Further Advancement of HWRF Self-Consistent Ensemble-Variational Hybrid Data Assimilation System to Improve High Resolution Hurricane Vortex Initialization

Xuguang Wang

School of Meteorology
University of Oklahoma, Norman, OK, USA

Collaborators

Vijay Tallapragada, Mingjing Tong, Jason Sippel, NOAA/NCEP/EMC, College Park, MD
Jeff Whitaker, NOAA/ESRL/PSD, Boulder, CO
Frank Marks, NOAA/AOML/HRD, Miami, FL

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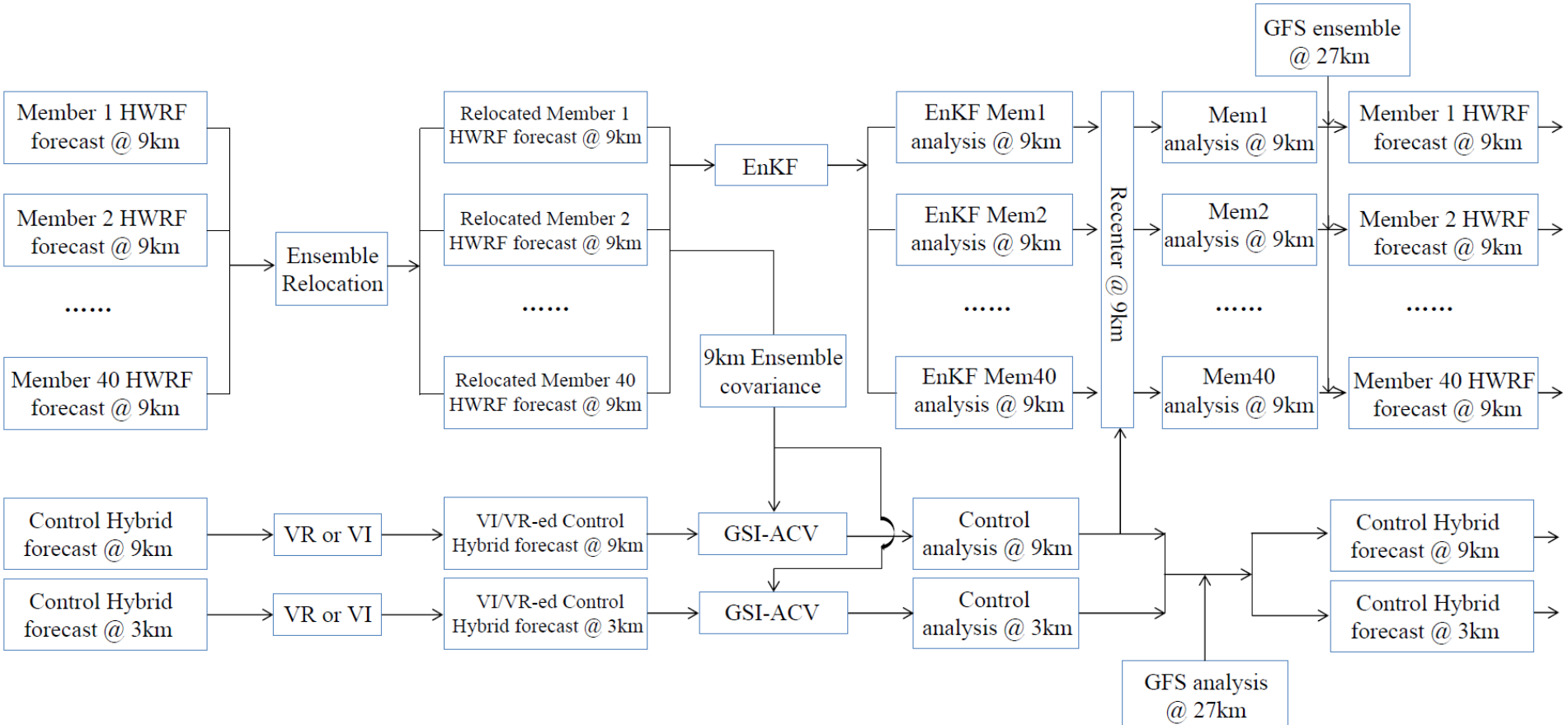
Previous R&D for HWRF Hybrid DA

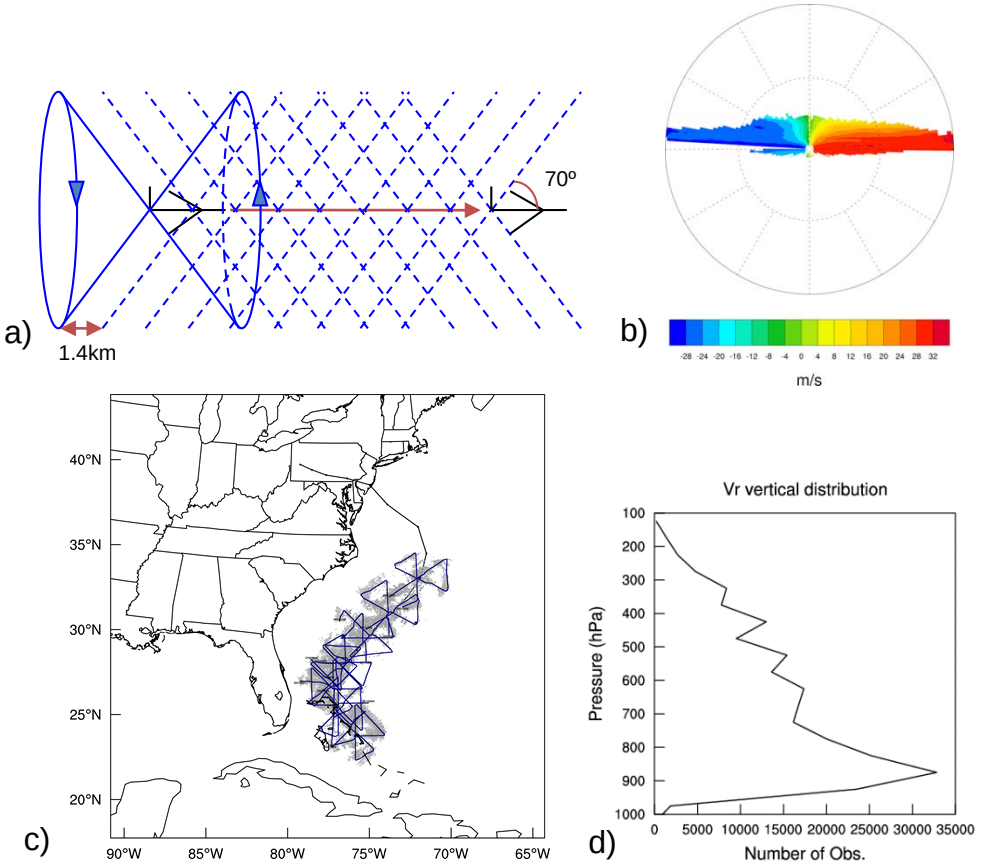
- The GSI based hybrid DA system is developed with the following capabilities: (1). continuously cycling, (2). dual resolution, (3). 3DEnVar/4DEnVar, (4). assimilating all operational observations including TDR, HDOB, dropsonde, satellite radiances, etc., (5). integrated with VI (Lu and Wang 2017a).



Previous R&D for HWRF Hybrid DA: impact of different ensemble covaraiances

Lu, Wang, Tong, et al. 2016, QJRMS

- Impact of using different sources of ensemble covariances for hybrid on Tail Doppler Radar (TDR) assimilation was studied.



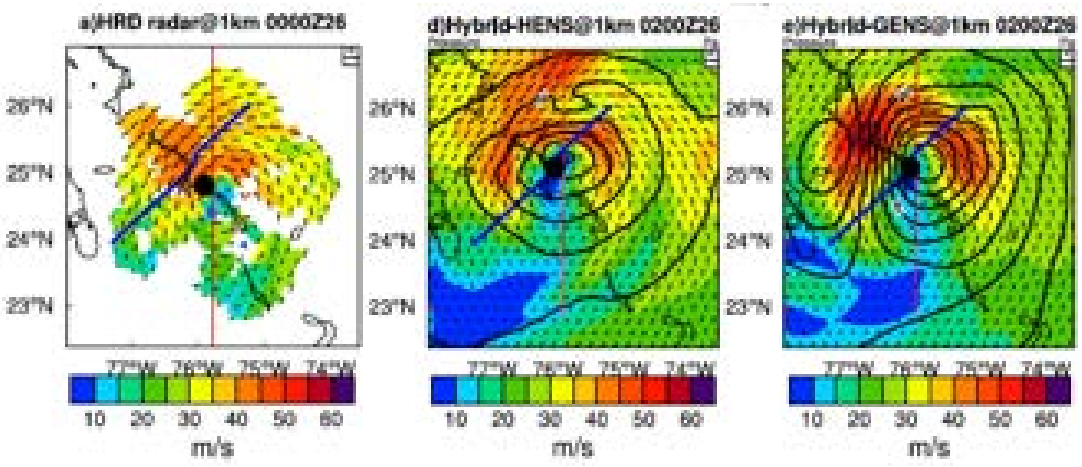
a) Scan scheme of the TDR (Tail Doppler Radar);
b) An example of a Tail Doppler Radar sweep. （Blue for wind towards the radar, red for the wind away from the radar);
c) Flight tracks (blue line) and horizontal distribution of airborne radar data (grey dot) for P3 tail Doppler radar missions during Sandy (2012). The black line is the best track from NHC;
d) Vertical distribution of the number of Tail Doppler Radar data collected during the first NOAA P3 mission of Sandy.

