Improving CONUS Convective-Scale Forecasting with Simultaneous Multiscale EnVar Data Assimilation

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Introduction

- Regional convective-allowing model (CAM) (e.g. RRFS) is capable of resolving convective storms and the large-scale environment where storms evolve.
- Over CONUS, a myriad of observation platforms (e.g., conventional in-situ, satellite radiance, and radar observations) are available to sample a wide range of scales.
- For skillful storm prediction, a multiscale data assimilation (MDA) is required to accurately estimate the atmospheric state from synoptic scale to convective scale by properly extracting info. from all available observations for CAM.
- Past studies developed the simultaneous MDA, which allows all resolved scales to be updated simultaneously and all observations to be assimilated at once.
- Simultaneous MDA was developed in both EnVar (e.g., Buehner and Shlyaeva 2015; Huang* et al. 2021) and pure EnKF (MLGETKF, Wang* X. et al. 2021).

*denote OU MAP authors

Introduction

- These studies enable simultaneous MDA through implementing scale-dependent localization (SDL) in model space.
- Wang, Y. and X. Wang (2023) further developed simultaneous MDA through integrating SDL and variable-dependent localization (VDL). Their studies revealed the critical impact of both SDL and VDL for convective scale prediction.
- Wang, Y. and X. Wang (2023) only explored the impact of SDL and VDL with an isolated supercell storm and through the assimilation of only radar observations.
- Limited studies have implemented and evaluated simultaneous MDA with SDL and VDL on convective-scale forecasts over CONUS where 1) multiple observation platforms sample various scales and 2) multiple weather scales from synoptic scale to convective scale co-exist.

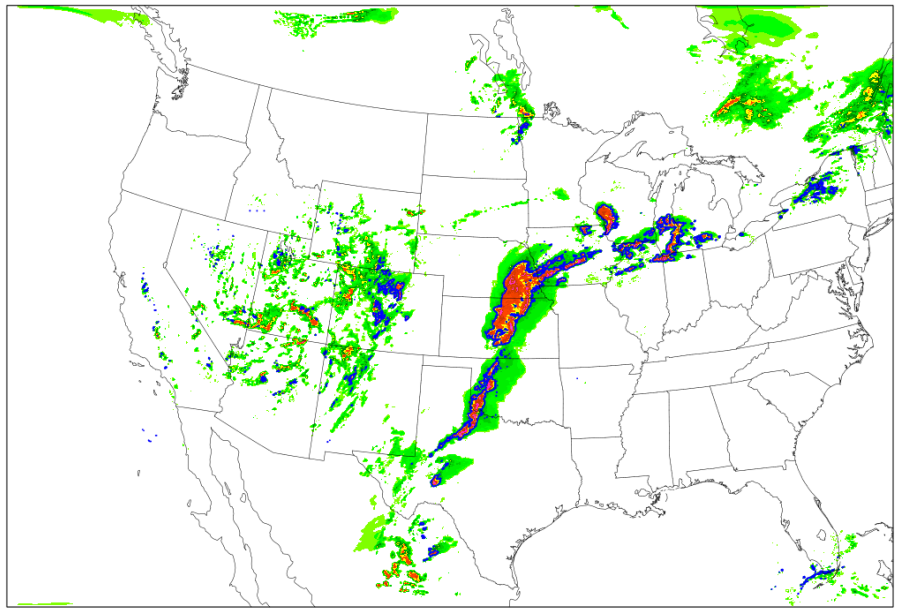
Objectives

- This study aims to

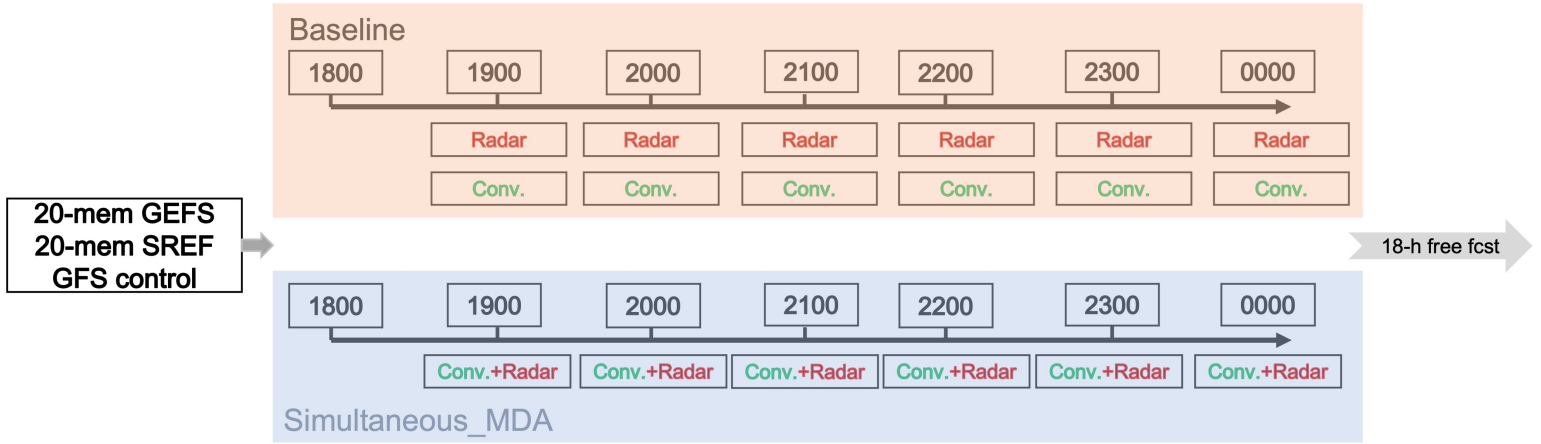
1) implement and evaluate simultaneous EnVar MDA system with SDL and VDL for CONUS convective-scale prediction with various observation platforms sampling multiple scales;

2) understand the impact of simultaneous MDA on analysis and forecast of CONUS convective storms from the physical understanding perspective.

