Assimilation of Pseudo-GLM Observations Into a Storm Scale Numerical Model Using the Ensemble Kalman Filter

Blake Allen
University of Oklahoma

Edward Mansell
NOAA / National Severe Storms Laboratory

Funding Provided by NOAA-NESDIS/JCSDA

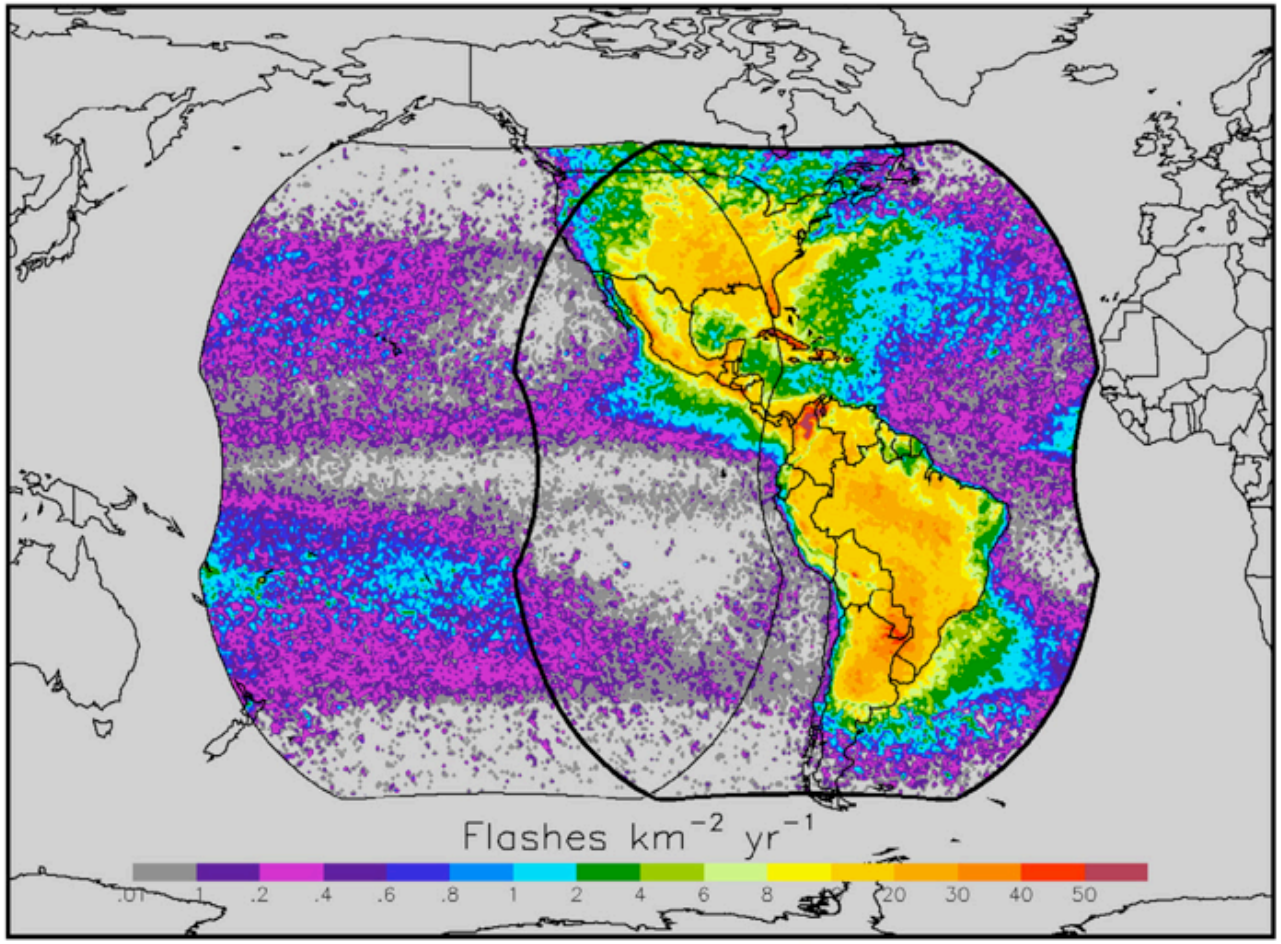
GSI Workshop, August 8, 2013

Motivation: Launch of the GLM

Among the instruments that will be aboard the GOES-R series of satellites will be the Geostationary Lightning Mapper (GLM).

Total lightning data, like radar data, can be used to locate and determine the strength of convection.

Radar data is limited in mountainous areas and especially over oceans, but the GLM will provide spatially continuous total lightning data over a very large area.



