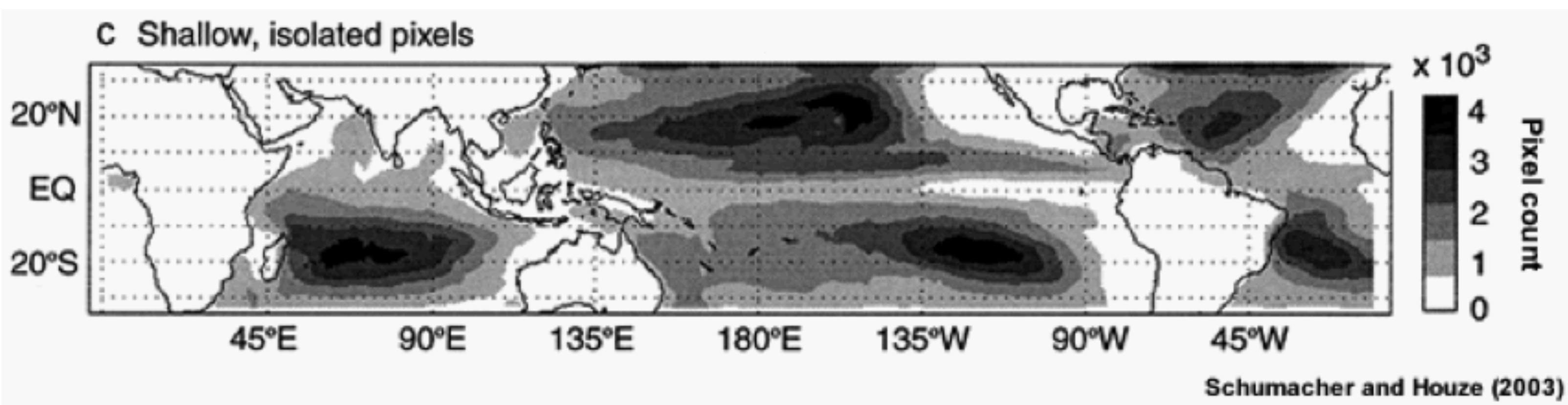
Liang & Fritsch 1997

From S. Nesbitt (U. Illinois)



