

LI Mission Advisory Group & GOES-R Science Team Workshop
27-29 May 2015

Deterministic and Ensemble Storm-scale Lightning Data Assimilation

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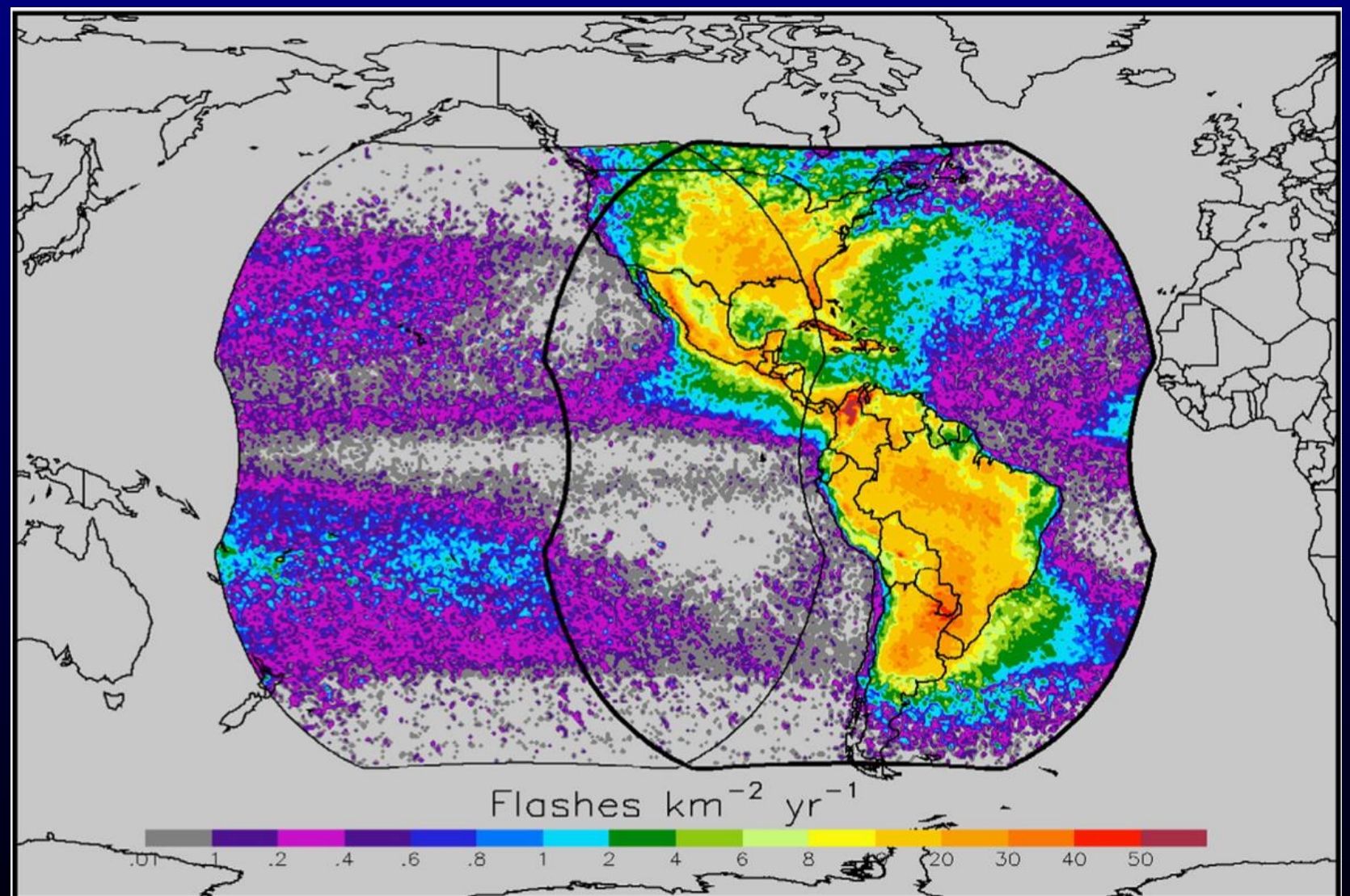
National Weather Center, Norman, Oklahoma, USA

Why (Total) Lightning Assimilation?

- Unambiguous indicator of deep electrified storms. GLM will detect total lightning over huge region continuously with >70% detection efficiency.
- Total lightning correlates far better with storm characteristics (e.g., ice water path) than cloud-to-ground (CG) only.
- Intracloud flashes tend to occur 5-30 minutes before CGs & IC:CG is 3 typically (less lag from convection initiation & more samples)

Average yearly
lightning density (from
TRMM/LIS) for GOES
fields of view

Far greater coverage
than radars.



Three methods of storm-scale lightning data assimilation:

1. “Deterministic”: Nudging water vapor (and/or θ_e to force convection initiation where lightning is observed but convection is absent in WRF. Forcing is maintained for 10s of minutes to achieve a model response to sustain the storms.

(Fierro et al. 2012) Used ENTLN total lightning as national stand-in for GLM.

2. “Ensemble”: Kalman Filter to modulate convection (e.g., strengthen or weaken) in the ensemble members. Ensemble covariances provide adjustments to all state variables (e.g., temperature, winds, liquid water, & ice particles). Lightning observations are assimilated on 1-3 minute intervals.

(Mansell 2014, Allen 2014) Used regional pseudo Geostationary Lightning Mapper (p-GLM) data derived from LMA

3. 3-D VAR: Just starting work on this.

