領域アンサンブルデータ同化を用いたメソ対流系の予測可能性に関する研究

Masashi Minamide[1,2]

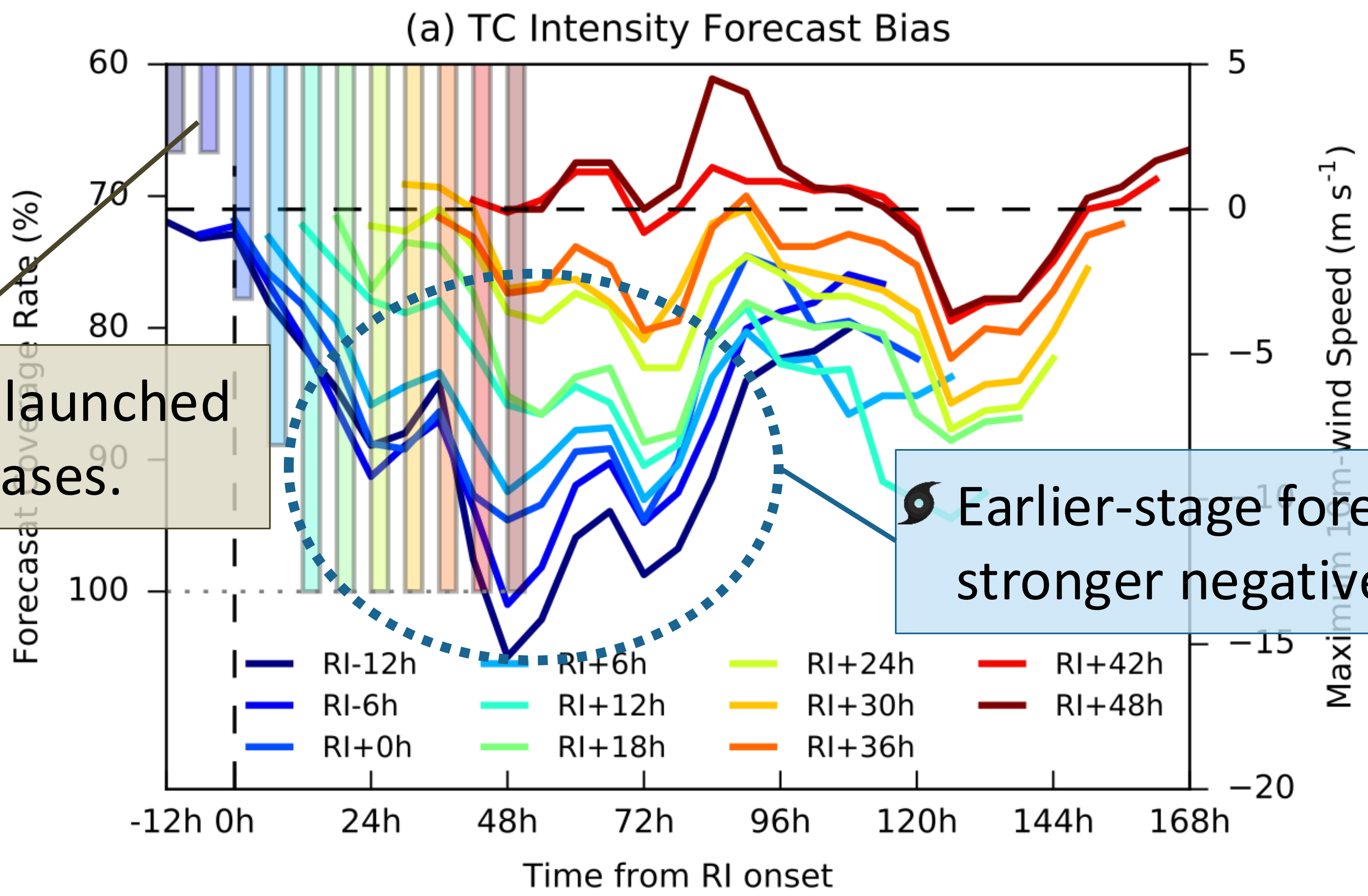
[1]Dept. of Civil Engineering, The University of Tokyo

[2]Jet Propulsion Laboratory, California Institute of Technology

Coauthors: Fuqing Zhang (PSU), Eugene Clothiaux (PSU),
Derek Posselt (JPL), Namal Rathnayake (JAMSTEC), Kotaro Kubo (UTokyo)

2025.12.12 第16回気象庁数値予報モデル研究会 @気象庁

Predictability of TC intensification: onset is challenging



Forecast was launched for only 2/3 cases.

Earlier-stage forecast: stronger negative bias

(Minamide & Posselt, 2025, *QJRMS*)

Limited predictability of intensification onset

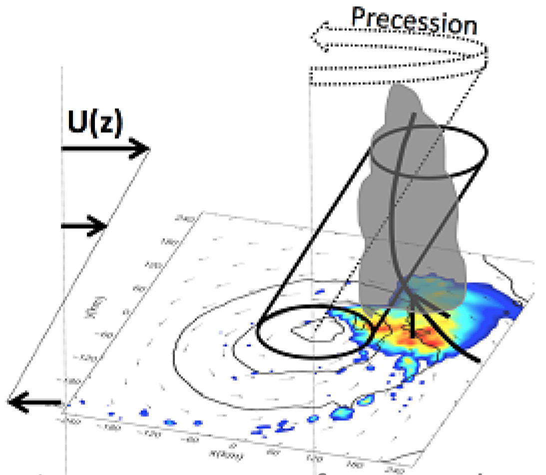
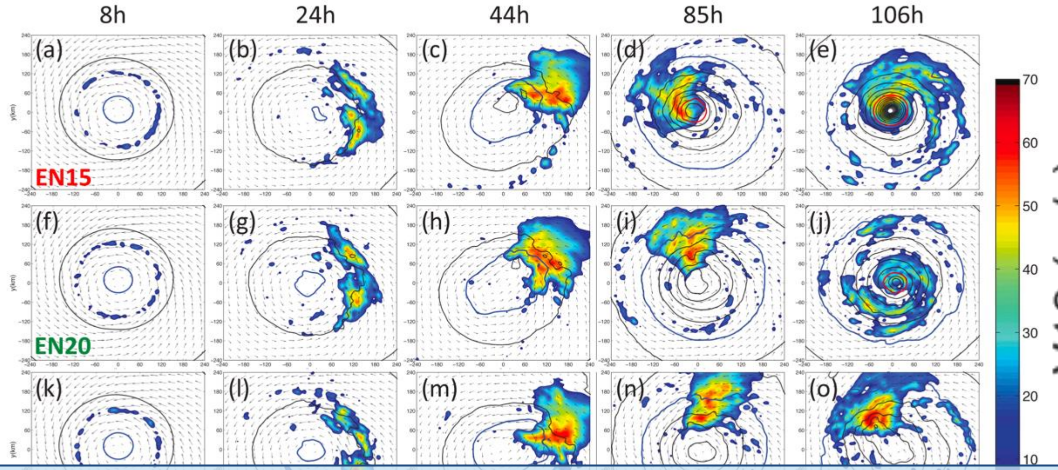
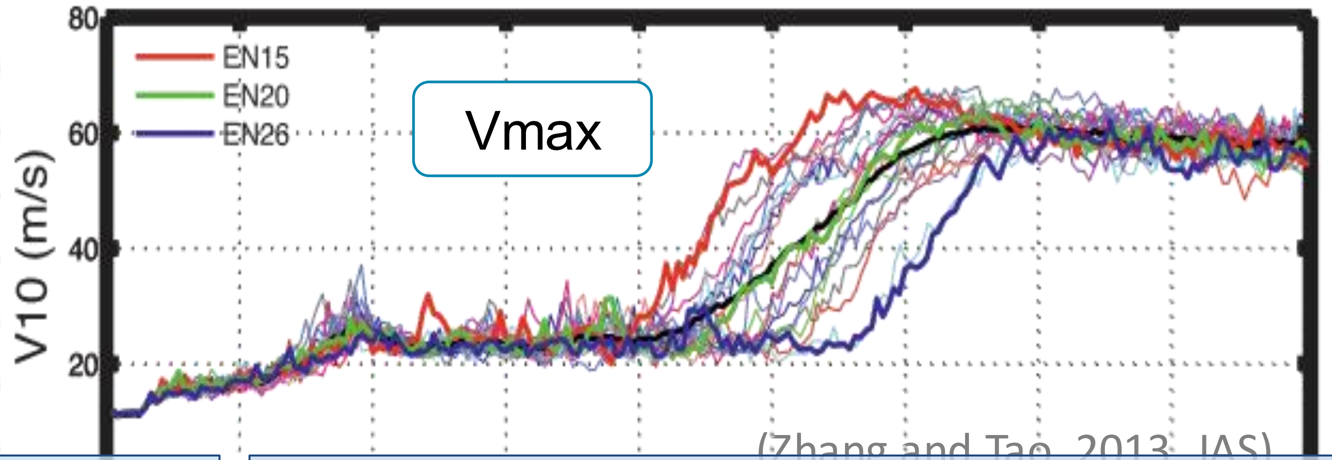