Shallow convective precipitation

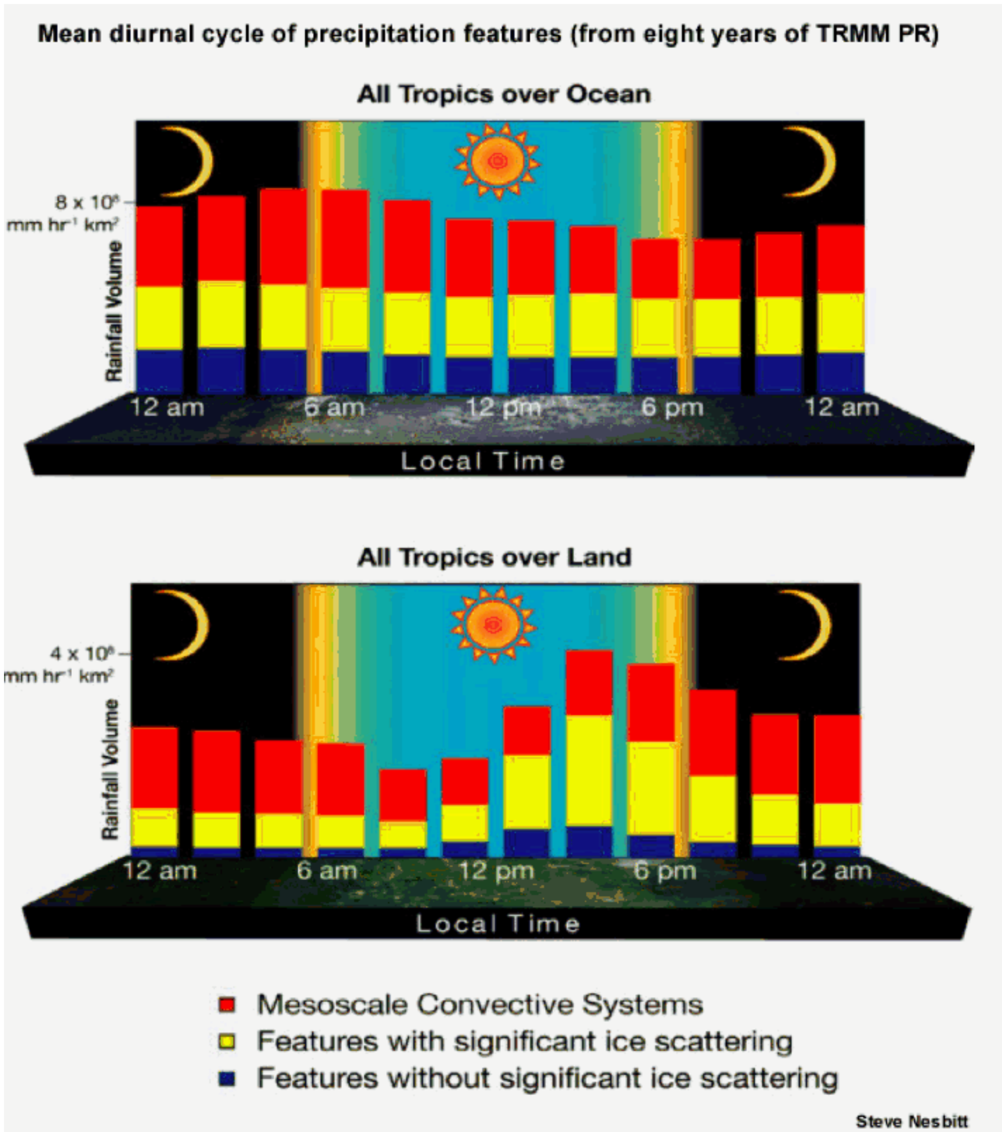
- Another category of tropical rainfall which occurs in isolated cumulus clouds [i.e., not associated with MCSs]
- Shallow convective precipitation is generally weak and is largely confined to the ocean basins adjacent to stronger convection.



