Assimilation Radar Data with WRF-based 4DREKF and a PECAN case study

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DA for Mesoscale Processes

- Complex dynamics and physics
  - Impact of fine-res terrain, land use, snow cover and soil
  - Multi-scale interactions (1~1000 km)
  - Rich features and fast changing

need flow dependent weight to balance model and obs

- Dynamic and diabatic “spin-ups”, irregularly distributed obs in space and time, spare obs in regions

need model constraints continuously

- Practical and operational Data Assimilation

need more efficient and effective assimilation approach

Current DA systems for Radar DA

- WRFDA system (3DVar, 4DVar, Hybrid)
- VDRAS (4DVar)
- DART system (EAKF)
- GSI system (3DVar, Hybrid)
- NOAA RUC, RAP and HRRR system (3DVar, Hybrid)
- UK Unified Model (3DVar + Latent Heat Nudging)
- ECMWF (4DVar)
- JMA Mesoscale Analysis (4DVar, Reflectivity→RH)
- Canadian HREnKF

Recap Data Assimilation Schemes

$$\frac{\partial T}{\partial t} = F(x,t,T)$$

analysis | 1st guess | obs | Pseudo-obs

$$T_t^a = T_t^f + K\left((T_t^{obs} - \mathrm{H}(T_t^f) \right)$$

$$K = K_e = P^f H^T (HP^f H^T + O)^{-1}$$

3D-DA

Deform

$$\frac{T_t^a - T_{t-\Delta t}^f}{\Delta t} = \frac{T_t^f - T_{t-\Delta t}^f}{\Delta t} + K\left((T_t^{obs} - \mathrm{H}(T_t^f) \right) / \Delta t$$

$$\frac{dT_t}{dt} = F(x,t,T_t) + \sum_{i=1}^{N} \mathrm{K}\delta(t - t_i)\left((T_{t_i}^{obs} - \mathrm{H}(T_{t_i}) \right)$$

4D-DA

4DREKF Scheme

Obs-nudging FDDA:

$$W_{xy} = \frac{R^2 - d^2}{R^2 + d^2}$$

$$\frac{\partial T}{\partial t} = F(T, x, y, \sigma, t) + G_\alpha \sum_{i=1}^{N} \frac{\boxed{W_{xy,i}^2} W_{\sigma,i}^2 W_{t,i}^2 \cdot \gamma_i}{\sum_{i=1}^{N} \boxed{W_{xy,i}} W_{\sigma,i} W_{t,i}} \left(T_i^{obs} - T\right)$$

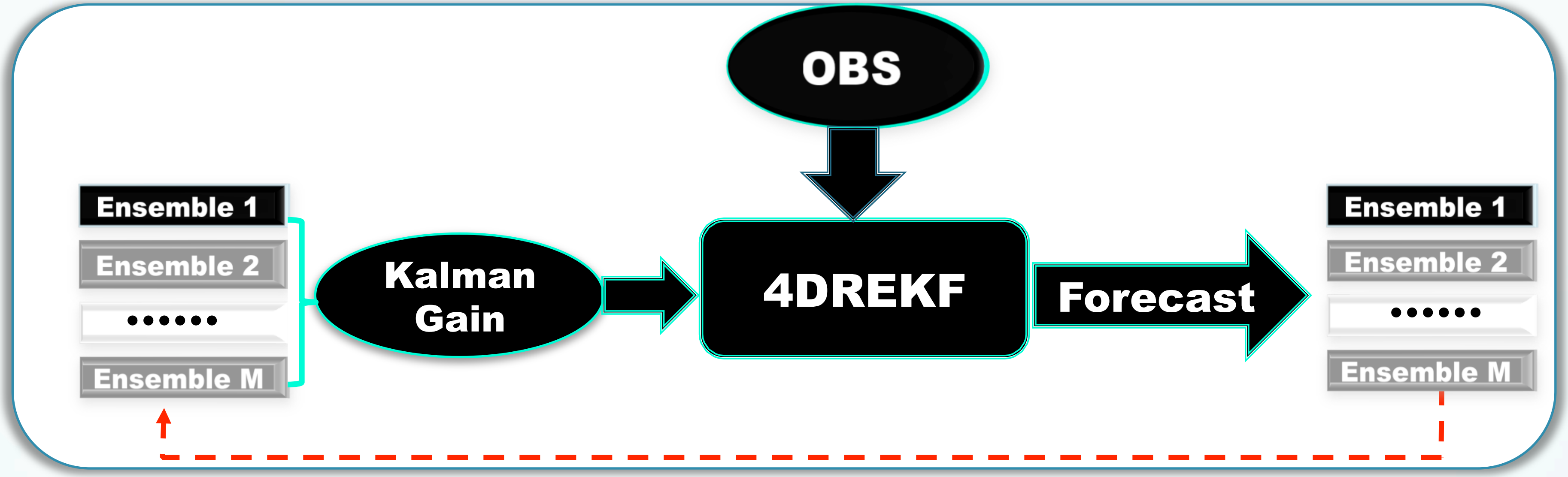
$$W_{xy} = \text{Kalman Gain}$$

4DREKF
(4D Relaxation Ensemble Kalman Filter)

Characteristics of 4DREKF

1. Replaces the "obs-nudging" FDDA empirical Cressman-type data weight functions with an ensemble-based "flow-dependent" Kalman gains.
2. Blends the advantage of both "obs-nudging" and EnKF technologies.
3. Can efficiently assimilate all obs available at different times and locations and provide spun-up NWP I.C.s.
4. Ultimately, all obs, direct (i.e. U, V, T, and Qv) or indirect (e.g. radar radial winds and reflectivity, satellite radiance …) can be assimilated.

4DREKF Data Flow Diagram



- **Note:**

✓ **Needs to run along with a "good" ensemble system;**

✓ **Many algorithms in the existing EnKF systems can be adopted, such as the adaptive covariance localization;**

✓ **Needs to deal with spatiotemporal interpolation of the gains;**

Real Weather Case Study

- Domain: 2 nested domains
- Grid No: 212(E) X 160(N) X 57(V) : grid size 15km

  411(E) X 321(N) X 57(V) : grid size 5km

Ra_lw = 1,1   Ra_sw = 2,2

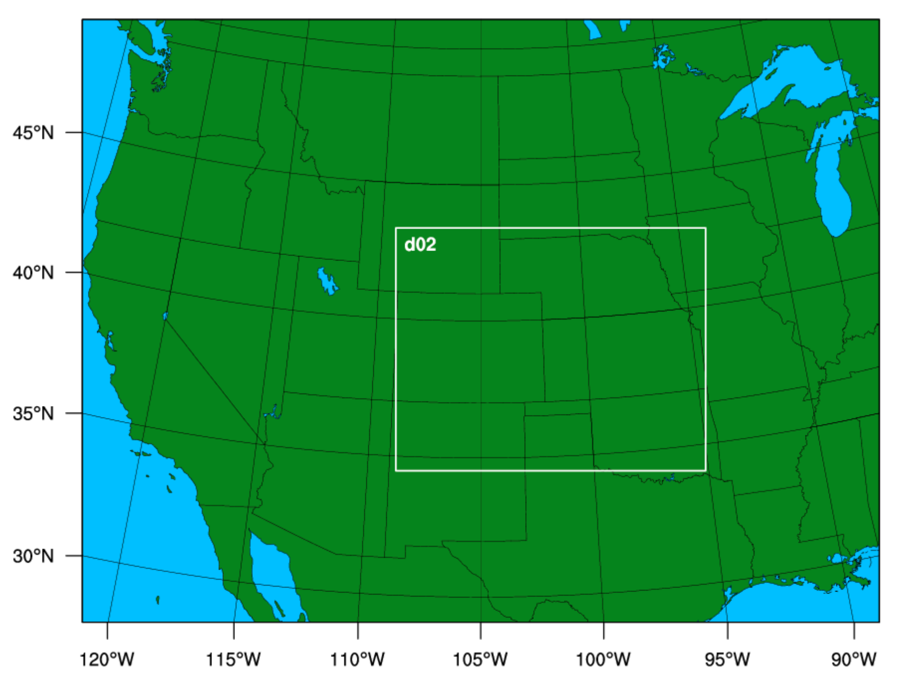
Sf_sfclay_phy = 1,1

Sf_surface_phys = 2,2

Bl_pbl_phys =1,1

Mp_phys = 6,6

Cu_physics =1,1



Thunderstorm in Nebraska

- **Model Initial Time**: 06Z July 2nd, 2015
- **Assimilation Window**: 6h
- **Obs**