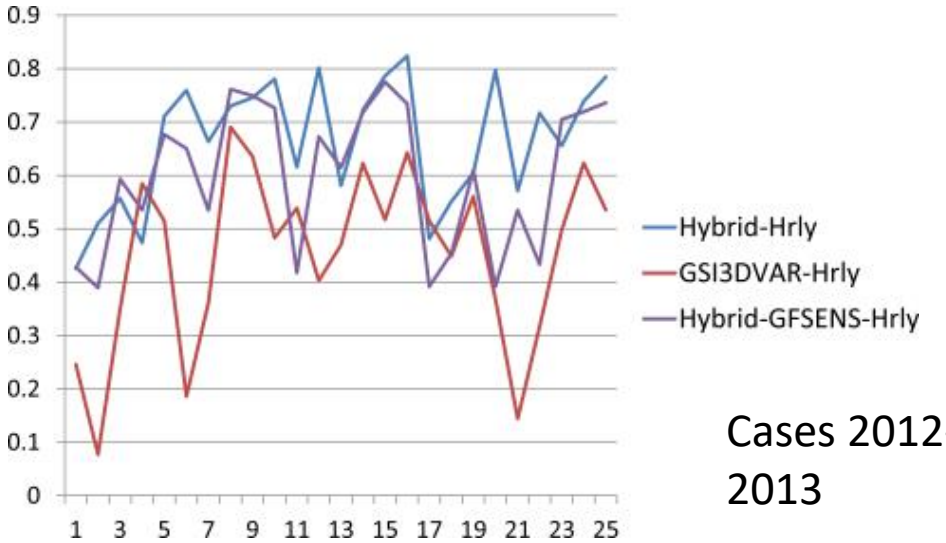
Previous R&D for HWRF Hybrid DA: impact of different ensemble covaraiances

Lu, Wang, Tong, et al. 2016, QJRMS

Sandy 2012

TDR obs | Hybrid | Hybrid-GFSENS



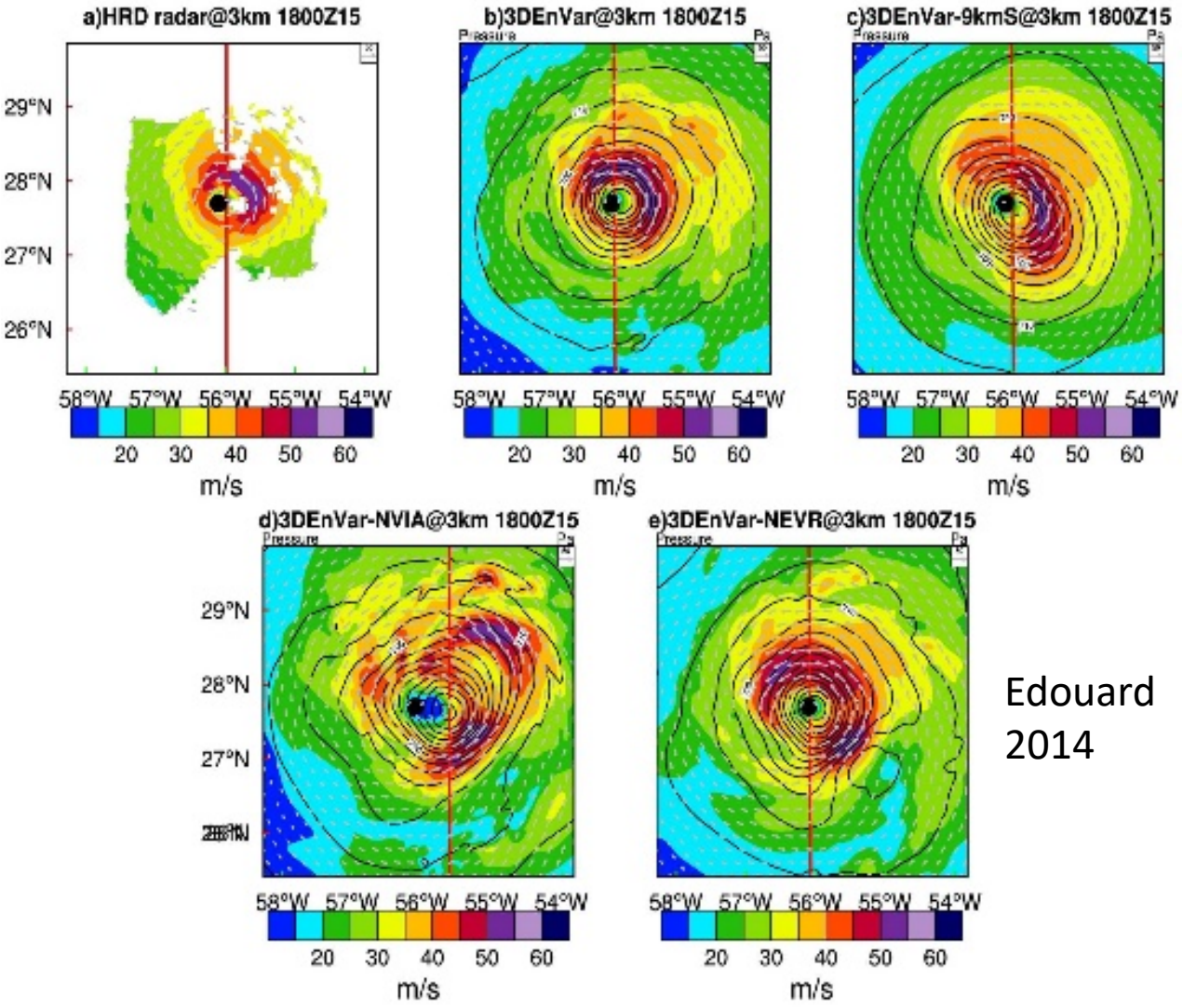


Cases 2012-2013

- The hybrid system using self-consistent HWRF EnKF ensemble (Hybrid) was found to improve both the analyzed TC structures and forecasts relative to GSI-3DVar and the hybrid ingesting GFS ensemble (Hybrid-GFSENS).
- Hybrid provided the largest positive impact of the airborne radar data (TDR).

Previous R&D for HWRF Hybrid DA: Impact of dual resolution and integration with VI

Lu and Wang, 2017a, MWR

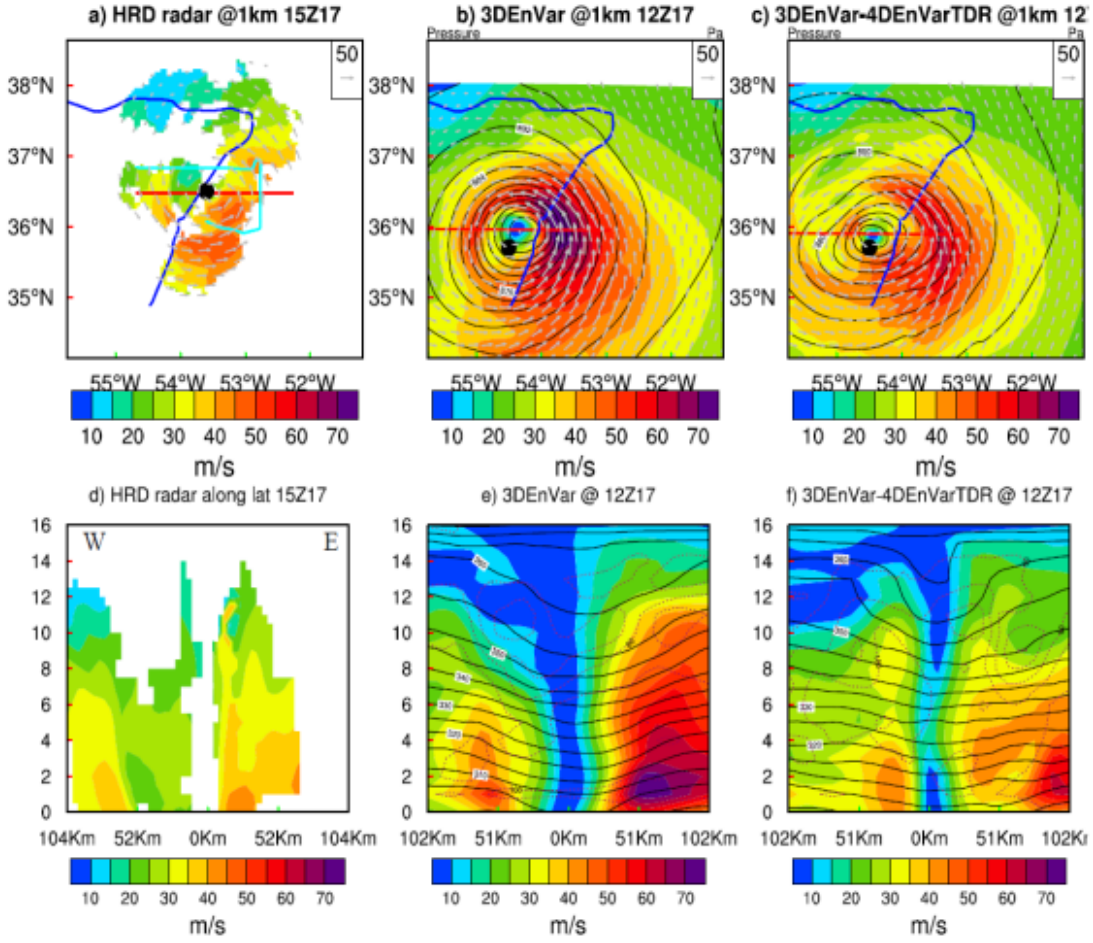


Edouard 2014

- High resolution analysis produced through dual resolution hybrid DA improves structure analysis and intensity (Vmax and MSLP) forecasts.
- Vortex relocation/initialization integrated with 6-houlry Hybrid DA improves forecasts.

