Evaluation of the Performance of Radial Velocity Assimilation with WRF-3DVAR System and Simulated Multiple-Doppler Radar Data

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Motivation

-The use of a NWP model for QPF of convective weather is plagued by …

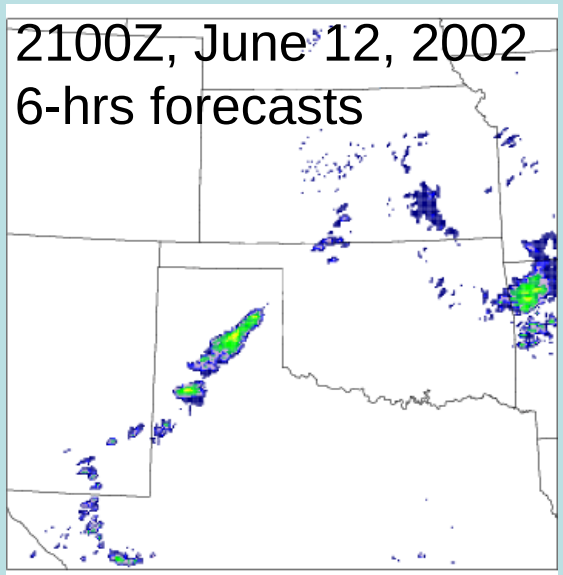
1. Poor specification of the initial and boundary conditions
2. The improper evolution of convection

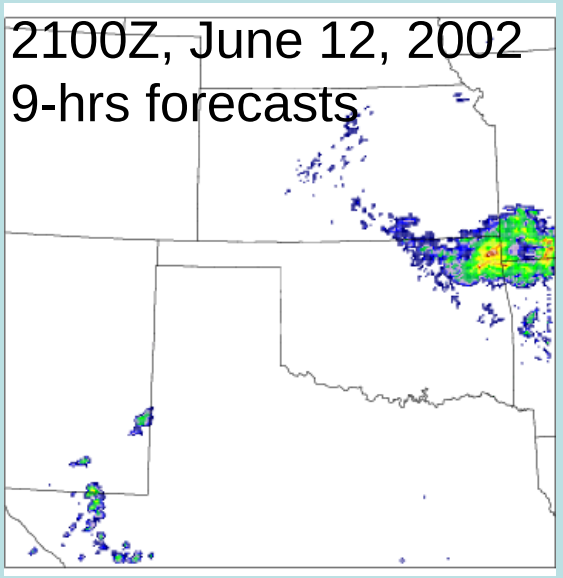
-Better initial and boundary conditions are required.

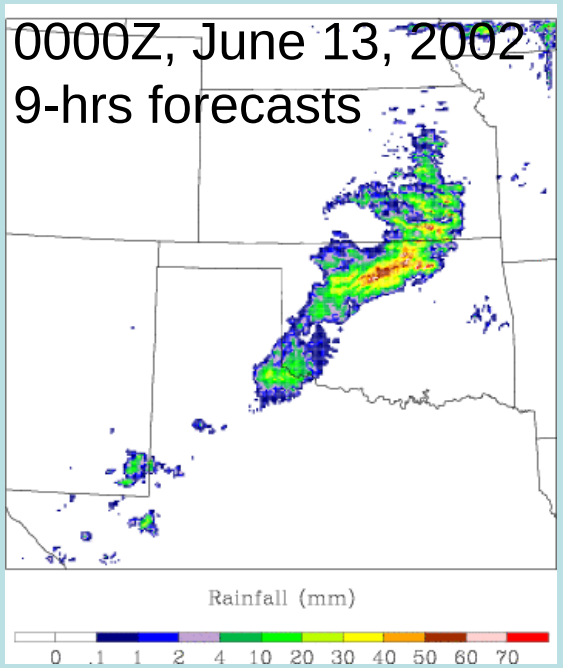
Improvements of the wind field via **radial velocity assimilation** with WRF-3DVAR system

-Evaluation of the maximum potential of the methodology with simulated data

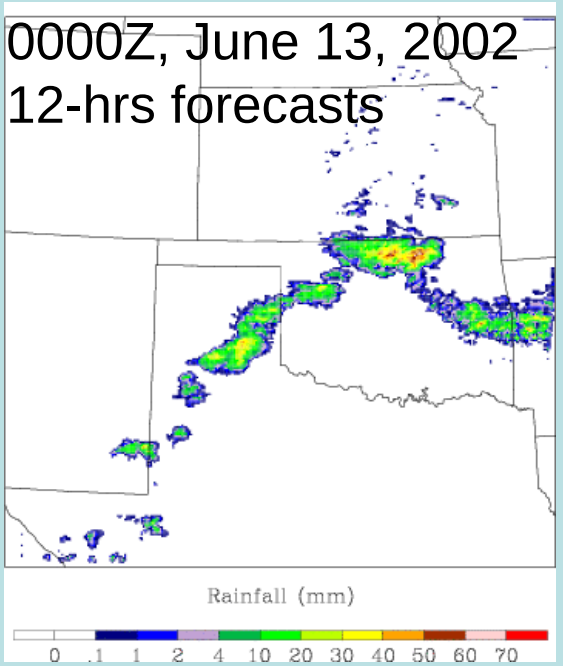
WRF simulations for a dryline case (1-h accumulated precipitation)







