An FV3-LAM multiscale EnVar data assimilation System for 2021 and 2022 Hazardous Weather Testbed Spring Forecast Experiments: System development and systematic impact of valid time shifting (VTS) to increase ensemble size

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UFS Short Range Weather Application Session
Unifying Innovations in Forecasting Capabilities Workshop
College Park, MD

*denote MAP student and early career scientists work

Motivation

- This study describes a EnVar/EnKF hybrid data assimilation (DA) system developed by the OU MAP lab in collaboration with NOAA that includes **multiscale (radar + conventional in situ) DA and is fully coupled with the FV3-LAM toward RRFS implementation.**
- This system was implemented for testing in the realtime 2021 and 2022 NOAA HWT Spring Forecast Experiments (SFEs)
- Controlled experiments each year to test **Valid Time Shifting (VTS; Huang* and Wang 2018, Gasperoni* et al. 2022)** method to increase ensemble size for DA at only fraction of added costs
  - High-dimensional NWP models require large ensembles to sample flow-dependent forecast errors in ensemble-based data assimilation (DA) systems.

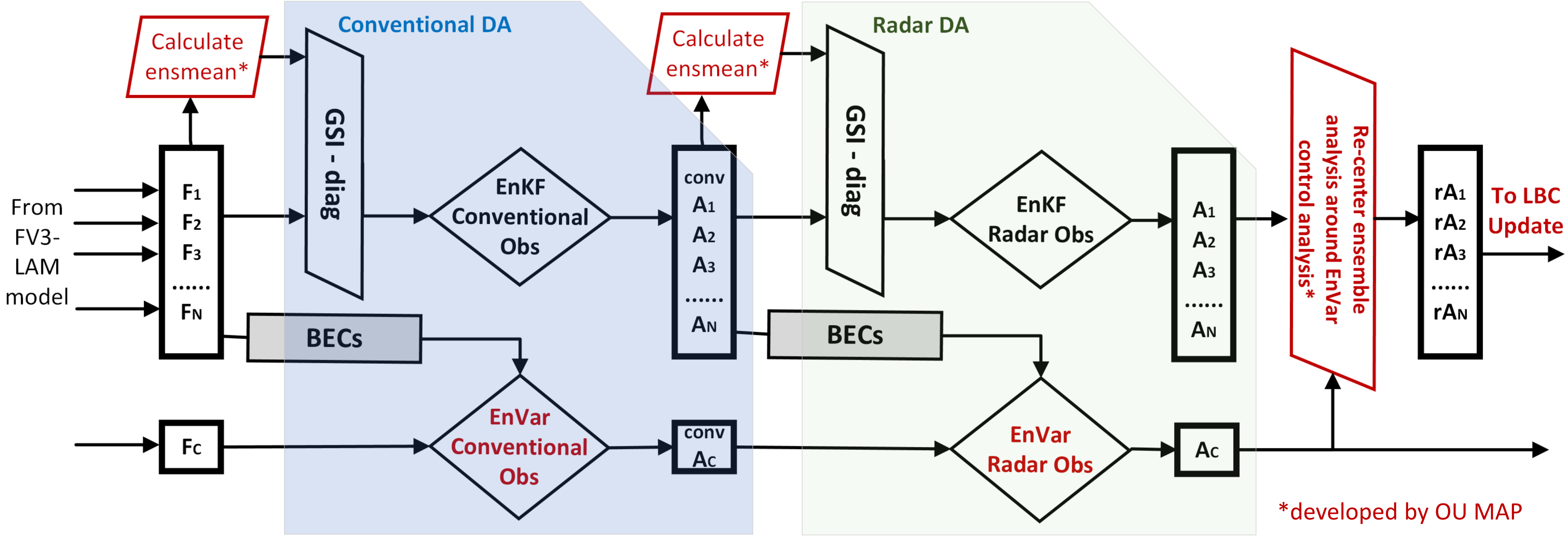
UFS Short-Range Weather App and RRFS

- Collaborative effort among OU MAP, NOAA EMC & GSL and UFS community

- Development efforts for RRFS and UFS short range applications have enabled **developments** of OU MAP multiscale EnVar hybrid system (with direct radar reflectivity DA) **to interface with new FV3LAM model and associated UFS utilities**

- Research and development at OU MAP in turn **directly contribute to the DA developments for the RRFS system**, e.g.
  - Direct assimilation of radar reflectivity in hybrid EnVar system (Wang* and Wang 2017)
  - Convective scale static covariance (Wang* and Wang 2021a)
  - Utilities that enable two way coupled EnVar/EnKF hybrid DA for RRFSv1
  - Potential future implementation of VTS to increase ensemble size at fraction added costs for hourly DA in RRFS

Convective-Scale EnVar System Interfaced with FV3-LAM



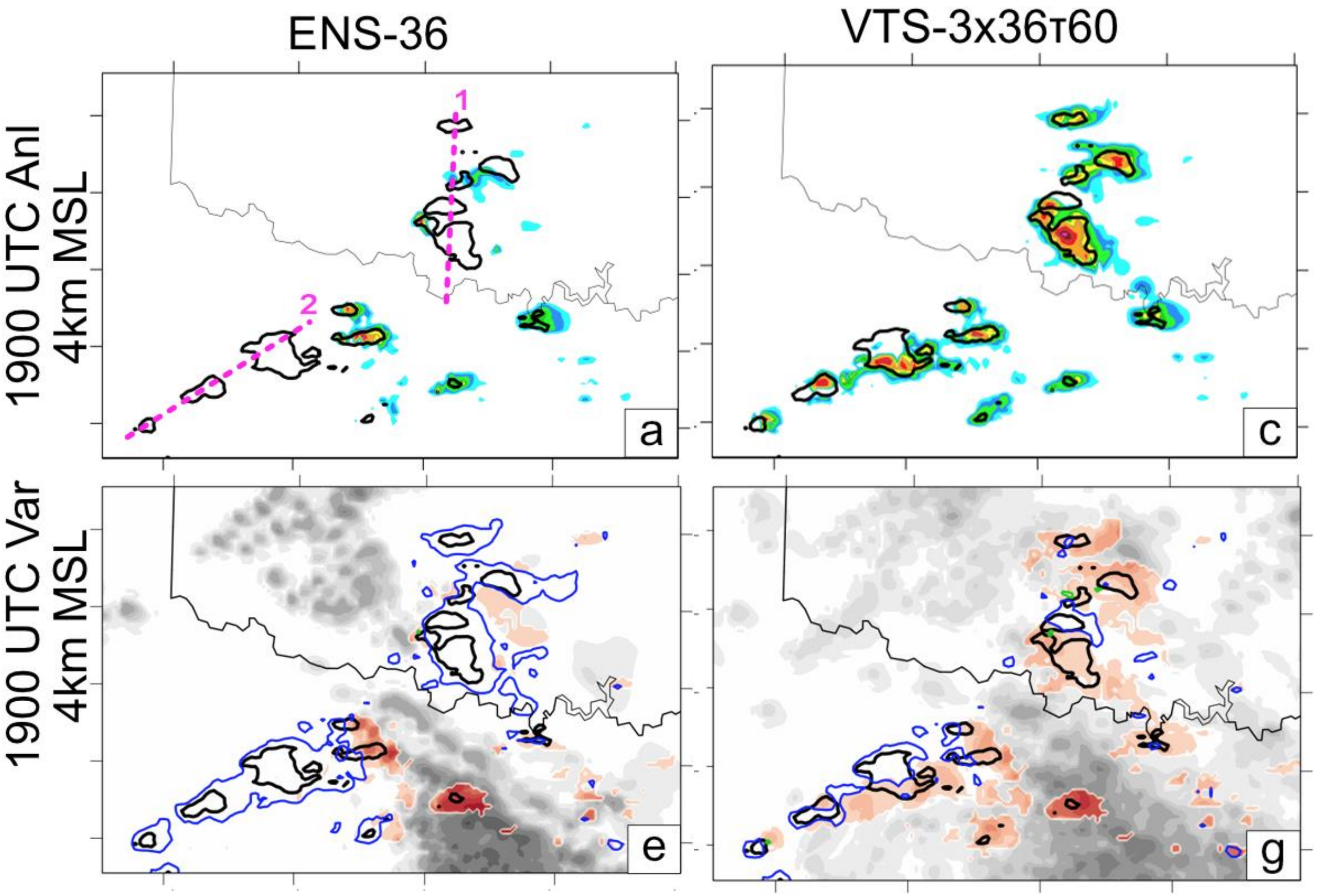
- First attempt for cycled assimilation of both mesoscale in-situ and storm-scale observations with EnVar for FV3-LAM
- Direct radar reflectivity assimilation for hybrid EnVar follows the approach of Wang* and Wang 2017 (direct dBZ assimilation) and Wang* and Wang 2021a (convective scale static B)
- Utilities added and enhanced for the FV3LAM GSI-based EnVar system includes calculation of ensemble mean, recentering, enhanced LBC update, and ensemble parallel I/O for EnVar