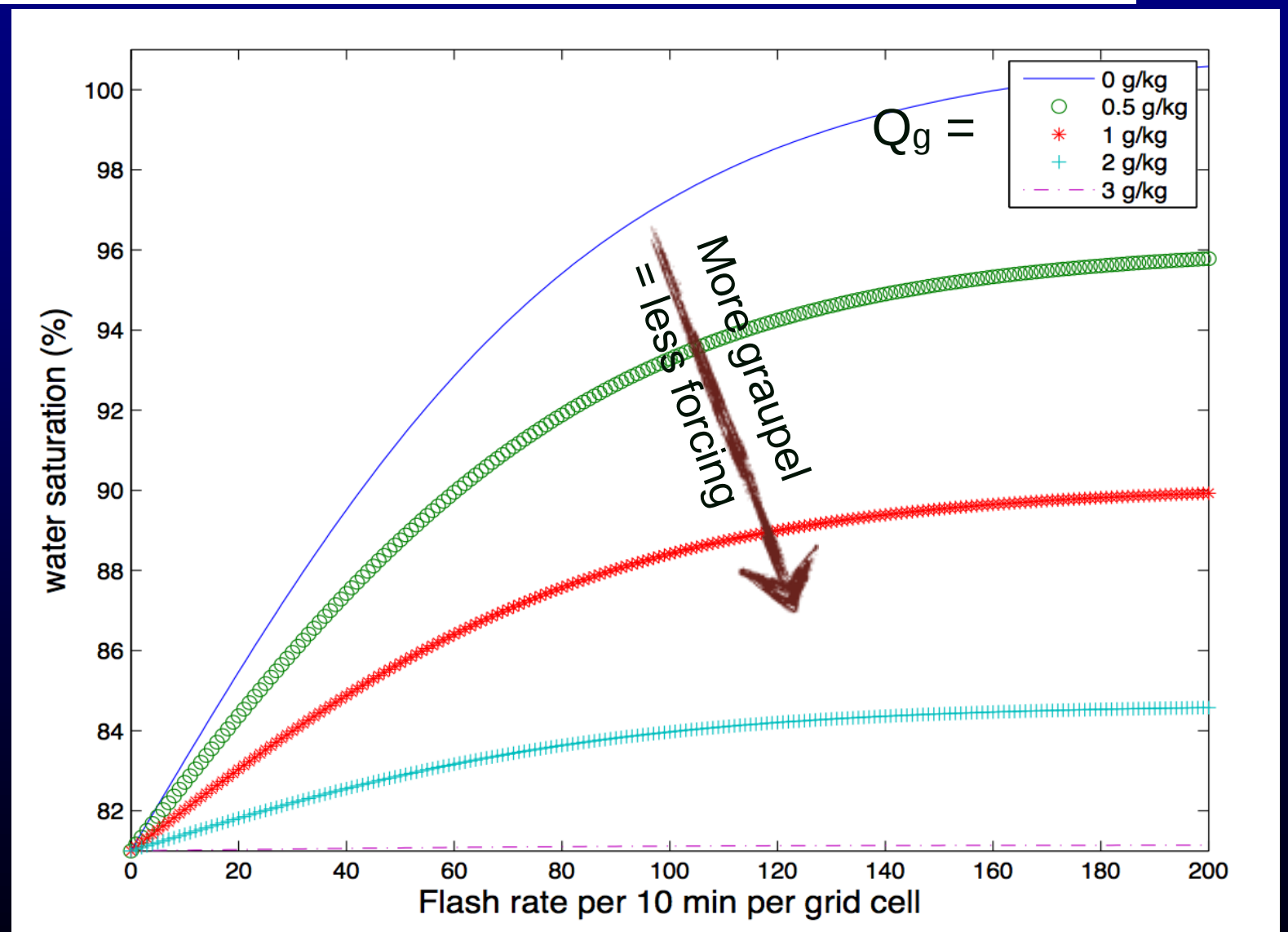
Lightning assimilation nudging function

Water vapor mixing Q_v within the 0°C to -20°C layer was increased as a function of 9-km gridded flash rates N_{flash} (X) and simulated graupel mass mixing ratio Q_g and saturation vapor mixing ratio Q_{sat} . Increasing Q_v at constant temperature T increases buoyancy (virtual potential temperature θ_v) and ultimately generates an updraft.

$$Q_v = A Q_{\text{sat}} + B Q_{\text{sat}} \tanh(CX) [1 - \tanh(D Q_g^\alpha)]$$

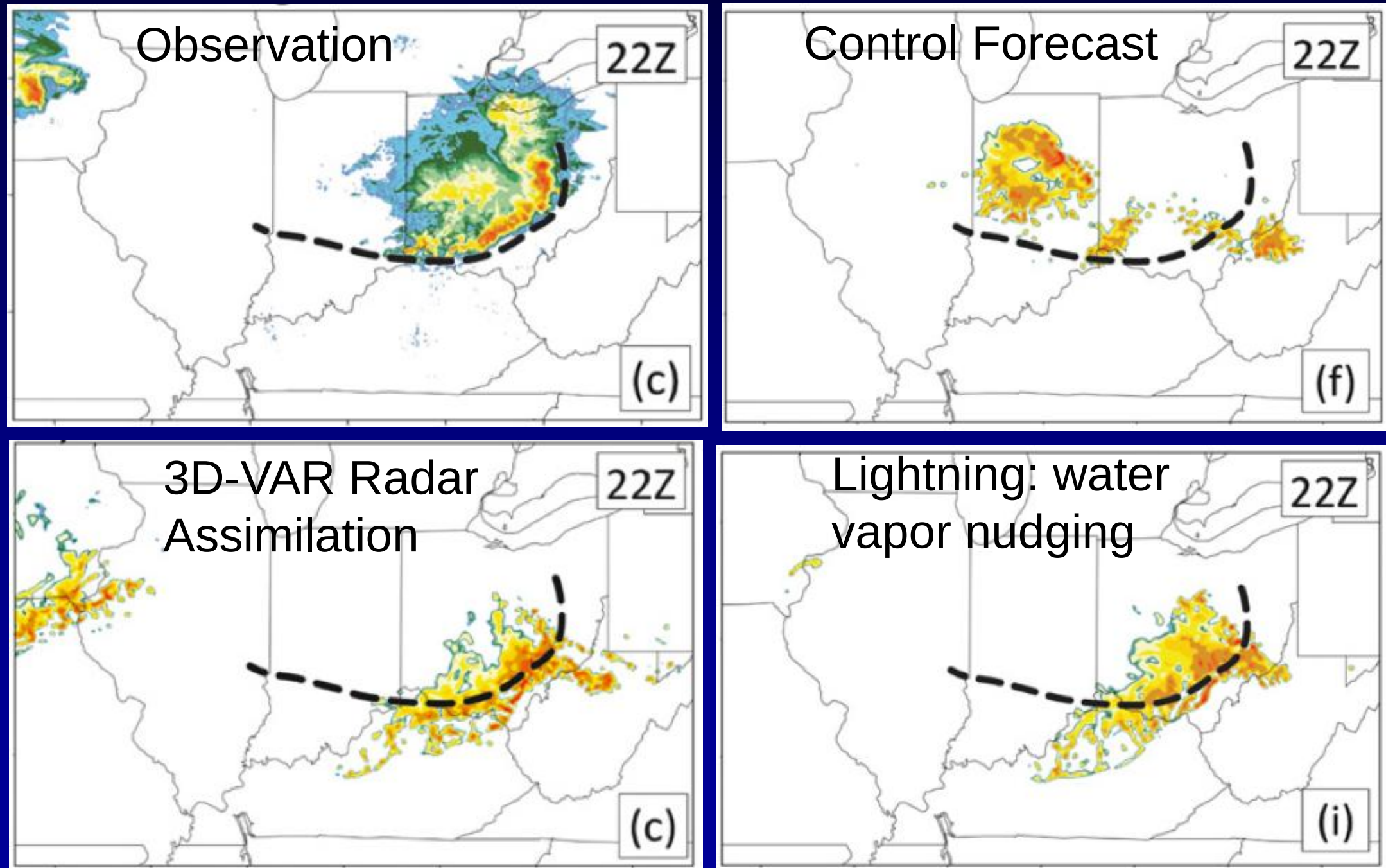
- Only applied whenever simulated $\text{RH} \leq A \cdot Q_{\text{sat}}$ and simulated $Q_g < 3 \text{ g/kg}$.
- A controls minimum RH threshold (here 81%).
- B and C control the slope (how fast to saturate)
- D affects how much water vapor (Q_v) is added at a given value of graupel mixing ratio (Q_g).