Initial: 1500Z, June 12



Initial: 1200Z, June 12

Assimilation of radial velocity data from Doppler radar

Cost function

$$\boldsymbol{J}(\boldsymbol{x}) = \frac{1}{2}(\boldsymbol{x}-\boldsymbol{x_b})^T \boldsymbol{B}^{-1}(\boldsymbol{x}-\boldsymbol{x_b}) + (\boldsymbol{y}-\boldsymbol{y^o})^T \boldsymbol{R}^{-1}(\boldsymbol{y}-\boldsymbol{y^o}),$$

x: a vector of analysis
X_b: a vector of background (first-guess)
y: a vector of model-derived observation (y=*H*(x))

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y^o: a vector of observation
B: the background error covariance matrix
R: the observation and representative error covariance matrix

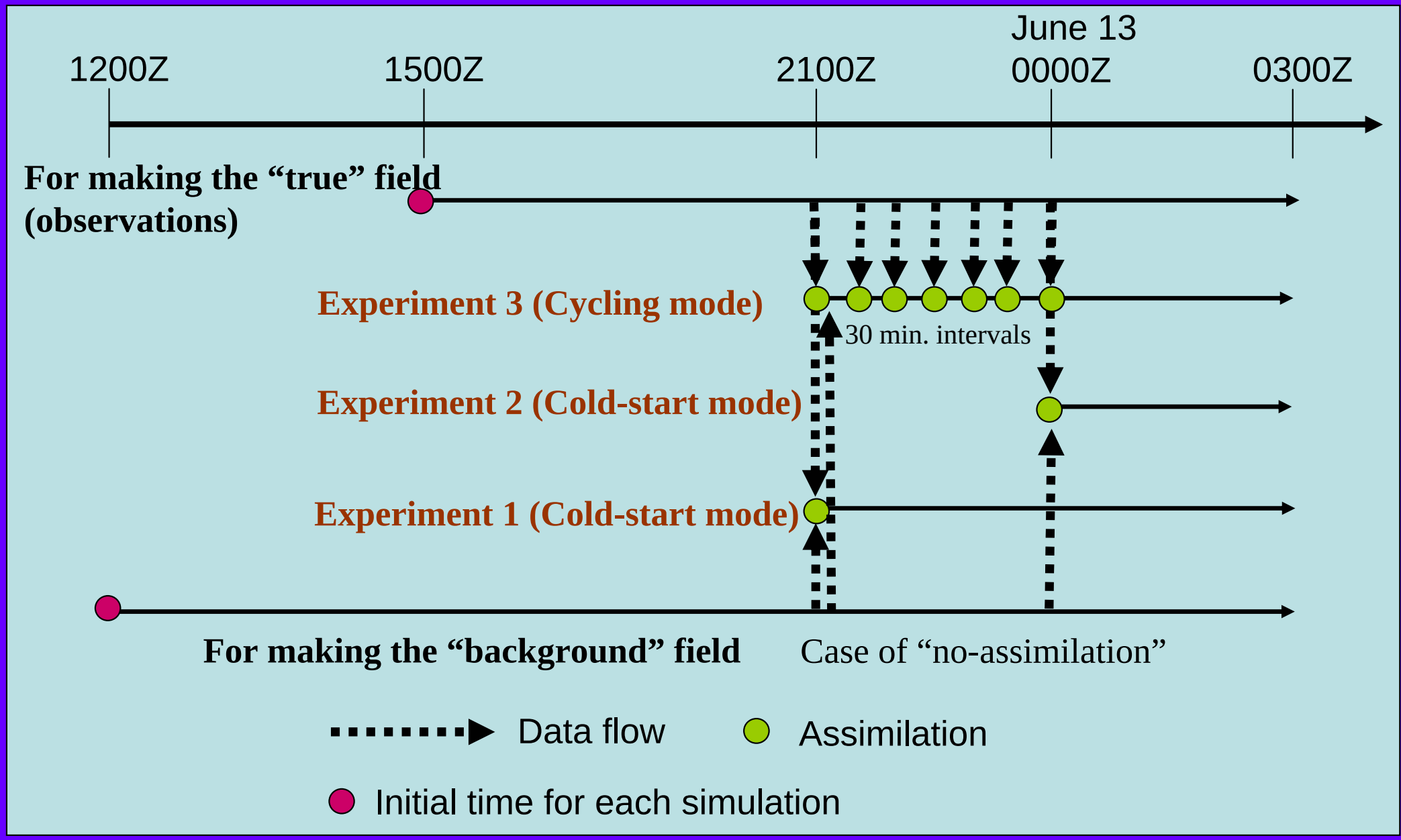
Observation Operator H

$$V_r = \frac{1}{R}\left\{(x-x_R)u + (y-y_R)v + (z-z_R)(w-V_t)\right\},$$

$$R = \sqrt{(x-x_R)^2 + (y-y_R)^2 + (z-z_R)^2},$$

(*u*,*v*,*w*): the three-dimensional wind field, *Vt*: the fallspeed of hydrometeor
(*x*,*y*,*z*): the location of observation, (x_R,y_R,z_R): the location of a radar site

