Exploring the Key Features of Tropical Cyclogenesis using Satellite Data

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Motivating Questions

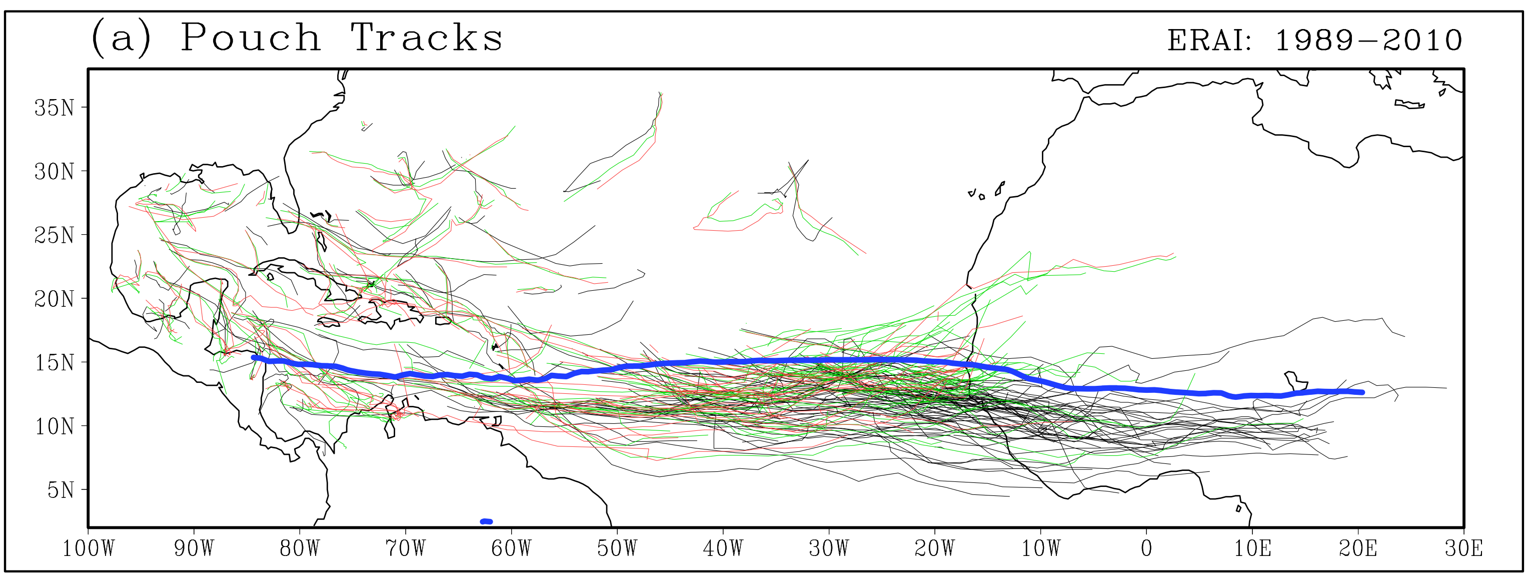
Q1: What is the key feature(s) of convection leading up to genesis?

Q2: What thermodynamic conditions promote the development of such a key feature?

Q3: What are the relative roles of different types of precipitation in TC genesis?

Data

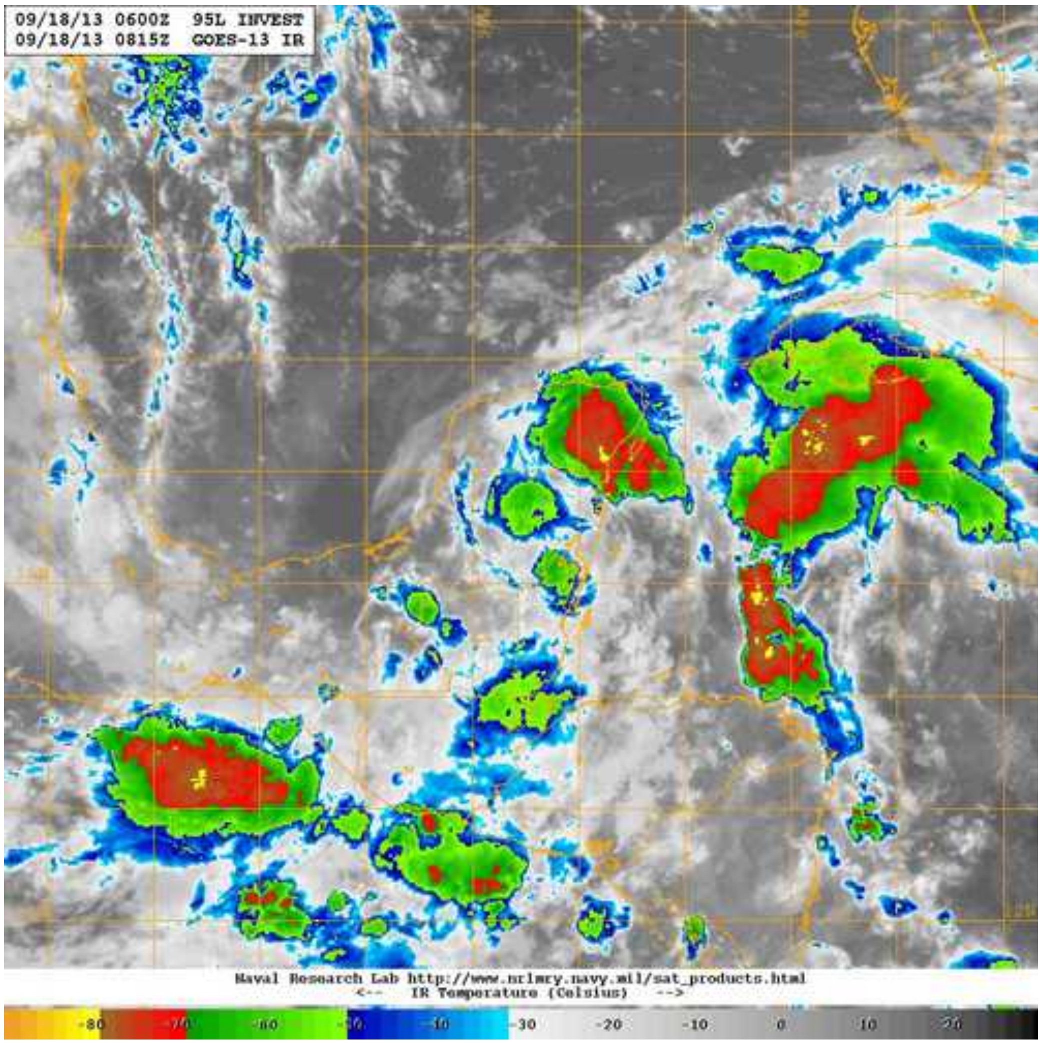
- GribSAT-B1 IR (Knapp et al. 2011)
  - 3-hour data; resolution: ~ 7 km
- Rain rate and column water vapor (CWV) from SSMI/SSMIS
- Rain rate and reflectivity from TRMM PR 2A25
- Best track data to define genesis: the formation of a TD in most cases
- A pouch track dataset for 164 named storms over the Atlantic from 1989-2010 (Wang and Hankes 2014)
  - Like the best track data but for precursors
- 6 hourly data from ERA-Interim Reanalysis

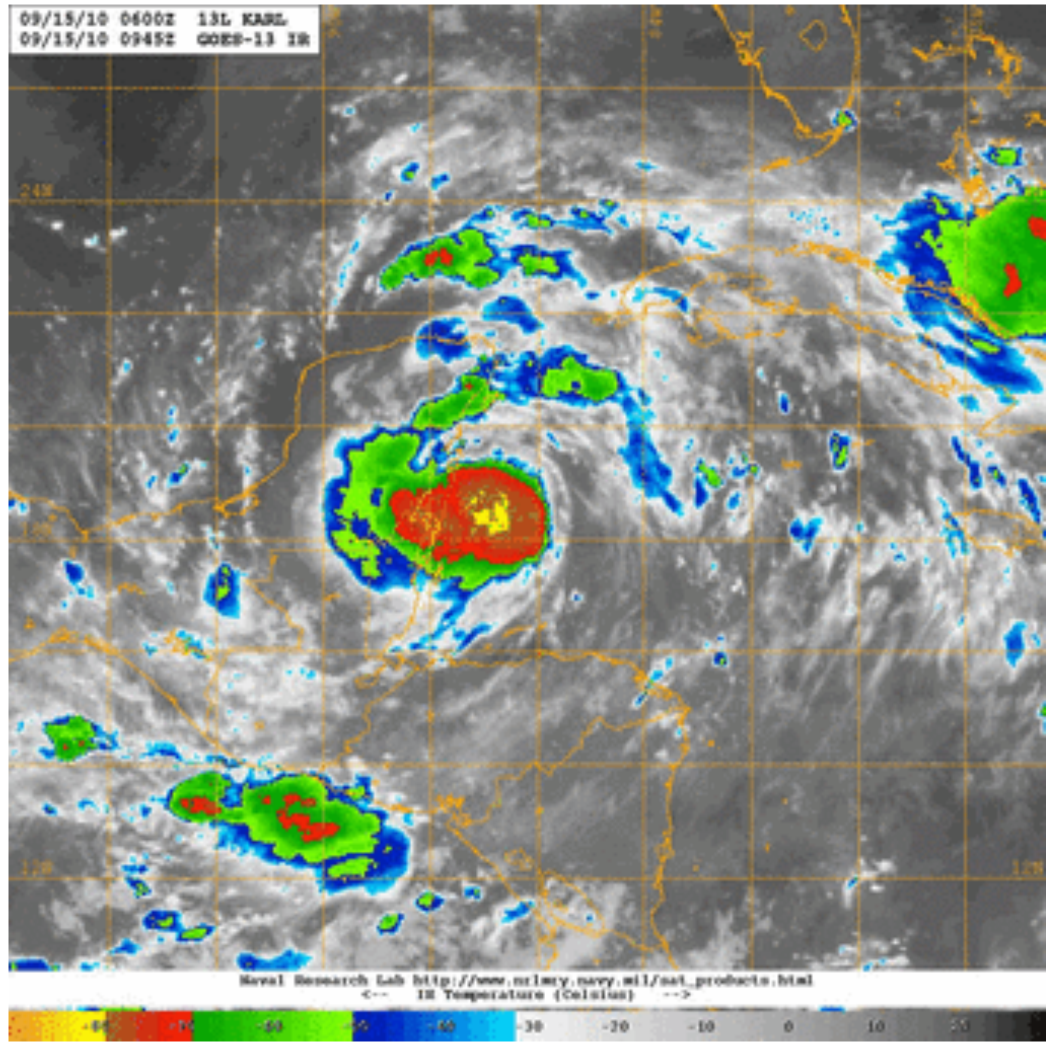


Q1: What is the key feature of convection leading up to genesis?