Diurnal cycle of precipitation

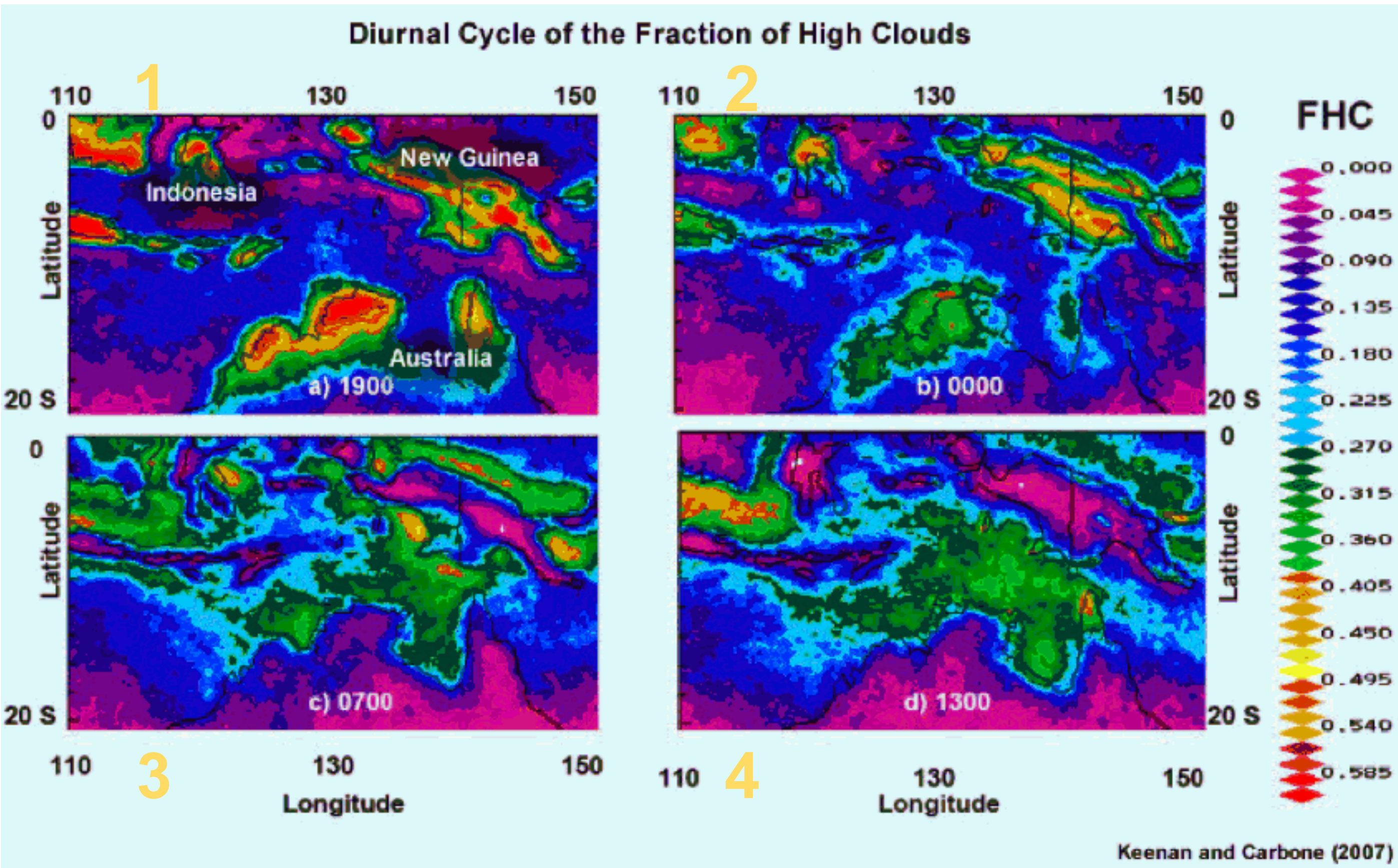
- *Q: When does it rain in the Tropics?*
- A zeroth-order answer is late afternoon, when solar heating and ABL height are maximized.
- However, other factors, such as surface effects, land-ocean contrasts, topogaphy, and MCSs may substantially modulate the diurnal cycle.