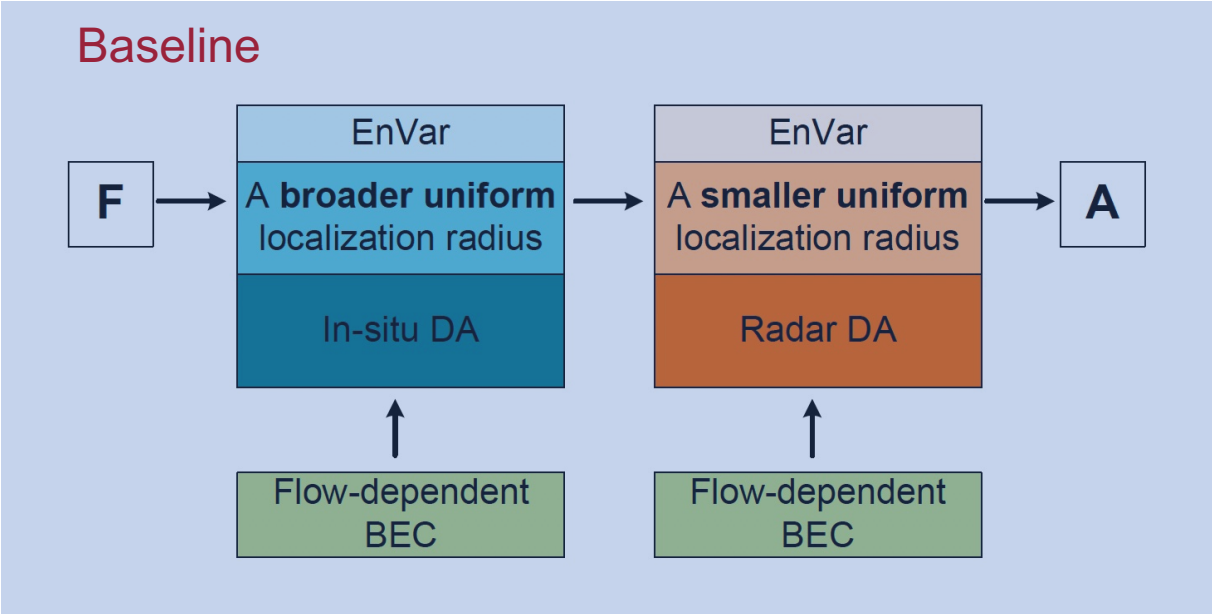
Experiment design
Model and DA configuration

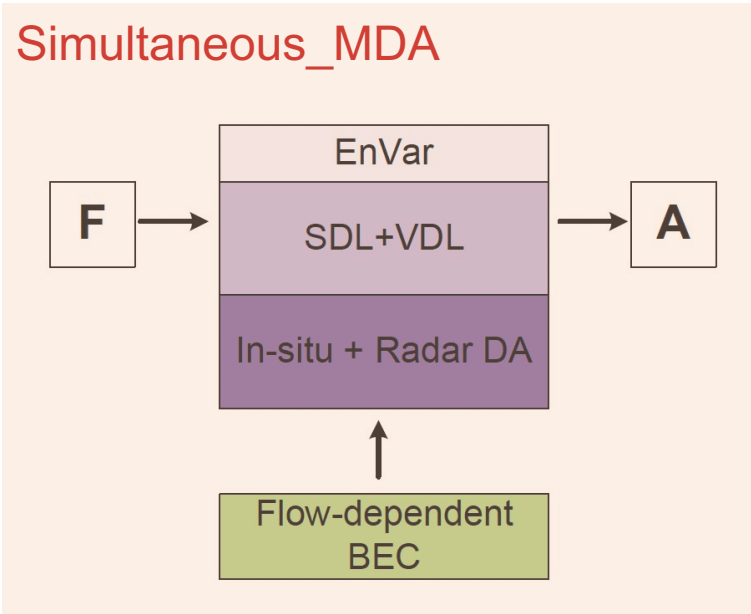


Model options	Specification
Grid size and resolution	1621×1121×51; 3 km
Microphysics	Thompson
PBL	MYNN
Radiation	RRTMG
Land surface model	Noah