Valid Time Shifting (VTS) for Convective-scale DA

Results of radar VTS case study

Gasperoni*, Wang and Wang* 2022a

- **Valid Time Shifting (VTS)** increases (triples) ensemble size for DA by including ensemble members **valid at different lead times** but initialized from same previous analysis.
  - VTS samples **time-related uncertainty**, *e.g.* timing errors of convection initiation or phase errors in established MCS's
  - Better analysis fit to radar obs due to increased ensemble variance



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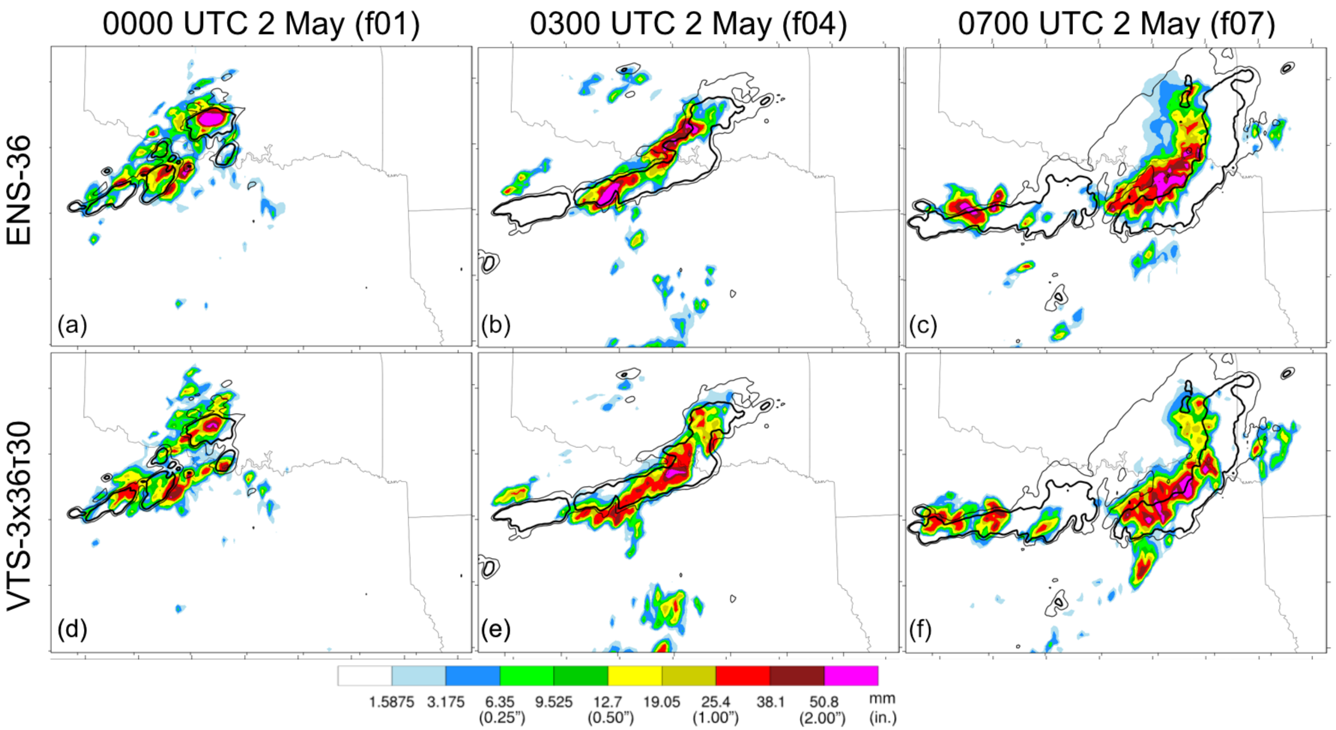
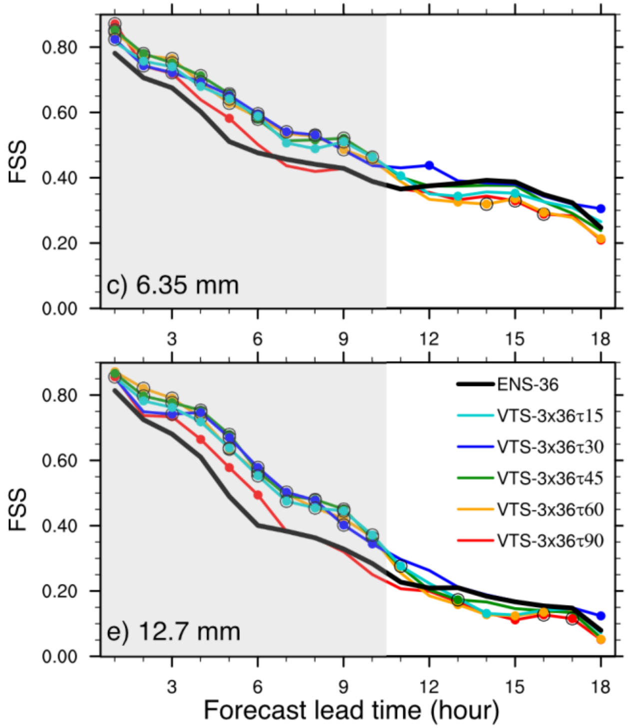
Valid Time Shifting for Convective-scale DA

Results of radar VTS case study

Gasperoni*, Wang and Wang* 2022a

- **Improvements to control free forecast** in storm location, coverage, and MCS structure
- **Larger FSS** than no VTS run (ENS-36) throughout first 12 hours of forecast, statistically significant up to hr 10
  - Optimal **time shifting interval, *τ*,** is between **30-60 min**





