Advancing the assimilation of airborne vortex-scale hurricane observations using the GSI-based high-resolution hybrid ensemble-variational data assimilation system for HWRF

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Acknowledgement

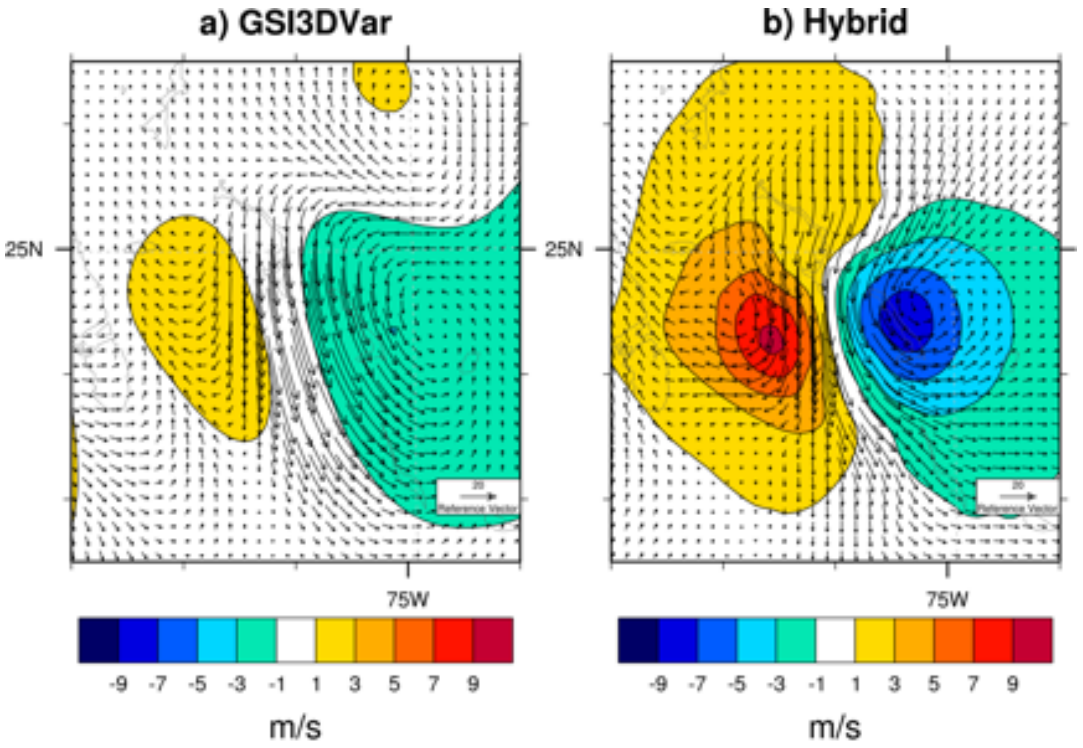
Mingjing Tong , Sam Trahan, Vijay Tallapragada, NCEP/EMC, College Park, MD
Henry Winterbottom, Jeff Whitaker, NOAA/ESRL, Boulder, CO
Ligia Bernardet, DTC, Boulder, CO

HFIP annual review meeting
June 11-12, 2015

Early R&D for HWRF Hybrid DA

Lu et al. 2015, QJRMS

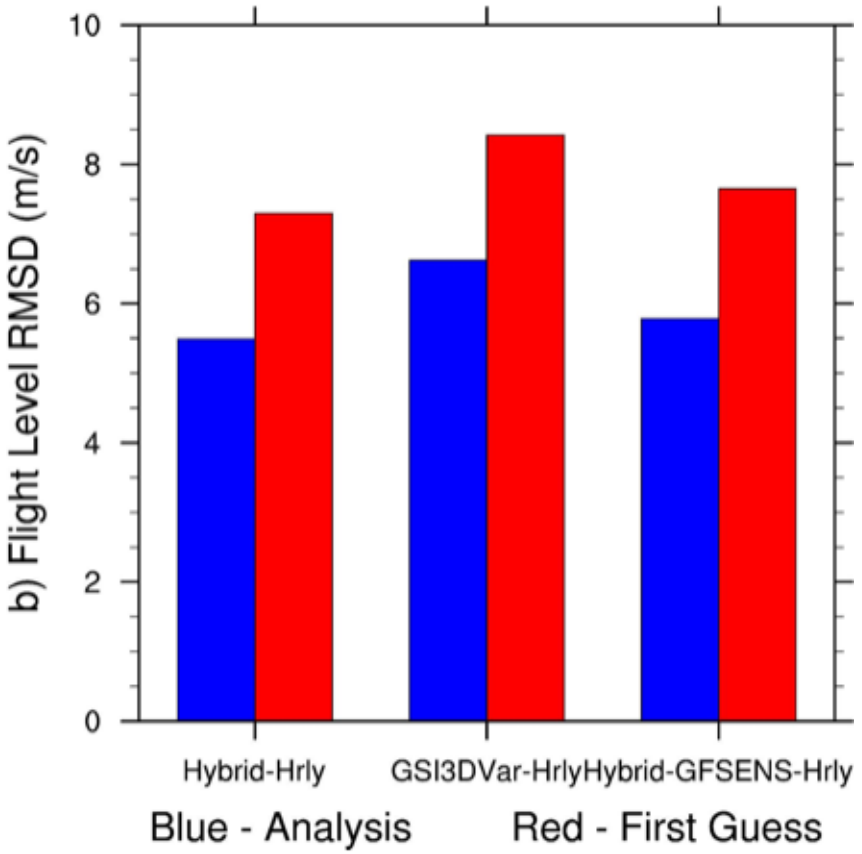
- The GSI-based hybrid EnKF-Var data assimilation (DA) system (Hybrid) was integrated for HWRF.
- Experiments focused on the assimilation of airborne radar data for 2012-2014 seasons.
- Hybrid was able to correct both the wind and mass fields in a dynamically and thermodynamically coherent fashion. In contrast, the wind and pressure adjustment by GSI 3DVar were inconsistent.



Early R&D for HWRF Hybrid DA

Lu et al. 2015, QJRMS

- Hybrid improved the analyzed TC structure, track and intensity forecasts not only when compared to GSI 3DVar, but also compared to using a GFS ensemble (Hybrid-GFSENS).
- Hybrid provided the largest positive impact of the airborne radar data (TDR).
- Hourly or leg-based TDR data assimilation performed similarly.



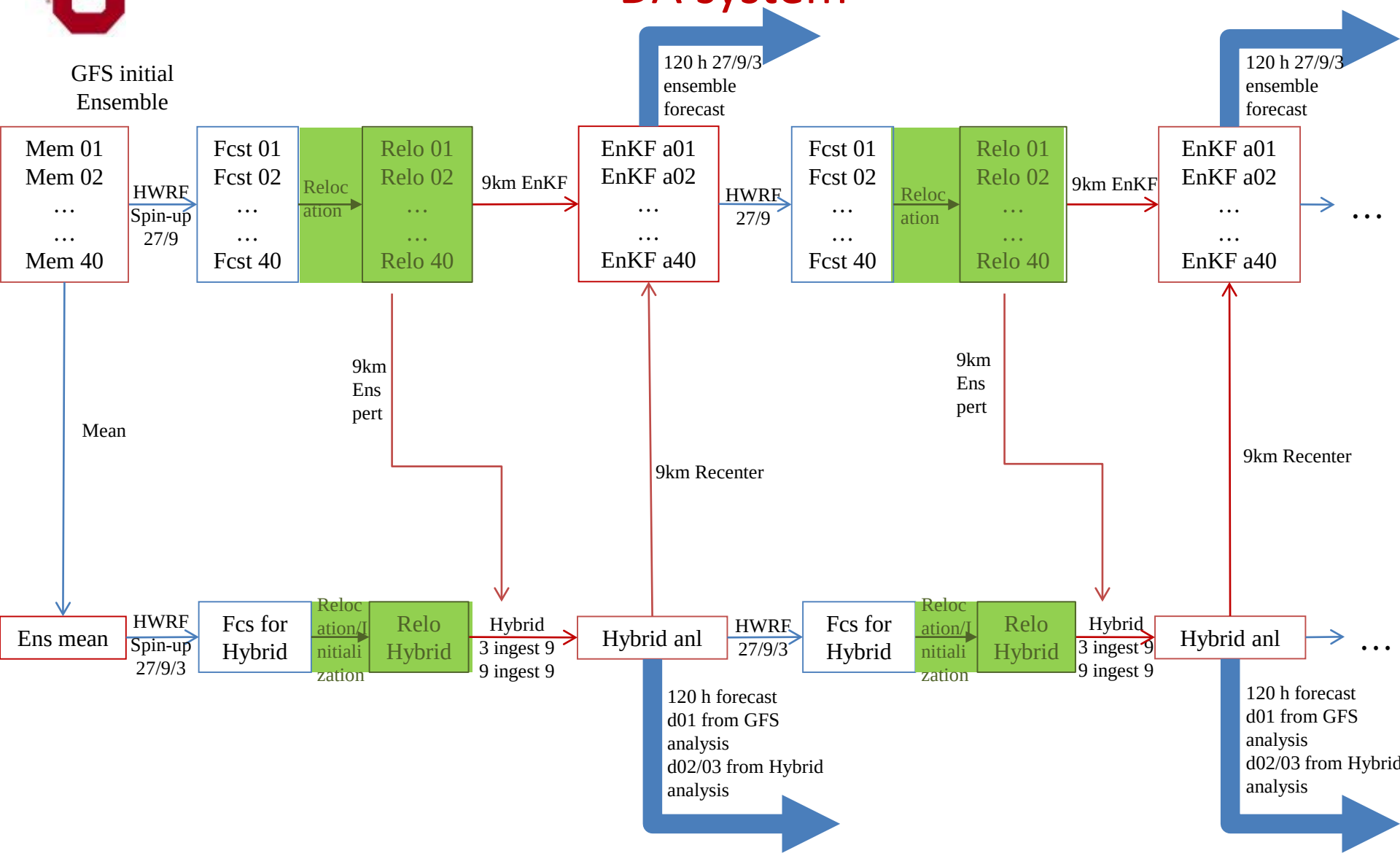
Motivation of Further Development of GSI-based, Continuous Cycling, Dual-resolution, Hybrid EnKF-Var Data Assimilation for HWRF

- Early efforts (Lu et al. 2015) focus on assimilation during TDR periods
  - ➢ The system is therefore extended to conduct DA and forecast cycles from the beginning to the end of the storm and to assimilate all operational observations

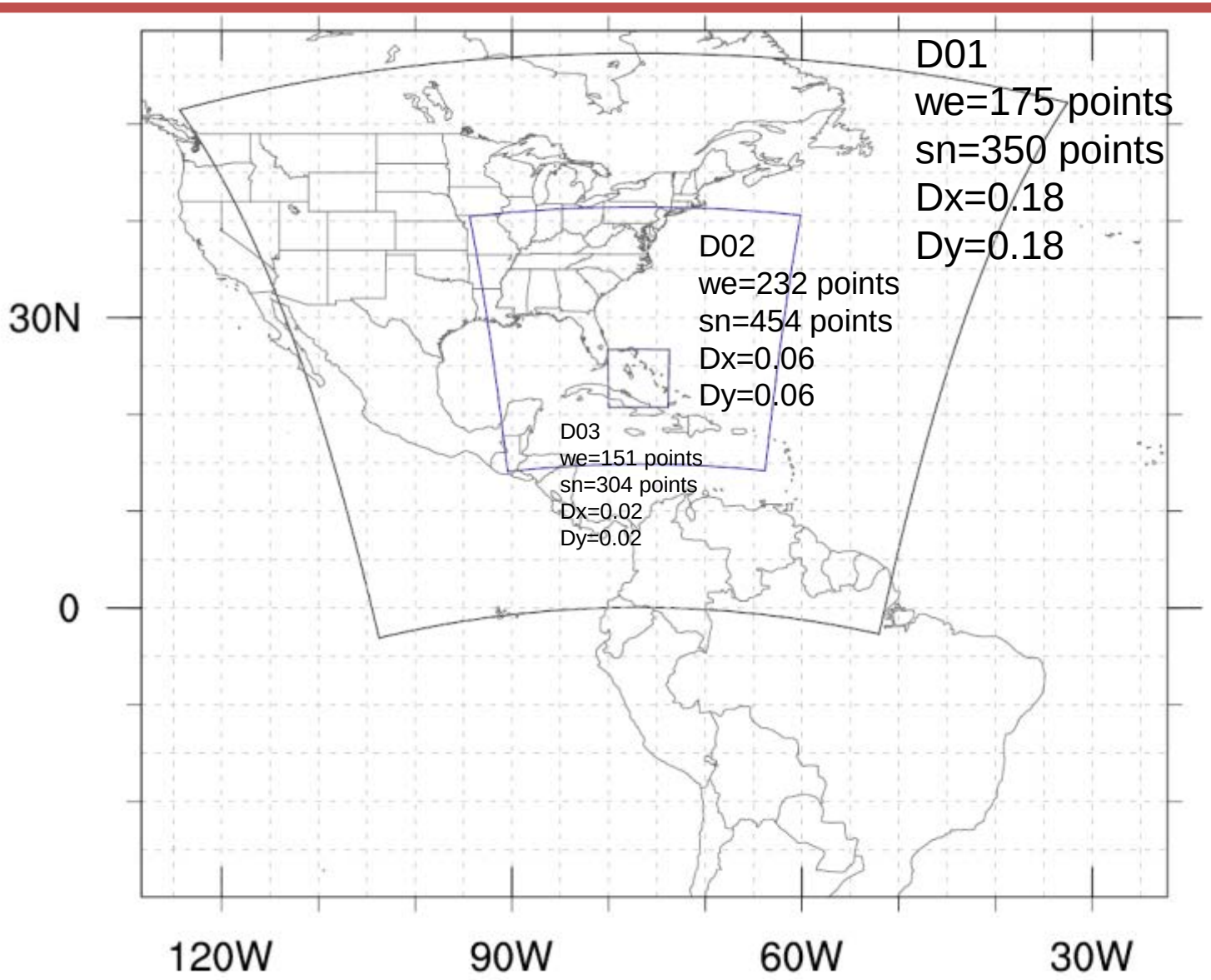
- Early efforts assimilate TDR data more frequently (hrly or leg based) than operational HWRF (6hrly)
  - ➢ Optimize DA configuration in the context of end to end cycling

- Dual resolution Hybrid can save computational cost while still maintain improvement
  - ➢ Continuous DA cycling system with dual resolution DA capability