Experiment design
Model and DA configuration



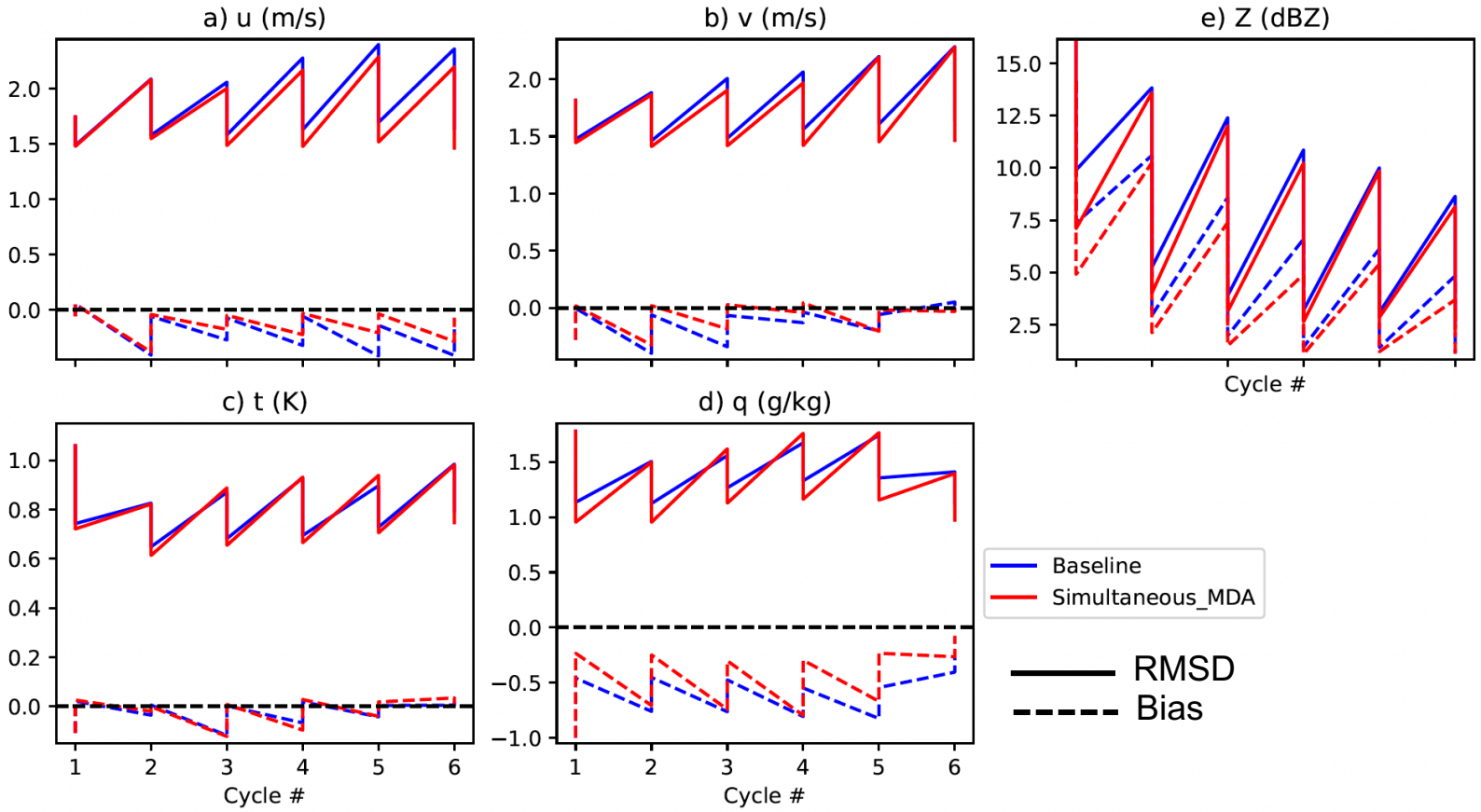


Exps	Assimilation Strategy	Localization scales	
Baseline (Ope.-like)	Separate assimilation of in-situ and radar obs.	In-situ obs.	300 km
		Radar obs.	15 km
Simultaneous_MDA	Simultaneous assimilation of in-situ and radar obs.	Small scale	15 km: hydrometeors, and *w*
			60 km: *u*, *v*, *t*, *q*, and ps
		Large scale	60 km: hydrometeors, and *w*
			500 km: *u*, *v*, *t*, *q*, and ps

Results

1. Comparison between Simultaneous_MDA and Baseline

a. DA cycling



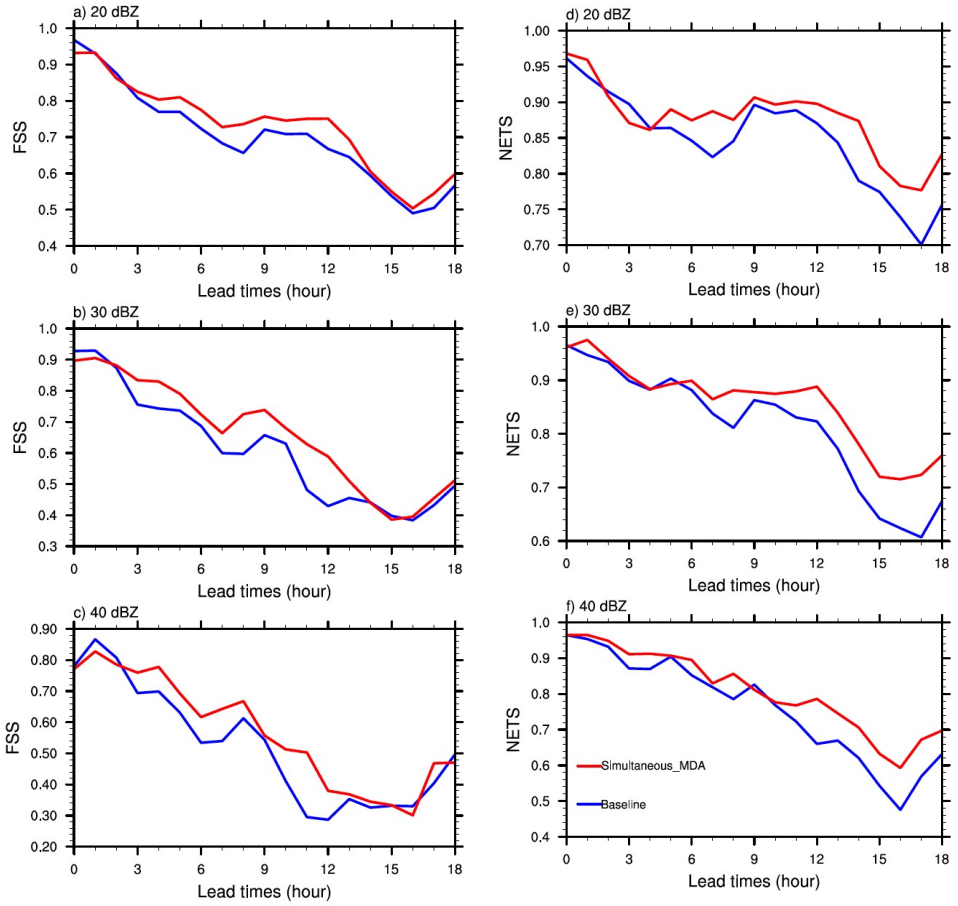
RMSD & Bias of OMA & OMB for *u*, *v*, *t*, *q*, and *Z* in DA cycling

- The priors of Simultaneous_MDA fit better to *u*, *v*, *q*, and radar observations than Baseline.
- These results indicate that Simultaneous_MDA produces more accurate multiscale analyses, and its advantage can be maintained in the subsequent 1-h forecasts, compared to Baseline.

Results

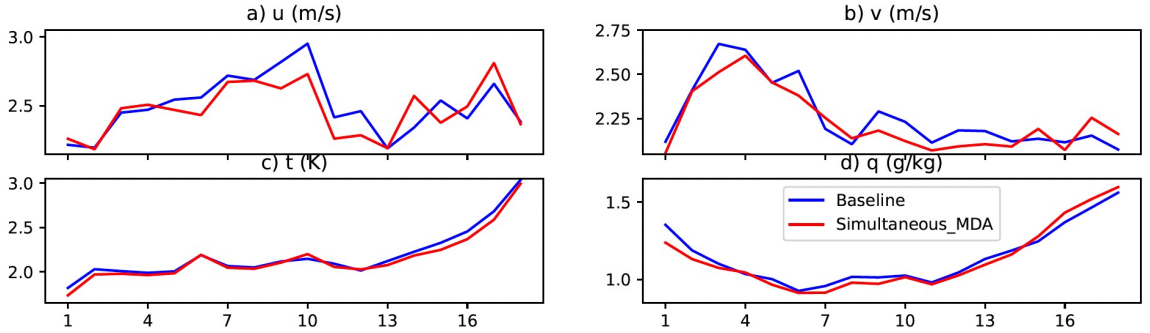
1. Comparisons between Simultaneous_MDA and Baseline

b. Free forecast



FSS and NETS for composite reflectivity

- For composite reflectivity forecast, Simultaneous_MDA remarkably outperforms Baseline in the majority of forecast leading time.