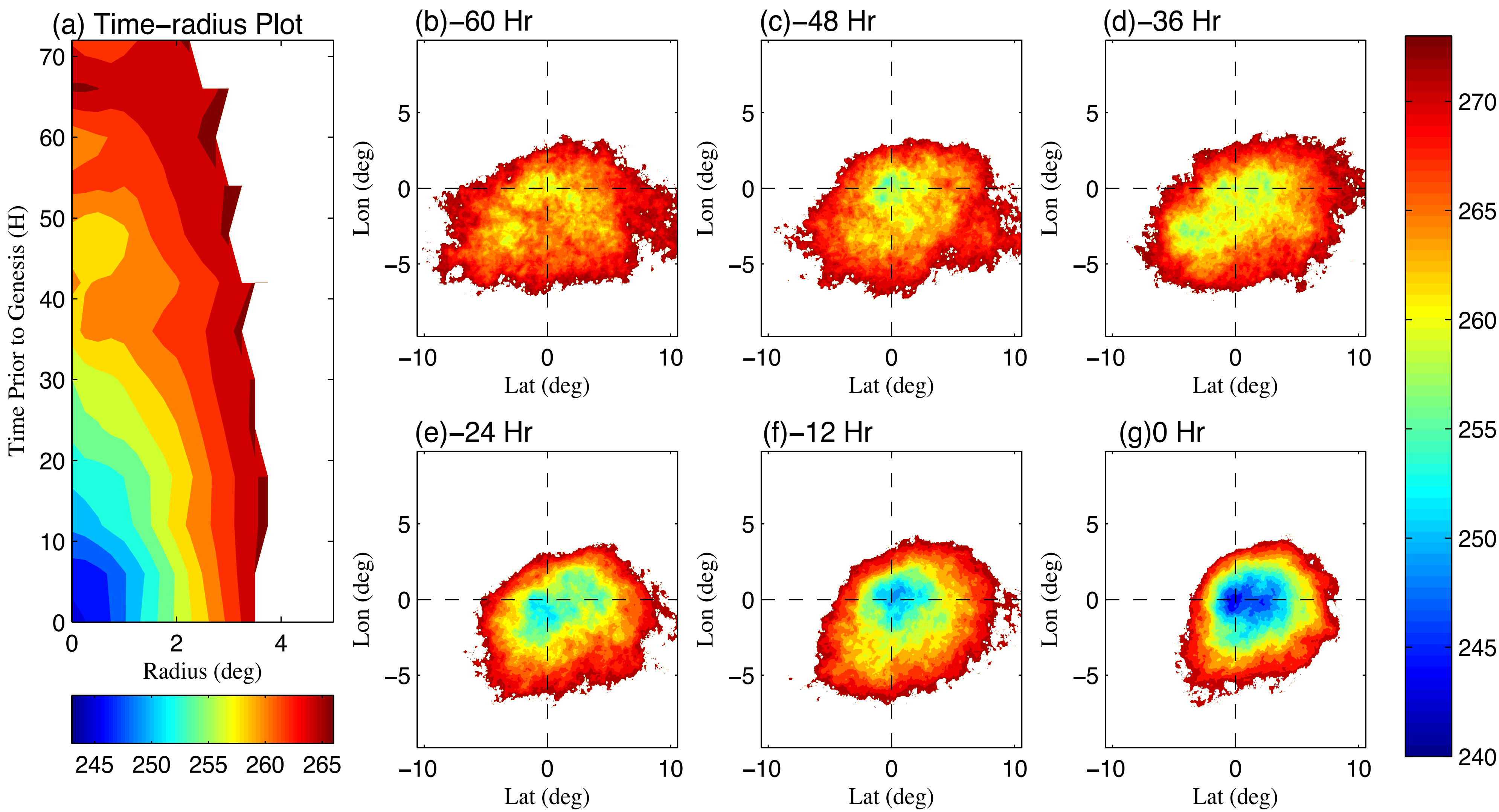
--- GRIBSAT IR data: high spatial and temporal resolution with continuous observation

IR imagery: which one is a tropical cyclone?





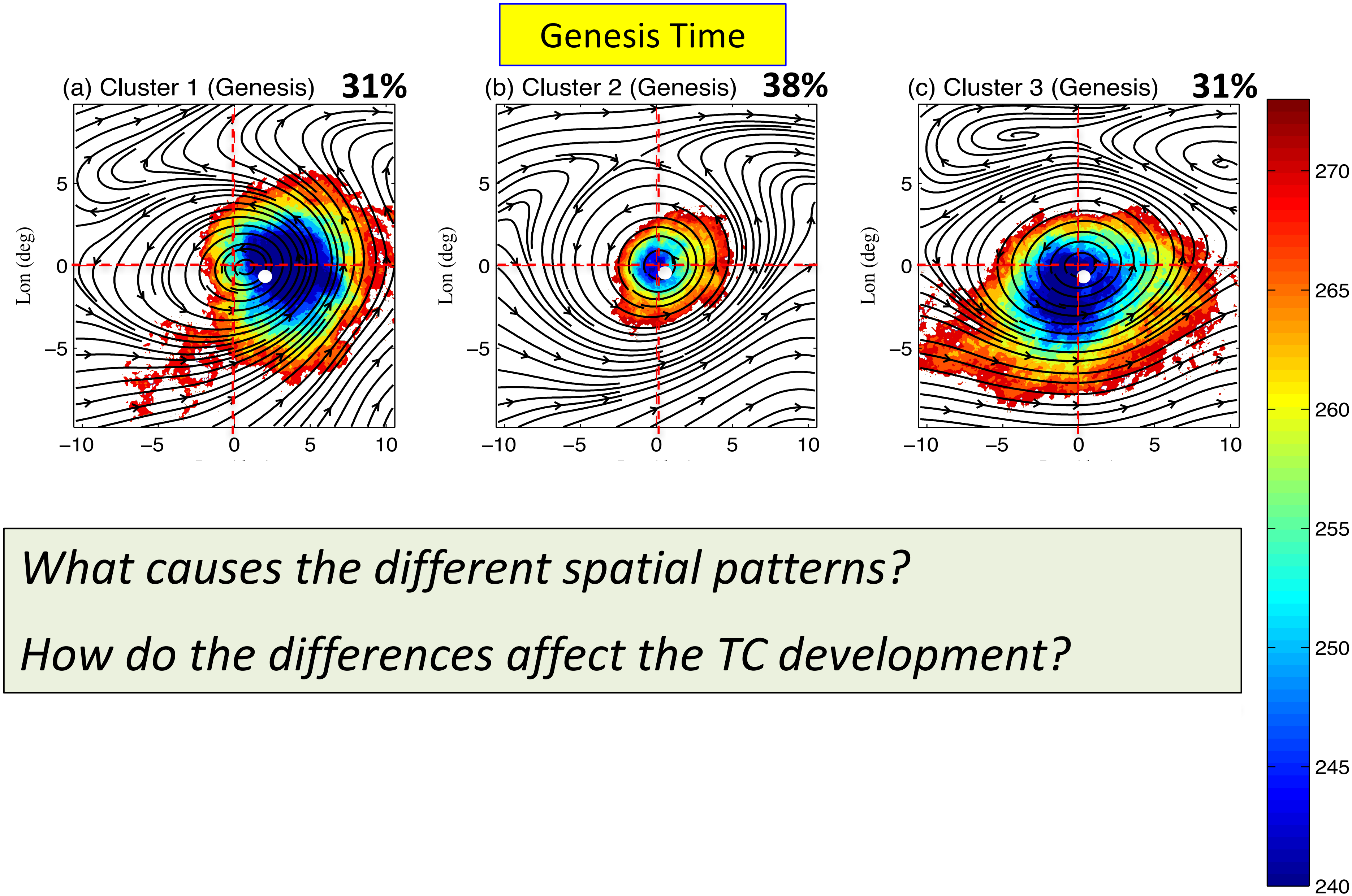
IR Composites



Composites with respect to the pouch center.

Wang 2017

Three Clusters of Different Spatial Patterns: IR



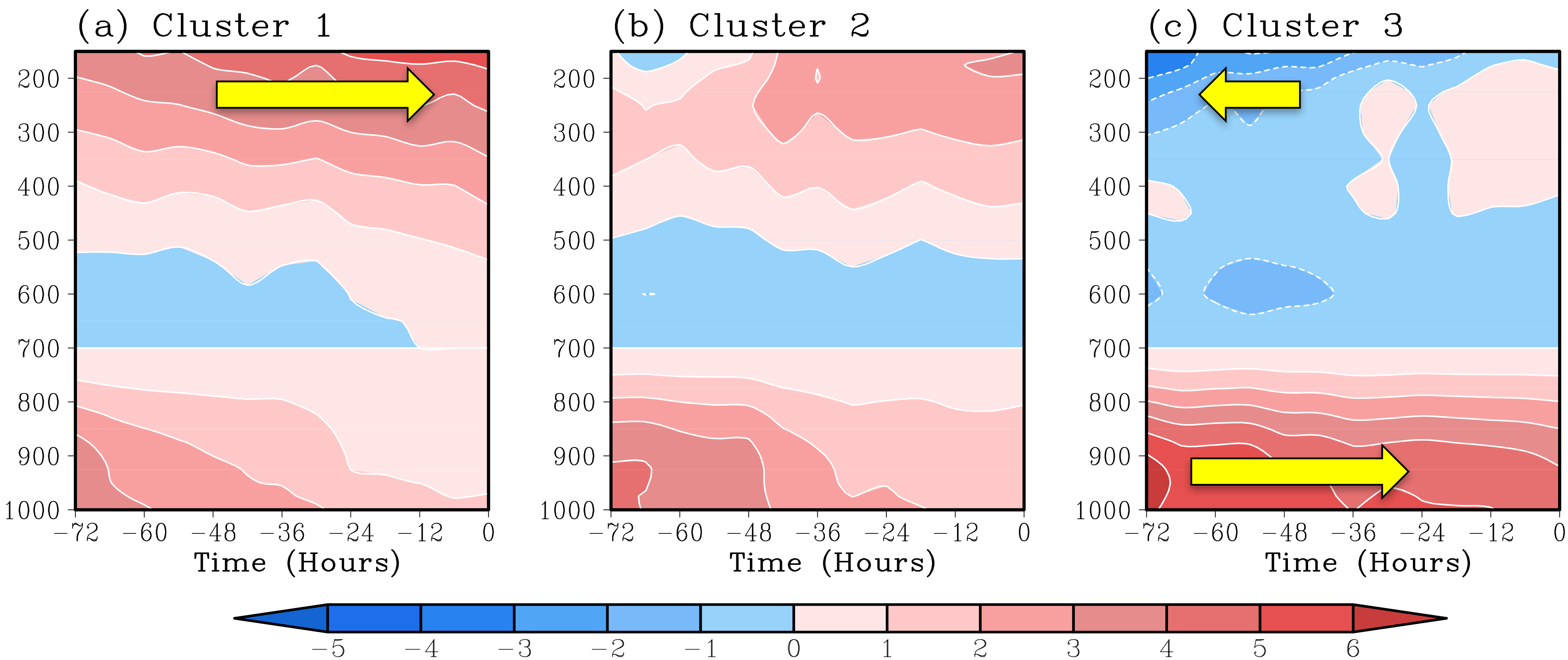
What causes the different spatial patterns?

How do the differences affect the TC development?

