A multi-platform observational approach to studying controls on the organization and upscale growth of mesoscale deep convection

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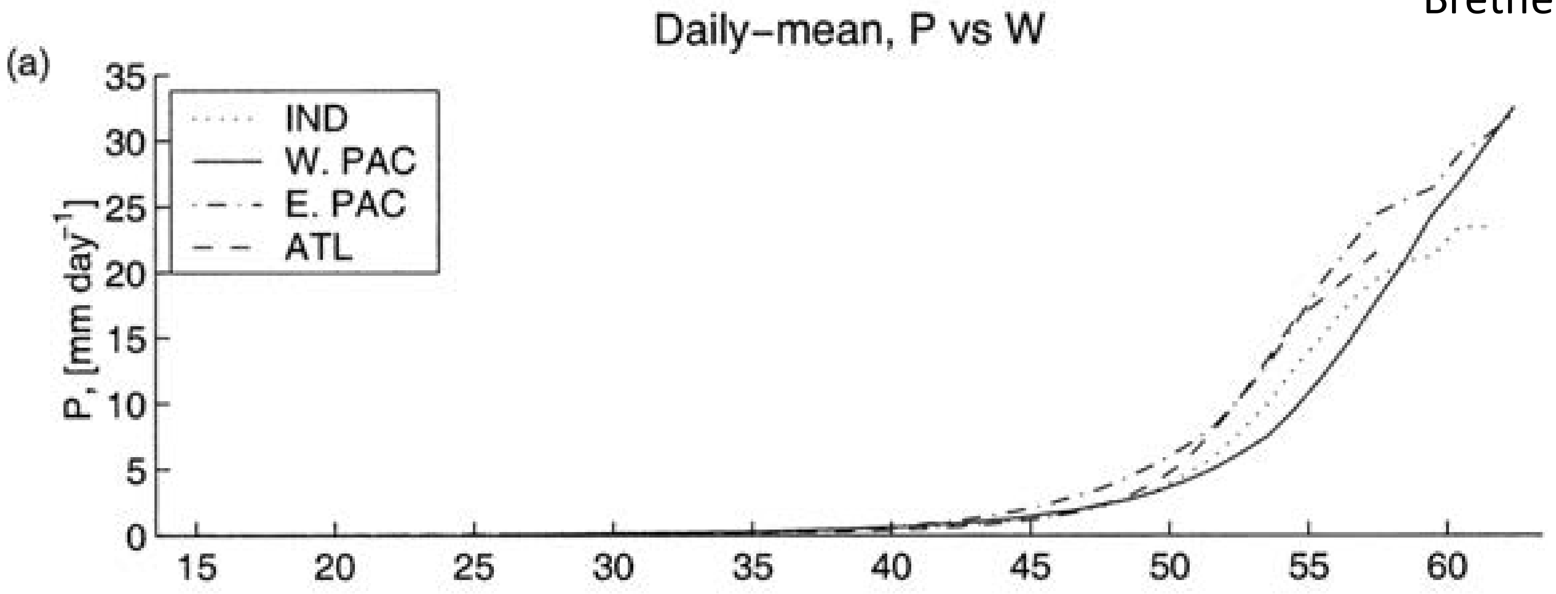
DOE ARM/ASR PI Meeting
Convective Processes Breakout
3 March 2025

Background

Precipitation strongly dependent on total column moisture in the tropics.

Bretherton et al. (2004)



Column water vapor (CWV; mm)

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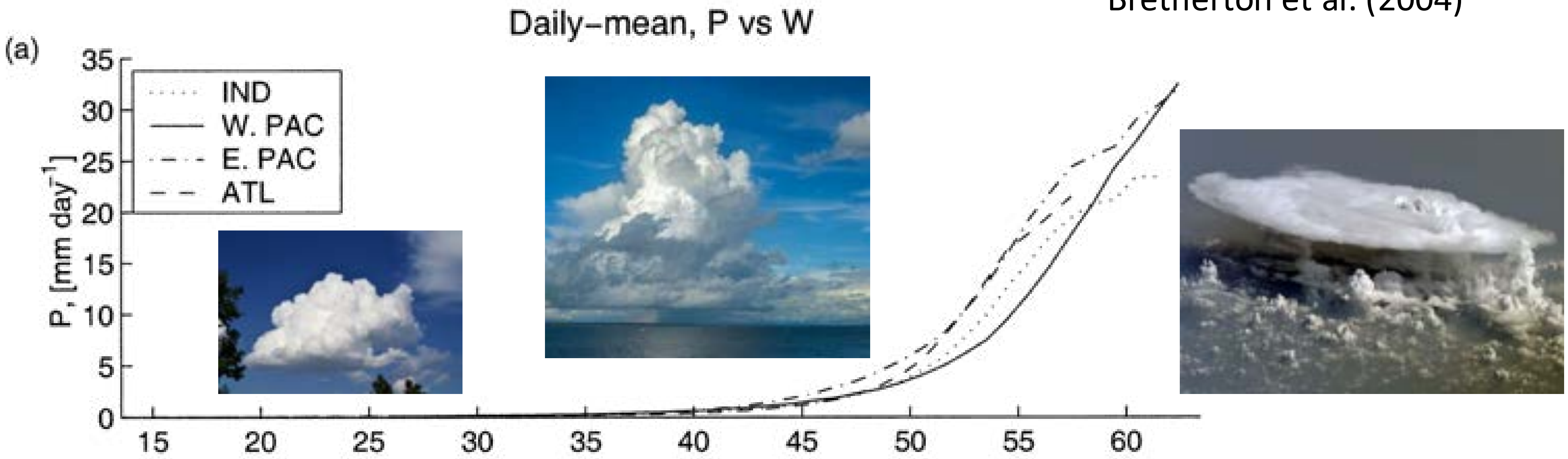


Column water vapor (CWV; mm)

Where do different convective modes and convective lifecycles fall along this curve?

Are MCSs associated with higher CWV/buoyancy than isolated deep convection (IDCs)?

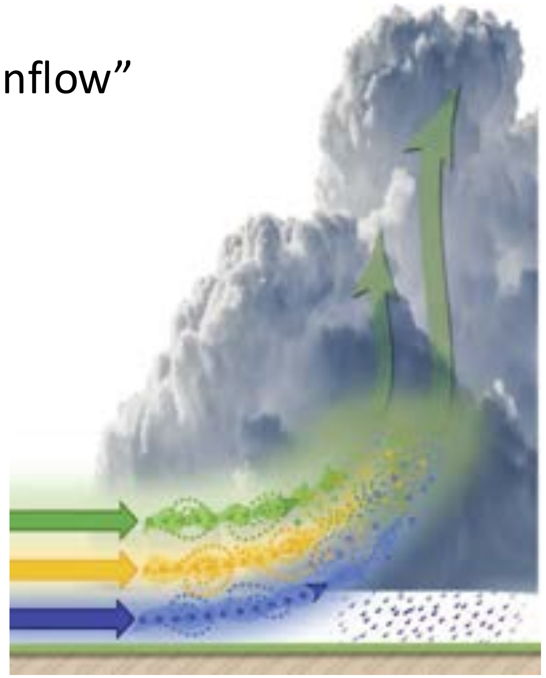
Background

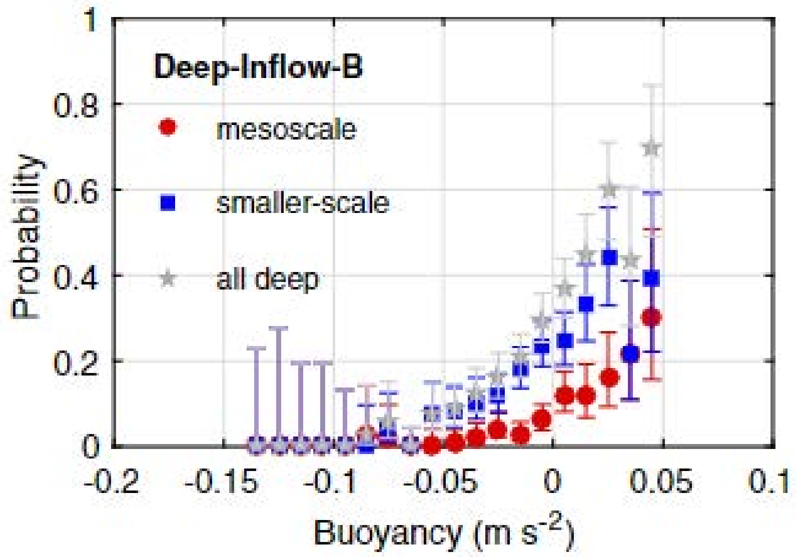
Precipitation strongly dependent on total column moisture in the tropics.

- Proxy for strongly entraining plume buoyancy

"Deep-layer inflow"

Schiro et al. (2018)





Example 1: from DOE ARM site data in Amazon (GoAmazon2014/5)

Are MCSs associated with higher CWV/buoyancy than isolated deep convection (IDCs)?

Some evidence suggests yes. Does this mean that higher CWV/buoyancy helps to organize deep convection?

