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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In collaboration with EMC and HRD

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Impact of Vortex Relocation Strategies on Hurricane Inner-core Data Assimilation and Prediction in the HWRF EnVar DA System
- 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.
Errors of targeted location(s)

- **Blue** – TCV
- **Red** - Flight-determined Track
- **Orange/Pink** – EnSRF updated
- **Green/Cyan** - Background

First guess

- 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)
### Experiment Design

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

<table>
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<tr>
<th>Experiment</th>
<th>VR targeted location</th>
<th>Ensemble</th>
<th>Location</th>
<th>Spread</th>
<th>DA method</th>
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Move all members to TCVital (3DEnVar)

- 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)
Move all members to flight-determined location (3DEnVar)

- 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
Impact of Vortex Relocation Strategies on 4DEnVar

- Interpolated TCVtial have more errors.
- Relocating all the members to the interpolated TCVtial 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?

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)?
Implementation of 4DIAU in regional HWRF model
-- Surface Wind Analysis (4DEnVar v.s. Back)

- 4DEnVar can produce analyses more consistent with the observations than Back. E.g. reducing size.
Nonlinearity can cause 4DIAU to degrade the analysis -- Surface Wind Analyses (4DEnVar v.s. 4DIAU)

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.
Reducing nonlinearity effect: 4DIAU using a relocated initial background

Inconsistency due to large increment and nonlinear model evolution during IAU is reduced when the background to calculate increments is initially relocated.

As a result, Vmax at the end of IAU is improved.
Reducing nonlinearity effect: 4DIAU using a relocated initial background

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

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

![Graphs showing 10-m Maximum Wind Forecast and MSLP Forecast](image-url)
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
6-hourly 3DEnVar ignores temporal variation of errors within 6 hour window.

Both 6-hourly 4DEnVar and hourly 3DEnVar can potentially improve this aspect (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!