Previous R&D for HWRF Hybrid DA: 4DEnVar vs 3DEnVar

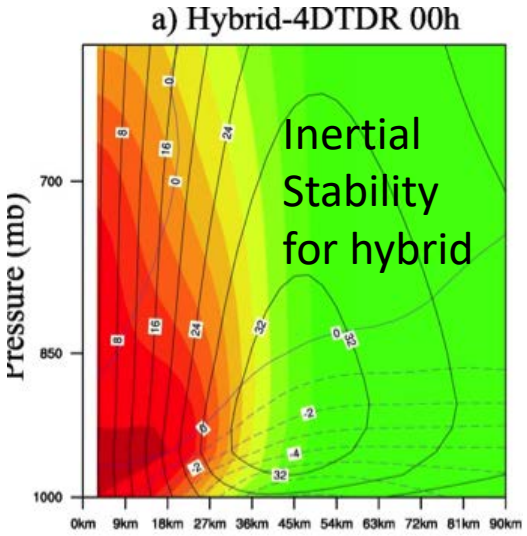
Lu and Wang, 2017a, MWR

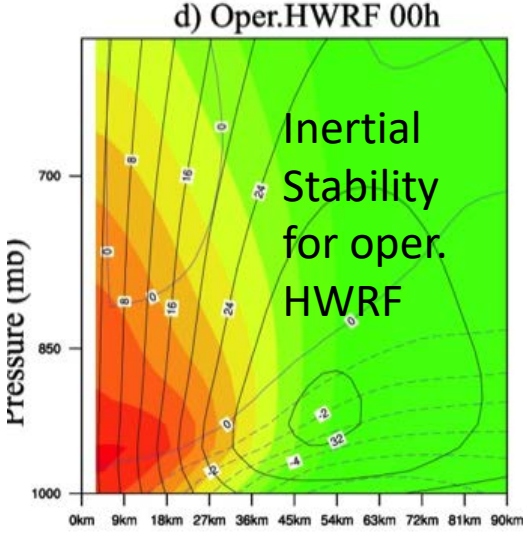


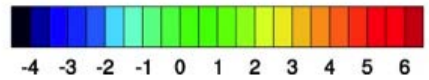
- 4DEnVar improves the intensity forecasts for early lead times compared to using 3DEnVar.

Previous R&D for HWRF Hybrid DA: alleviation of spin down

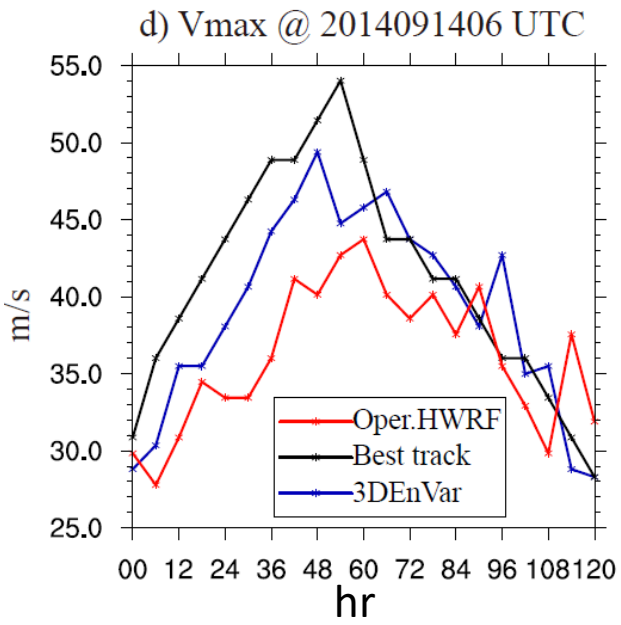
Lu and Wang, 2017a, MWR

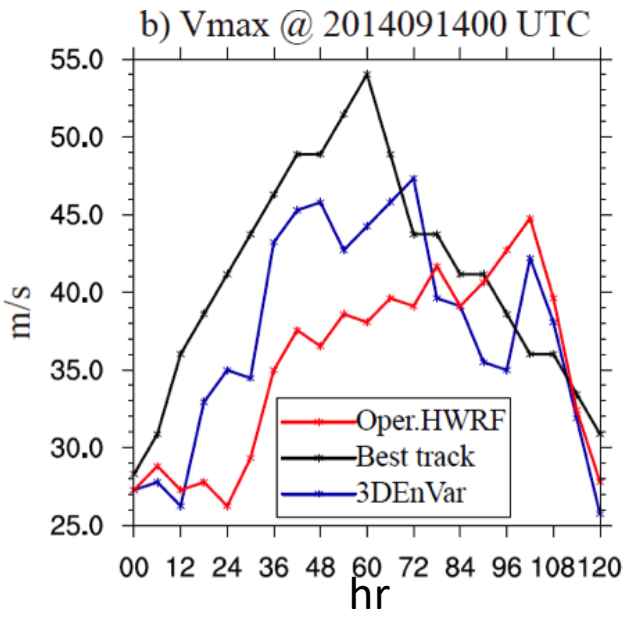






$10^{-5}s^{-1}$

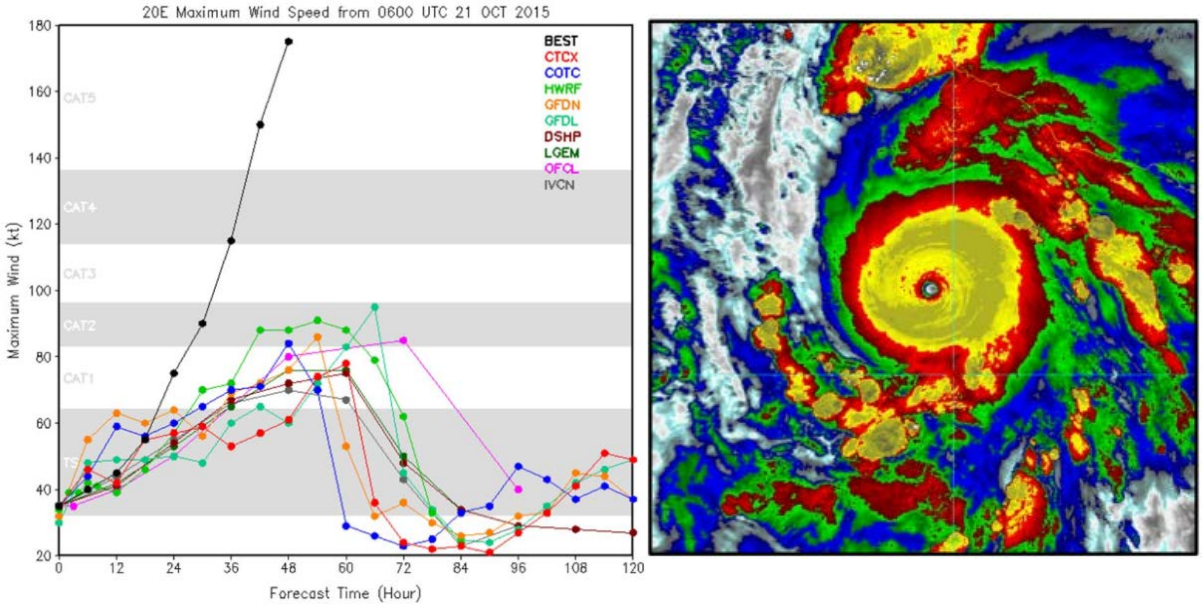




- The new hybrid system improves Vmax forecast due to the alleviation of spin down issue during RI.
- Analyzed storm by hybrid is more consistent with an intensifying TC (e.g. larger inertial stability)