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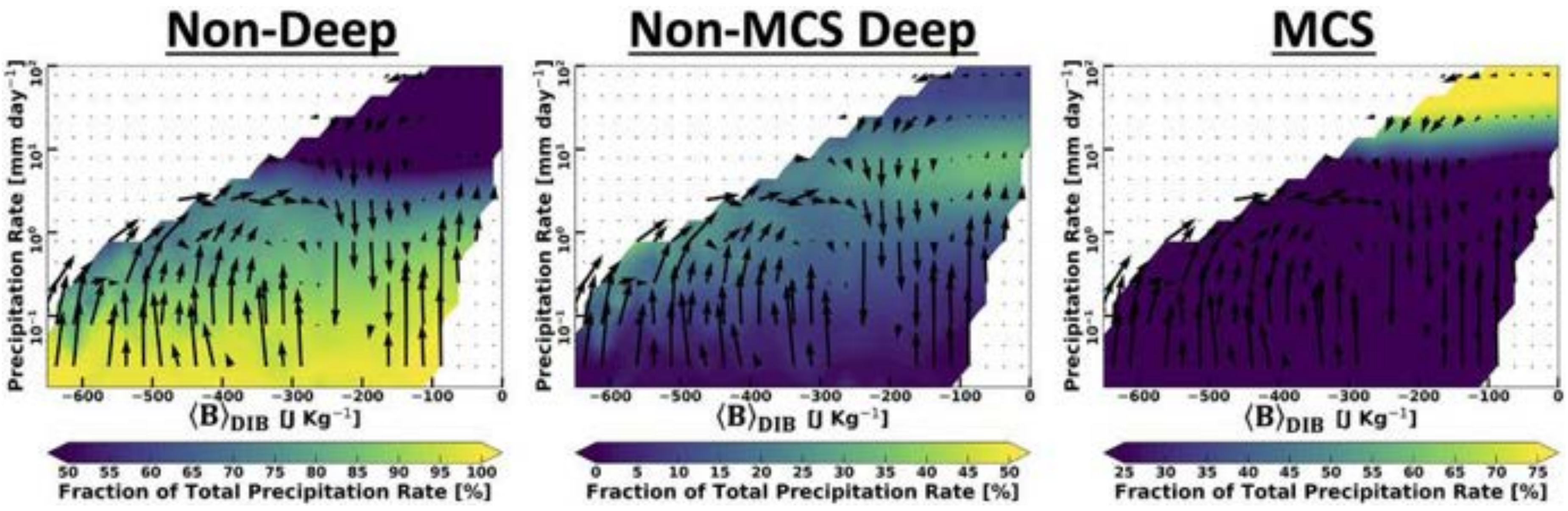

Example 2: from Wolding et al. (2024) using MCS tracking/IMERG precip and ERA5 thermodynamics

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Project Summary

<u>GOALS</u>: To identify environmental thermodynamic perturbations that may support the “organization” and maturation of deep convective cells into heavily precipitating MCSs.

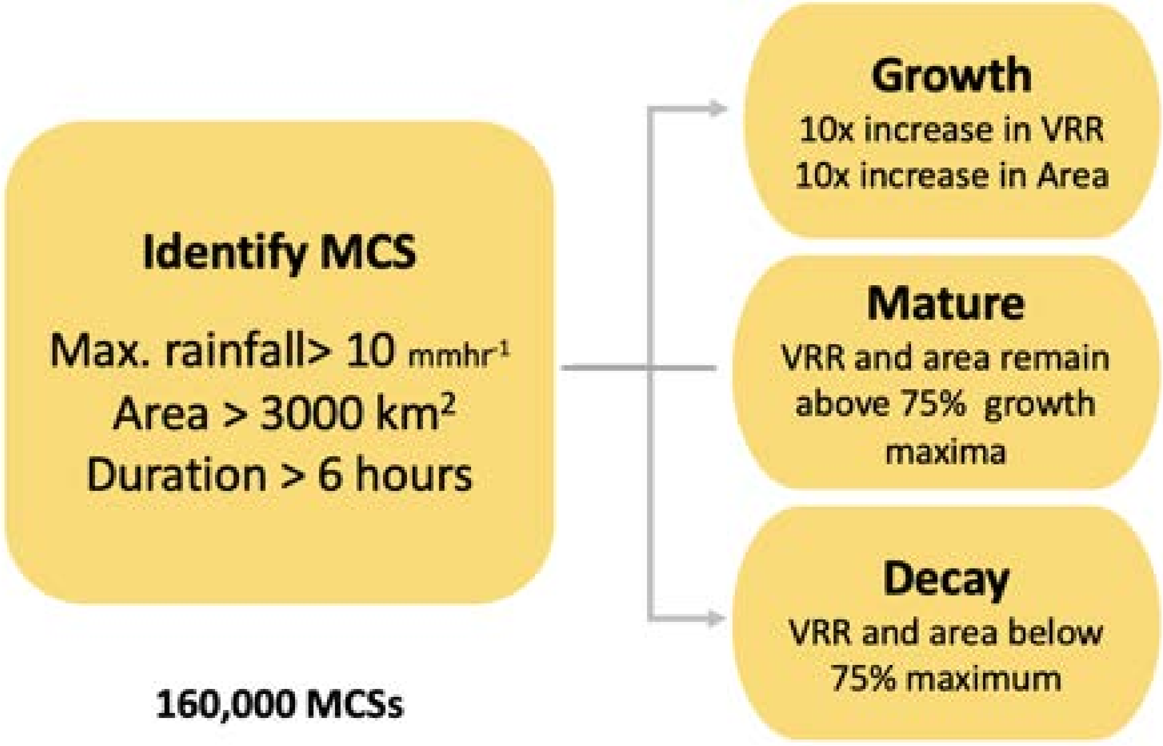
<u>APPROACH</u>: Use an MCS/IDC identification/tracking database to compare

(a) the environment across the MCS lifecycle from growth to decay (in space and time)

(b) the pre-MCS and pre-IDC thermodynamic environments (in time)

Data and Methods

1. Thermodynamic profiles: AIRS level 2, ERA5 reanalysis, and ARM site radiosondes
2. MCS tracking datasets:
   a) Tracked IMERG Mesoscale Precipitation System (TIMPS; U of Utah; Rajagopal et al. 2023)
   - 0.1° spatial and 30-min temporal resolution; from 2011-2020
   - Based on volumetric rain rate and area, MCS can be segregated into growth, mature, and decay stages



Rajagopal et al. (2023)

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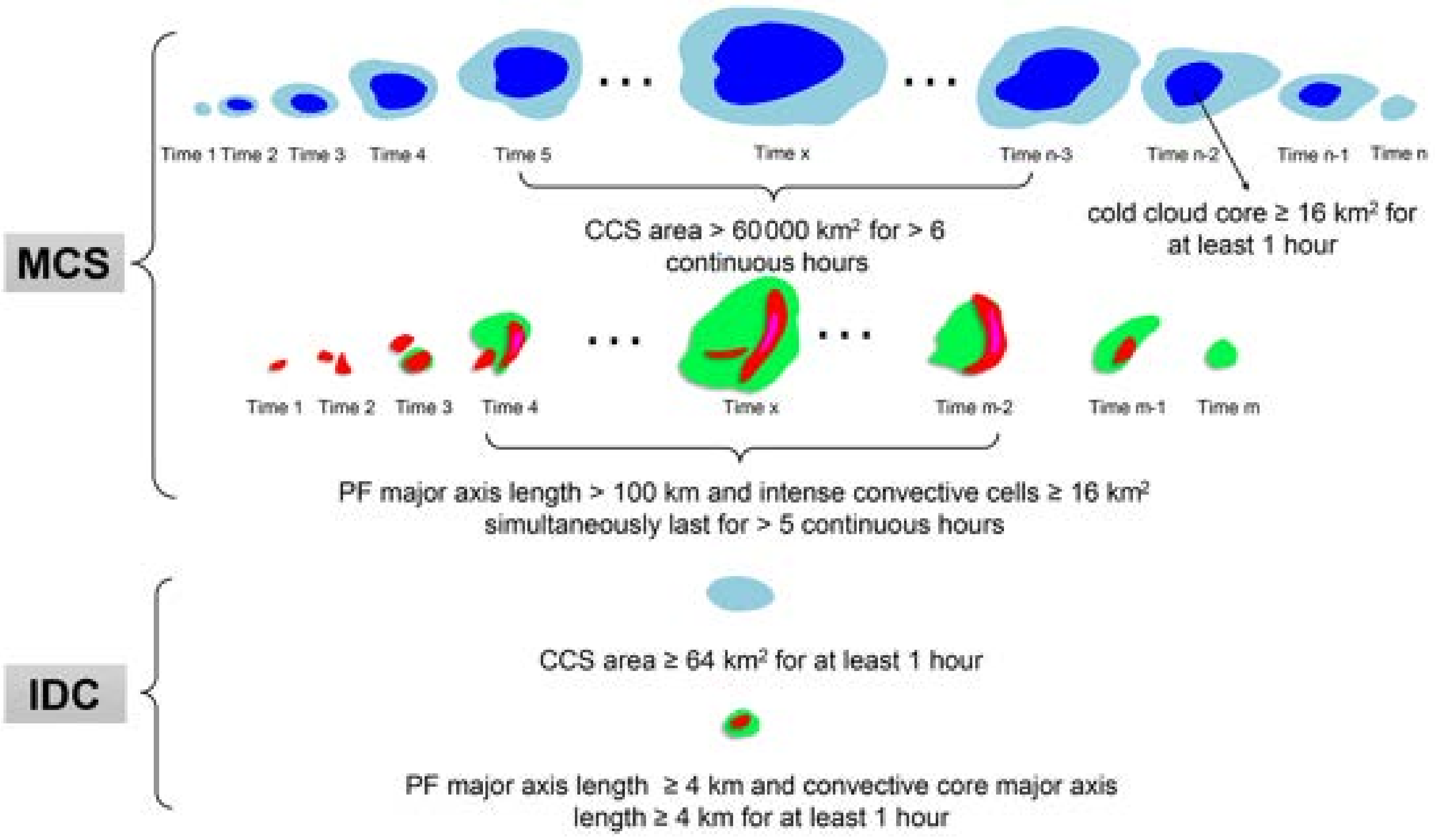
   b) Global and US-based FLEXTRKR (Feng et al. 2018; Li et al. 2021)



