A Question of Scale: Using Ensemble Data Assimilation to Understand Convective Dynamics

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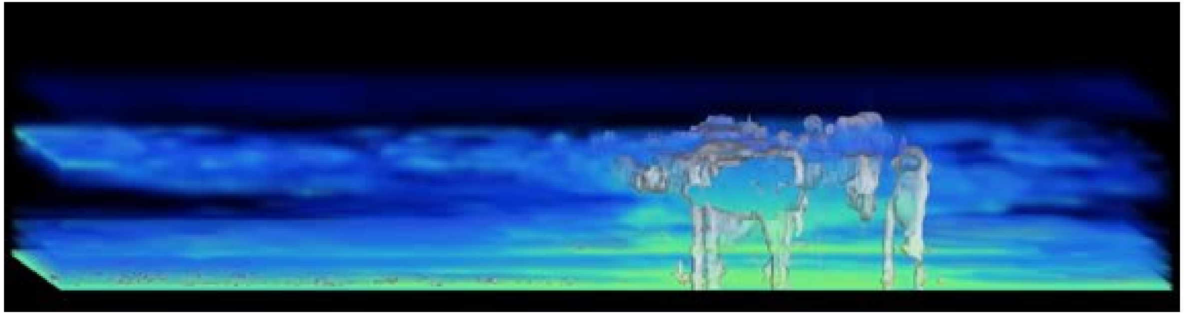
Ensemble Data Assimilation for Convective Dynamics

- Sensitivity of convection to its environment is well known
- What are the scales at which this interaction happens?



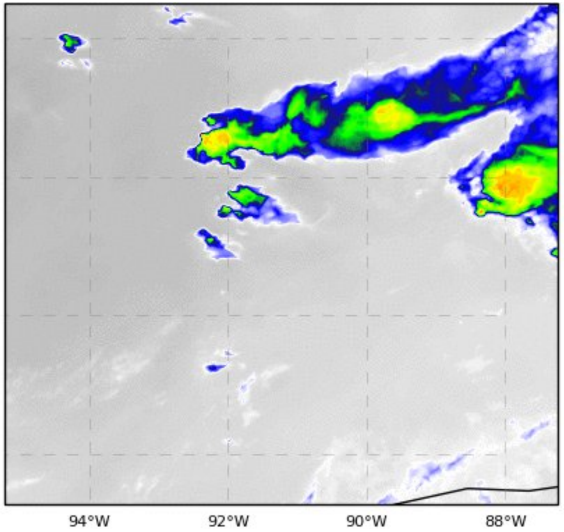
Posselt et al., 2012, J. Clim.

- Ensemble *prediction* produces multiple realizations
- Ensemble *DA* produces multiple realizations *constrained by observations*
- This ensemble contains **covariances among variables**, including updrafts and environment
- Can we use these covariances to understand convective processes?

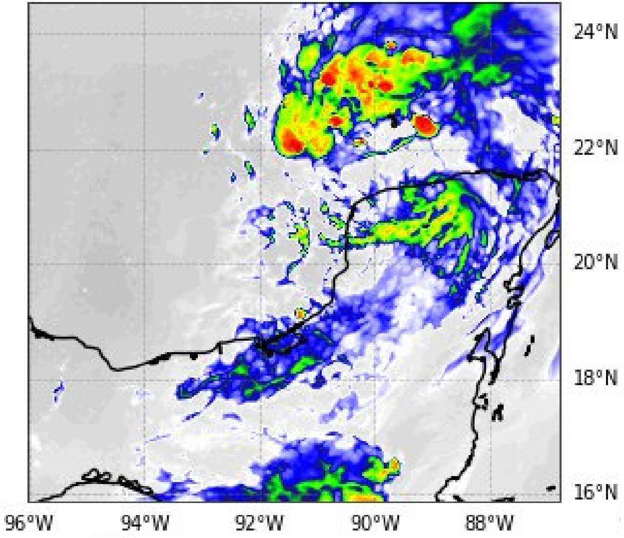
Experimental Design

- Use ensemble data assimilation to produce analysis of two different convective events

Tropical squall line



Intense Hurricane



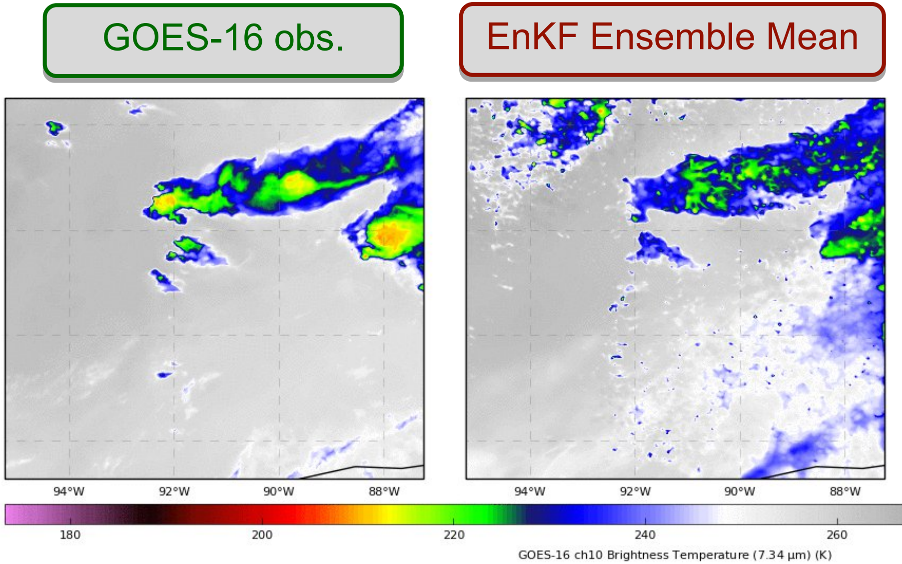
- Use ensemble covariance decomposition to
    - Understand convection – environment interaction
    - Study the influence of convection on upscale growth of dynamics

Analysis of Convection-Environment Interactions

Minamide and Posselt, 2022, J. Atmos. Sci.

- Ensemble DA produces model realizations of the atmosphere constrained by observations
- This ensemble contains covariances among variables, including updrafts and environment
- (How) can we use these covariances to understand convection-environment interaction?

1. Consider a fixed location with large vertical motion at a given time. Examine covariance between w and moisture preceding convection
2. Composite on all convective updrafts and explor
changes in moisture preceding convection



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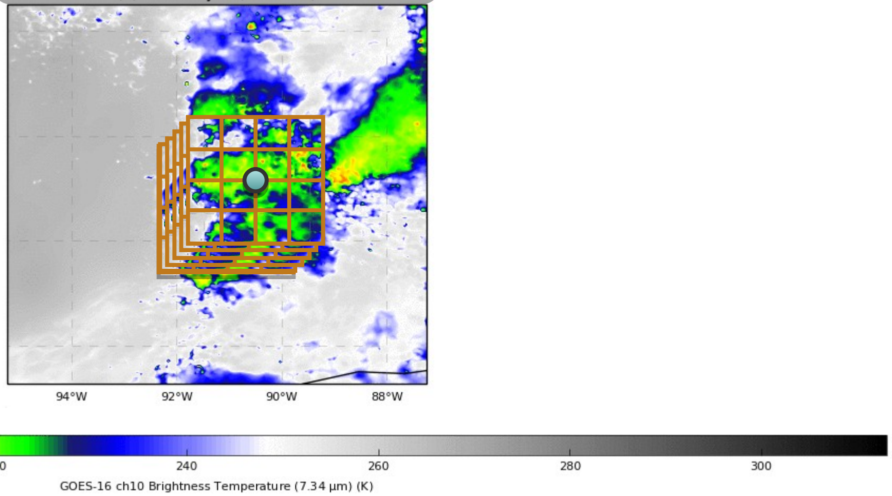
Eulerian Approach to **Locating Convection**

EnKF Analysis
(BT+conventional)



