Recent research and development of inner core data assimilation: impact of relocation strategy; 4DIAU; and comparison of hourly 3DEnVar vs 6-hourly 4DEnVar

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Impact of Vortex Relocation Strategies on Hurricane Inner-core Data Assimilation and Prediction in the HWRF EnVar DA System
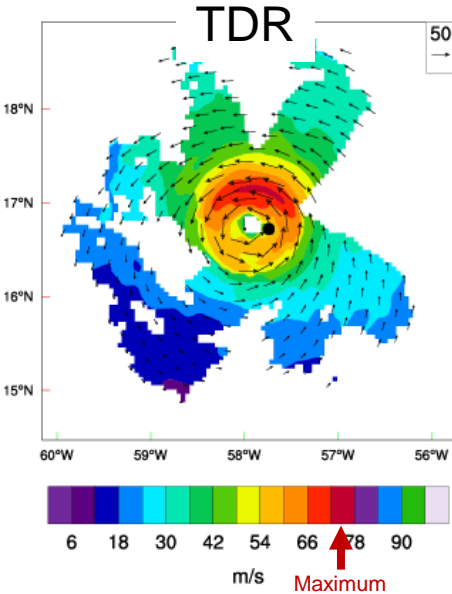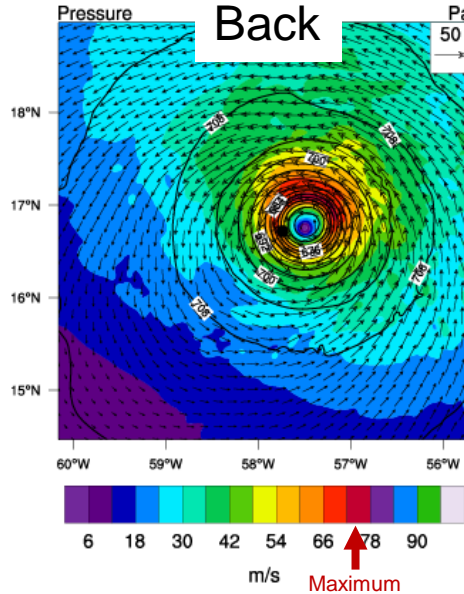
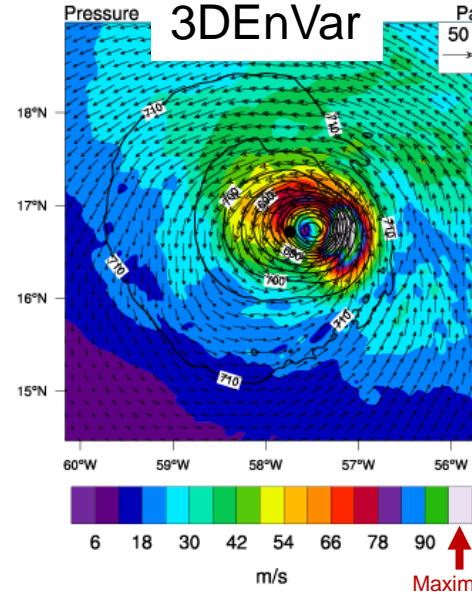# Do where and how to relocate before DA matter?

Irma (2017)

a) HRD @ 3km 1230 UTC 05 — TDR
b) Background @ 3km 1200 UTC 05 — Back
c) 3DEnVar @ 3km 1200 UTC 05 — 3DEnVar
d) 4DEnVar @ 3km 1200 UTC 05 — 4DEnVar
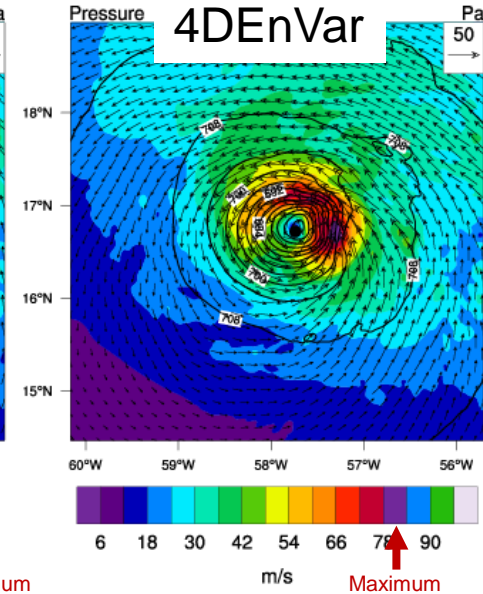
- VM is turned off when TDR is available and VR is used to relocate background before the assimilation

- 3DEnVar analysis produces spuriously strong wind

- In Lu et al. (2017), 4DEnVar is found to be better than 3DEnVar when the storm evolves fast and/or the data distribution is uneven within the DA window