Eventual Geostationary Lightning Mapper Coverage (From Goodman et al. 2013)

Motivation: Launch of the GLM

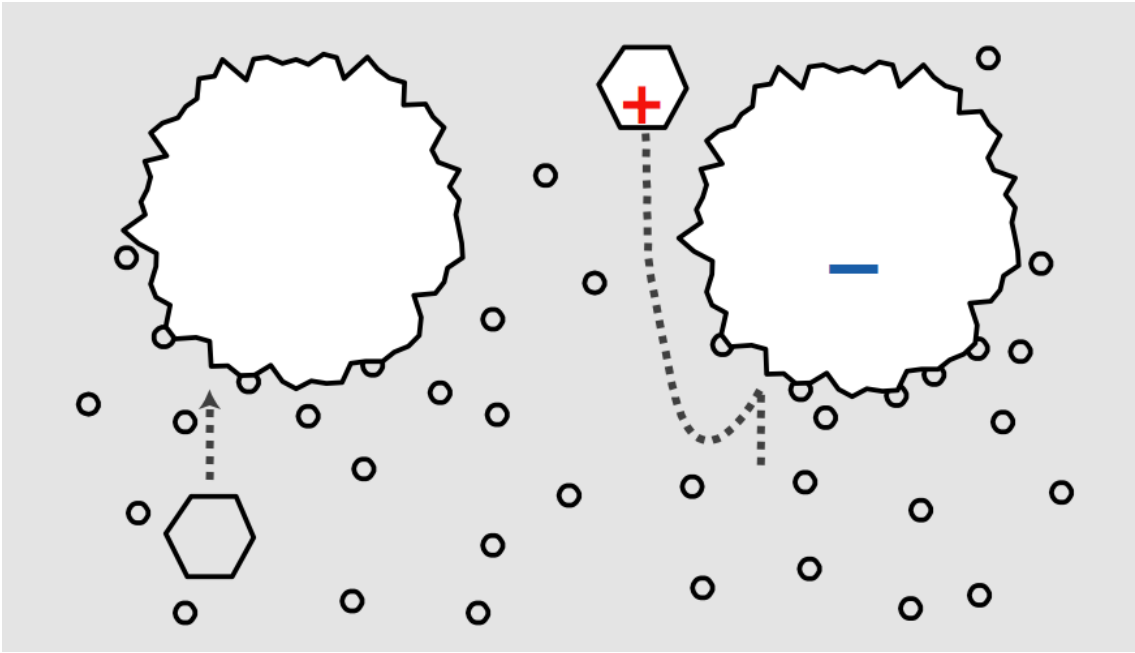
Radar data has been shown to be very useful for initializing convection in forecast models.

In the absence of quality radar data, how well can lightning data of the sort that will be provided by the GLM serve the same purpose?

Background: The lightning – microphysics connection (in the lab)

Lab studies have shown that significant charge separation occurs during rebounding collisions between cloud ice and riming graupel.

The oppositely charged ice crystals and graupel particles are then separated from each other owing to their different terminal velocities.



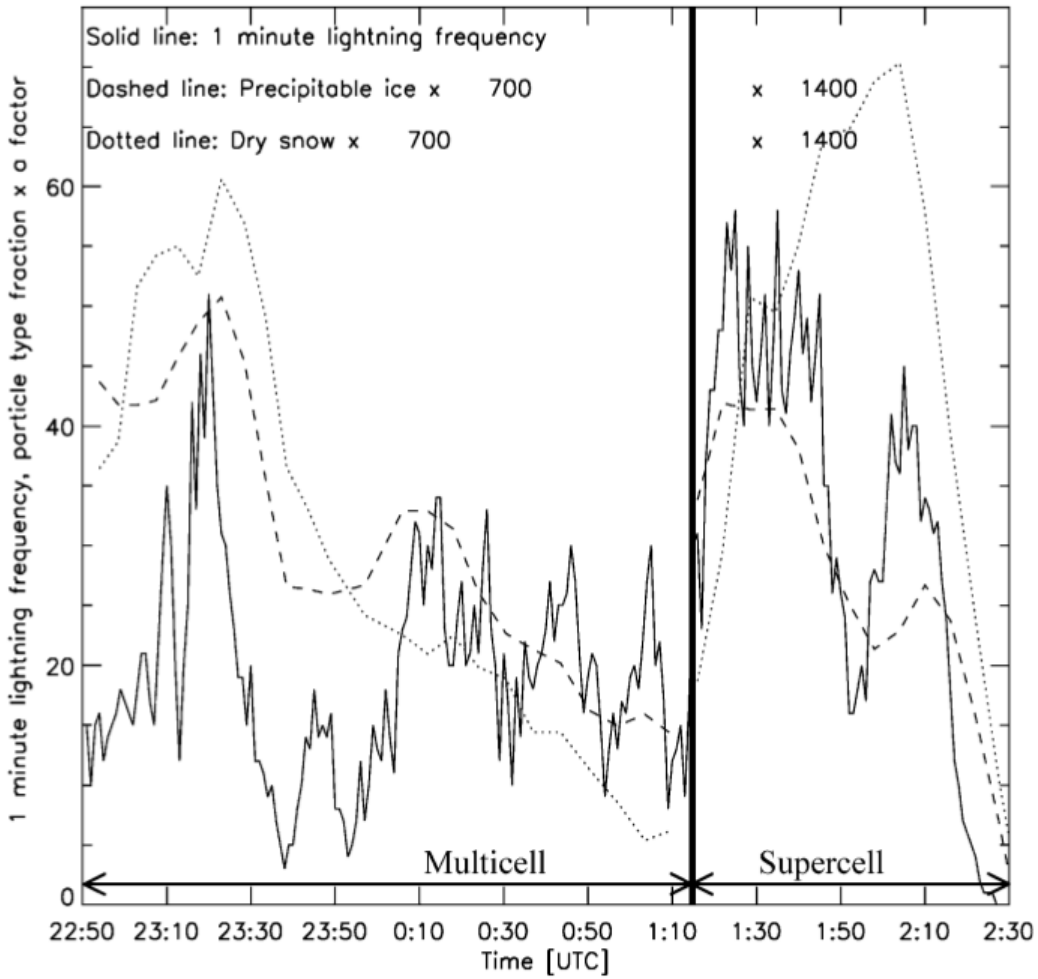
Before collision After collision

Background: The lightning – microphysics connection (individual storms)

Observational Studies have shown correlations between precipitation ice content and total lightning activity in individual storms. (Plot from Deierling et al. 2005).