Fierro et al. (2012)



Nudging: 29 June 2012 Derecho Event

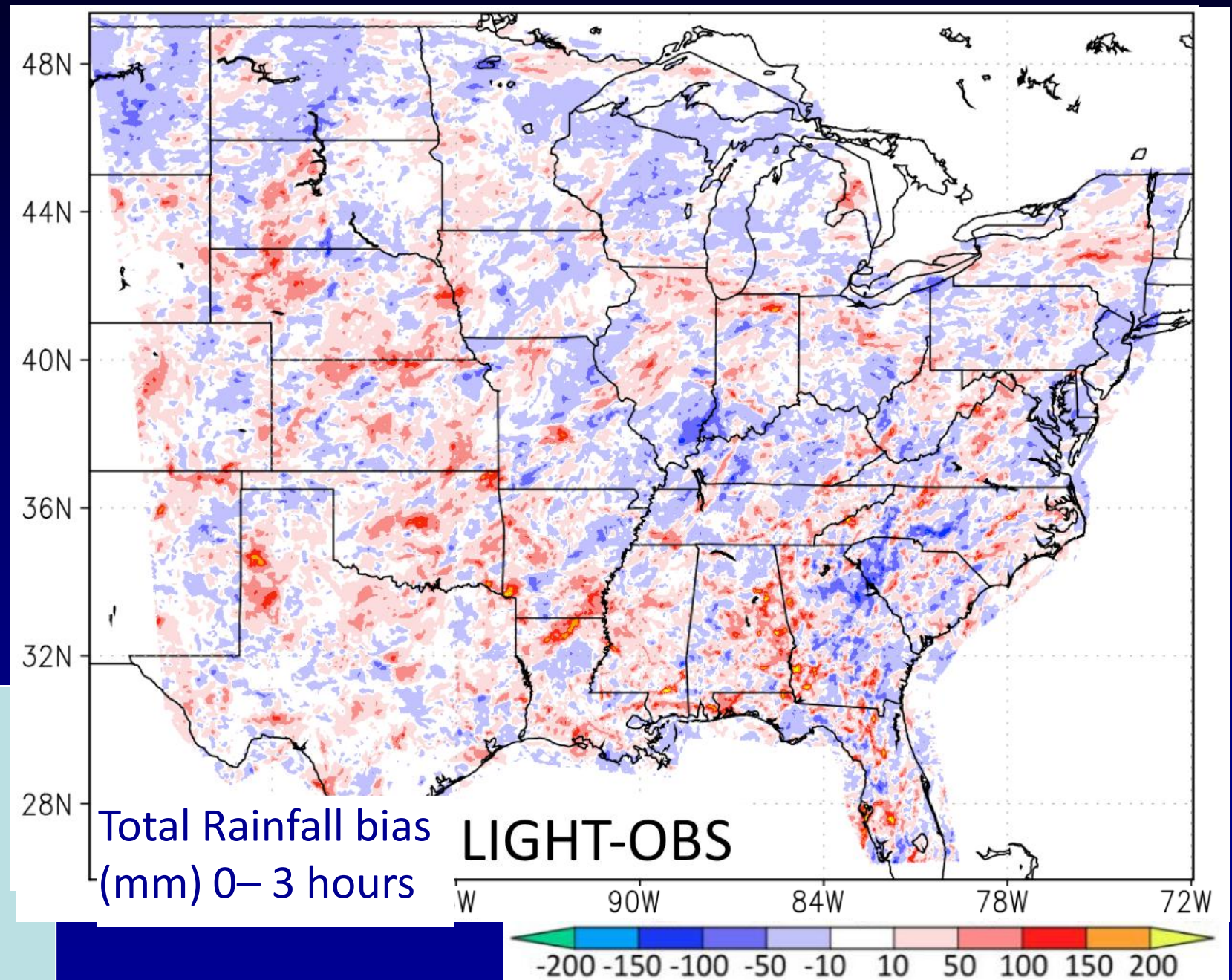
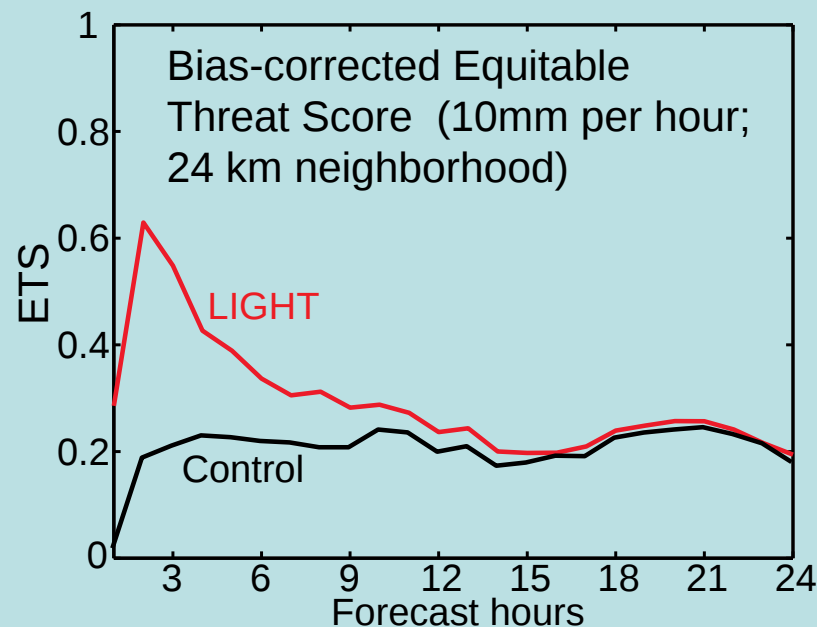
Comparison of 6-hr forecasts at 22 UTC (3-km resolution): Observed radar, No Assimilation (Control, 14 UTC starting time), 3D-var assim. of radar data (10-minute cycling, 14-16UTC), and lightning data (ENTLN) assimilation (14-16 UTC).