- 4DEnVar can alleviate the issue but still too strong

- Issues are found to be associated with large location error in the relocated background.
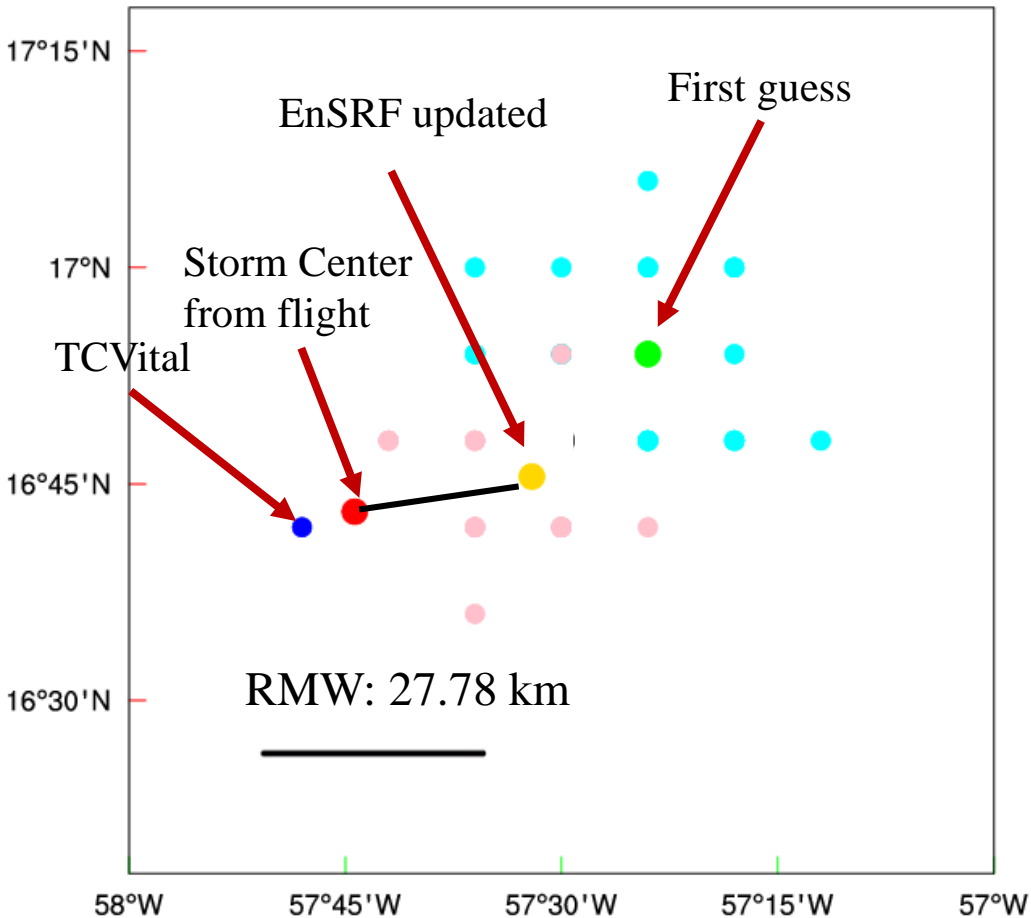
Blue – TCV
Red - Flight-determined Track
Orange/Pink – EnSRF updated
Green/Cyan - Background

- The ensemble positions are updated using EnSRF toward TCVital before VR. The updated location error could still be large.

- TC vital itself has ~8-10km error.

- Large un-fixed location error could lead to un-reasonable increments (Chen and Snyder 2007)

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- Experiments are therefore conducted to investigate the different VR strategies on the inner-core DA