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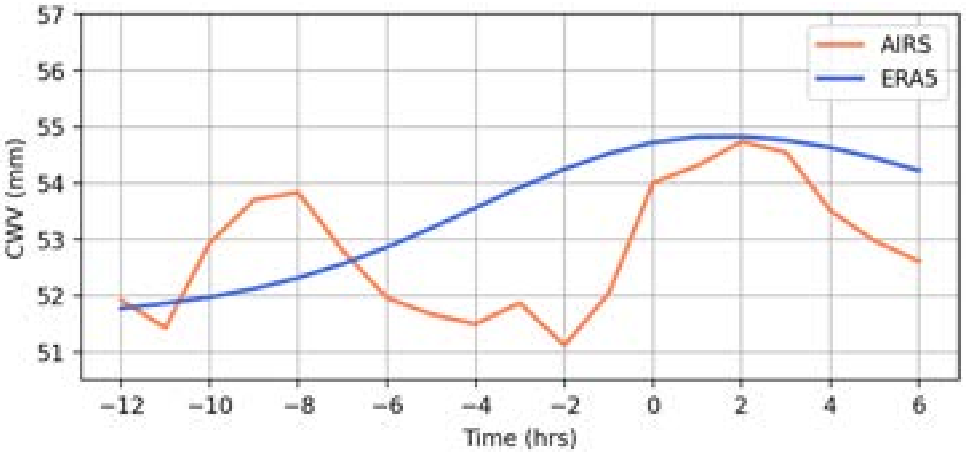
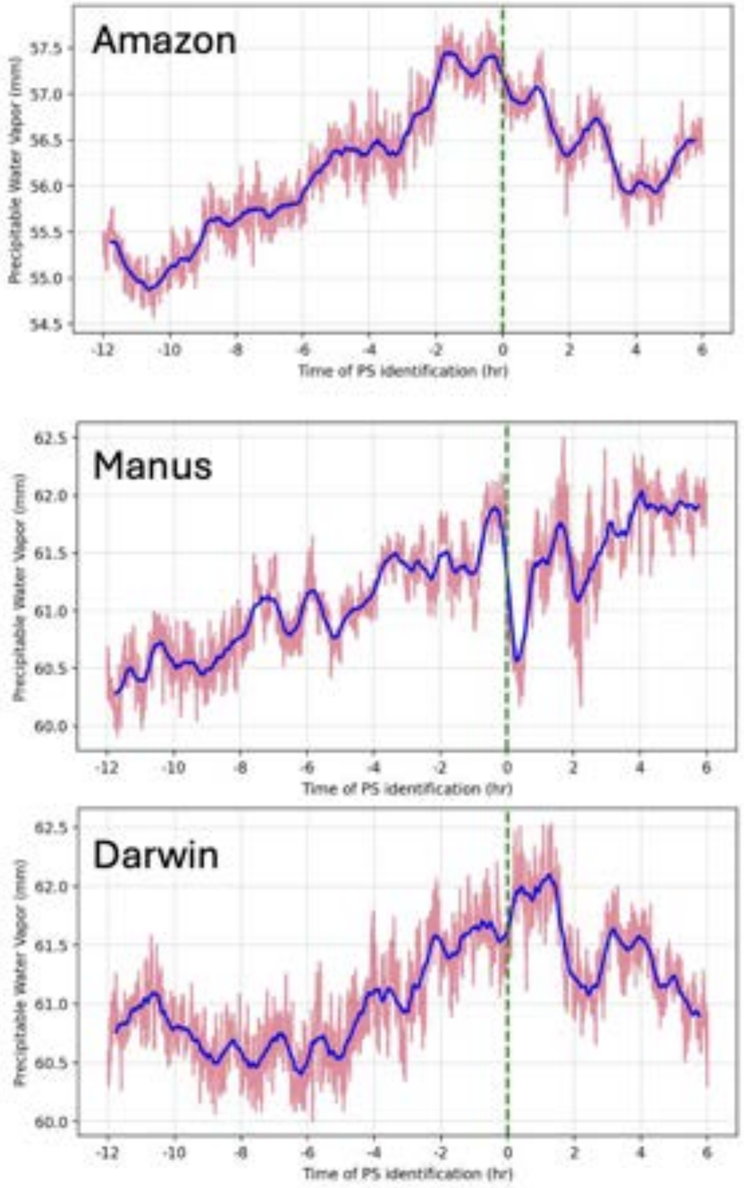
What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

Data: TIMPS MCS tracking



- Increased CWV ahead of MCSs in ERA5, ARM site data
- CWV reduces ahead of MCSs in AIRS – sampling ??? BL moisture bias ???

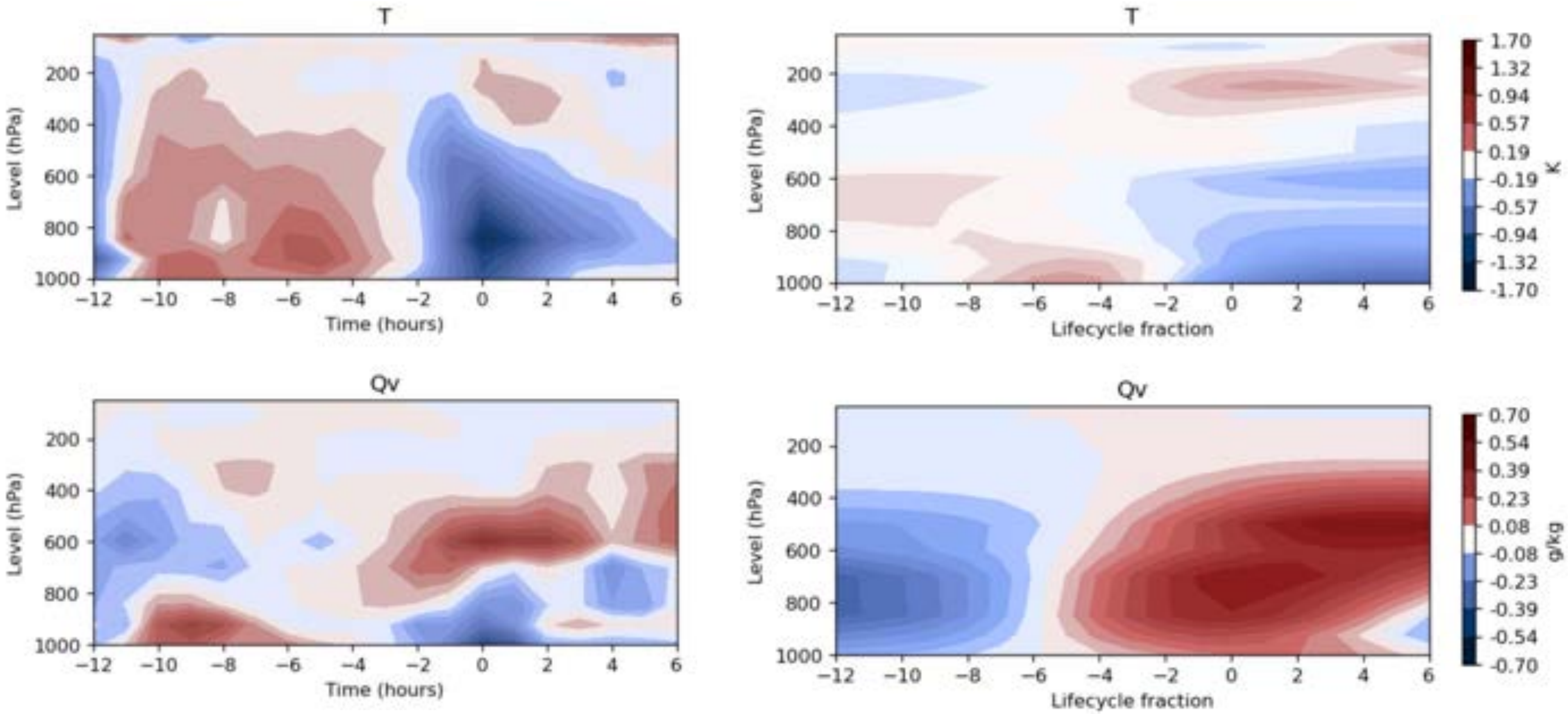


What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

Data: TIMPS MCS tracking

Anomalies are with respect to the mean profiles in each hourly bin in the lead-lag composite

AIRS **ERA5**



Temperature

Specific Humidity

Warmer/moister before convection onset in both datasets, but T more confined to surface in ERA5 and q increase smoother than in AIRS where there is clear BL drying.