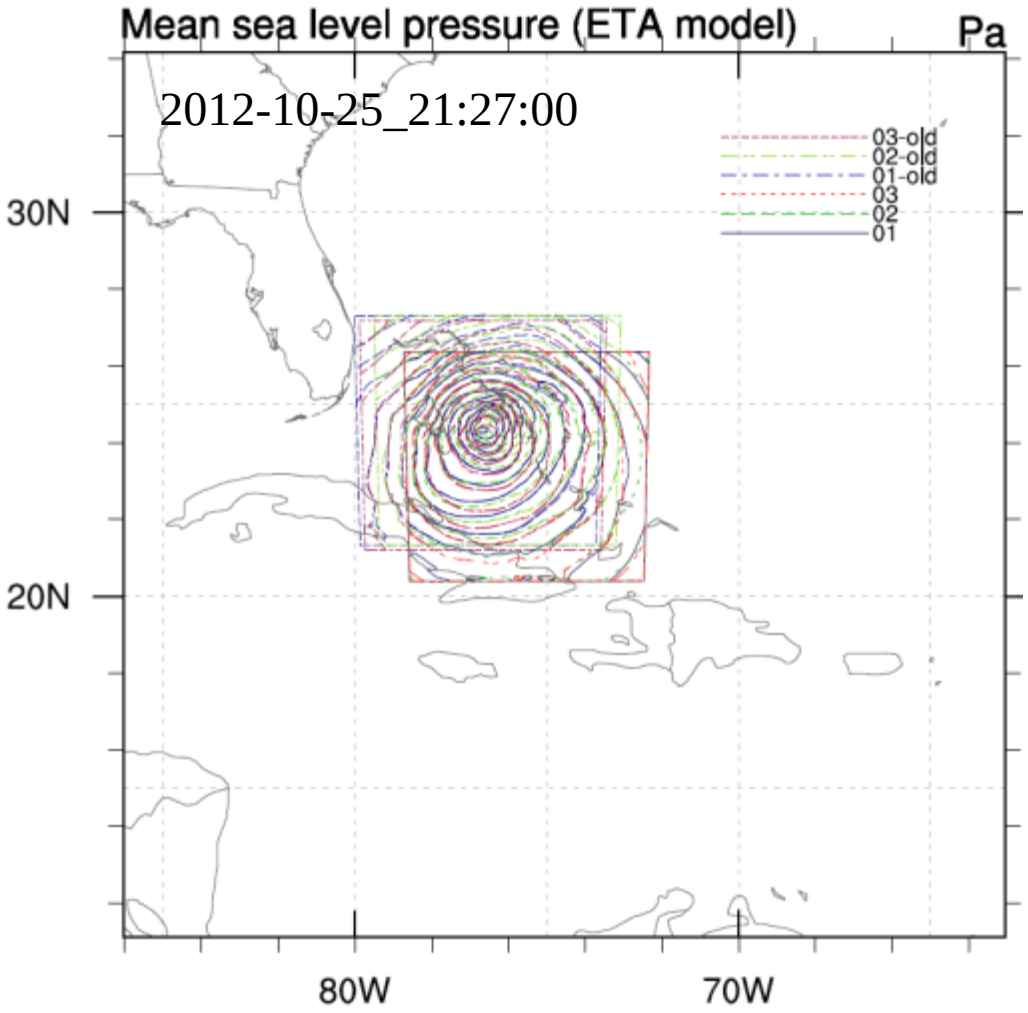
Continuously cycled, Dual-resolution, HWRF hybrid DA system



Example of domain configuration for Edouard



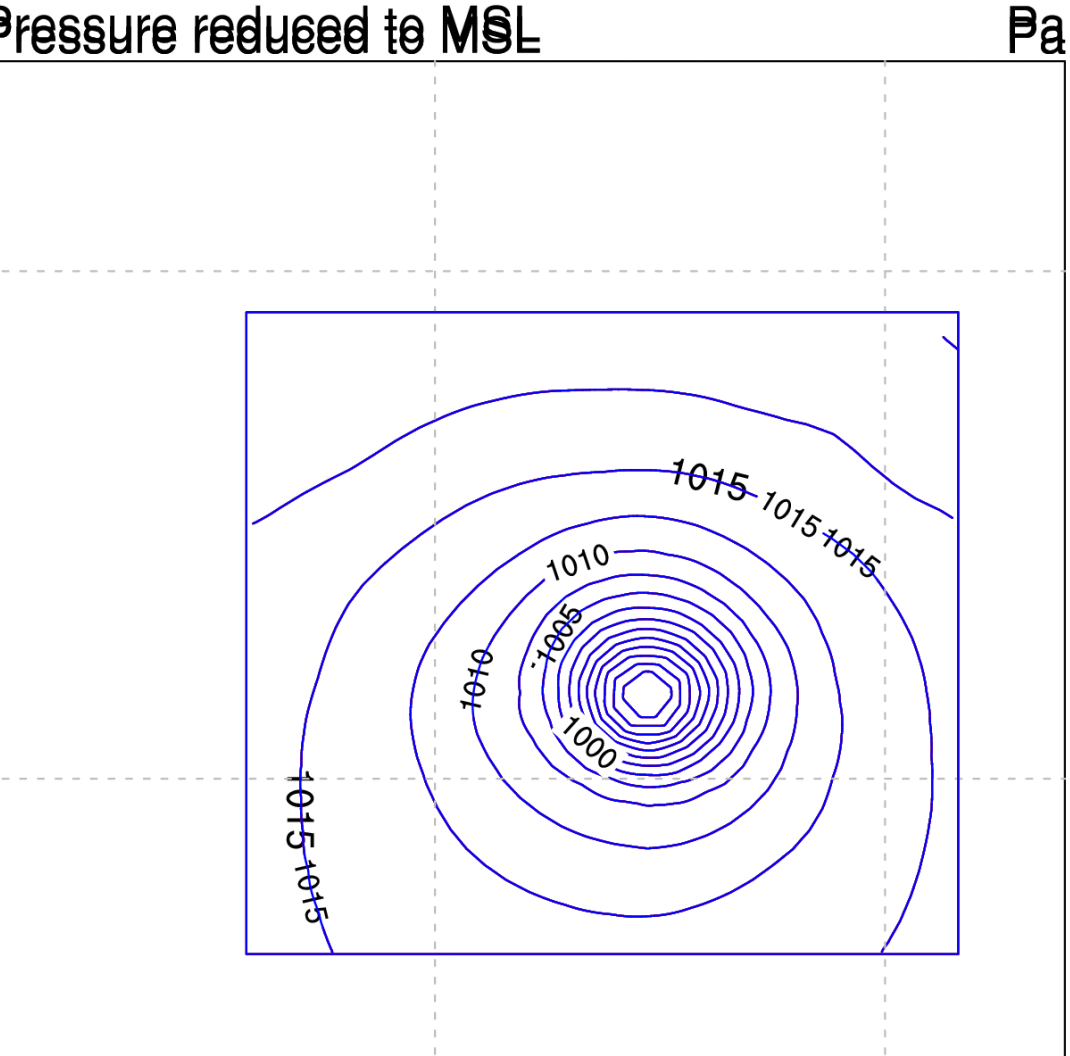
Directed moving strategy: move ensemble of domains to a same location



d01:
member 1 with domain moving fixed
d02:
member 2 with domain moving fixed
d03:
member 3 with domain moving fixed

d01-old:
member 1 with domain moving
d02-old:
member 2 with domain moving
d03-old:
member 3 with domain moving

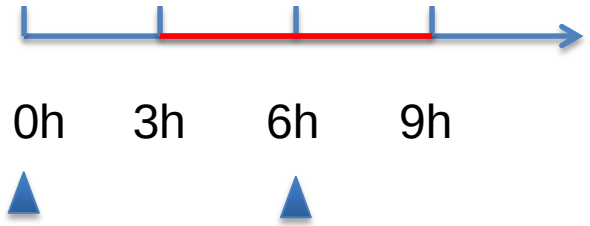
Directed Moving Strategy: flexibility to move and stop



Black domain:
Original HWRF moving strategy.

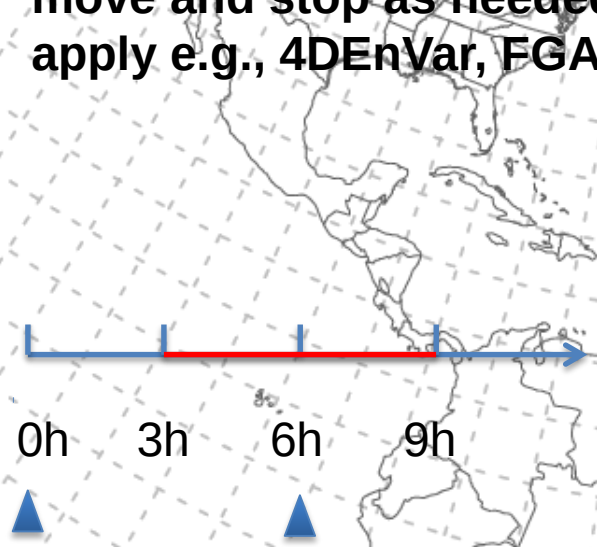
Red domain:
Directed moving til +03:00. Domain stops for model integration during +03:00~+09:00

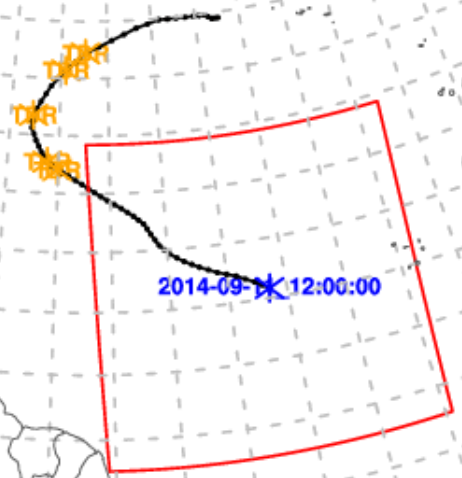
Blue domain:
As red but domain stops at a different location at +03:00. In this case, the directed moving is faster than red.



Example of end-to-end 6-hourly cycling (Edouard 2014)

- **Directed moving strategy: Move ensemble of nests to prescribed location to solve issue of non-overlapped domains for ensemble DA**
- **Moving nest has capability to move and stop as needed to apply e.g., 4DEnVar, FGAT**





- **No blending with GFS analysis needed and thus avoid discontinuity.**
- **Simple to implement. No DA code changes needed**

Experiments for Edouard 2014

Experiment name	Description
Hybrid	• 6-hourly continuous end to end cycling; • 3DEnVar hybrid with FGAT • Dual-resolution hybrid (3km control ingests 9km ensemble); • Adopted new directed moving nest strategy, and domains move for first 3 hour integration and stay for the next 6-hour integration. • Control background: vortex relocation and initialization for the control background when no TDR; vortex relocation only when TDR • Ensemble backgrounds: vortex relocation
Hybrid-279	• Same as "Hybrid" except it is not dual-resolution hybrid. Both hybrid control and ensemble are done at 9km resolution.
Hybrid-norelo	• Same as Hybrid except it does not do any vortex initialization or relocation on control and ensemble backgrounds.
Hybrid-noensrelo	• Same as Hybrid except it does not do relocation for ensemble backgrounds.
Hybrid-notdr	• Same as Hybrid except it will not assimilate TDR data.

Experiments for Edouard 2014

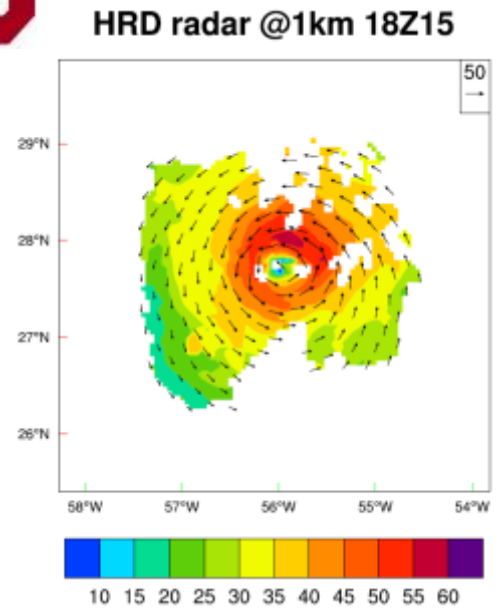
Observations assimilated:

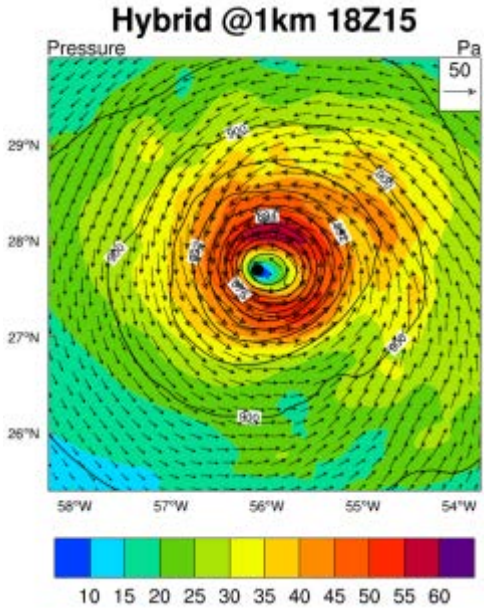
3km domain:
Conventional in-situ data in prepbufr, satellite wind, TDR and tcvital

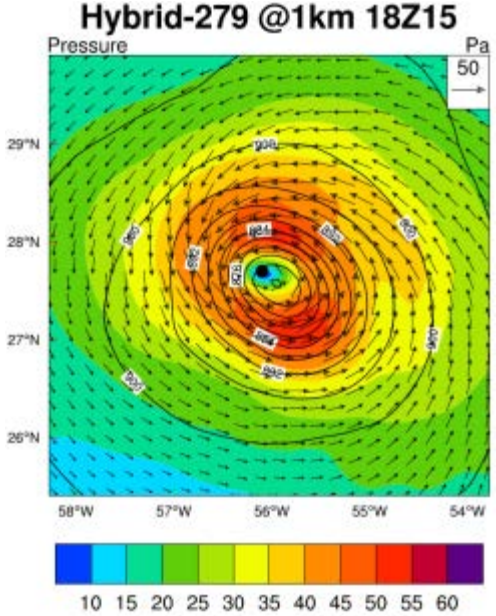
9km domain:
Conventional in-situ data in prepbufr, satellite wind, TDR and tcvital
Satellite radiances