Eulerian approach

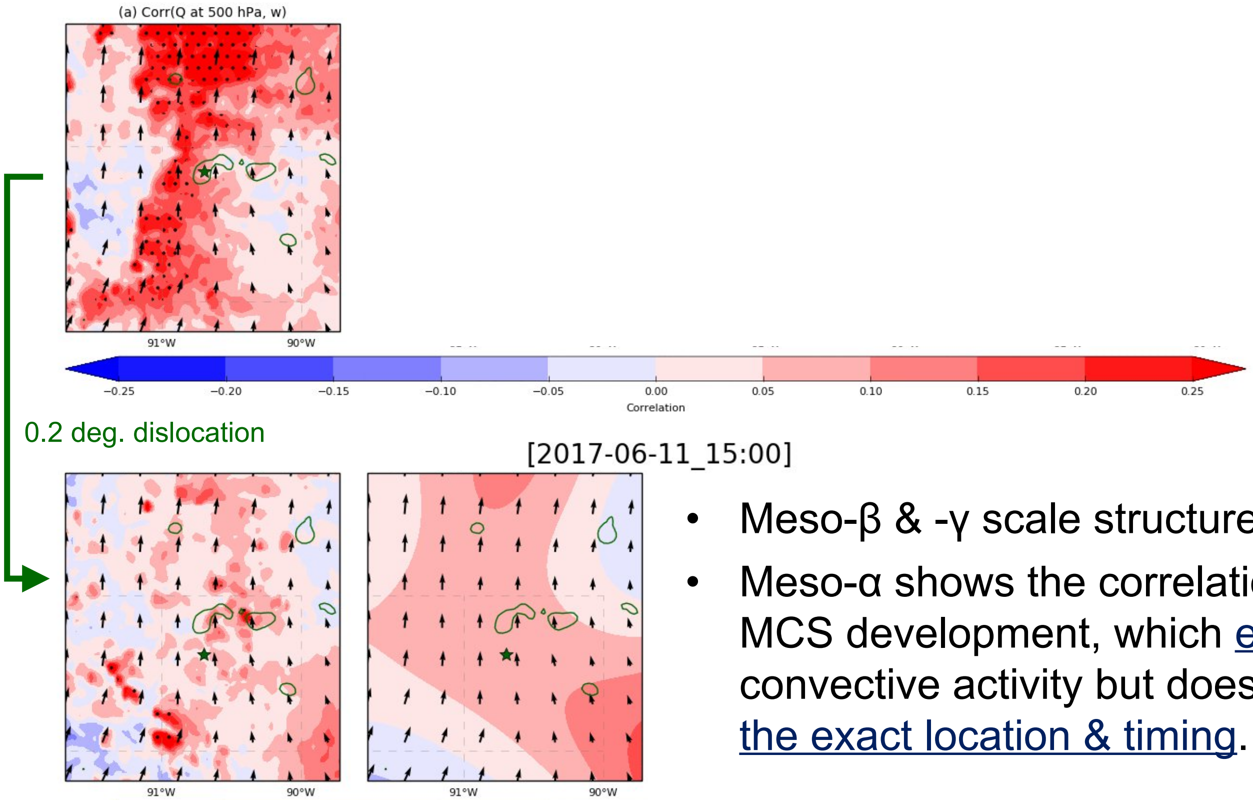
ID convection using vertical velocity at a specific time and location

What determines exactly when and where convection occurs?

Minamide & Posselt (2022), *JAS*

Eulerian correlation analysis

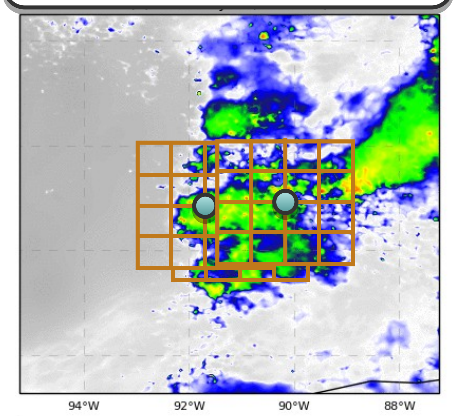
corr{Qv at 500hPa, w(300-500hPa average) <u>at star at 18Z/11</u>}



- Meso-β & -γ scale structures are noisy.
- Meso-α shows the correlation with general MCS development, which <u>enhances</u> convective activity but does <u>not determine the exact location & timing</u>.

Object Oriented Approach to **Locating Convection**

EnKF Analysis
(BT+conventional)