| Experiment	VR targeted location	Ensemble Location Spread	DA method
3DEnVar	EnSRF analyses	Yes	3DEnVar
3DEnVar-TVnoS	TCVital	No	3DEnVar
3DEnVar-TVS	TCVital	Yes	3DEnVar
3DEnVar-FTnoS	Flight-determined	No	3DEnVar
3DEnVar-FTS	Flight-determined	Yes	3DEnVar
4DEnVar	EnSRF analyses	Yes	4DEnVar
4DEnVar-TVnoS	TCVital	No	4DEnVar
4DEnVar-TVS	TCVital	Yes	4DEnVar
4DEnVar-FTnoS	Flight-determined	No	4DEnVar
4DEnVar-FTS	Flight-determined	Yes	4DEnVar
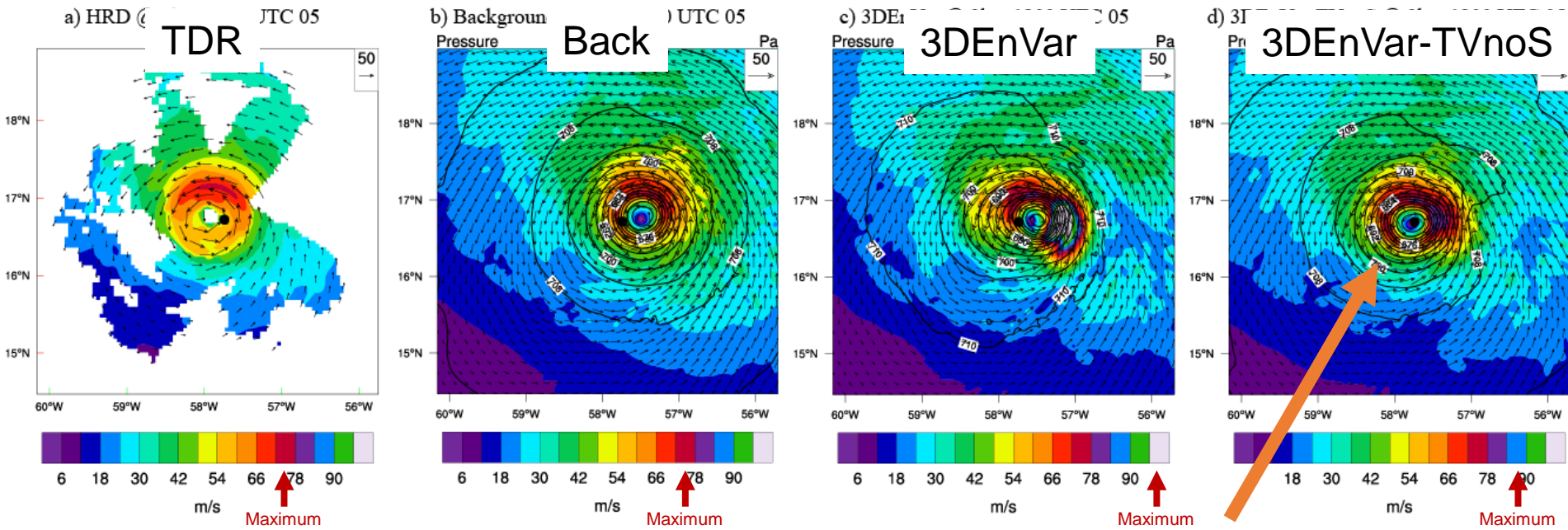
- Moving all members directly to the TCVital position, the analysis pattern is better but still spuriously too strong likely due to TCVital's errors (8-10km)
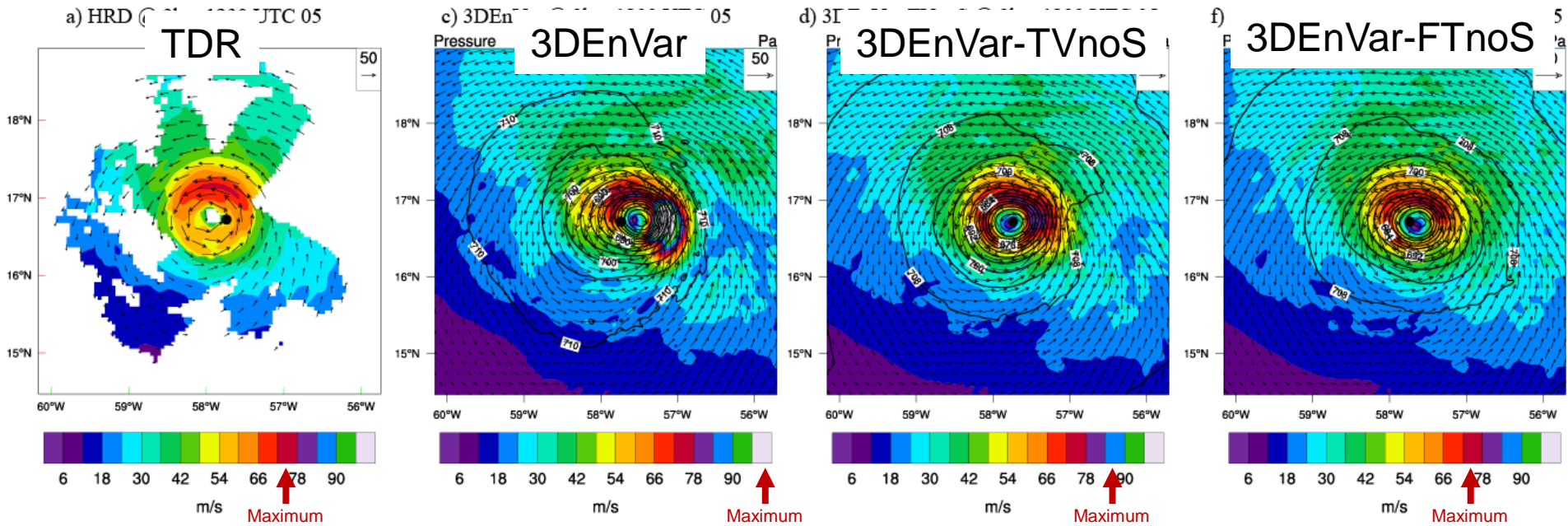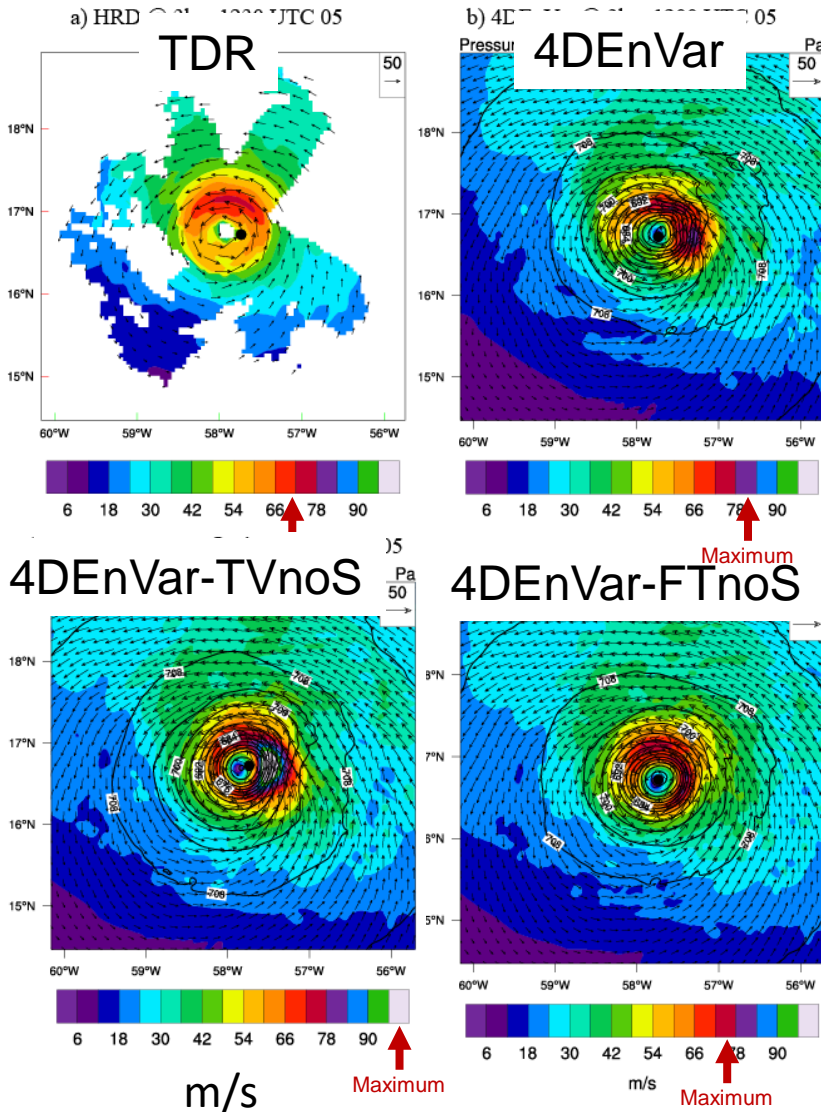
- The observation error of the flight-determined track is more accurate (observation error about 3km for intense storms, Willoughby and Chelmow, 1982)

- The analysis pattern in 3DEnVar-FTnoS is much improved than 3DEnVar-TVnoS

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Impact of Vortex Relocation Strategies on 4DEnVar

- **Interpolated TCVtial** have more errors

- Relocating all the members to the **interpolated TCVital** position worsen the analysis (4DEnVar-TVnoS), unless proper location spread is added (not shown).