Figure courtesy of Dr. Dandan Tao

- Thermodynamic process contributes to vortex alignment to initiate rapid intensification. (Rios-Berrios et al,, 2018; Stone et al., 2023)
- Large prediction uncertainty is induced by chaotic nature of moist convection. (Zhang & Tao, 2013)

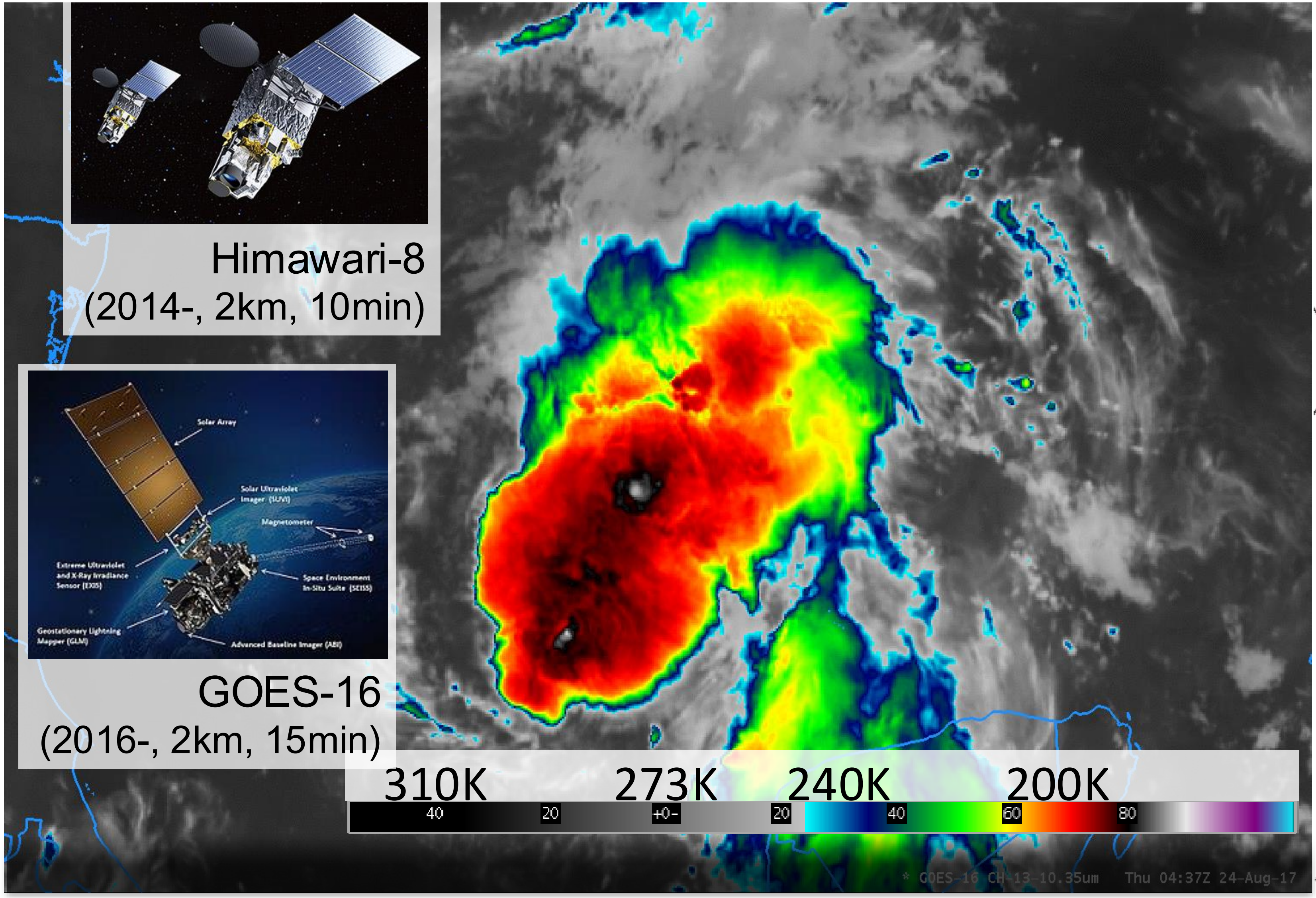


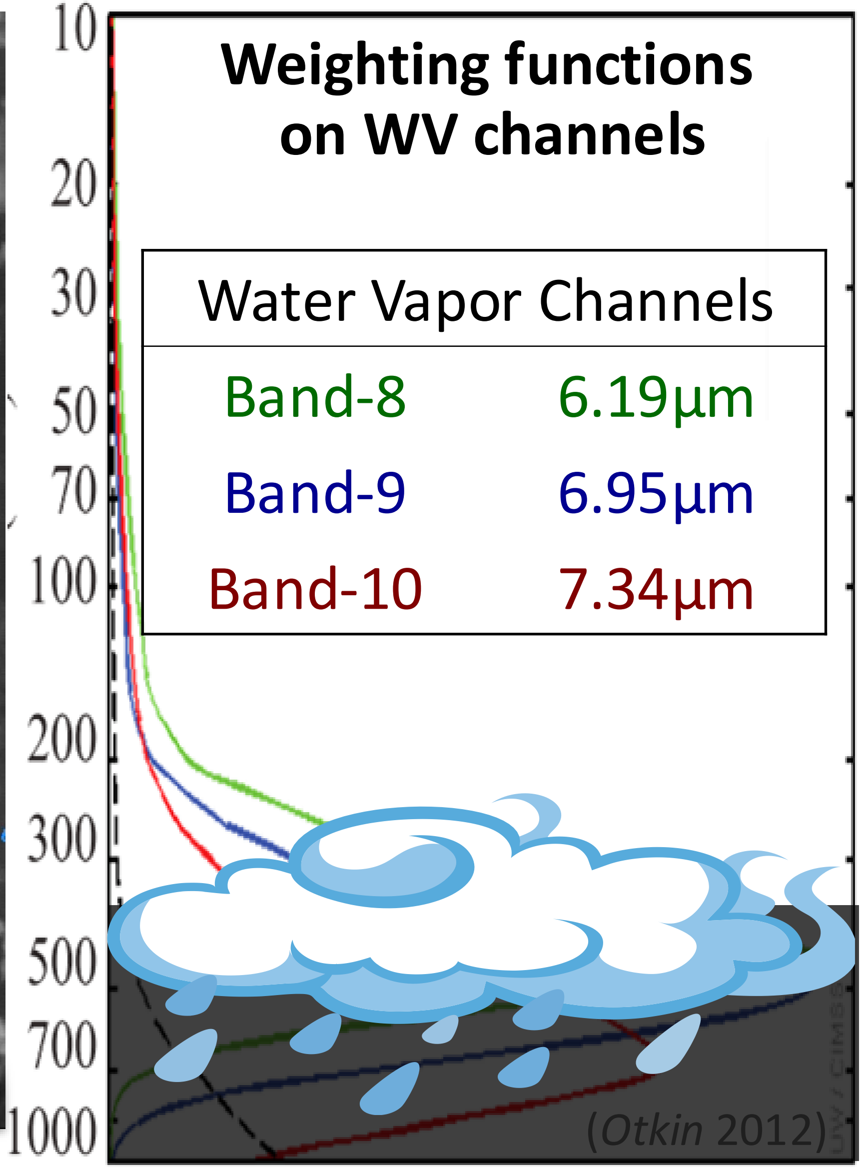


Impacts of moist convection are key to better understand/predict intensification onset.

Hard to capture/reproduce/predict the individual convective activity

Solution: geostationary satellites?