  Routine sfc and upper air Obs from MADIS

  Radar data: NOAA Level II Data with VDRAS QC Process

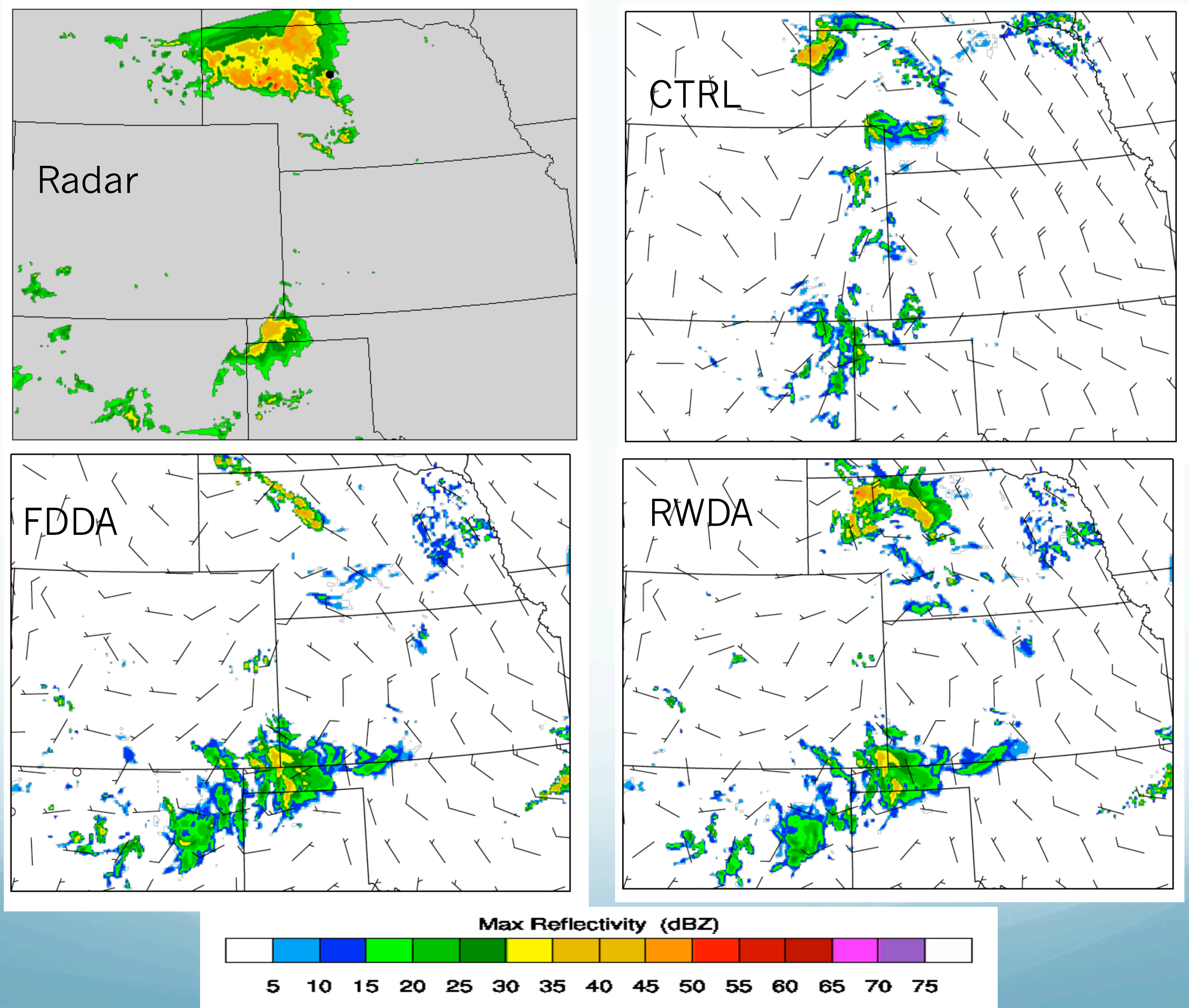
- **Experiments**

  CTRL: No DA

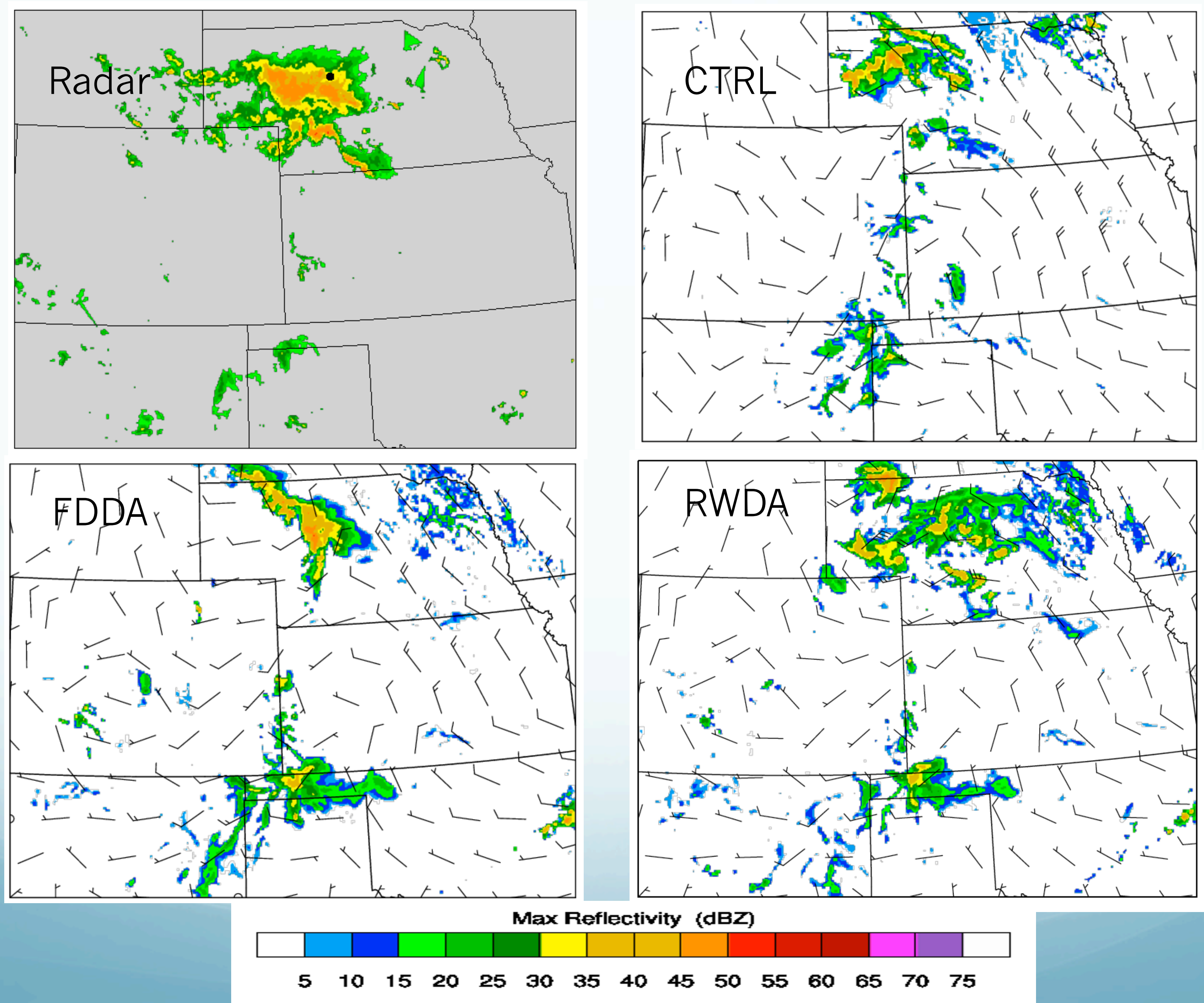
  FDDA: DA of Routine Obs with RTFDDA

  RWDA: DA of Radar KLNX Radial Wind with 4DREKF

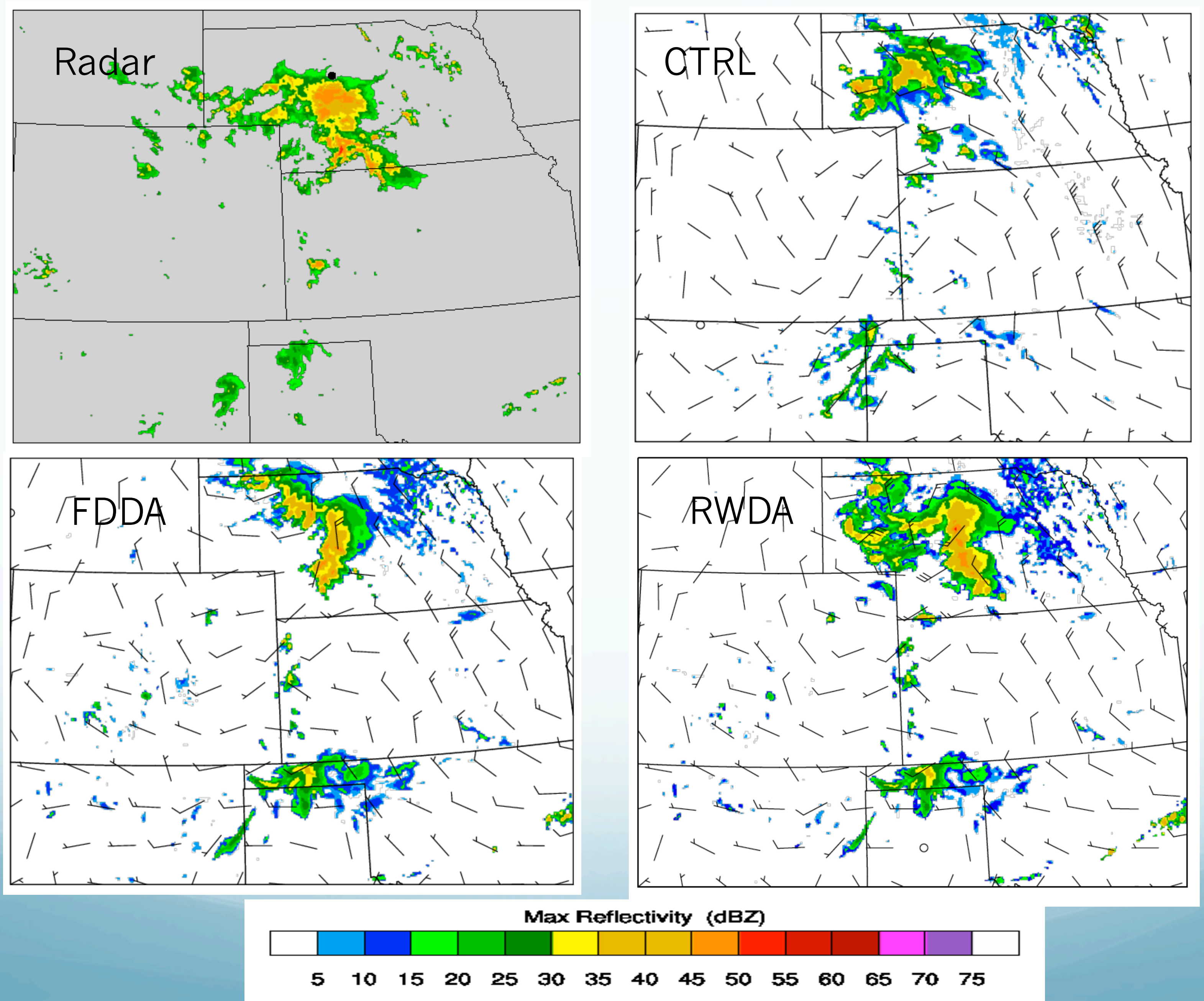
Mdbz and wind$_{700mb}$ at 08Z



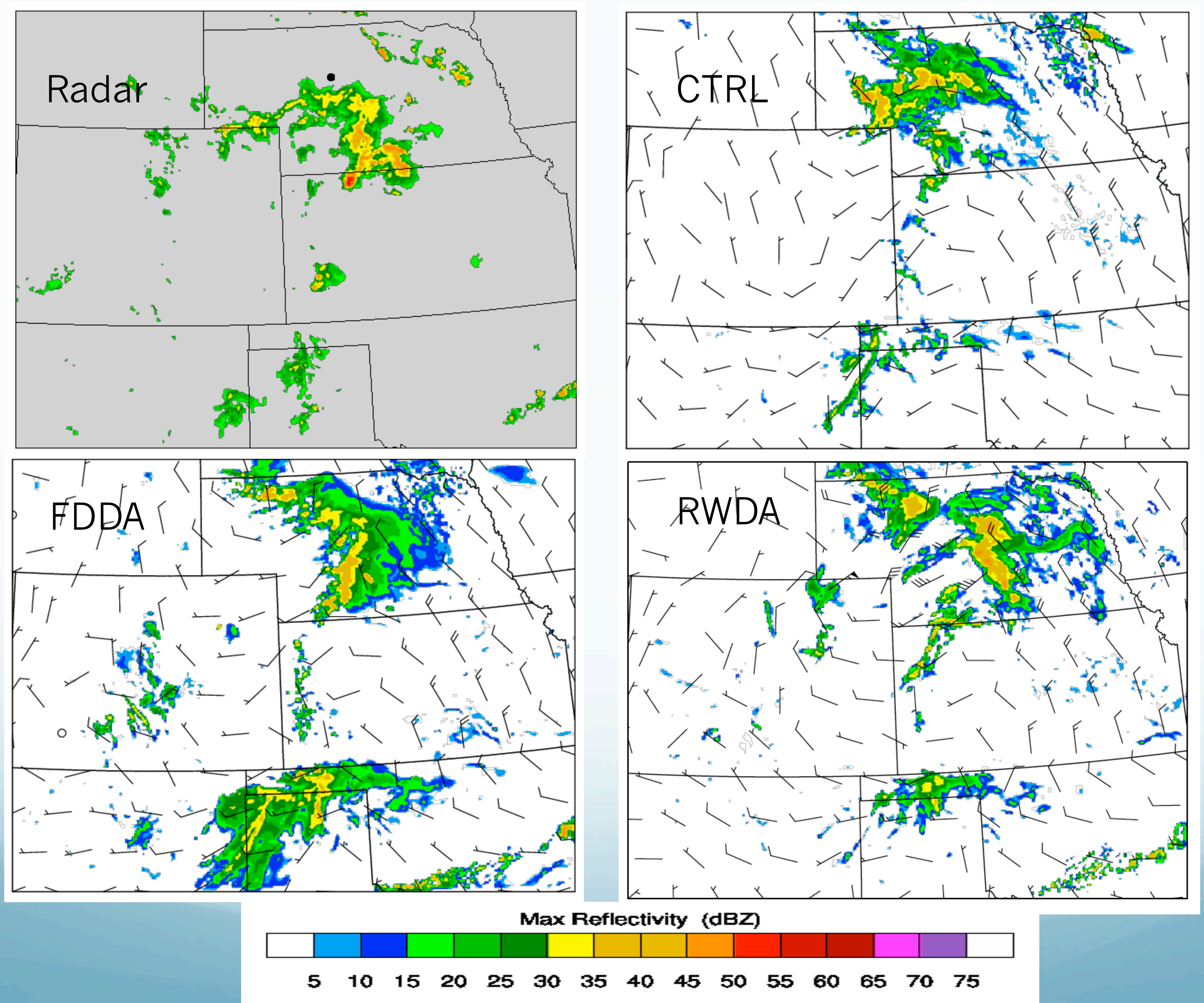
Mdbz and wind$_{700mb}$ at 10Z



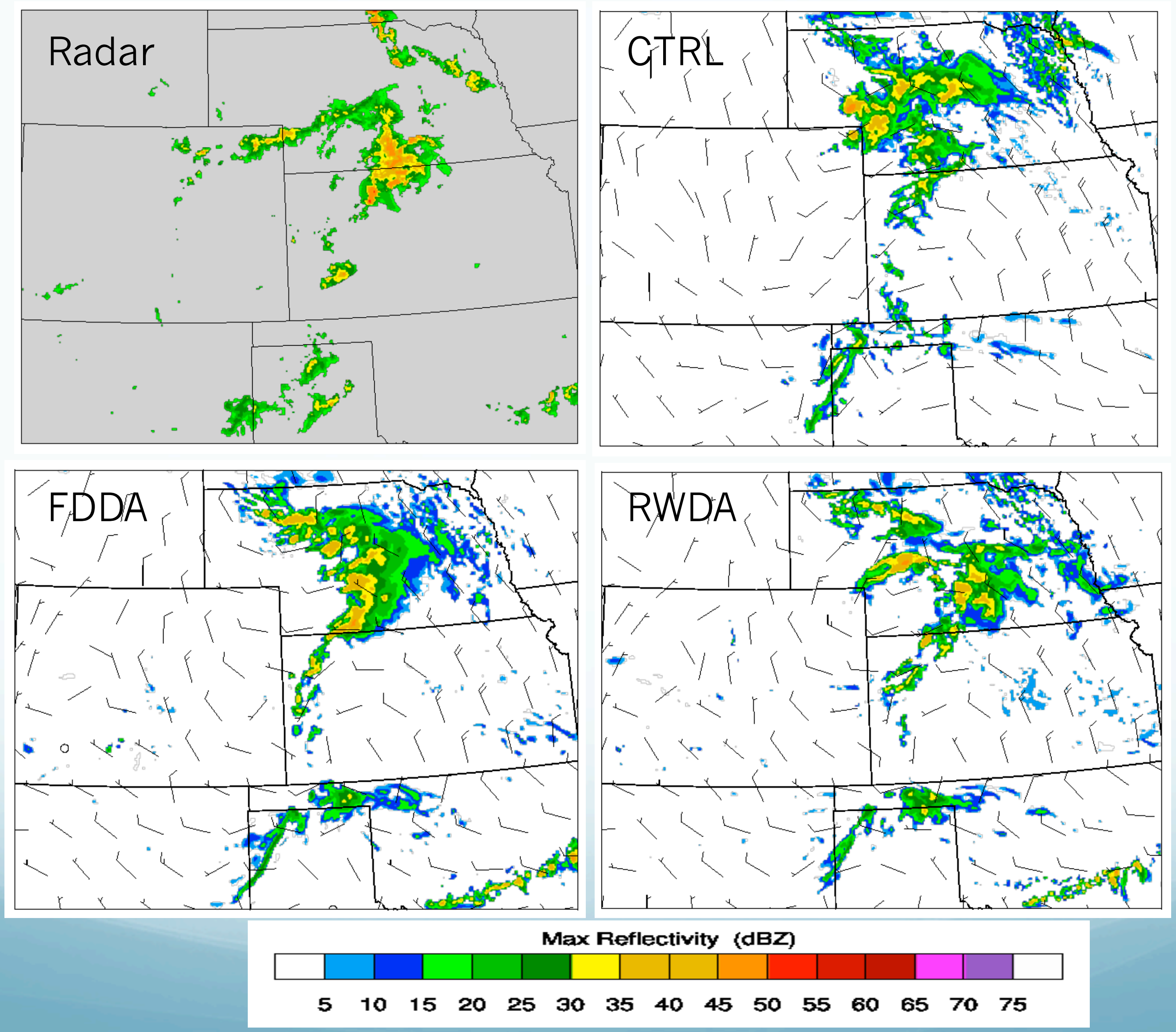