Wang 2017

Three Clusters : Relative Flow (10deg Box)

U(p)-U(700 hPa)



Cluster 1: strong westerly relative flow in the upper troposphere

Cluster 3: weak easterly relative flow in the upper troposphere; strong westerly relative flow in the boundary layer

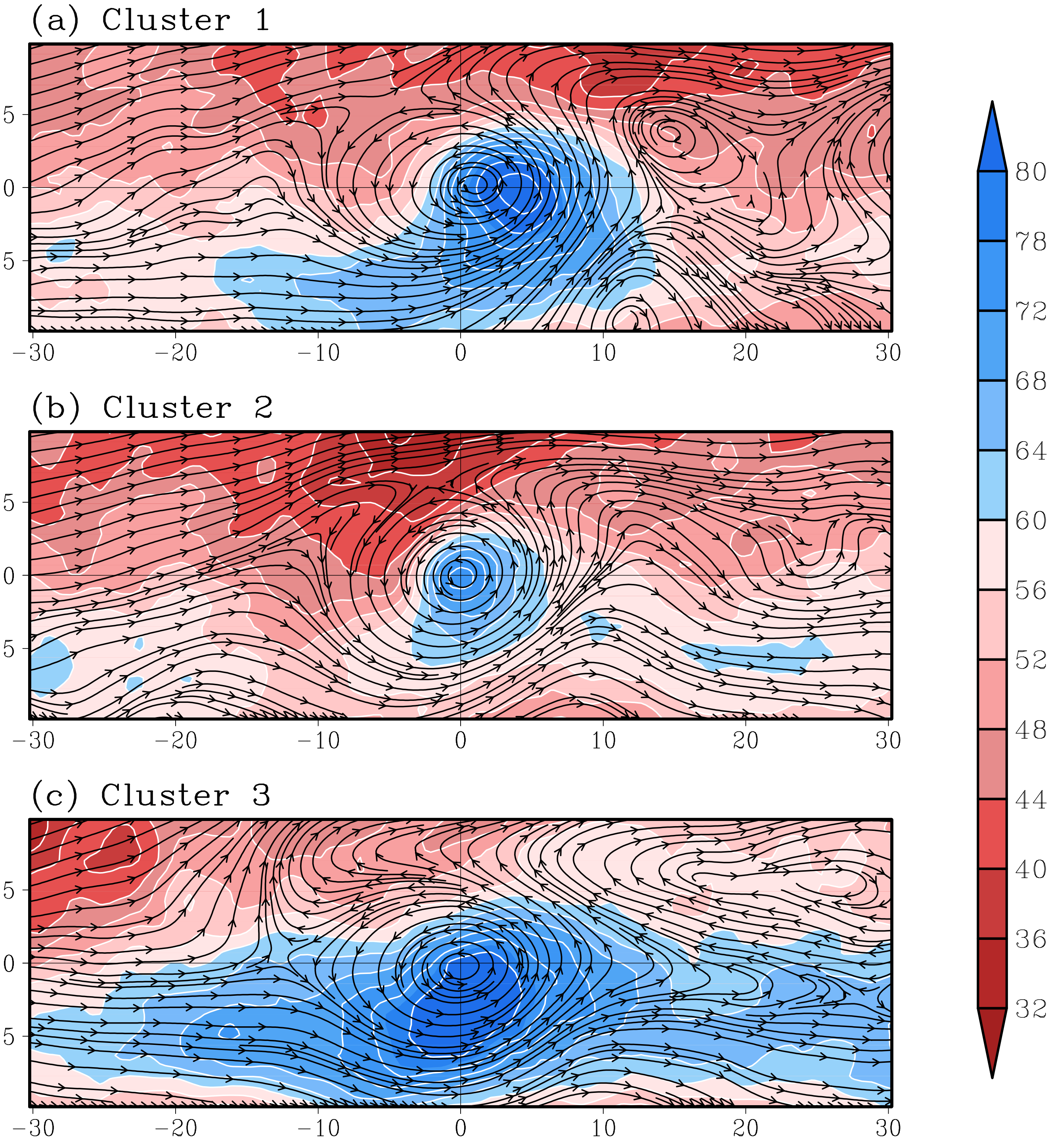
Wang 2017

Three Clusters : Relative Humidity (600 hPa)

Cluster 1: A moist pouch detached from the ITCZ?

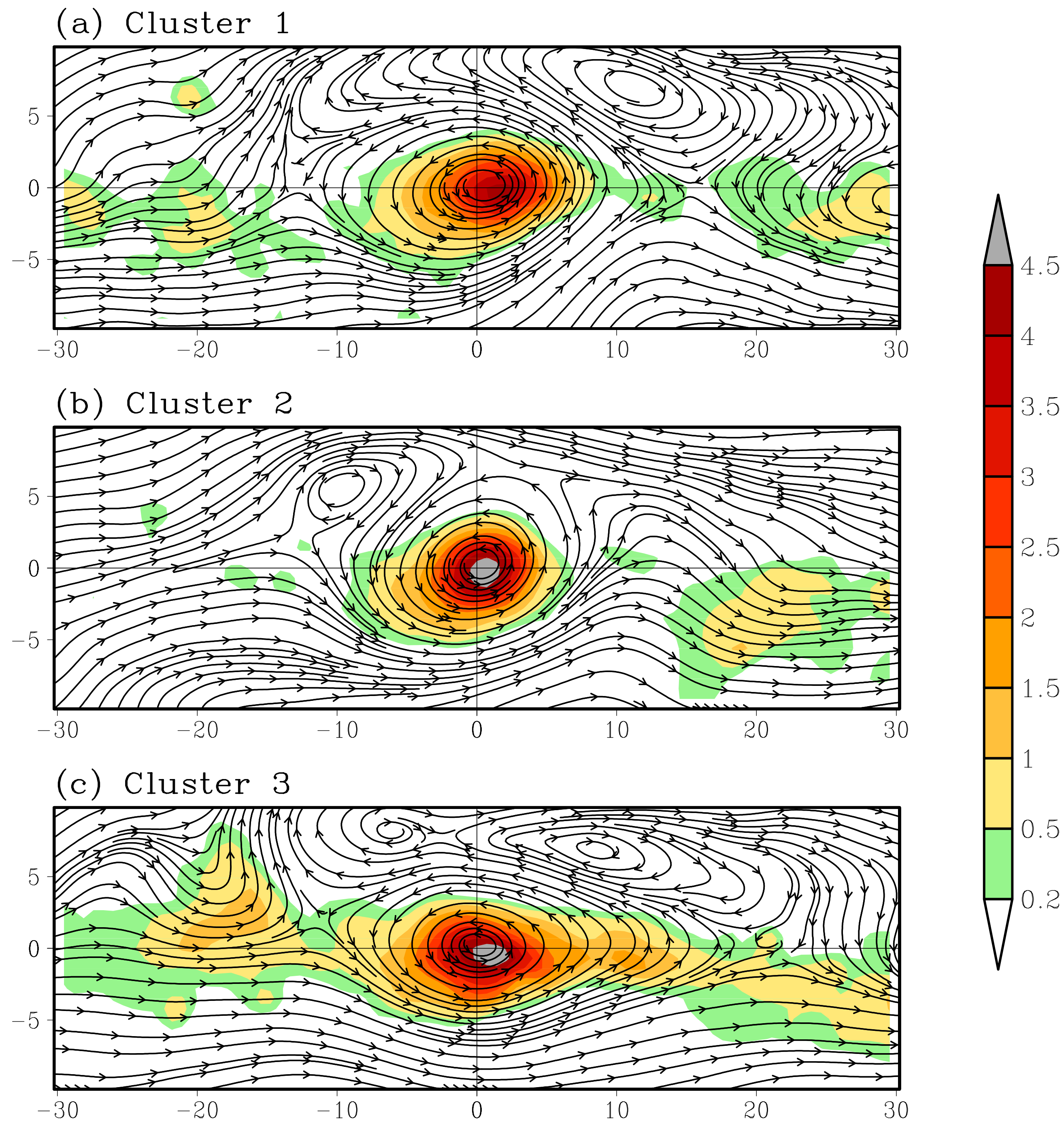
Cluster 2: An isolated moist core surrounded by dry air.

Cluster 3: A large moist pouch embedded in the ITCZ



Wang 2017

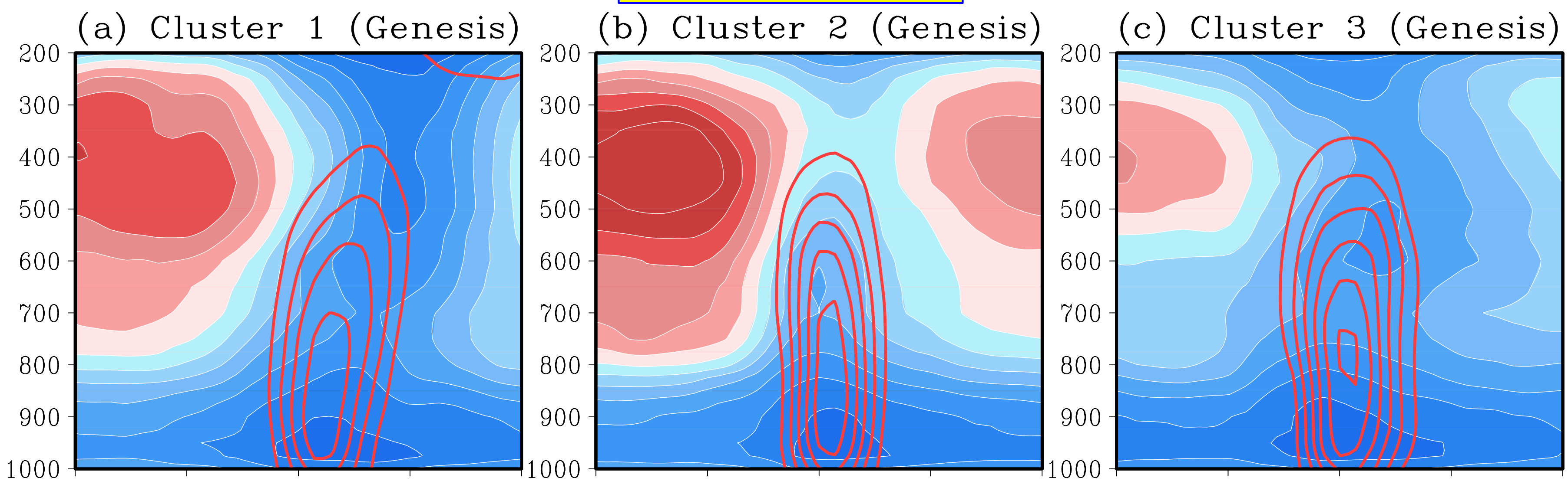
Three Clusters : Relative Vorticity (700 hPa)



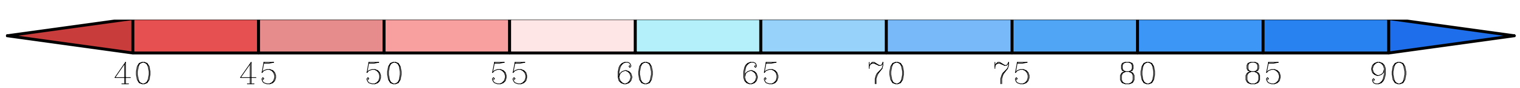
Wang 2017

East-west Vertical Cross Section: OW (contours) and RH

Genesis Time

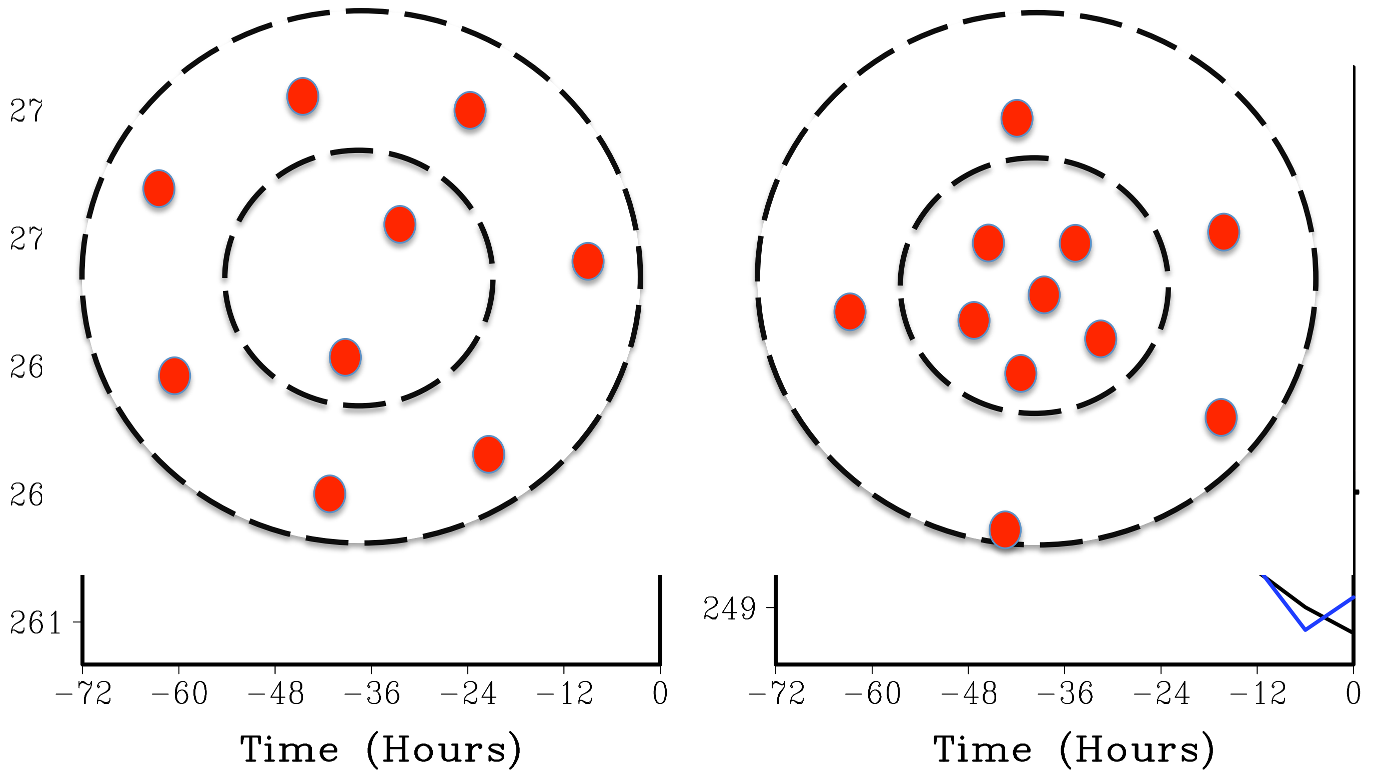


- A small convective core does not mean a weaker vortex.
- Displacement of convection off the pouch center is associated with a weaker vortex.