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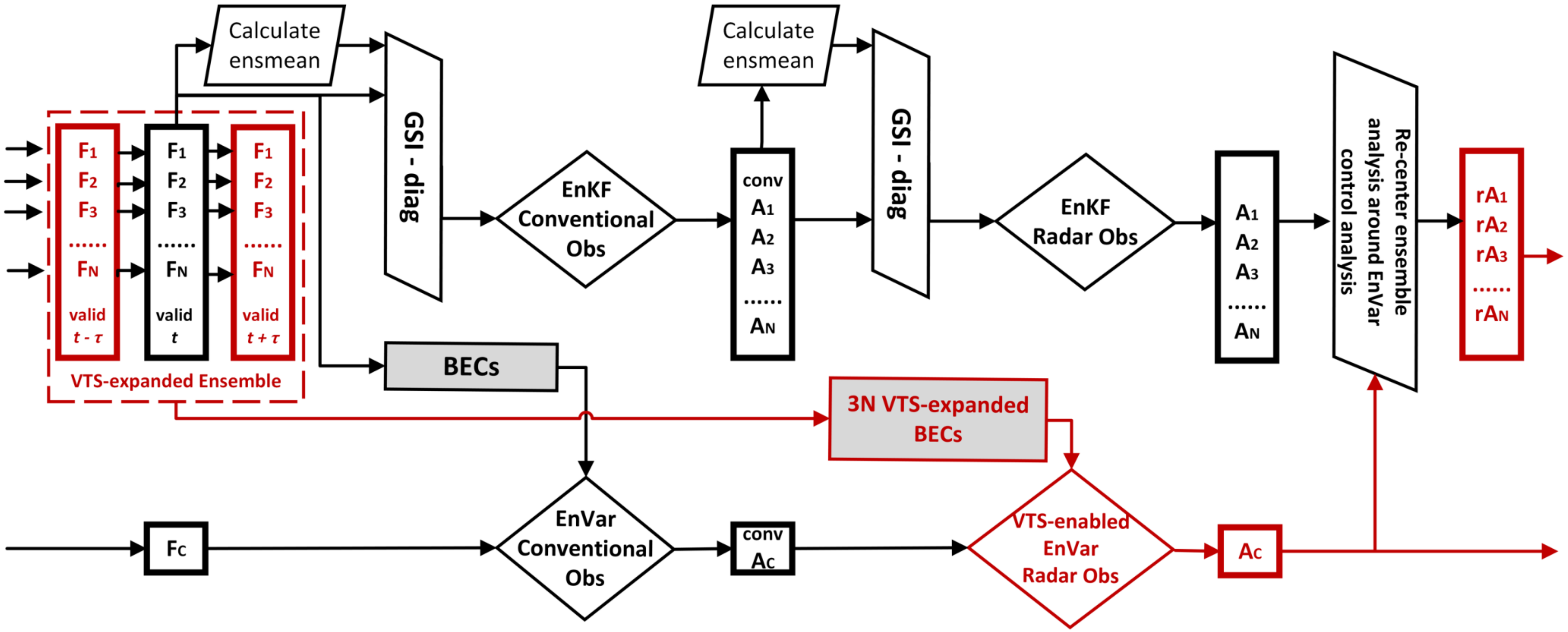
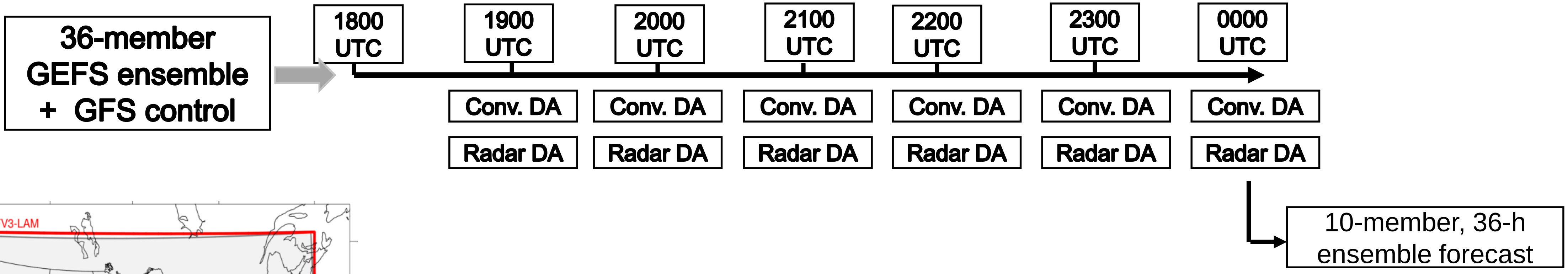
FV3-LAM VTS DA Component Flowchart

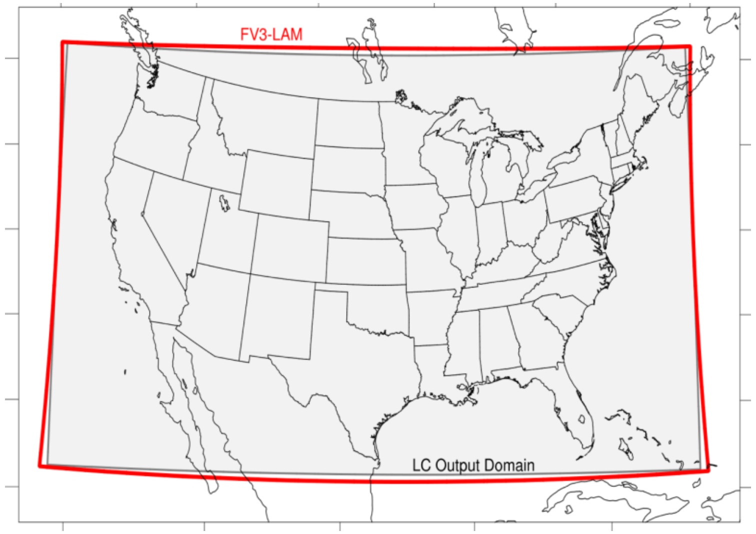


- Red indicates steps modified by enabling VTS
- **Time shifting interval, τ**, defines difference between central analysis time and valid time of shifted sub-ensembles
- Based on case study results (Gasperoni et al. 2022a), during 2021 SFE we applied **30-min. τ and double localization scale (30 km) for radar DA.**
- The recentered ensemble is also different due to recentering (indirect effect of VTS)

Realtime 2021 HWT SFE Experiment Design

Gasperoni*, Wang and Wang* 2022b



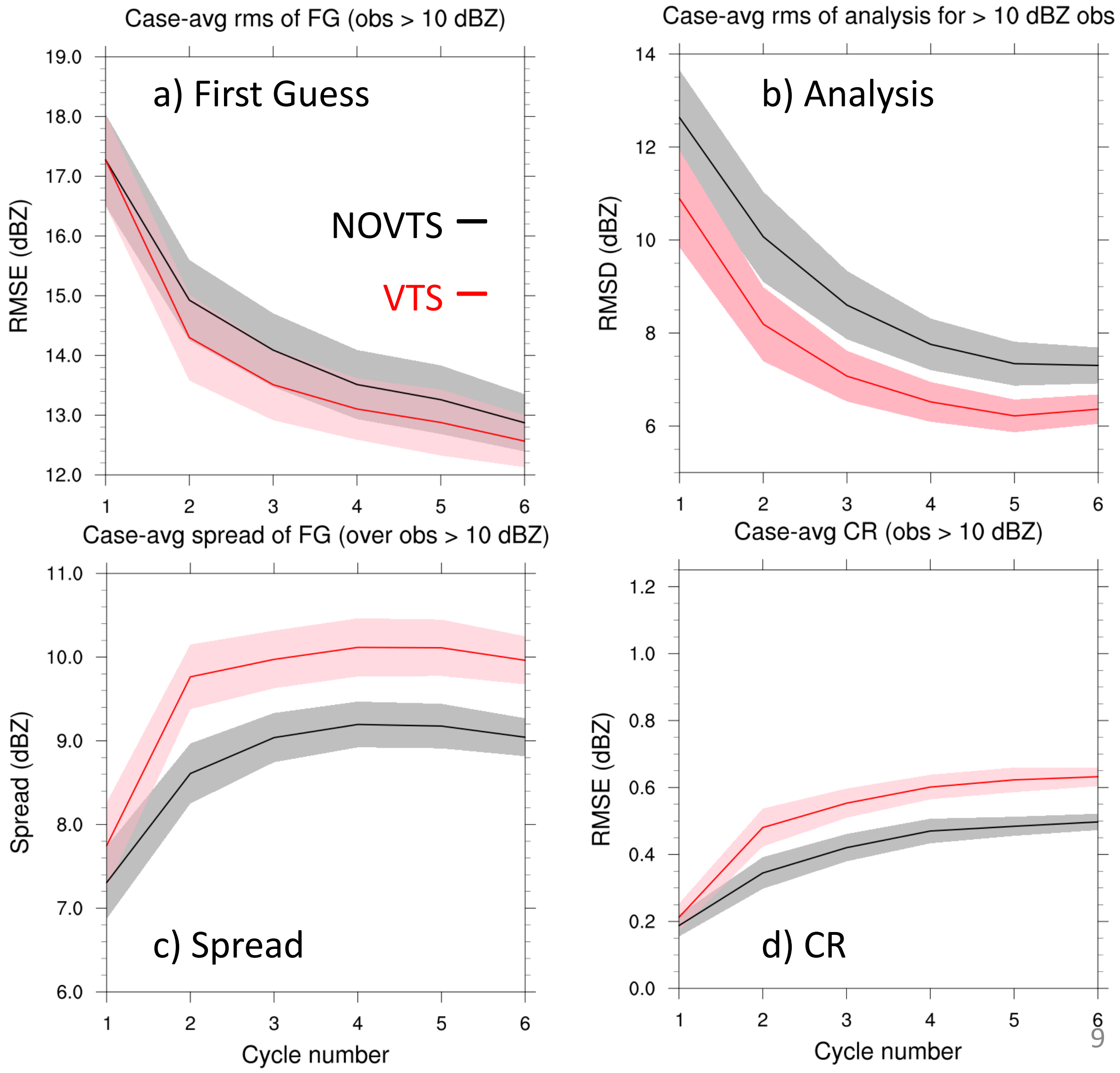


- Both conventional (in situ) and radar observations are assimilated **hourly.**
- **Both VTS and NoVTS (RRFS) systems share the same DA and model configuration except one uses VTS for radar DA and the other without.**
- 3km horizontal resolution, CONUS domain, HRRR physics (single physics ensemble)