Fierro et al. (2014)

Real-time implementation into WRF-NSSL 4-km CONUS runs

A quasi-operational test of daily forecasts parallel to the daily NSSL convection-allowing forecasts (4-km horizontal grid spacing), initialized at 00 UTC. Lightning data (ENTLN) were assimilated for first two hours (0-2 UTC) of forecast to nudge deep convection.



Fierro et al. (2015)

Ensemble Kalman Filter (EnKF) Assimilation

Example of suppression using lightning density at 8x8km resolution (model at 1km resolution). One cycle (about 10 observations!) achieves significant reduction in updraft and hydrometeor mass.

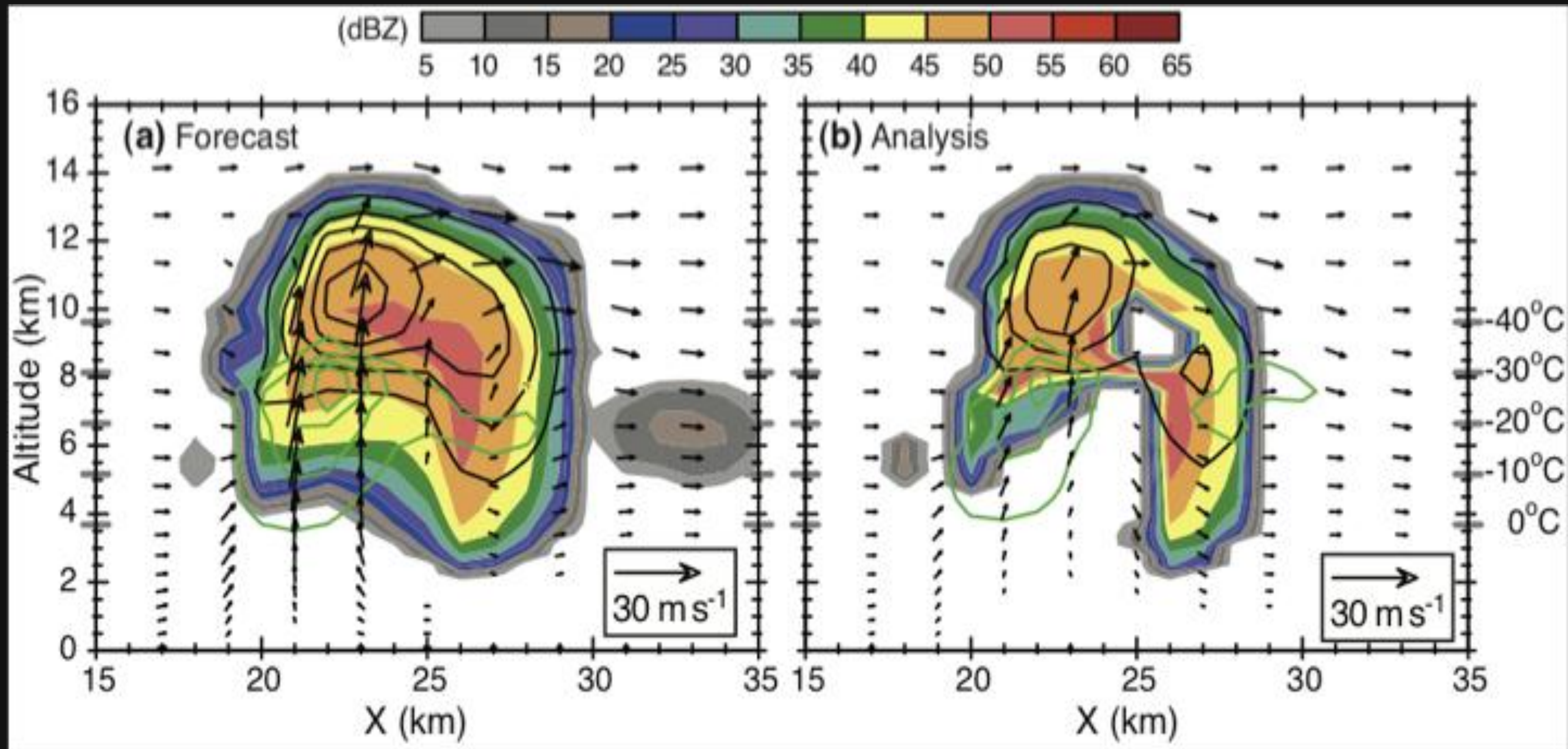


Figure: updraft (vectors) and graupel mass (black contours) and radar reflectivity (color-filled contours)