Design of Observation System Simulation Experiments (OSSEs)

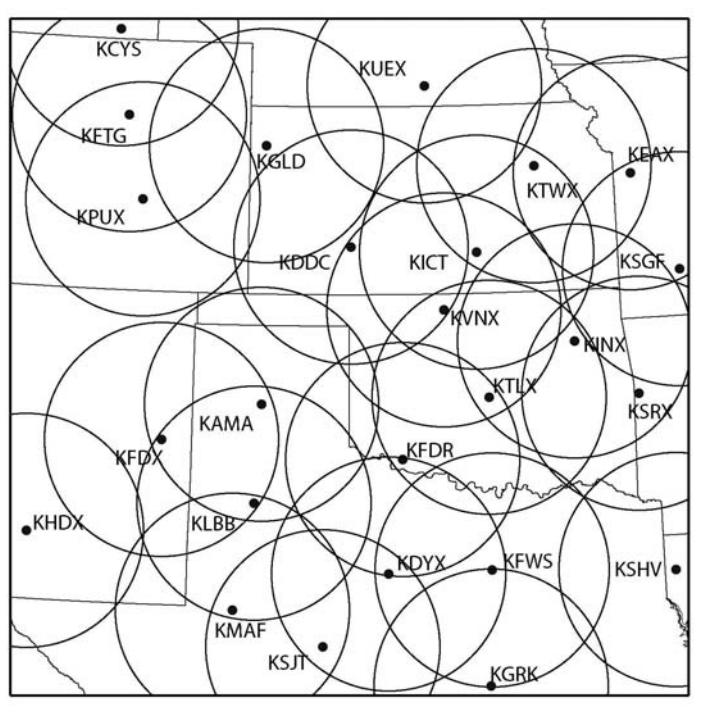


#Two WRF simulations use the same configuration of the WRF model.

Simulated observation and errors of observation and background

WRF model and grid configuration

- WRF model: Version 2.0.3.1
- Horizontal grid spacing: 4 km (300x300) (right panel)
- Vertical level: 36 full sigma



Observations

- 25 WSR-88D radar sites (actual locations)
- Range of each radar: 200 km radius
- Estimated on model grid points within observation area
  - All grid points (Cold start mode 3DVAR)
  - Storm regions (Cycling mode 3DVAR)

Errors of observations and background

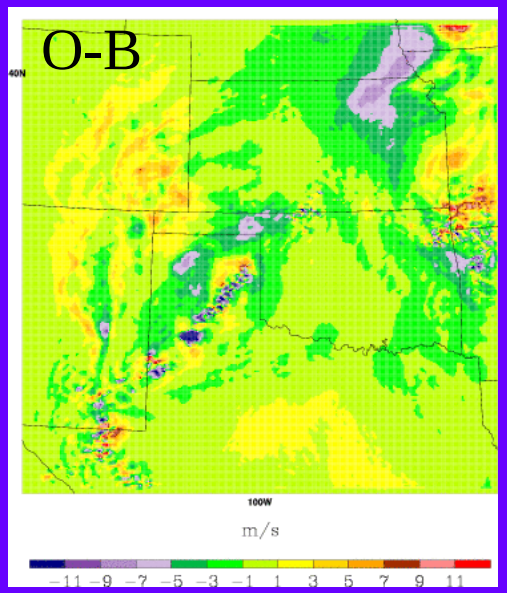
- Observation: unbiased Gaussian (standard deviation of 1 m s^{-1}), Random noise
- Background error covariance matrix: Statistical analysis via the NMC method
  - A series of 10 comparisons between 12-hrs and 24-hrs forecasts
  - Use of cv-option 5 for control variable transformation