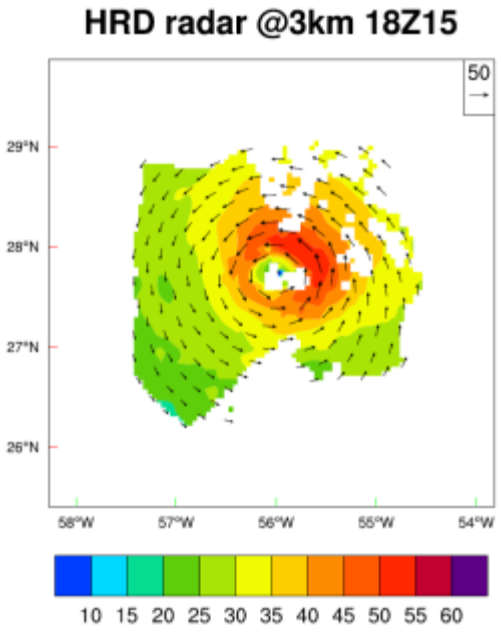
Hybrid vs Hybrid-279

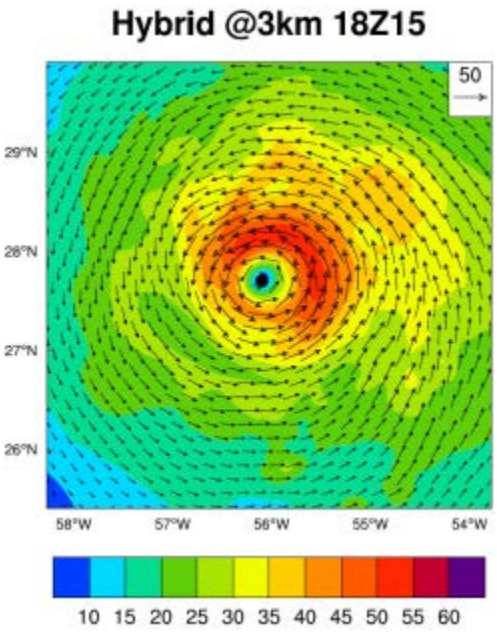
analyzed Edouard structure @2014091518

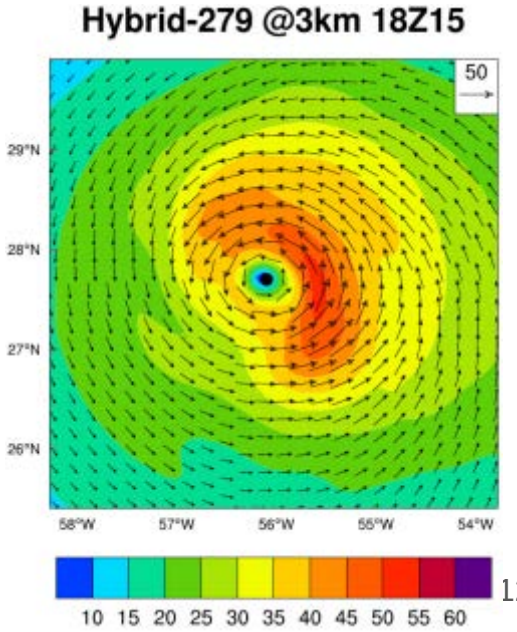








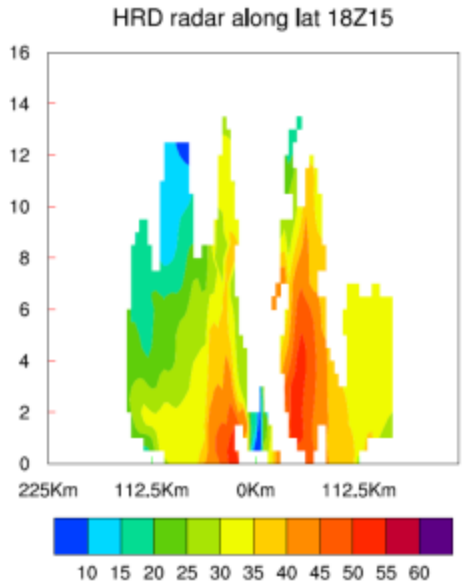


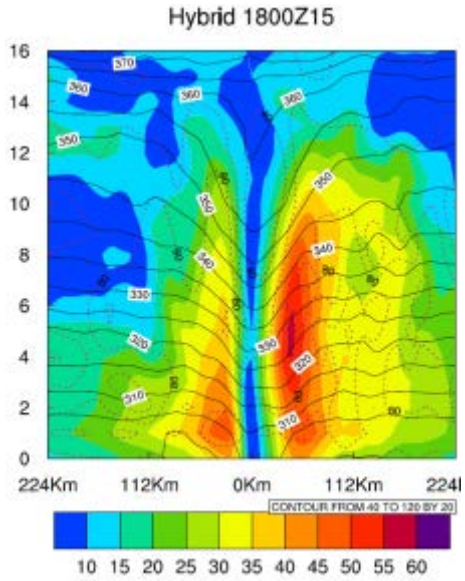


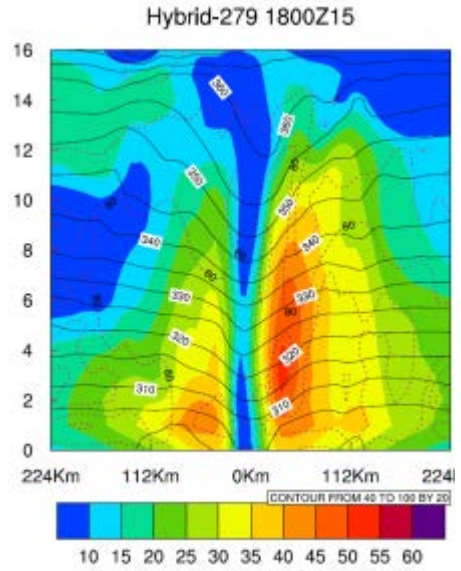
Hybrid vs Hybrid-279

analyzed Edouard structure @2014091518

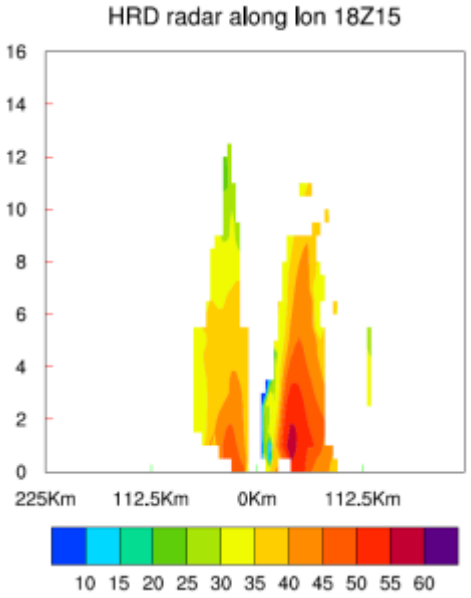
km

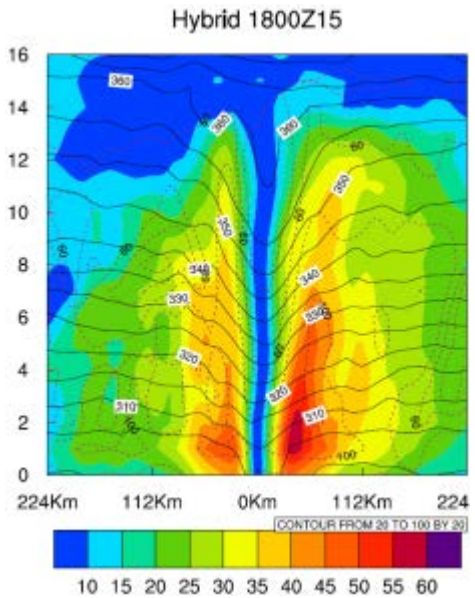


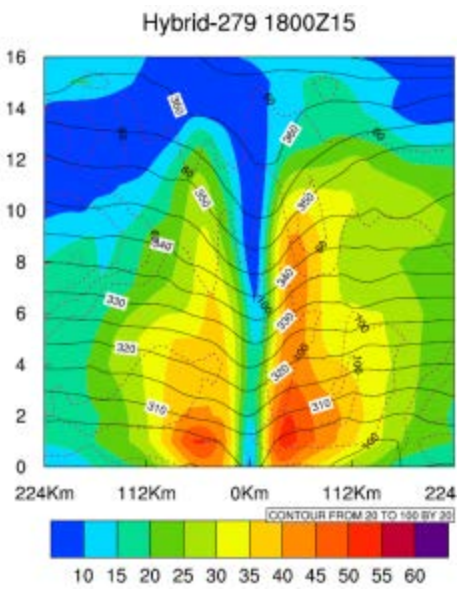




km



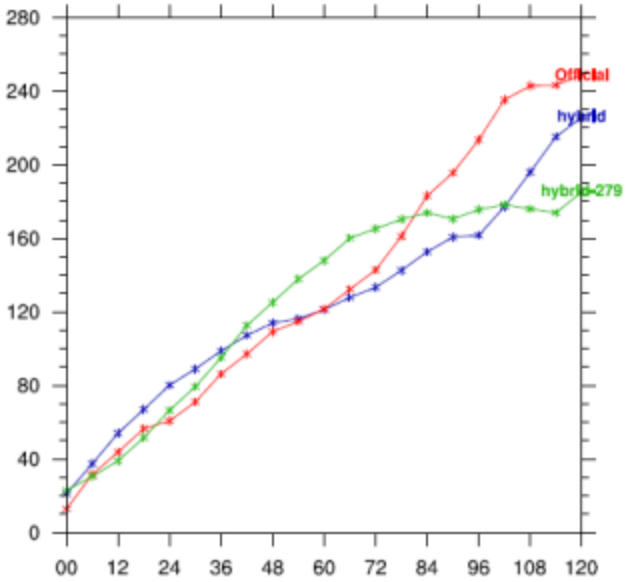




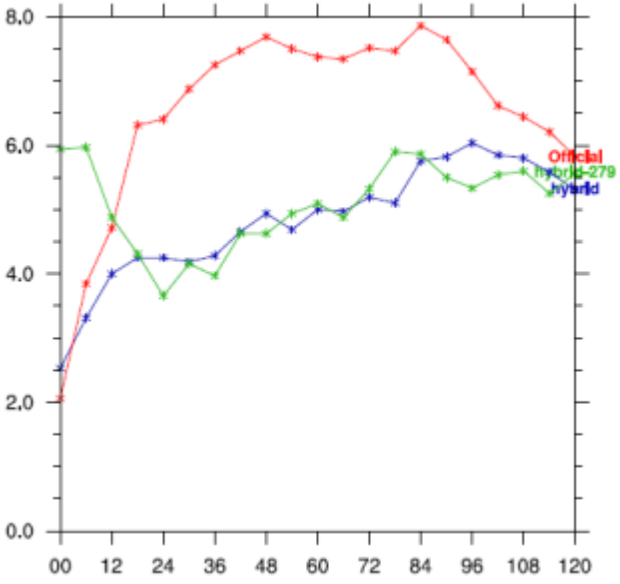
Hybrid vs Hybrid-279 vs operational HWRF

RMSE for all cycles

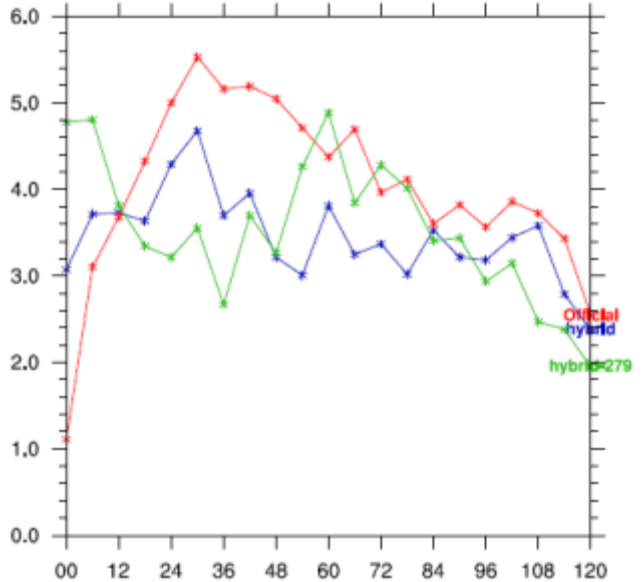
Track (km)



MSLP (hPa)



Vmax (m/s)

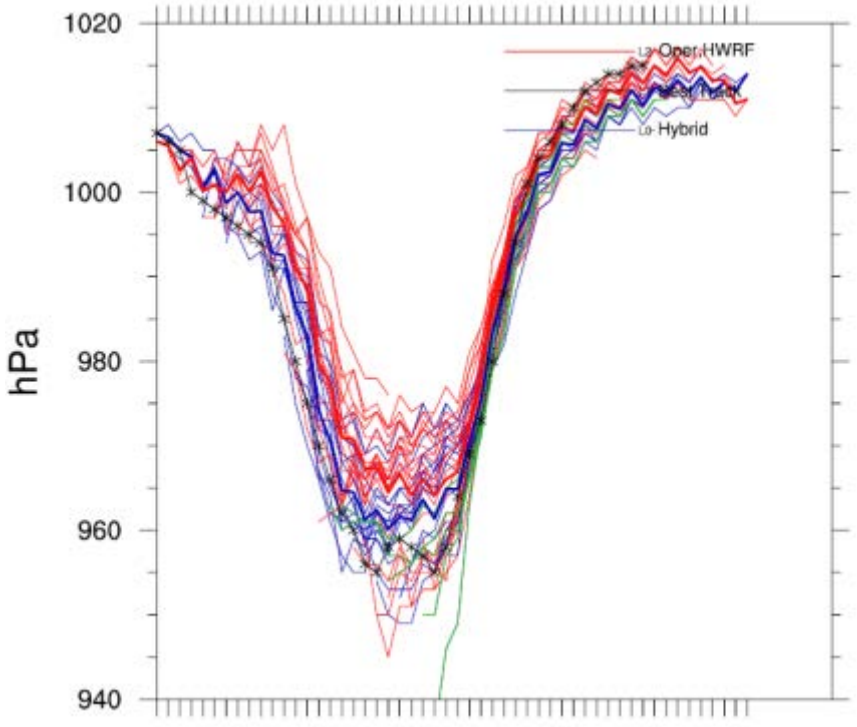


- Hybrid improved especially MSLP and Vmax forecasts compared to operational HWRF
- Dual resolution hybrid improved MSLP and Vmax forecast for the first 12/18 hours than single 9km resolution hybrid