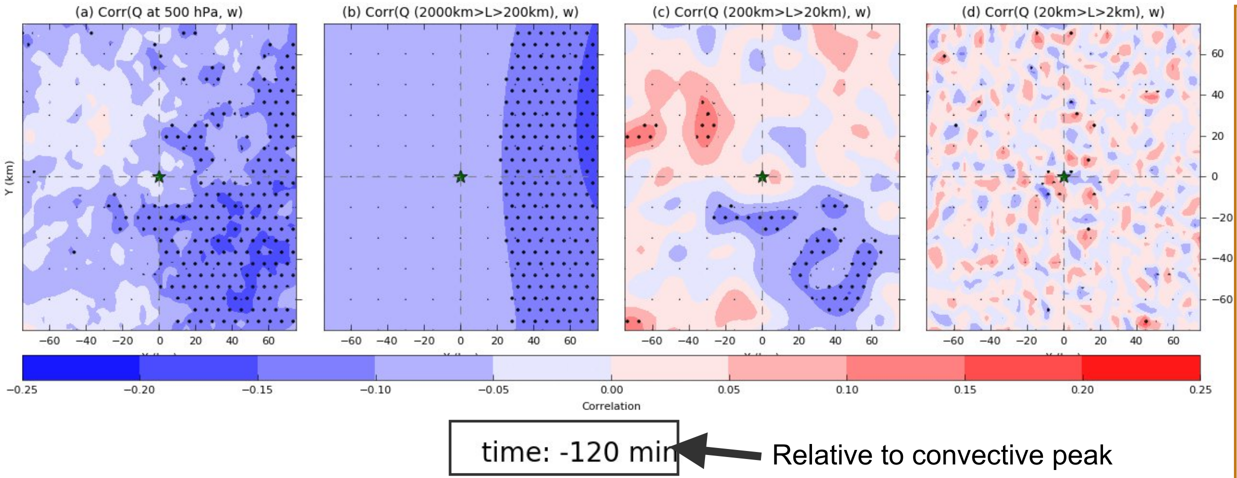
Object-based approach

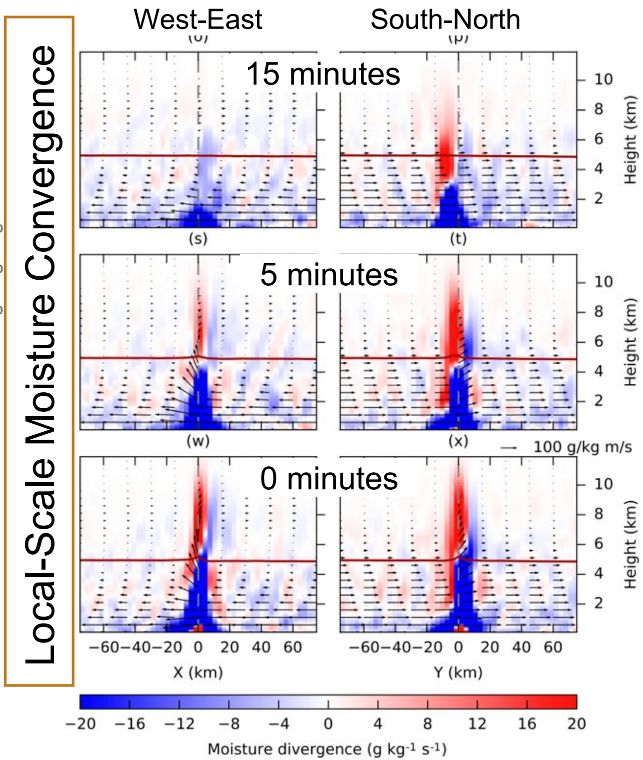
Composite the convective centers

Examine composite of convective updrafts

Object-Based Correlation Analysis: Lag-Time Ensemble Correlation

corr{Qv at 500hPa, w(300-500hPa average) <u>at convection peak</u>}

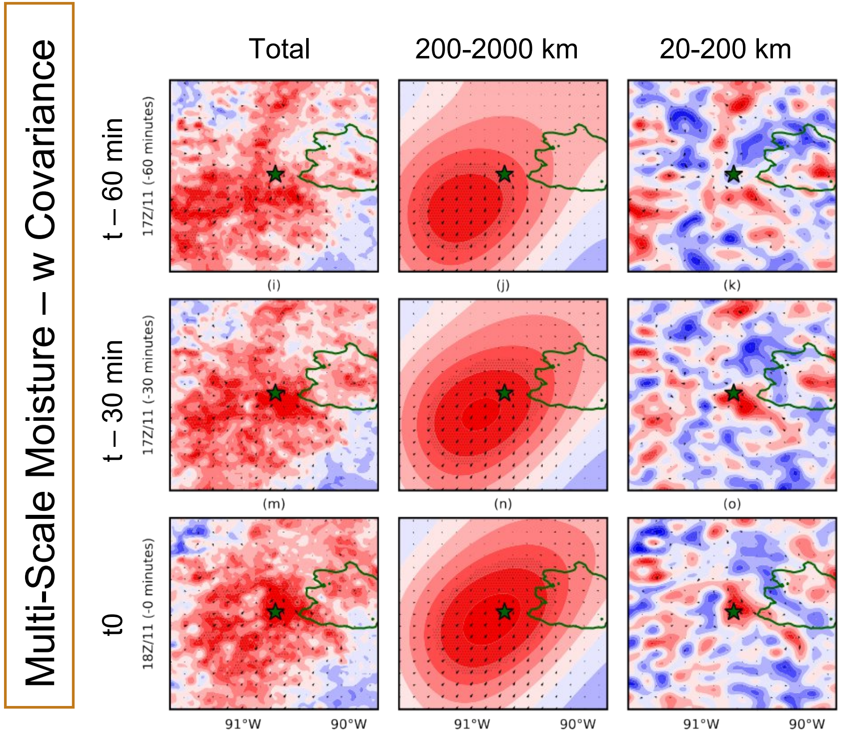




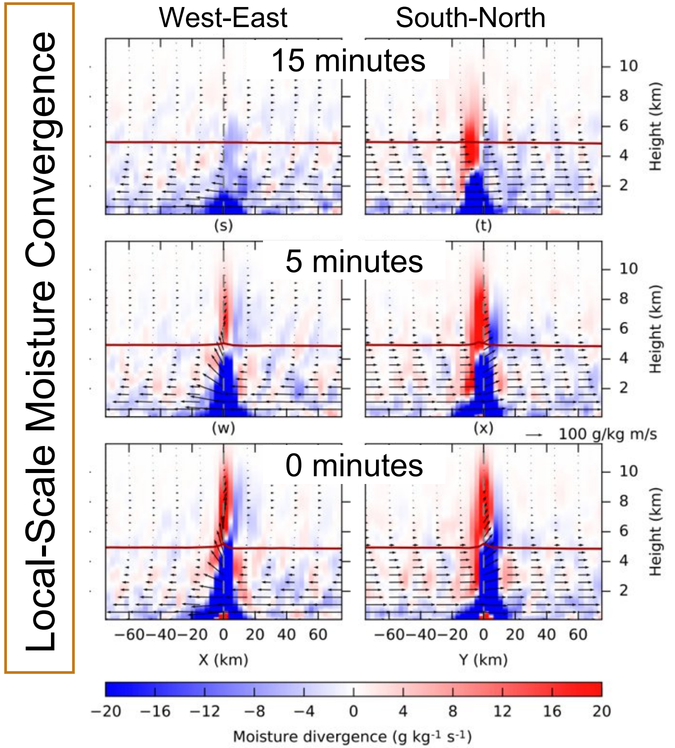
Information that determines the exact position & timing of convective occurrence is in meso-β & -γ scales (< 30 mins).

Eulerian vs. Lagrangian Perspectives: Two Different Scales

Fixed Point / Eulerian

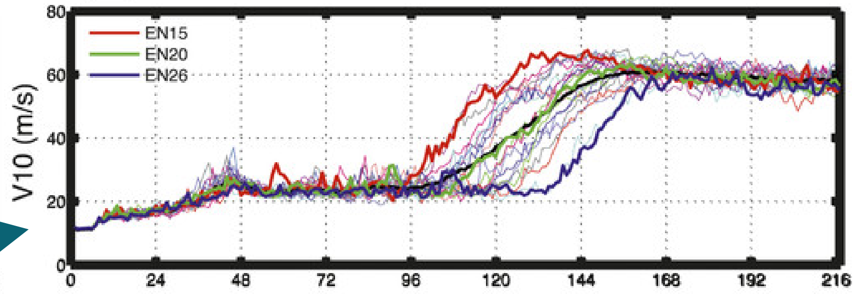


Updraft-Relative / Lagrangian



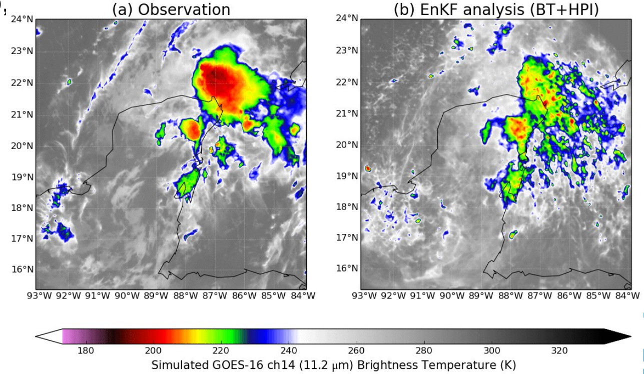
Apply Perturbation Analysis to TC Intensification

- Convection near the TC inner core is key to intensification; e.g., through vortex alignment (Rios-Berrios et al, 2018; Stone et al., 2023)
- Small moisture perturbations can significantly change RI timing (Zhang and Tao, 2013)
- **What is the role of small-scale moisture perturbations in TC RI?**
- Utilize a successful ensemble DA experiment for Hurricane Harvey (2017)



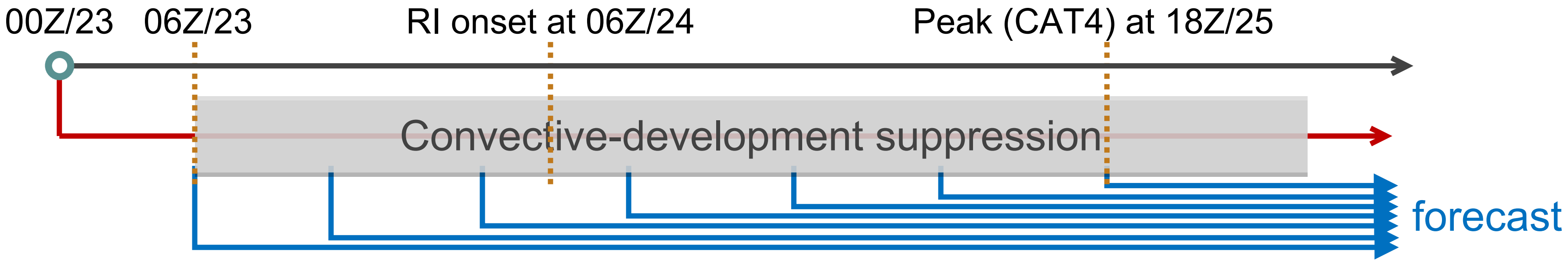
Simulation Time (hours)