Today’s outline

Part 1. Data Assimilation Methodology Development

1. Adaptive observation error inflation (AOEI)
2. Adaptive background error inflation (ABEI)

Part 2. Forecast Improvement Assessment

3. Tropical cyclones applications:

Part 3. all-sky satellite DA to explore convective predictability

4. Insights for convective signals:

Today's outline

Part 1. Data Assimilation Methodology Development

1. Adaptive observation error inflation (AOEI)

- **Minamide, M.**, and F. Zhang, 2017: Adaptive Observation Error Inflation for Assimilating All-sky Satellite Radiance, *MWR*, 145,1063-1081

2. Adaptive background error inflation (ABEI)

- **Minamide, M.**, F. Zhang, 2018: An Adaptive Background Error Inflation Method for Assimilating All-sky Radiances, *QJRMS*, doi:10.1002/qj.3466

Part 2. Forecast Improvement Assessment

3. Tropical cyclones applications:

- Zhang, F., **M. Minamide**, E.E. Clothiaux, 2016: Potential Impacts of Assimilating All-sky Satellite Radiances from GOES-R on Convection-Permitting Analysis and Prediction of Tropical Cyclones, *GRL*, 43
- **Minamide, M.**, F. Zhang, 2018: Assimilation of All-sky Infrared Radiances from Himawari-8 and Impacts of Moisture and Hydrometer Initialization on Convection-Permitting Tropical Cyclone Prediction, *MWR*, 146 ,3241-3258
- ***Minamide, M.**, F. Zhang, E.E. Clothiaux, 2020: Nonlinear Forecast Error Growth of Rapidly Intensifying Hurricane Harvey (2017) Examined through Convection-permitting Ensemble Assimilation of GOES-16 All-sky Radiances, Journal of the Atmospheric Sciences, doi: 10.1175/JAS-D-19-0279.1*
- ***Minamide, M.**, D. J. Posselt, 2025: Improving tropical cyclone intensification prediction using high-resolution all-sky Geostationary Operational Environmental Satellite data assimilation, Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.4958.*

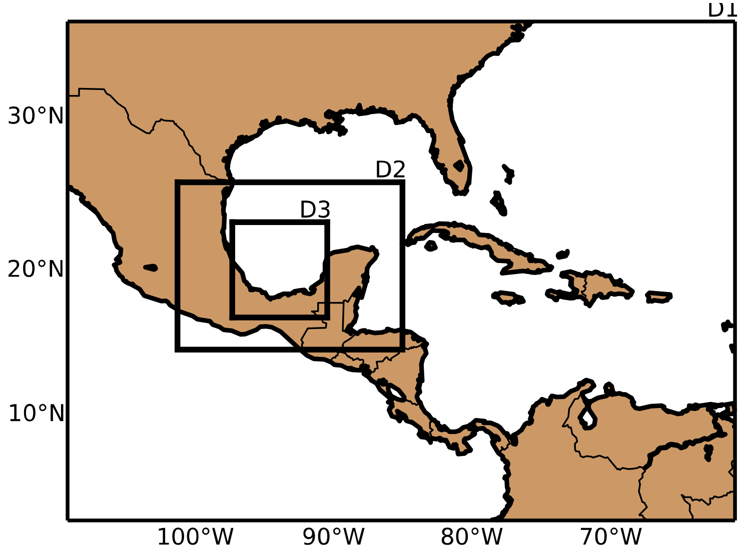
Part 3. all-sky satellite DA to explore convective predictability

4. Insights for convective signals:

- **Minamide, M.**, D. J. Posselt, 2022: Using Ensemble Data Assimilation to Explore the Environmental Controls on the Initiation and Predictability of Moist Convection, Journal of the Atmospheric Sciences, doi:10.1175/JAS-D-21-0140.1.

Real-data Experimental settings for TCs

Advanced PSU WRF-EnKF (APSU) DA system
(Weng and Zhang, 2016; Zhang, Minamide and Clothiaux, 2016)
Model: **WRF** ver.3.6.1(Skamarock 2008), **CRTM** (Han et al. 2006)



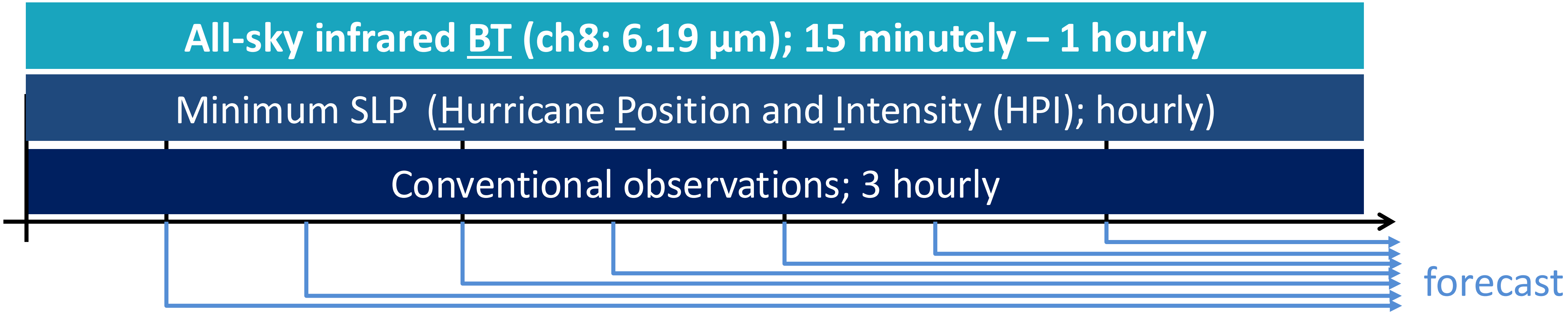
Ensemble-based data assimilation system (60-1024 ensemble)

Regional convective-permitting model

- Resolution: 27, 9 & 3 km (D1-D3)

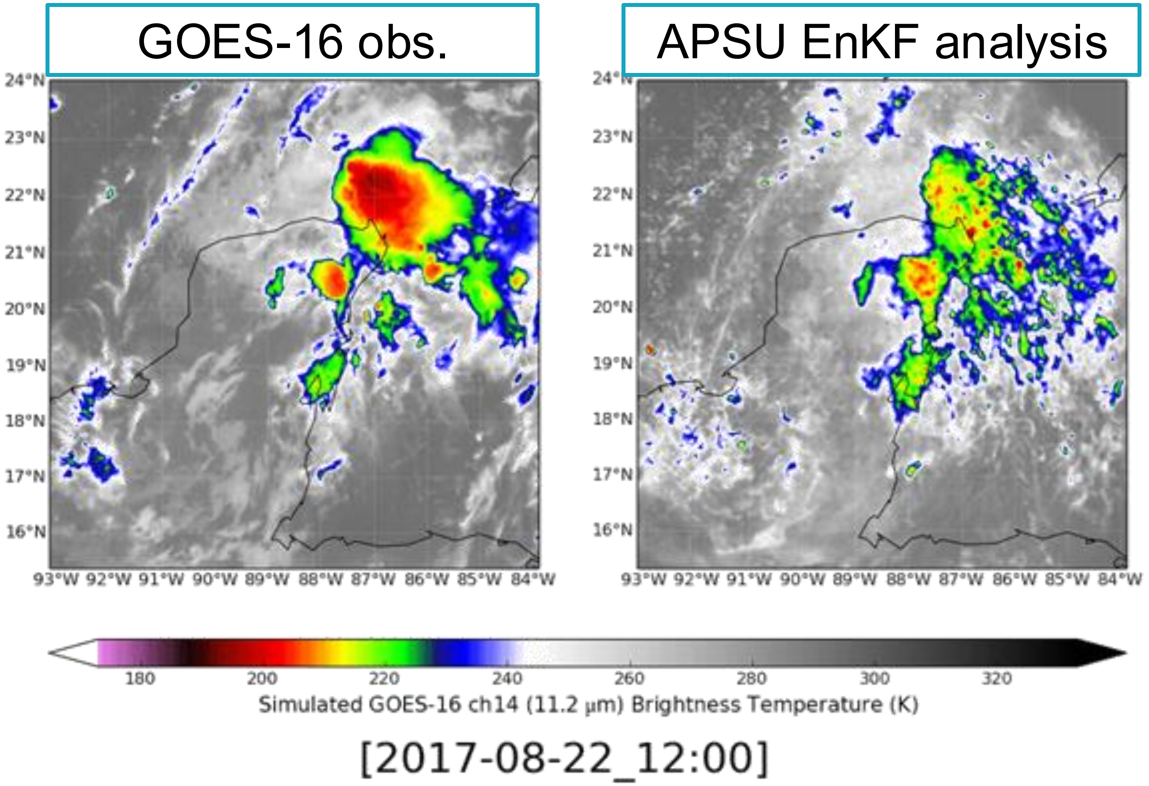
Error modeling

- Adaptive Observation Error Inflation (AOEI) (Minamide & Zhang, 2017, *MWR*)
- Adaptive Background Error Inflation (ABEI) (Minamide & Zhang, 2019, *QJRMS*)