Mean tropical diurnal precipitation: land versus ocean



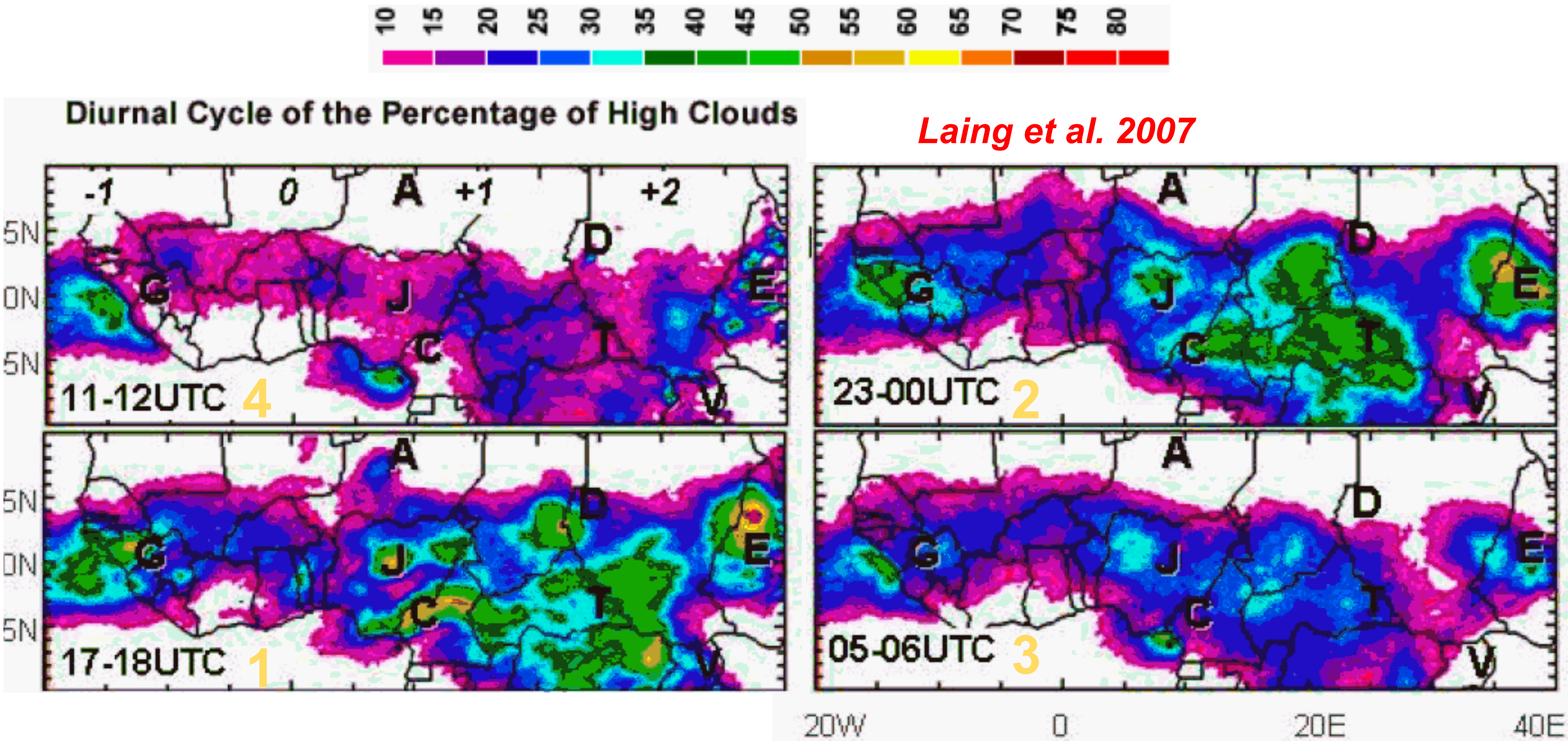
- Tropical land regions have a strong diurnal precipitation maximum in late afternoon (bottom).
- Tropical oceanic regions experience a weak but significant precipitation maximum around local sunrise (top).
  - Possible explanations include: interactions between convection and surrounding environment; 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