Gasperoni, N.A., X. Wang, and Y. Wang (2022b): A multiscale RRFS-like FV3-LAM convection-allowing GSI-based EnVar data assimilation and forecast system for the real-time 2021 HWT Spring Forecast Experiment: System description and experiments with valid time shifting, *Mon. Wea. Rev.*, in review

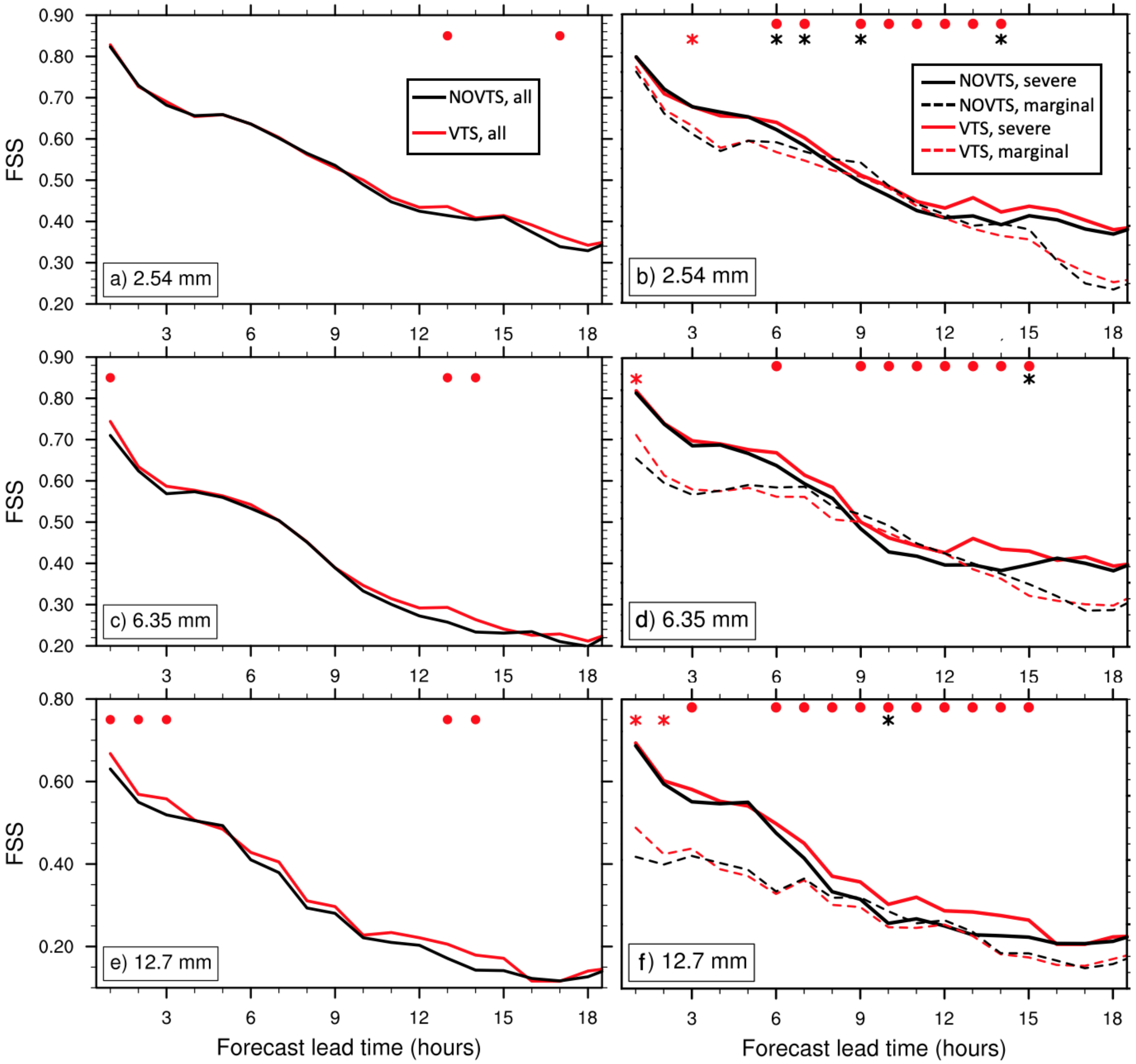
2021 HWT Objective Results: DA Cycling

- VTS has lower average first guess RMSE (0.5-1 dBZ), significantly closer analysis fit to observations (1-2 dBZ), higher spread (1 dBZ), and higher consistency ratio (0.1-0.2)