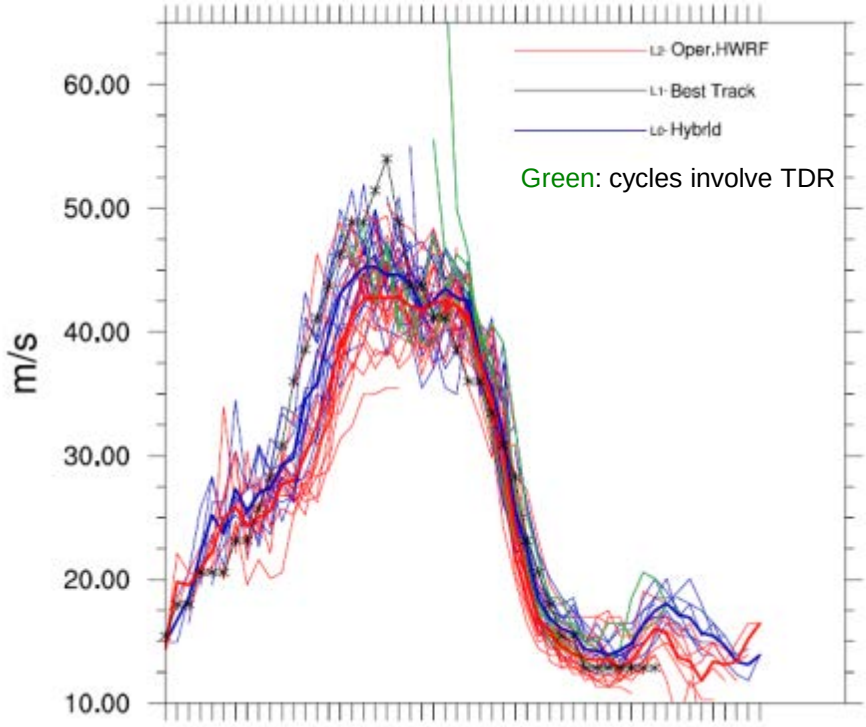
Affected by two cycles with TDR. Fixed by hrly assimilation when TDR available. See later slides

Hybrid vs operational HWRF

MSLP



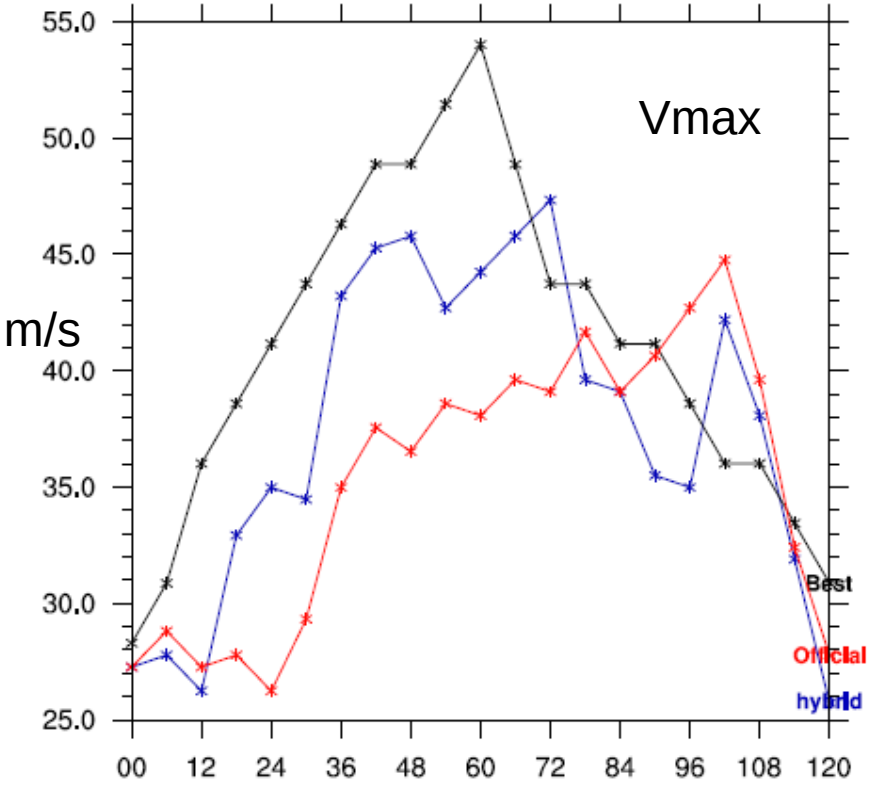
Vmax



- Hybrid improved MSLP and Vmax forecast relative to operational HWRF during RI and when Edouard reached intensity max

Hybrid vs operational HWRF: Alleviation of spin-down issue during RI

2014091400



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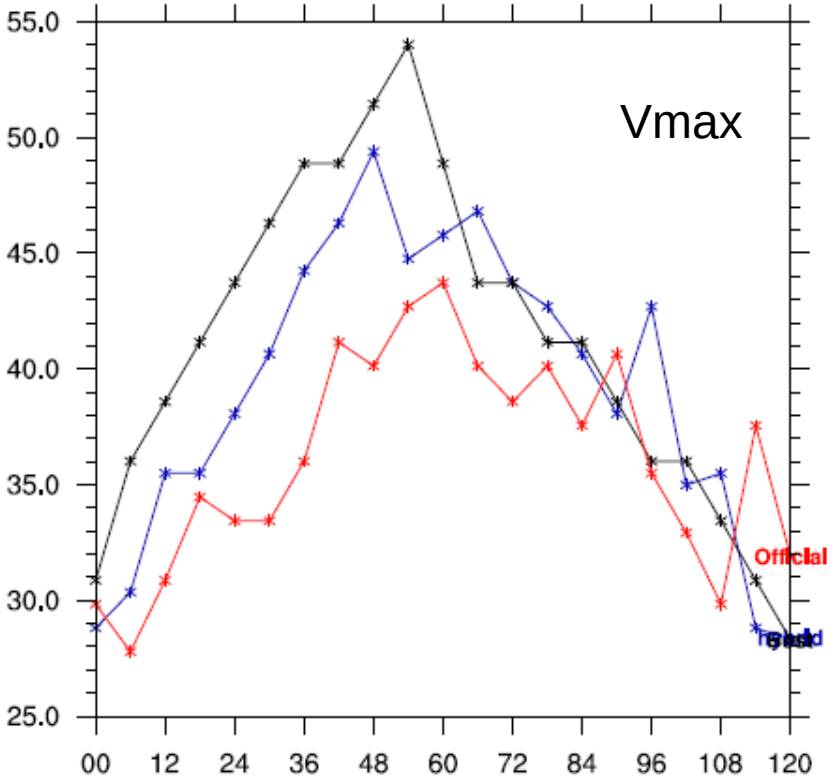
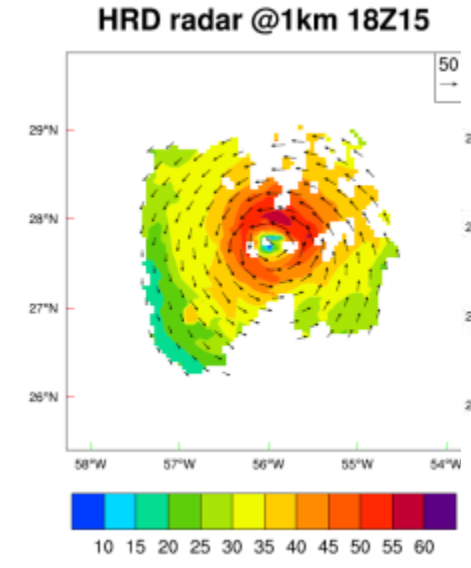
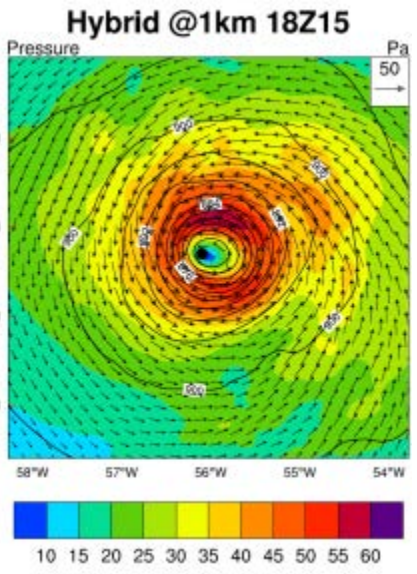
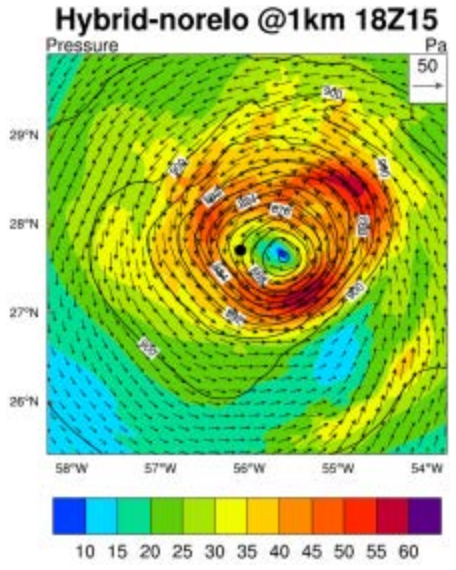


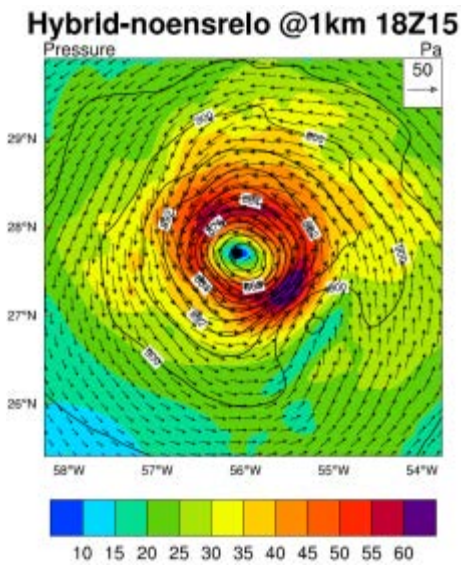
Hybrid vs Hybrid-norelo vs Hybrid-noensrelo