- Relocating the first guess to the flight-determined track significantly improves the analysis pattern.
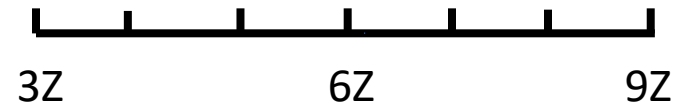
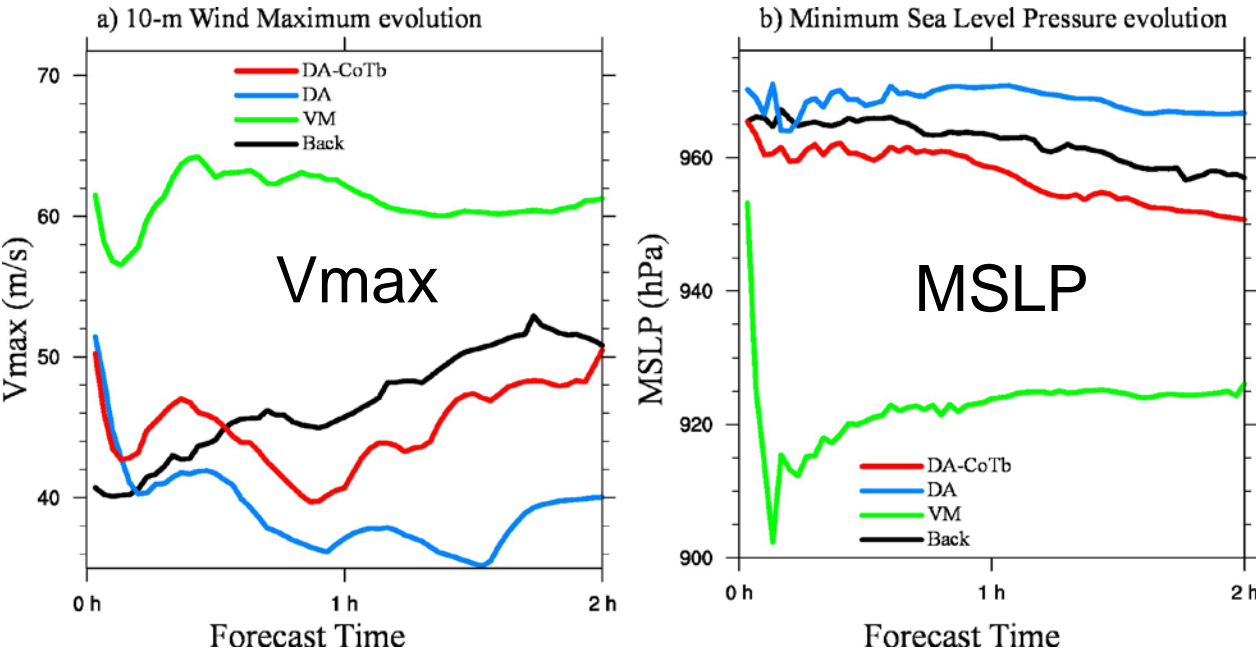# Further Development of Four-Dimensional Incremental Analysis Update (4DIAU) for HWRF 4DEnVar

Would IAU help alleviate the initial shock?

Patricia 2015

a) 10-m Wind Maximum evolution — Vmax

b) Minimum Sea Level Pressure evolution — MSLP

Lu and Wang 2018, MWR

- Using the modified physics (reduced coac+turbulent layer mixing), "spin down" is reduced (Lu and Wang 2018). Initial shock however is still seen.

- 4DIAU is shown to help for global 4DEnVar (Lei and Whitaker 2017).

- However, 4DIAU assumes the model evolution is linear or near linear.

- Does 4DIAU still work for the highly nonlinear case like Patricia (2015)?