Pseudo-GLM EnKF Assimilation

P-GLM grid flash counts from LMA data
(flashes per grid column per time)

EnKF observation operator: linear
relationship between graupel echo
volume & flash rate:

$$\text{FED} = (0.017) * (\text{graupel volume})$$

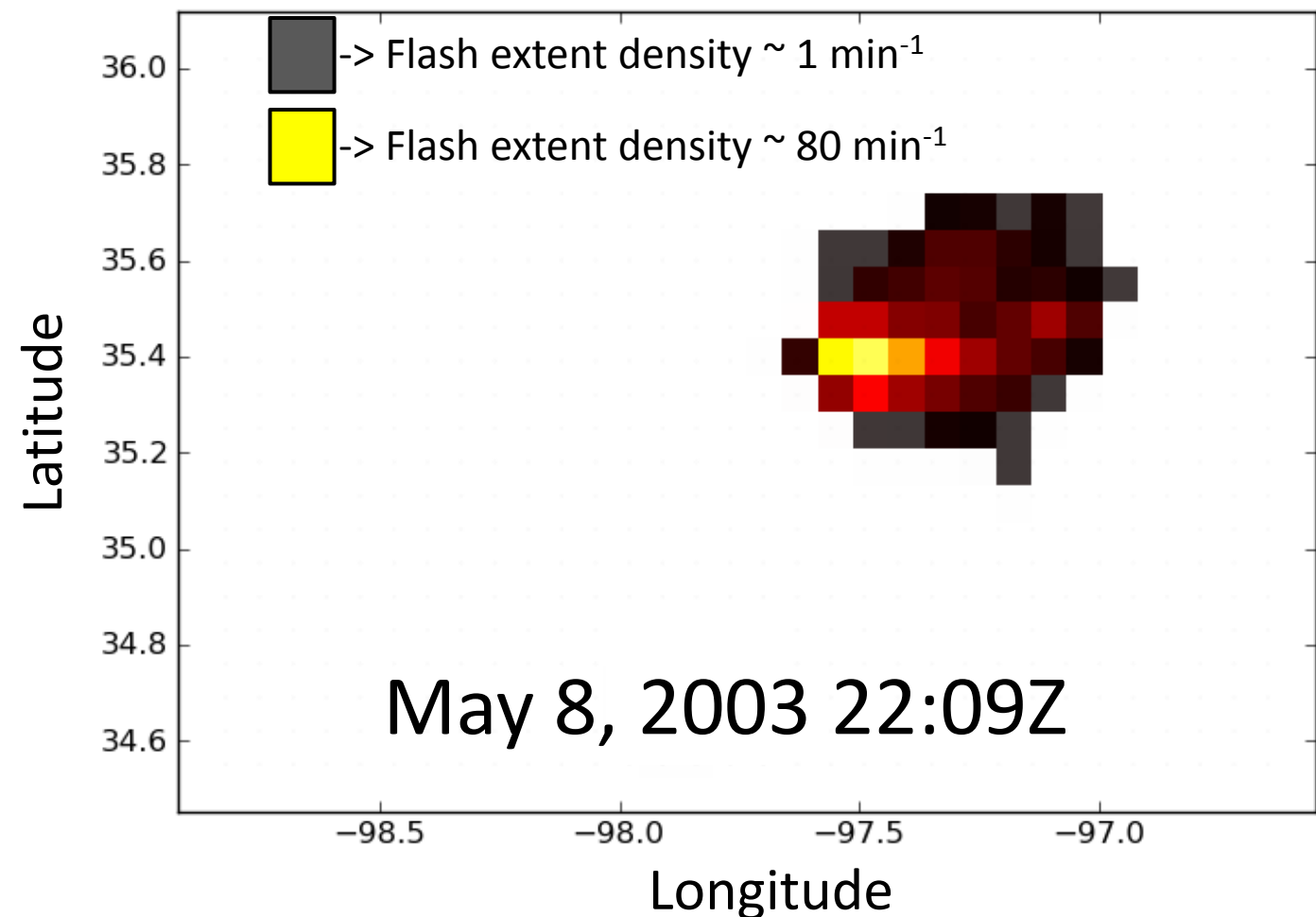
where graupel volume = number of grid
cells with graupel mixing ratio > 0.5 g/kg
in a 16-km box centered on p-GLM pixel.

Radar radial velocity data assimilated for
comparison.

Ensemble:

40 members, 1-km horizontal resolution.