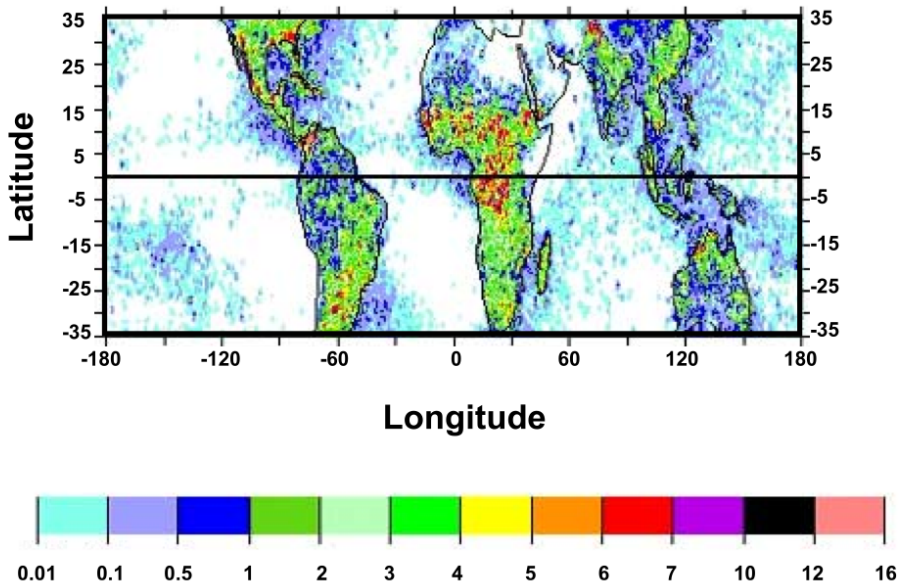
Variables	r^2 for linear fit
Flash rate and graupel mass	0.94
Flash rate and flux product	0.96

(From Deierling et al. 2008)

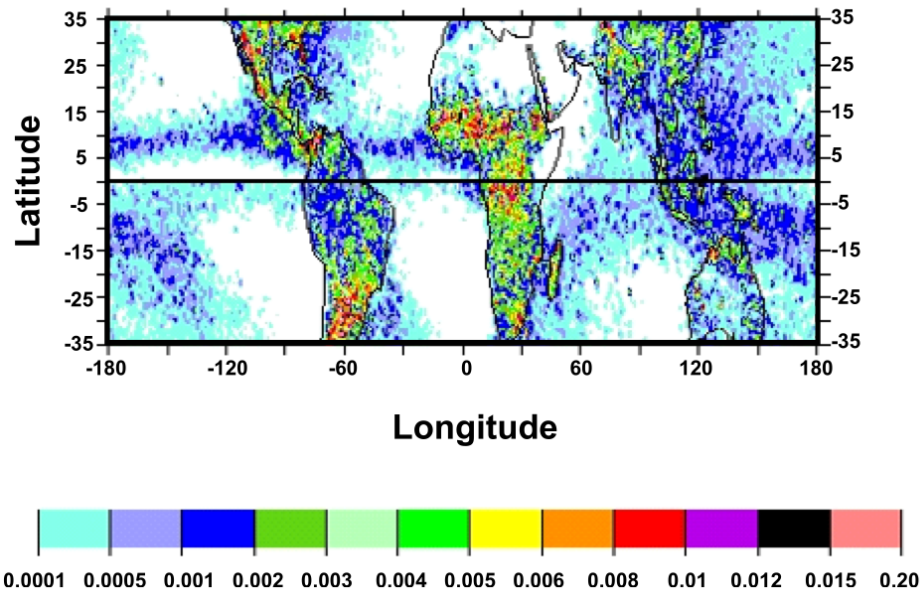


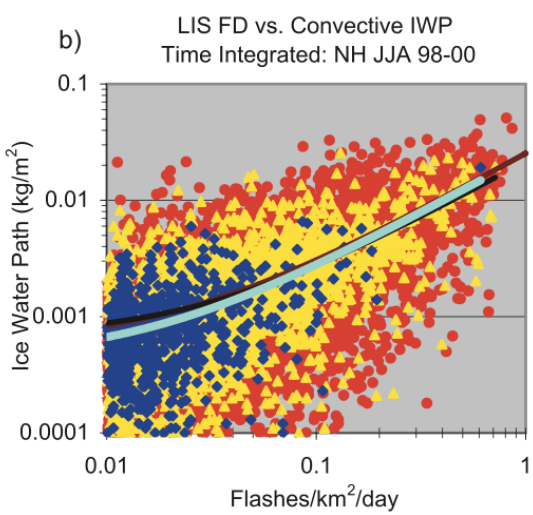
Background: The lightning – microphysics connection (globally)

Lightning Imaging Sensor Flash Density



TRMM Precip Radar Ice Water Path





Additionally, Satellite data has been used to show flash rates are correlated with ice water path globally, with only small differences between the relationships in different convective regimes. (Plots from Petersen et al. 2005. In lower left blue, yellow, and red points correspond to marine, coastal, and continental regimes.)