4DEnVar

15   16   17   18   19   20   21

Back

HIRAD
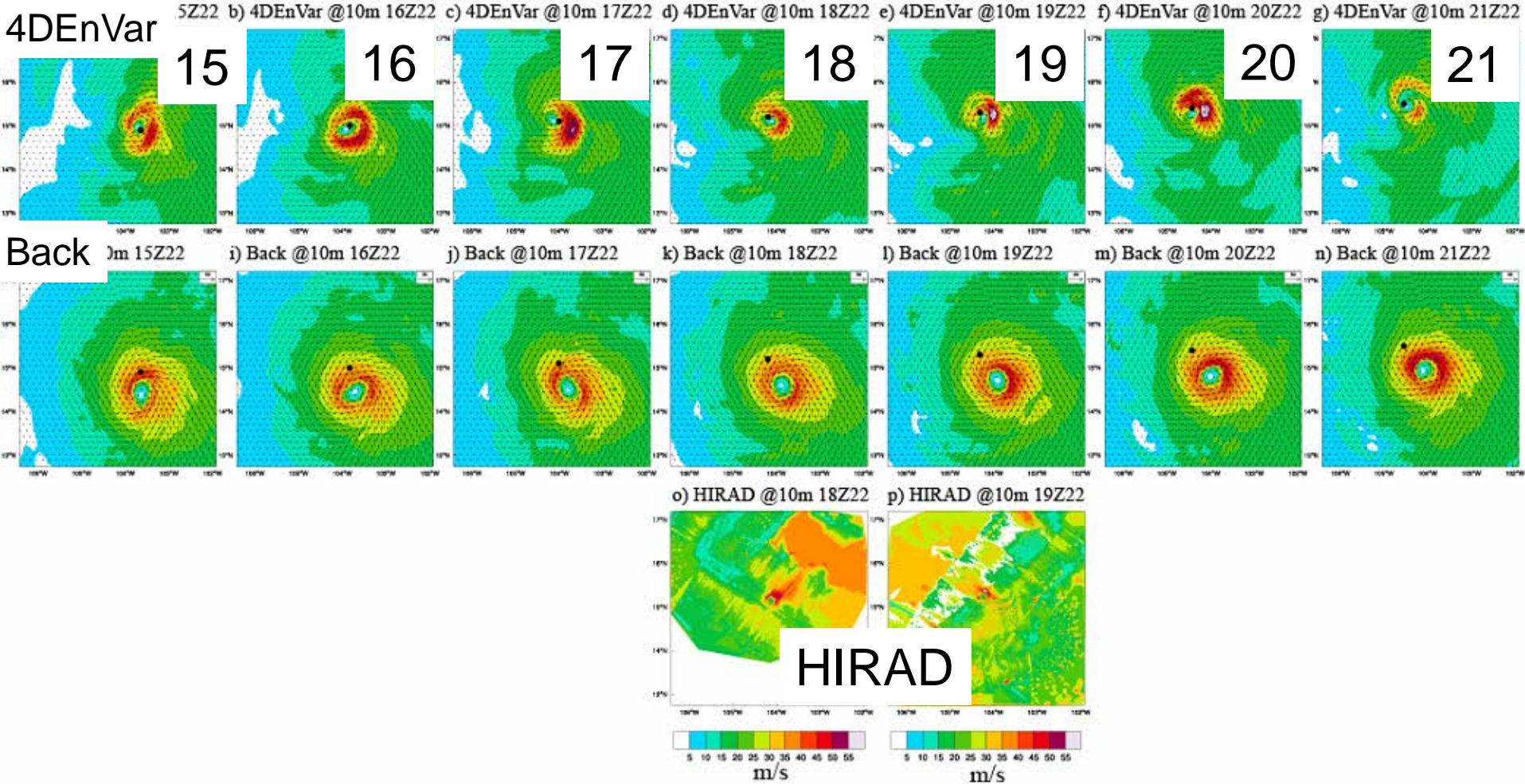
o 4DEnVar can produce analyses more consistent with the observations than Back. E.g. reducing size.
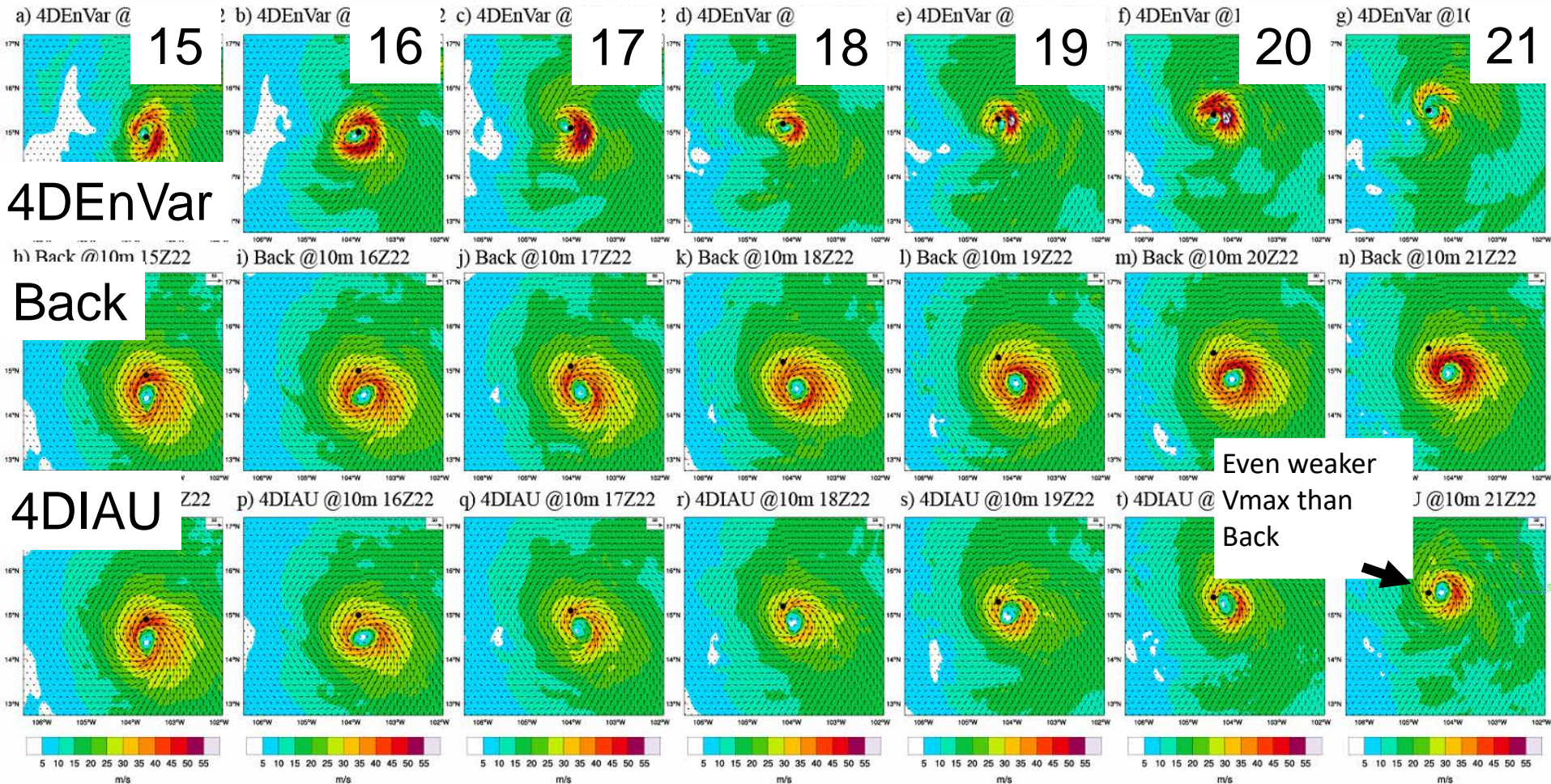
o Diagnostics show that large increment (due to fixing both size and location) will produce a trajectory that is different from the original background due to nonlinearity, which creates inconsistency during IAU that leads to too weak of Vmax.
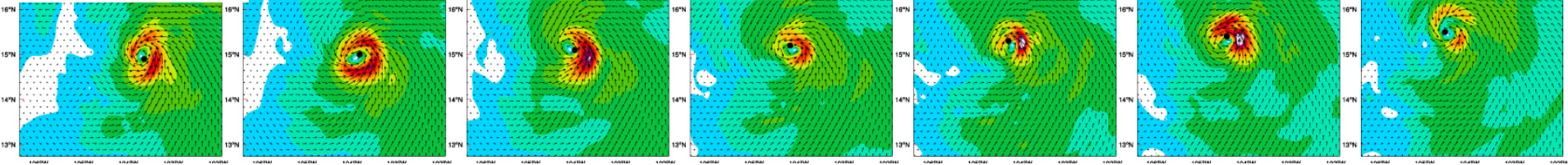
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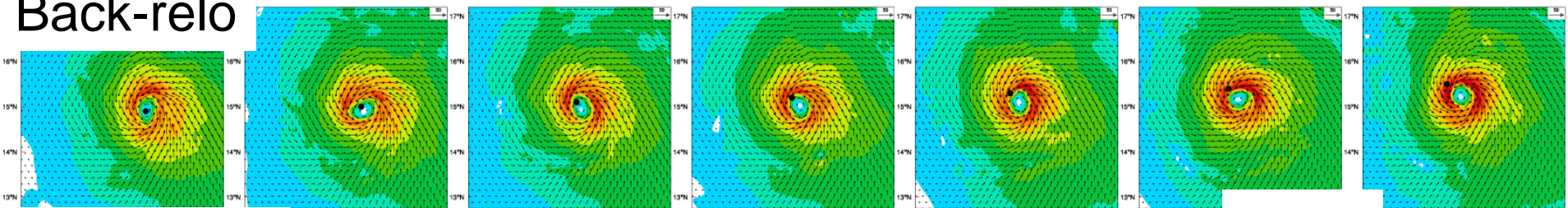# Reducing nonlinearity effect: 4DIAU using a relocated initial background
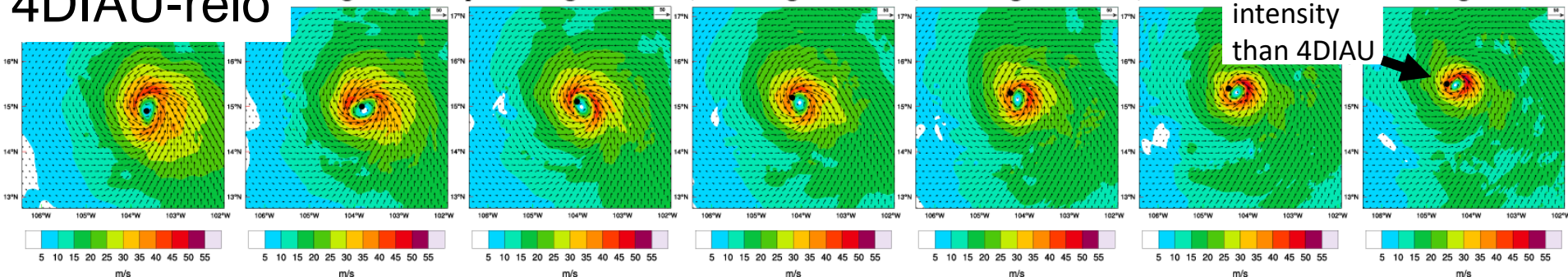
- o Inconsistency due to large increment and nonlinear model evolution during IAU is reduced when the background to calculate increments is initially relocated.
- o As a result Vmax at the end of IAU is improved.