Outstanding issues

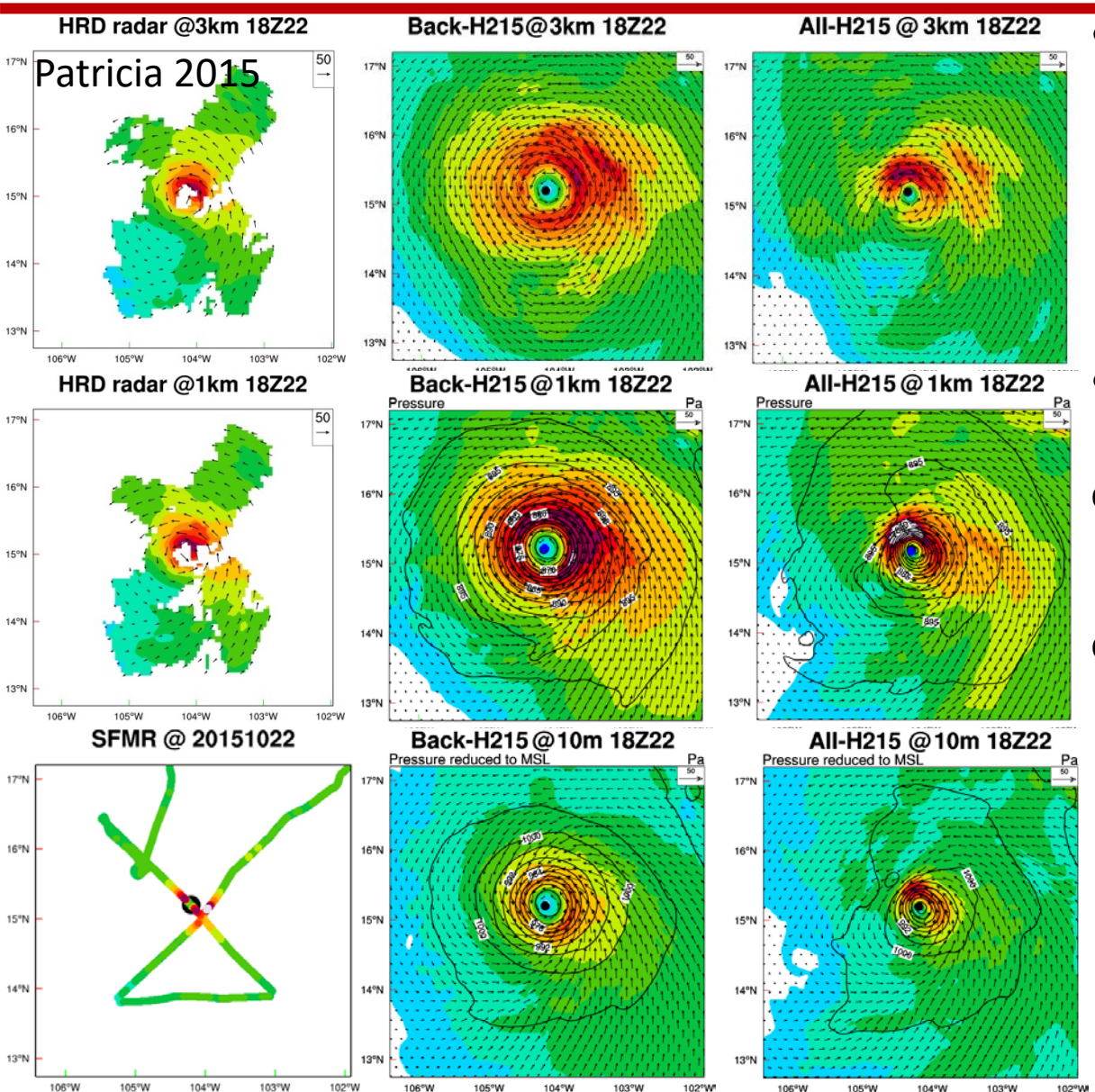
Patricia 2015



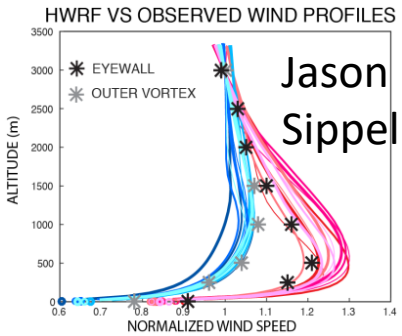
From NHC

- Very fast RI
- Very small hurricane with a small eye

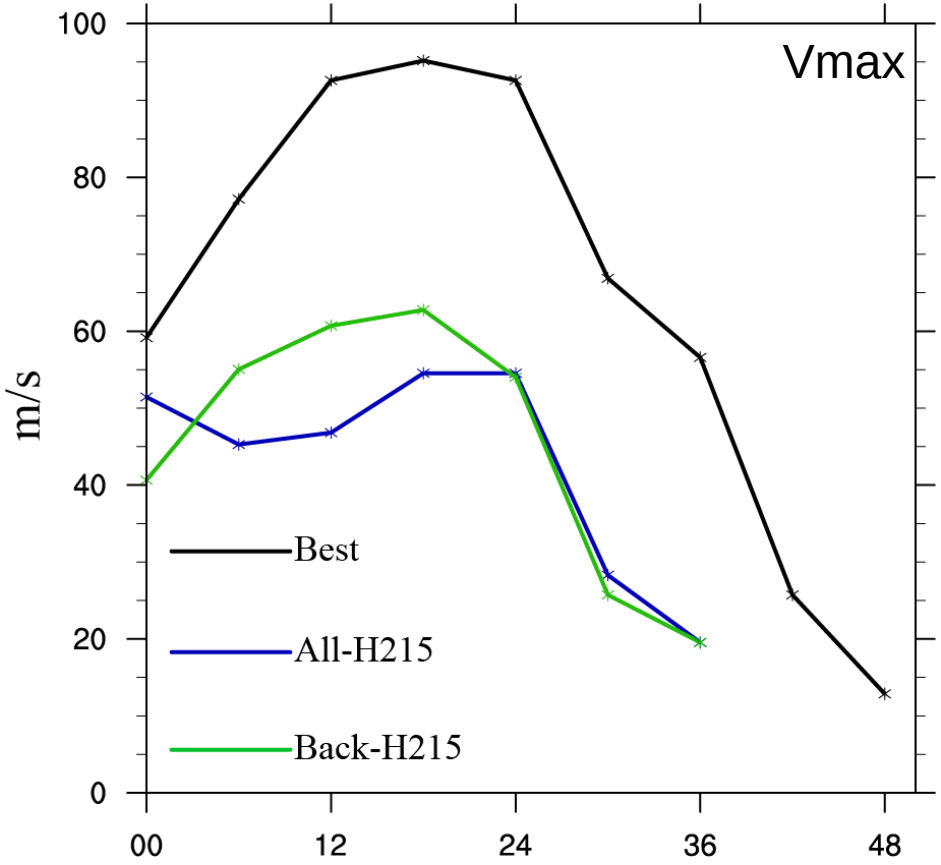
Outstanding issues: model biases



- Inner core structures are much improved upon the background after assimilating TDR, FL, SFMR, dropsondes using the new hybrid DA system (Lu and Wang 2017b)
- HWRF model biases:
  - o Wind speed maximum at the surface is much weaker than the observation.
  - o Wind speed maximum above the surface are stronger/comparable with the observations.

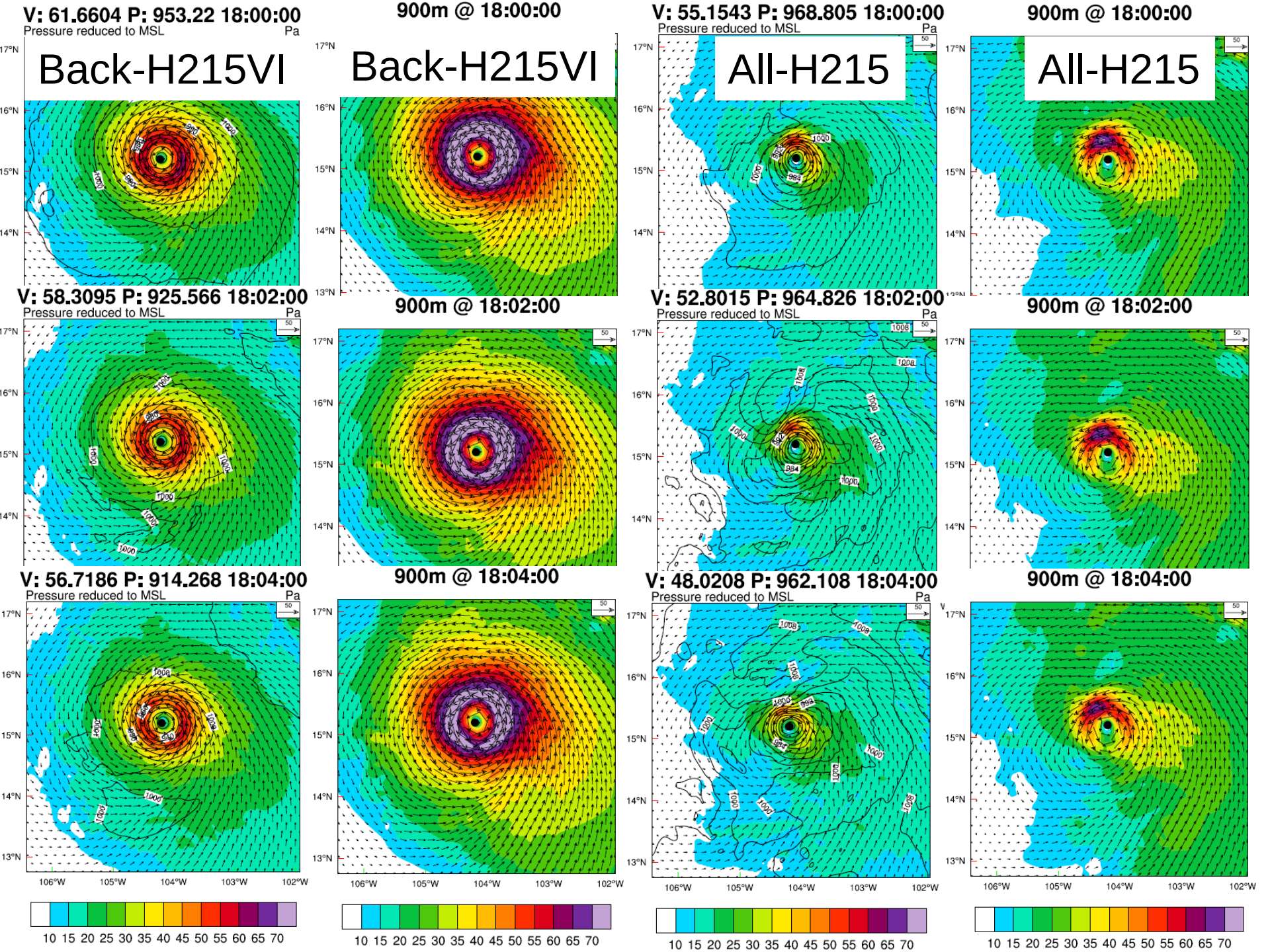


Outstanding issues: spin down



- Vmax analyses is much improved after hybrid DA.
- Spin-down occurred even when inner-core TC structures are well captured by hybrid DA.
- As shown in next slide, HWRF is not trained to digest the analysis produced by advanced DA! Or it does not like the amount of changes (even correct) that advanced DA produces!