Wang 2017

Time Series of Median IR for Each Cluster

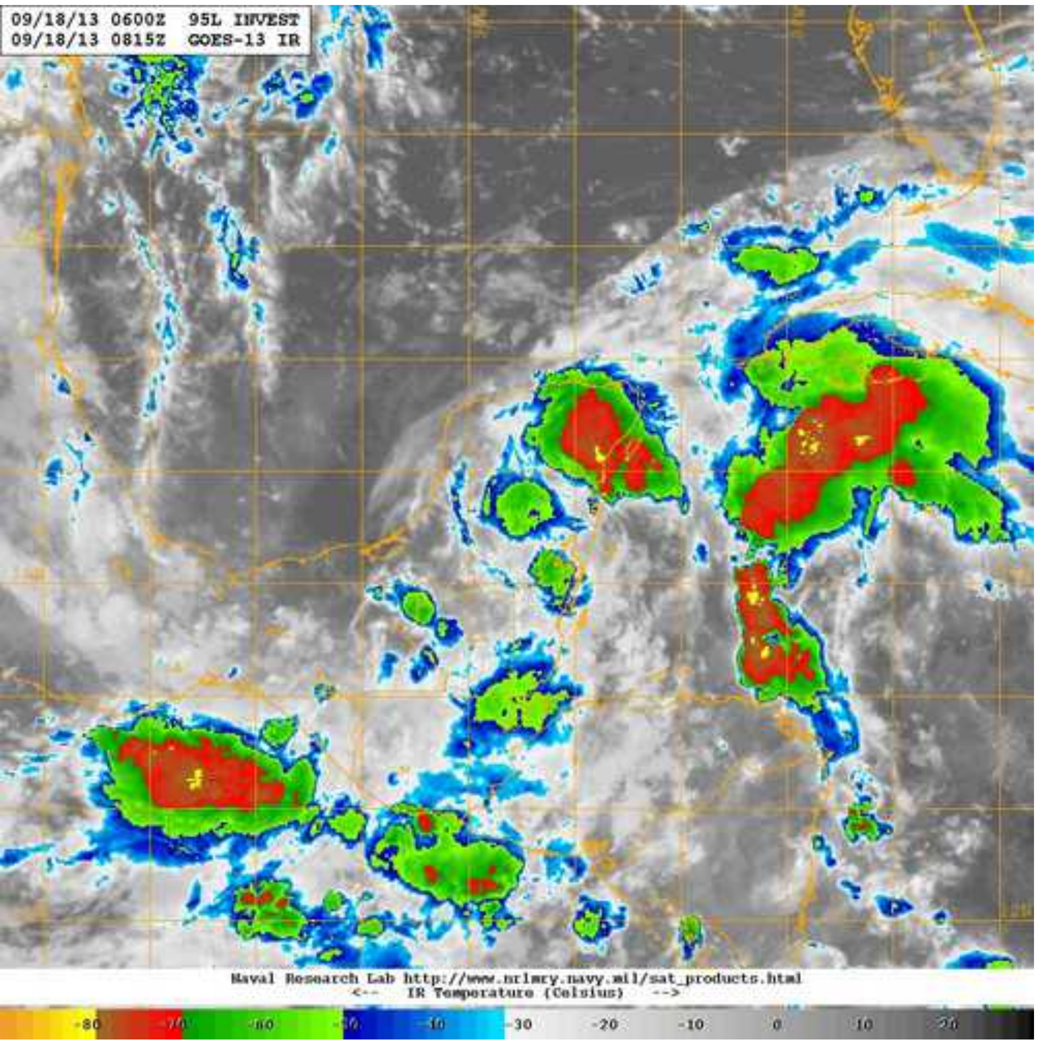


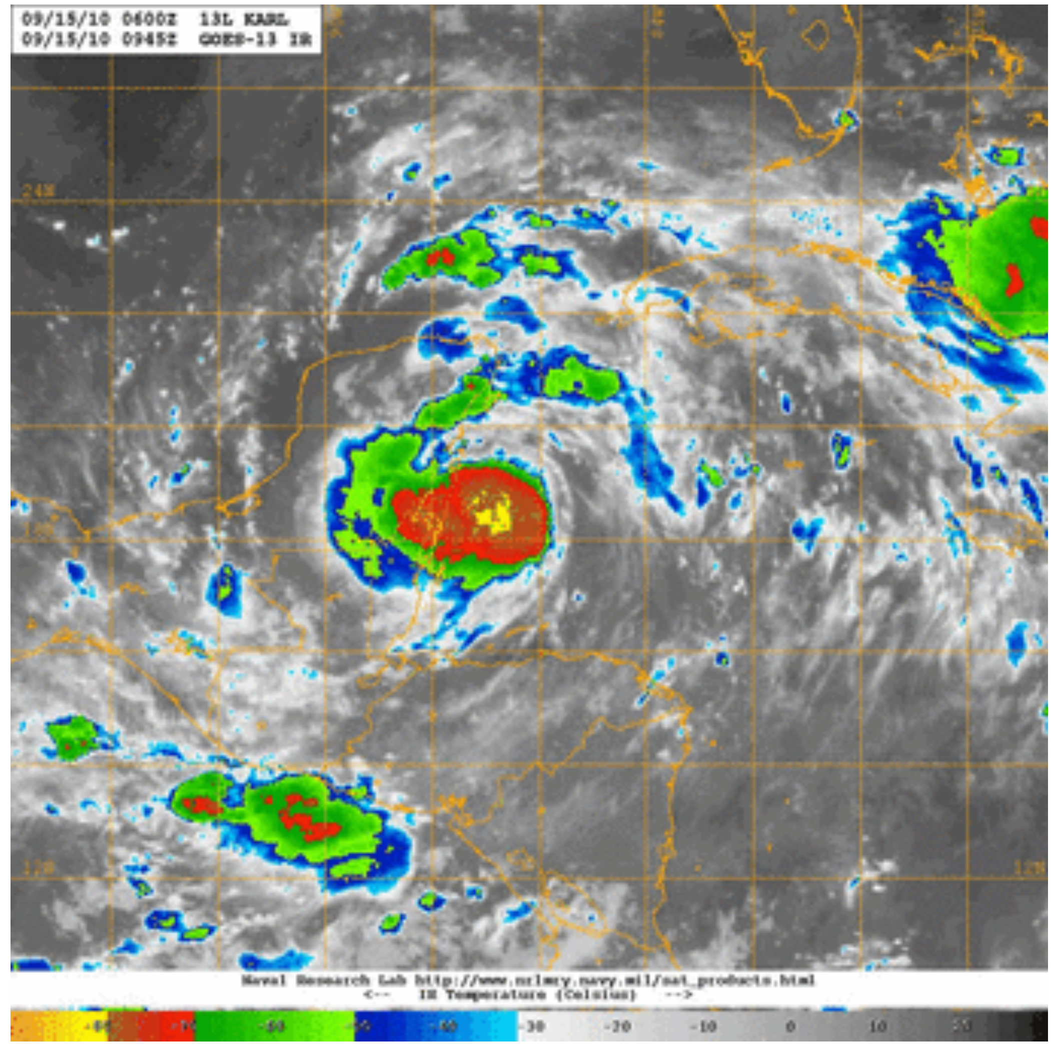
$$\frac{\partial}{\partial r}\left(A\frac{\partial r\psi}{r\,\partial r}+B\frac{\partial\psi}{\partial z}\right)+\frac{\partial}{\partial z}\left(B\frac{\partial r\psi}{r\,\partial r}+C\frac{\partial\psi}{\partial z}\right)=\boxed{\frac{g}{\theta}\frac{\partial Q}{\partial r}}$$

The transverse circulation is driven by the gradient of diabatic heating, instead of the heating itself! Heating is most effective when the maximum is collocated with the vorticity center.

Wang 2017

IR imagery: which one is a tropical cyclone?





Three Clusters : TC Size

Cluster	1	2	3
Mean AR34	72	59	66
Median AR34	72	53	62

AR34: Radius of 34-knot winds averaged over one day after the declaration of a tropical storm.

Restricted to a latitude band 10-25N.