Reducing nonlinearity effect: 4DIAU using a relocated initial background

a) 10-m Maximum Wind Forecast

b) MSLP Forecast
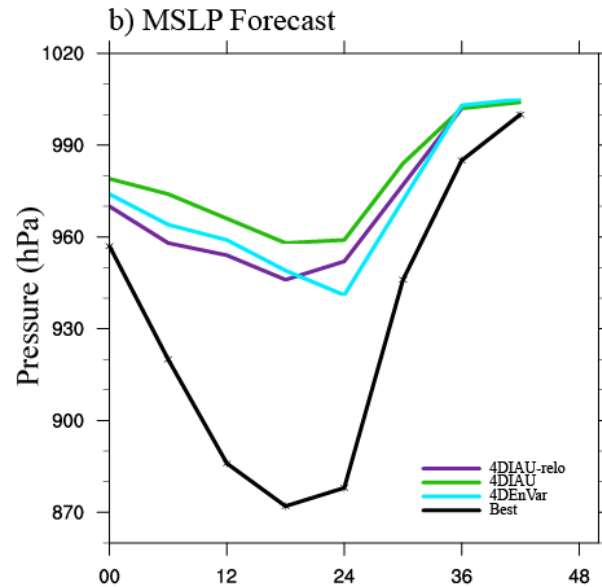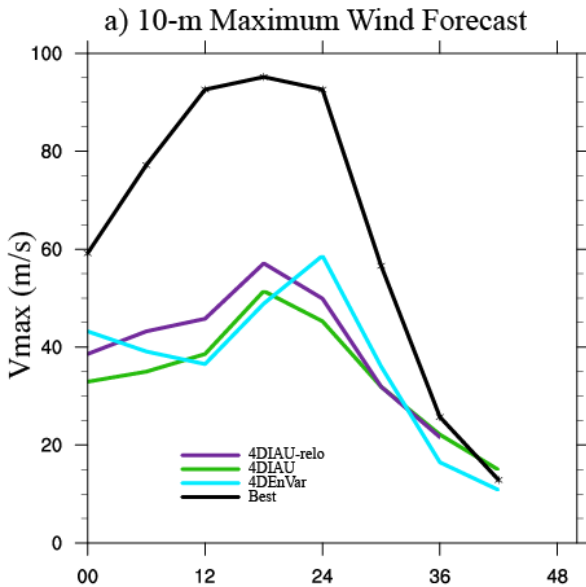
o 4DIAU-relo produces improved intensity forecast compared to 4DEnVar such as timing of peak intensity given spin-down is alleviated.

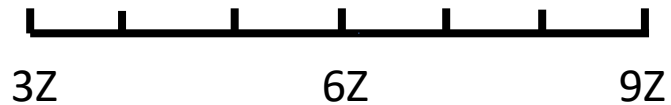o 4DIAU-relo produces improved peak intensity forecast compared to 4DIAU.