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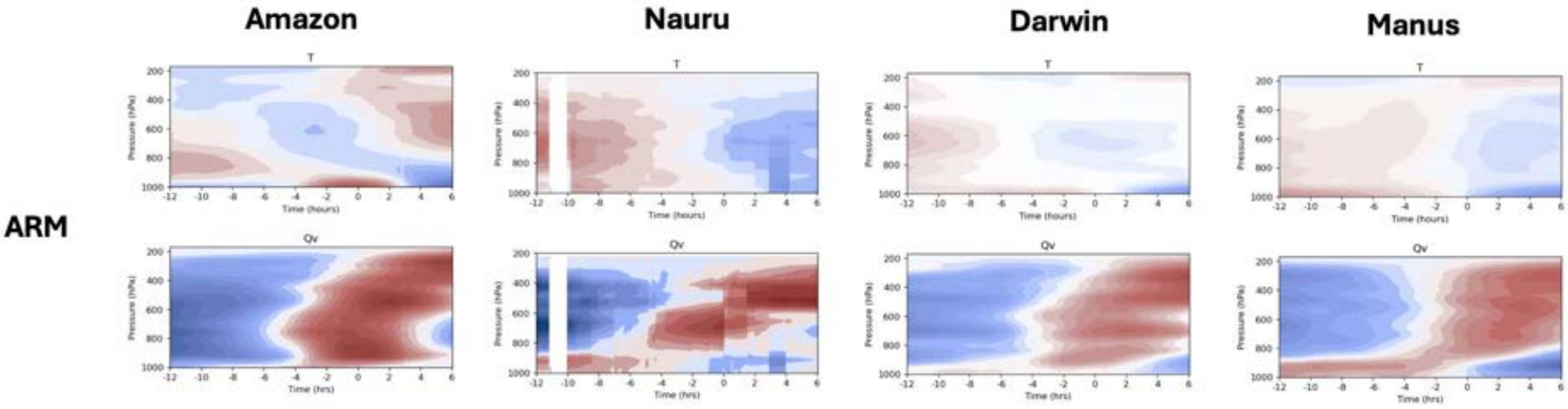
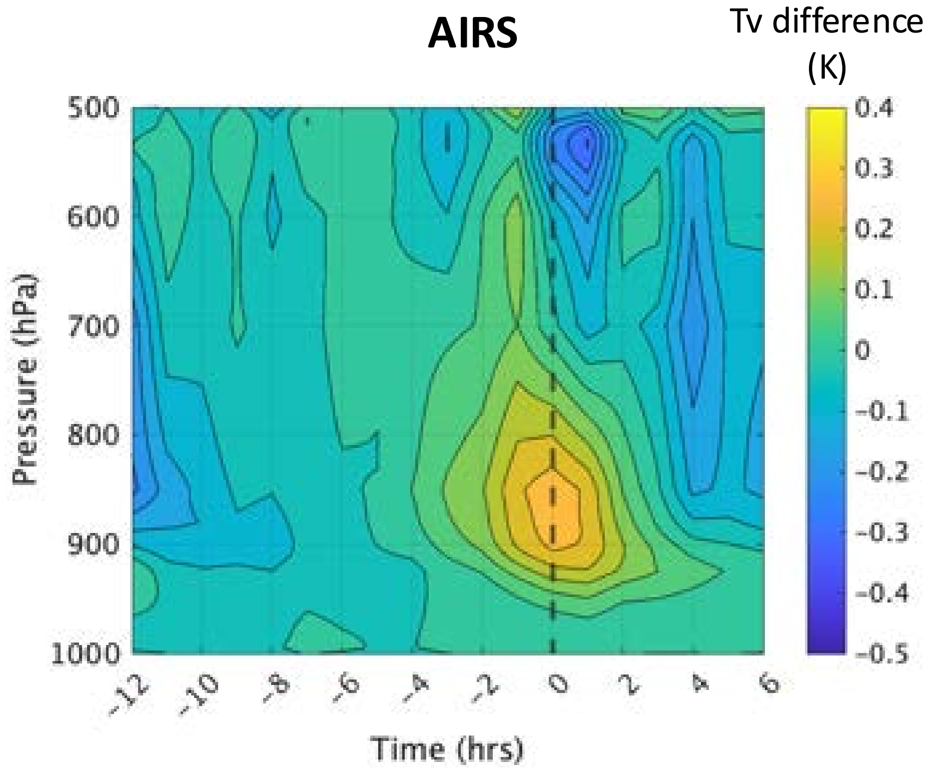


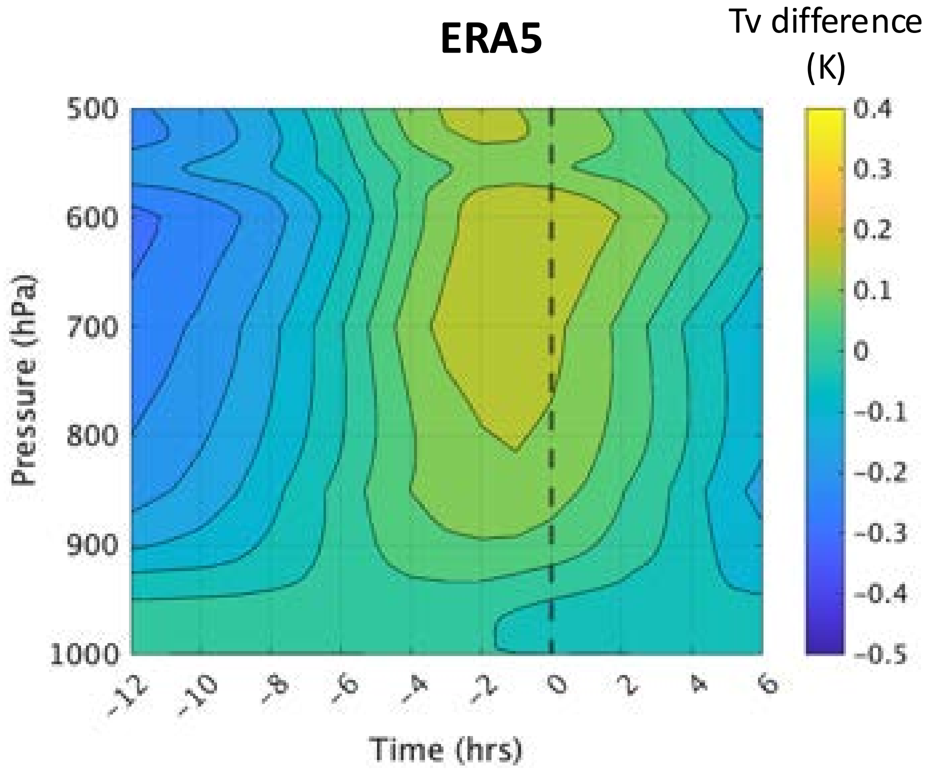
Warmer/moister before MCS detection – consistent with both AIRS and ERA5

<u>ARM data is somewhat of a mix of what ERA5 shows and what AIRS shows</u>: more BL drying than ERA5, less than AIRS (regionally dependent? see Amazon)

What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

- Here, we estimate the **buoyancy of an entraining plume (B)** using a “deep-layer inflow” mixing assumption



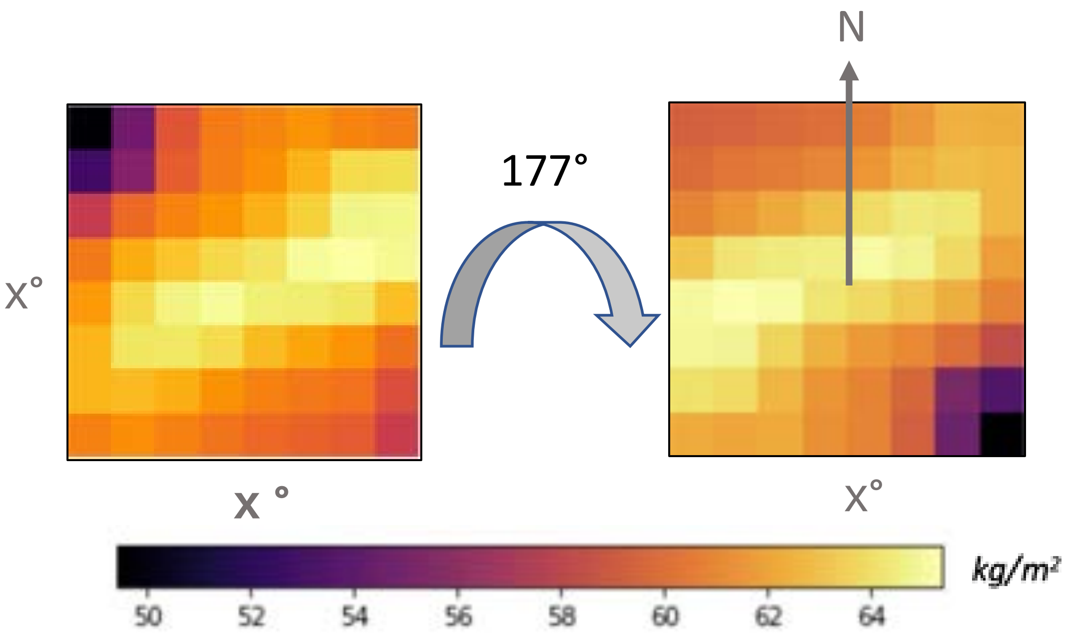


Increase in buoyancy below freezing level ahead of MCS detection in both AIRS and ERA5, despite differences in observational products

Anomalies are with respect to the mean profiles in each hourly bin in the lead-lag composite

What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

Data: TIMPS MCS tracking



TCWV around the storm extracted, rotated, and composited such that system's direction of motion is at 0° (North)

(Analysis controls for MCS sizes)

Motivation: to see if thermodynamic perturbations exist ahead of the system in space.