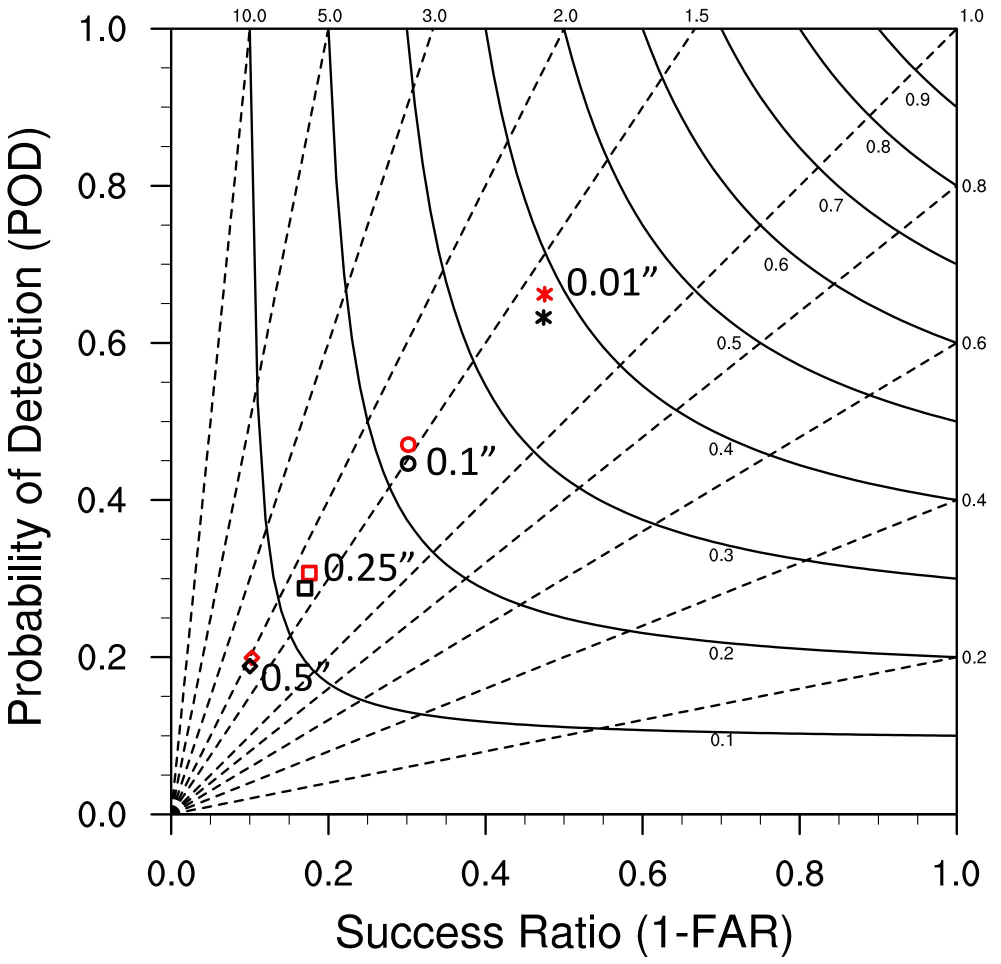


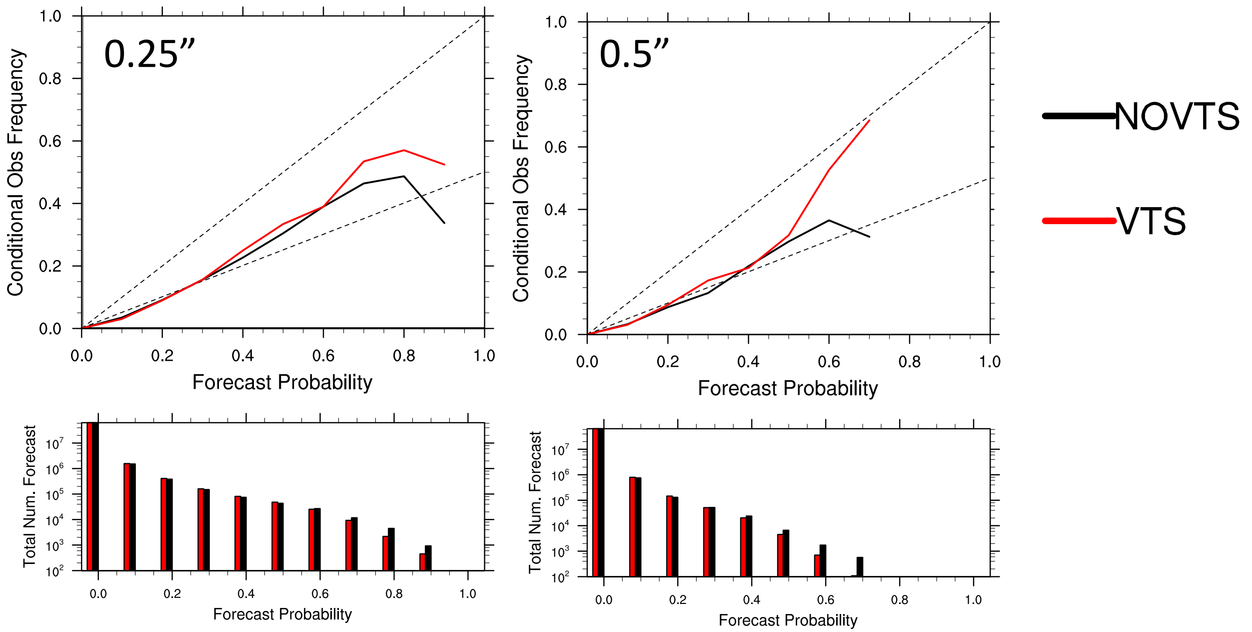
2021 HWT Objective Forecast Verification: FSS

- 48-km FSS of 1-h precip. shows **skill improvements** throughout first 18 hours of forecast
  - Systematic improvement across all thresholds (22 HWT cases total)
- Largest, significant improvements seen for **severe cases from f6-15** (right column)
  - "severe" – minimum SPC slight risk and at least 50 observed storm reports
  - "marginal" – all other cases



HWT Objective Verification: 1-h Precipitation (Reliability, Perf. Diagram)

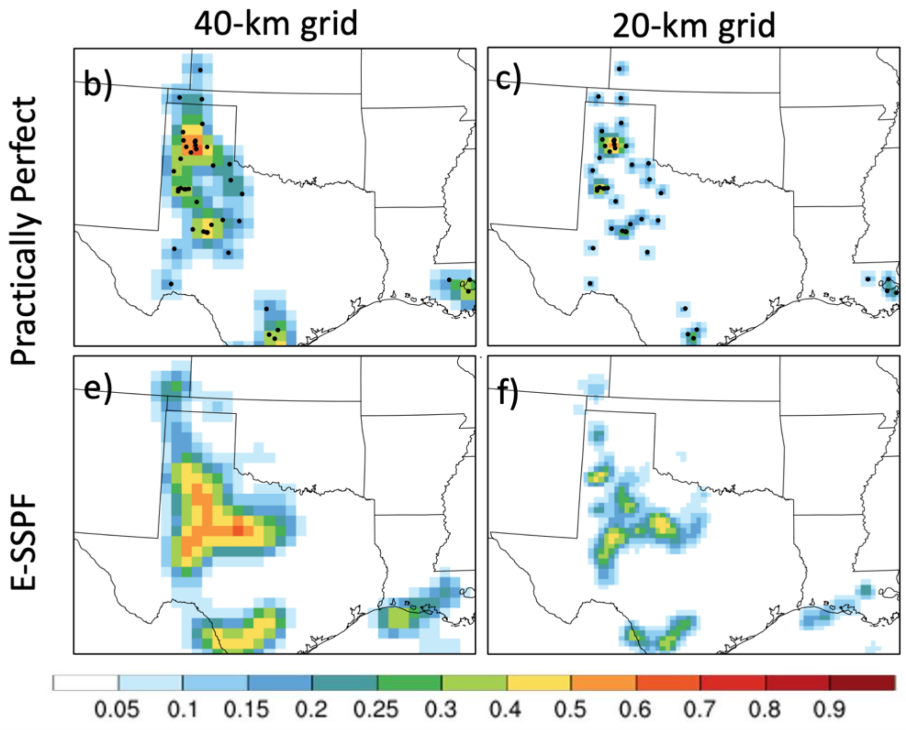


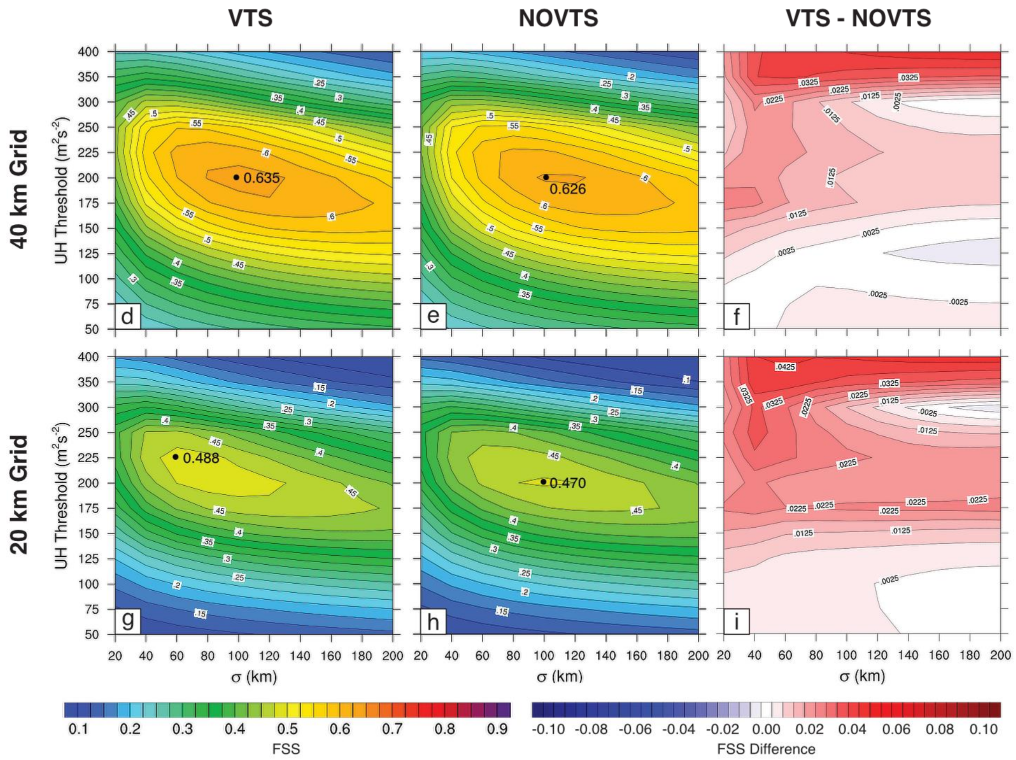


- Shown for forecast hours 1-3
- Systematic increased **POD (CSI)** and **reliability** for early forecast hours 1-3