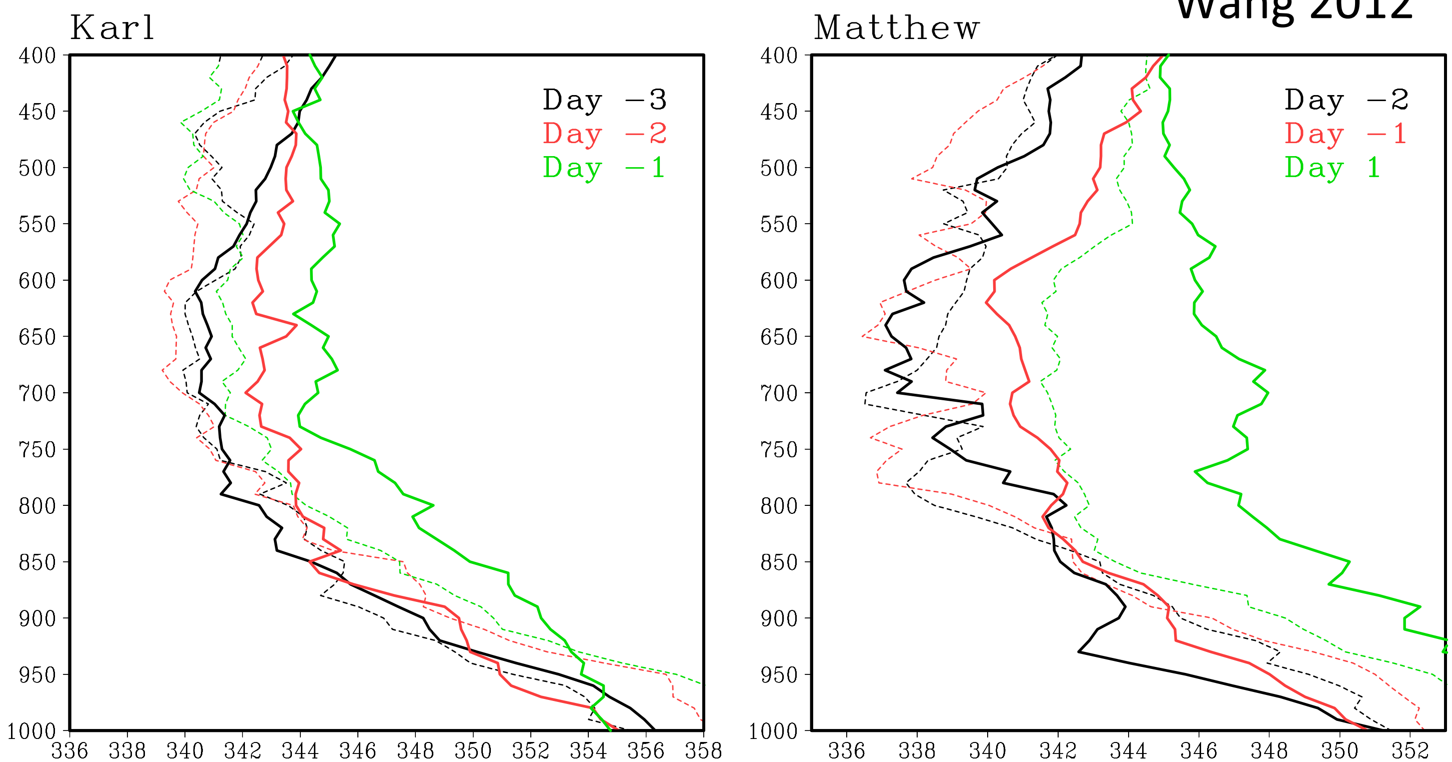
Wang 2017

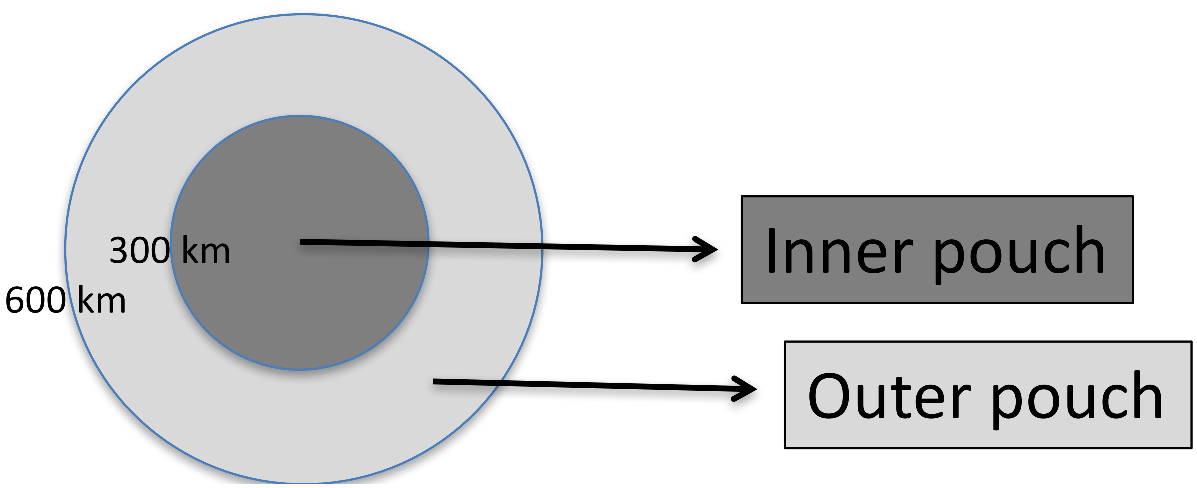
Q2: What thermodynamic conditions promote convective organization near the pouch center?

--- SSMI/SSMIS data: simultaneous rain rate and CWV retrievals

Equivalent Potential Temperature Profiles: inner vs. outer pouch region

Wang 2012

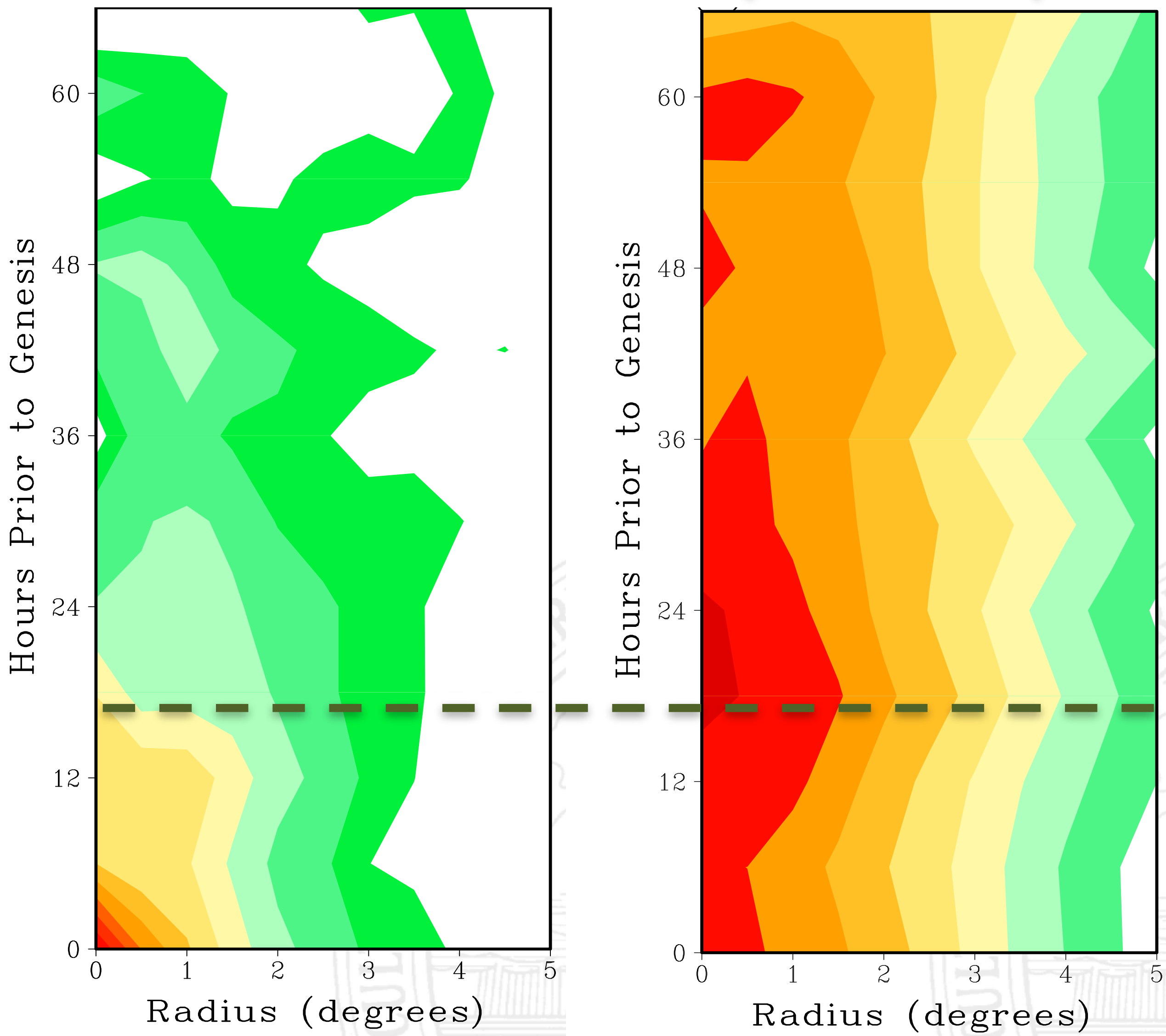




- The midlevel θe increases significantly near the pouch center one to two days prior to genesis but changes little away from the pouch center.
- This may be an indicator of the impending TC genesis.
- Consistent with Nolan (2007)