What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

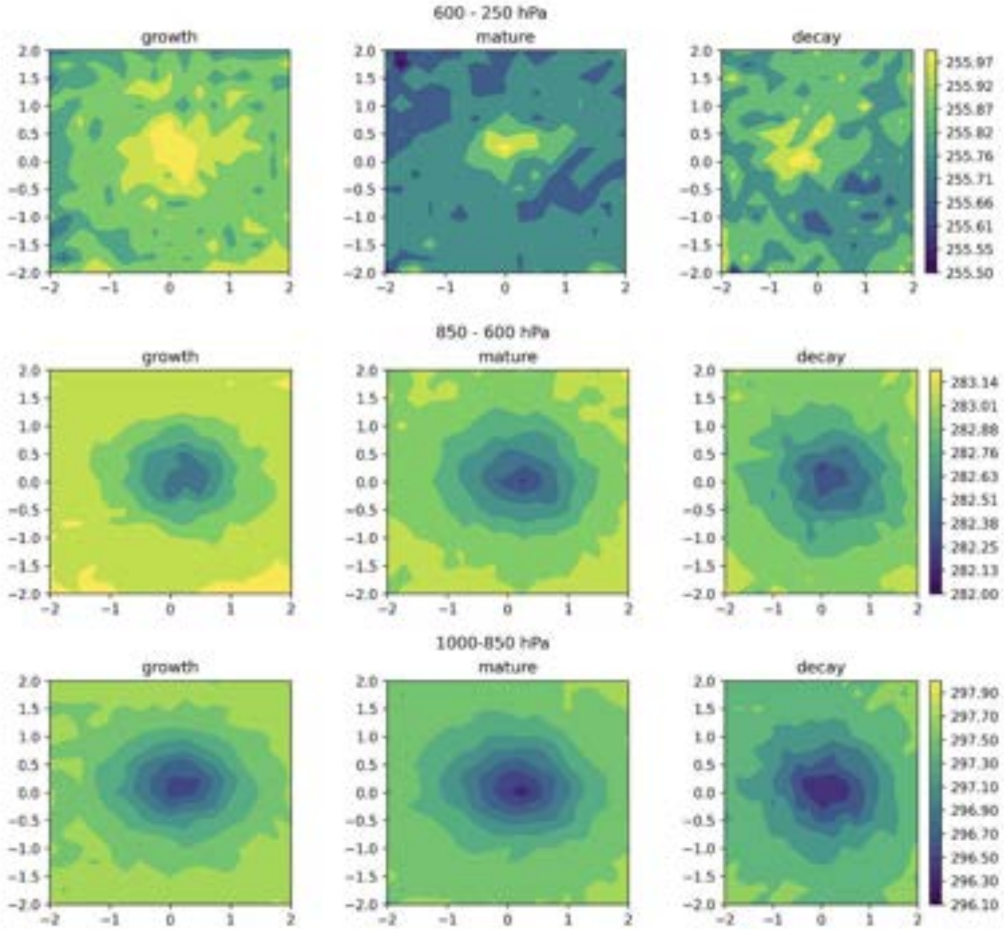
Data: TIMPS MCS tracking

T (K) **AIRS**

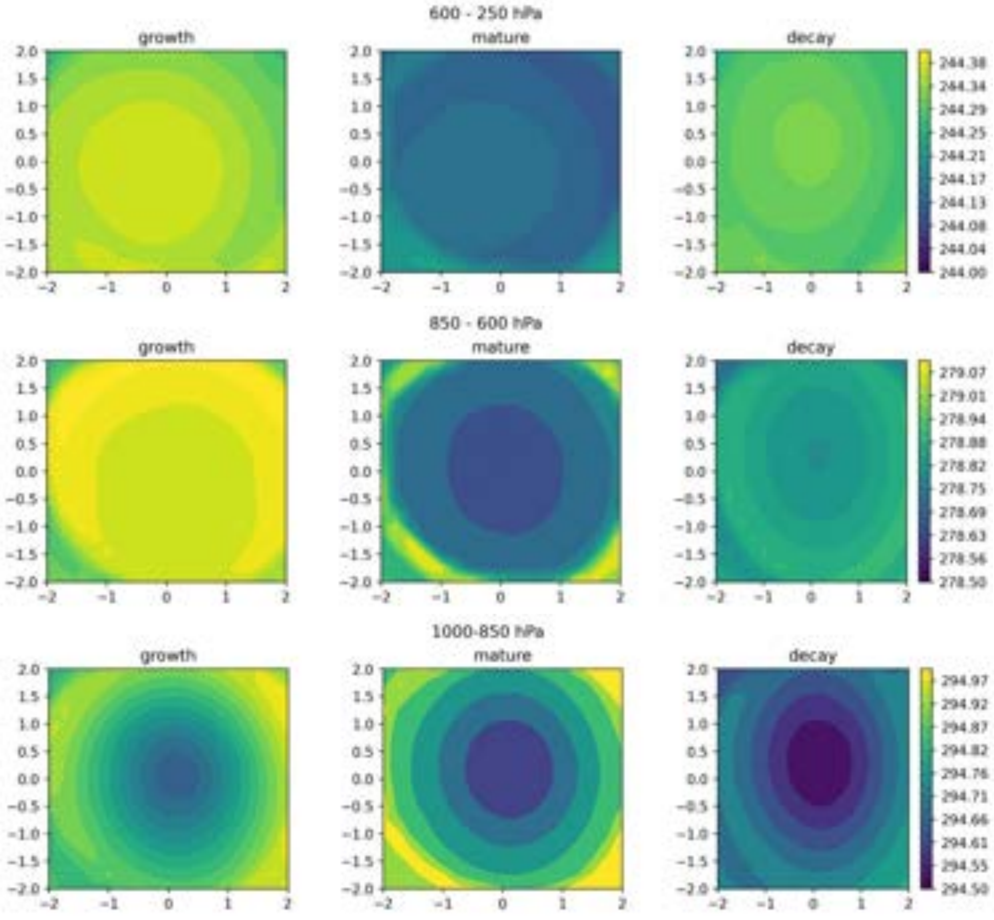
UT

FT

BL



T (K) **ERA5**



Similar results among datasets – BL cooling

What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

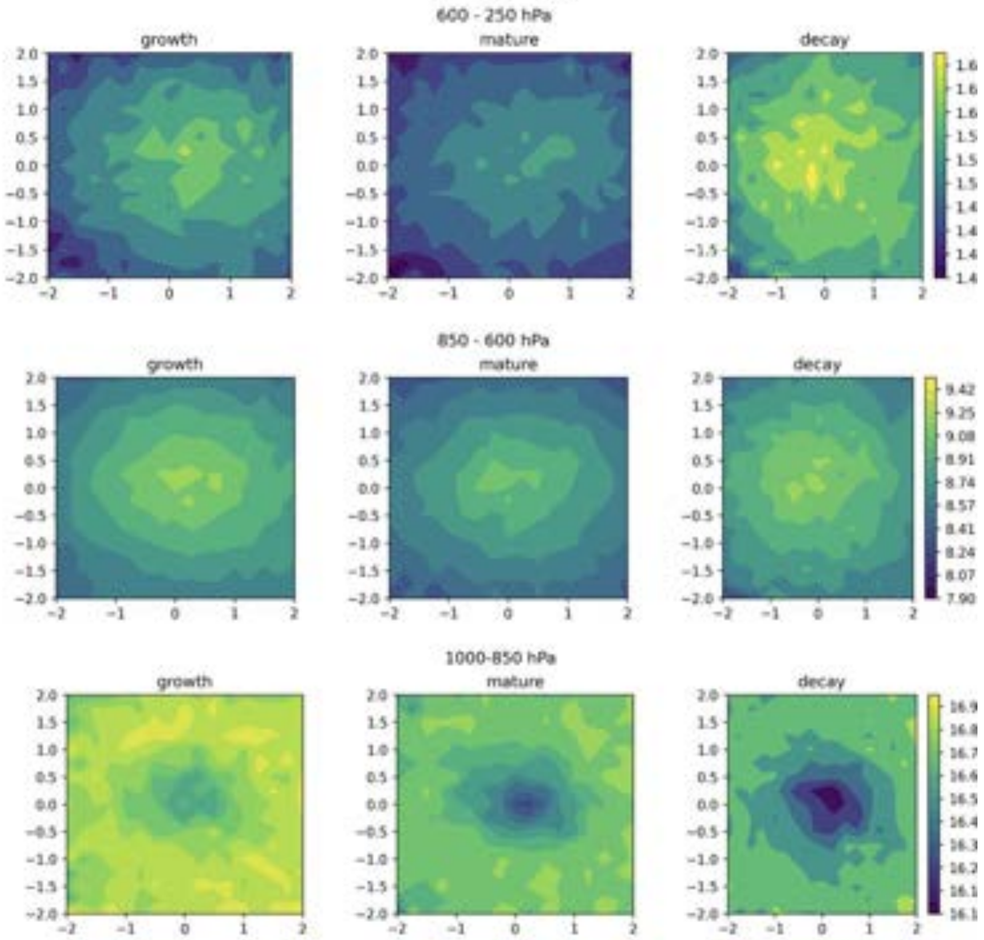
Data: TIMPS MCS tracking

Qv (g/kg) **AIRS**

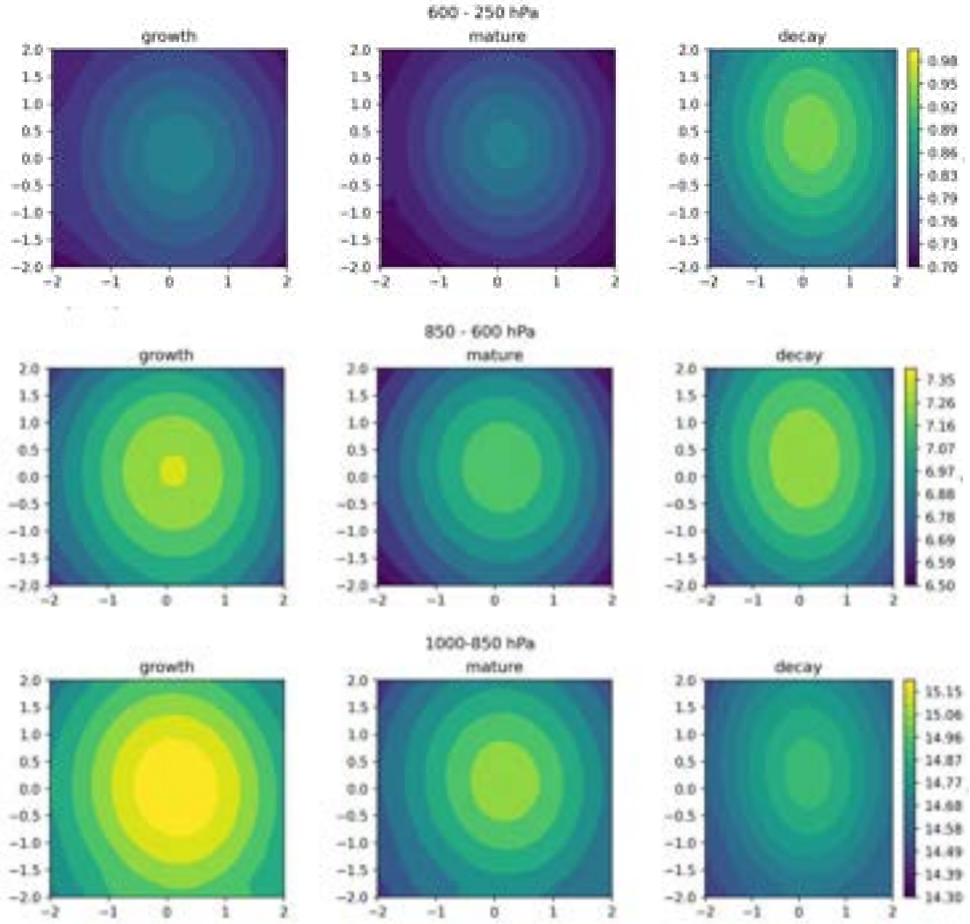
UT

FT

BL



Qv (K) **ERA5**



BL q reduction across lifecycle stages in both datasets, but MCS centroid never drier w.r.t. environment in ERA5

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How do pre-IDC and pre-MCS thermodynamics compare?