Combined effect of 4DIAU and modified physics
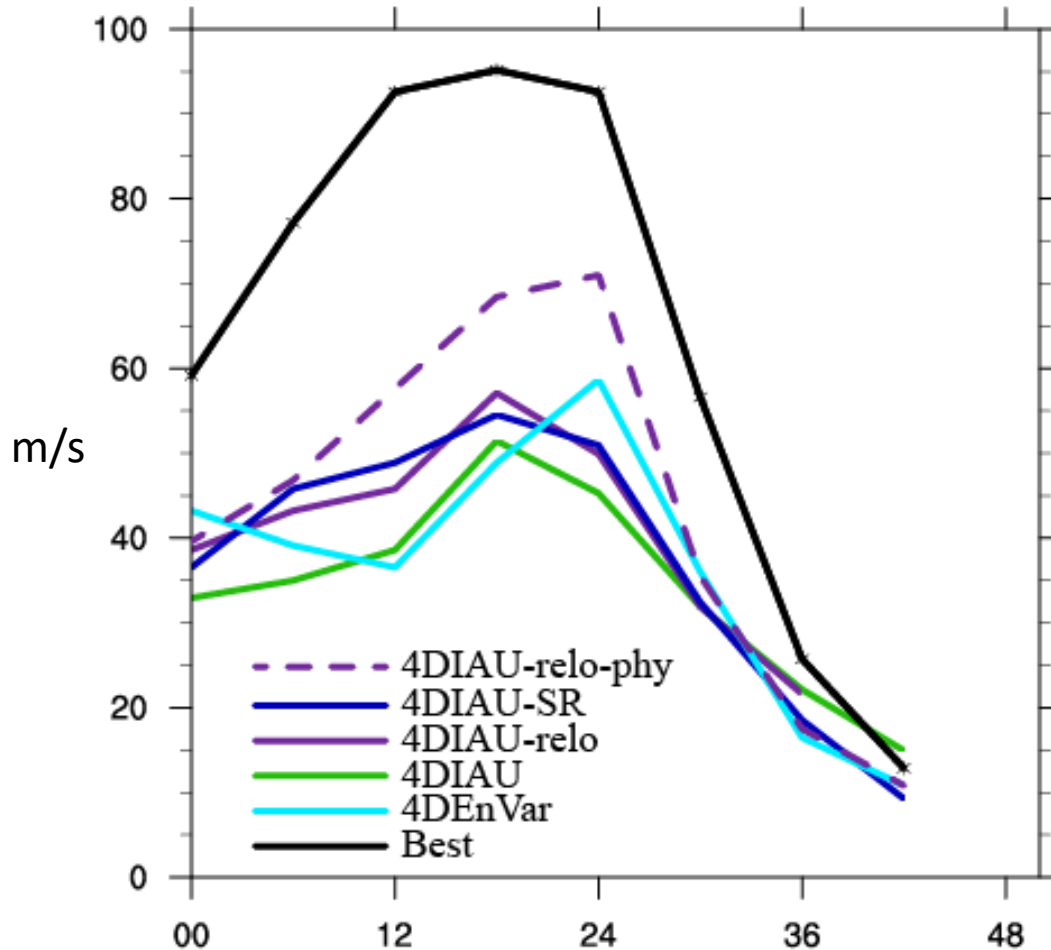
- 4DIAU shows bigger impact with improved model physics (reduced coac+turbulent mixed layer PBL, Lu and Wang 2018)

- Finer resolution is needed to improve analyzed and peak Vmax (not shown)

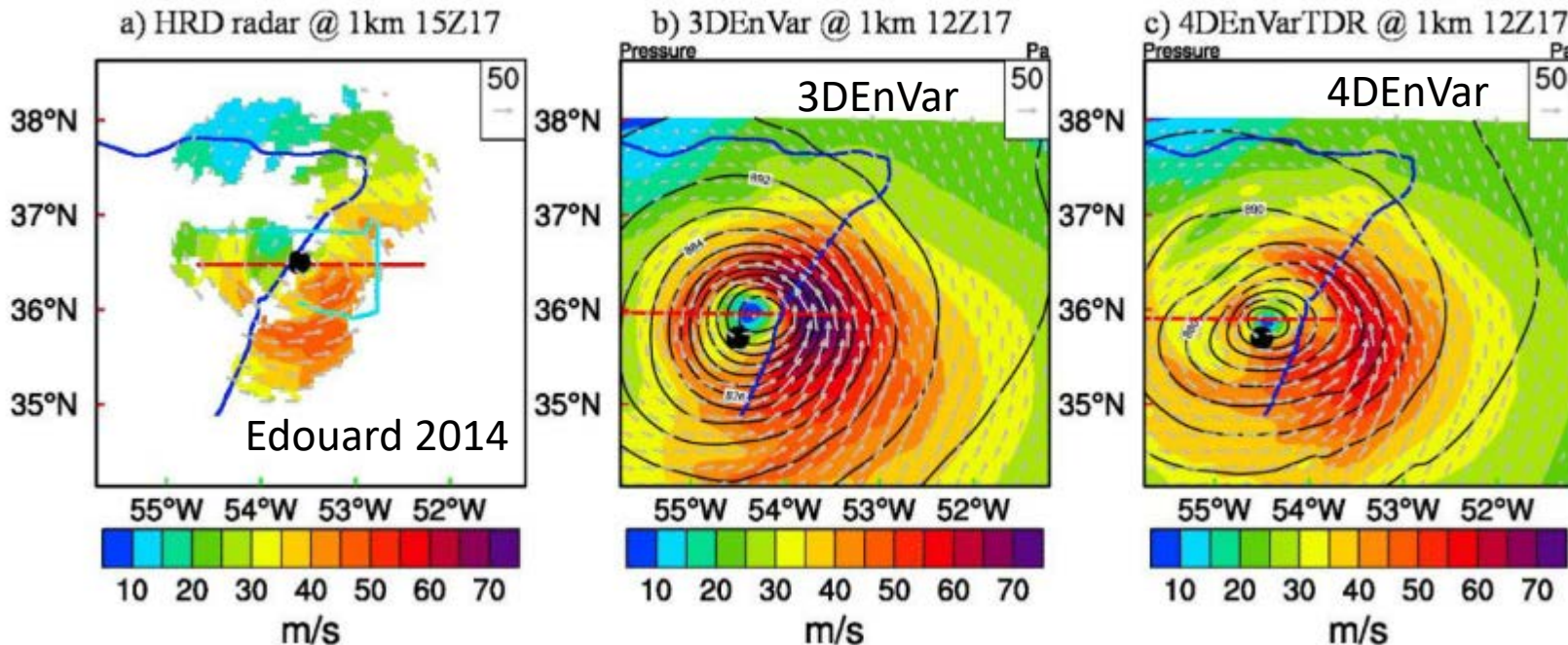# 6-hourly 3DEnVar, hourly 3DEnVar, 6-hourly 4DEnVar