Effect of small random near-surface moisture perturbations on the evolution of an idealized TC. Adapted from Fig. 2, Zhang and Tao,



Assimilation of All-Sky GOES-16 data for Harvey (2017)

TC RI Sensitivity Experiment Design



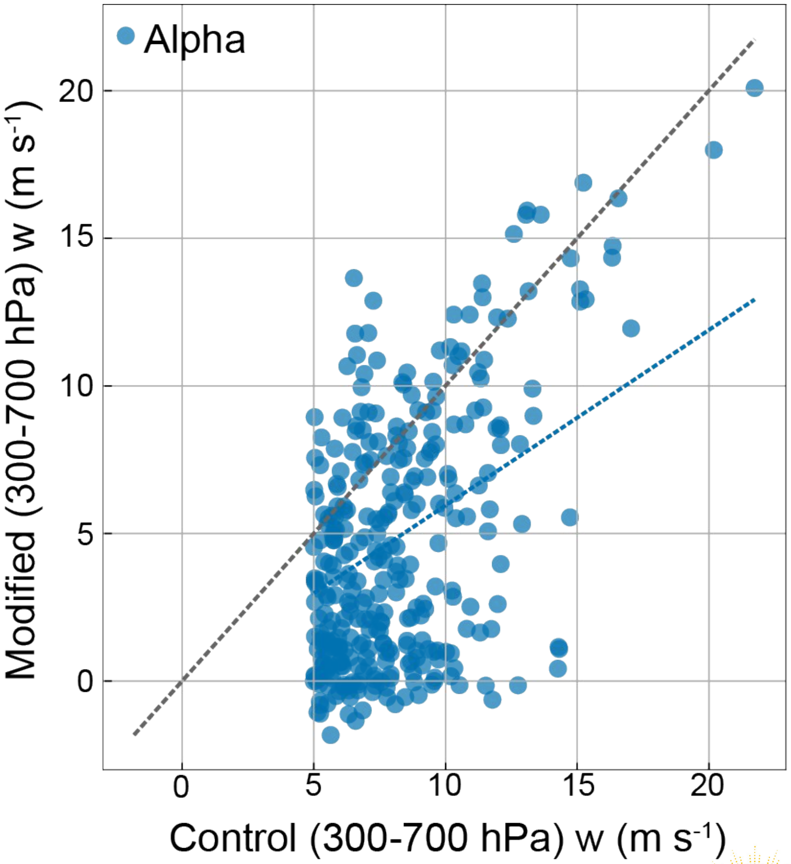
(Minamide and Posselt, 2026)

- Identify deep convection within 75 km of the TC center
  - Vertically-averaged (300-500hPa) vertical wind > 5 m/s
  - Spatio-temporally local maxima
- Isolate and remove meso-α,β,γ scale moisture variability within 10-20 minutes from peak-time of convective features
  - Only removes meso- α,β,γ scale moisture *variability* within 30-km from convection at 20-minute prior to its peak
  - ***No change in total amount of water***

How does removal of small scale moisture variance affect individual convective cores?

Test Moisture Modification

- Select a random sample of 333 identified convective cores
- Remove variability on alpha, beta, gamma, and beta+gamma scales 20 minutes prior to time of convective identification
- Compare resulting updraft strength with unmodified updraft



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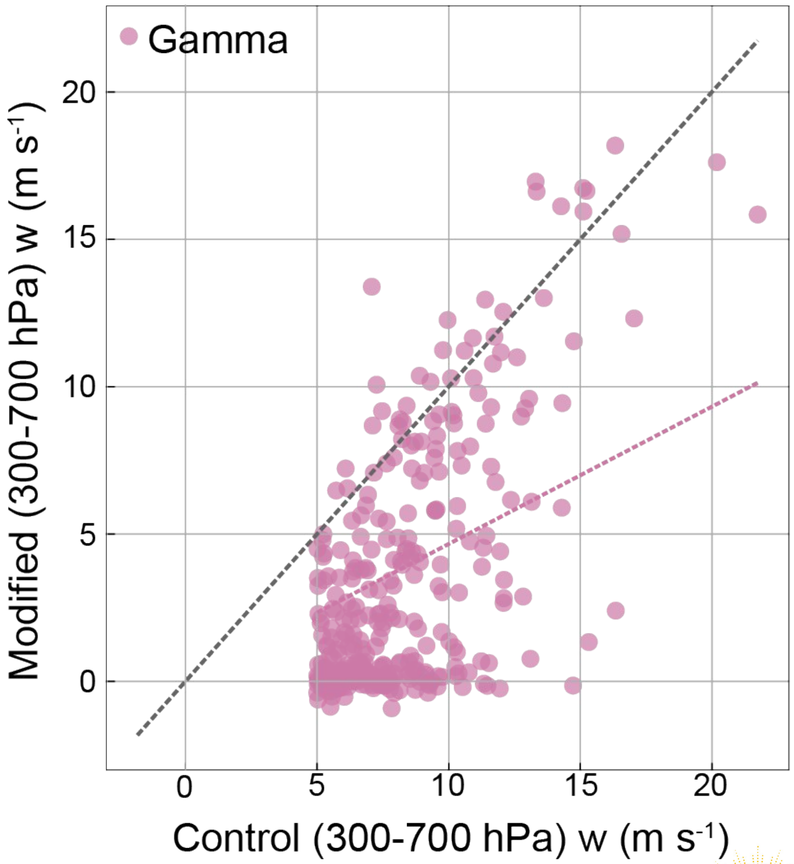

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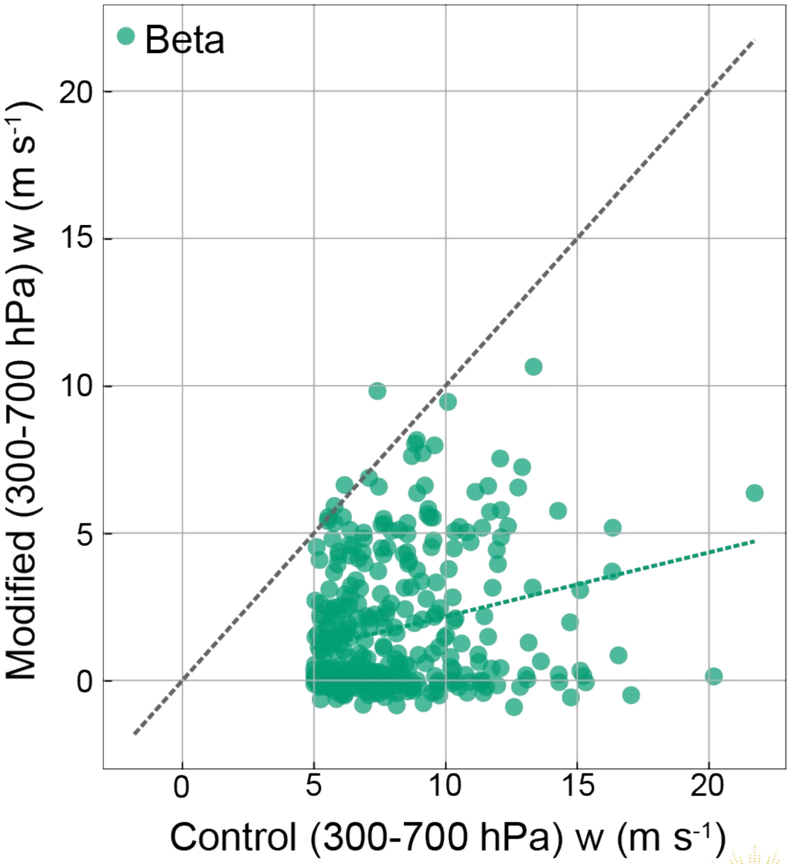