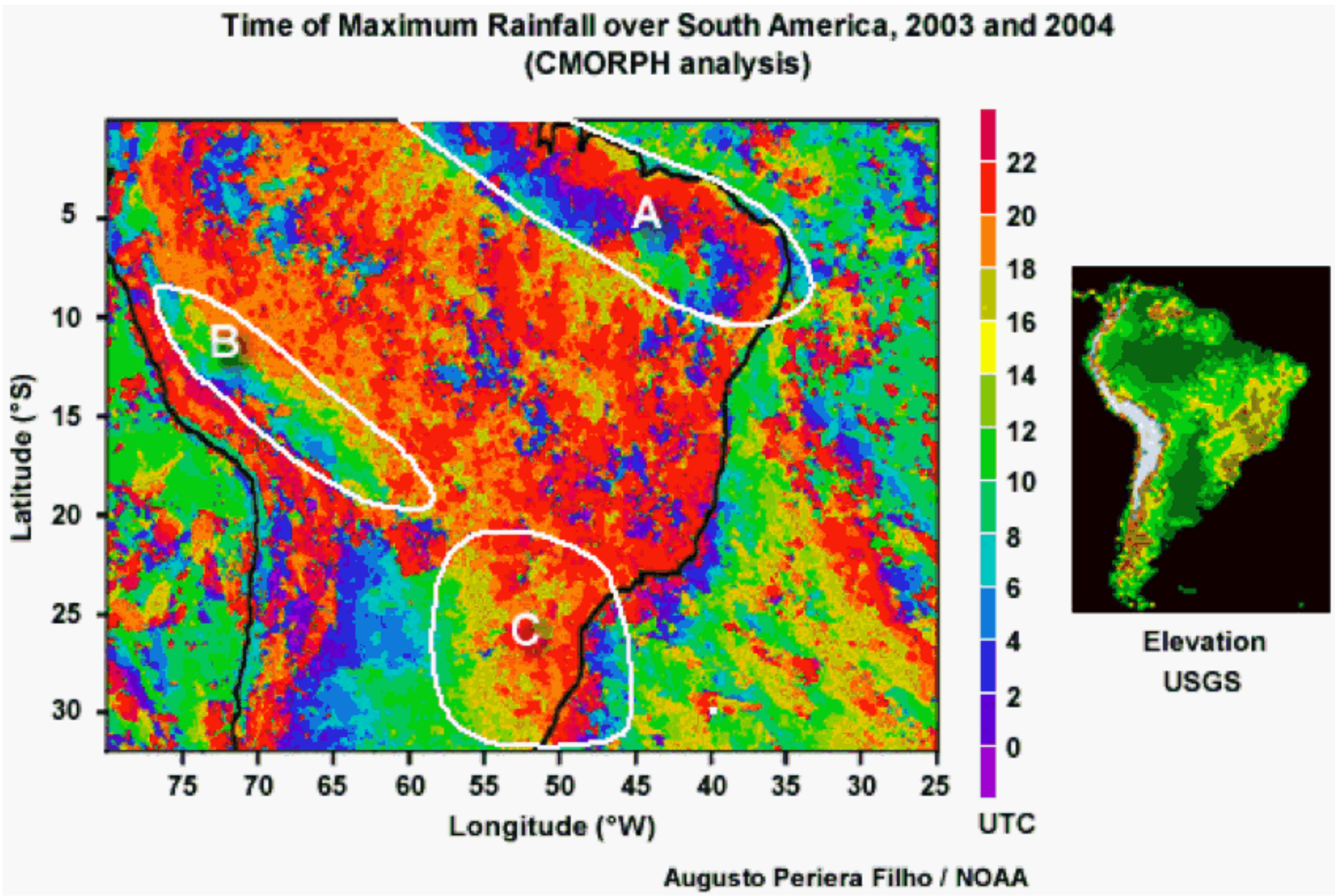
1. Late evening: maximum precipitation near high topography
2. Midnight
3. Morning: max rainfall over ocean/ min over land
4. Early afternoon