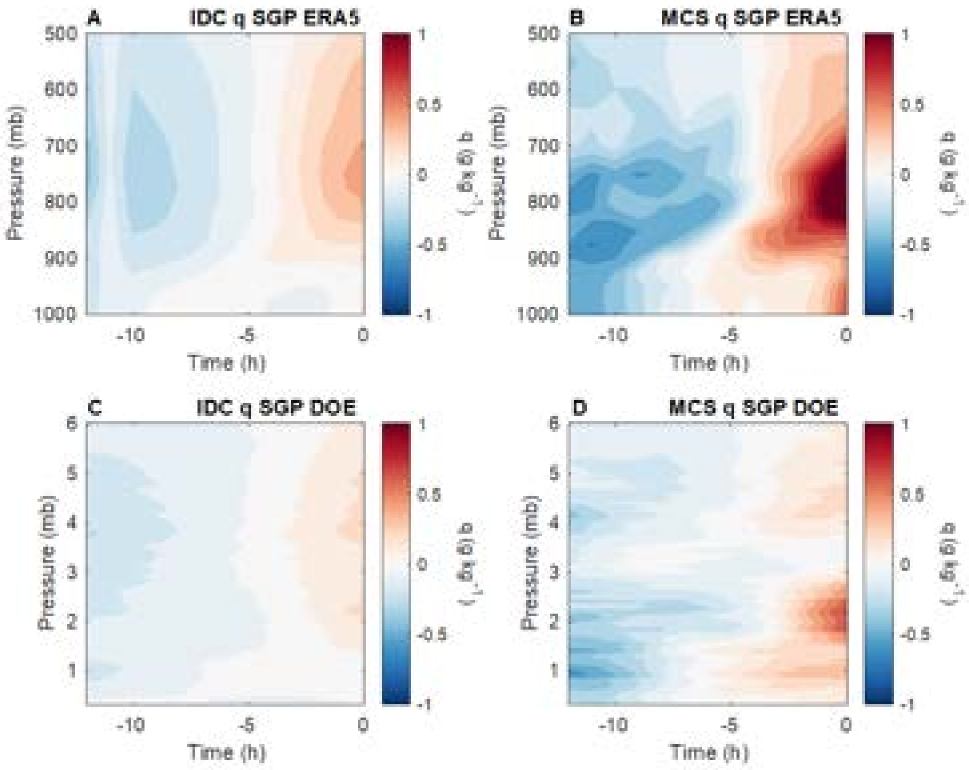
ARM vs. ERA5 Comparison @ SGP (JJA)

Data: US-based FLEXTRKR, ERA5

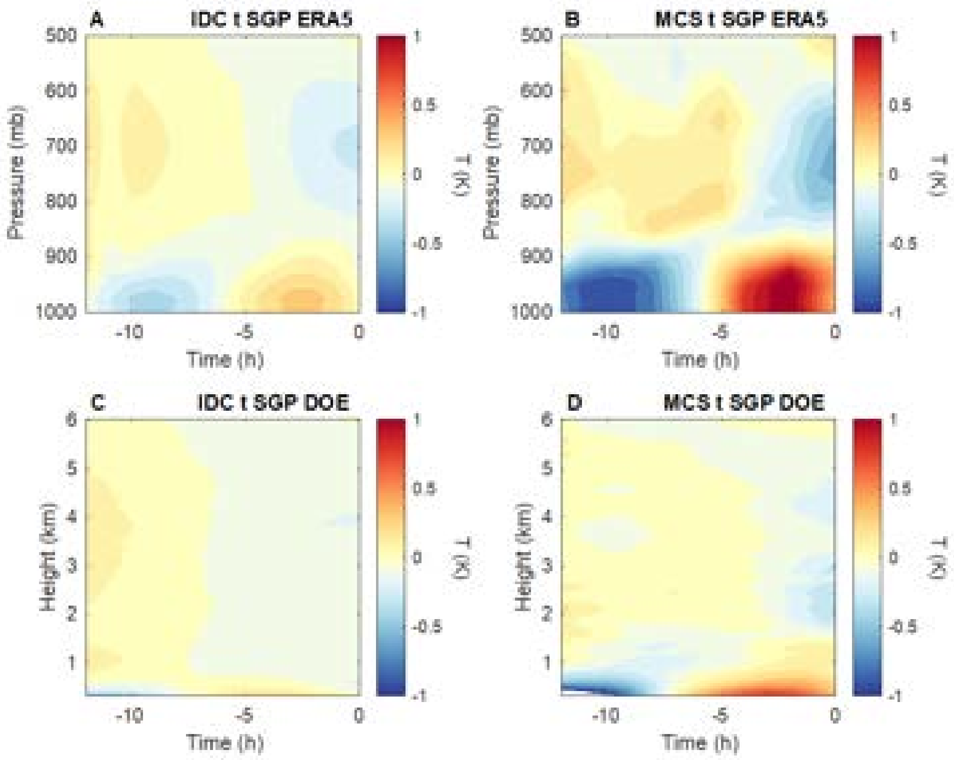
- Enhanced moisture, especially in lower free troposphere, ahead of MCS and IDC occurrence
- Enhanced T in PBL
- ARM data results consistent with ERA5 results.

Anomalies are with respect to the mean profiles in each hourly bin in the lead-lag composite

Specific Humidity



Temperature



How do pre-IDC and pre-MCS thermodynamics compare?

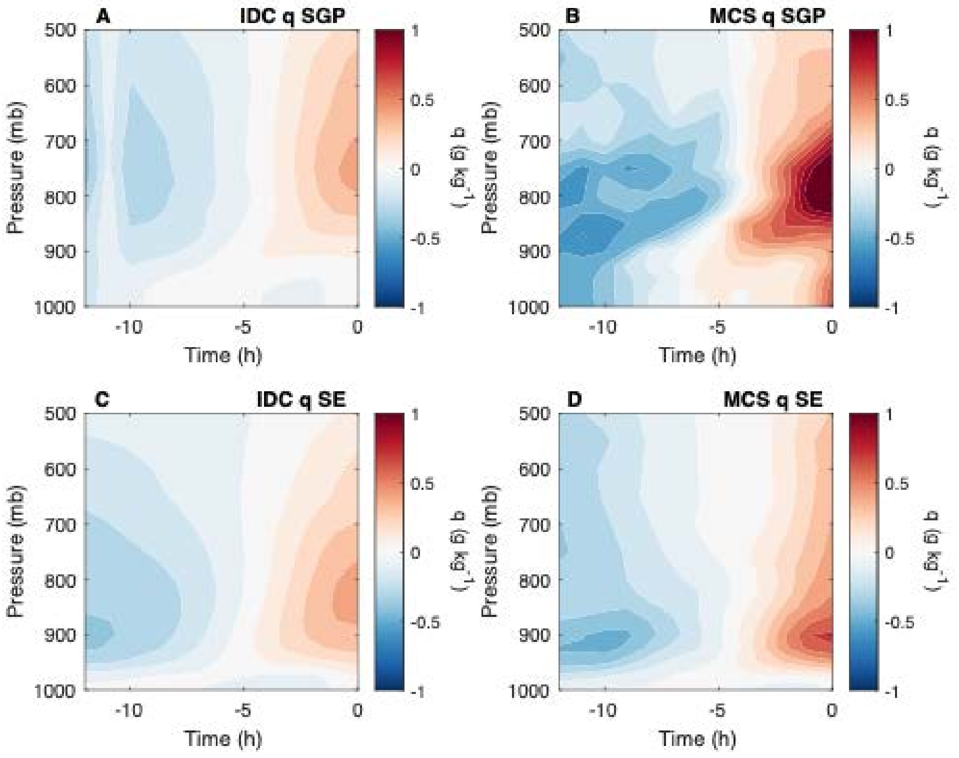
ERA5 Comparison of SGP and SE US (JJA)