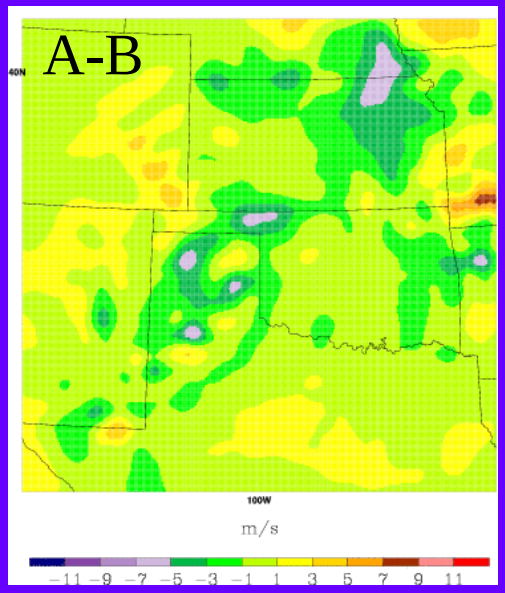
Retrieval of the wind field (Horizontal wind, experiment 1)

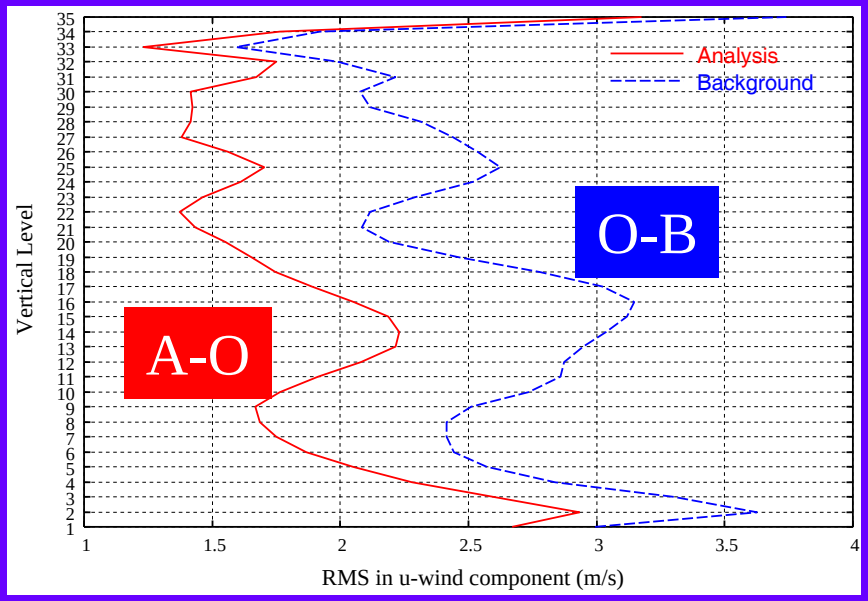
Points

Analysis minus Background (A-B) matches Observation minus Background (O-B)?
RMS error in Analysis minus Observation (A-O) is reduced from O-B?