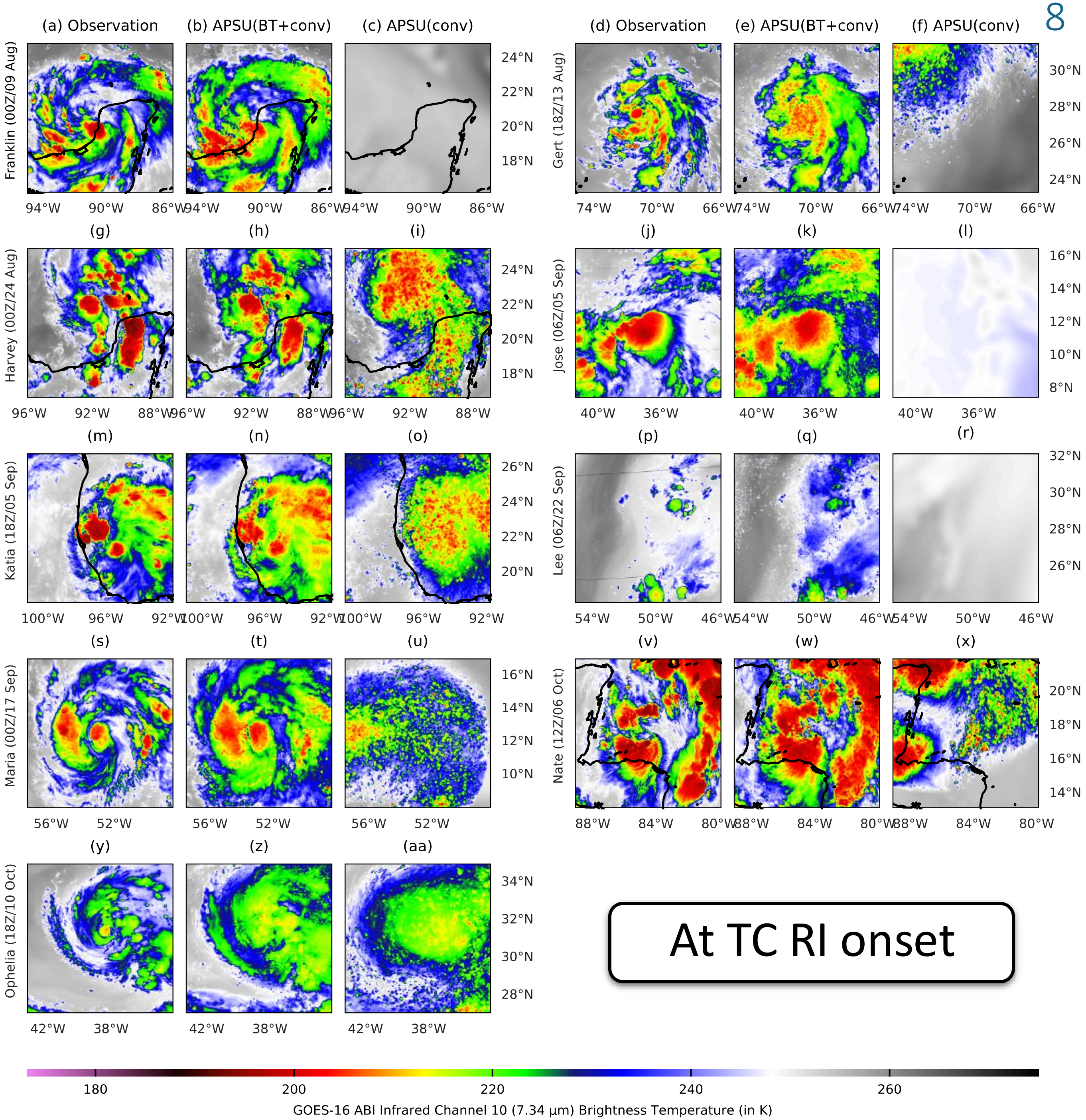


EnKF Performance

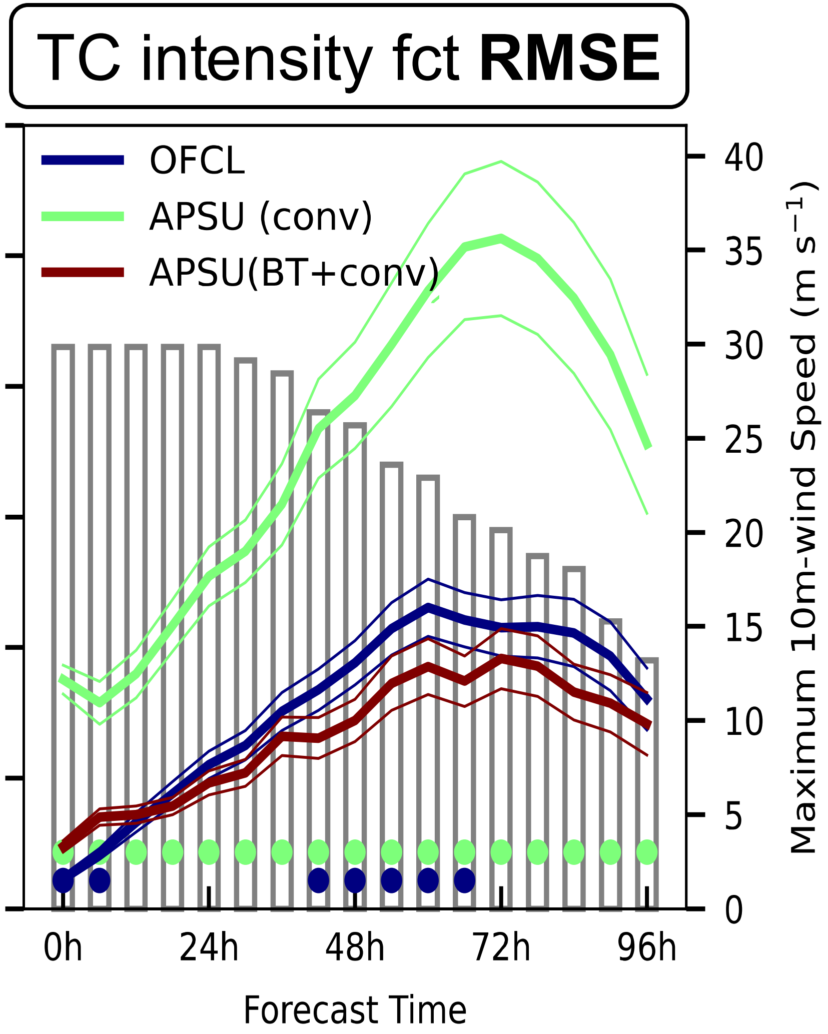
- **All-sky infrared satellite DA** well constrained the TC inner-core structure through entire TC lifecycle.