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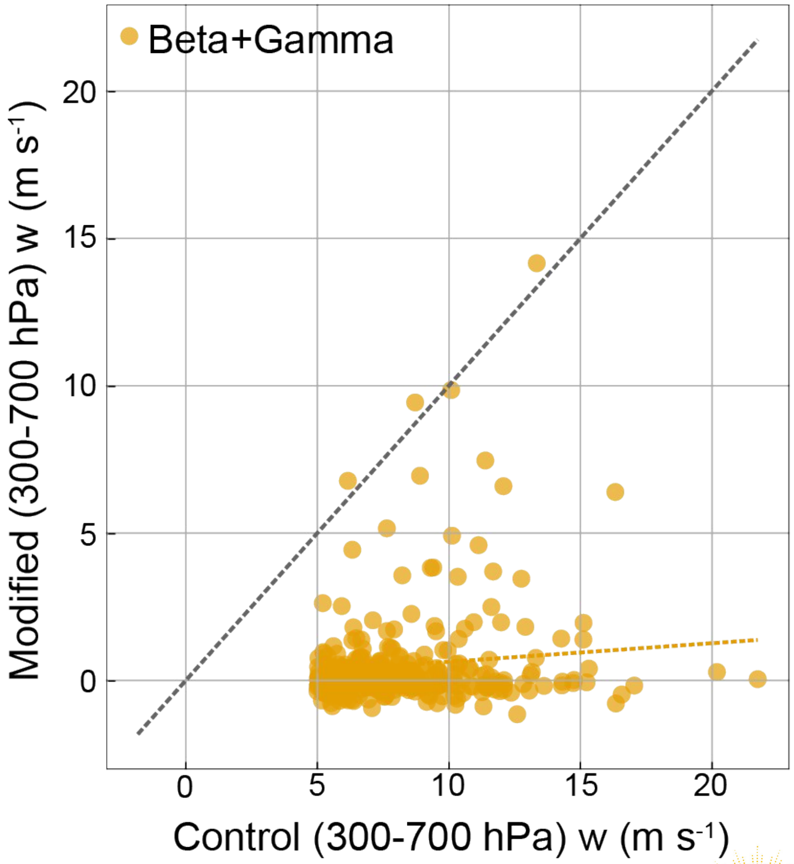
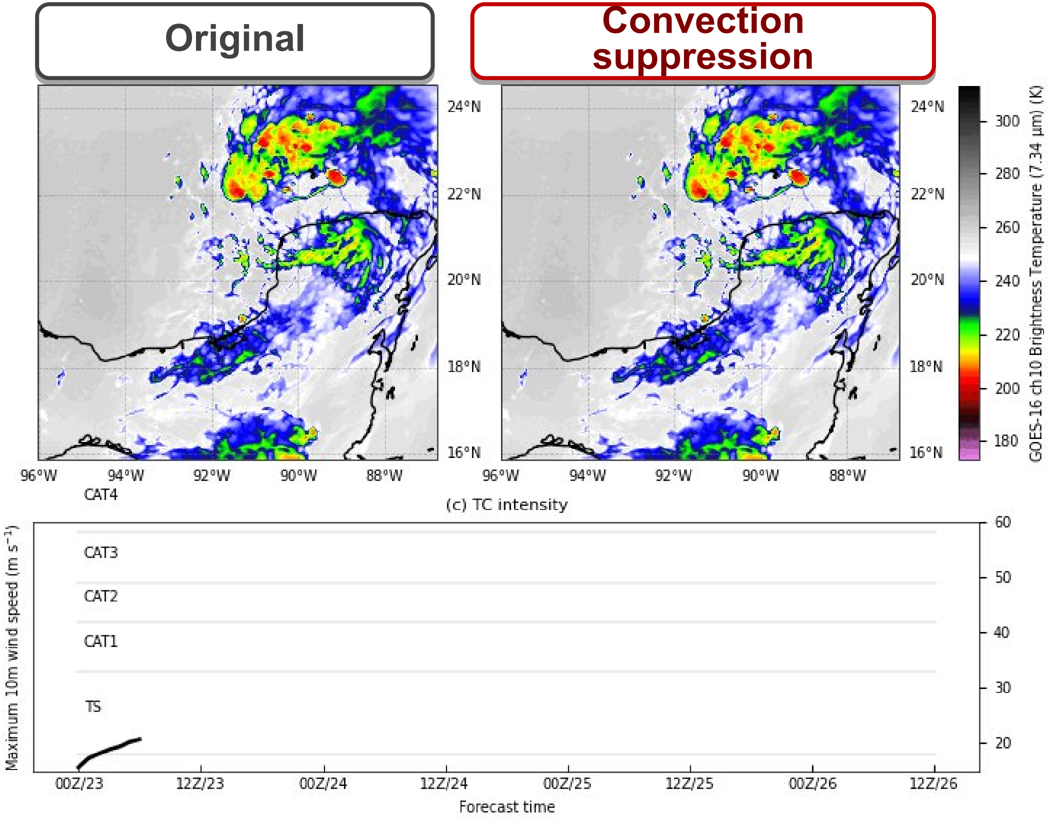


How does removal of small-scale moisture variance affect TC evolution?

Upscale Cascade, Convective to TC Scales

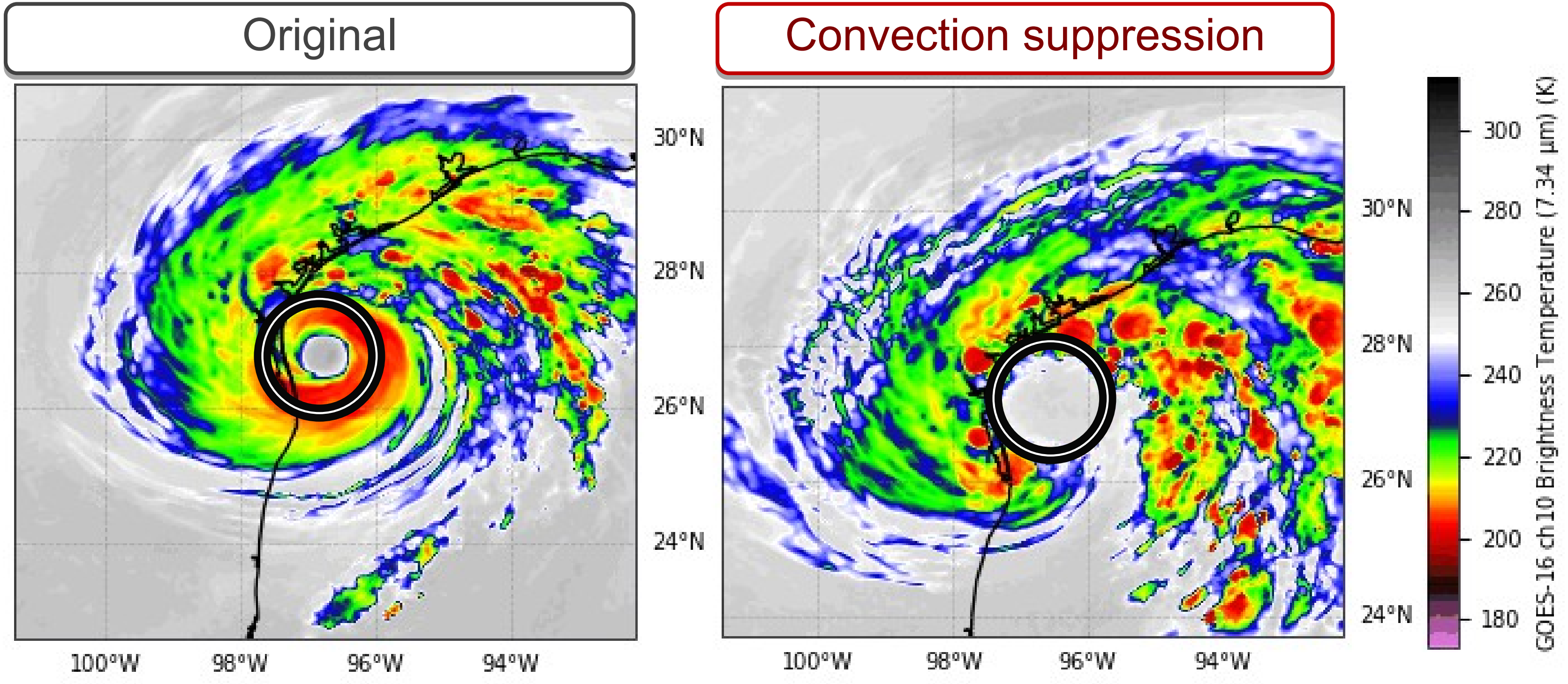


- Changes in the horizontal moisture distribution at small scales suppresses convective activity.
- Via the upscale cascade from convective to vortex-scale, TC intensification processes took very different pathways.