- Significant improvement on model itself is needed as evidenced by
  - Sensitivity of Vmax forecast to model physics
  - Higher resolution significantly increases peak intensity (not shown)


V: 61.6604 P: 953.22 18:00:00
Pressure reduced to MSL
Pa
Back-H215VI
900m @ 18:00:00
Back-H215VI
V: 55.1543 P: 968.805 18:00:00
Pressure reduced to MSL
Pa
All-H215
900m @ 18:00:00
All-H215
V: 58.3095 P: 925.566 18:02:00
Pressure reduced to MSL
Pa
900m @ 18:02:00
V: 52.8015 P: 964.826 18:02:00
Pressure reduced to MSL
Pa
900m @ 18:02:00
V: 56.7186 P: 914.268 18:04:00
Pressure reduced to MSL
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V: 48.0208 P: 962.108 18:04:00
Pressure reduced to MSL
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17°N
16°N
15°N
14°N
13°N
106°W
105°W
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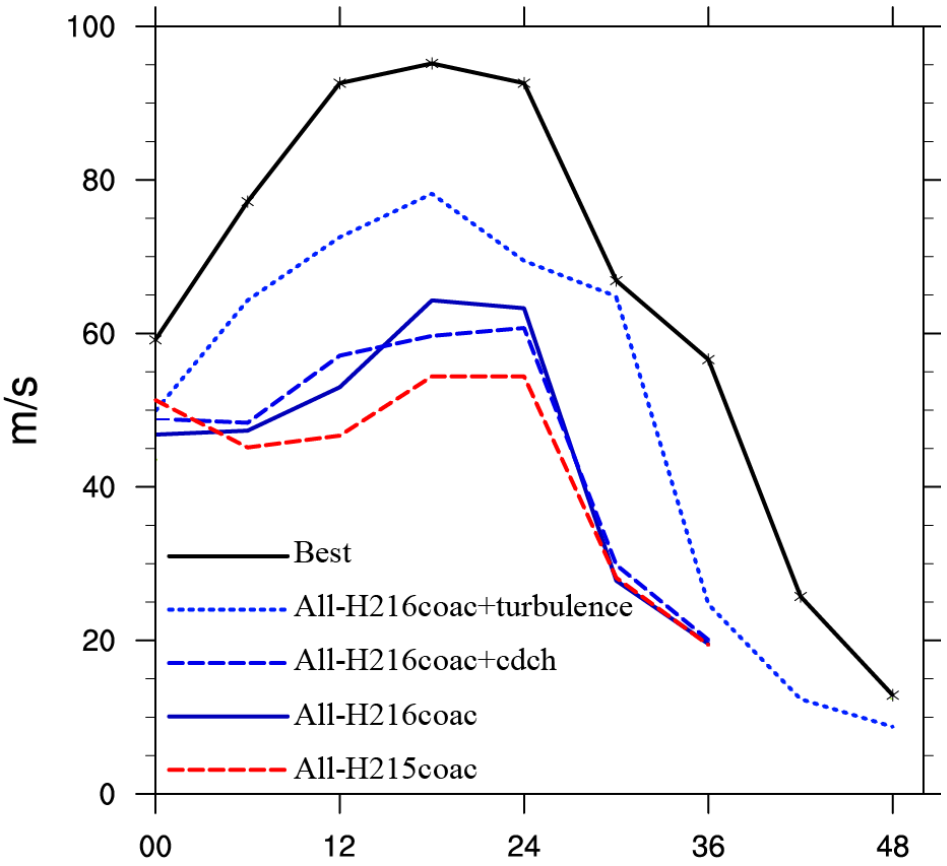
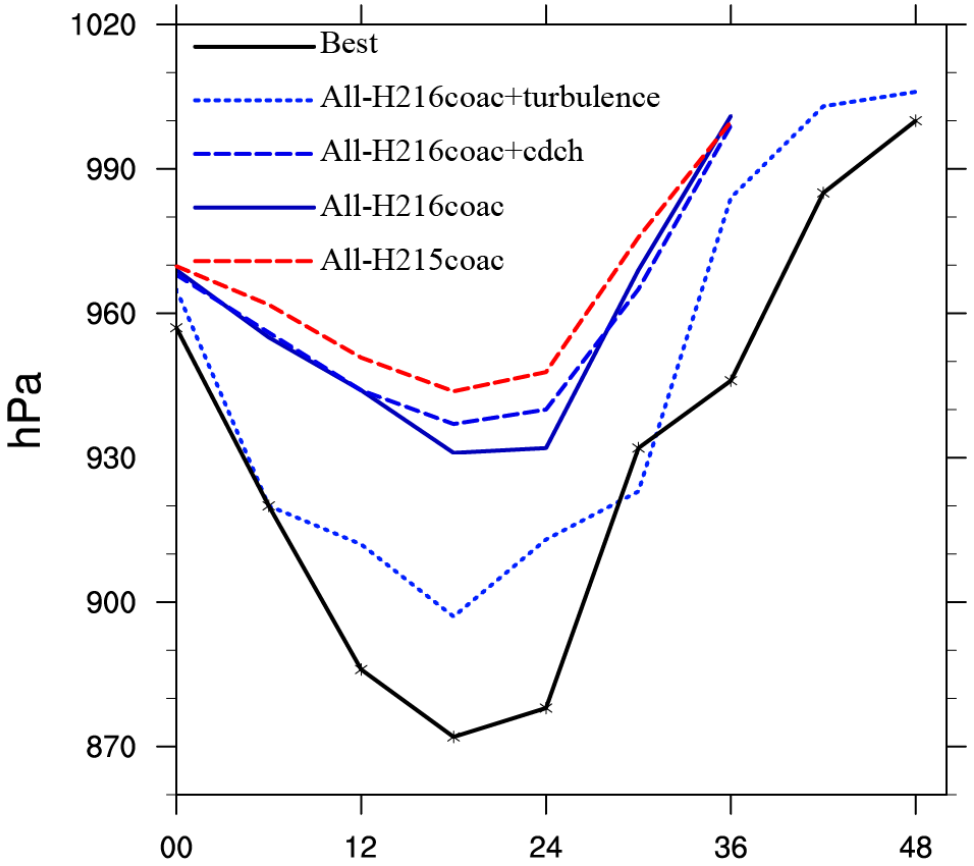
103°W
102°W
10 15 20 25 30 35 40 45 50 55 60 65 70