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

Regional diurnal cycles: South America

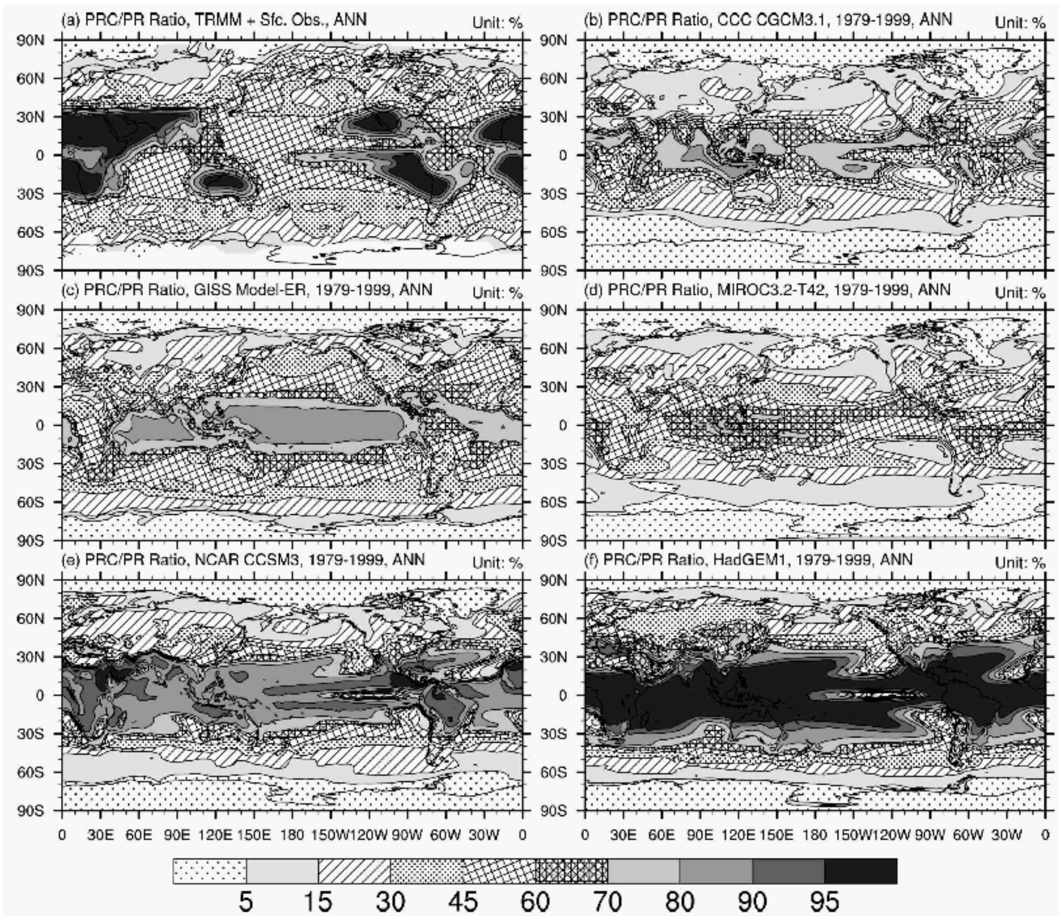


A. Amazon Basin: coupling to the land surface

B. Eastern flank of the Andes: mountain breeze circulations

C. Northern Patagonia: MCSs propagating eastward from the Andres