(Minamide and Posselt, 2026)

Effect on TC Inner Core

(Minamide and Posselt, 2026)



Convective activity was indeed suppressed by removing horizontal moisture perturbations in the TC inner-core

Summary

- Ensemble ***prediction*** can produce multiple plausible realizations of a convective event
- Ensemble ***data assimilation*** produces multiple *observation-constrained* realizations
- The covariances in an observation-constrained ensemble can be used to explore relationships among properties (controls) and outcomes of convection
- Examination of a tropical mesoscale convective system indicates different moisture scales exert different effects
    - Meso-alpha environment must be moist enough to support convection
    - Meso-gamma environment controls specific location/timing as well as exerting a strong influence on TC intensification
- Select removal of meso-beta and meso-gamma moisture variability in simulated TC significantly weakens the storm and suppresses RI

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Backup Slides

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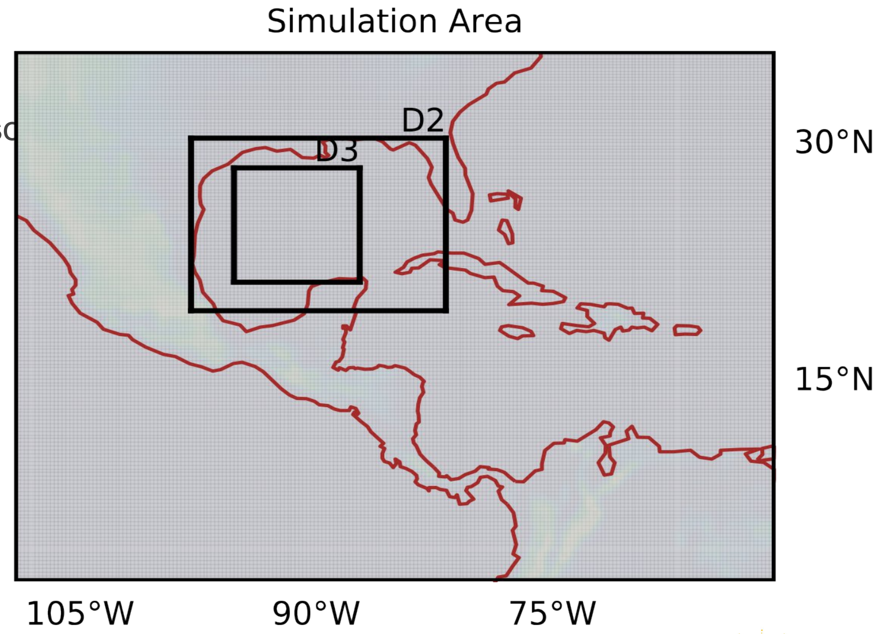
Model and Ensemble DA Configuration and Settings

Minamide and Posselt, 2022, J. Atmos. Sci.

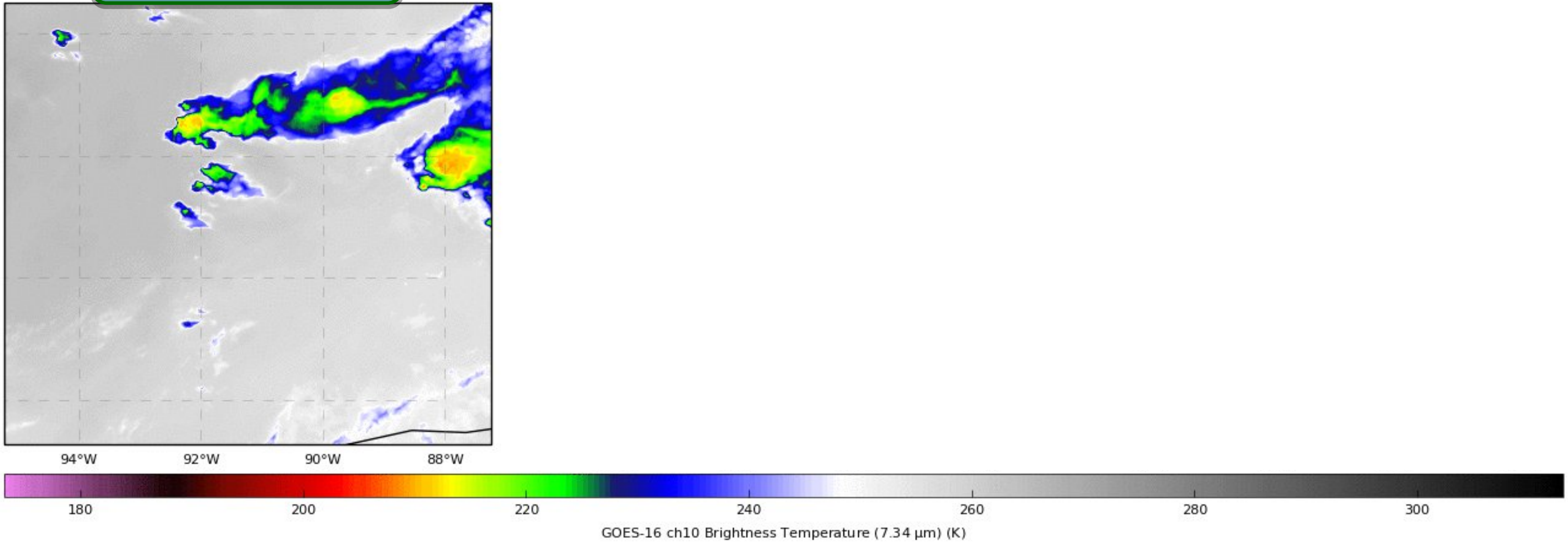
- CPEX 11 June 2017 Case
- Assimilation of all conventional observations
- Hourly assimilation of all-sky radiances from GOES-16
- WRF-based ensemble Kalman filter convection-system-resc
  Minamide and Zhang, 2019, QJRMS
- 60-member ensemble



CPEX Case Ensemble Data Assimilation

Minamide and Posselt, 2022, J. Atmos. Sci.

GOES-16 obs.