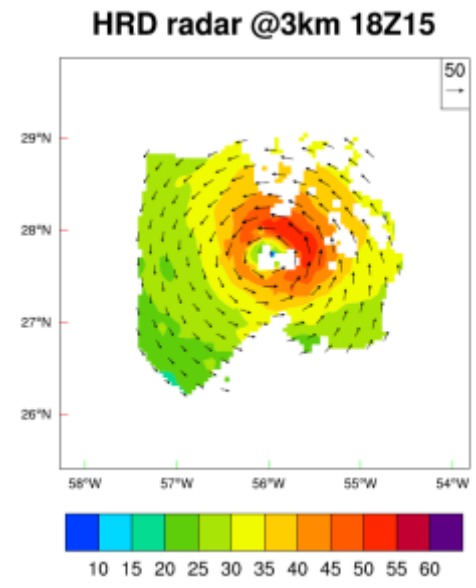
analyzed Edouard structure @2014091518

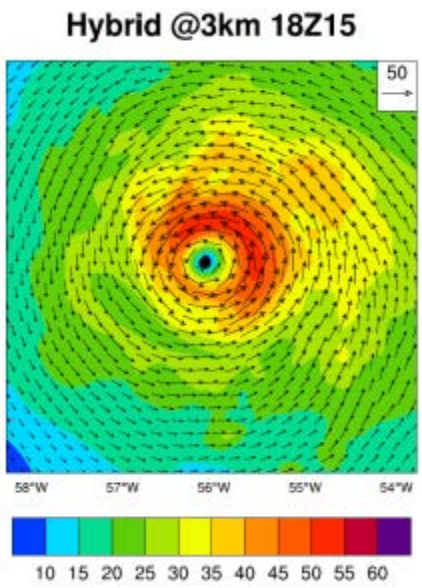


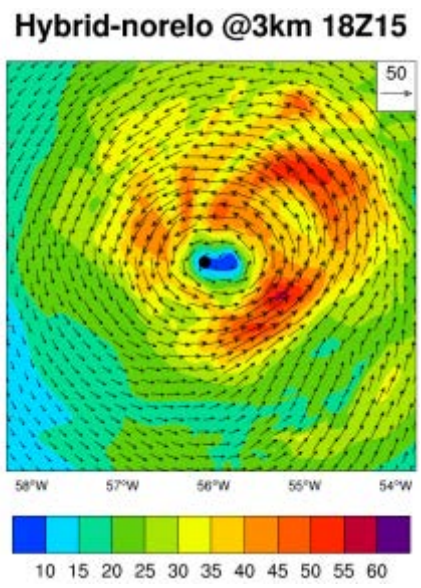


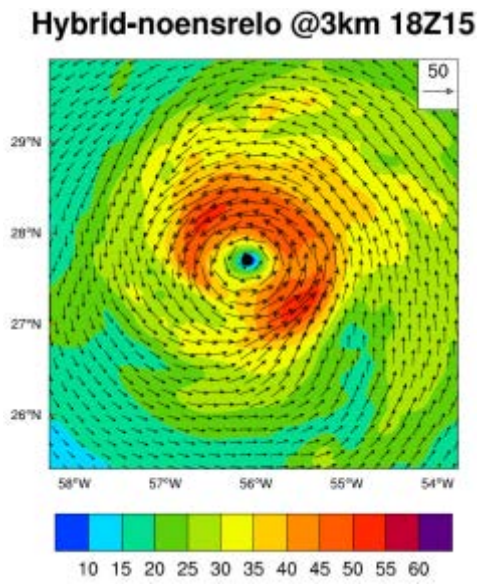






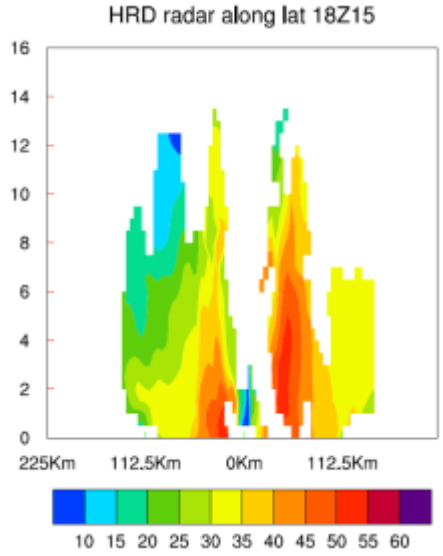


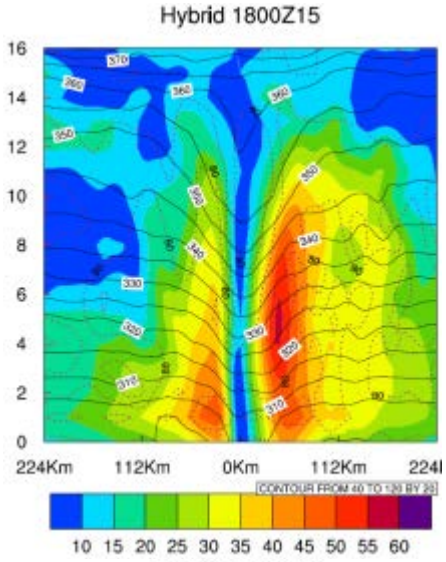


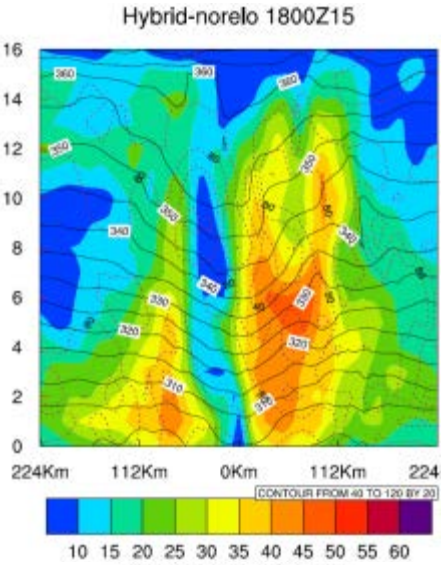


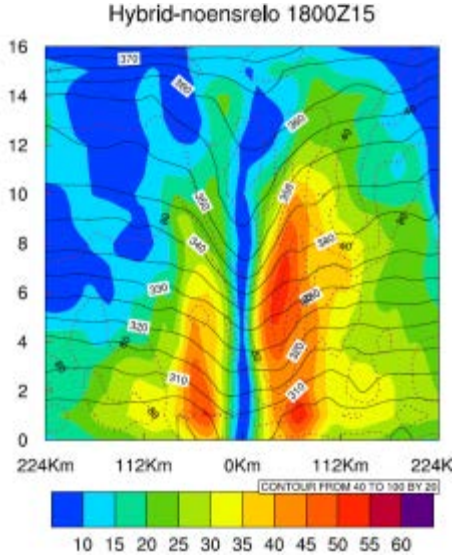
Hybrid vs Hybrid-norelo vs Hybrid-noensrelo

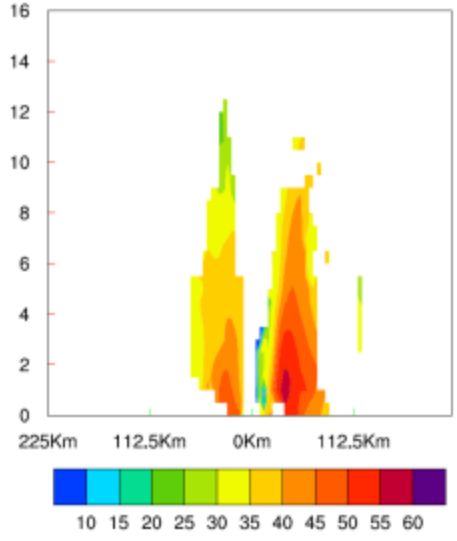
analyzed Edouard structure @2014091518

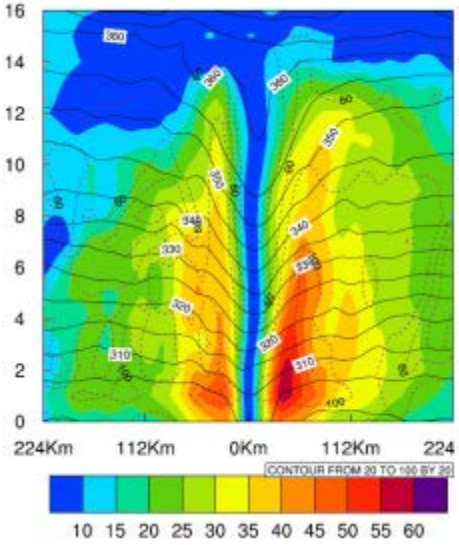


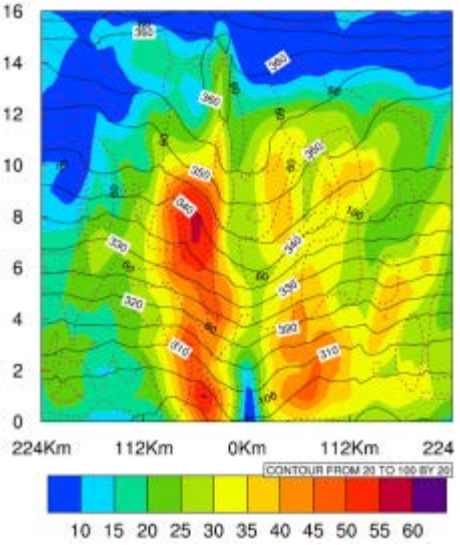


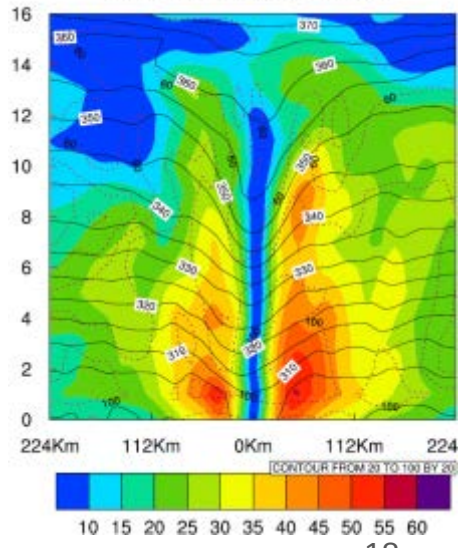






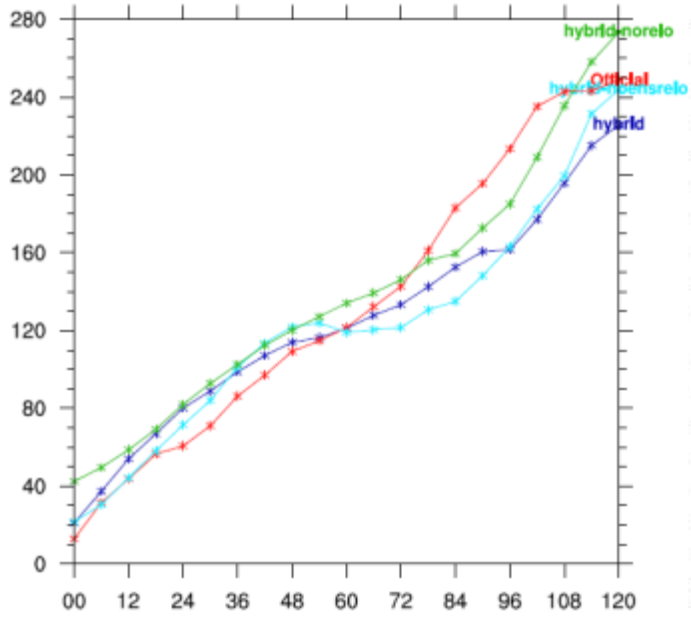




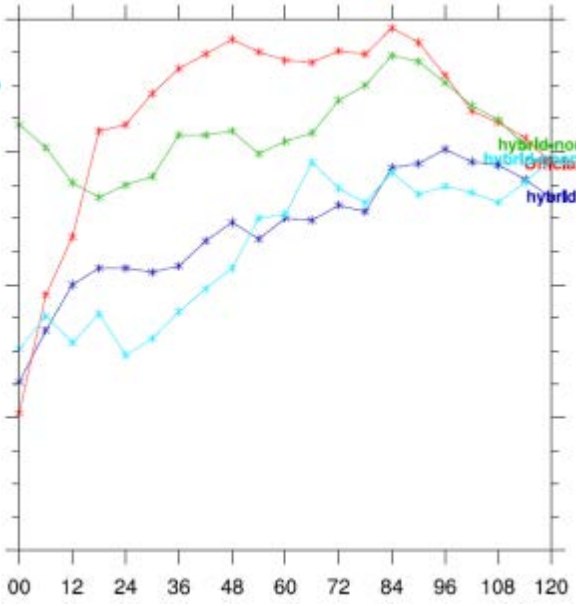


Hybrid vs Hybrid-norelo vs Hybrid-noensrelo
RMSE for all cycles

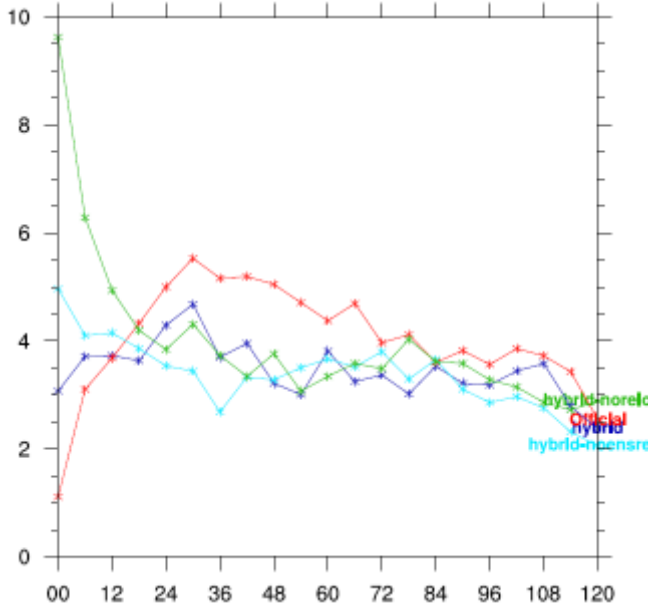
Track (km)



MSLP (hPa)



Vmax (m/s)

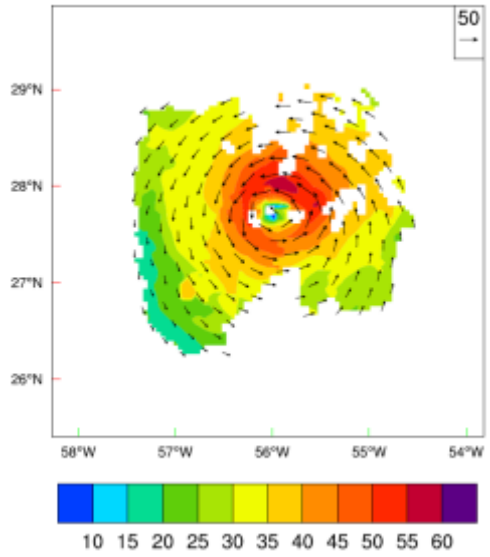


- Vortex relocation/initialization integrated with 6-houlry Hybrid DA improved forecasts