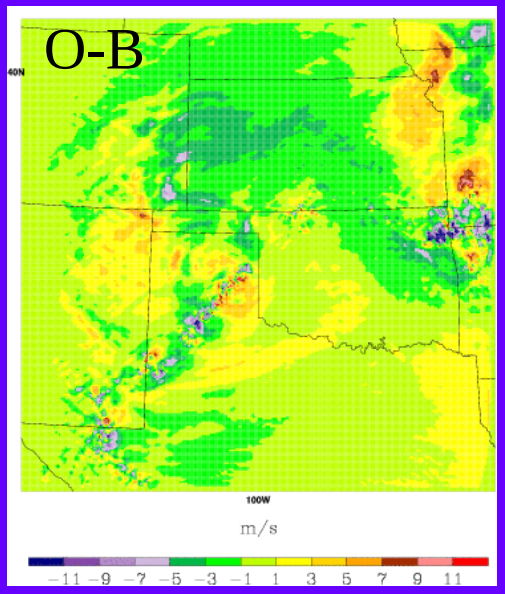
u-wind

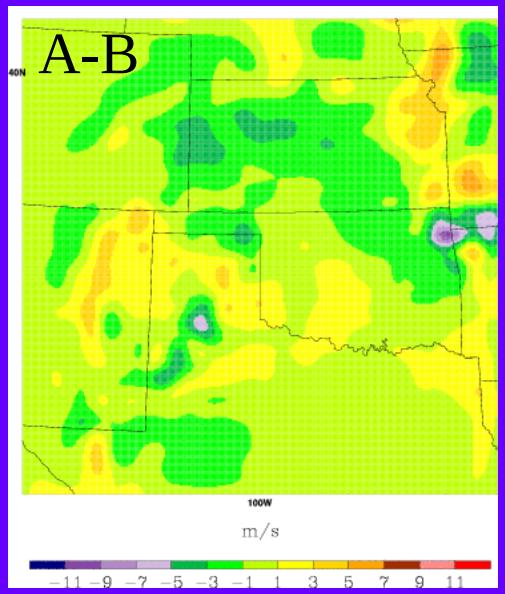


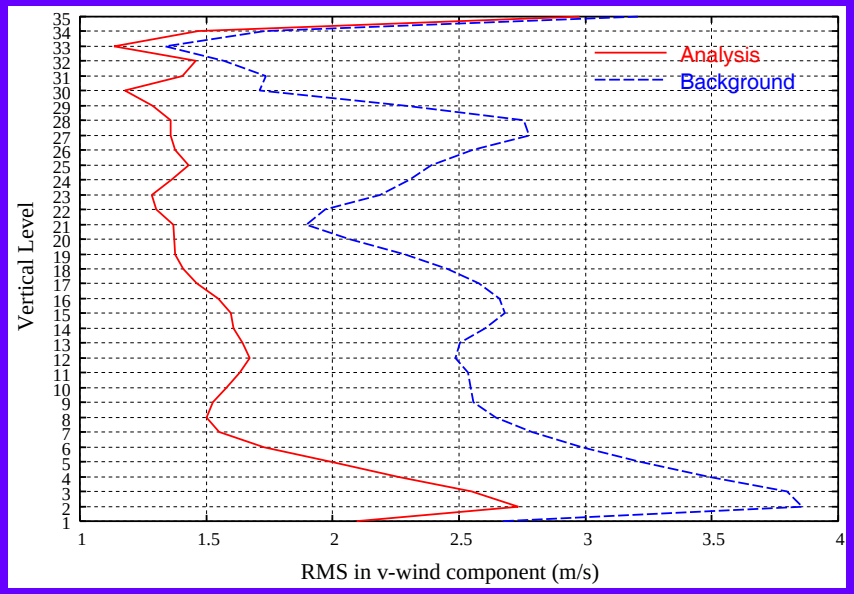




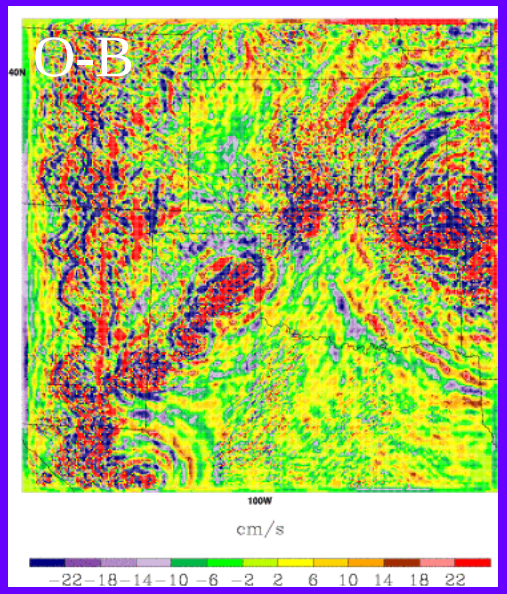
v-wind

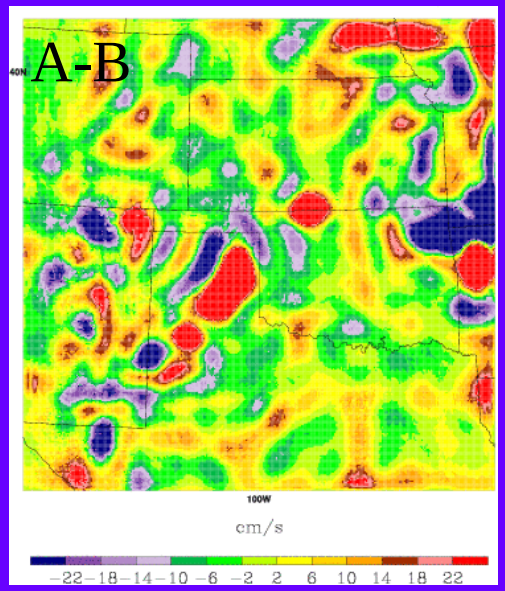


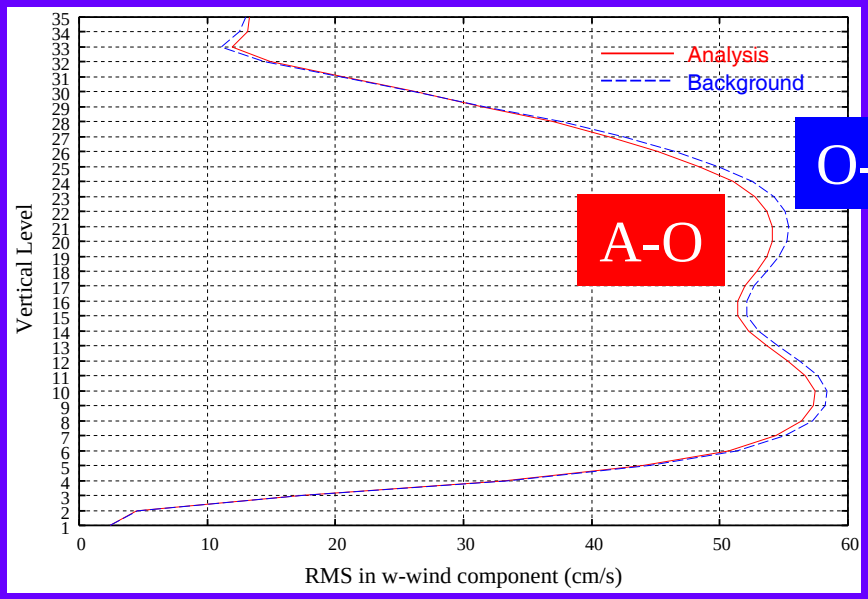




Retrieval of the wind field (Vertical wind, experiment 1)







- Benefit of assimilation on the vertical velocity is smaller than the one on horizontal winds.