Data: US-based FLEXTRKR, ERA5

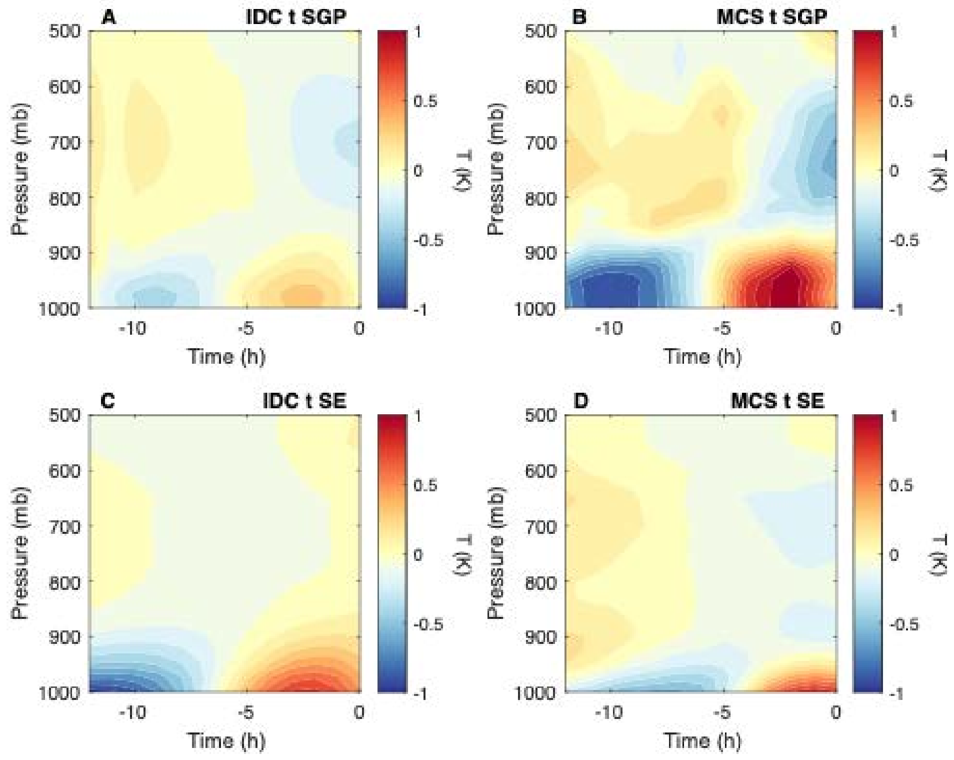
- Enhanced moisture, especially in lower free troposphere, ahead of MCS and IDC occurrence
- Enhanced T in PBL
- **LET'S COMPARE MORE CLOSELY**

Anomalies are with respect to the mean profiles in each hourly bin in the lead-lag composite

Specific Humidity



Temperature



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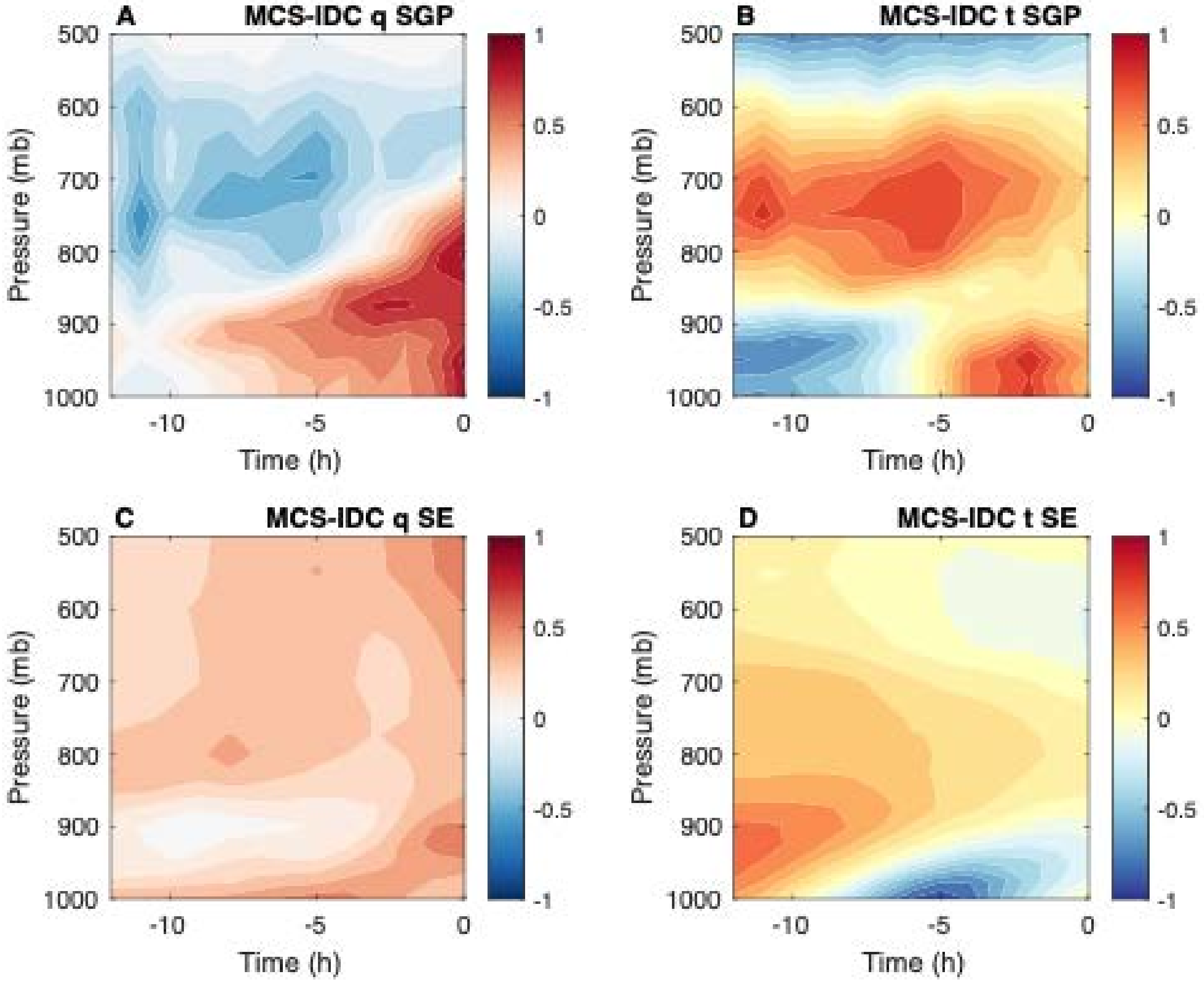


- Moister environment ahead of MCSs
- Warmer BL and LFT for MCS in SGP
- Cooler BL and warmer LFT for MCS in SE

- **What does this mean in terms of instability w.r.t. an entraining plume?**

How do pre-IDC and pre-MCS thermodynamics compare?

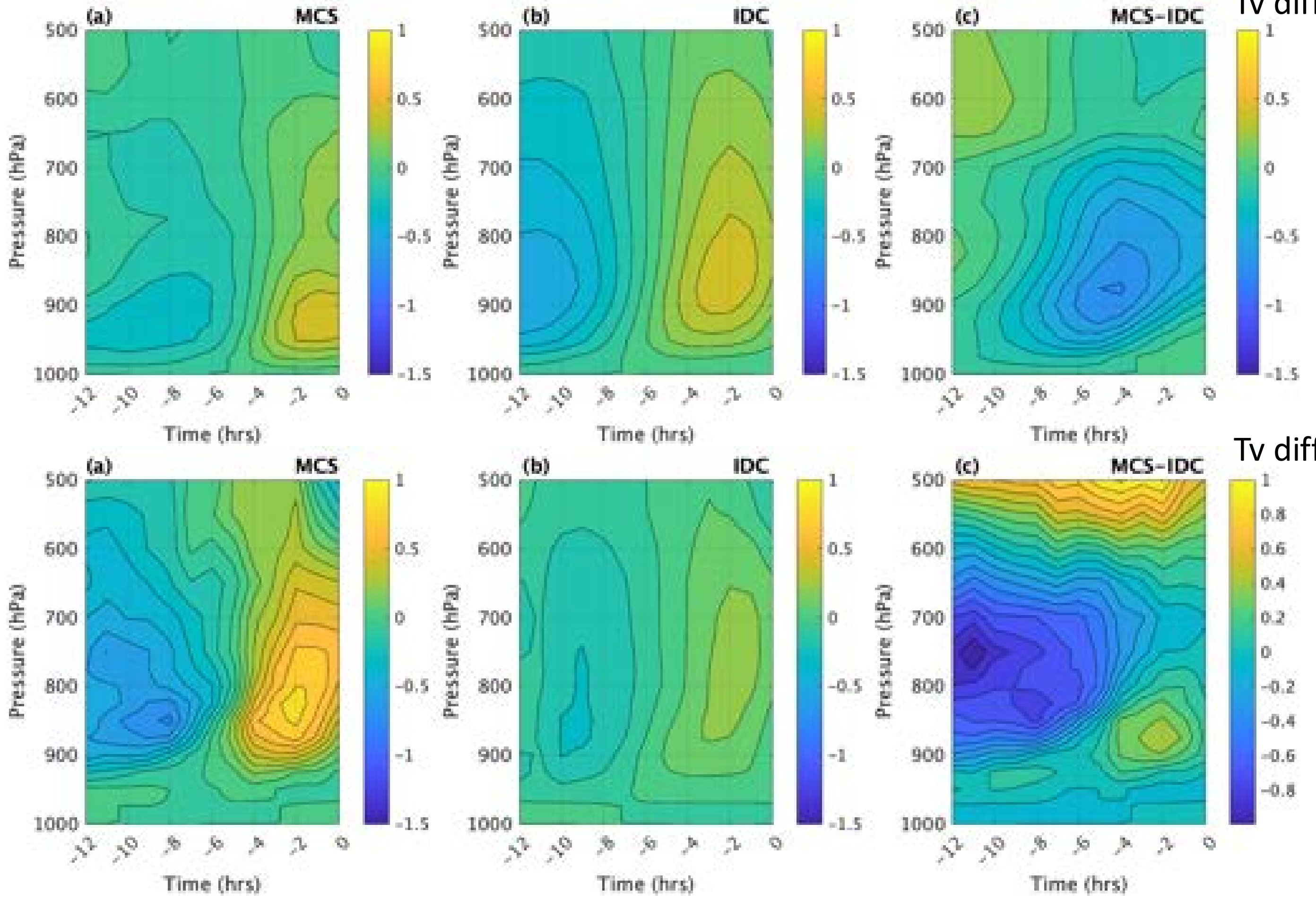
ERA5 Comparison of SGP and SE US（JJA）

Data: US-based FLEXTRKR, ERA5

- Enhanced buoyancy ahead of both MCSs and IDCs
- BUT the buoyancy is higher ahead of IDCs than MCSs in SE, the opposite of what we see at SGP

SE US

SGP



Tv difference (K)

IDCs have higher B

Tv difference (K)

MCSs have higher B

Anomalies are with respect to the mean profiles in each hourly bin in the lead-lag composite

How do pre-IDC and pre-MCS thermodynamics compare?