Mdbz and wind$_{700mb}$ at 11Z



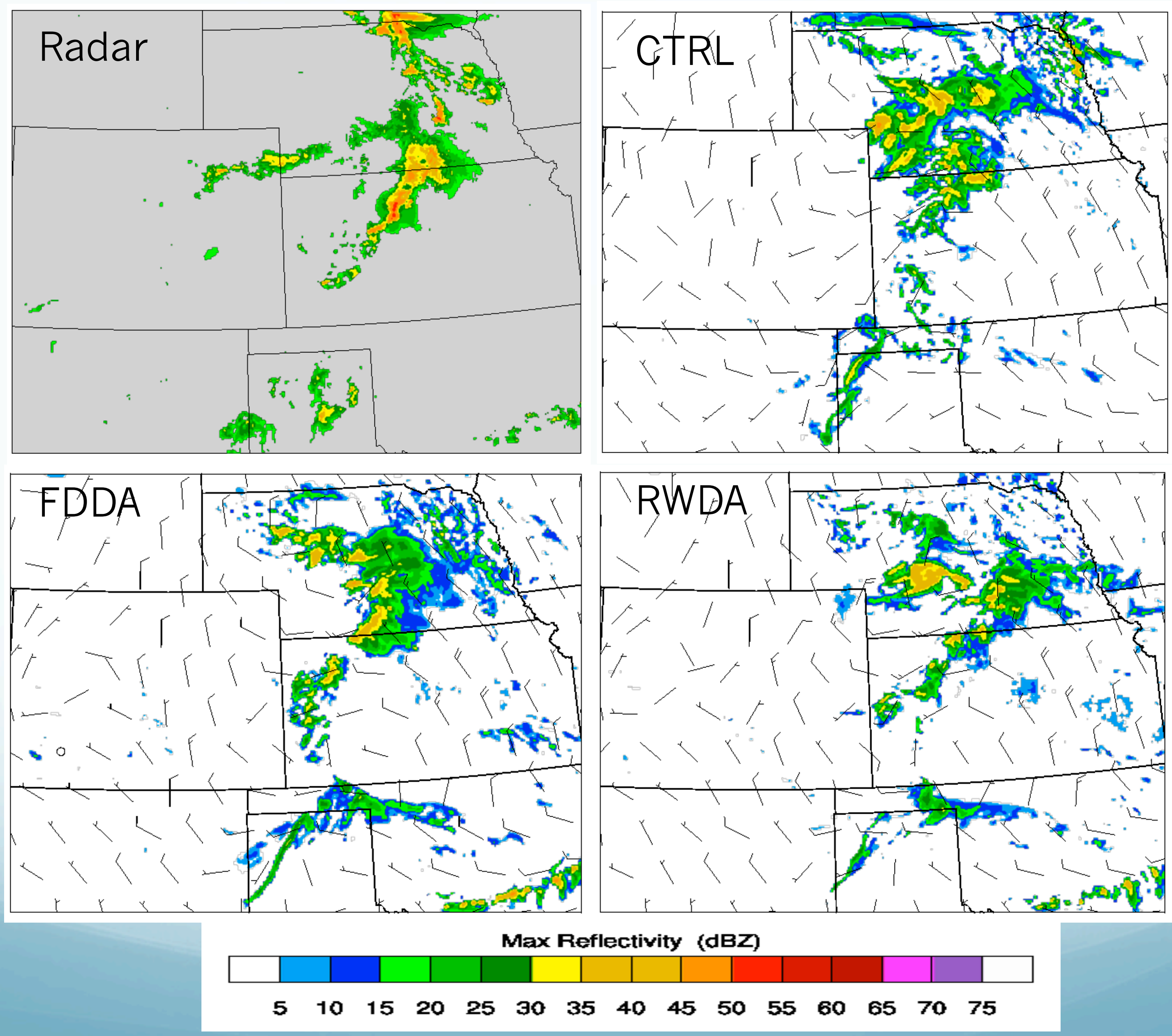
Mdbz and wind$_{700mb}$ at 12Z



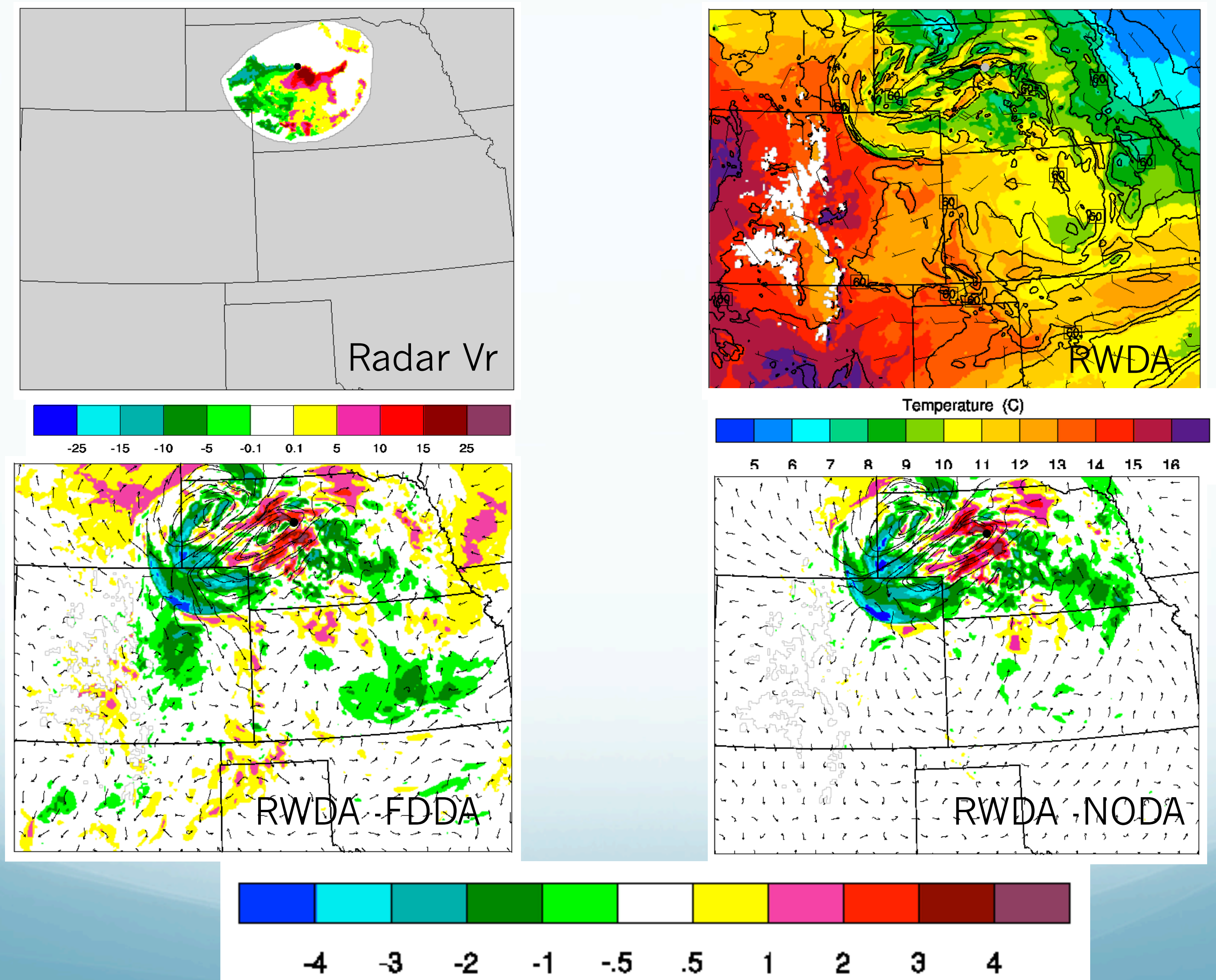
1h Fcst Mdbz and wind700mb at 13Z



2h Fcst Mdbz and wind700mb at 14Z



(T, RH, wind)$_{700hPa}$ and their Diff at 11Z July 2



Summary

- 4DREKF is a hybrid DA system of Ensemble KF and RTFDDA
- 4DREKF inherits the advantages of both EnKF and observational nudging