- Increment of the vertical velocity is estimated from the Richardson equation (ignoring diabatic heating) in the minimization procedure.

  Hopefully, the increment of the vertical wind is balanced with the increment of the horizontal winds.

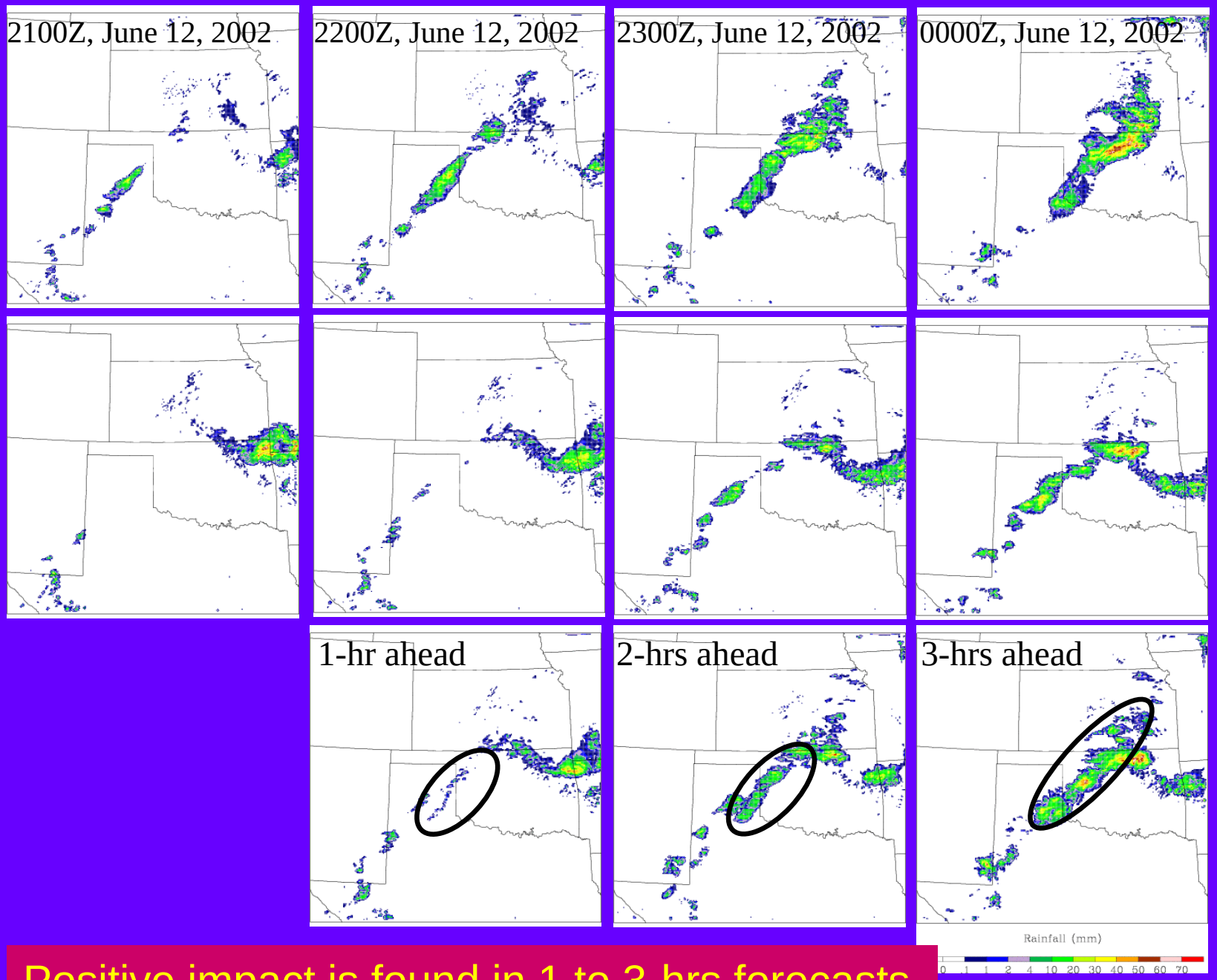
- Scales applicable for WRF-3DVAR depends on the BES.