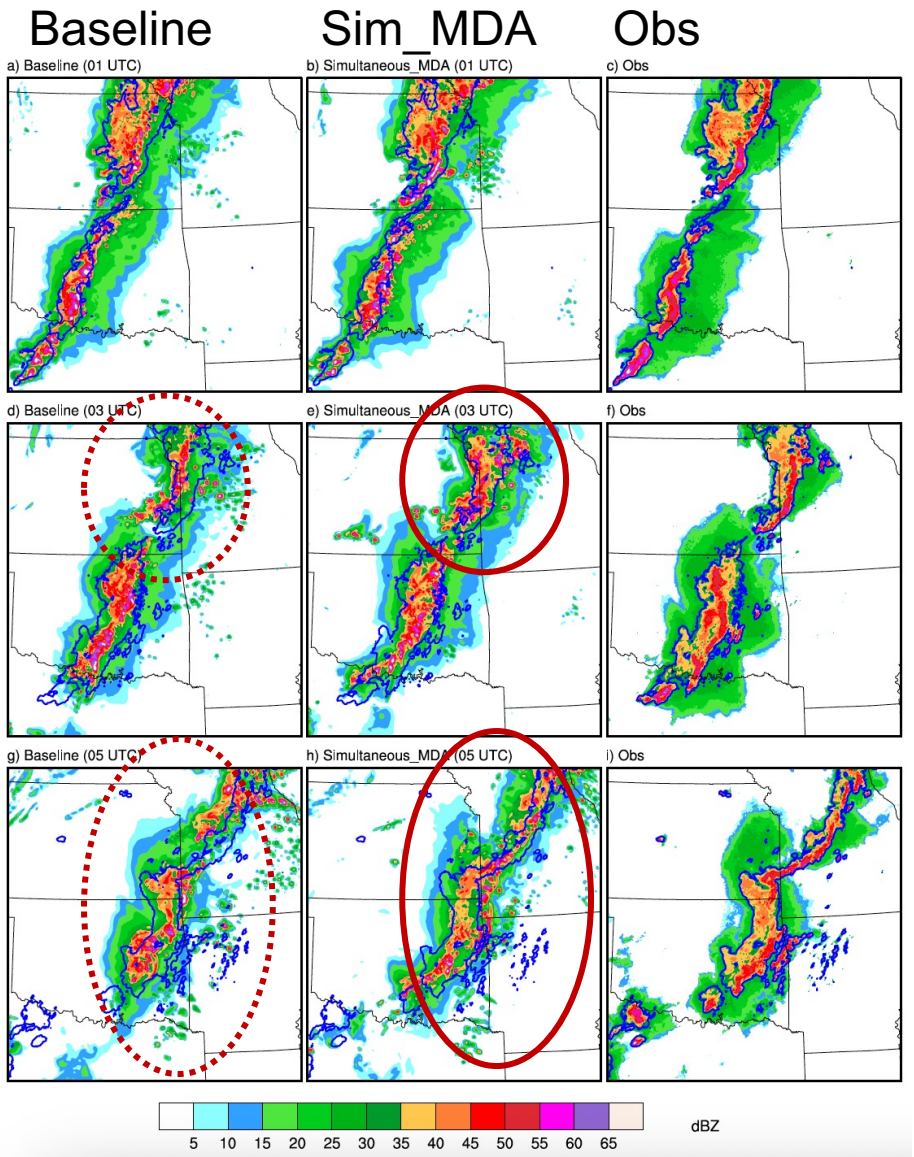


- Verification against in-situ observations shows that Simultaneous_MDA produces better forecasts of *u, v, t*, and *q* than Baseline in the majority of the 18-h forecast leading time.

Results

1. Comparisons between SDLVDL_MDA and Baseline

b. Free forecast



- Consistent with the quantitative verifications, large differences between Baseline and Sim._MDA appear from the forecast hour 3.
- The outperformance of Sim._MDA over Baseline is attributed to its improved reflectivity coverage and organization.

Results
2. Understanding the impact of Simultaneous_MDA

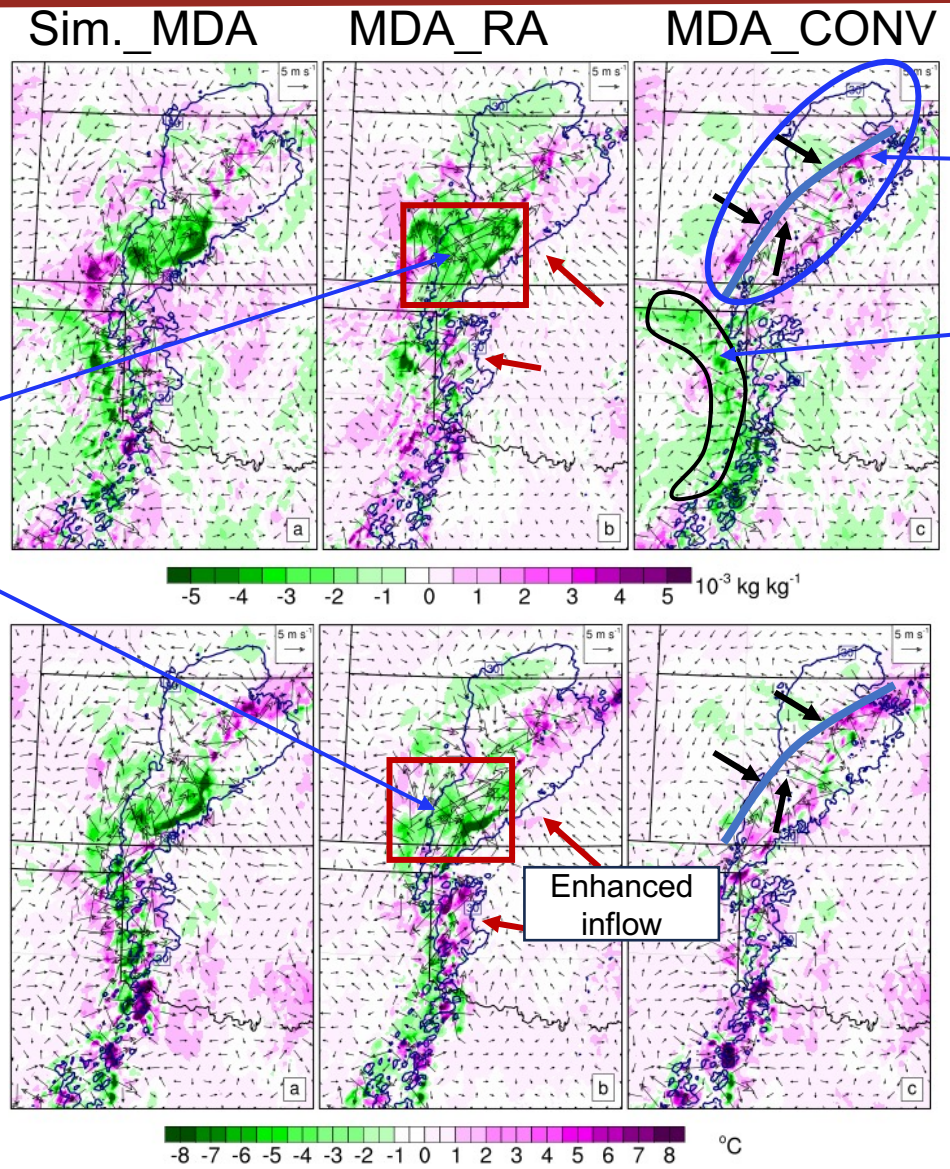
- Additional experiments are designed to test the hypothesis that Sim._MDA can more effectively extract information from radar observations and meso/synoptic-scale in-situ observations to update all resolved scales.