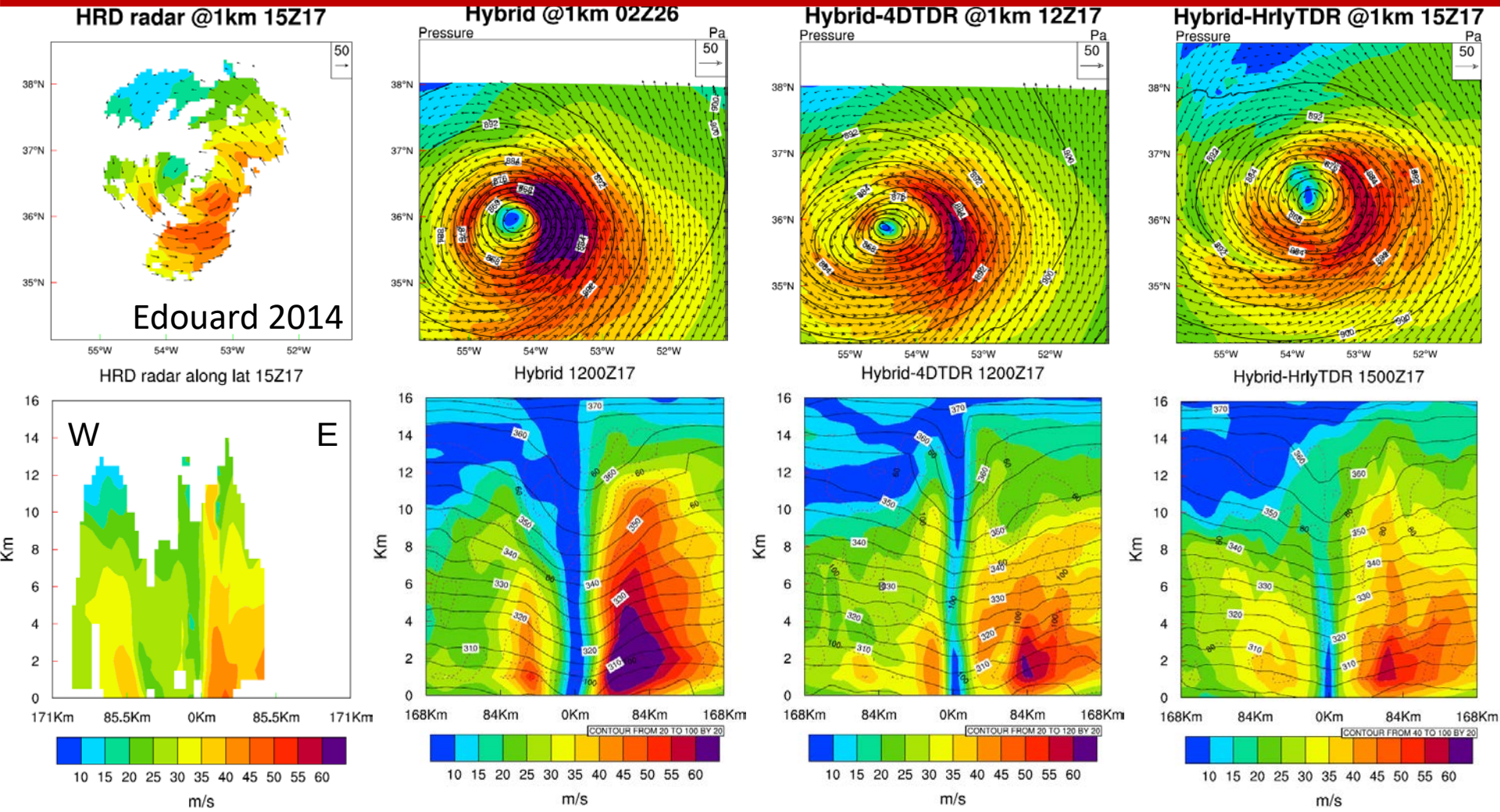
Outstanding issues: spin down due to model physics errors





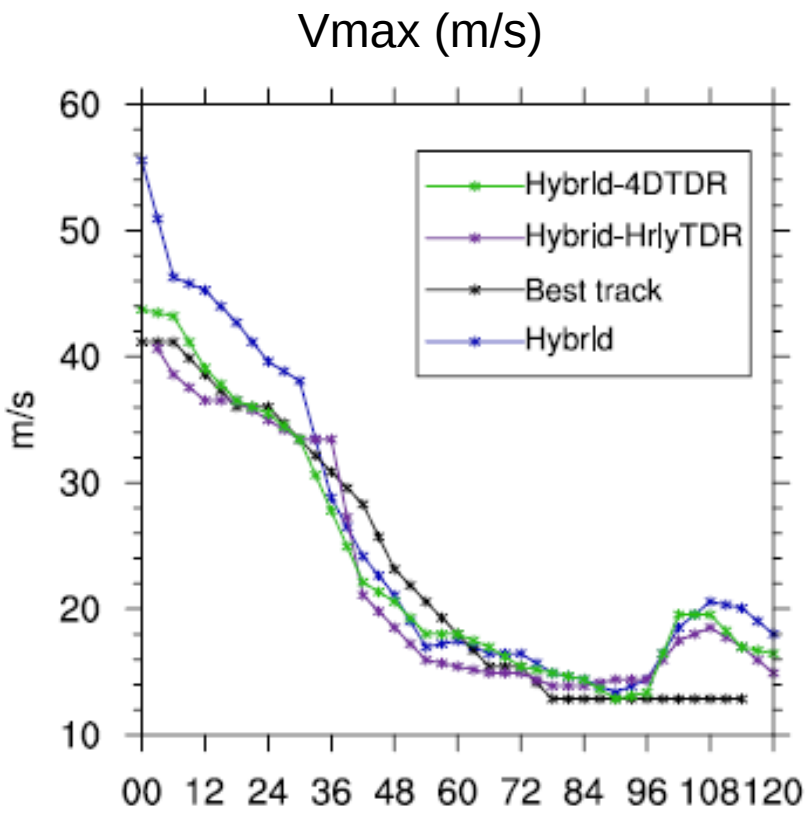
- Vmax forecast initialized by hybrid DA during RI for Patricia 2015 is sensitive to physics in HWRF (turbulent mixing provided by Ping Zhu, discussion with HRD and EMC).
- Solving spin down issue should not consider DA or model issue in isolation. Advanced DA provides opportunity to identify issue in the model that is responsible for spin down and vice versa.

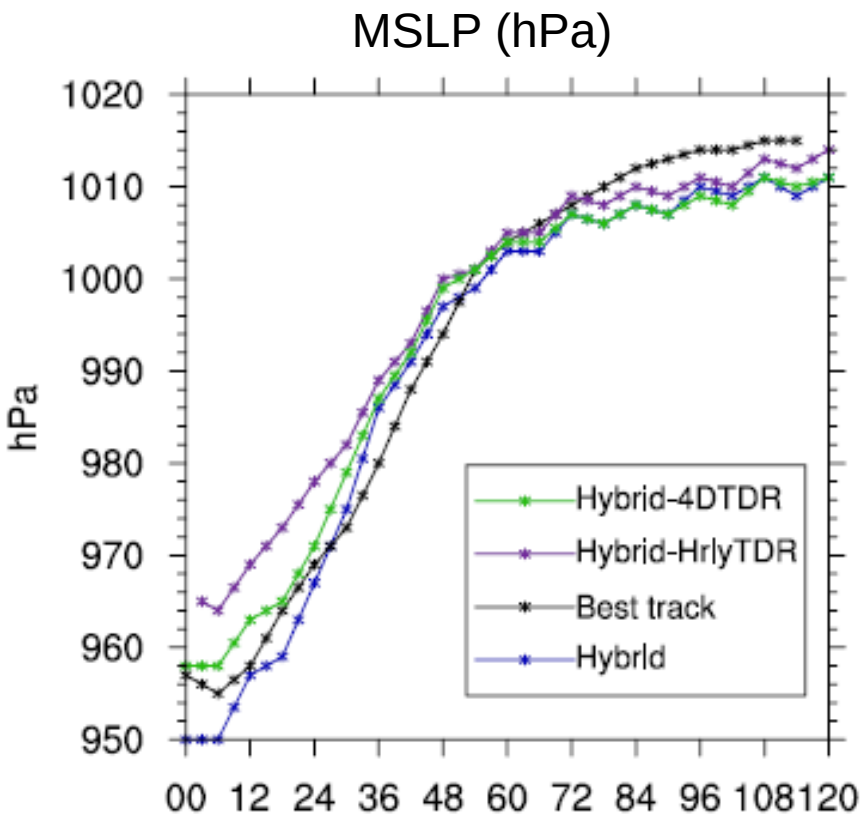
Outstanding issue: imbalance
3DEnVar vs Hourly vs 4DEnVar



- Using 4DEnVar or Hrly, the spurious wind maximum was reduced and the wind pattern was more consistent with HRD radar composite as compared to 3DEnVar. Lu and Wang, 2017a, MWR