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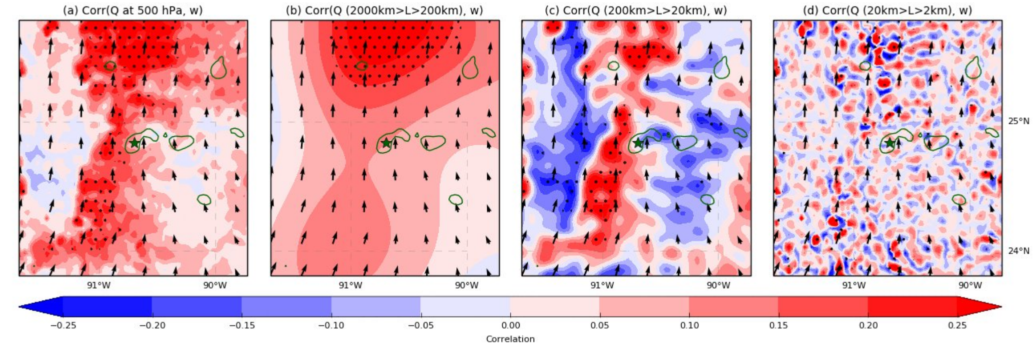
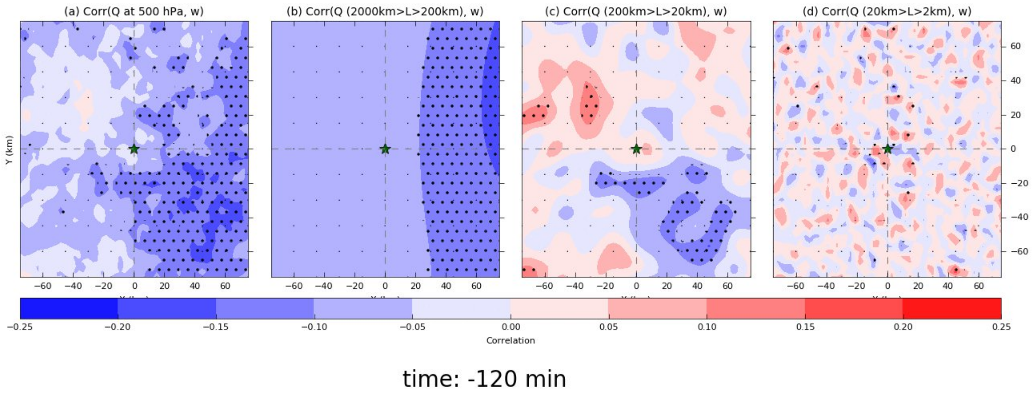
Eulerian vs. Lagrangian: Apparent Inconsistency?

Eulerian
Positive q_v – w correlation



Lagrangian
Negative q_v – w correlation



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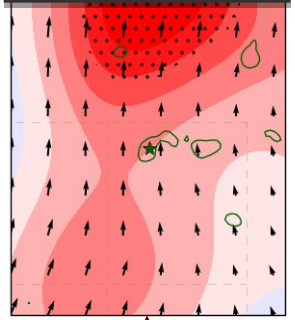
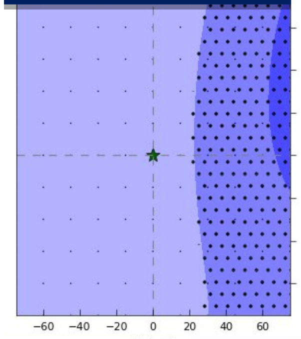
Dry or Wet Meso-α Scale Environment?

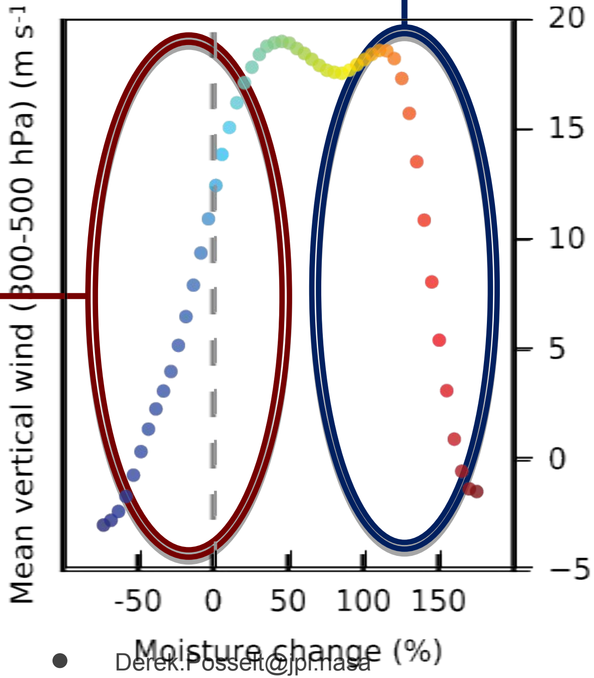
Eulerian



vs

Lagrangian





Sensitivity experiment: modify moisture correlated with a particular convective cell and examine effect on convective dynamics

Relatively dry regime:

- needs to be moist enough to develop convection

Relatively wet regime:

- More moisture → more enhanced convective activity in the surroundings → consumption of convective energy

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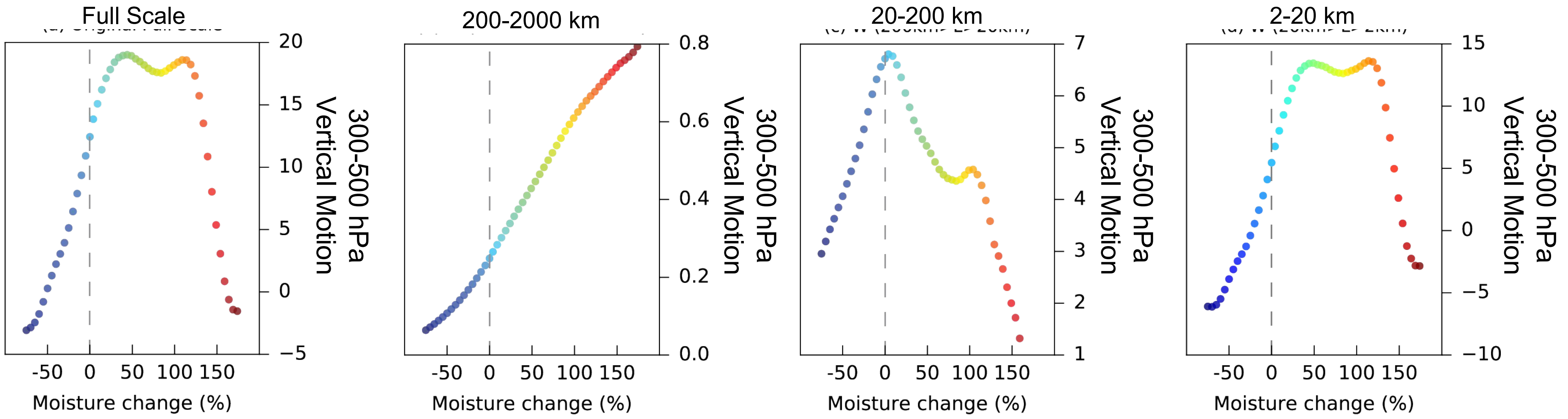
Scale-Dependent Effect of Changes in Moisture

- See effect of meso-alpha changes in moisture on specific cell
- What about the region around the cell of interest?



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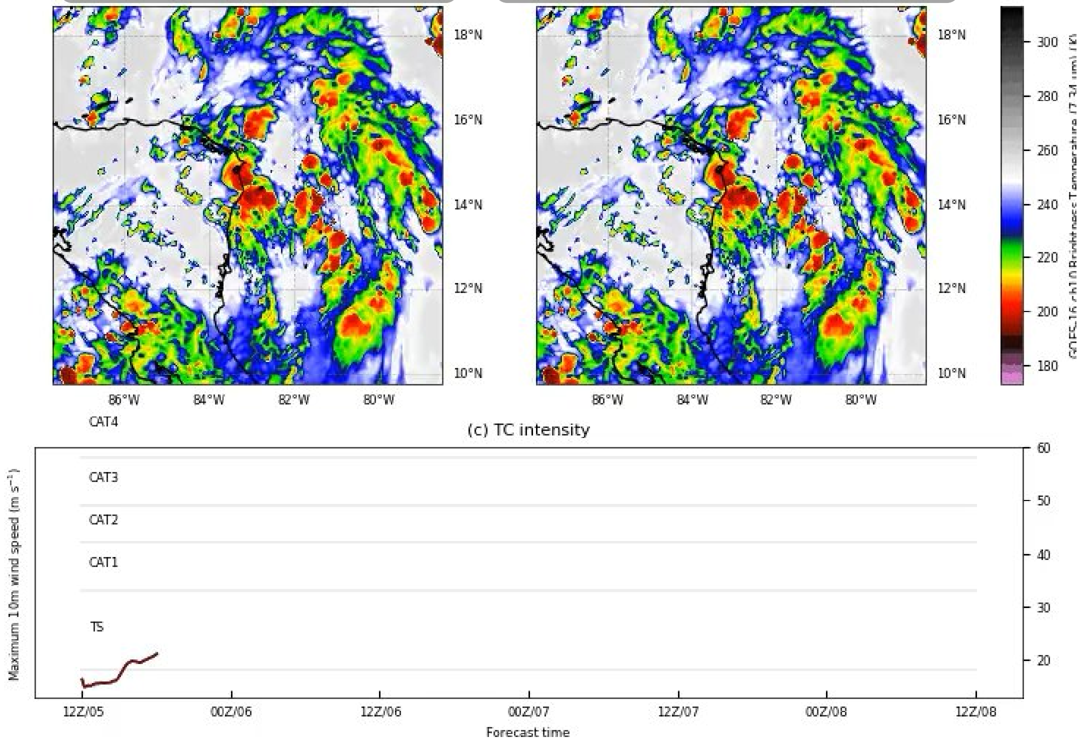
Upscale Cascade, Convective to TC Scales

Original

Convection suppression



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- Hurricane Nate (2017)
- Changes in the horizontal moisture distribution at small scales suppresses convective activity.
- Via the upscale cascade from convective to vortex-scale, TC intensification processes took very different pathways.