Exps	Assimilation Strategy	Localization scales	
Baseline (Ope.-like)	Separate assimilation of in-situ and radar obs.	In-situ obs.	300 km
		Radar obs.	15 km
MDA_RA	Separate assimilation of in-situ and radar obs.	In-situ obs.	300 km
		Radar obs.	The same conf. as Sim._MDA
MDA_CONV	Separate assimilation of in-situ and radar obs.	In-situ obs.	The same conf. as Sim._MDA
		Radar obs.	15 km

Results

2. Understanding the impact of Simultaneous_MDA

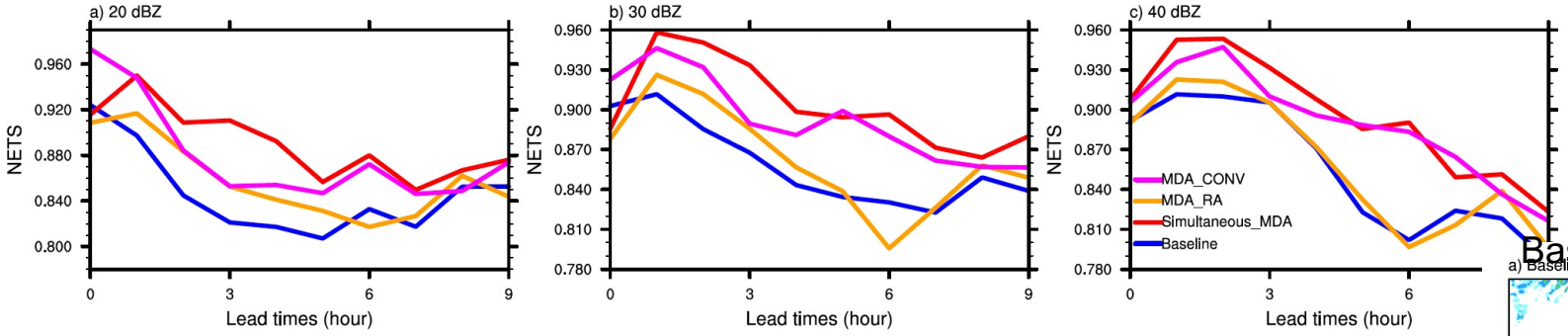
Analysis differences with Baseline



- Compared to Baseline, MDA_RA has stronger cold pools and enhanced east-southeastern inflow;
- MDA_CONV produces greater convergence along the front and larger moisture gradient along the dryline than Baseline.
- The differences between Sim._MDA and Baseline can be partially attributed to the combined effects of MDA_RA and MDA_CONV.

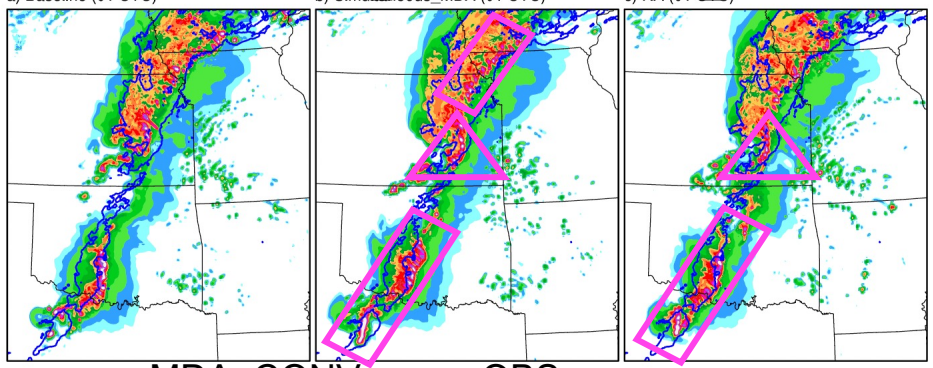
Results

2. Understanding the impact of Simultaneous_MDA

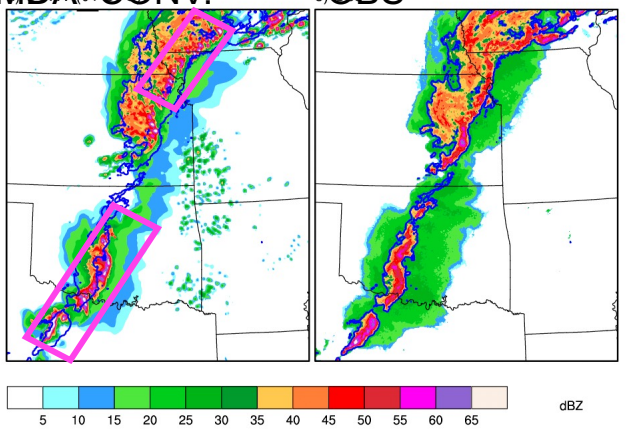


4-h Fcst

Baseline Sim._MDA MDA_RA



MDA_CONV. OBS



- ✓ The free forecast also demonstrates the substantial performance of Sim._MDA over Baseline.
- ✓ MDA_CONV and MDA_RA have the forecast skills between Baseline and Sim._DA; MDA_CONV outperforms MDA_RA.

