Three-dimensional ARM Constrained Variational Analysis as Initial Condition of WRF to Forecast Convection over the SGP

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1. Introduction

- Accurately characterizing the three-dimensional atmospheric dynamics and thermodynamics at mesoscale is important to study cloud and precipitation systems and their coupling with atmospheric circulations.
- Over the US SGP, operational data assimilation can reliably provide atmospheric circulations at synoptic scale, but not at mesoscale. Operational mesoscale analysis still suffer from large errors, as seen in the timing, area coverage, and intensity of precipitation.
- This study aims to improve the accuracy of mesoscale atmospheric analysis through data assimilation by introducing dynamical constraints in the operational WRF GSI assimilation system.

2. Method

1) The cost function in the operational GSI data assimilation system is modified to include additional dynamical constraints from precipitation:

$$J(X,\lambda) = X^T B^{-1} X - \ln(w\exp(-[H(X+Xb)-O)^2/R^2]+u)) + 2(AX-b)\lambda$$

where *X* is the analysis increments; *B* is the error covariance matrix; *H* is the observational operator; *AX-b=0* represents the imposed dynamical constraints; λ is the Lagrange multiplier.

2) The dynamical constraints are the column-integrated conservation of mass and moisture in each grid column :

$$\left[\frac{\partial \pi^*}{\partial t}\right]_\eta + \int_0^1 \nabla_\eta \cdot \left(\vec{V}_h \pi^*\right) d\eta = 0$$

$$\frac{1}{g}\int_0^1 \frac{\partial \pi^* q}{\partial t} d\eta + \frac{1}{g}\int_0^1 \nabla\left(\pi^* q \vec{V}\right) d\eta = (SFCEVP - RAIN)$$

SFCEVP and *RAIN* are surface evaporation and precipitation.

3) The GSI minimization algorithm is modified as follows:

$$x = \begin{pmatrix} X \\ \lambda \end{pmatrix}, \qquad y = \begin{pmatrix} B^{-1} & 0 \\ 0 & I \end{pmatrix} x$$