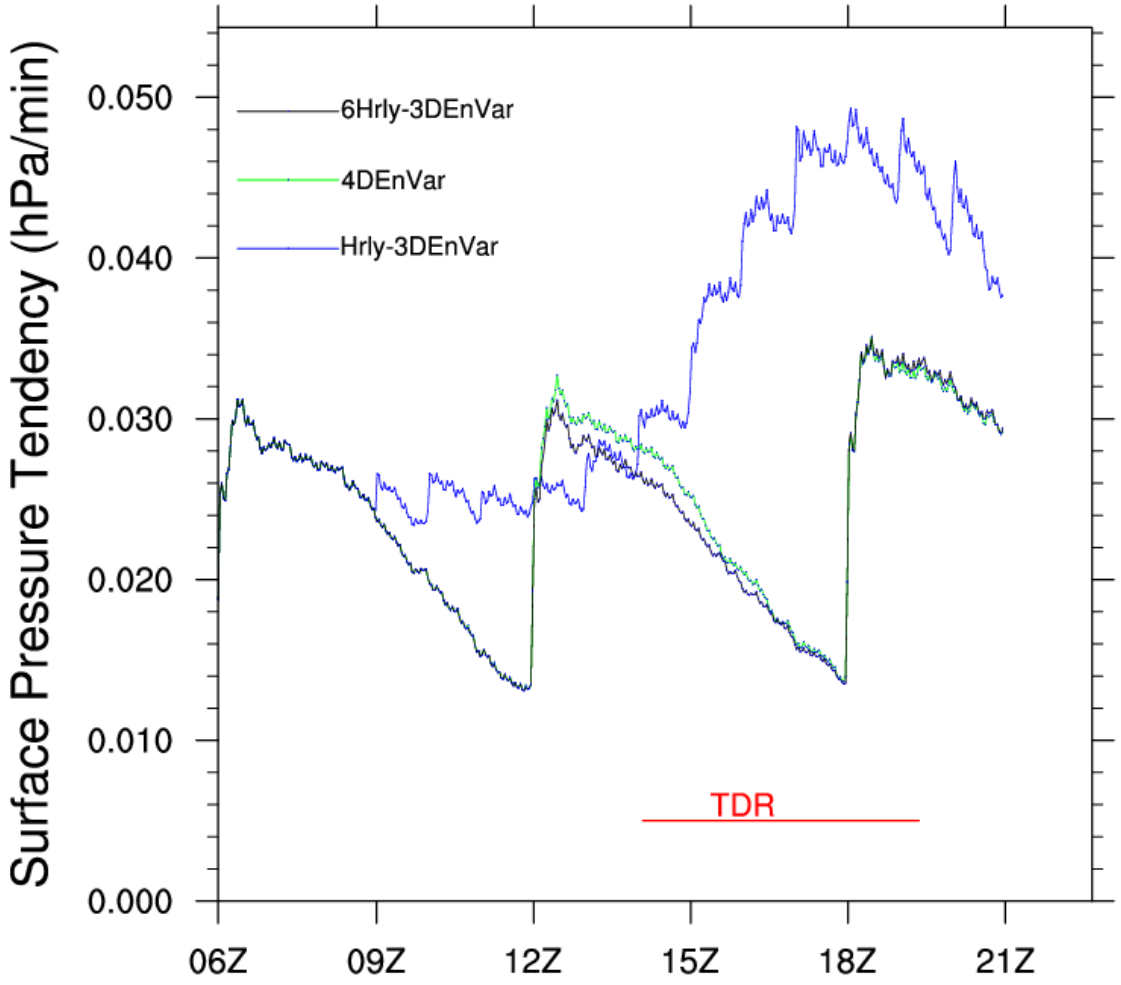
Outstanding issue: imbalance



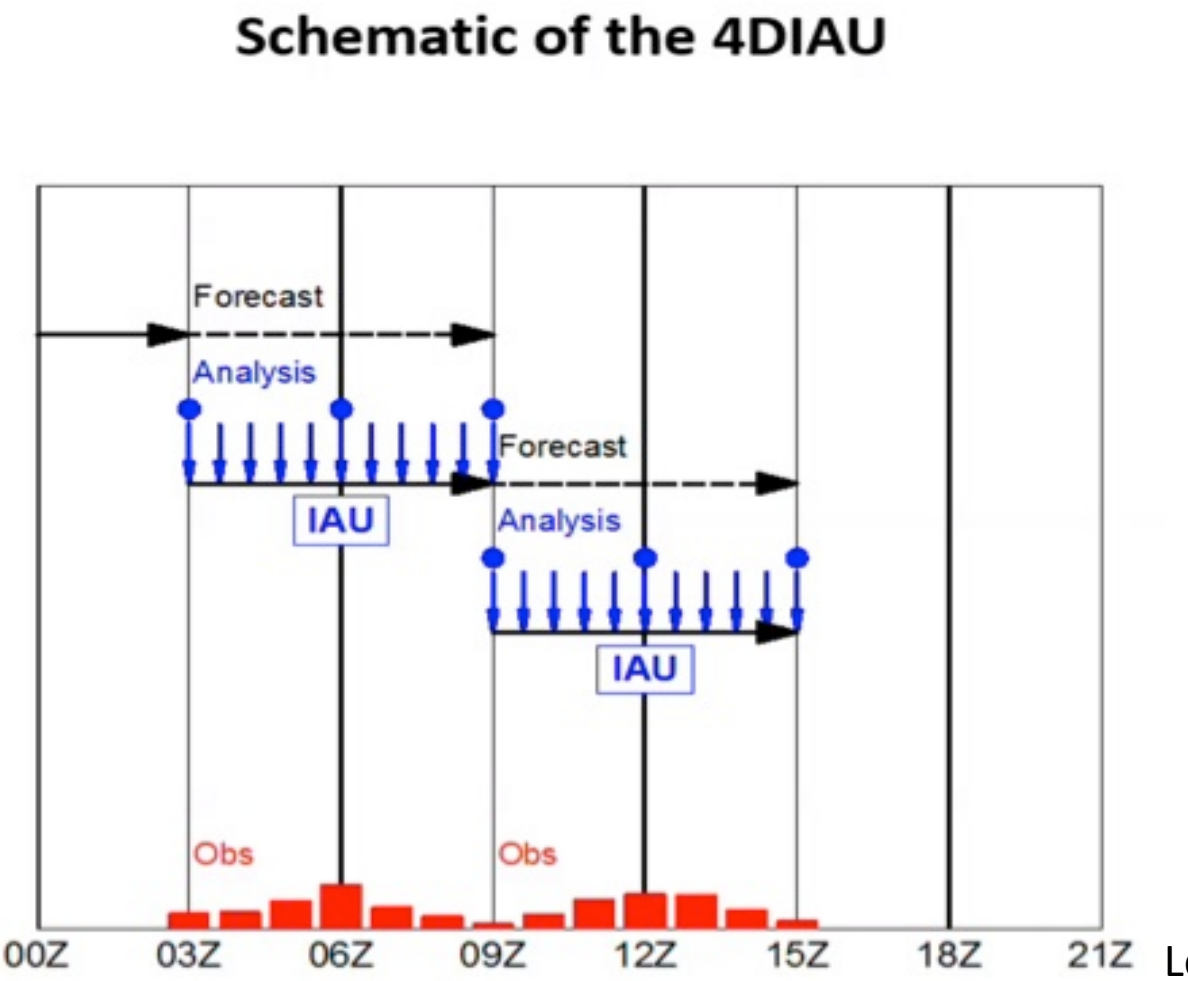


- Using 4DEnVar (Green)/Hrly (Purple), intensity forecasts especially Vmax are improved for the first 36 hours compared to Hybrid using 3DEnVar (Blue).
- 4DEnVar forecasts MSLP better than hrly.

Outstanding issue: imbalance



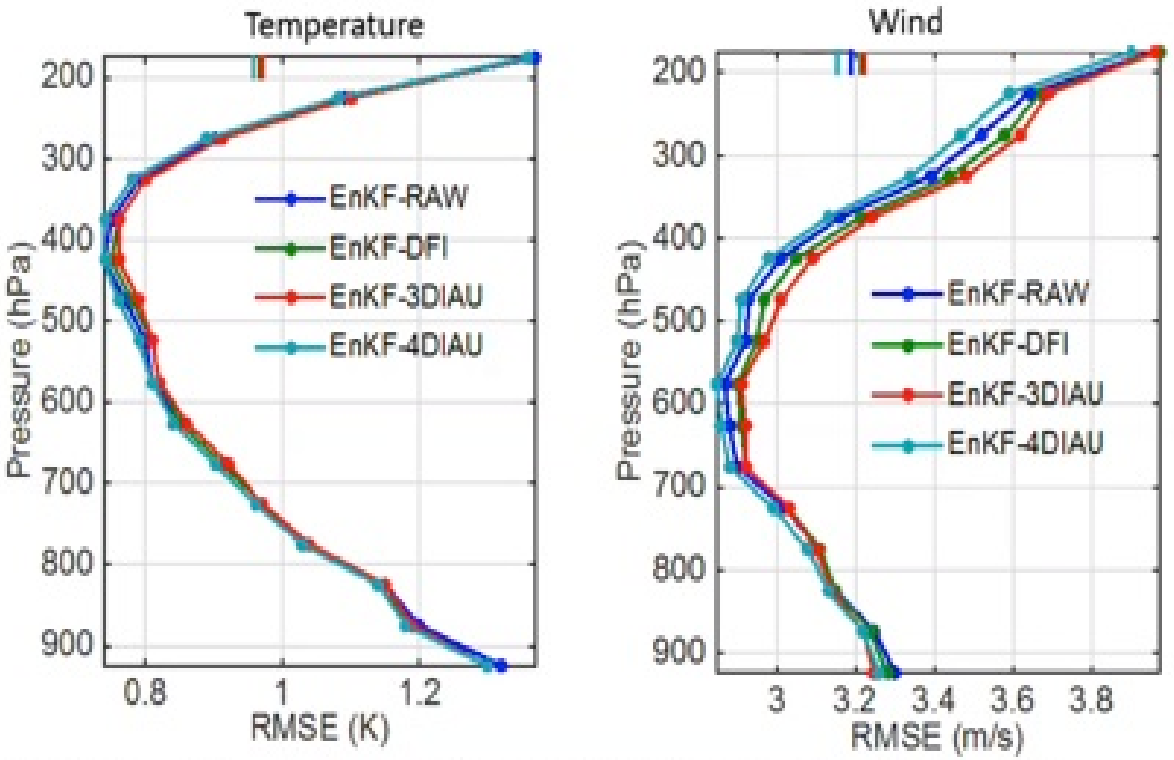
IAU (Incremental Analysis Update)



Lei and Whitaker 2016

IAU (Incremental Analysis Update)

Verification of 6-h Prior Against Conventional Obs



EnKF-DFI has slightly larger errors than EnKF-RAW (more noticeable for wind).

EnKF-3DIAU produces the largest errors except below 800 hPa.

EnKF-4DIAU is noticeably better than the other experiments.