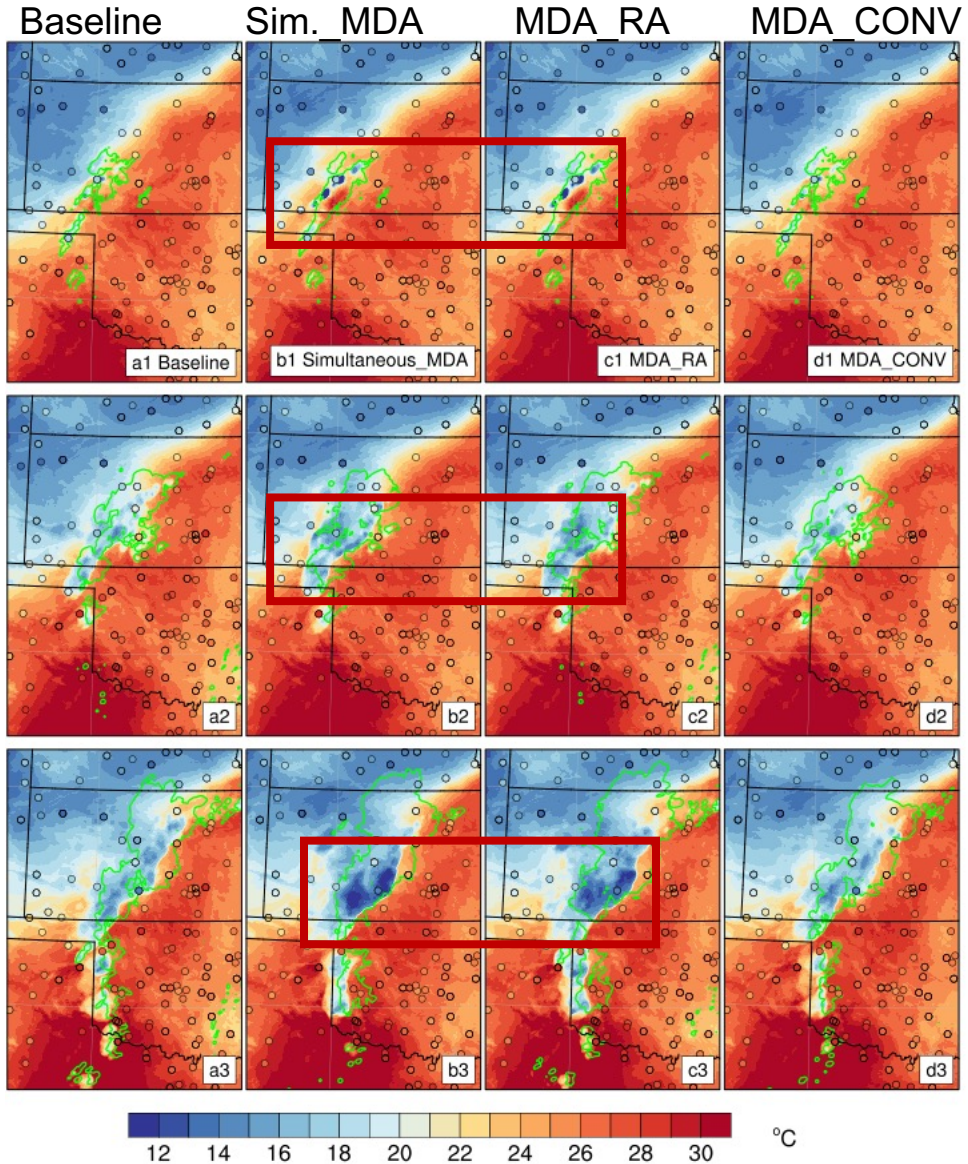
- ✓ Compared to Baseline,
  1) MDA_RA and Sim._MDA improve the bow-echo structure within the triangle and the storms over central OK and northern TX;
  2) MDA_CONV and Sim._MDA enhance the northern storms and storms over central OK and northern TX

Results

2. Understanding the impact of Simultaneous_MDA

Impact of MDA_RA

- Compared to Baseline, the stronger and broader cold pools in MDA_RA agree better with the observations.



ANA @ 19z (1st cycle)

FG @ 20z (2nd cycle)

FG @ 21z (3rd cycle)

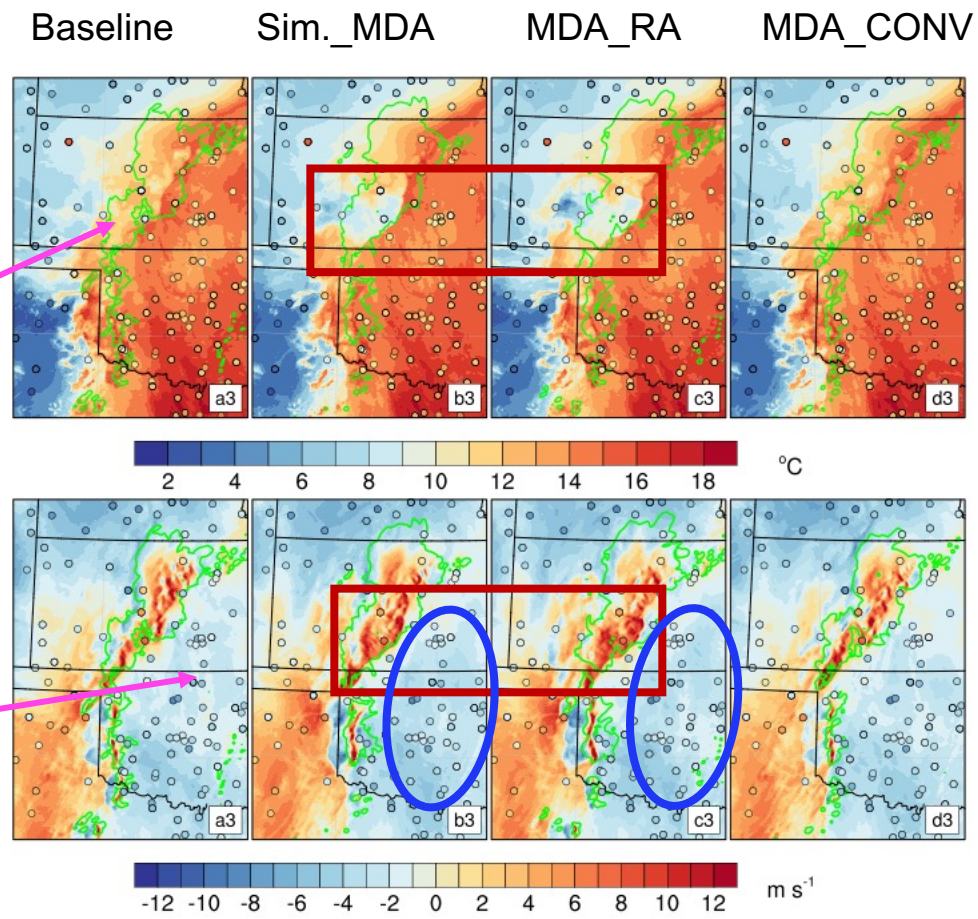
Results

2. Understanding the impact of Simultaneous_MDA

Impact of MDA_RA

Baseline fails to generate cold pools aiding the bow-echo

Baseline has weaker inflows than MDA_RA and in-situ verifying observations



FG @ 21z (3rd cycle)

- Compared to Baseline, MDA_RA also agree better with the observed q and u within the cold pool regions.
- MDA_RA has stronger eastern inflows than Baseline. The enhanced inflow in MDA_RA matches with the observations.
- These differences are achieved by the ability of MDA_RA in making larger-scale increments in compared to Baseline. This result is consistent with Y. Wang and X. Wang (2023) and Fabry and Meunier (2020).