Methods

Basic Approach (part 1):

Assimilate radial velocity data while running explicit lightning model

⇩

Use relationships between microphysical variables and flash rates in analyses to create first guesses for observation operators

Basic Approach (part 2):

Convert LMA data into pseudo-GLM obs

⇩

Assimilate pGLM obs

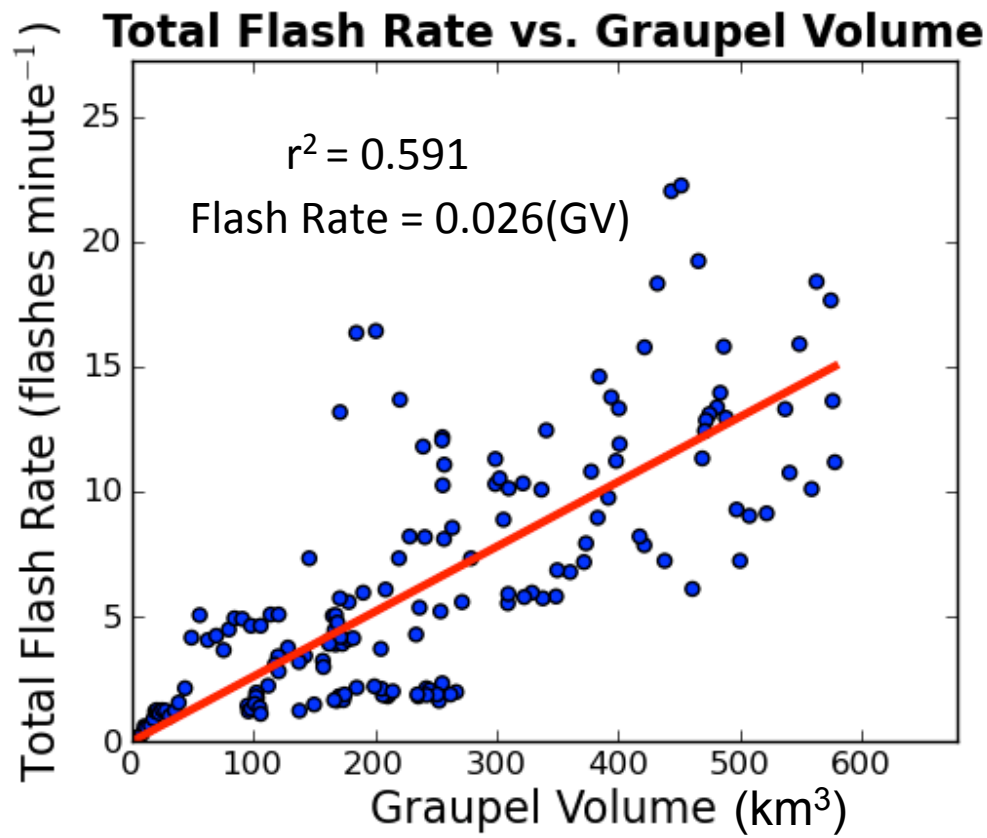
⇩

Compare analyses with radar obs and with analyses from radial velocity assimilation

Methods: Observation Operator Development

First guesses at observation operators were produced by finding a linear fit between flash rate and microphysical variables from simulations using an explicit lightning model while assimilating radial velocity radar data.