2021 HWT Storm-surrogate Verification

- Verification of severe hazards via **"ensemble storm surrogate probabilistic forecast**" (Sobash et al. 2016)
  - 2-5km ensemble max UH as surrogate for severe wind/hail/tornado reports
  - Verified against "practically perfect" probabilities, created from observed storm report locations
- Systematic FSS improvements of VTS compared to NOVTS, with largest differences at **extreme UH thresholds (≥ 300 m^2 s^{-2}) and smaller scales (20 km grid, less spatial smoothing)**

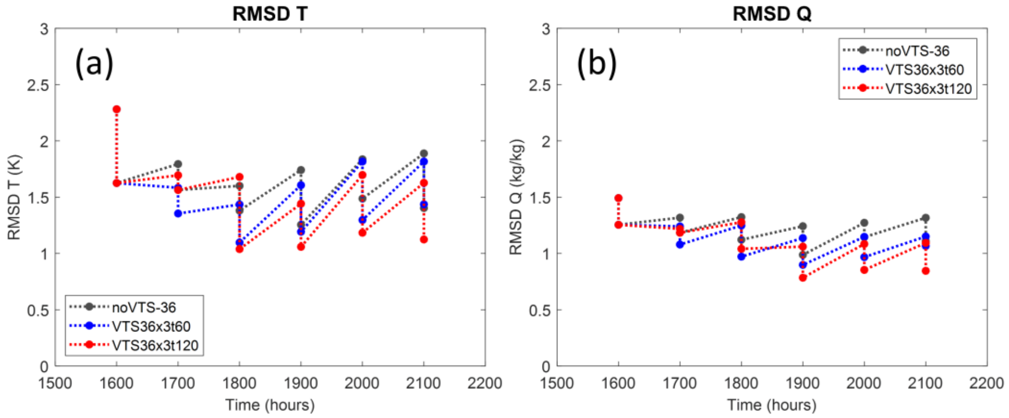


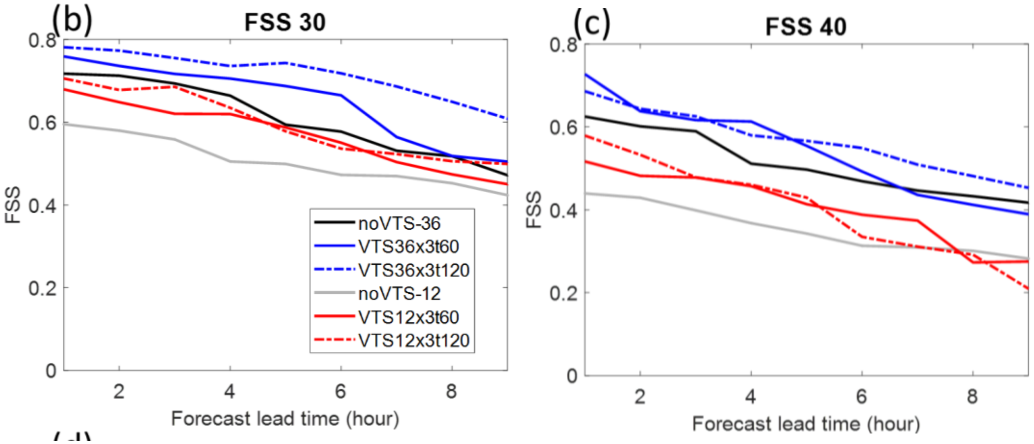


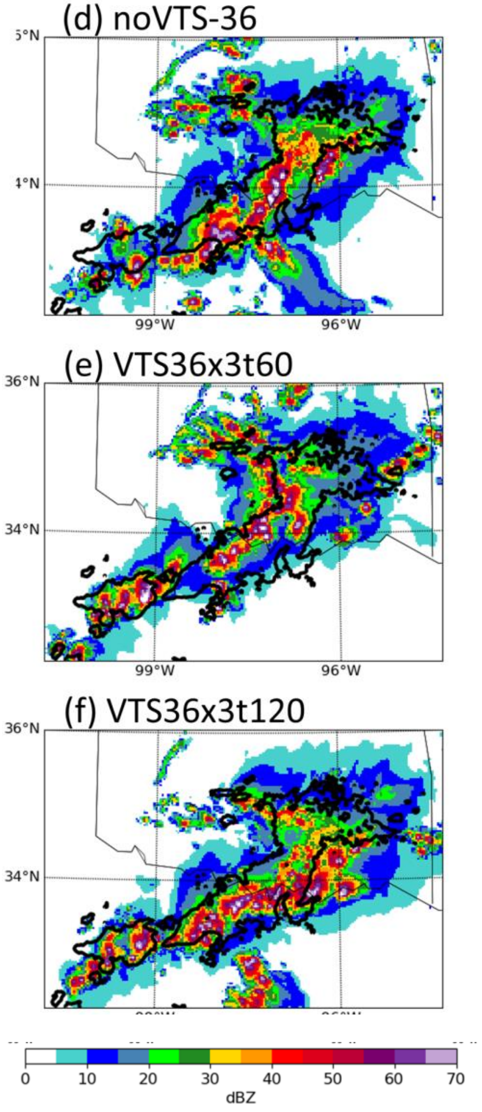
VTS for mesoscale in-situ data assimilation: 1-2 May 2019 Case Study

(Li*, Wang, Gasperoni*, Wang* et al. 2022)

- Also tested VTS for conventional in situ observations DA for mesoscale environment analysis
- Reduced error in EnVar analysis and first guess during DA cycling (T and q obs)
- Improvements in 3x36 VTS compared to noVTS for 9-hour forecast, with improved location and storm coverage







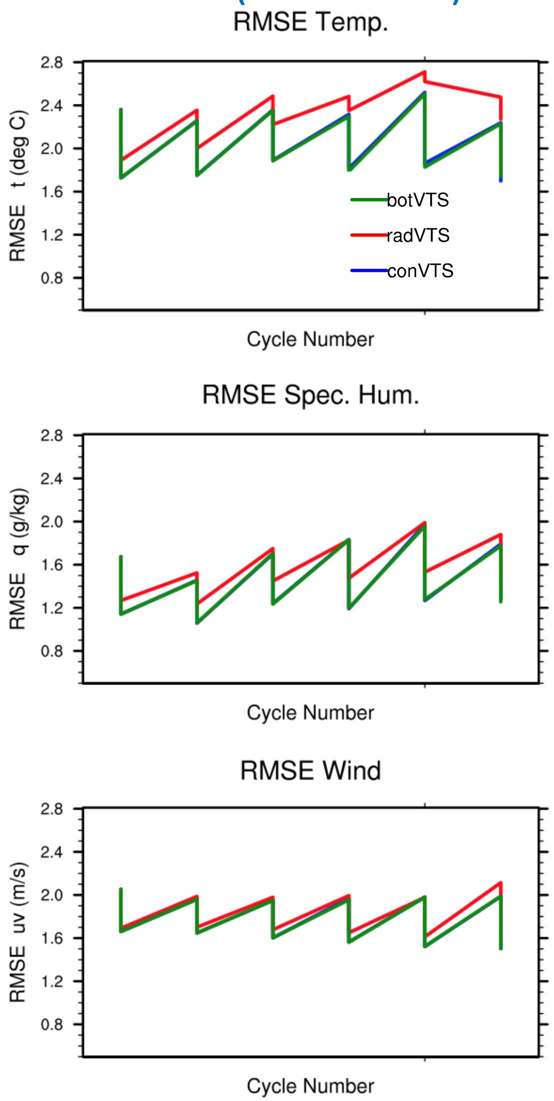
Li, T.-H., X. Wang, G. Nicholas, Y. Wang, 2022: Assessing the impact of the cost-effective valid-time-shifting method on the EnVar analysis of the storm environment. to be submitted.