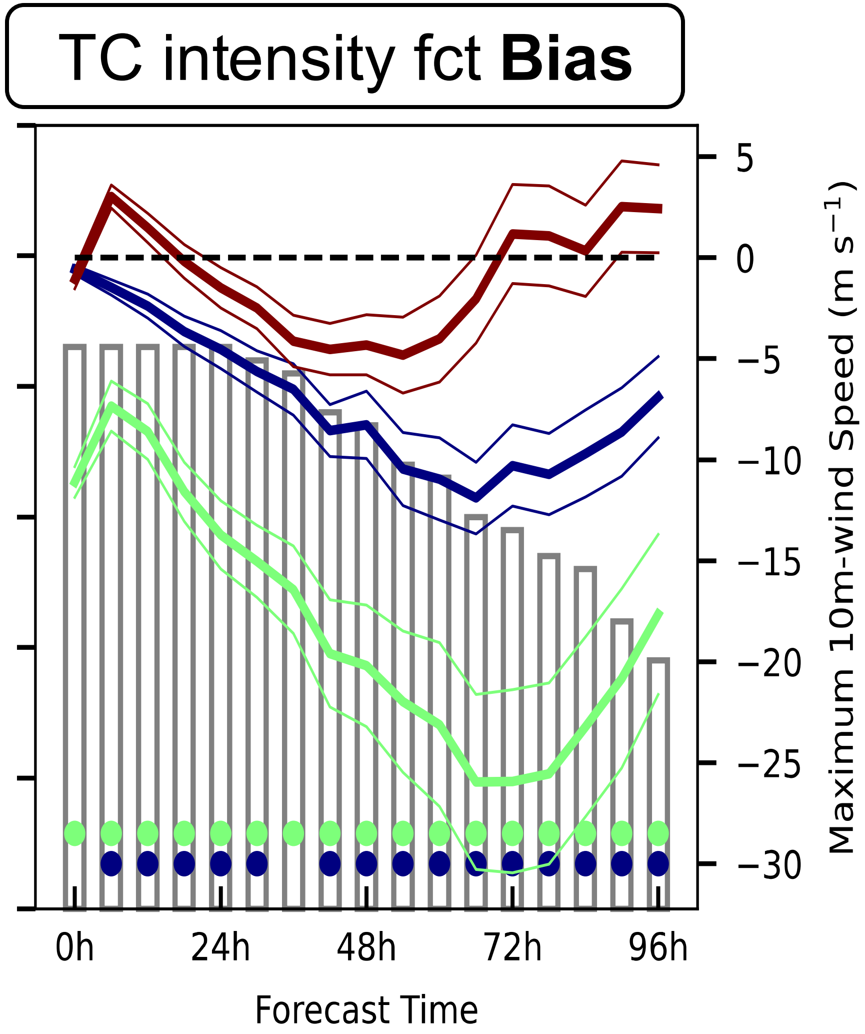


(Minamide & Posselt, 2025, *QJRMS*)



Hurricane-seasonal analysis of TC intensity forecast





- ~20% RMSE reduction at their peak-time intensities.
- Mitigating the weak intensity bias
  - Inner-core convective structures

    ↓
  - intensification onset

(Minamide & Posselt, 2025, *QJRMS*)

Today’s outline

Part 1. Data Assimilation Methodology Development

1. Adaptive observation error inflation (AOEI)

- **Minamide, M.**, and F. Zhang, 2017: Adaptive Observation Error Inflation for Assimilating All-sky Satellite Radiance, *MWR*, 145,1063-1081

2. Adaptive background error inflation (ABEI)

- **Minamide, M.**, F. Zhang, 2018: An Adaptive Background Error Inflation Method for Assimilating All-sky Radiances, *QJRMS*, doi:10.1002/qj.3466

Part 2. Forecast Improvement Assessment

3. Tropical cyclones applications:

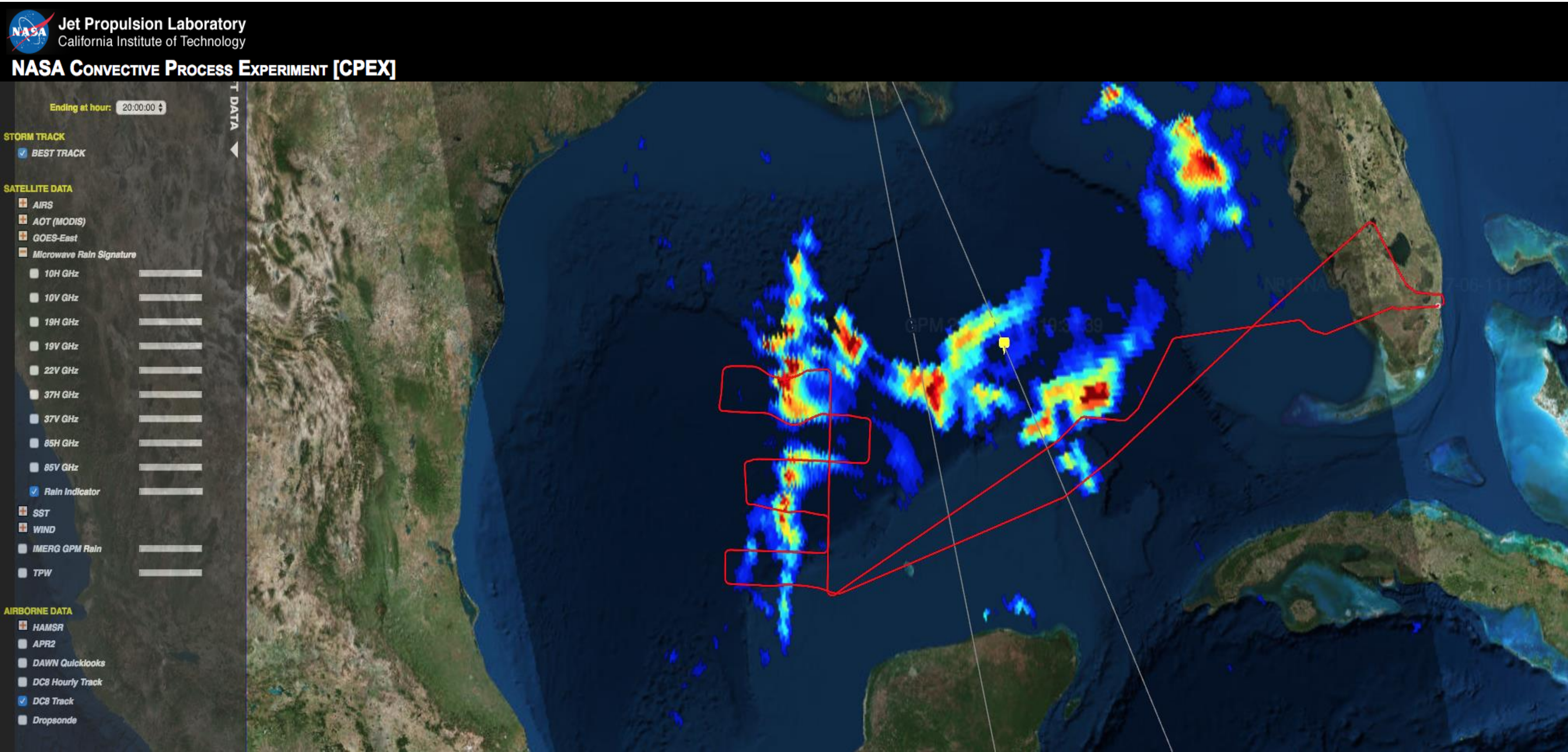
- Zhang, F., **M. Minamide**, E.E. Clothiaux, 2016: Potential Impacts of Assimilating All-sky Satellite Radiances from GOES-R on Convection-Permitting Analysis and Prediction of Tropical Cyclones, *GRL*, 43
- **Minamide, M.**, F. Zhang, 2018: Assimilation of All-sky Infrared Radiances from Himawari-8 and Impacts of Moisture and Hydrometer Initialization on Convection-Permitting Tropical Cyclone Prediction, *MWR*, 146 ,3241-3258
- ***Minamide, M.**, F. Zhang, E.E. Clothiaux, 2020: Nonlinear Forecast Error Growth of Rapidly Intensifying Hurricane Harvey (2017) Examined through Convection-permitting Ensemble Assimilation of GOES-16 All-sky Radiances, Journal of the Atmospheric Sciences, doi: 10.1175/JAS-D-19-0279.1*
- ***Minamide, M.**, D. J. Posselt, 2025: Improving tropical cyclone intensification prediction using high-resolution all-sky Geostationary Operational Environmental Satellite data assimilation, Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.4958.*