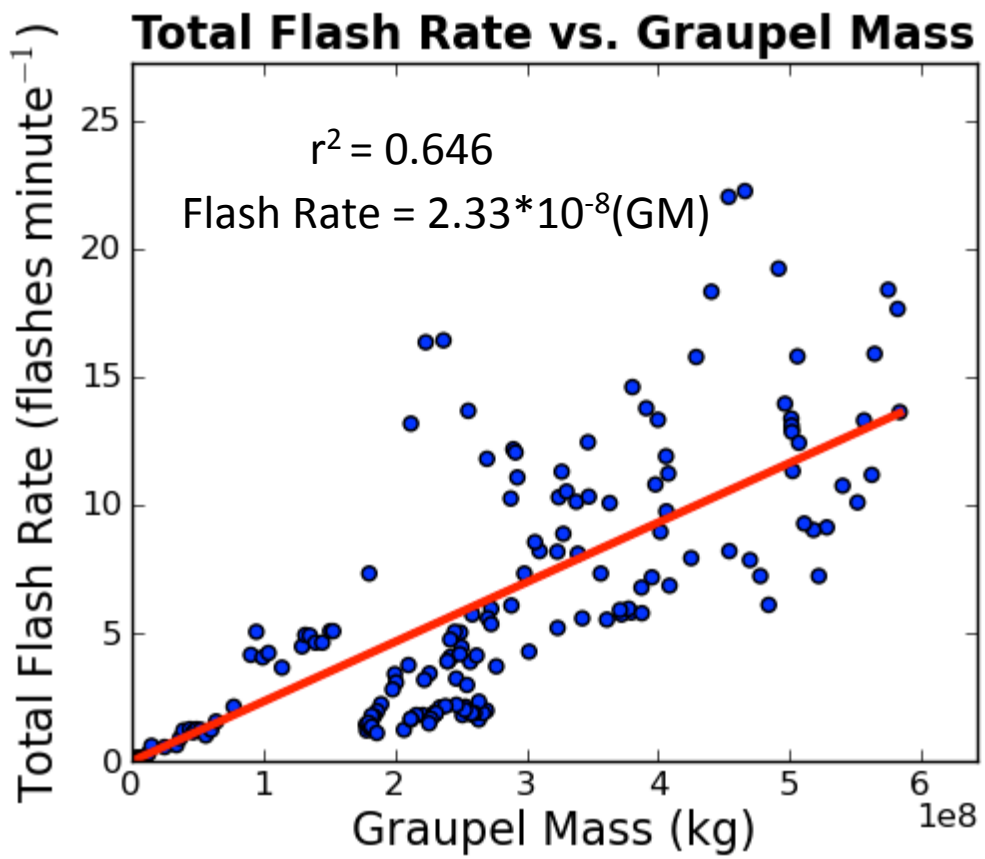
From 6 June 2000 airmass storm



Methods: Observation Operator Development

First guesses at observation operators were produced by finding a linear fit between flash rate and microphysical variables from simulations using an explicit lightning model while assimilating radial velocity radar data.

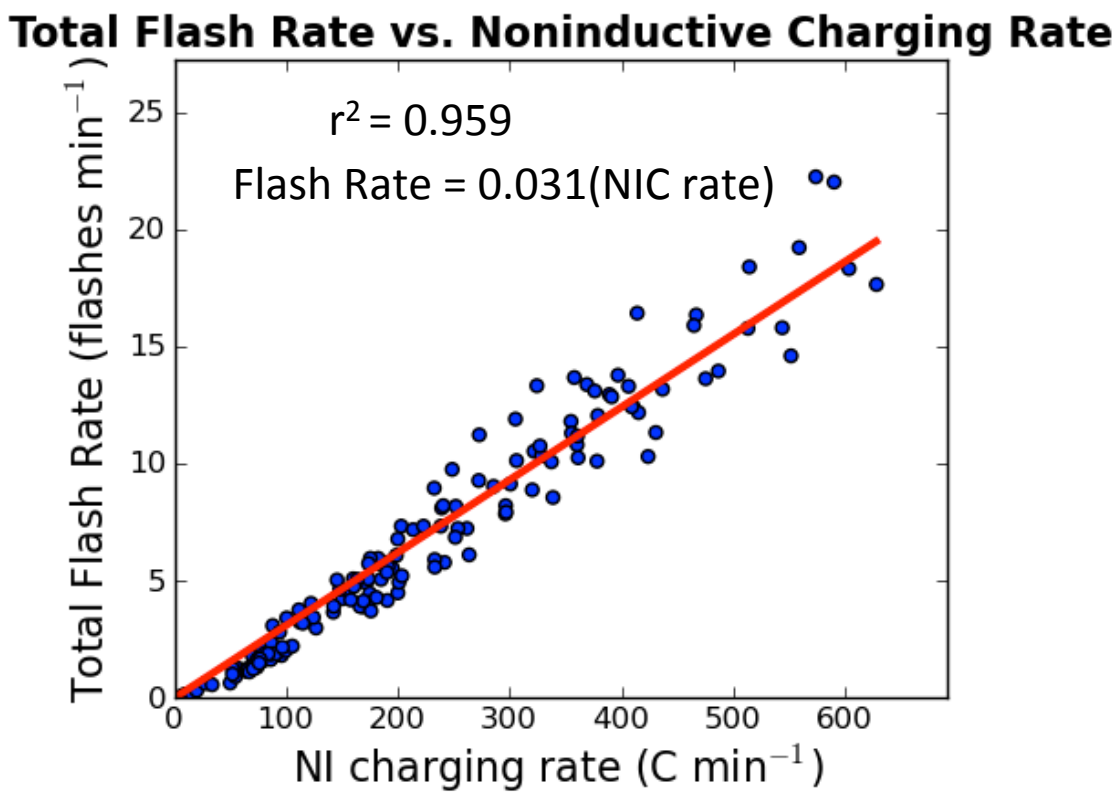
From 6 June 2000 airmass storm



Methods: Observation Operator Development

First guesses at observation operators were produced by finding a linear fit between flash rate and microphysical variables from simulations using an explicit lightning model while assimilating radial velocity radar data.