Time-Radius Plots of Rain Rate and CWV

Differential Moistening

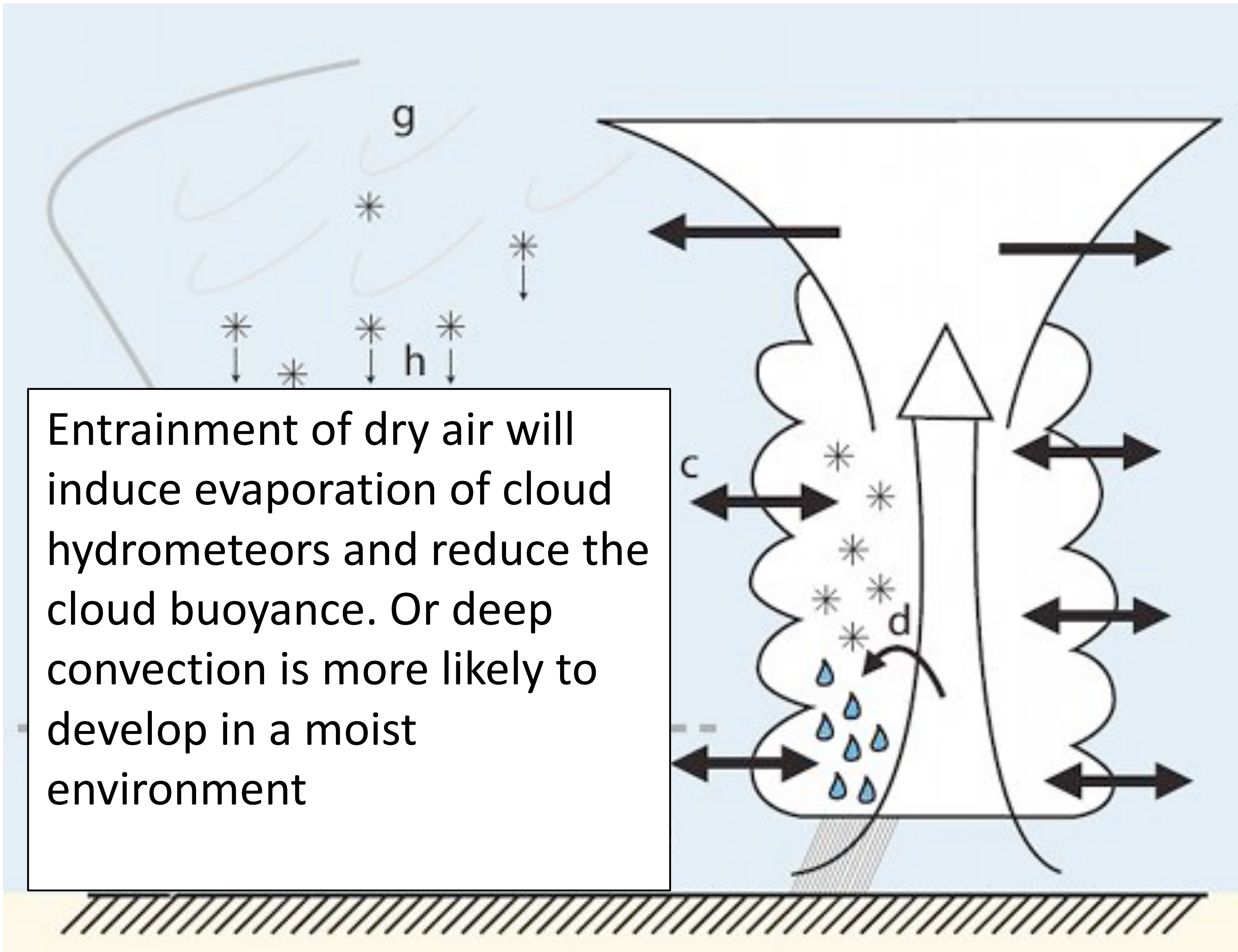


Stage One: Moisture Preconditioning

Stage Two: Transition to Sustained Deep Convection

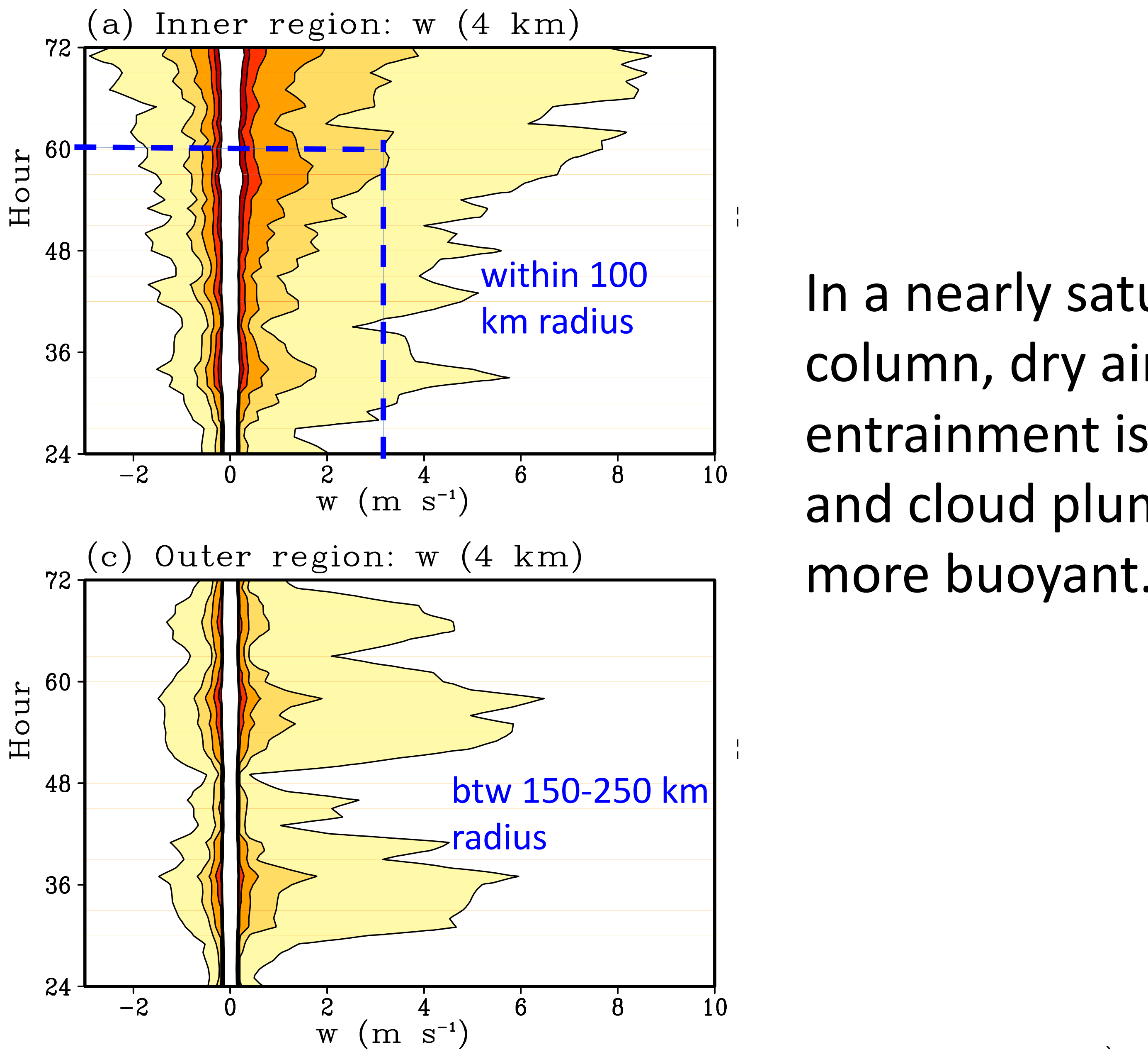
Wang and Hankes 2016

Dry air and Cloud Buoyance



Entrainment of dry air will induce evaporation of cloud hydrometeors and reduce the cloud buoyance. Or deep convection is more likely to develop in a moist environment

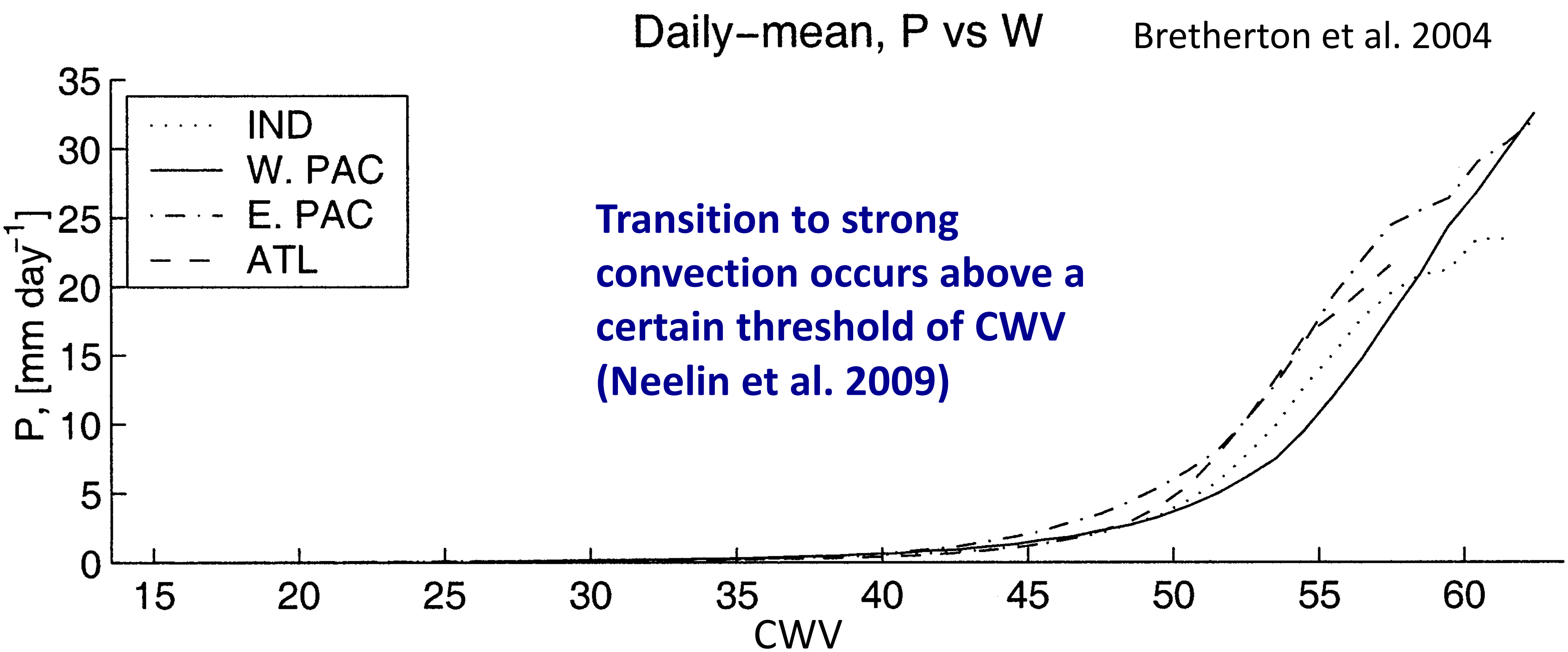
WRF Simulations: Cumulative Distribution of w



In a nearly saturated column, dry air entrainment is reduced and cloud plumes are more buoyant.

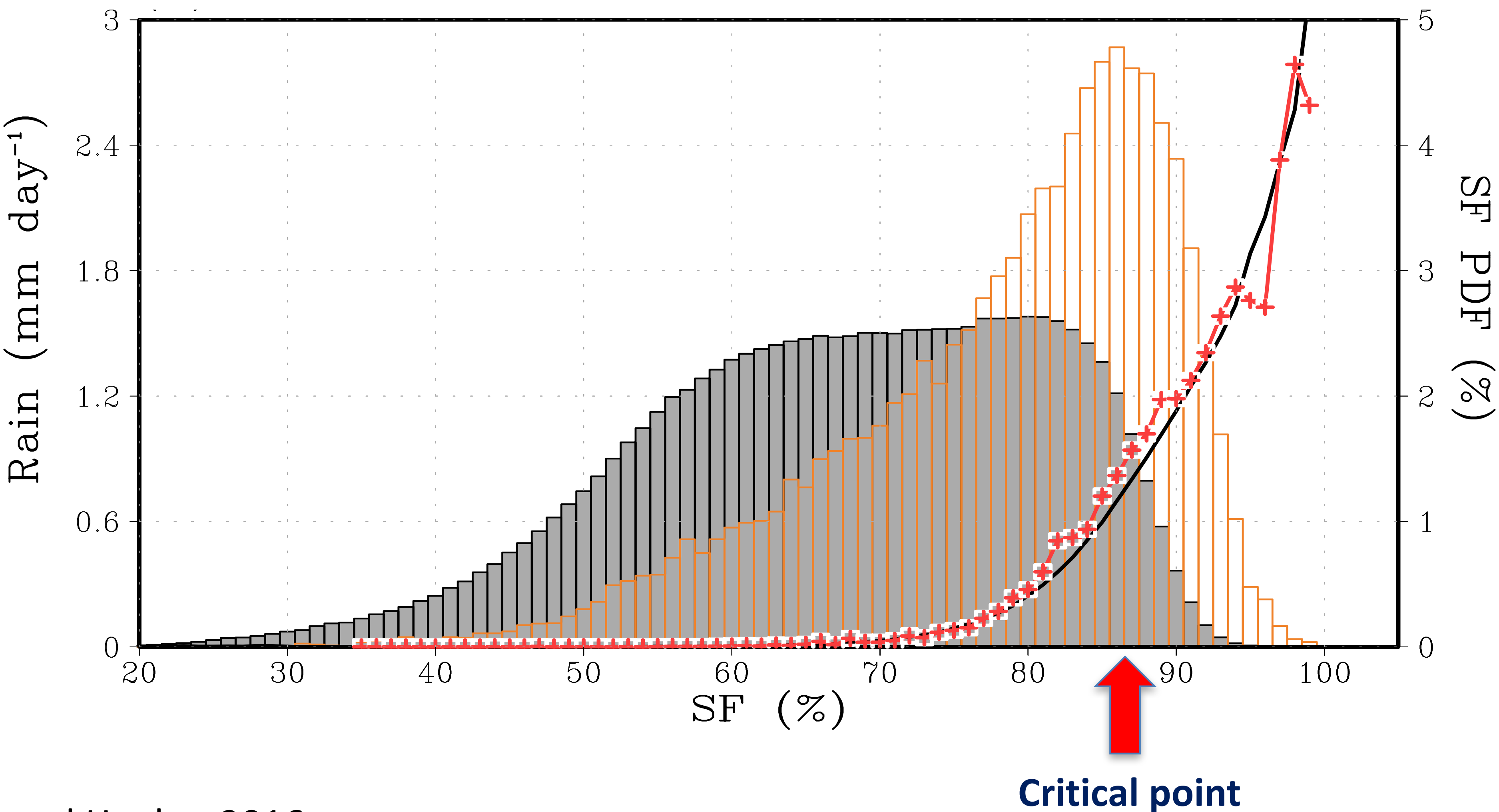
Wang 2012

Precip vs. Column Water Vapor



Precip increases exponentially with the column water vapor (Raymond 2000; Bretherton 2004).