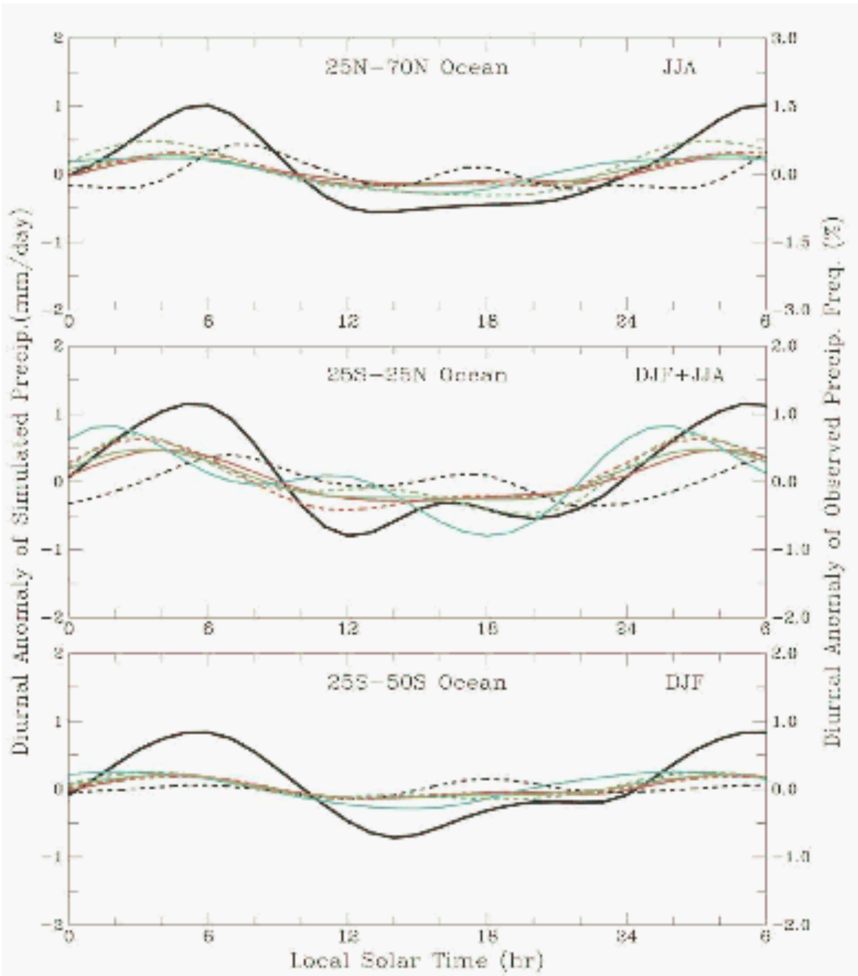
Challenges for modeling: MCSs

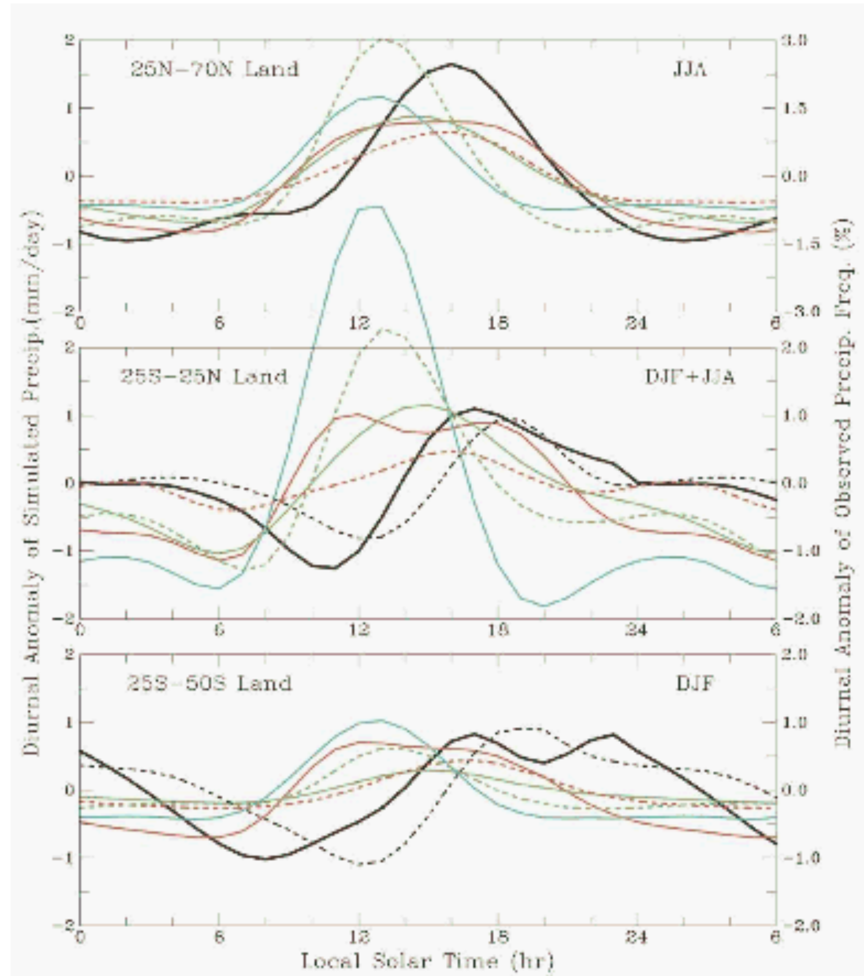


Dai 2006

- 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)

Challenges for modeling: diurnal cycle





Dai 2006

- 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.