- Real time case study exhibits its capability on assimilating Doppler radar radial velocity observations.

Discussion

- 4DREKF, like other EnKFs, depends heavily upon the quality of the Kalman gain. How to obtain reliable gain from the limited available ensemble forecast is still a big challenge.

- Like 4DVAR, 4DREKF use a lot of memory to save obs and model info. How to optimize the memory usage is still an issue. At present we have combined the distributed with the shared memory architecture to save memory.

- Localization of different obs type needs to be optimized for meso- to small-scale data assimilation.

Question?

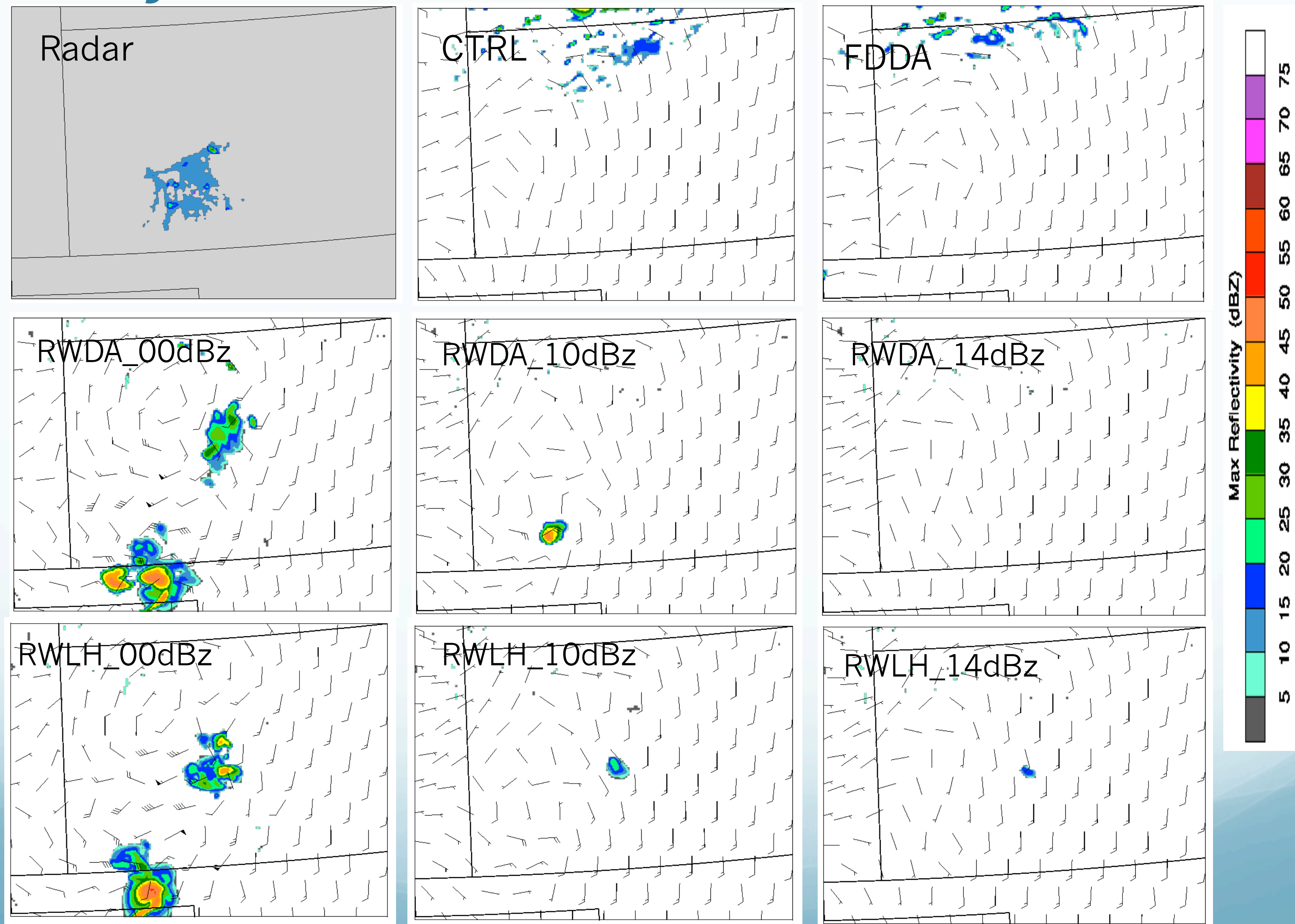
Thanks for your attention!

Kansas Supercell Experiment

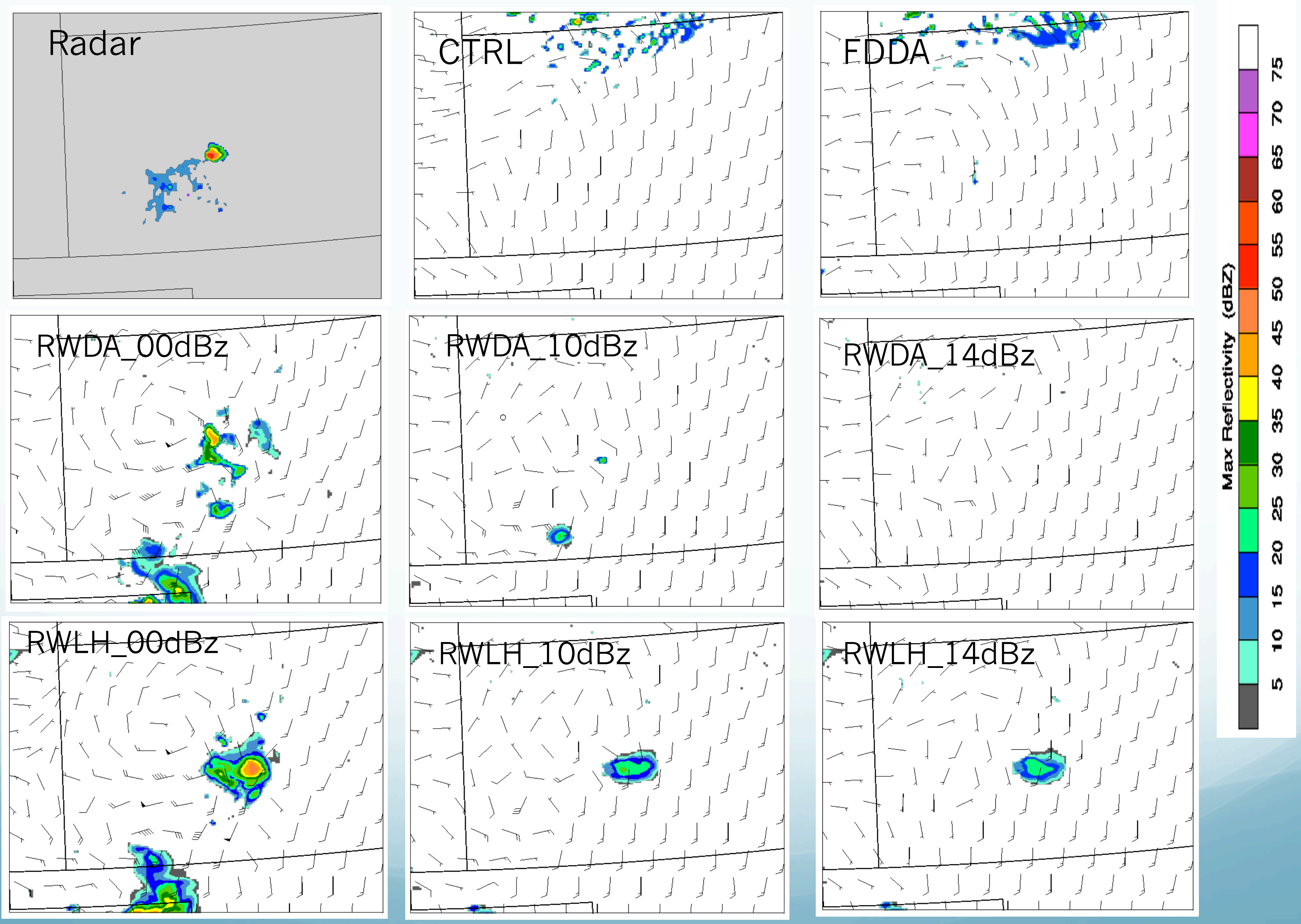
- Model Initial Time: 21Z June 3
- Assimilation Window: 3h
- Obs: Routine sfc and upper air Obs, Radar data
- Experiments:
- CTRL: No DA
- FDDA: Routine obs DA
- RWDA: Radial wind DA
- RWLH: Radial wind and reflectivity DA