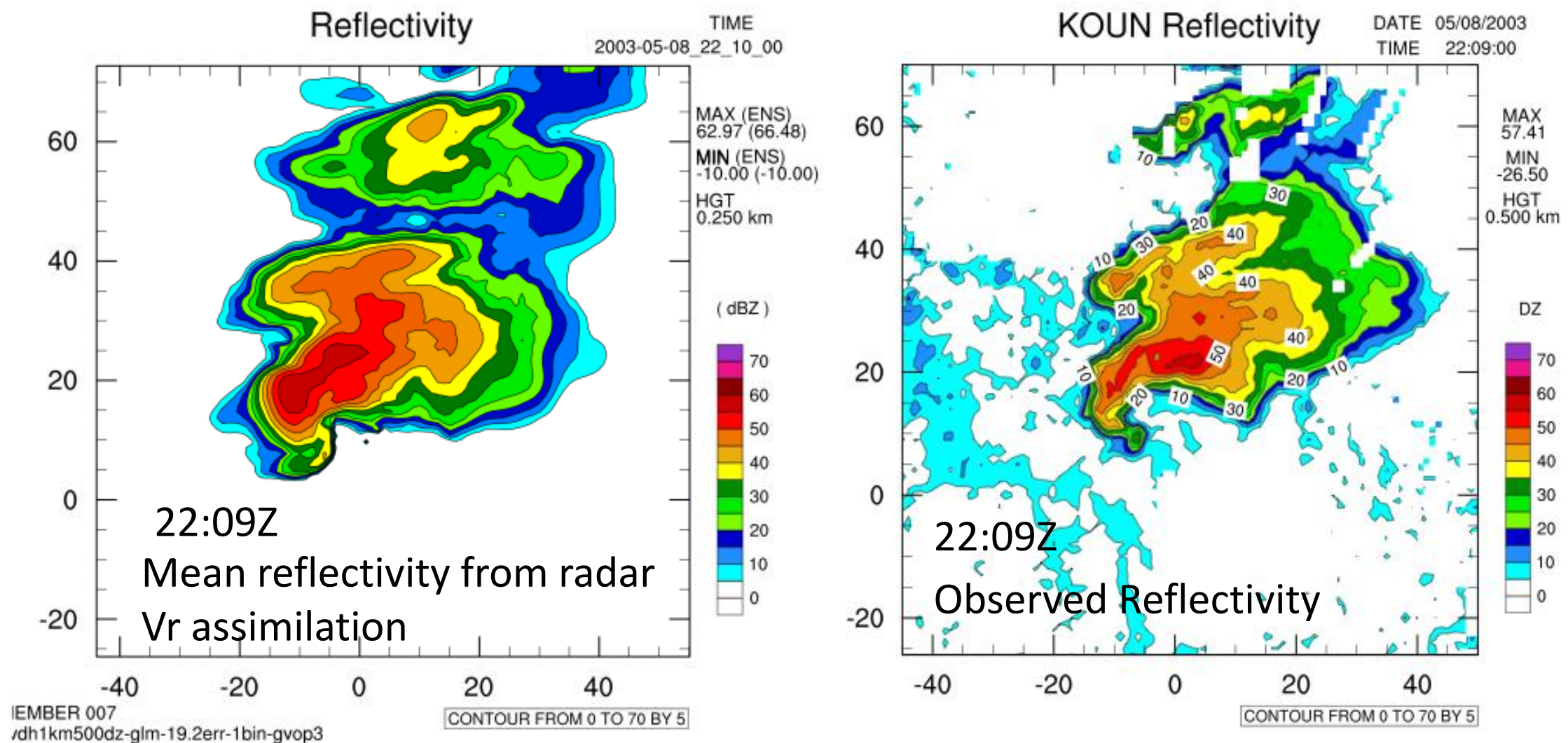
Cloud model is COMMAS with NSSL 2-
moment microphysics.



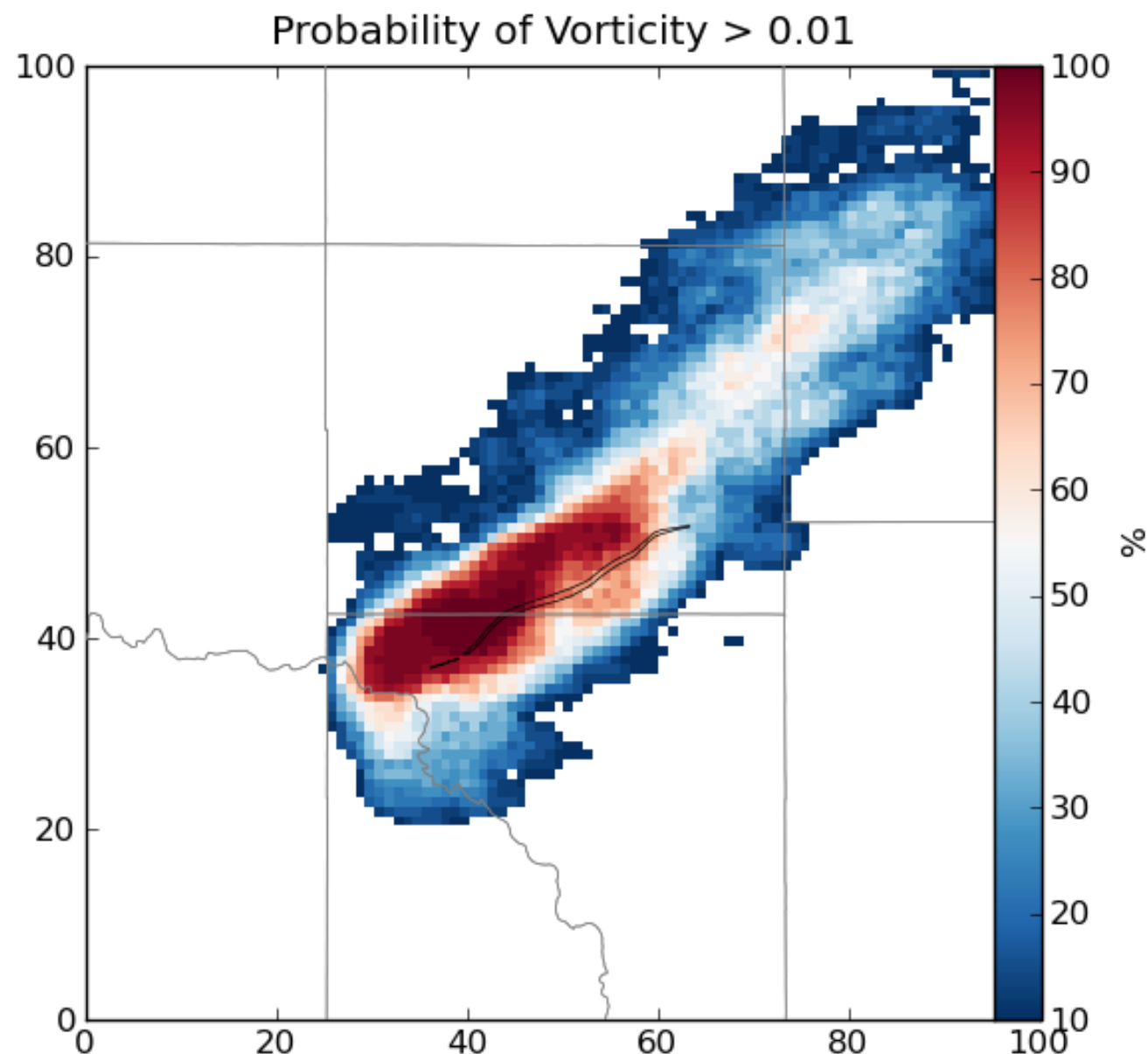
Example of 8-km pseudo-GLM Flash extent
density (FED) derived from Oklahoma LMA for
8 May 2003 tornadic supercell storm from
Allen (2014).