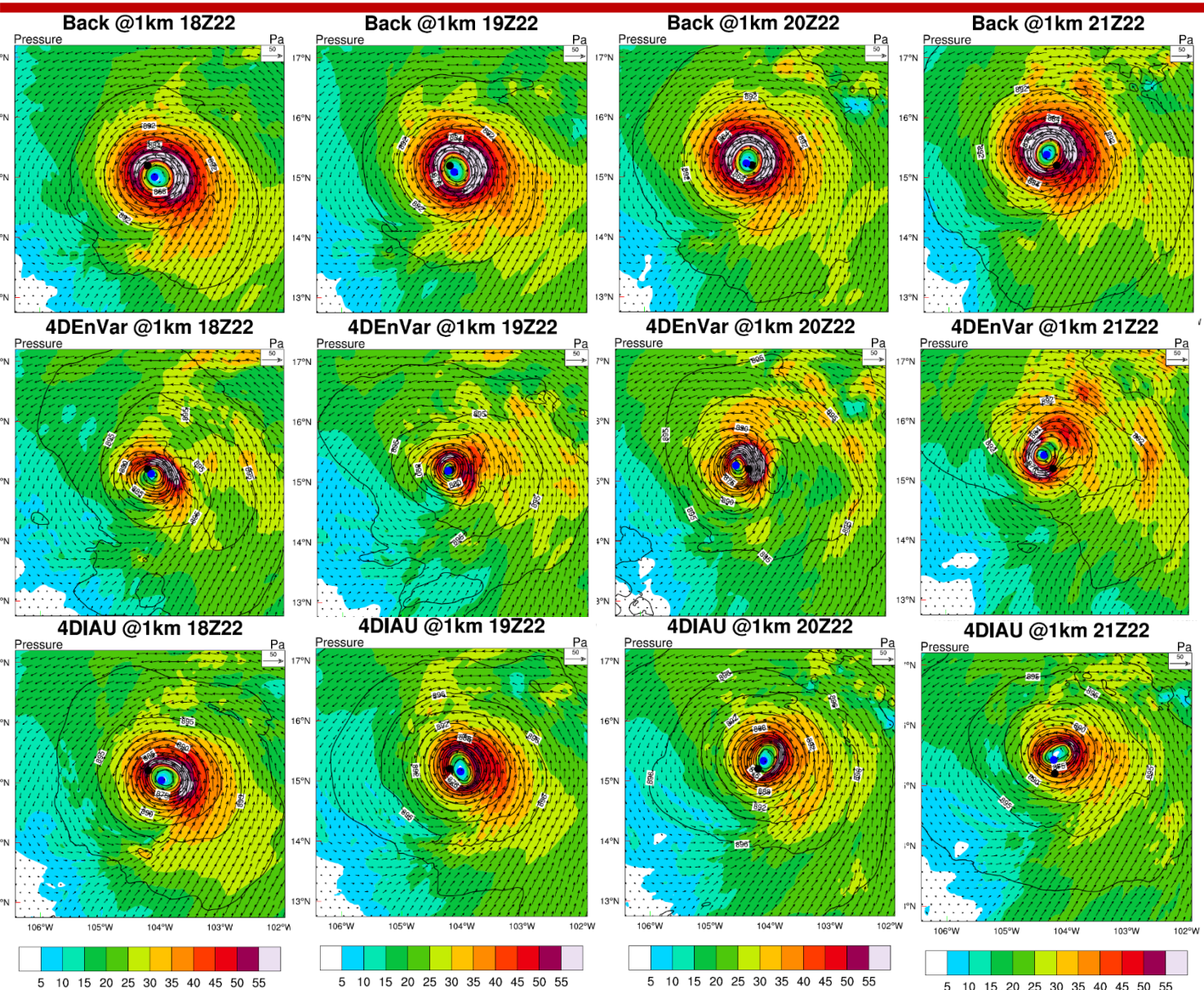
Lei and Whitaker 2016

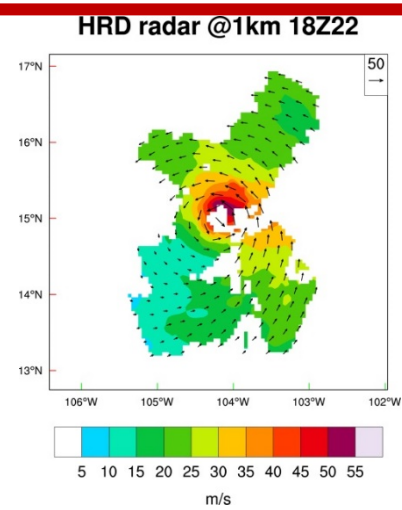
Objectives and plans

- further extend the capability of the fully cycled, self-consistent GSI-based hybrid DA system for HWRF to include the 4DIAU capability;
- design and conduct extensive experiments to investigate the best DA configuration (e.g., 4DEnVar vs. Hourly w/o IAU; full vs dual resolution hybrid DA);
- systematically explore the impact of aircraft data on the analysis, deterministic and ensemble forecasts of the TCs by using the best configuration of the newly extended hybrid DA system for HWRF;
- Extend the hybrid DA system to update hydrometeors and/or w (if additional funding available);
- investigate and document the ability of the extended system in improving TC intensity and track forecasts, as compared to the current operational capabilities.

4DEnVar v.s. 4DEnVar+4DIAU (preliminary results)

Low Level Wind Structure Evolution

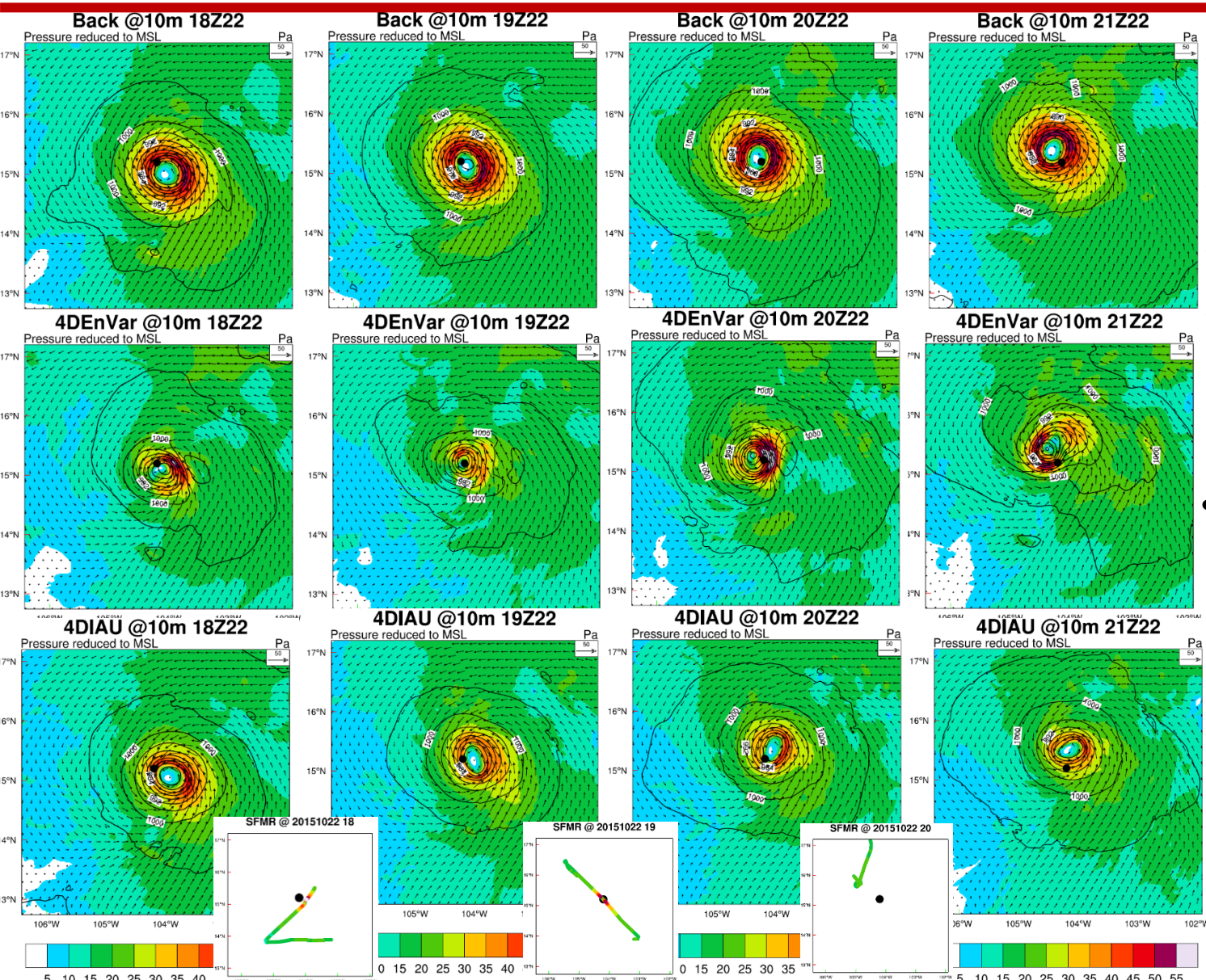




- Compared to 4DEnVar, 4DEnVar+4DIAU shows a smoother wind and SLP change.

4DEnVar v.s. 4DEnVar+4DIAU (preliminary results)

Surface Wind Structure Evolution



- Compared to 4DEnVar, 4DEnVar+4DIAU shows a smoother wind and SLP change.