_**dBz: use radial winds whose reflectivities are greater than **dBz.

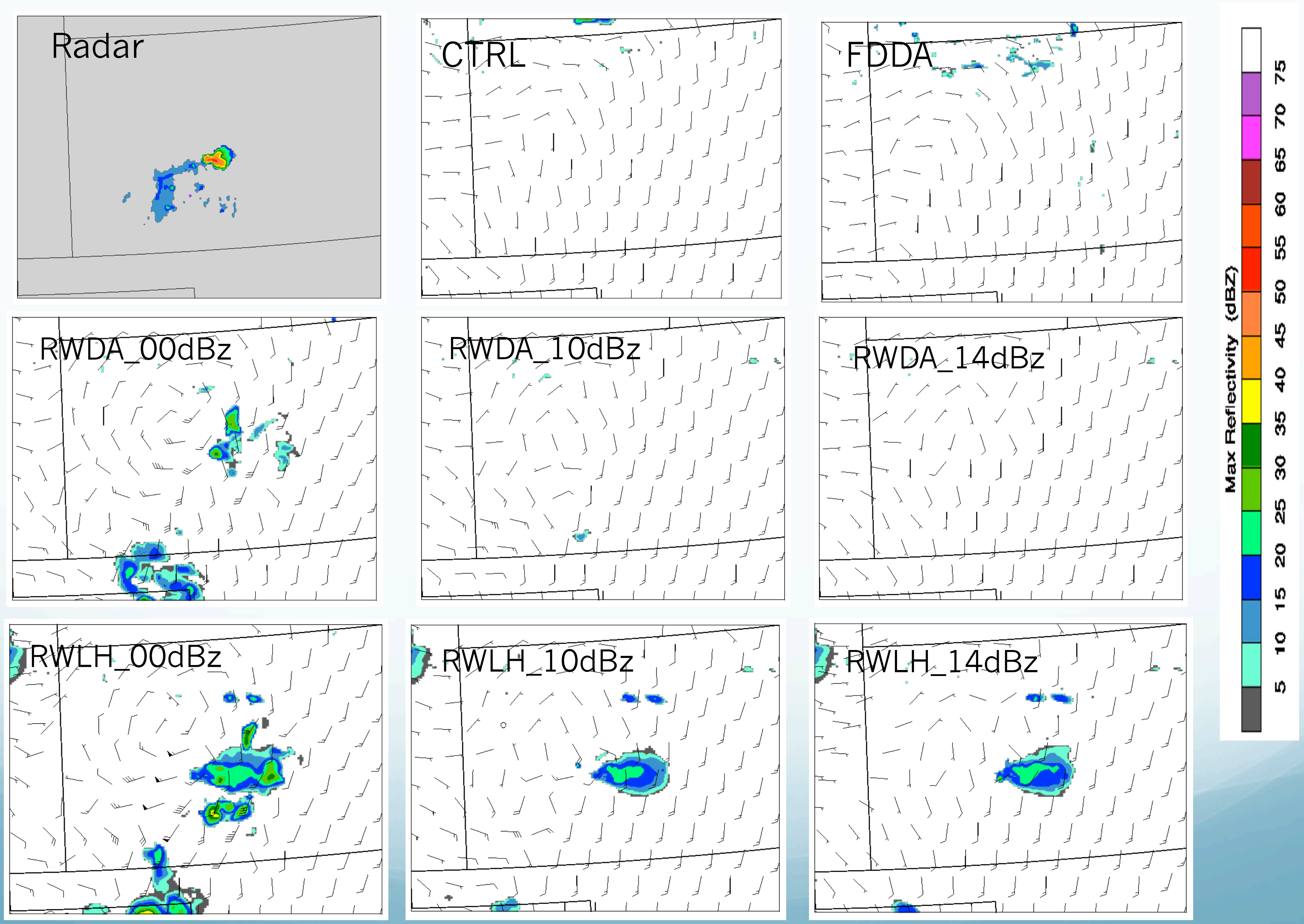
Analysis Mdbz and wind850mb at 23Z June 3



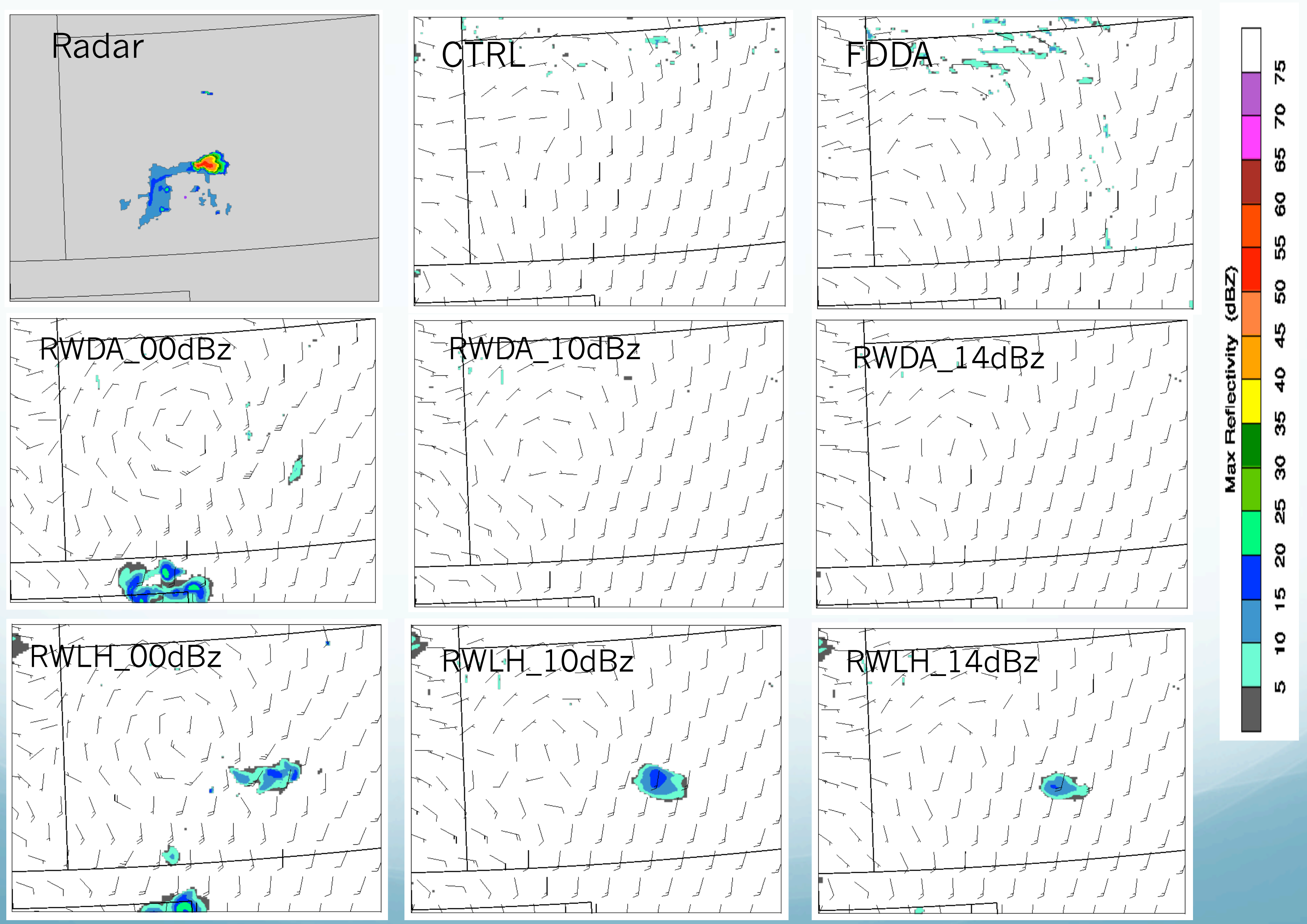
Analysis Mdbz and wind$_{850mb}$ at 00Z June 4