P-GLM EnKF: 8 May 2003 Supercell

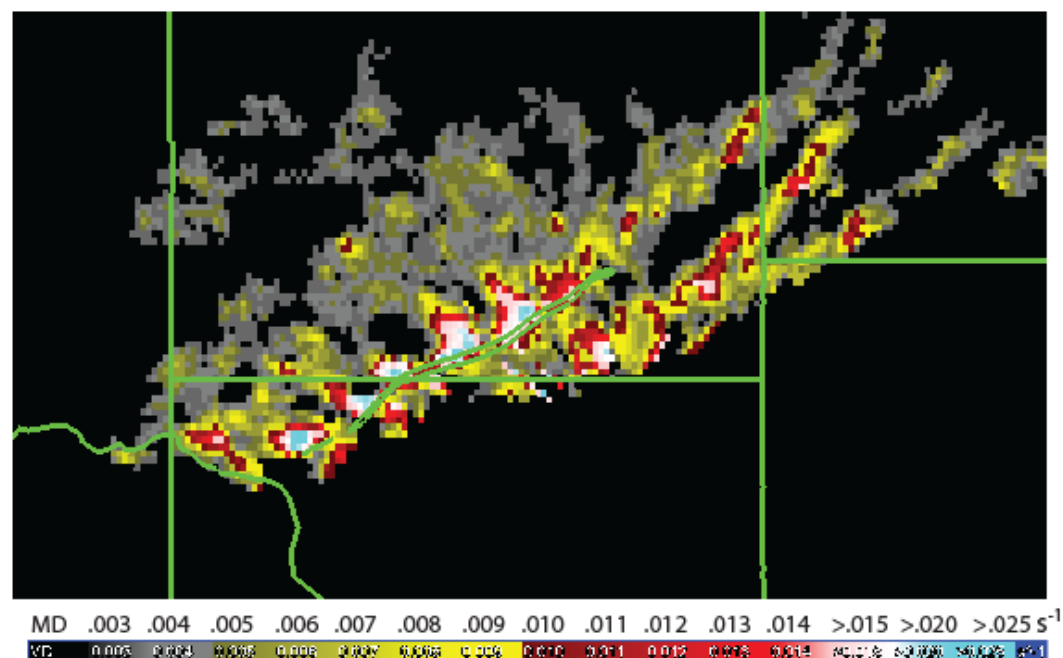
Low-level analysis of radar reflectivity around the time of the first tornado (Moore/Oklahoma City, OK EF4 tornadic storm)



Some broadening of the storms is expected from the 8-km resolution of the pseudo-GLM data. Excessive coverage of high-reflectivity regions is not unexpected, but also is rather good for a simple linear lightning observation operator.



Ensemble probability of Vorticity $> 0.01 \text{ s}^{-1}$ at 1.25 km AGL from 2200 UTC to 2300 UTC, assimilating 1 minute pGLM data with graupel volume observation operator. Tornado track is given by thin black outline near center of plot.



WDSS-II 0-2 km rotation track derived from KTLX radial velocity data from 2200 UTC to 2300 UTC. Tornado track given by green outline near center of plot. (From Yussouf et al. 2013)

Summary:

- Lightning effectively identifies deep convection and is useful for forcing convection in the early hours of a forecast. Sustained nudging of water vapor forms updrafts and allows storms to develop in a balanced manner within the model. For simple convection initiation, it is more efficient, e.g., than 3D-VAR radar analysis.
- Spring 2013 forecasts using lightning nudging increase the bias-corrected precipitation threat scores out to 6-9 hours.
- The Ensemble Kalman Filter method can modulate convection (e.g., strengthen or weaken) and help suppress spurious storms using flash extent density

Allen, B. 2014, Assimilation of Pseudo Geostationary Lightning Mapper Data Using the Ensemble Kalman Filter, M.S. Thesis, Univ. of Oklahoma, 87pp.

Fierro, A. O., E. R. Mansell, C.L. Ziegler, and D.R. MacGorman, 2012: Application of a Lightning Data Assimilation Technique in the WRF-ARW Model at Cloud-Resolving Scales for the Tornado Outbreak of 24 May 2011, *Monthly Weather Review*, vol. **120**, 2609-2627.