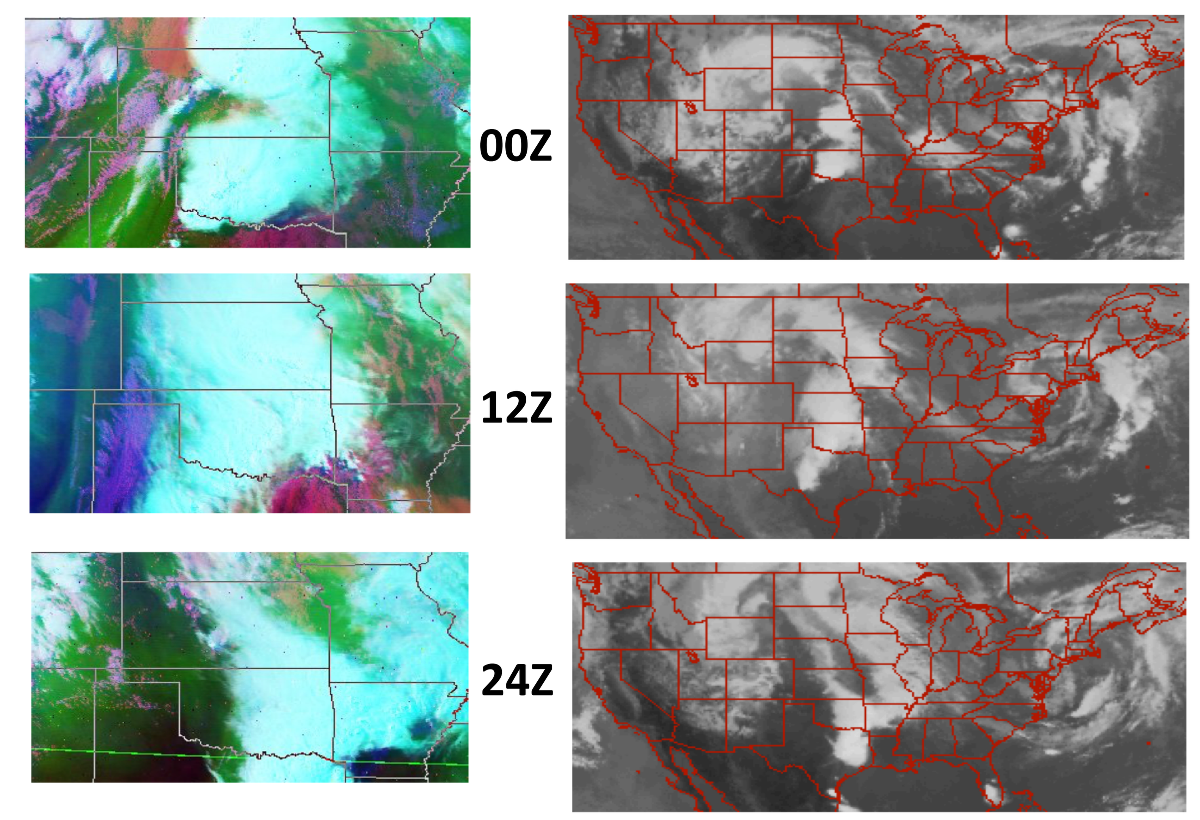
$$x^{n+1} = x^n + \alpha \cdot dirx^n$$

$$y^{n+1} = y^n + \alpha \cdot diry^n$$

$$\alpha = -\frac{(J_x^n)^T \cdot (J_y^n)}{(dirx^n)^T \cdot [\begin{pmatrix} I & A^T \\ AB & I \end{pmatrix} diry^n + \begin{pmatrix} H^T R^{-1} H \\ 0 \end{pmatrix} dirx^n]}$$

3. Results

3. 1 The MC3E case on May 20, 2011

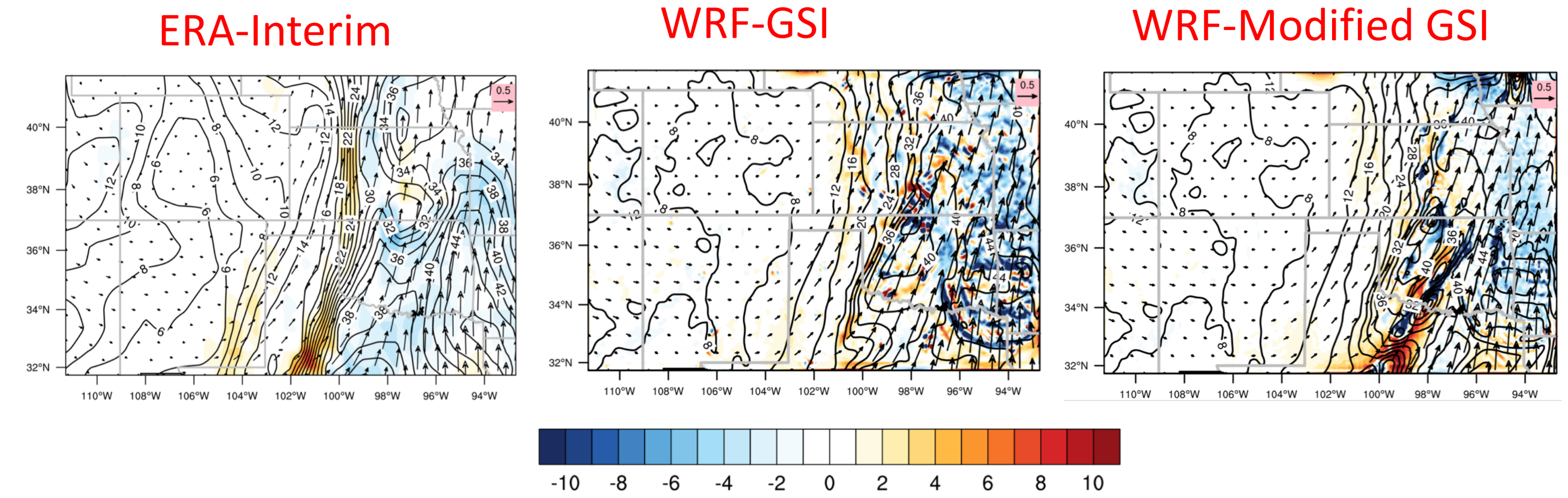


A mesoscale convective system passed through the ARM SGP at 12Z on May 20, 2011 during the ARM MC3E field campaign . This system is embedded within the cold front of a synoptic scale cyclone.