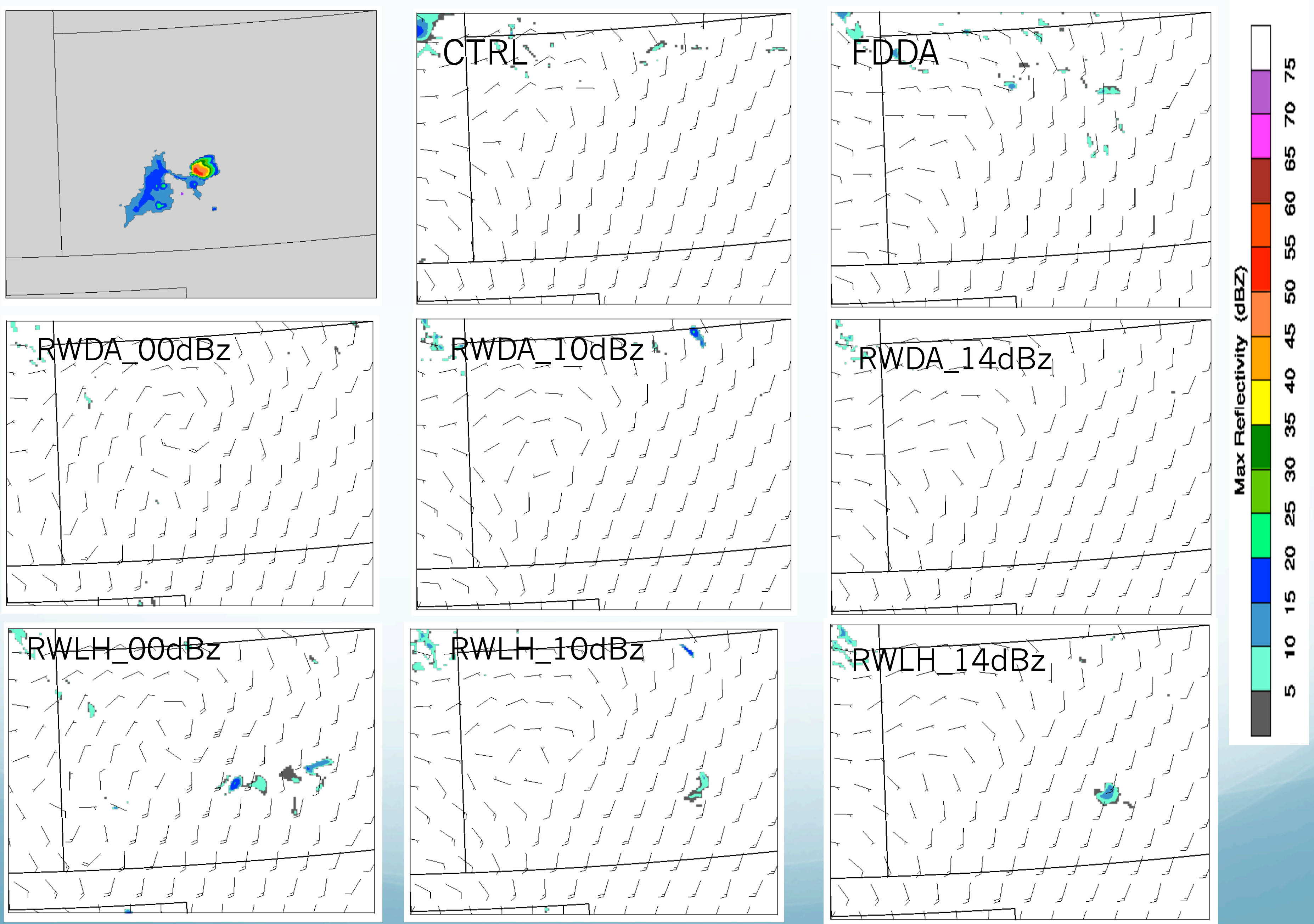
FCST Mdbz and wind$_{850mb}$ at 00:30Z June 4



FCST Mdbz and wind$_{850mb}$ at 01Z June 4



FCST Mdbz and wind$_{850mb}$ at 02Z June 4



Calculation of Kalman Gain

$$G = P^f H^T (HP^f H^T + O)^{-1}$$

$$P^f = \tilde{X}^f \left(\tilde{X}^f\right)^T$$

$$G = \tilde{X}^f (H\tilde{X}^f)^T [H\tilde{X}^f (H\tilde{X}^f)^T + O]^{-1}$$

$$\tilde{Y}^f = H\tilde{X}^f$$

$$G = \tilde{X}^f (\tilde{Y}^f)^T [\tilde{Y}^f (\tilde{Y}^f)^T + O]^{-1}$$

$$G = COV(\tilde{X}^f, \tilde{Y}^f) / [VAR(\tilde{Y}^f) + O]$$

In case of perfect obs: $O = 0$

$$G = COV(\tilde{X}^f, \tilde{Y}^f) / VAR(\tilde{Y}^f)$$

Assimilation of Reflectivity

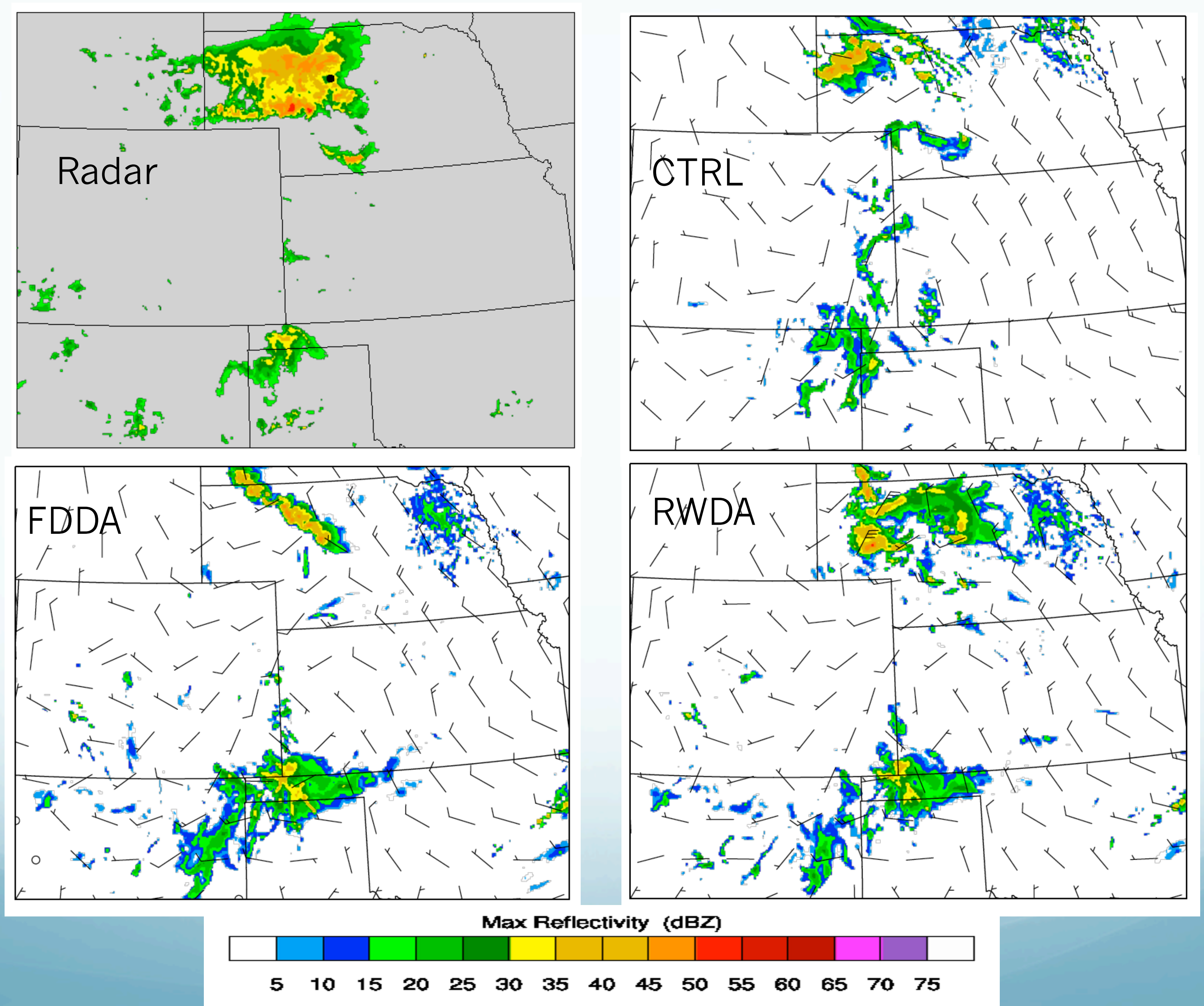
Convert 3D mosaic radar reflectivity to 3D precipitation

Interpolate the precipitation onto model grid

Precipitation tendency is calculated based on the difference between the observed precipitation and the model one.