From 6 June 2000 airmass storm

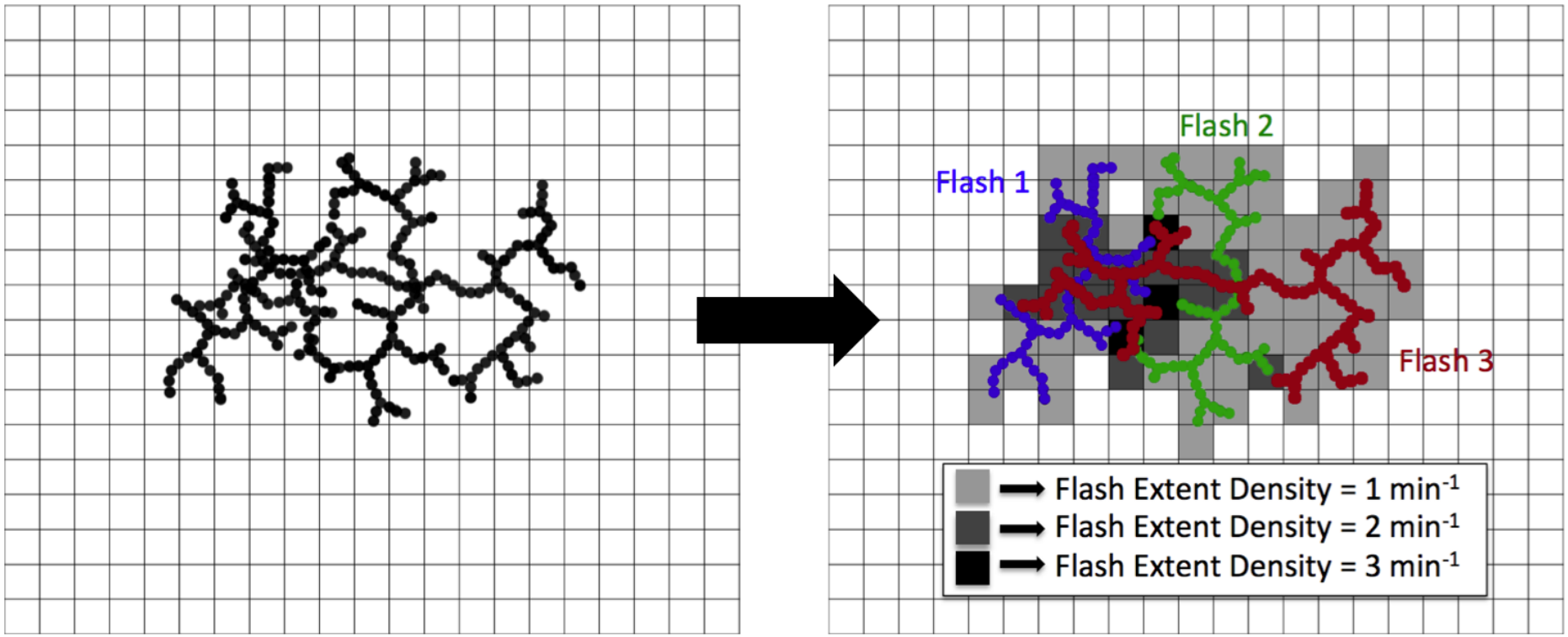


Methods: Observation Operators Tested

Observation Operator Type	Relation
Graupel Volume	FED = 0.040(GV) – 3.64
Graupel Volume	FED = 0.017(GV)**
Graupel Mass	FED = $2.088*10^{-8}$(GM)
Noninductive Charging Rate	FED = 0.039(NIC rate)