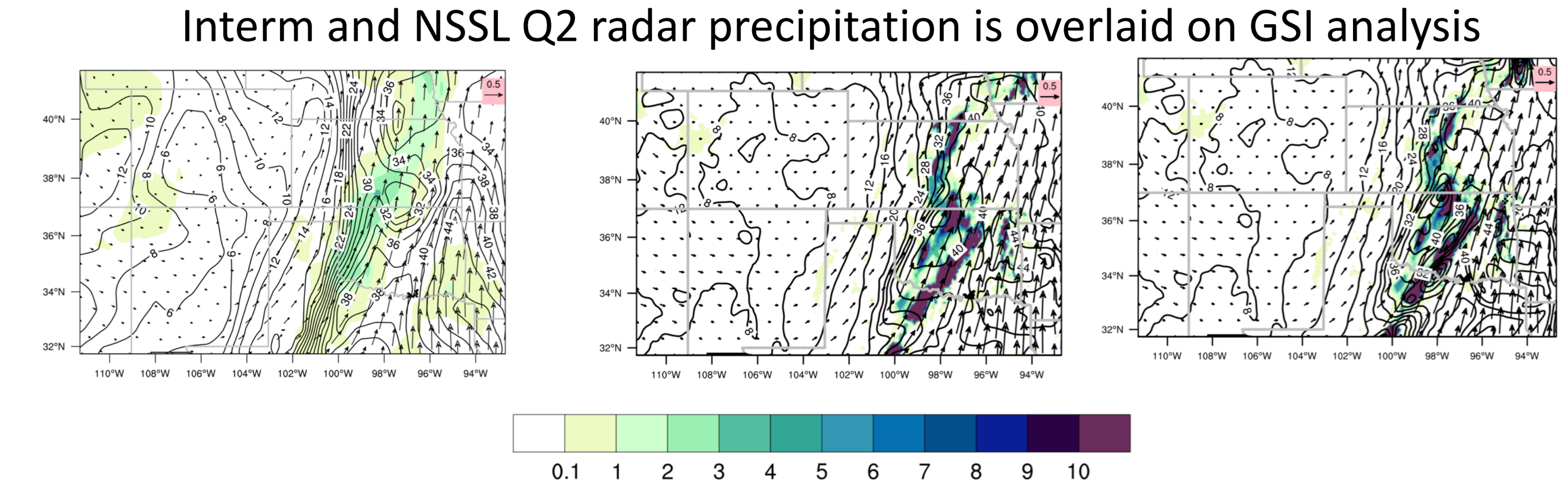
3. 2 Comparison of analysis from the standard and modified GSI

Vertically integrated moisture flux ,flux convergence (shaded, [mm/h]) and precipitable water (black, [mm]) at 12Z on 5/20/2011

ERA-Interim WRF-GSI WRF-Modified GSI



Same as above except that ERA precipitation is overlaid on ERA-Interm and NSSL Q2 radar precipitation is overlaid on GSI analysis

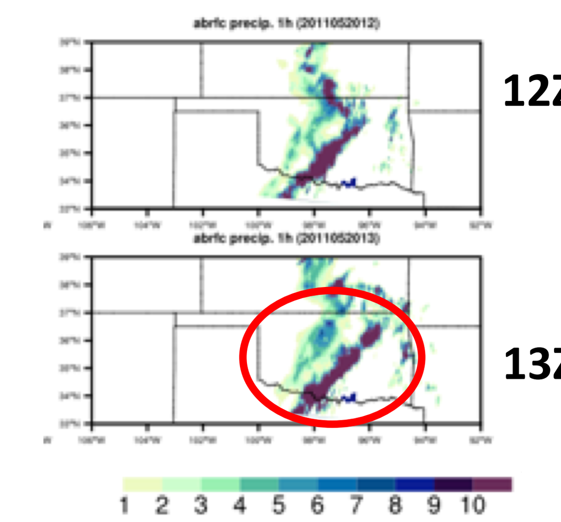


Although the wind and moisture patterns are similar in different analyses, the convergence fields are very different. The analysis from the modified GSI is more consistent with observed precipitation.

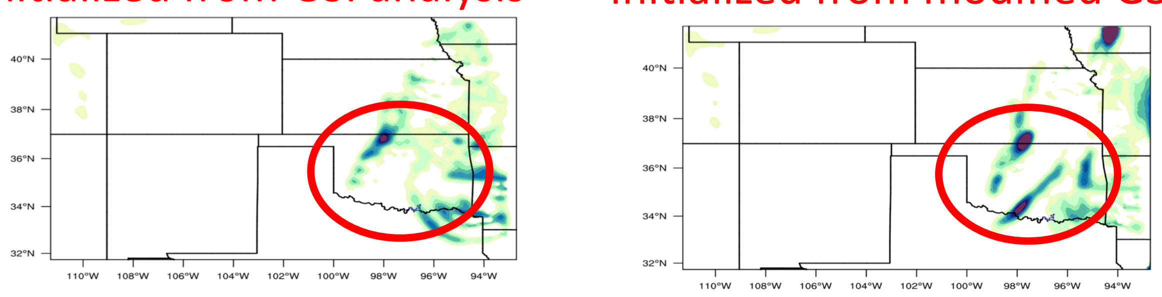
3. 3 Verification from forecast experiment

ABRFC radar precipitation from observation for 12Z and 13Z is shown on the left.

WRF forecasts of precipitation at 13Z when it is initialized by the assimilation system of standard GSI and modified GSI are shown below.



Initialized from GSI analysis Initialized from modified GSI



The atmospheric initial condition from the modified GSI system produced better short-term forecasts of the propagating precipitation band, indicating better quality of the new analysis.

4. Summary

- We have introduced new dynamical constraints of mass and water conservations to improve the operational WRF-GSI data assimilation system.
- The modified GSI assimilation system is applied to a convective event during the ARM MC3E campaign to derive atmospheric analysis. It is more consistent with observed mesoscale organization of convective.
- When the newly derived assimilation product is used as initial condition for WRF, it produces better forecast of precipitation system over the SGP.
- The new assimilation product provides the 4-D atmospheric dynamical and thermodynamic fields to study cloud and precipitation systems.

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