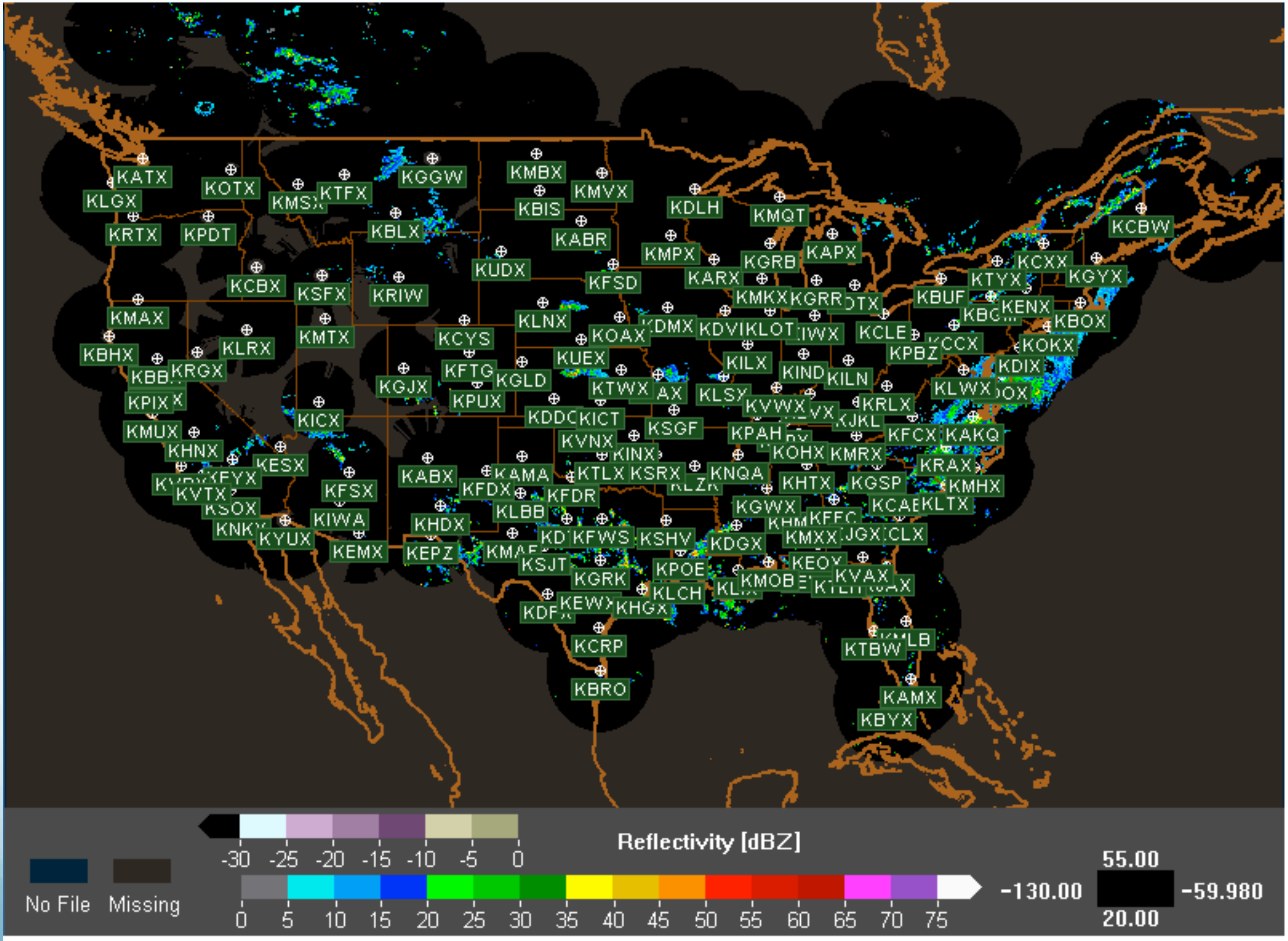
Latent heat increment is obtained based on the Precipitation tendency

Mdbz and wind$_{700mb}$ at 09Z

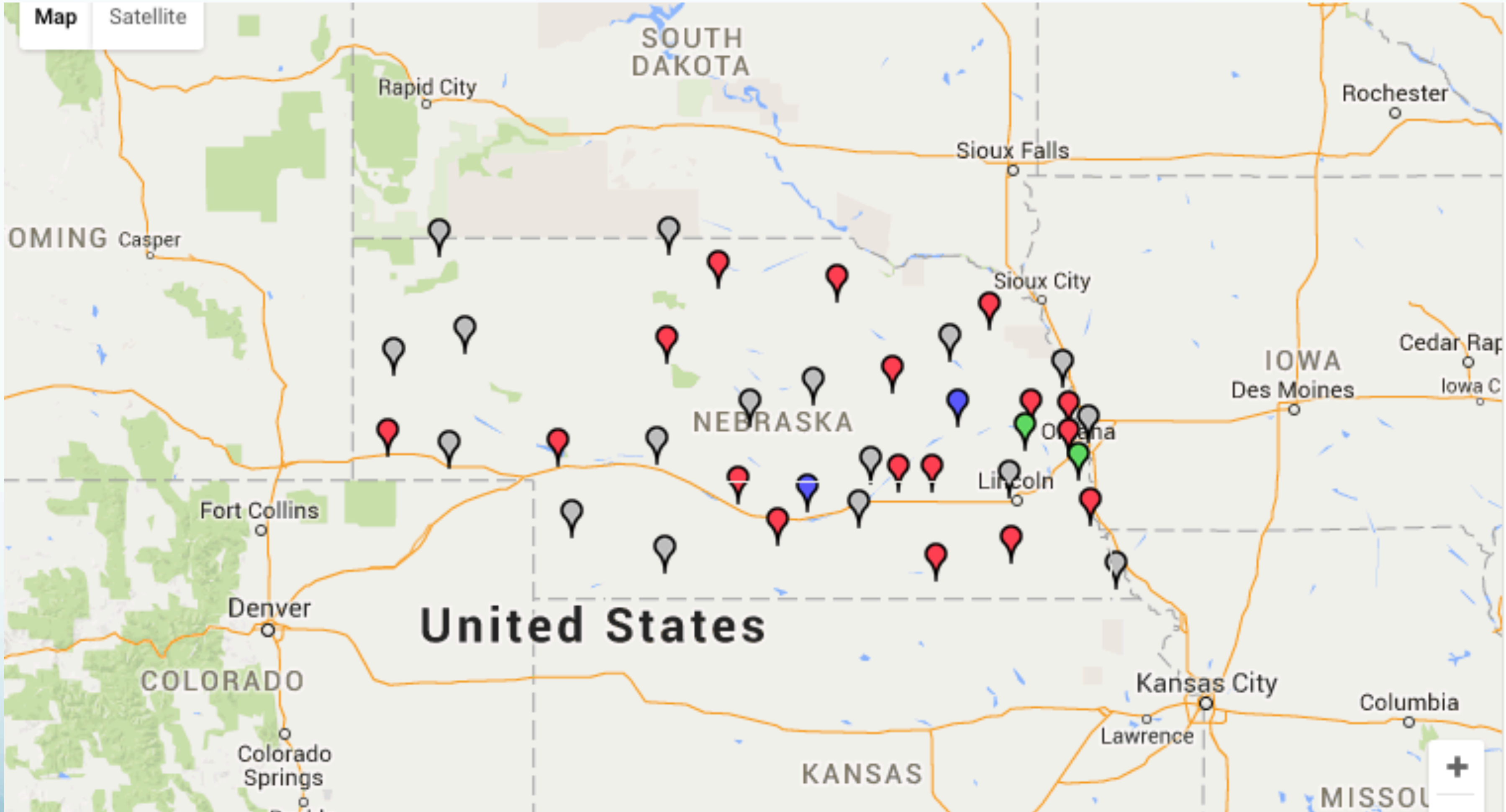


NWS Sounding System

NWS Radar Sites



Nebraska Surface Weather Obs Stations



Kansas Surface Obs stations