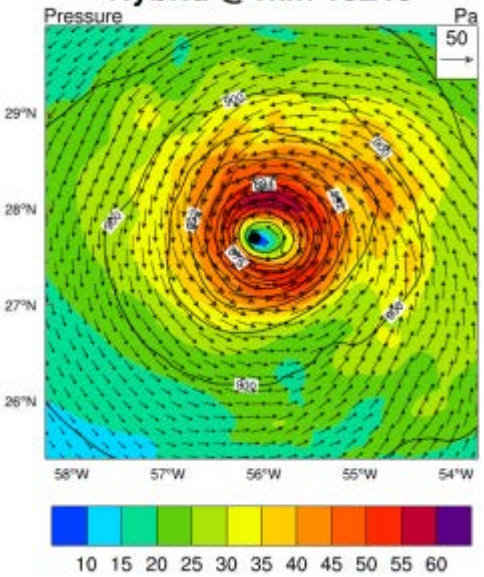
Hybrid vs Hybrid-notdr

analyzed Edouard structure @2014091518

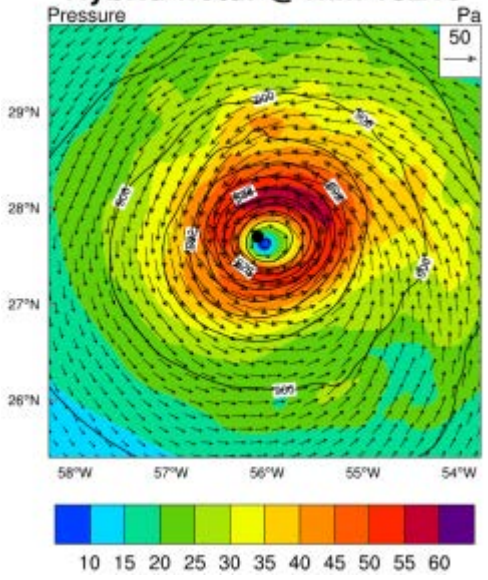
HRD radar @1km 18Z15



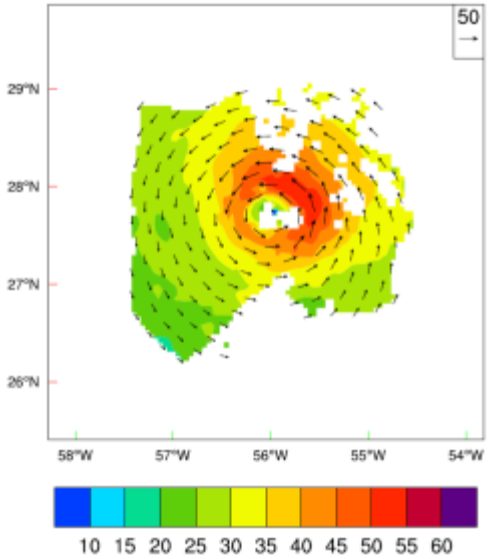
Hybrid @1km 18Z15



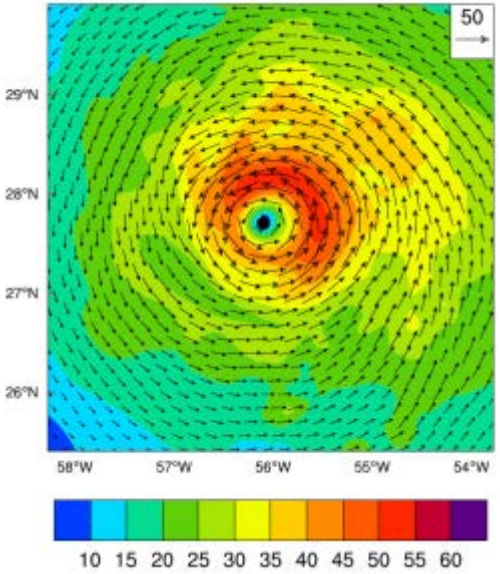
Hybrid-notdr @1km 18Z15



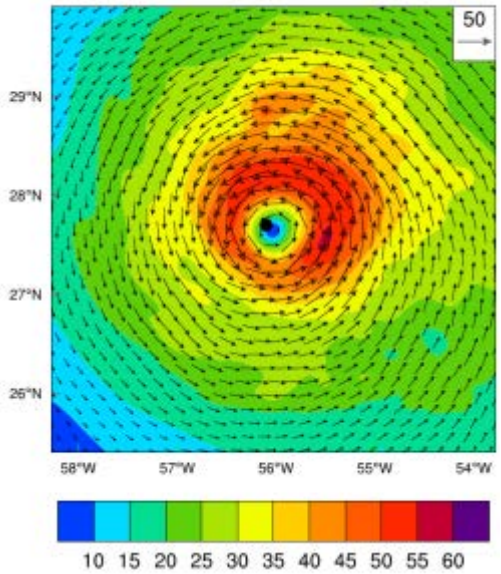
HRD radar @3km 18Z15



Hybrid @3km 18Z15



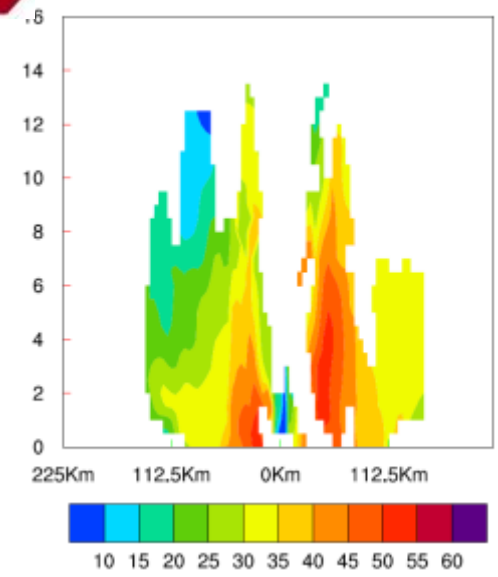
Hybrid-notdr @3km 18Z15



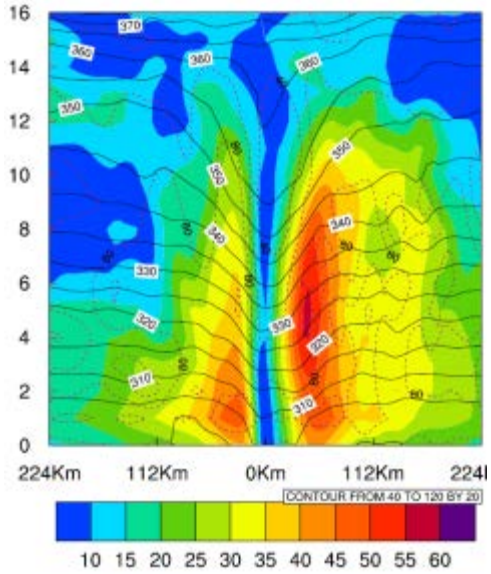
Hybrid vs Hybrid-notdr

analyzed Edouard structure @2014091518

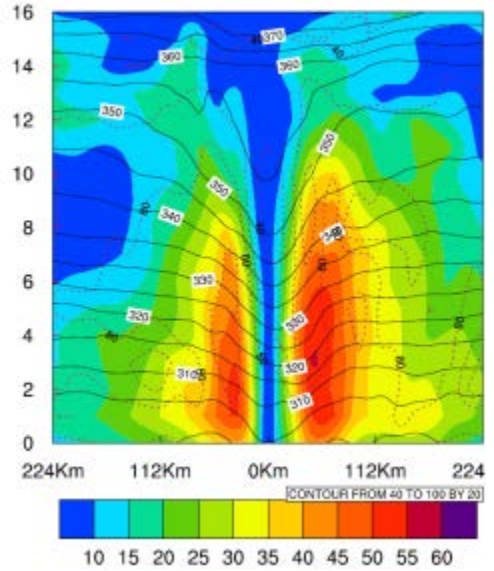
HRD radar along lat 18Z15



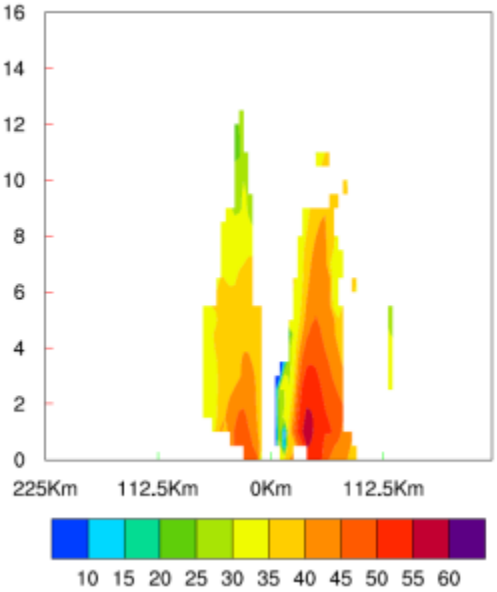
Hybrid 1800Z15



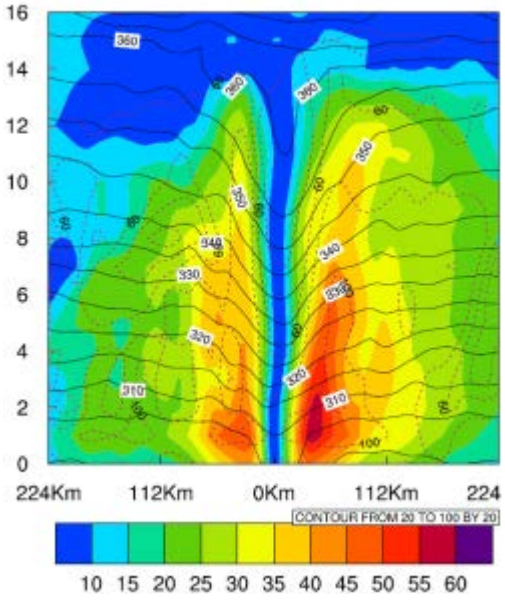
Hybrid-notdr 1800Z15



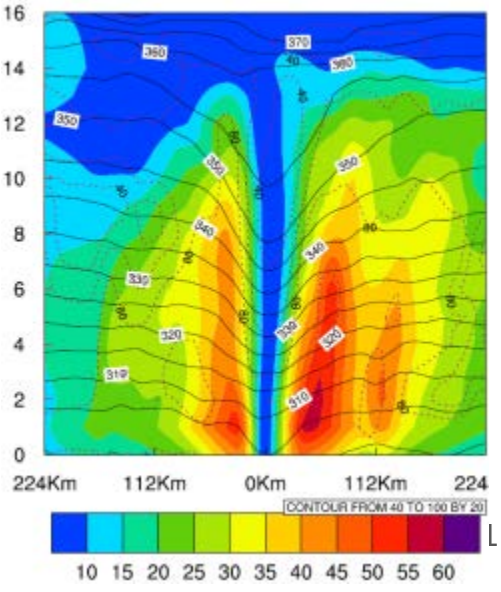
HRD radar along lon 18Z15



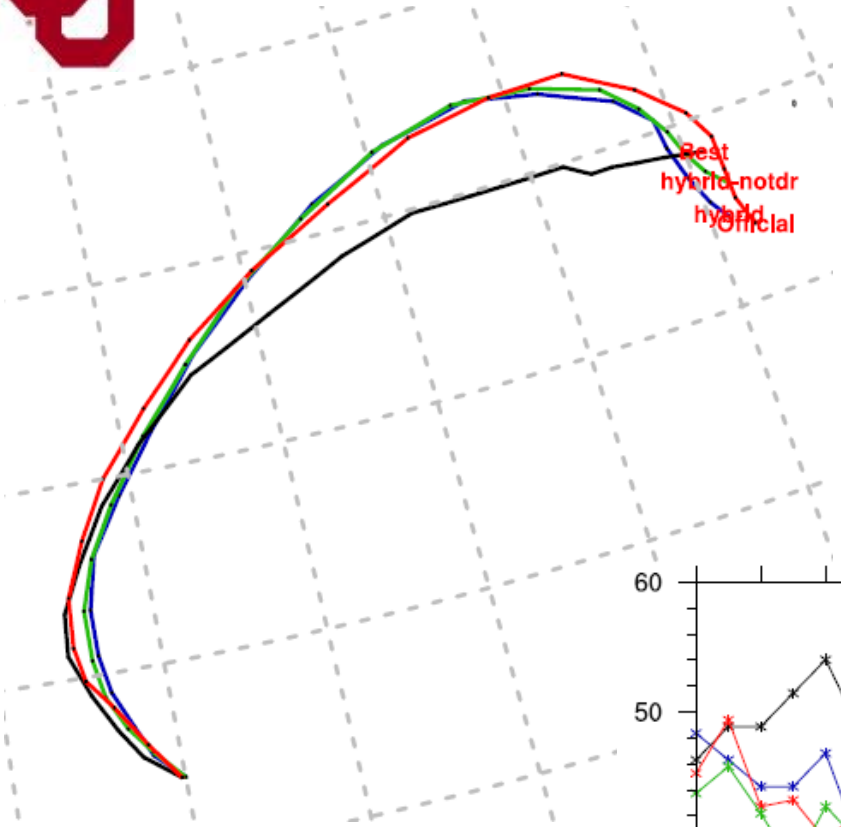
Hybrid 1800Z15

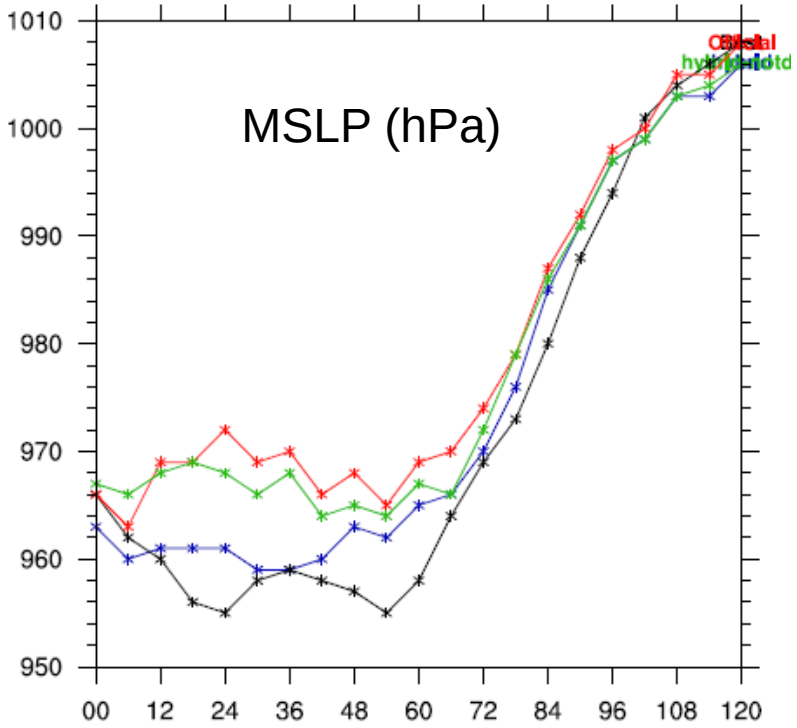


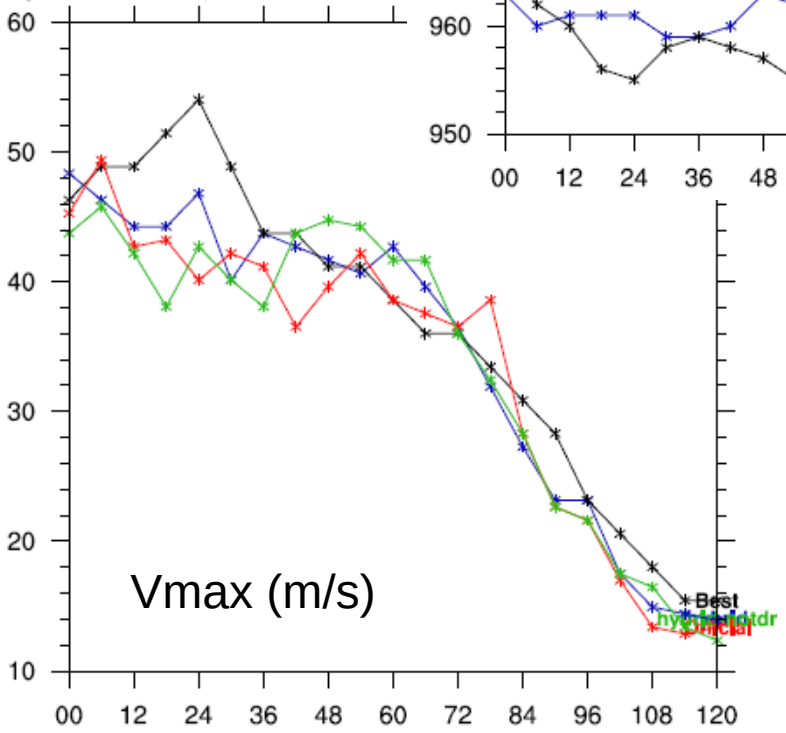
Hybrid-notdr 1800Z15



Forecast for 1st cycle with TDR



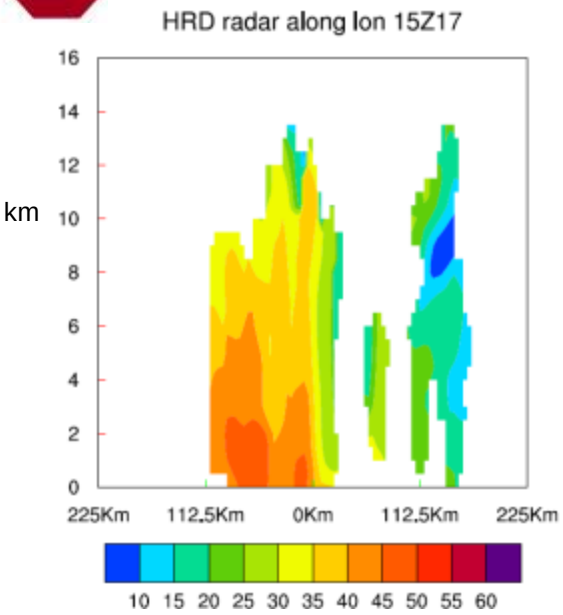


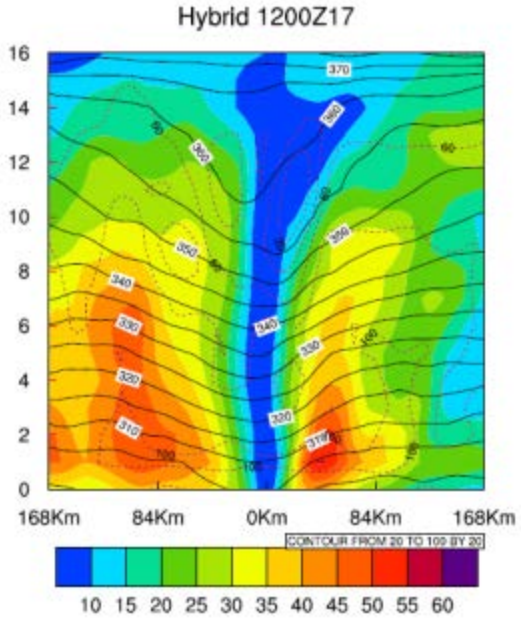


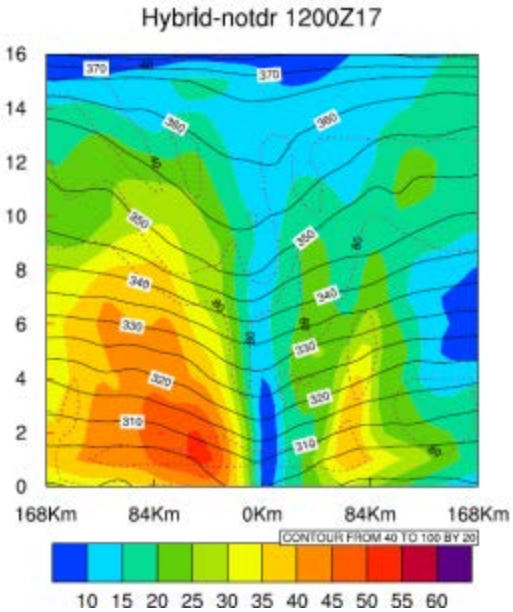
Blue-Hybrid