Data: US-based FLEXTRKR, ERA5

IDC = non-MCS deep < 40,000 km^2

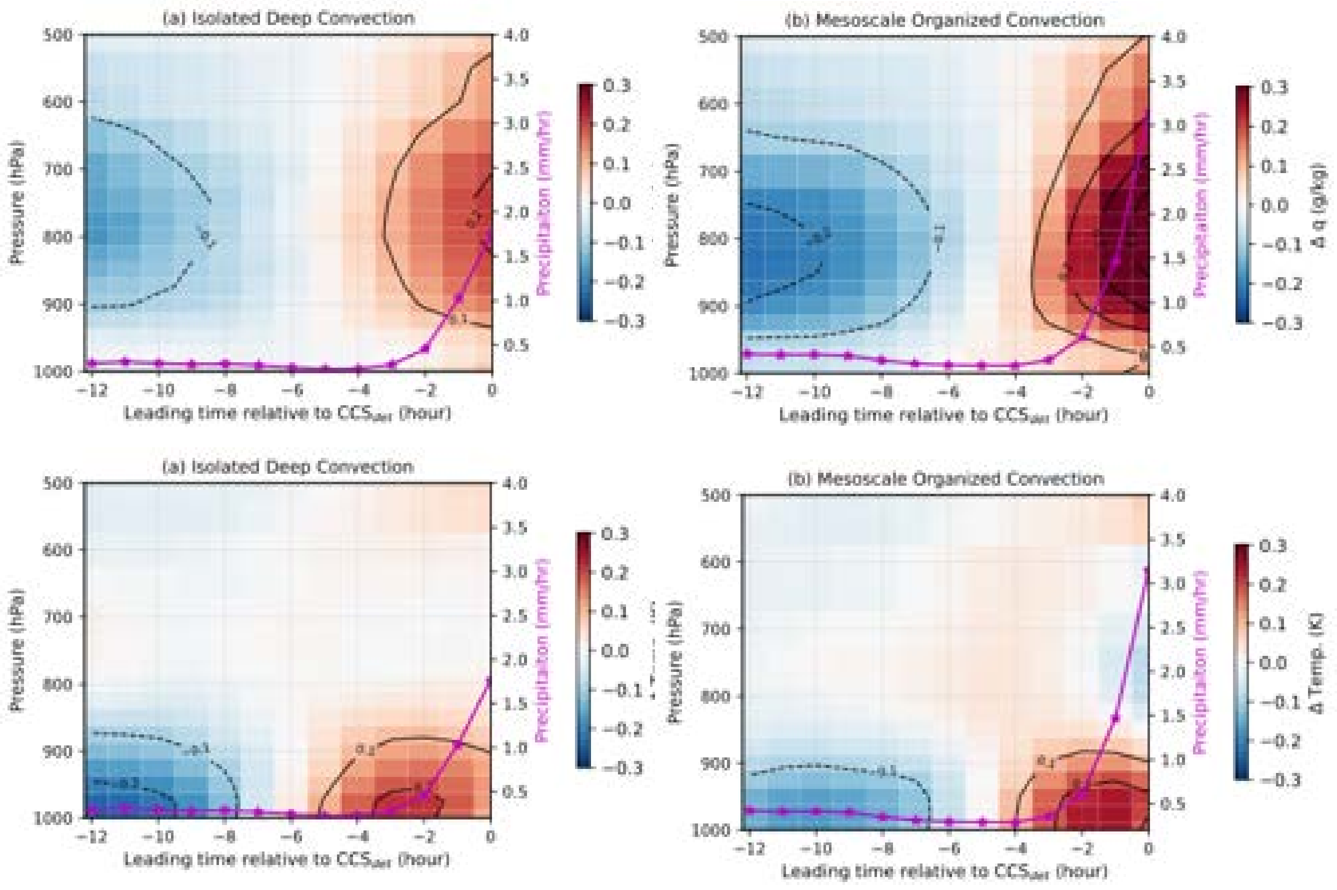
ERA5 Global FLEXTRKR

- Both IDC and MCS show enhanced T and q ahead of detection
- Buoyancy is higher ahead of MCSs than IDC

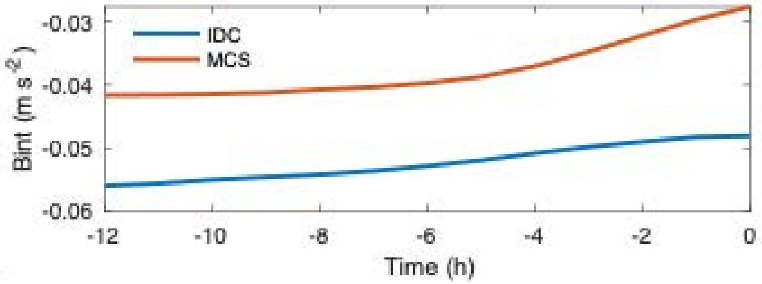
IDC **MCS**

q

T



Buoyancy



Conclusions

- Enhanced lower tropospheric moisture leads MCS (and IDC) occurrence by multiple hours – robust to chosen dataset
- Lower tropospheric moisture is higher ahead of MCSs than IDCs
- Pre-MCS conditions are generally more unstable w.r.t. an entraining plume than pre-IDC conditions, but not always – as shown in SE US vs. SGP example
- Enhanced BL cooling/drying and reduced buoyancy from growth to decay phases of the MCS lifecycle, aiding in MCS demise. Cooling/drying captured differently in the different datasets.

Thanks!

Contact: kschiro@virginia.edu

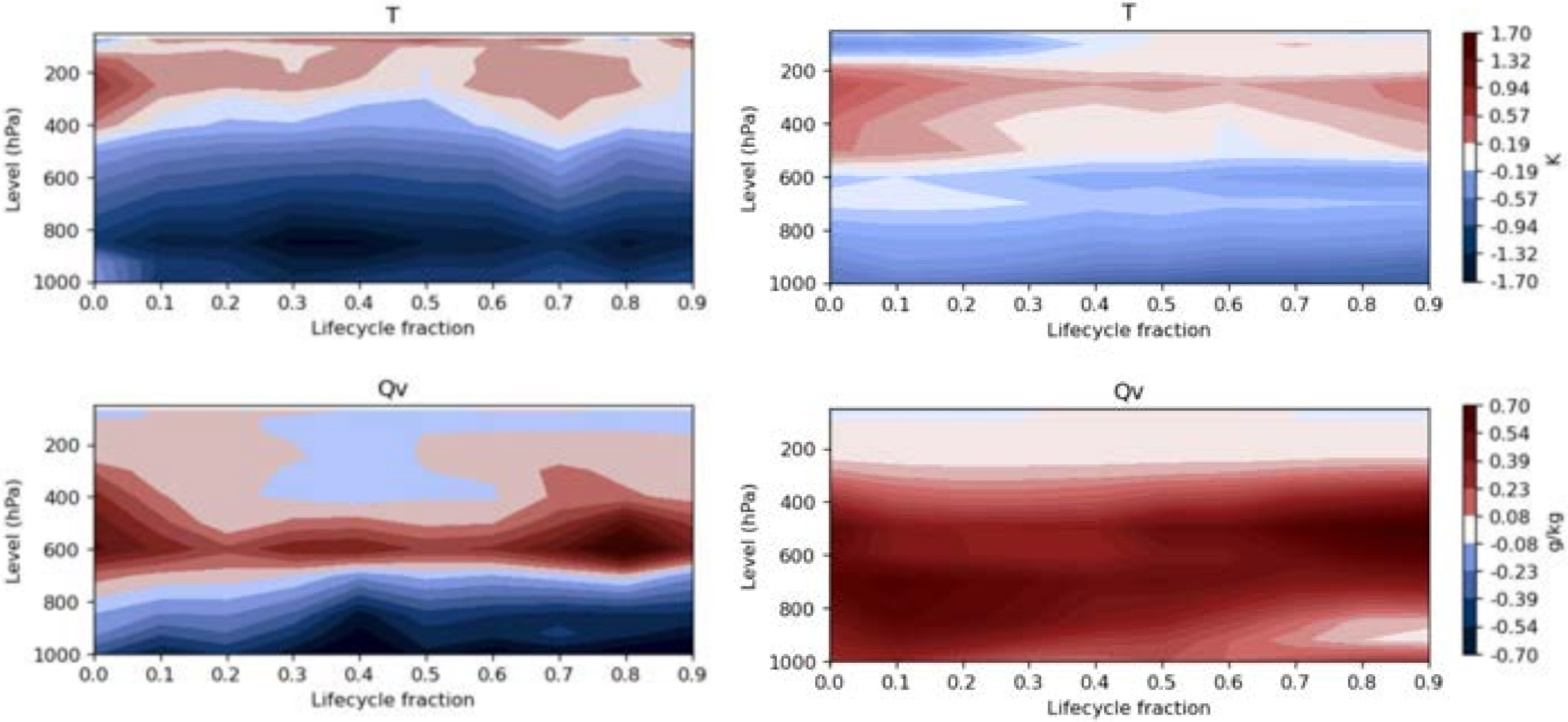
EXTRAS

What are the thermodynamic controls on tropical MCS lifecycles and upscale growth?

<u>Data</u>: TIMPS MCS tracking

Anomalies are with respect to the -12 to 0 average pre-MCS conditions

<u>AIRS</u> **<u>ERA5</u>**



Temperature

Specific Humidity

BL progressively dries and cools as lifecycle increases (except maybe for AIRS T)
**ERA5 still shows higher q than pre-MCS conditions