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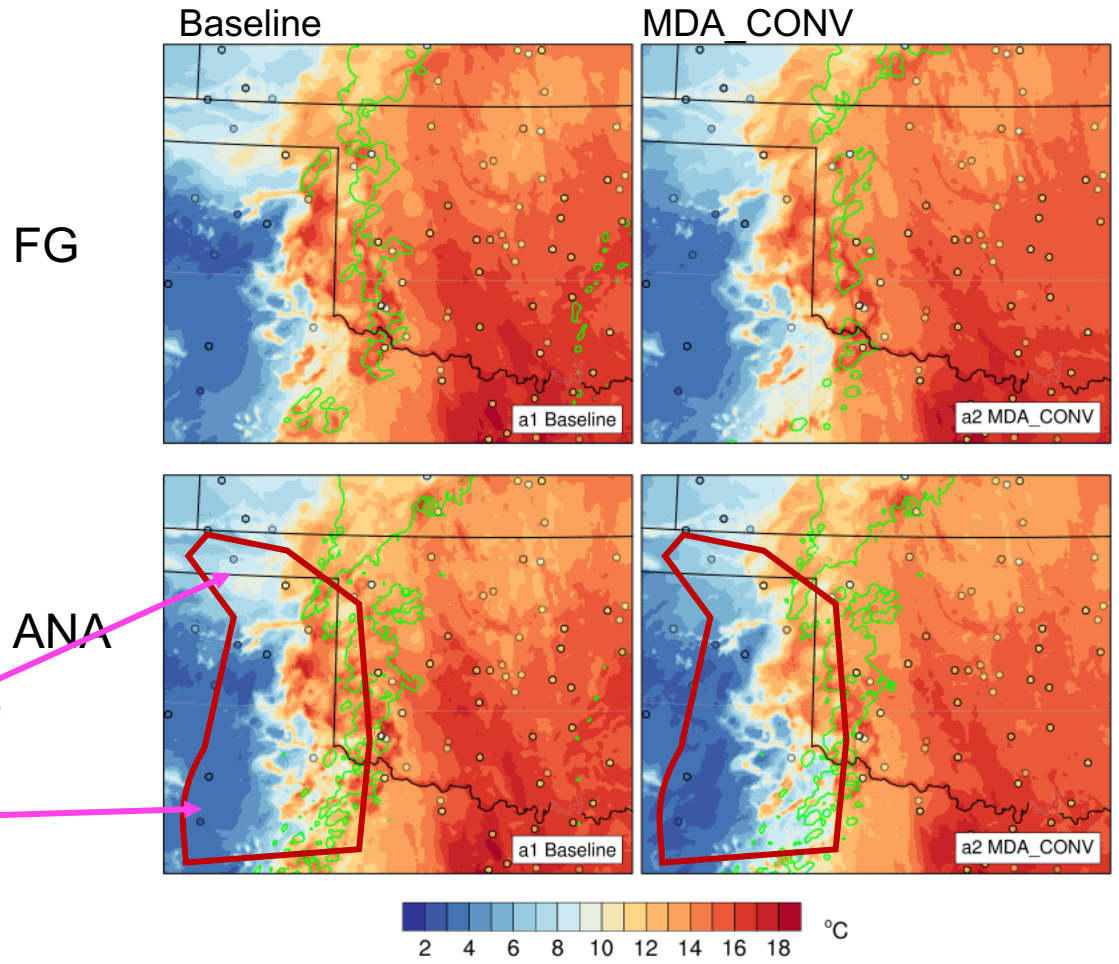
Results

2. Understanding the impact of Simultaneous_MDA

Impact of MDA_CONV

Along dryline



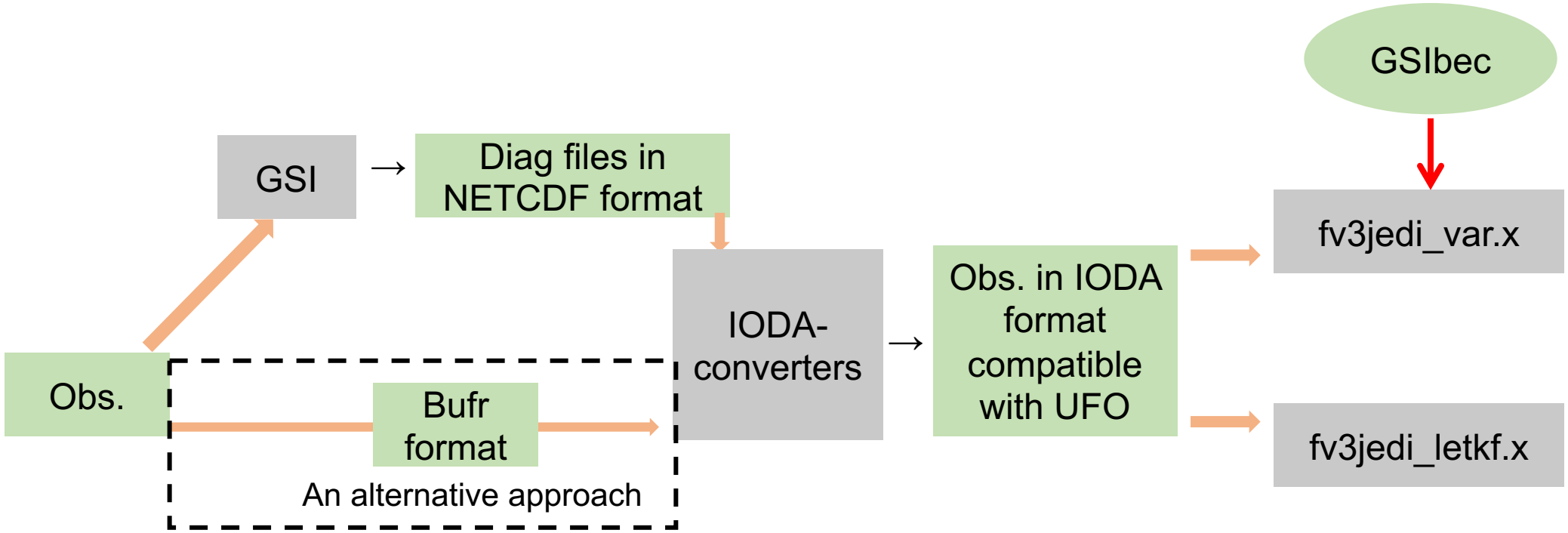
Baseline has more moisture than observations.

- The remarkable analysis differences between MDA_CONV and Baseline mostly coincide with the locations where small-scale covariances are dominated (not shown).
- Compared to Baseline, MDA_CONV better maintains the dryline in both analysis and first-guess.
- The ability of MDA_CONV in applying stricter localization to small-scale covariances improves the large gradient areas, probably by either suppressing noisy distant correlations or reducing the overestimated areal coverage of moisture increments.