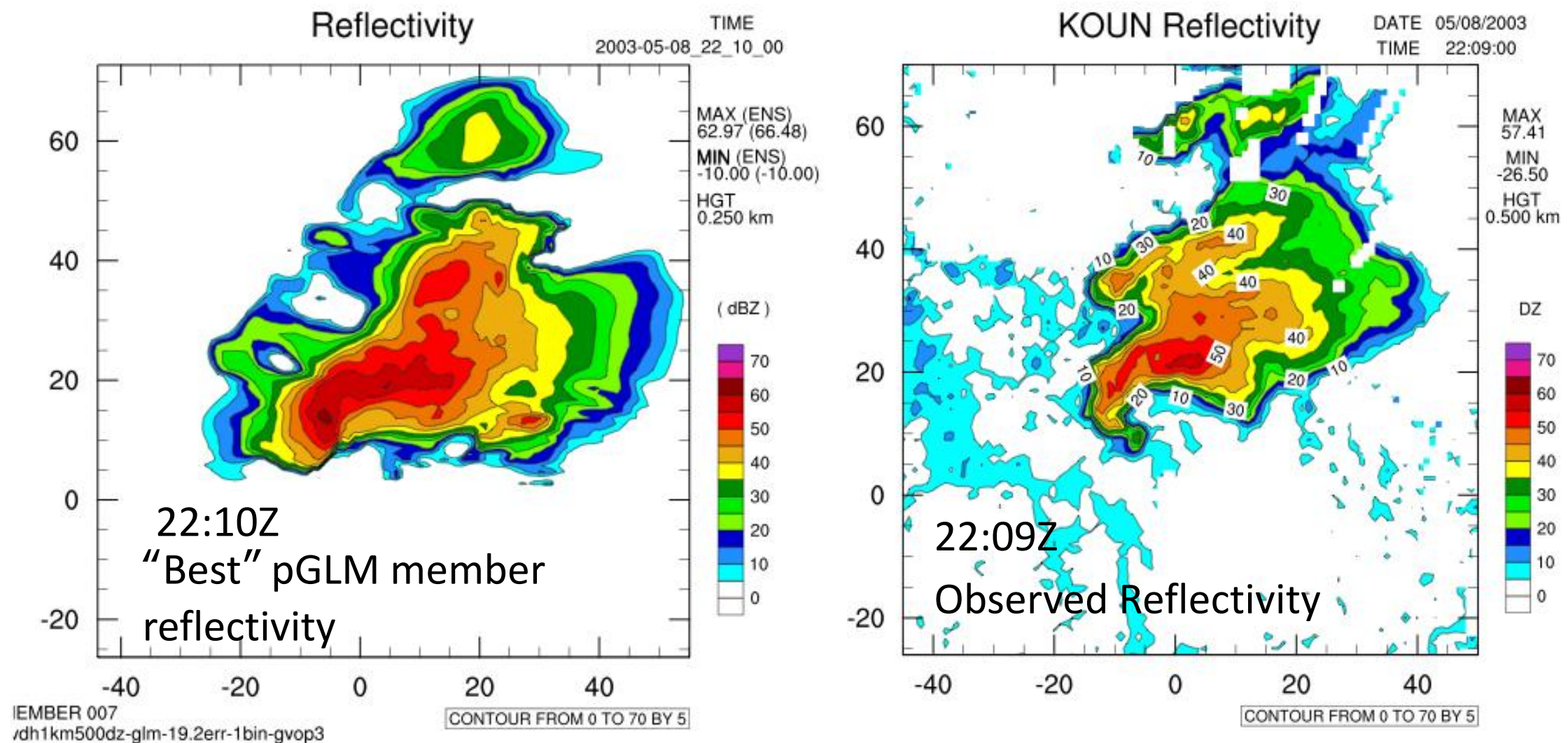
Fierro, A. O., J. Gao, C. Ziegler, E.R. Mansell, D. R. MacGorman and S. Dembek 2014: Evaluation of a cloud scale lightning data assimilation technique and a 3DVAR method for the analysis and short term forecast of the 29 June 2012 derecho event. *Monthly Weather Review-In Press*.

Fierro, A. O., A. J. Clark, E. R. Mansell, D. R. MacGorman, S. R. Dembek, C. L. Ziegler, 2015: Impact of storm-scale lightning data assimilation on WRF-ARW precipitation forecasts during the 2013 warm season over the contiguous United States. *Monthly Weather Review*, 143, 757–777, doi:10.1175/MWR-D-14-00183.1

Mansell, E. R., 2014: Storm-Scale Ensemble Kalman Filter Assimilation of Total Lightning Flash-Extent Data. *Monthly Weather Review*, 142, 3683–3695, doi:10.1175/MWR-D-14-00061.1

P-GLM EnKF: 8 May 2003 Supercell

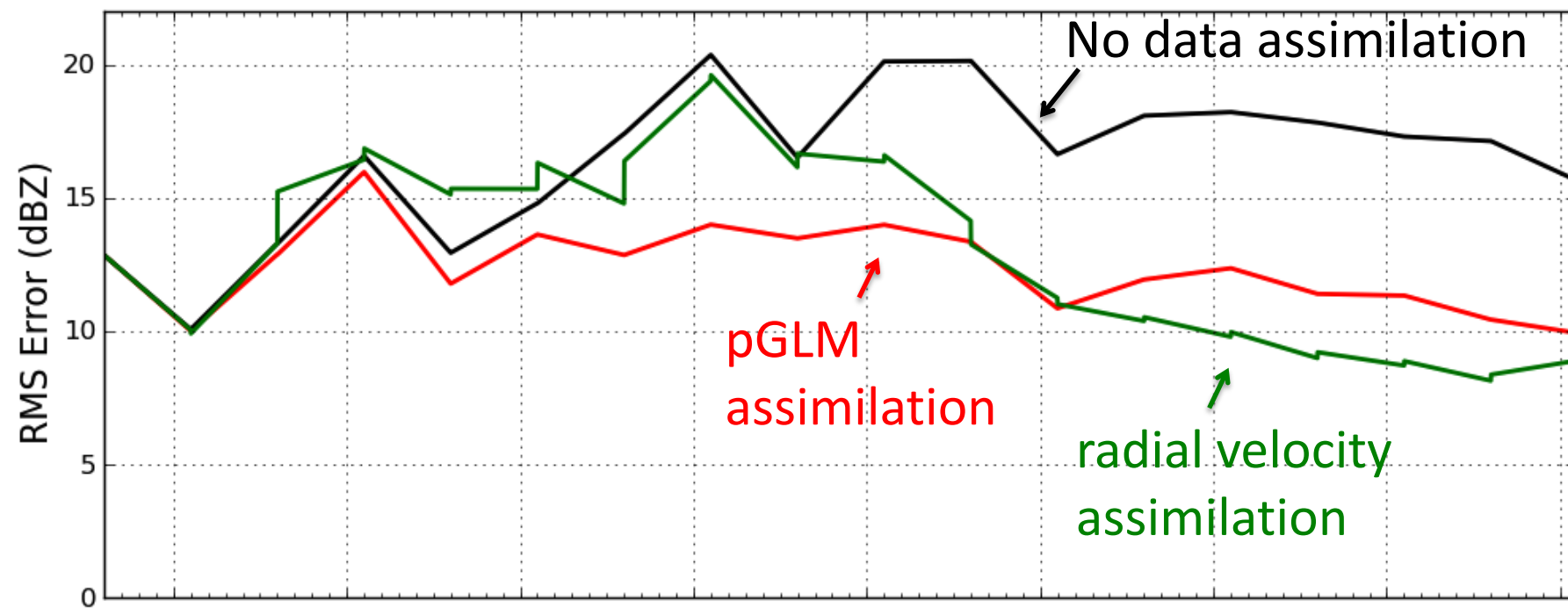
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8 May 2003: 1 minute pGLM data assimilation vs. radar radial velocity assimilation

Radar reflectivity error statistics



Innovation =
Ob - Model Mean