Part 3. Exploring convective predictability

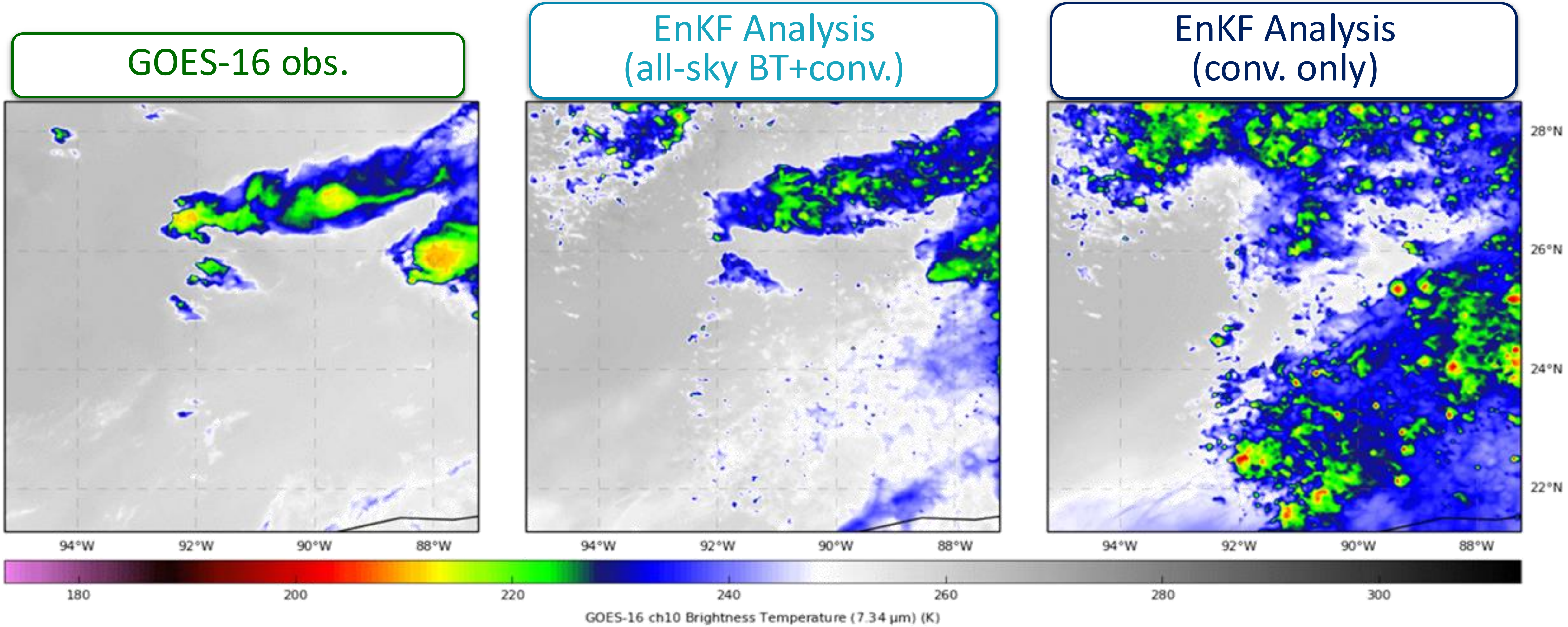
4. Insights for convective signals:

- **Minamide, M.**, D. J. Posselt, 2022: Using Ensemble Data Assimilation to Explore the Environmental Controls on the Initiation and Predictability of Moist Convection, Journal of the Atmospheric Sciences, doi:10.1175/JAS-D-21-0140.1.

Case: convections on 06/11/2017 during CPEX



EnKF Performances of All-sky Satellite DA (MCS case)

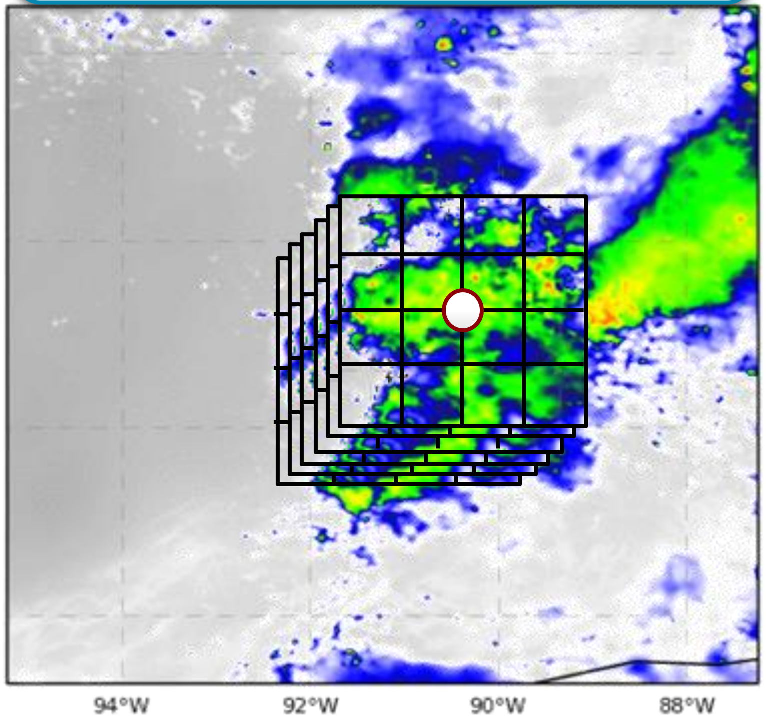


[2017-06-11_12:00]

(Minamide & Posselt, 2022, JAS)

How to find signals of convection?

EnKF Analysis
(all-sky BT+conv.)



Eulerian approach

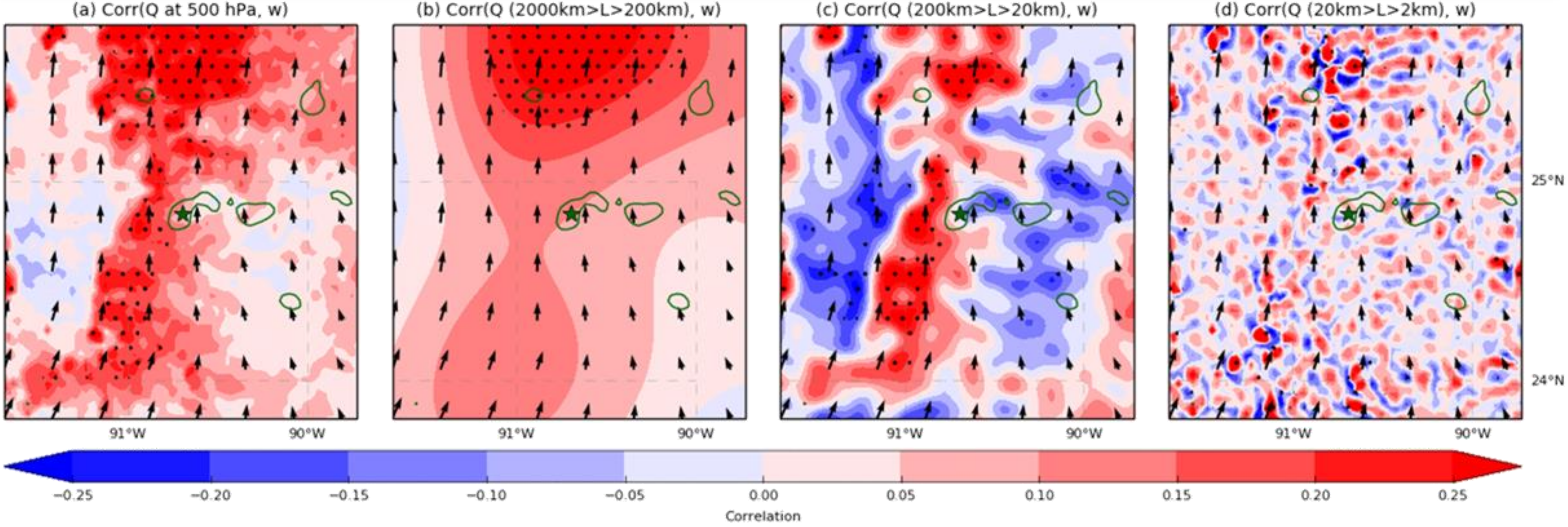
Vertical wind at the specific timing and location

What are the key signals to determine exactly when and where convection occurs?

(Minamide & Posselt, 2022, JAS)

Eulerian correlation analysis

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

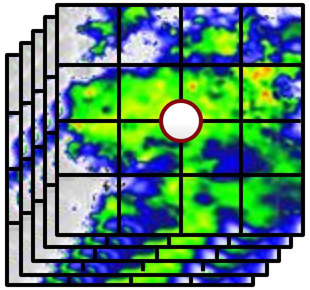


- Meso-α shows the correlation with general MCS development, which enhances convective activity but does not determine the exact location & timing.
- **Meso-γ** & -β scale structures are noisy.