  WRF-3DVAR works reasonably well at scales larger than the convective scale.

  Flow-dependent BES is expected for successful retrieval at the convective scale.

Impact on precipitation forecasting

(the initiation stage of convection, experiment 1)



Observations ("true")

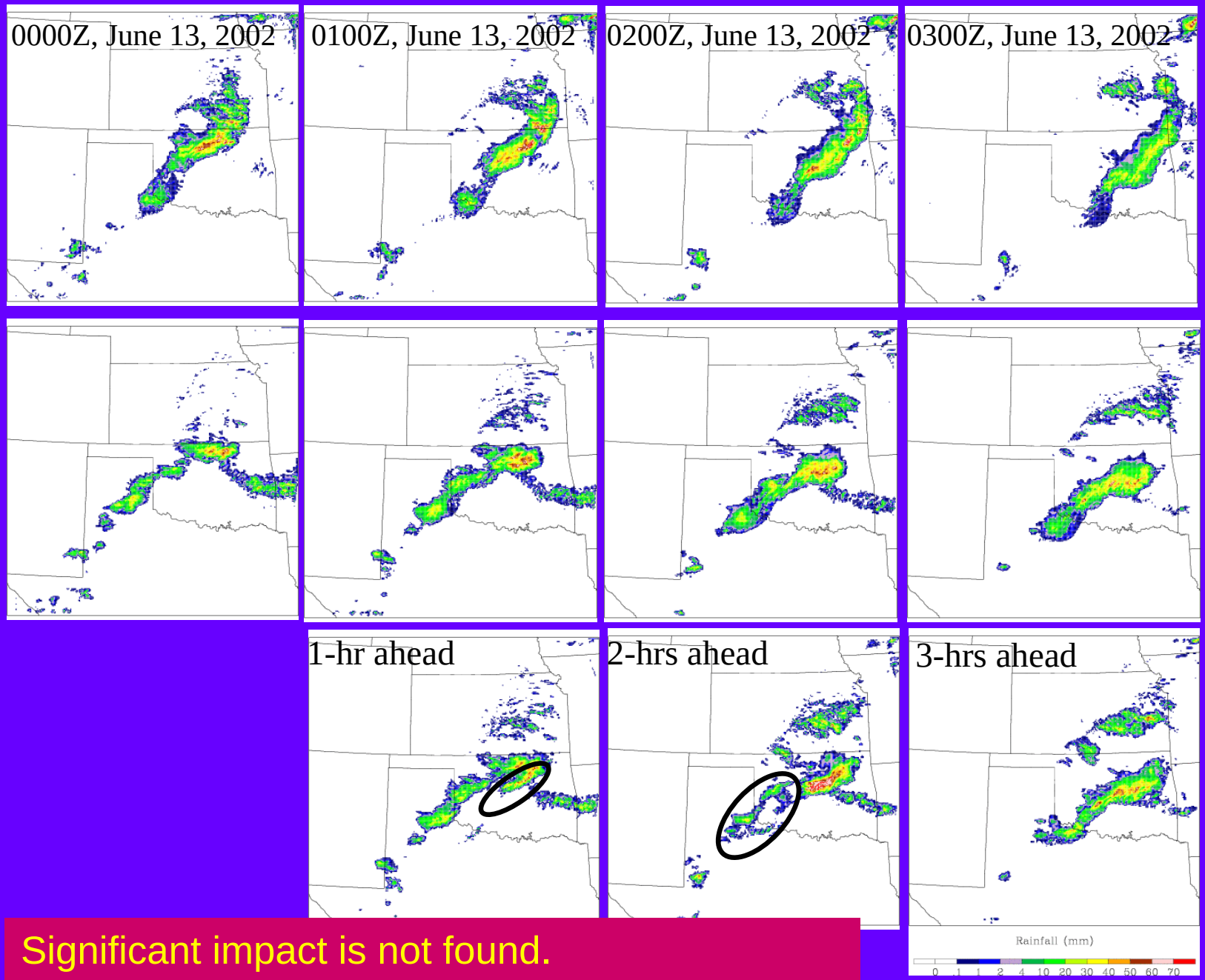
no-assimilation ("background")

3DVAR at 2100Z

Positive impact is found in 1 to 3-hrs forecasts.