** 'Optimal' Operator: produced best results across cases

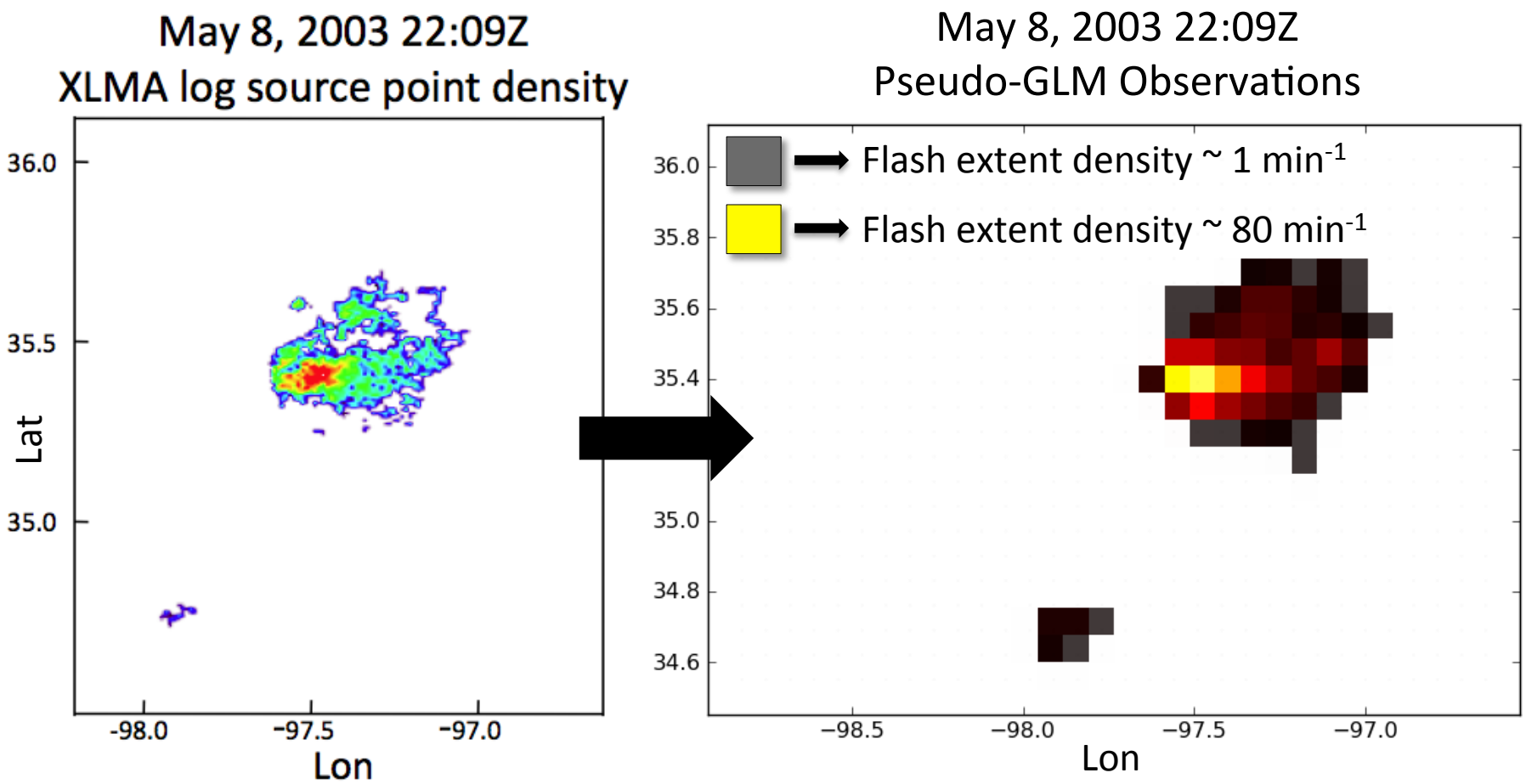
Methods: Pseudo-GLM Obs



Flash observations were generated from LMA data, using a flash separation algorithm (MacGorman et al 2008) to specify individual flashes.

Each flash was then mapped to an approximately 8km x 8km two dimensional grid. For each flash that crossed a grid box, a flash event was added to the box's total.

Methods: Pseudo-GLM Obs



Methods: EnKF Setup

Ensemble Square Root filter used to produce analyses at 1, 3, or 6 minute intervals with a 40 member ensemble.

Pseudo-obs were placed at 6500 m height, with a vertical localization radius of 35 km and a 16 km horizontal localization radius.

After some trial and error, observation error was set to 10%-15% of the maximum flash rate in each storm.

Thermal bubbles and smooth noise were used to initiate convection and create/maintain ensemble spread.

Methods: Model Setup

Model: NSSL COMMAS cloud model

Grid: 1 km horizontal spacing

Microphysics: NSSL double moment scheme
4 ice categories
(ice crystals, graupel, snow, hail)
Graupel density predicted

6 June 2000 Airmass Storm

Observed During STEPS

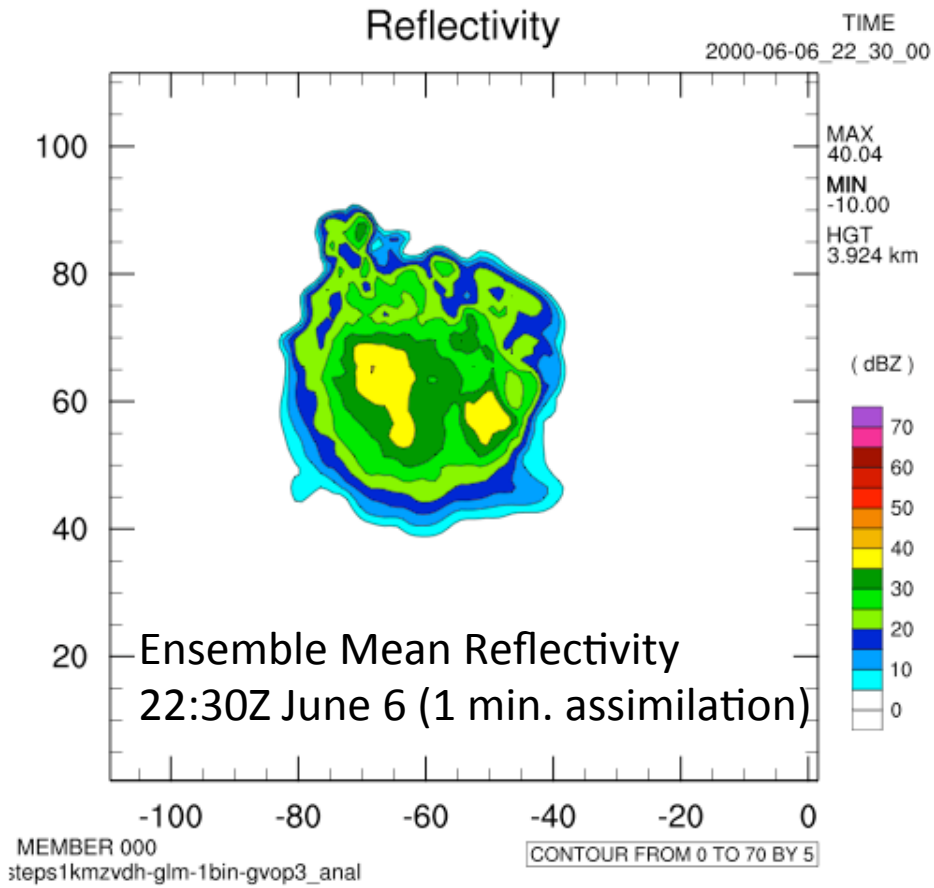
Moved through an area well-sampled by the STEPS LMA