(Minamide and Posselt, 2026)

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Upscale Cascade, Convective to TC Scales

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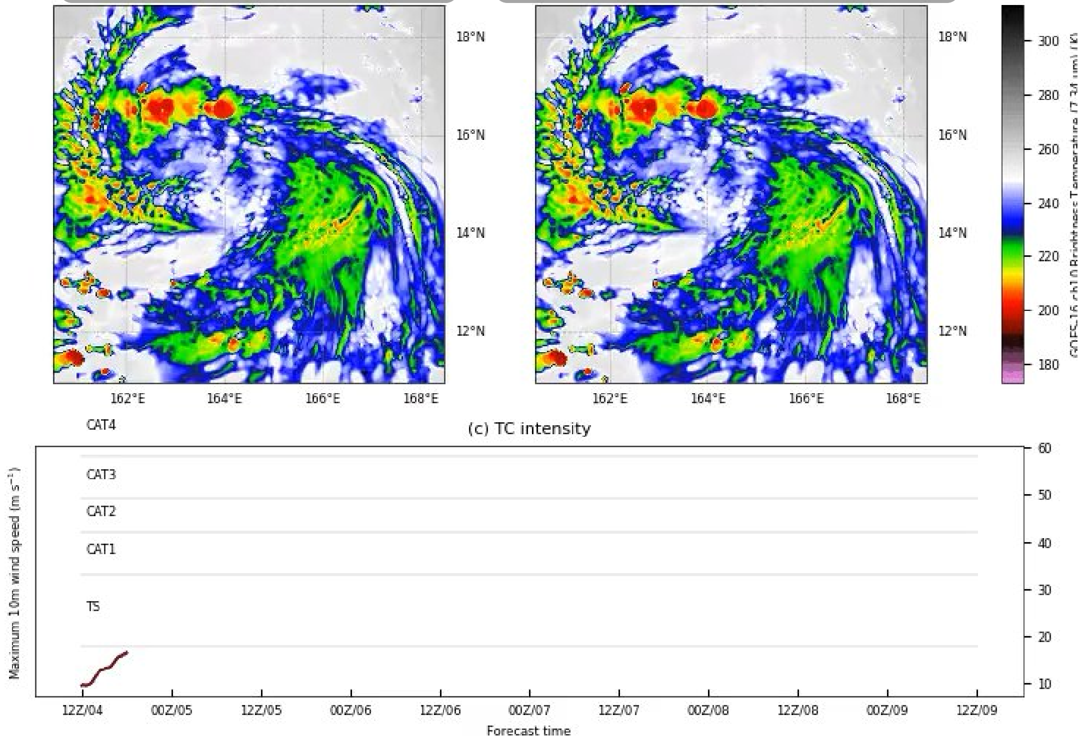

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- Supertyphoon Hagebis (2019)
- Changes in the horizontal moisture distribution at small scales suppresses convective activity.
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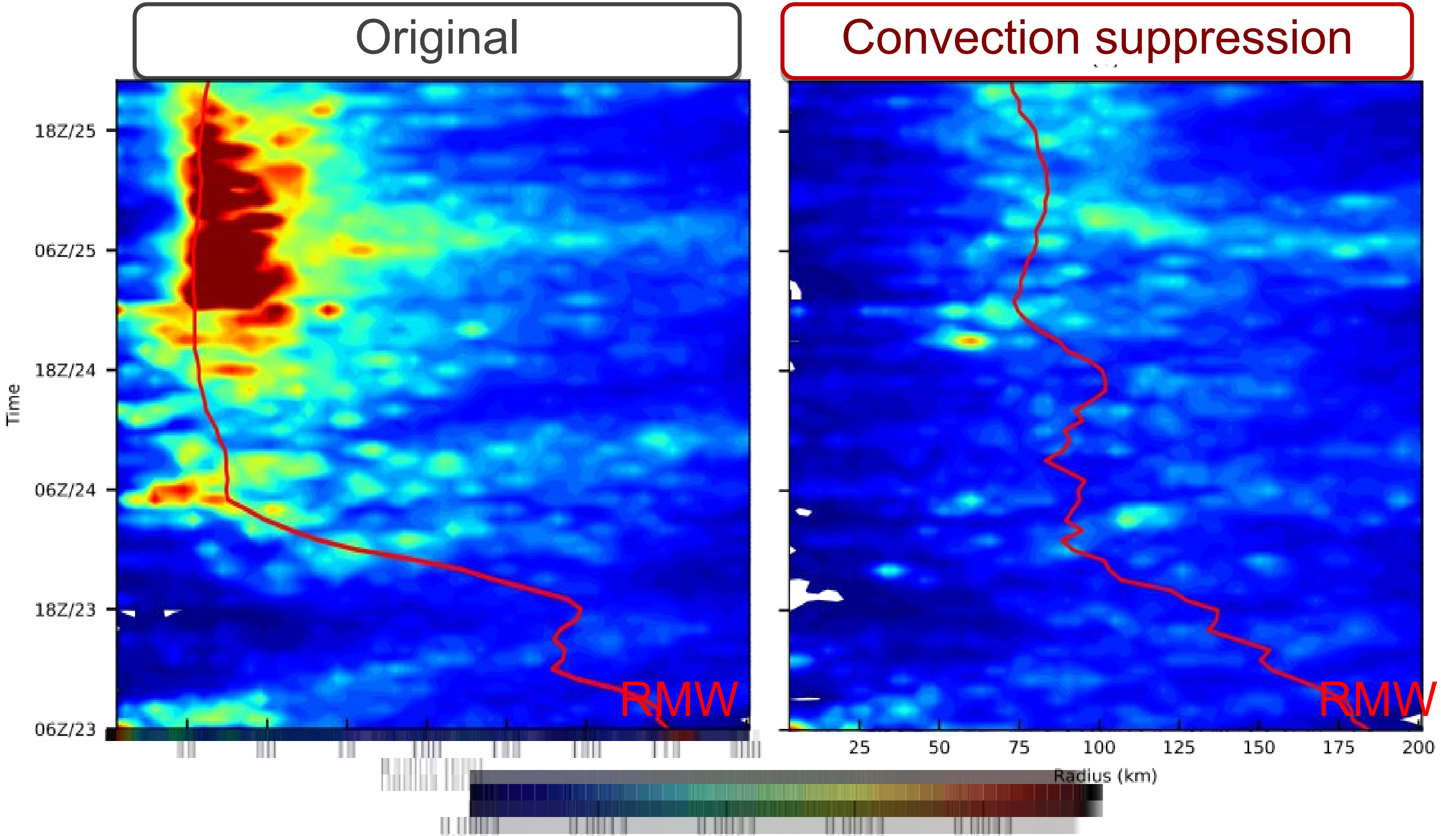
Effect on Latent Heating



In the absence of small scale horizontal moisture variability, TC vortex was not able to contract & to organize

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