Impact on precipitation forecasting

(the developing or the mature stage of convection, experiment 2)



Observations
("true")

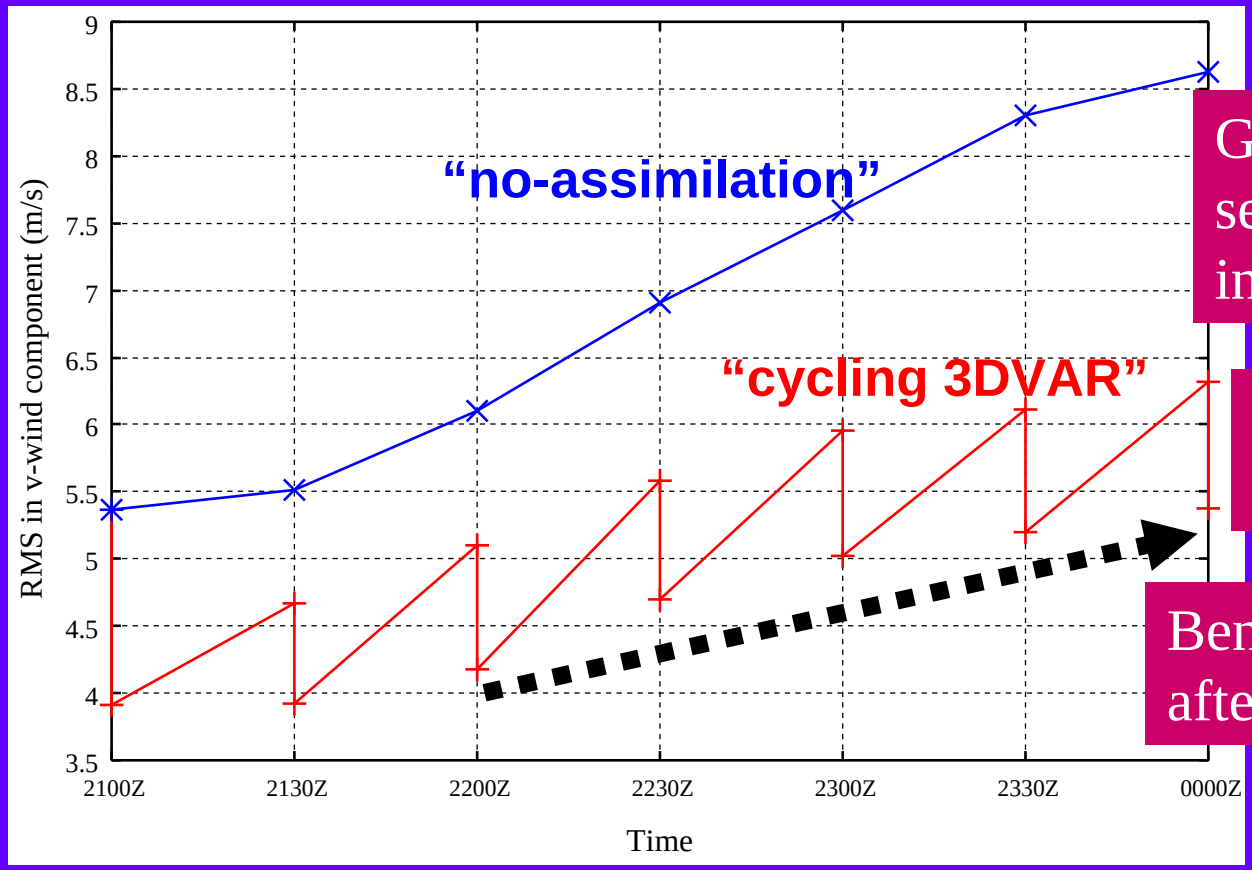
no-assimilation
("background")

3DVAR at 0000Z

Significant impact is not found.
Slight impact in 1, and 2-hrs forecasts is found.

Benefits by cycling mode 3DVAR (experiment 3)

Assimilation at an interval of 30-minutes during the 3-h time window (RMS error in v-wind component)



Generally, the use of cycling serves to prevent the rapid increase of the error.

Each of assimilation cycles reduces the RMS error.

Benefits would be disappeared after 2 to 3 hours after 3DVAR.

Initiation stage

Developing or mature stage

The RMS error is kept or even reduced.

Only radial velocity assimilation cannot prevent from the increase of the error.

Summary

1. Radial velocity assimilation with WRF-3DVAR works reasonably well for recovering the wind fields at scales larger than the convective scale.

2. The use of cycling 3DVAR serves to prevent the rapid increase of the RMS error. At least, the 30-minutes interval mode works well.

3. For successful retrieval at the convective scale, a more sophisticated dynamic framework for WRF-3DVAR as well as the use of flow-dependent BES will be needed.

4. Radial velocity assimilation is effective for convection in the initiation stage.

5. Only radial velocity assimilation cannot control convection developing to the mature stage. Assimilation of reflectivity factor or GPS-derived data are expected to retrieve temperature and moisture fields.