2022 HWT VTS experiments

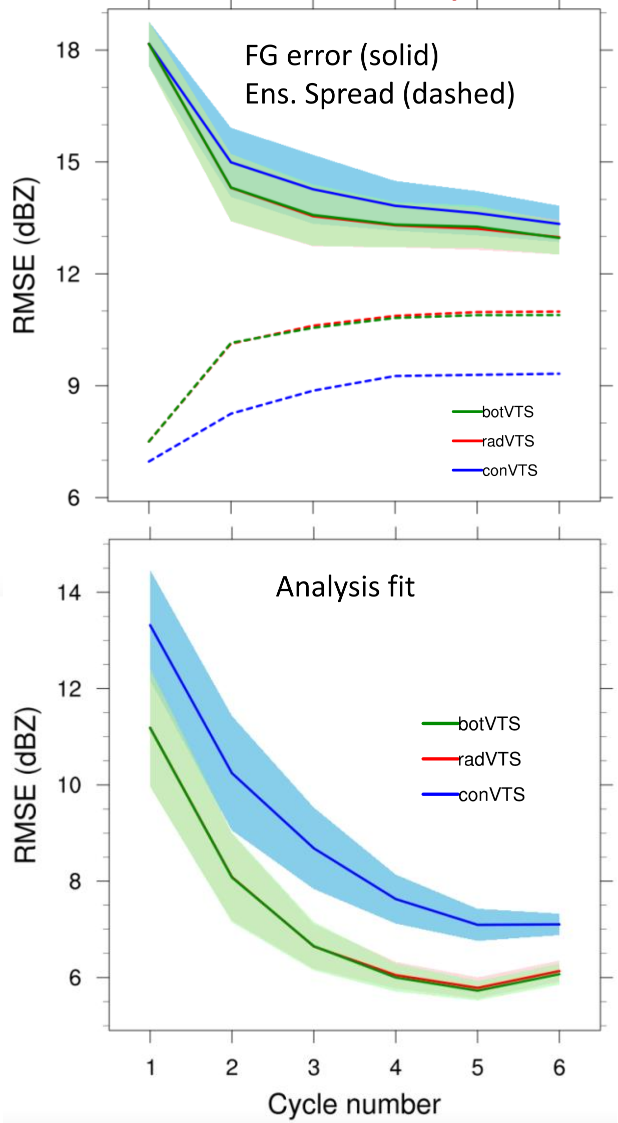
- In 2022 we tested both radar and conventional VTS separately and together for the first time.
  - ➢ **Three realtime configurations:**
  - **(1) radar VTS (radVTS)**
  - **(2) conventional in-situ obs VTS (conVTS)**
  - **(3) both component VTS (botVTS)**

- Verification of DA cycling indicates botVTS has similarly improved accuracy to radVTS for reflectivity DA, and similarly improved accuracy to conVTS for mesoscale DA (esp. T,q)

In Situ (mesoscale) DA



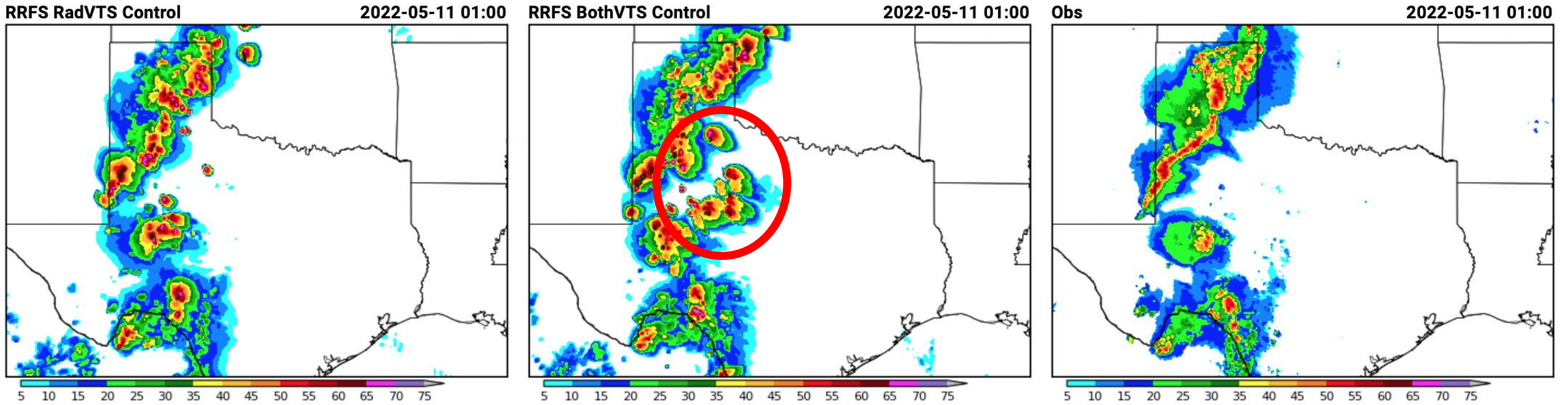
Radar reflectivity DA



Subjective results 2022 HWT

- Subjective results indicate radVTS tends to outperform botVTS for early forecast in terms of **spurious convection**

f01



Subjective results 2022 HWT

- Subjective results indicate radVTS tends to outperform botVTS for <u>early forecast</u> in terms of **spurious convection**

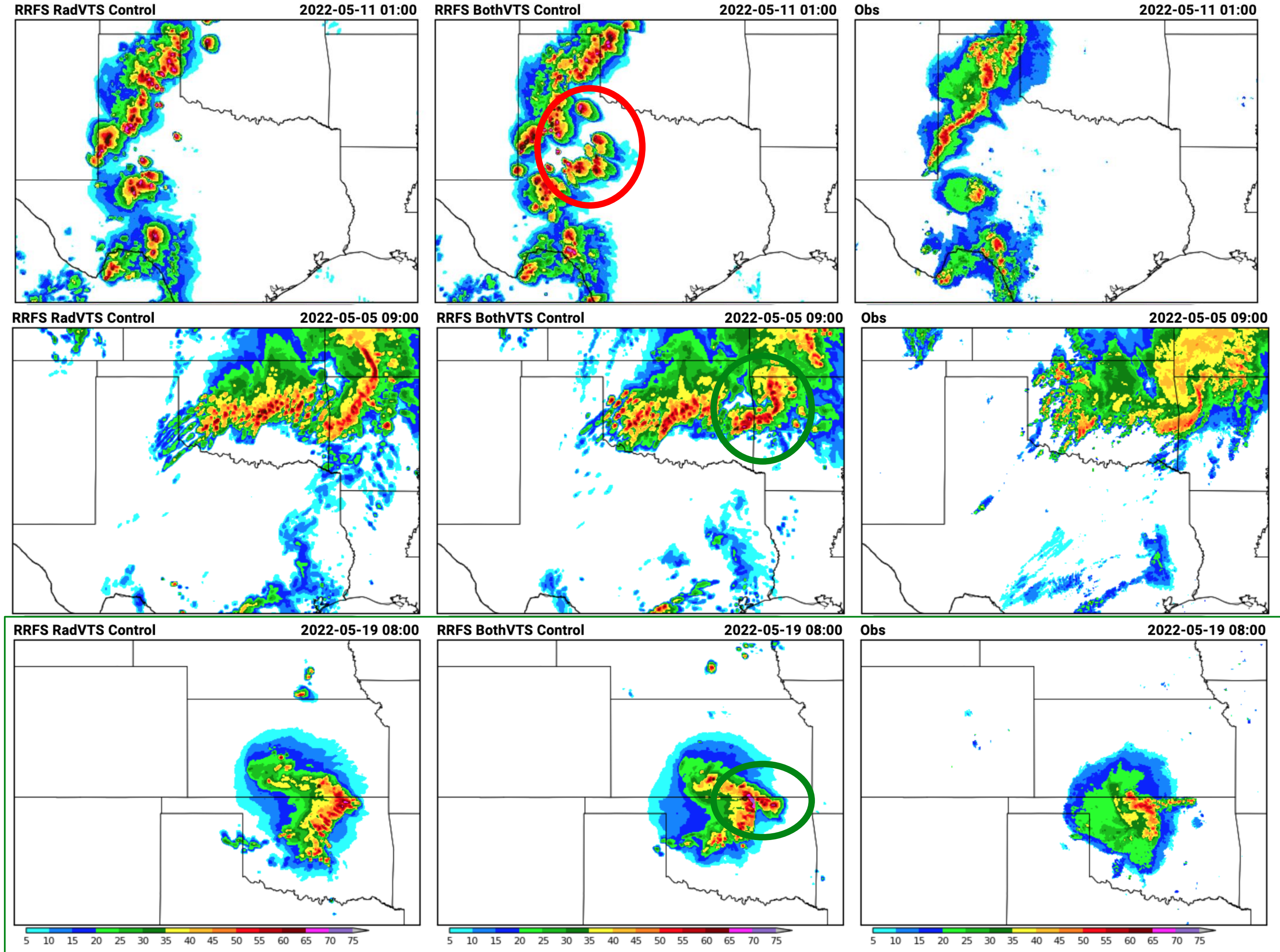
- However **subjective improvements for botVTS seen in forecast hours 6-12** relative to radVTS.