(Minamide & Posselt, 2022, JAS)

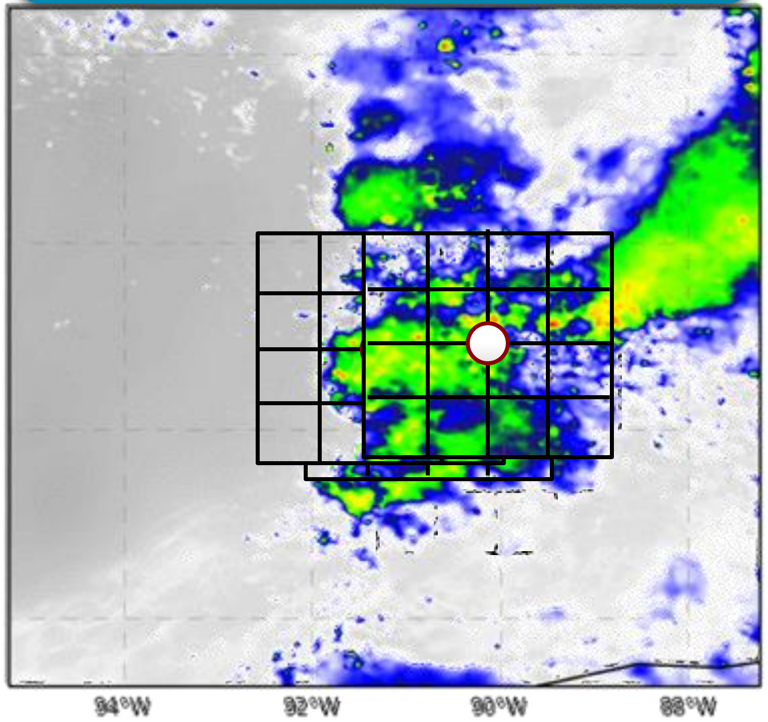
Lagrangian approach to find convective signals

EnKF Analysis
(all-sky BT+conv.)



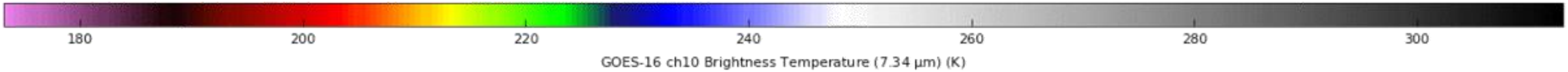
Eulerian approach

Vertical wind at the specific timing and location



Lagrangian approach

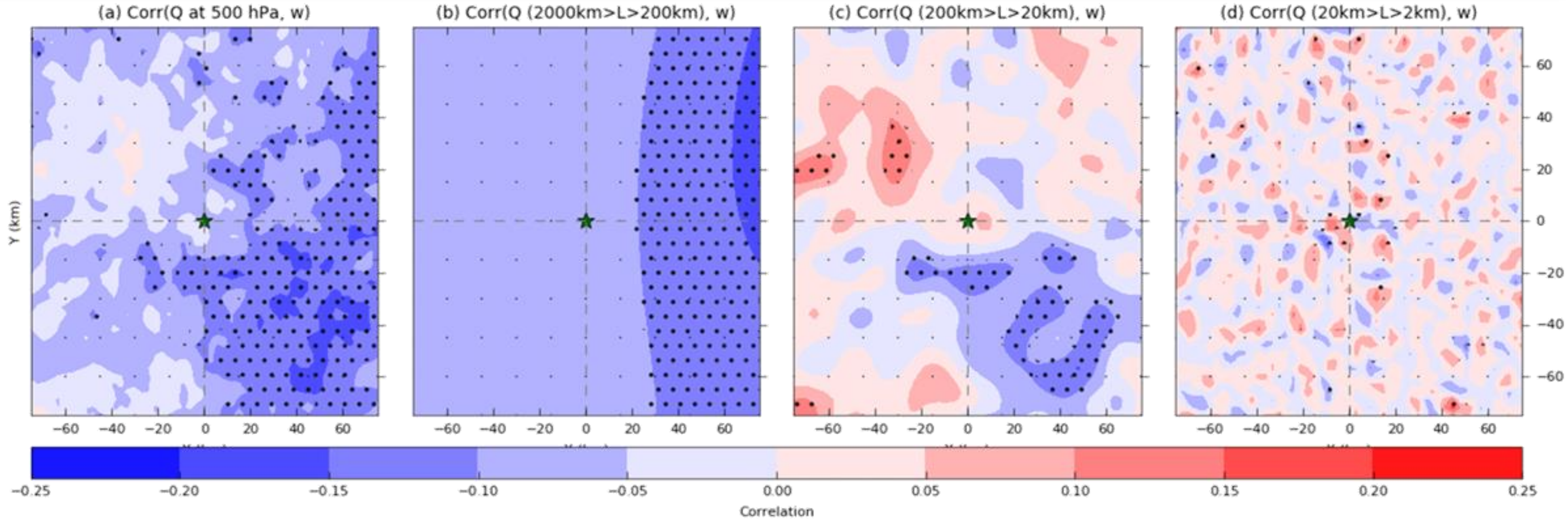
Compositing the convection centers



(Minamide & Posselt, 2022, JAS)

Lagrangian correlation analysis (lag-time ensemble)

corr{Qv at 500hPa, w(300-500hPa average) **at composite convective peak**

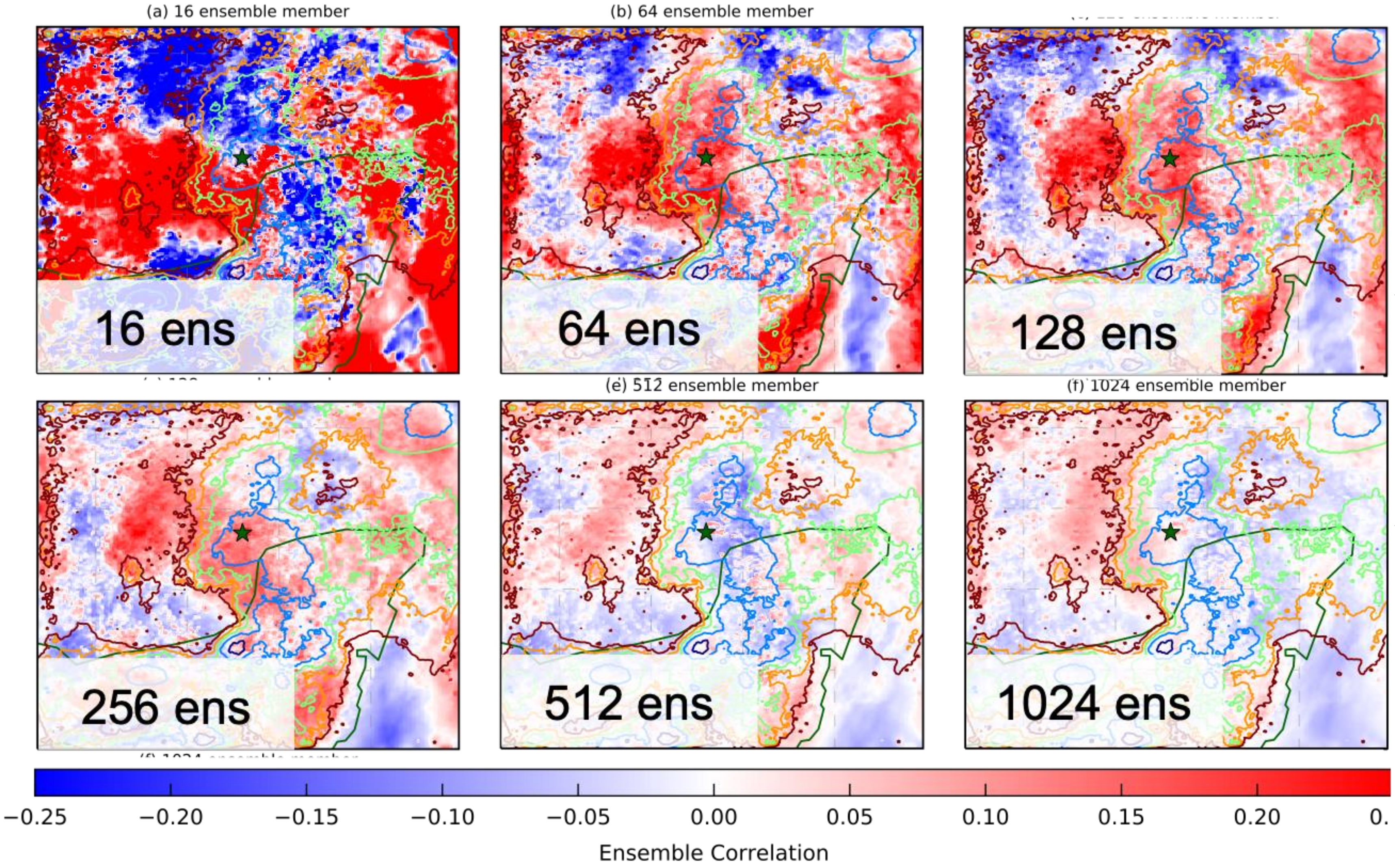


time: -120 min ← Relative to convective peak time

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

(Minamide & Posselt, 2022, JAS)