Column RH-Precipitation relationship

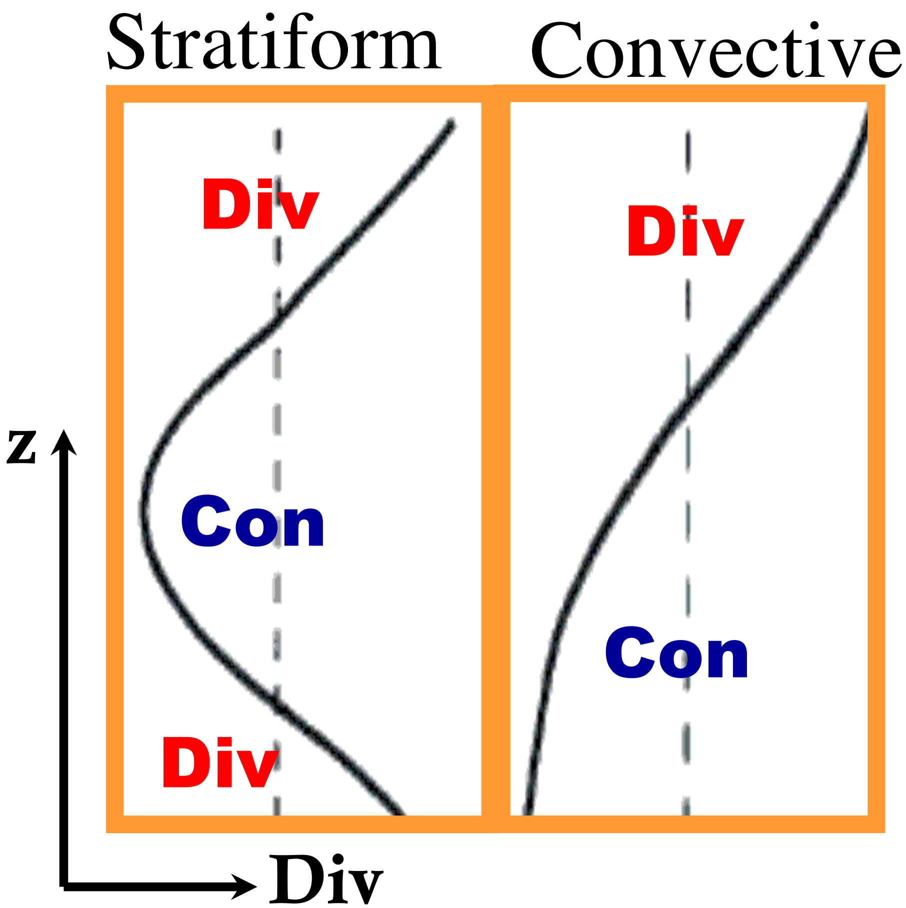


Wang and Hankes 2016

Q3: What are the relative roles of different types of precipitation in TC genesis?

--- TRMM PR 2A25: vertical profile of reflectivity

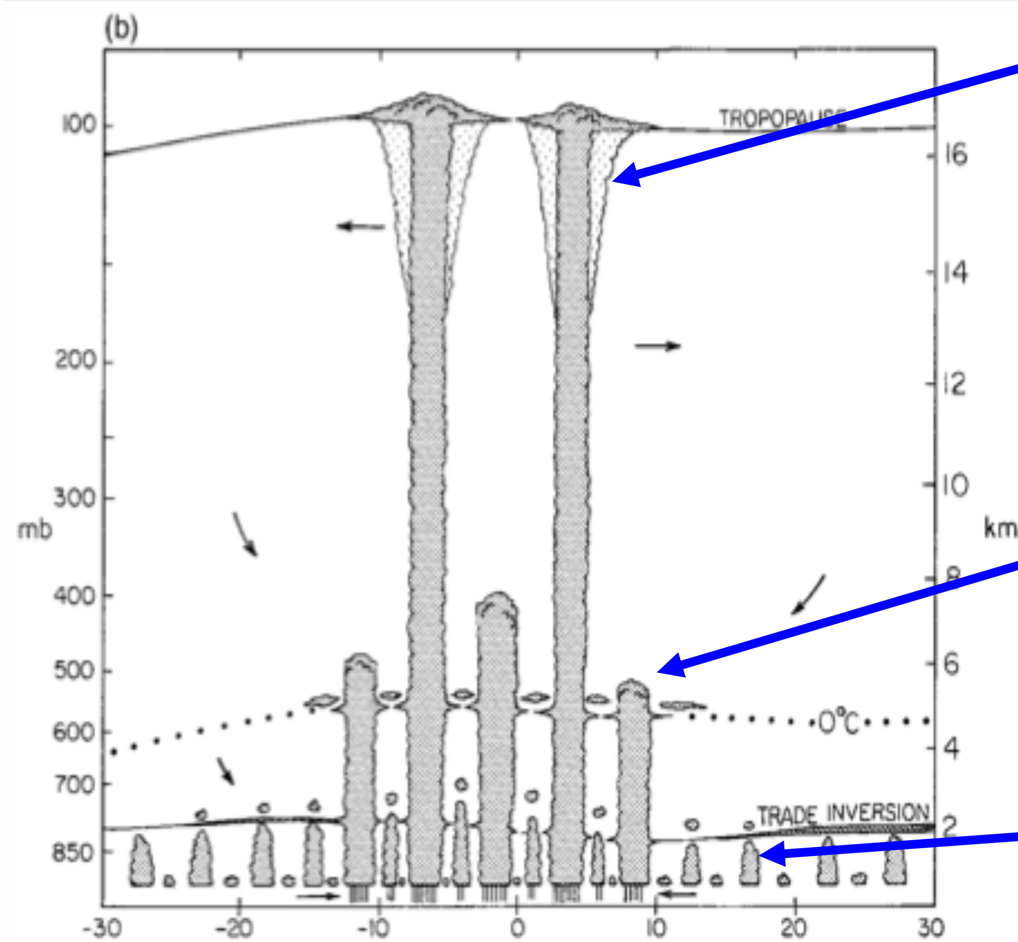
Stratiform vs. Convective Precipitation



- Stratiform process: favors the development of a mid-level vortex.

- Convective process: favors the spin-up of the low-level circulation.

Trimodal Distribution of Convective Clouds

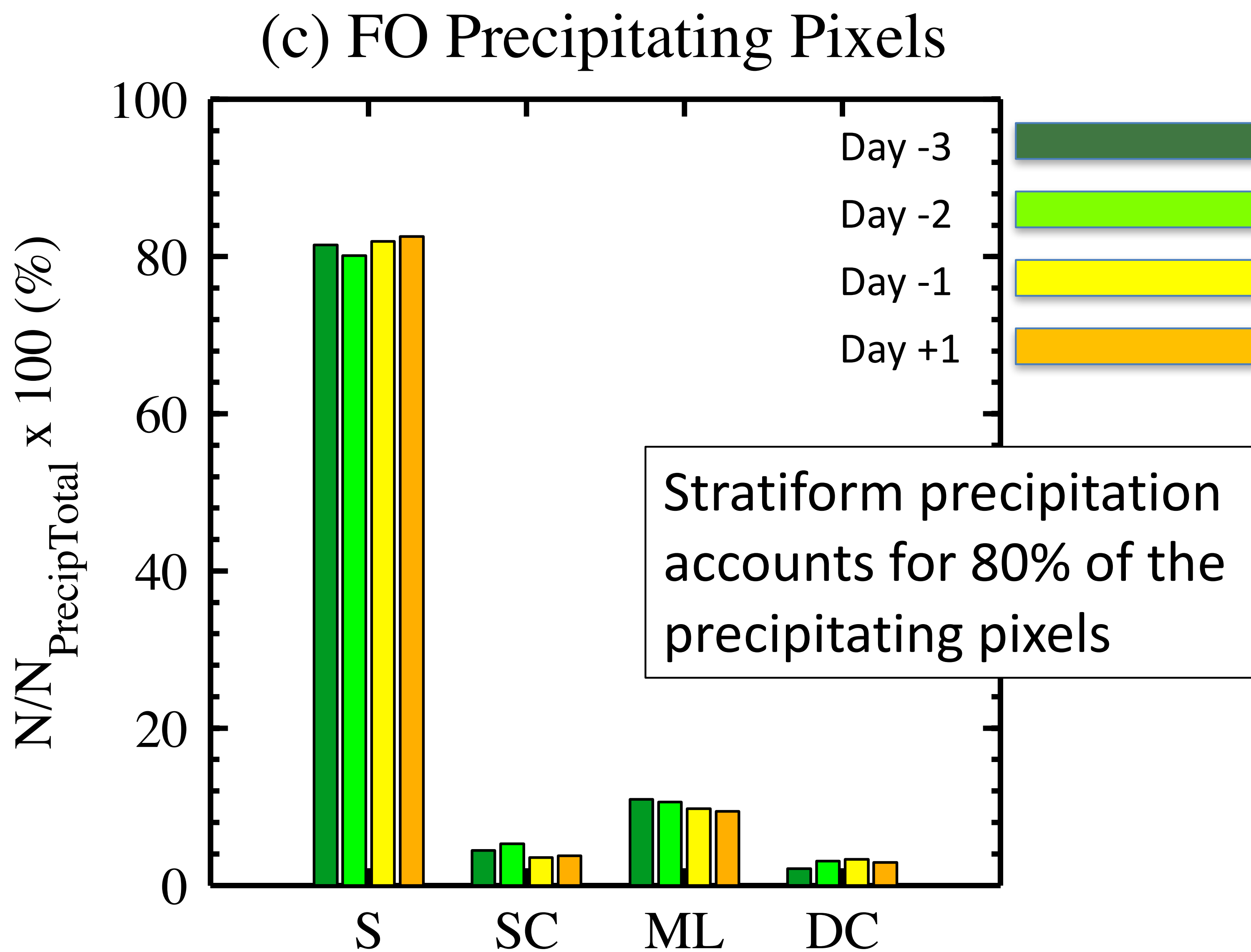


Johnson et al. 1999

Partitioning of convection:

Echo top height derived from 2A25 reflectivity was used to partition the three types of convection.

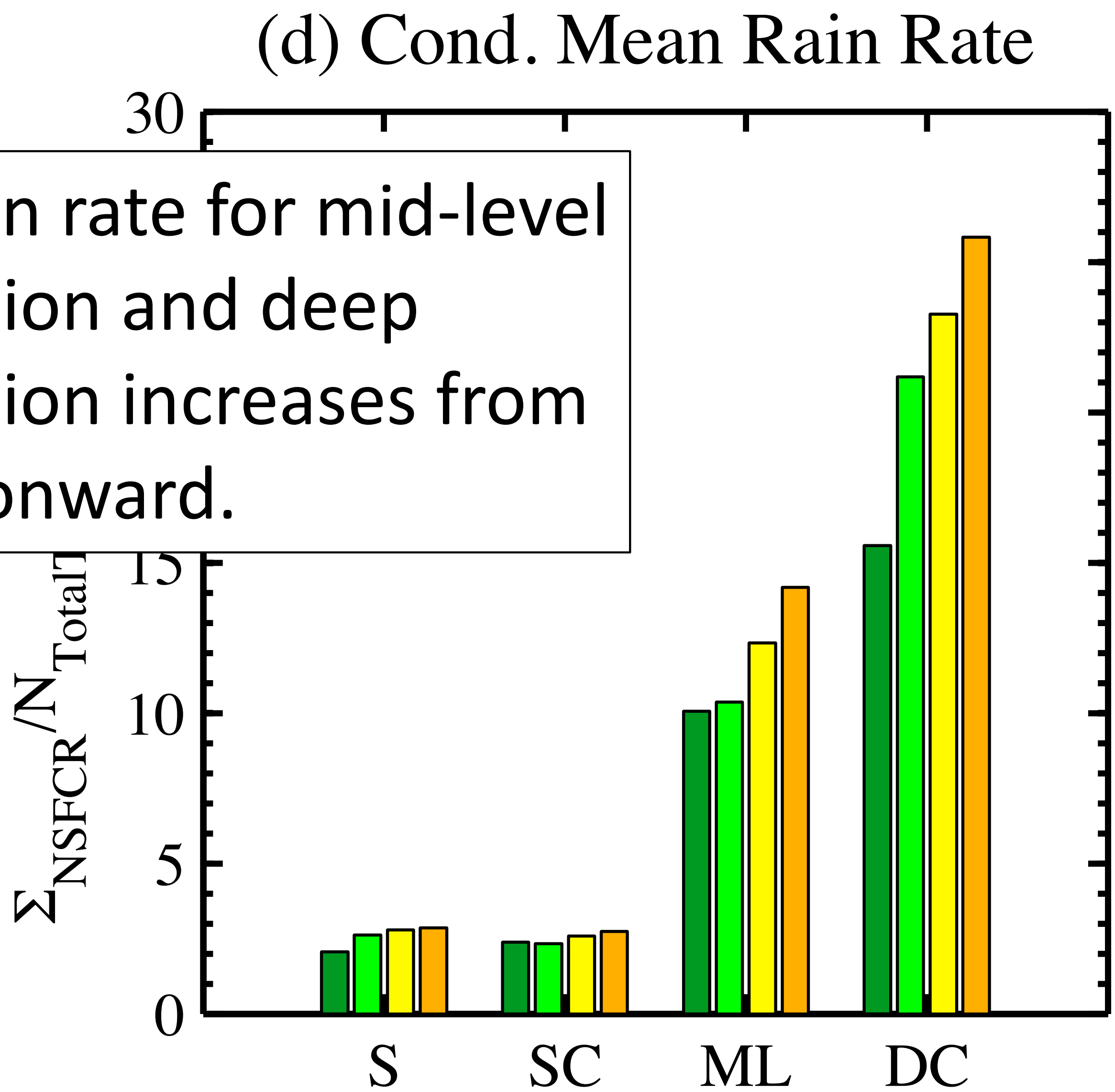
TRMM PR: Frequency of occurrence of Precipitating Pixels