- Case examples show better structure/location of MCS in botVTS compared to radVTS

f01

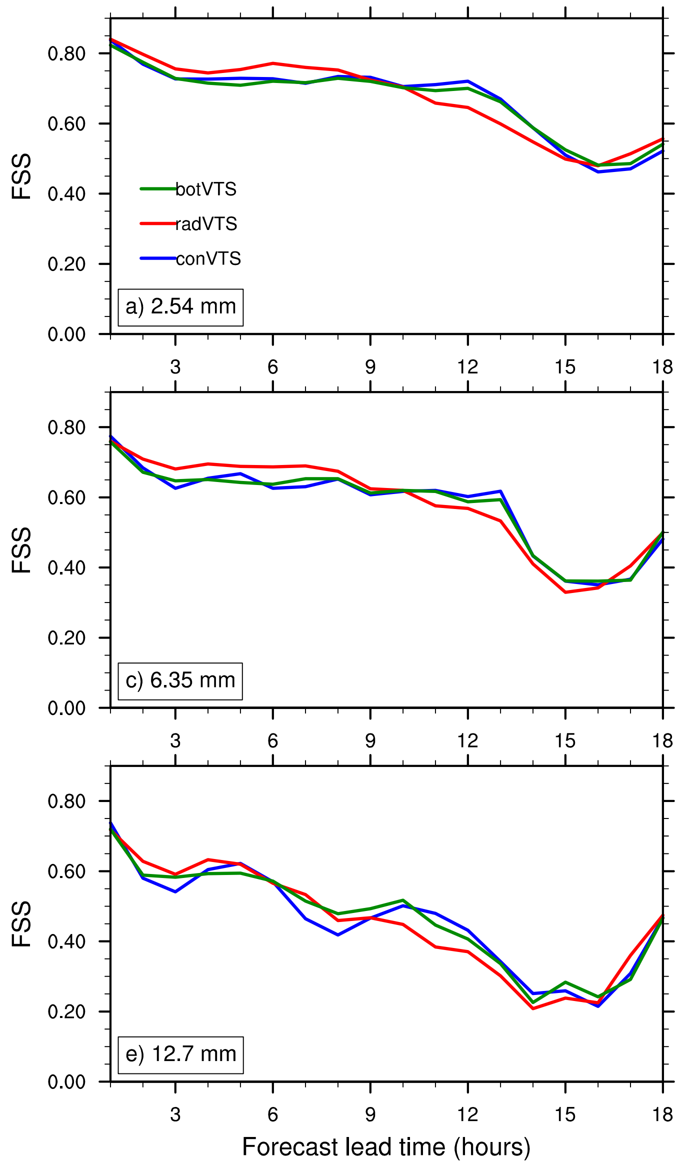
f09

f08



Preliminary Neighborhood Verification

- radVTS has highest scores in light and medium precip for f1-8
- botVTS, conVTS perform similarly, with higher scores than radVTS in f9-15
- Diagnostics are ongoing to further understand the results and to optimize the VTS configuration



Conclusions

- Two way coupled EnVar/EnKF hybrid DA with direct assimilation of radar reflectivity was developed for FV3-LAM for potential RRFS implementation.

- Valid Time Shifting (VTS) is further implemented in the hybrid DA and tested retrospectively and in real time during 2021 and 2022 HWT.

- For 2021 HWT SFE: Two parallel configurations with and without VTS for radar DA, to test impact on 00Z forecasts of convective systems
  - VTS increases ensemble size by factor of 3 at a fraction of the cost (estimated **40-50% added cost from SFE**)
  - Radar VTS has improved DA statistics; Better 1-12h forecast scores in 1-h precip (FSS; FBIAS; POD; reliability) and severe hazards prediction (esp. at small scales) using storm surrogate verification.

- For 2022 HWT SFE: Three configurations testing radar VTS only (radVTS), conventional VTS only (conVTS), and combined radar and conventional VTS (botVTS).
  - botVTS statistically matches benefits of radar VTS for storm-scale DA and conventional VTS for mesoscale DA
  - radVTS performed best in early forecast hours; con/botVTS performed better for later forecast hours

Ongoing and Future Work

- Further verification and diagnostics of 2022 HWT SFE configurations
- Continue focusing on improving mesoscale observations DA to improve storm environment analysis
- Optimize VTS and multiscale DA (see Xuguang Wang talk 9a Thur July 21 “Science Spotlight on Data Assimilation”)
- Assist NOAA to implement two way coupled EnVar/EnKF hybrid DA and additional new DA R&D for RRFS
- Transition developments into JEDI

Thank You! Questions?

References

Gasperoni*, N. A., X. Wang, & Y. Wang* (2022a). Using a cost-effective approach to increase background ensemble member size within the GSI based EnVar system for improved radar analyses and forecasts of convective systems, *Monthly Weather Review,* ***150****,* 667-689. https://doi.org/10.1175/MWR-D-21-0148.1

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Huang*, B., and X. Wang, 2018: On the use of cost-effective Valid-Time-Shifting (VTS) method to increase ensemble size in the GFS Hybrid 4DEnVar System. *Mon. Wea. Rev.*, **146**, 2973–2998, https://doi.org/10.1175/MWR-D-18-0009.1.

Li*, T.-H., X. Wang, N. Gasperoni*, Y. Wang*, 2022: Assessing the impact of the cost-effective valid-time-shifting method on the EnVar analysis of the storm environment. to be submitted.

Wang*, Y., and X. Wang, 2017: Direct assimilation of radar reflectivity without tangent linear and adjoint of the nonlinear observation operator in the GSI-based EnVar system: Methodology and Experiment with the 8 May 2003 Oklahoma City Tornadic Supercell. *Mon. Wea. Rev.*, **145**, 1447–1471, https://doi.org/10.1175/MWR-D-16-0231.1.

——*, and ——, 2021a: Development of convective-scale static background error covariance within GSI-based hybrid EnVar system for direct radar reflectivity data assimilation, *Mon. Wea. Rev.,* **149**, 2713-2736, https://doi.org/10.1175/MWR-D-20-0215.1

——*, and ——, 2021b: Rapid update with EnVar direct radar reflectivity data assimilation for the NOAA regional convection-allowing NMMB model over the CONUS: System description and initial experiment results. *Atmosphere*, **12**, 1286, https://doi.org/10.3390/atmos12101286.