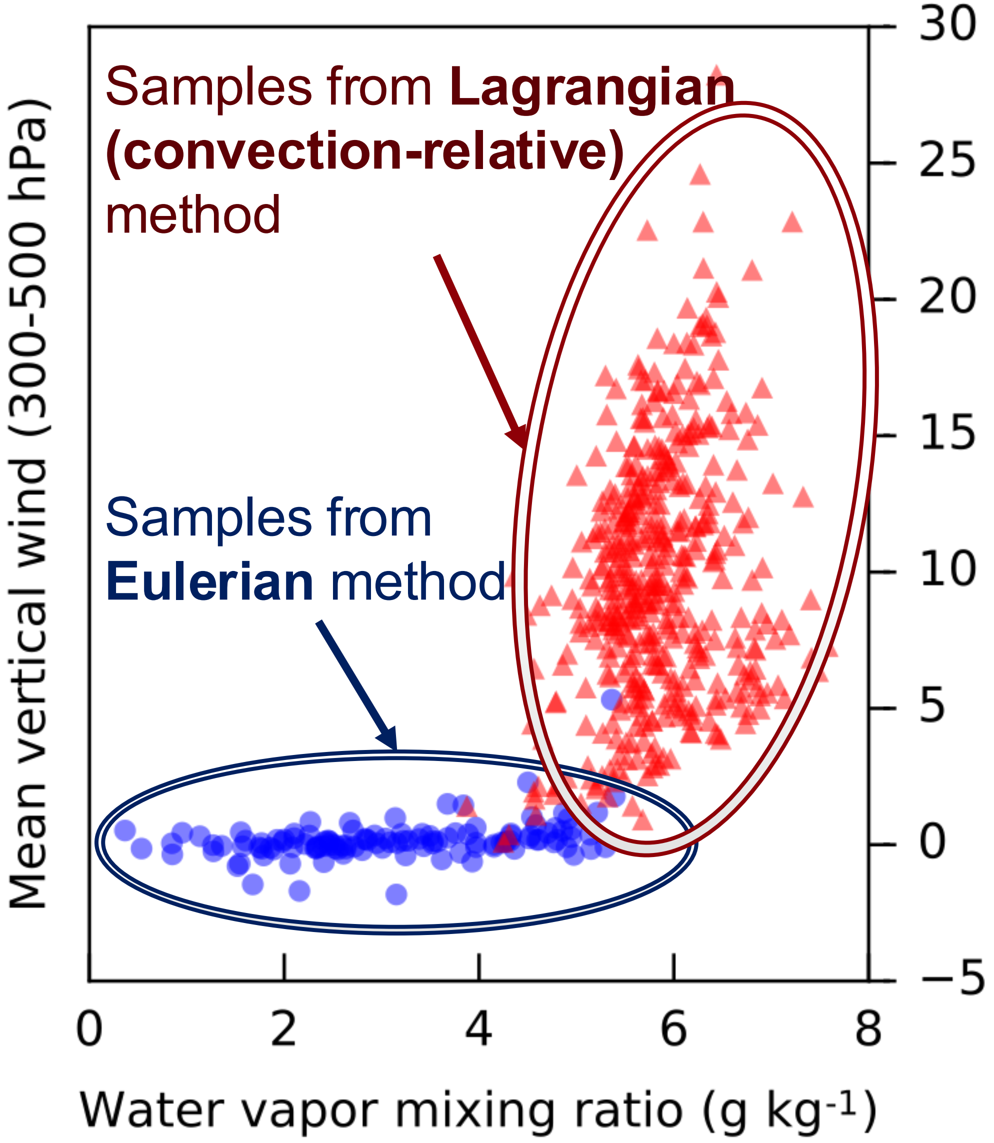
Eulerian limitation to capture convective scale features



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

- Larger ensemble helped to reduce noises even for convective scales
- "True" correlation structures (~ convective signals) was still not clear with thousands ensembles.

Why Eulerian approach is limited?



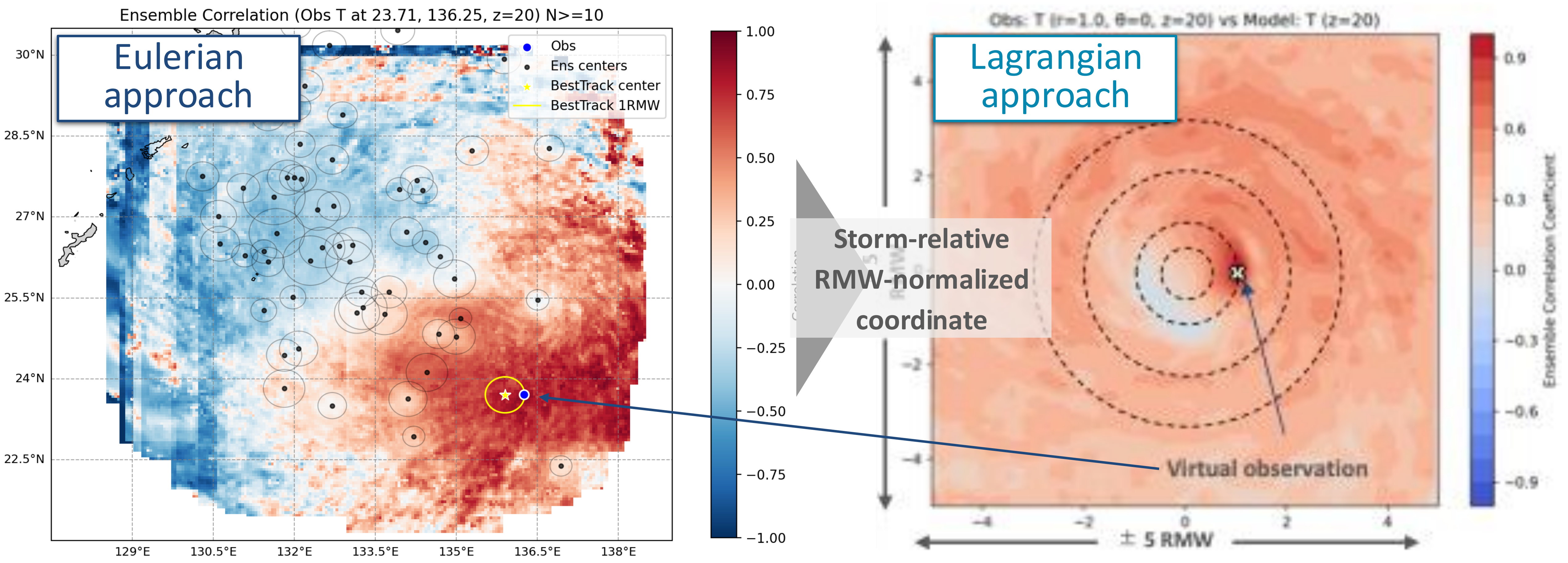
Original samples for correlation calculation

- Due to the chaotic nature of convection, only small part of ensemble captured the convection at the exact location
- Necessity to further constrain convective activity for ensemble-based DA
  - Potentially, denser observation with more frequent DA cycle and/or finer model resolution

(Minamide & Posselt, 2022, JAS)

Eulerian vs. Lagrangian: TC example

corr{T at 500hPa, T (synthetic observation)}



(Kubo and Minamide, submitted)

Summary

- With Adaptive Observation Error Inflation (AOEI) and Adaptive Background Error Inflation (ABEI), the promising positive impacts of assimilating all-sky BTs, in particular from new-generation geostationary satellites GOES-16 (and Himawari-8), on TC forecasts are demonstrated through the seasonal analysis on 2017 Atlantic hurricanes.

- Using the ensemble forecast constrained by all-sky satellite DA, we investigated the the convective predictability and necessity conditions for future observations to capture exactly when and where moist convection occurs: Meso-β (200-20km) to meso-γ (20-2km) scale information within less than 10-minute frequency will be indispensable.

Minamide, M., D. J. Posselt, 2022: Using Ensemble Data Assimilation to Explore the Environmental Controls on the Initiation and Predictability of Moist Convection, Journal of the Atmospheric Sciences, doi:10.1175/JAS-D-21-0140.1.

Minamide, M., D. J. Posselt, 2025: Improving tropical cyclone intensification prediction using high-resolution all-sky Geostationary Operational Environmental Satellite data assimilation, *Quarterly Journal of the Royal Meteorological Society*, doi:10.1002/qj.4958.

Thank you very much for your attention. (minamide@hydra.t.u-tokyo.ac.jp)