Green-Hybrid-notdr
Red-Official
Black-Best

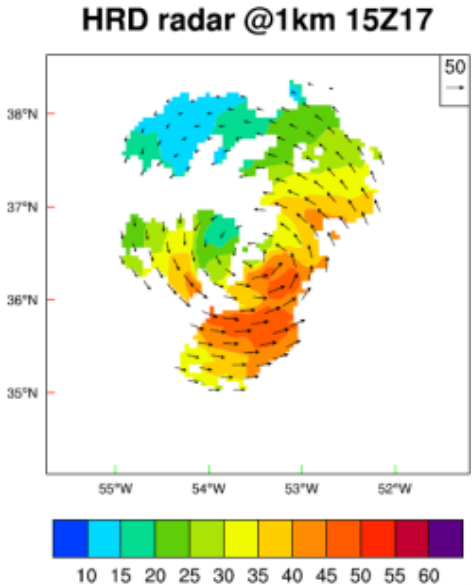
Hybrid vs Hybrid-notdr

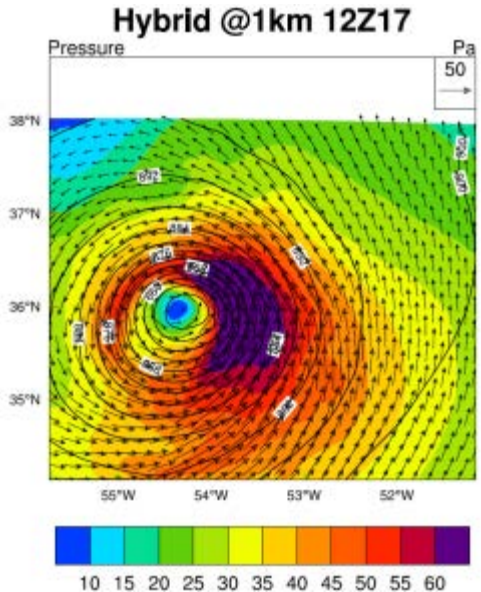
analyzed Edouard structure @2014091712

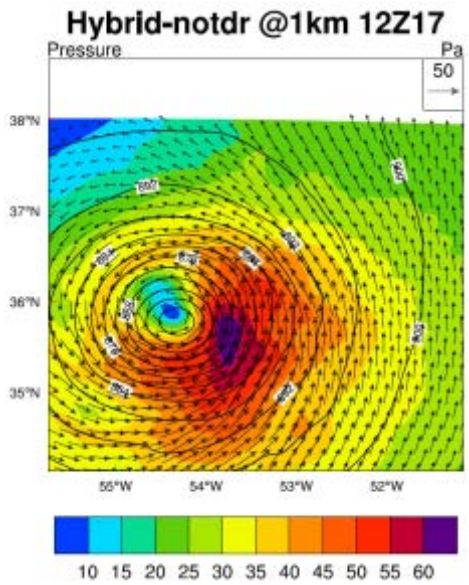






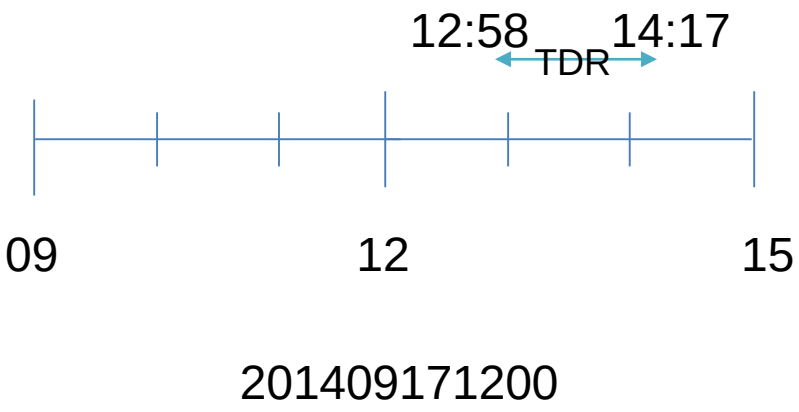


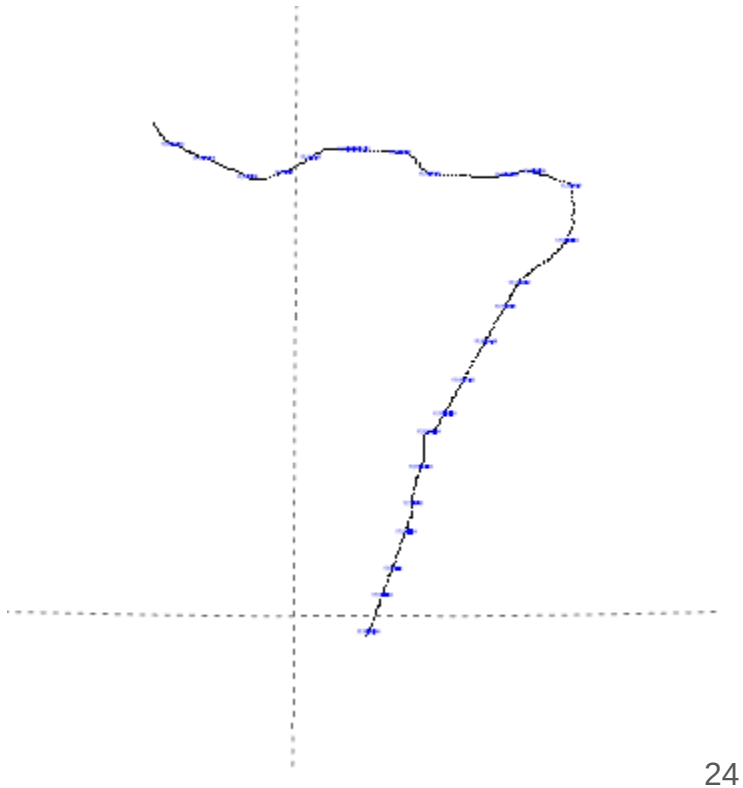




Reasons for the large Vmax in the last two TDR cycles

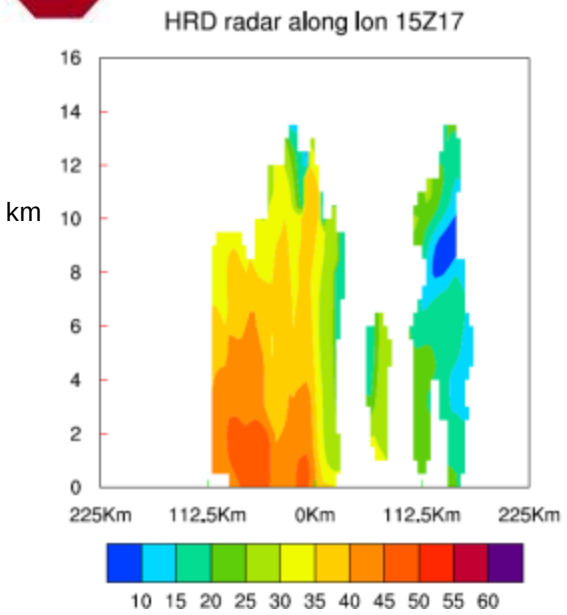
- Edouard went through complicated eyewall replacement process during these two cycles. Drastic change within 6-hr window.
- TDR coverage was very brief.
- Hourly DA or 4DEnVar (rather than 3DEnVar over 6-hr window) is needed based on our previous results (Lu et al 2015)

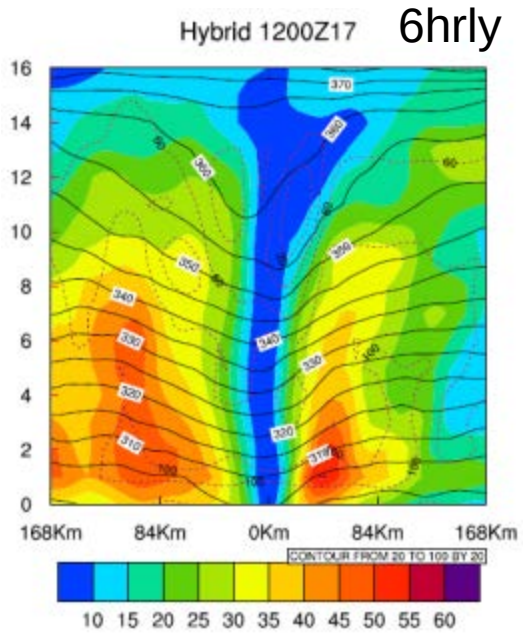


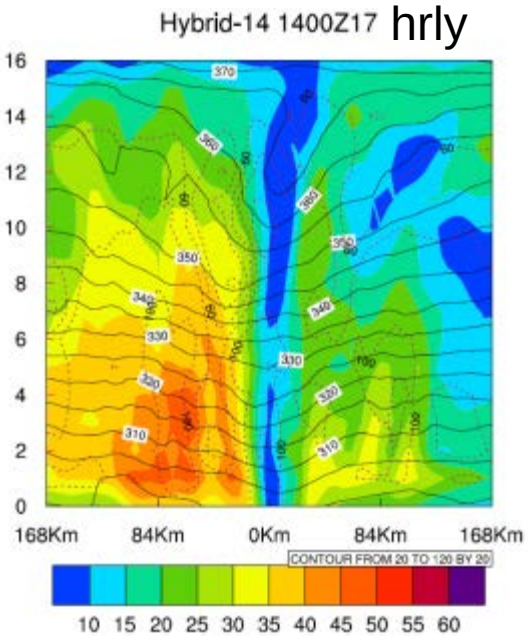


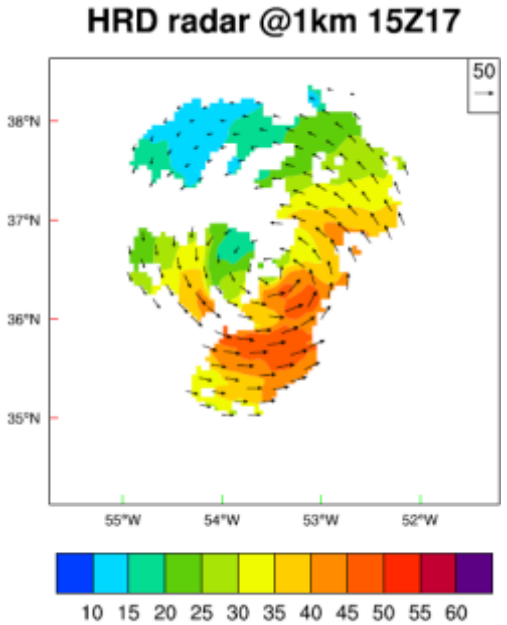
Hybrid vs Hybrid-hourly

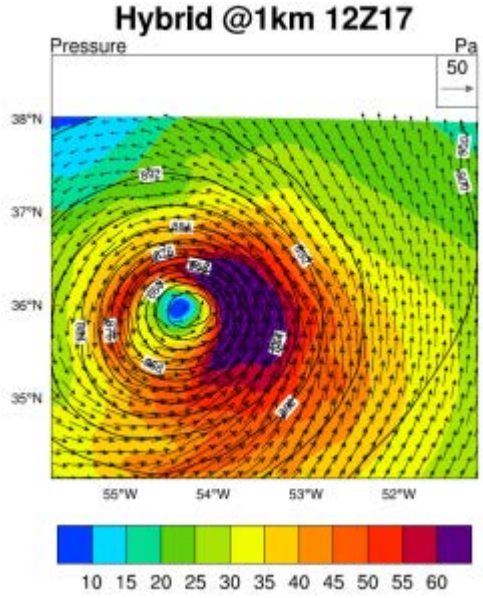
analyzed Edouard structure @2014091712

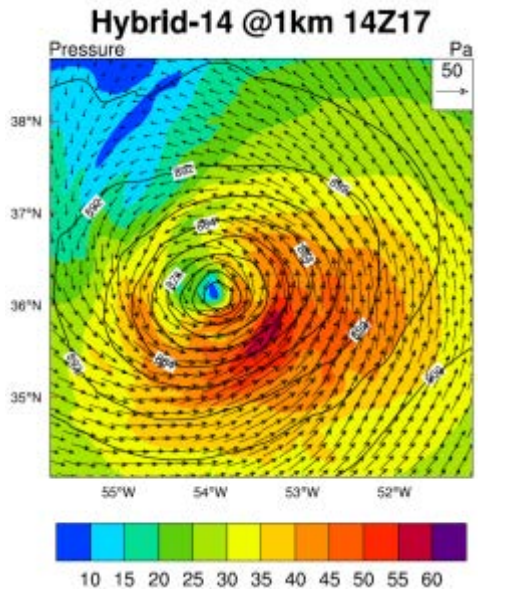












Efforts for Operational Implementation

- Primary components of the system are implemented in HWRF repository following the operational HWRF's python and Rocoto scripting environment.