Summary

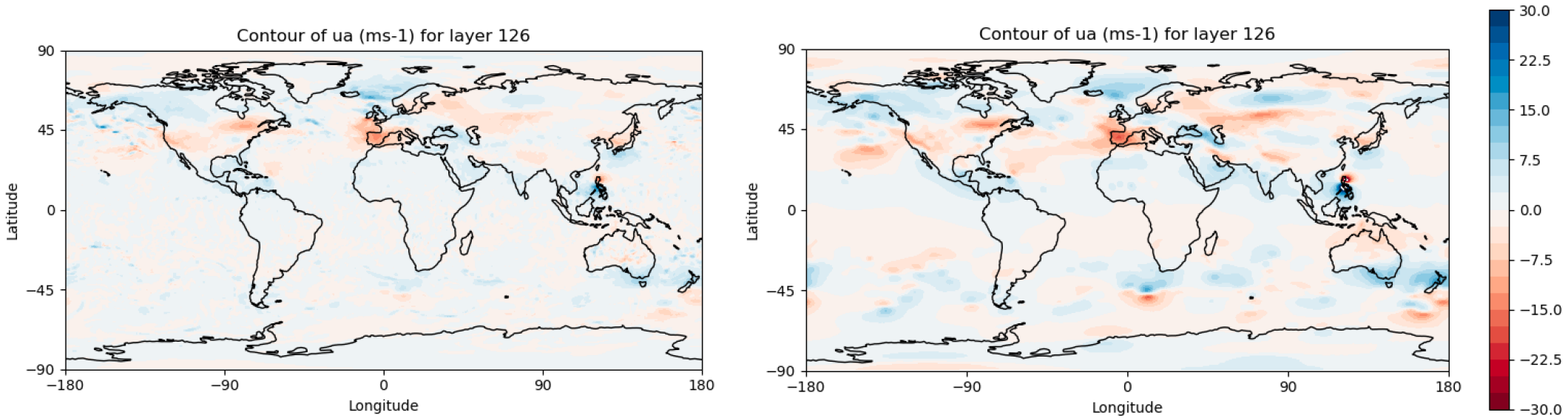
- Simultaneous EnVar MDA system with SDL and VDL for CONUS convective-scale prediction with various observation platforms sampling multiple scales is implemented and evaluated using the 3 May 2018 case.
- Comparisons of Simultaneous_MDA and Baseline (operation-like) suggest that:
  a. Simultaneous_MDA produces more accurate multiscale analyses of *u, v, q,* and reflectivity than Baseline.
  b. Compared to Baseline, Simultaneous_MDA improves *u, v, t, q,* and reflectivity forecasts at the most forecast hours.
  c. Their analysis differences show that Simultaneous_MDA obtains improved convection-favorable conditions at multiple scales, along the front, dryline, and surrounding storms than Baseline.
  d. Diagnostics show that
     1) Simultaneous_MDA improves the large-scale convergence along the front and dryline by eliminating noisy correlations in assimilation of in-situ observations;
     2) the improved conditions surrounding storms in Simultaneous_MDA are primarily obtained by keeping larger-scale increments in assimilation of radar observations.
- EMC (Dr. Sho Yokota) is testing the simultaneous EnVar MDA with SDL and VDL for RRFS toward potential RRFSv1 implementation.
- Ongoing work:
  Develop Simultaneous MDA in JEDI

Utilization and Development of JEDI in progress



Prototype developed in collaboration with EMC (Thanks to Dr. Cory Martin)

Utilization and Development of JEDI in progress



Hybrid

3DVar

Analysis increments @C192 of u-wind at the lowest model level with the assimilation of amsua_n19, sondes, surface pressure, and surface ship observations.

- Hybrid uses static/flow-dependent covariance weights of 0.128/0.875 with the flow-dependent error covariances estimated by a 10-member ensemble background.

Reference

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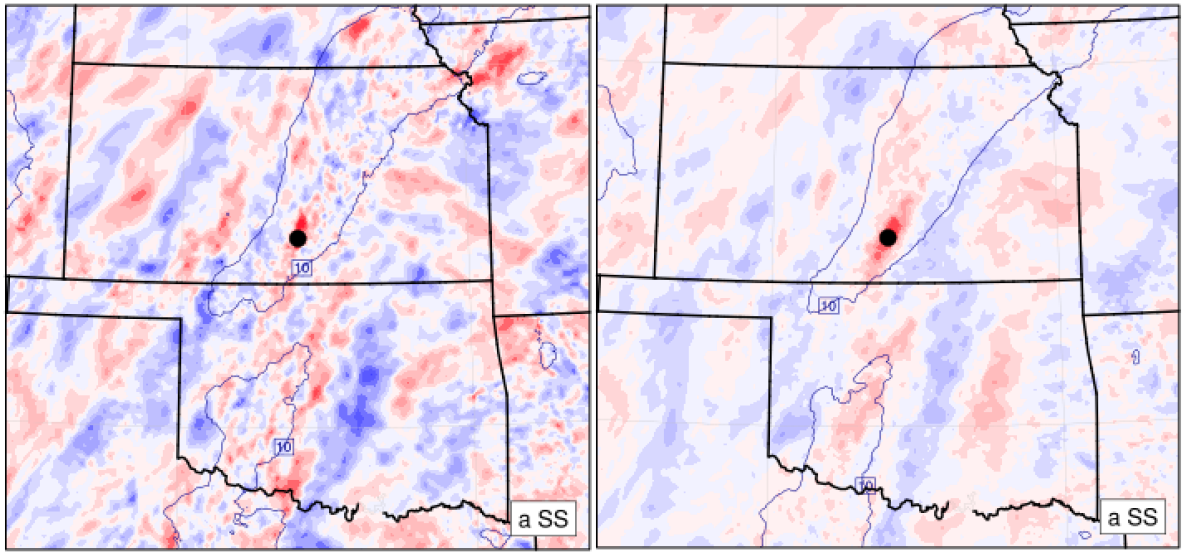
BACKUP

Results

2. Understanding the impact of Simultaneous_MDA

Impact of MDA_CONV

Along front



40-mem 200-mem

Spatial correlations of the small-scale *u* at a specified black point near the front with the small-scale *u* at all points.

- A 200-member ensemble is used as the reference and reflects more realistic covariances than the 40-member ensemble.
- At the small scale, 40-member ensemble shows noisy correlations away from the point selected near the front, whereas 200-member ensemble features a dipole shaped correlation near the point.
- A wide localization in Baseline applied to the small-scale covariances provided by the 40-member ensemble background may lead to inaccurate increments along the front. MDA can alleviate/fix this issue.