3Z   6Z   9Z

Background

- 6-hourly 3DEnVar ignores temporal variation of errors within 6 hour window.
- Both 6-houry 4DEnVar and hourly 3DEnVar can potentially improve this aspect (Lu et al, 2017)

Lu et al. 2017

- Frequent assimilation like hourly DA may lead to greater imbalance due to accumulated model shocks
- 6 hourly 4DEnVar may have less of an imbalance problem, but convective scale errors may reach saturation (loss of predictability) by a 9-hour model integration

Main findings with limited samples

- TDR missions from Edouard and Irma suggested

- ✓ Both 6 hourly 4DEnVar and hourly 3DEnVar are better than 6 hourly 3DEnVar (consistent with Lu et al. 2017)

- ✓ 6 hourly 4DEnVar and hourly 3DEnVar are comparable

- Imbalance from hourly 3DEnVar did not get accumulated given they propagate out of the inner most domain within one hour.

- Frequent assimilation likely hourly 3DEnVar when data are dense sometimes can lead to small spread which can cause in-effective correction of the storm location during the pre-DA VR step.

- Need run with more samples!

Is imbalance accumulated for hourly update?

- For Hourly 3DEnVar the wave is no longer in the inner domain by the next assimilation cycle → no accumulation of imbalance during hourly cycling in the inner most domain

- Therefore imbalance in hourly 3DEnVar does not appear to be more of an issue than 6 hourly 4DEnVar
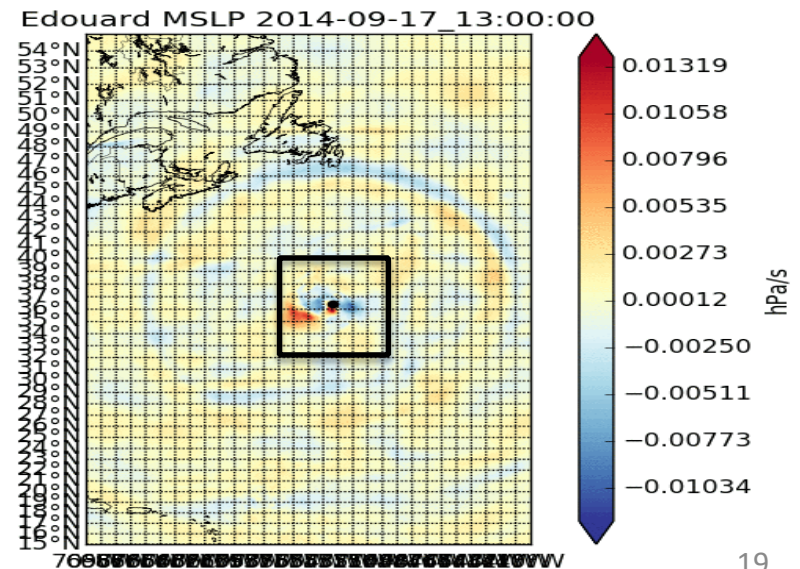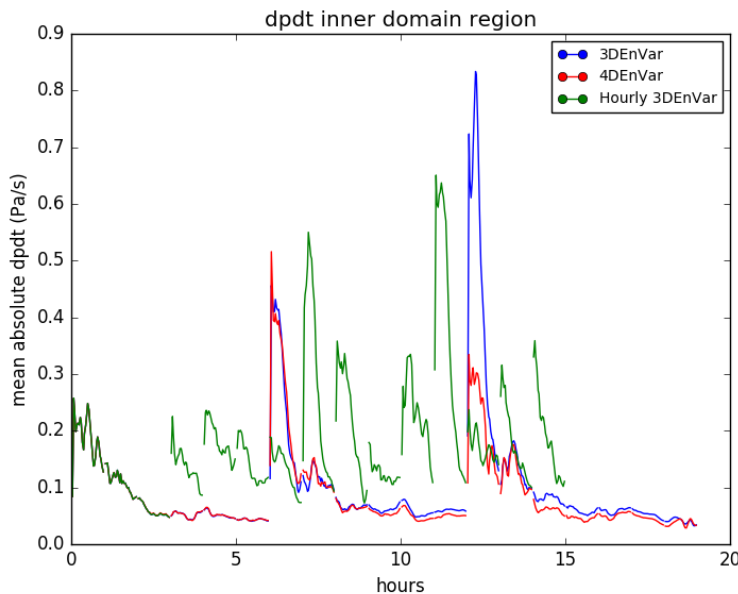
Summary and discussion

- ☐ Large location error of the background can cause spuriously large Vmax in the analysis. Relocation of the background toward a more accurately estimated position can help on the issue.

- ☐ Continue exploring frequent assimilation of inner core data and its comparison with 4DEnVar.

- ☐ IAU with proper treatment of model nonlinearity can alleviate the spin down issue. Larger impact is found with an improved model physics.

- ☐ Continue Investigating inner core DA issues (resolution, non-Gaussianity/nonlinearity, imbalance, new data, etc.)

- ☐ Shared development of DA and model physics

Regain NOAA HPC access by FN!