Stratiform precipitation accounts for 80% of the precipitating pixels

Fritz et al. 2016

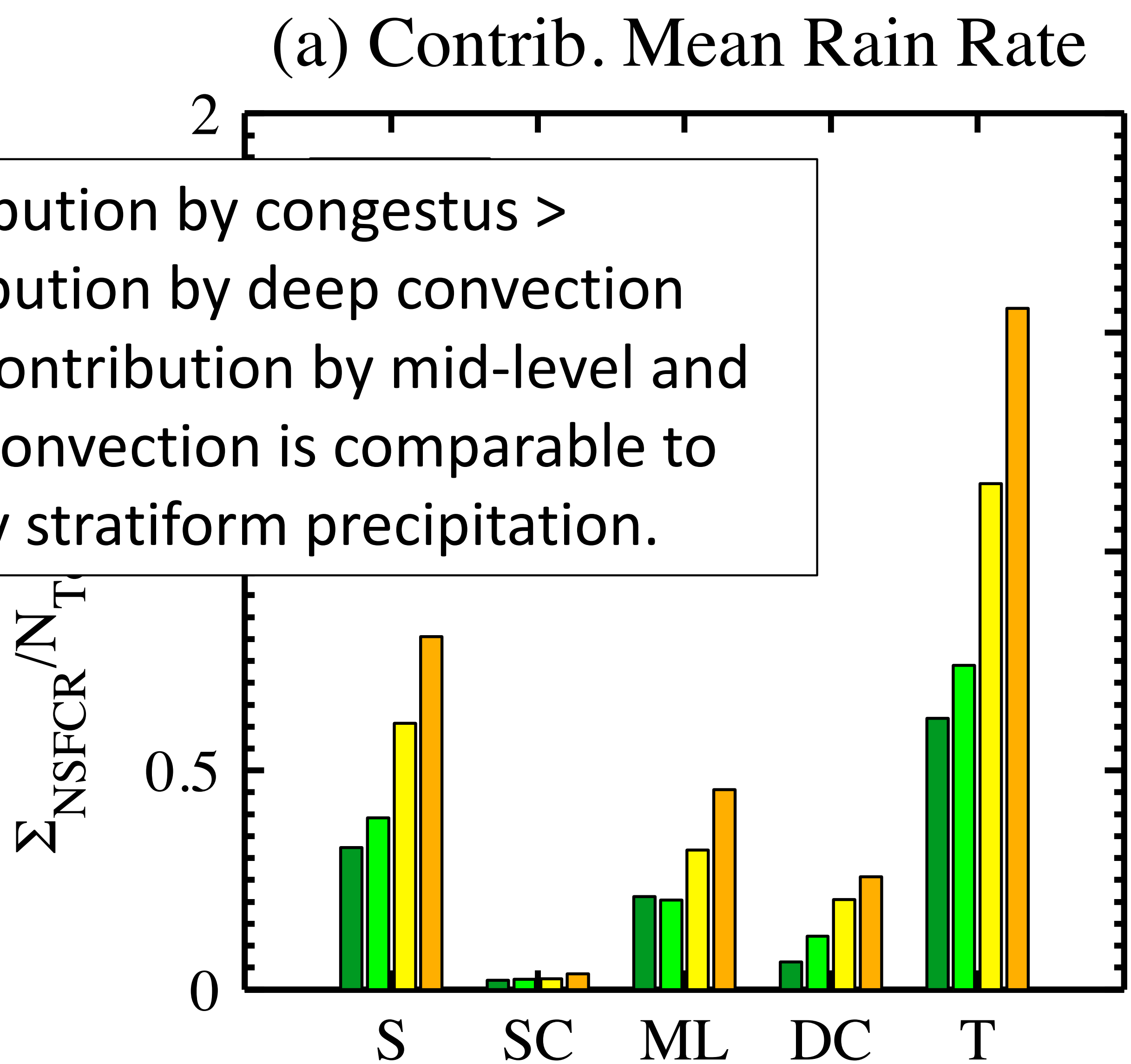
TRMM PR: Pixel Rain Rate



Pixel rain rate for mid-level convection and deep convection increases from Day -2 onward.

Fritz et al. 2016

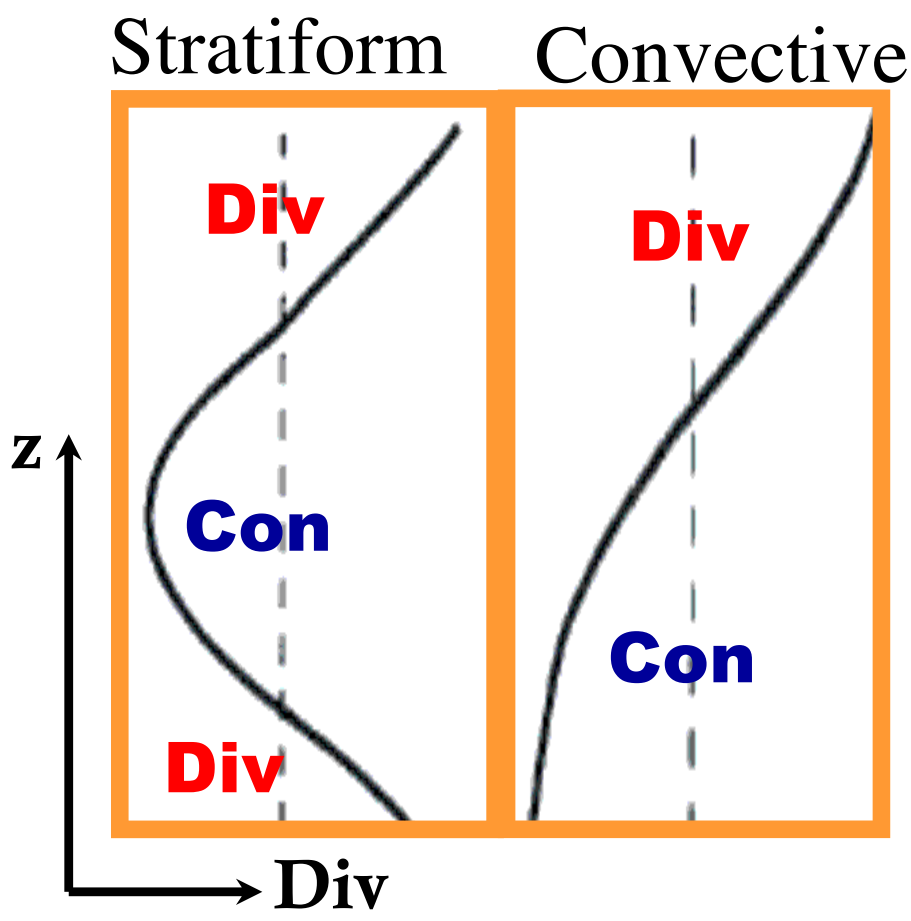
TRMM PR: Contribution to the Mean Rain Rate



1. Contribution by congestus > contribution by deep convection
2. Total contribution by mid-level and deep convection is comparable to that by stratiform precipitation.

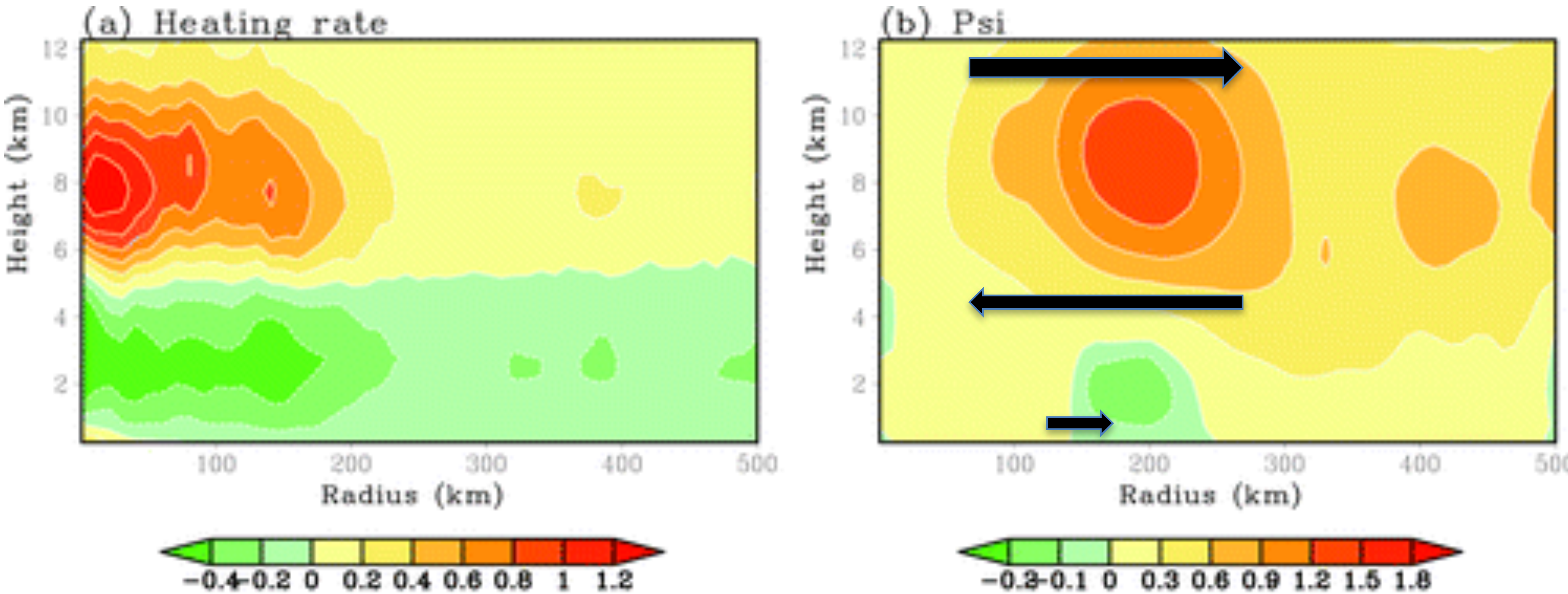
Fritz et al. 2016

Stratiform vs. Convective Precipitation



- Stratiform process: favors the development of a mid-level vortex.
- Convective process: favors the spin-up of the low-level circulation.

Stratiform Precipitation



Stratiform heating contributes to the midlevel spinup without significantly spinning down the low-level circulation.

Wang, 2012

Summary

- The key feature of convection for TC genesis is not the intensity or extent of deep convection, but the convective organization near the pouch center.
- Column moistening near the pouch center precedes the transition to sustained deep convection and tropical cyclogenesis.
- Tropical cyclogenesis may be an outcome of the collective contribution by different types of precipitation.