1) Add the new HWRF moving nest strategy;

2) Add the HWRF EnKF including both the calculation of Hx ensembles and the EnKF executable;

3) Add cycling HWRF ensemble to provide the ensemble covariance for dual resolution hybrid replacing cold started HWRF ensemble in the current operational HWRF system.

Summary and Ongoing Work

Summary

- GSI-based, continuous cycling, dual resolution, hybrid EnKF-Var DA system with new moving nest strategy, assimilating all operational observations for HWRF is developed.

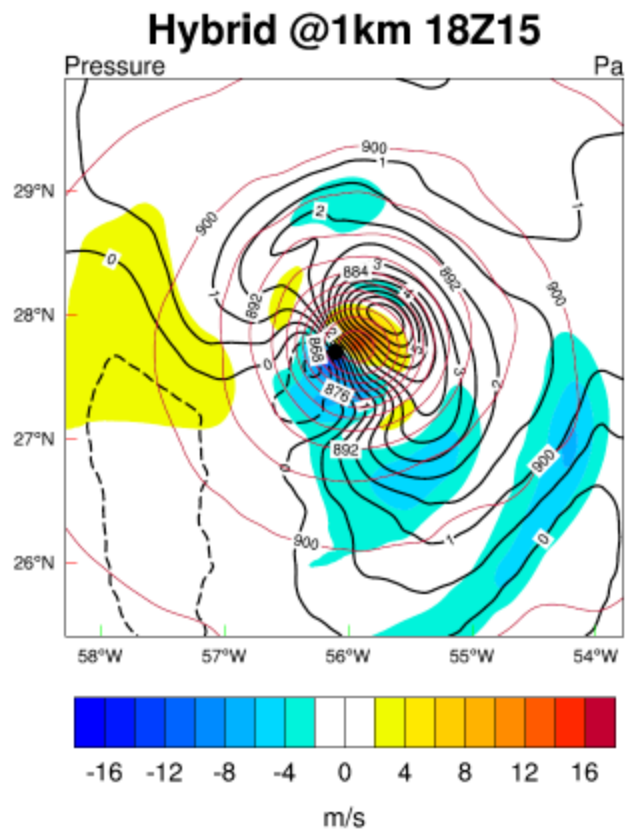
- Experiments with Edouard with 6-hourly continuous, end to end DA cycling suggest:
- ➢ The system improved MSLP and Vmax forecasts compared to operational HWRF especially during RI and max intensity periods through alleviation of spin down issue
- ➢ high resolution analysis produced through dual resolution hybrid DA improved structure analysis and intensity forecasts.
- ➢ Vortex relocation/initialization integrated with 6-houlry Hybrid improved forecasts
- ➢ Assimilation of TDR data (6hrly) improved MSLP and Vmax for later lead times. Diagnostics suggest further positive impact of TDR is expected with more frequent assimilation (hrly or 4DEnVar).

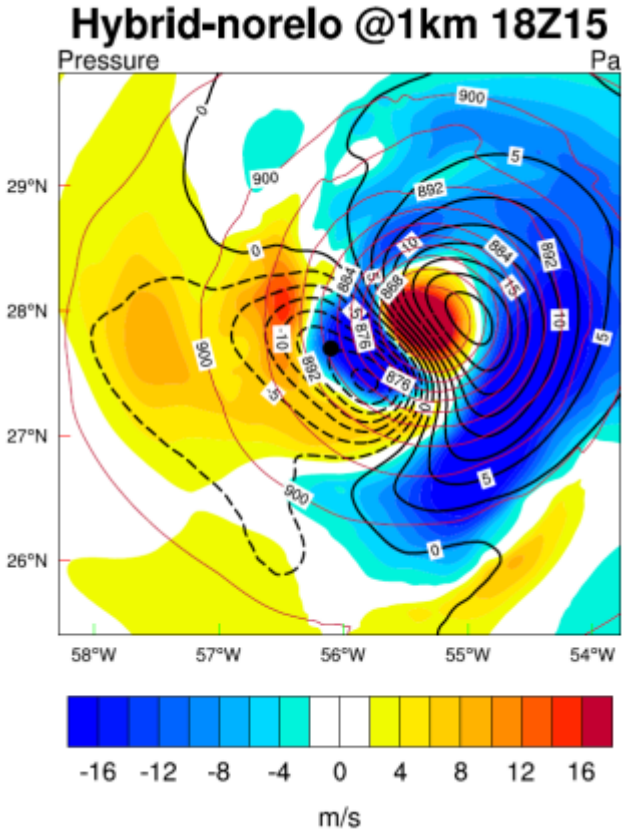
Ongoing work

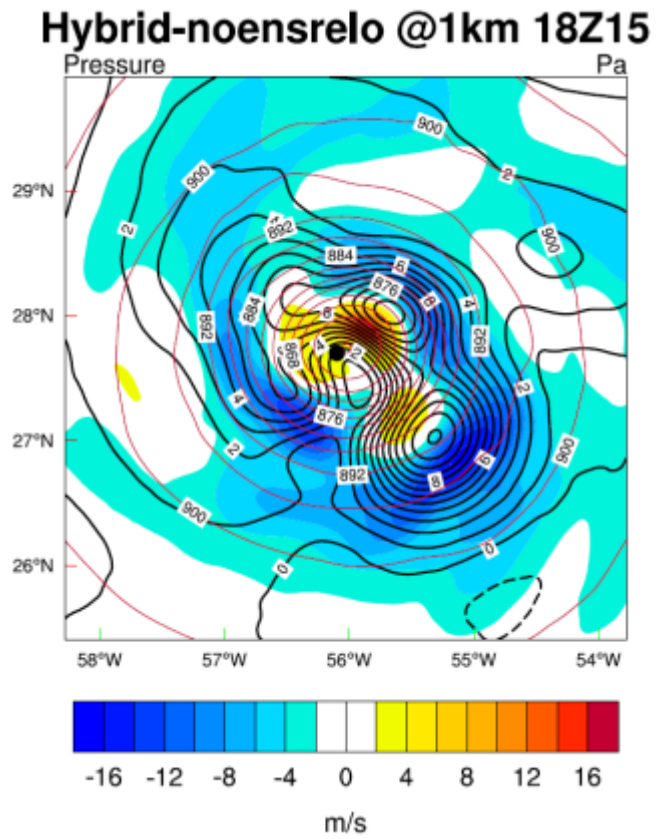
- Continue operational implementation.
- Explore the impact of using higher resolution ensemble in hybrid DA (9km vs 3km ensemble).
- Sensitivity to different, directed locations
- Include and test new obs. products.
- Continue optimizing system configuration (cycling frequency, 3DEnVar vs 4DEnVar, mixture of 6 hourly and hourly, storm relative DA.).
- Optimize the usage of and explore the impact of other airborne observations (P3, GIV radar, dropsonde, flight level, SFMR, etc.) using the new system. Including better preprocessing and assignment of obs. errors.

Hybrid vs Hybrid-norelo vs Hybrid-noensrelo

Increment @2014091518





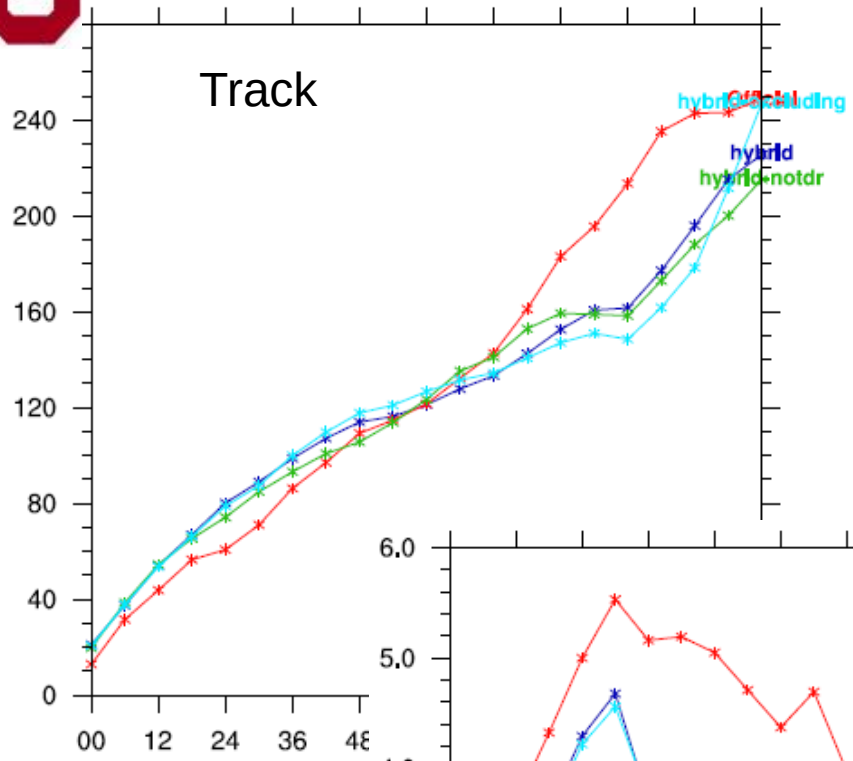


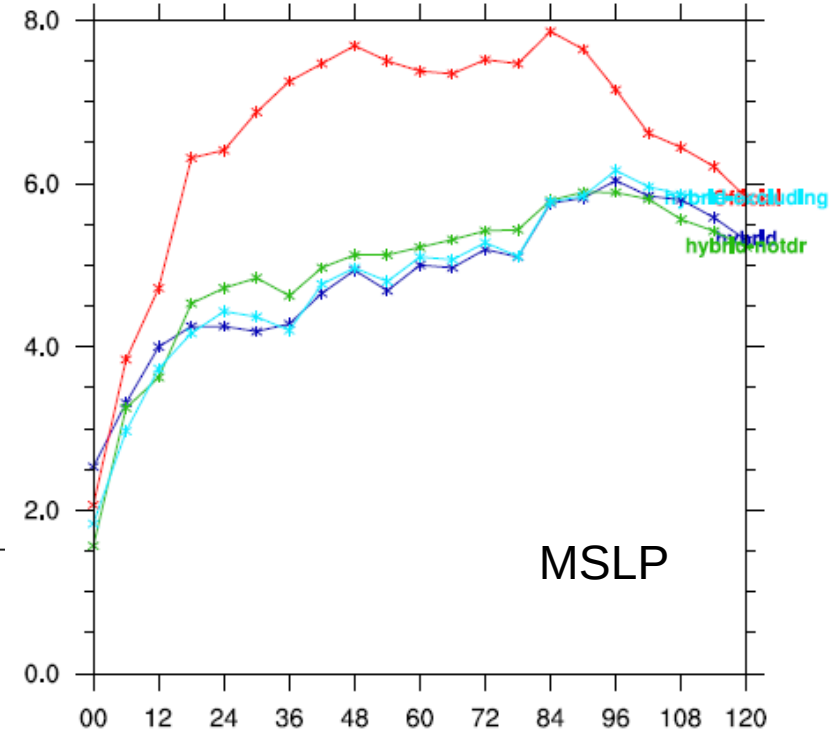
Red contour: pressure background @ 1km height

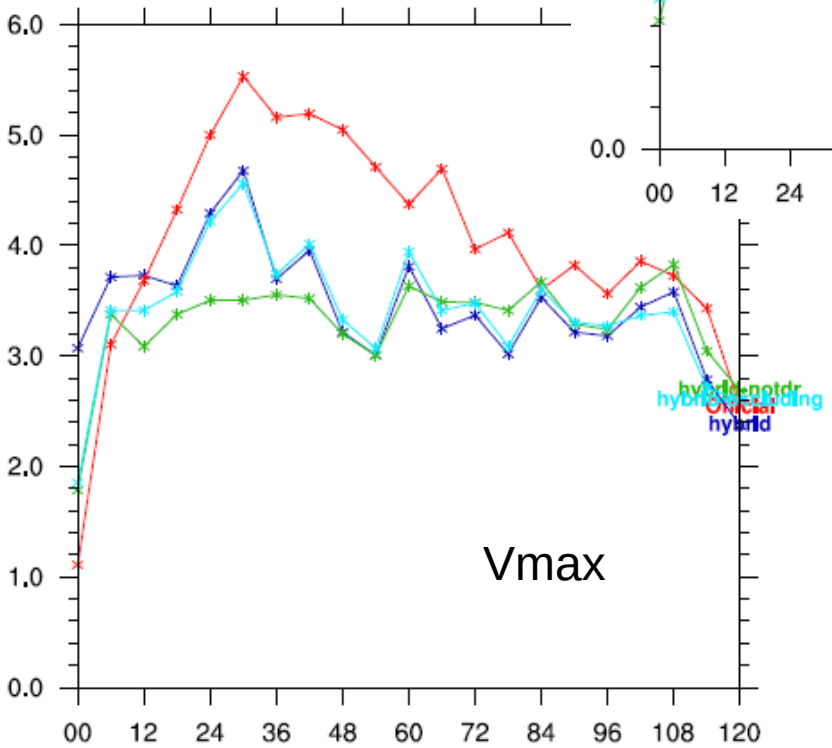
Black contour: positive (solid) and negative (dash) pressure increment @ 1km

Shaded: wind increment @ 1km

Hybrid vs Hybrid-notdr
RMSE for all cycles







- TDR (6hrly) improved MSLP and Vmax at later lead times.
- Hourly or 4DEnVar during TDR periods is expected to see more improvement.