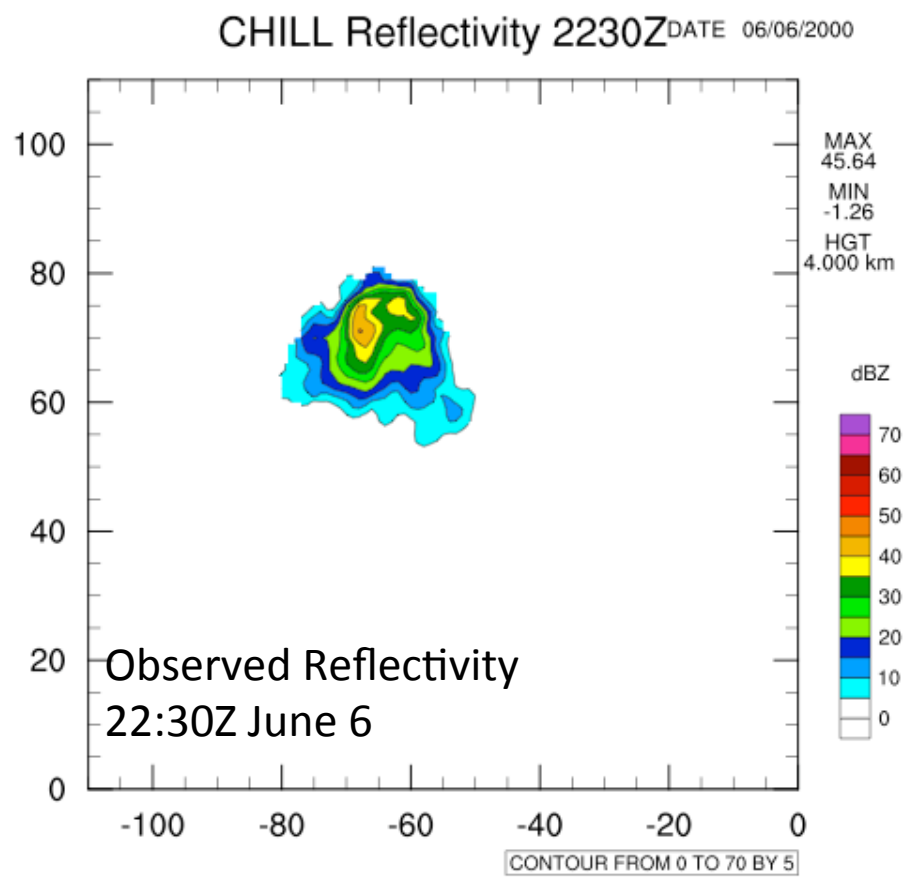
Radar data available from CHILL radar

Low-shear, low-CAPE environment

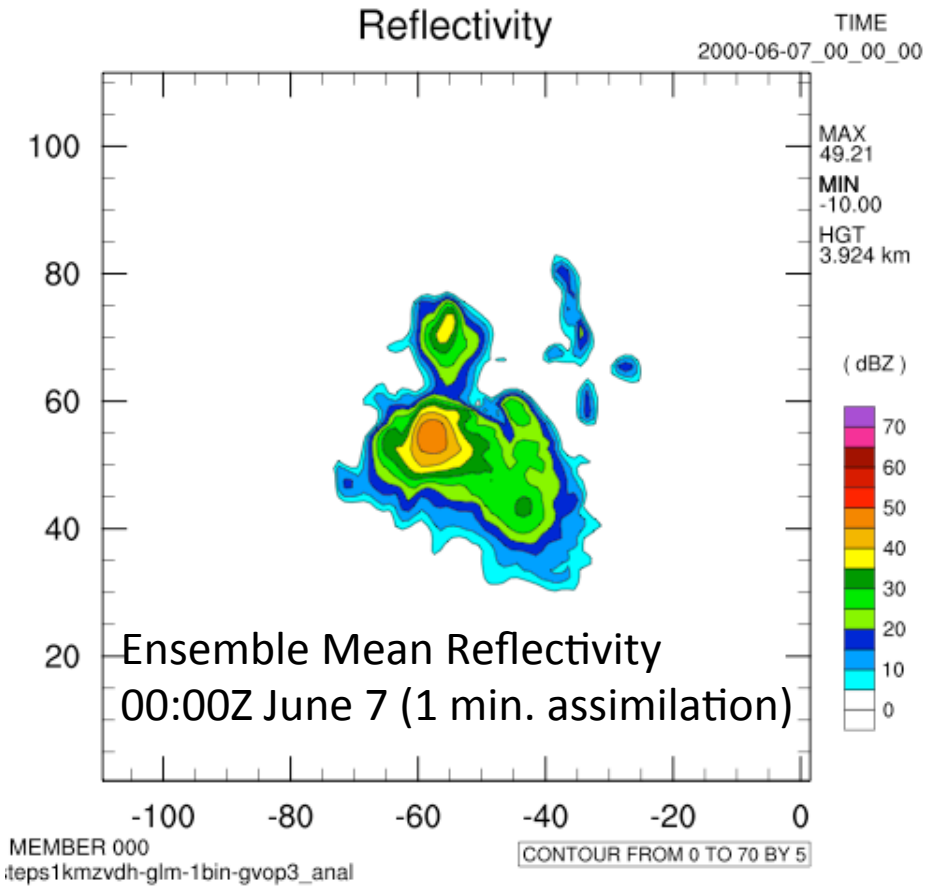
Evolved through multiple formations throughout its lifetime

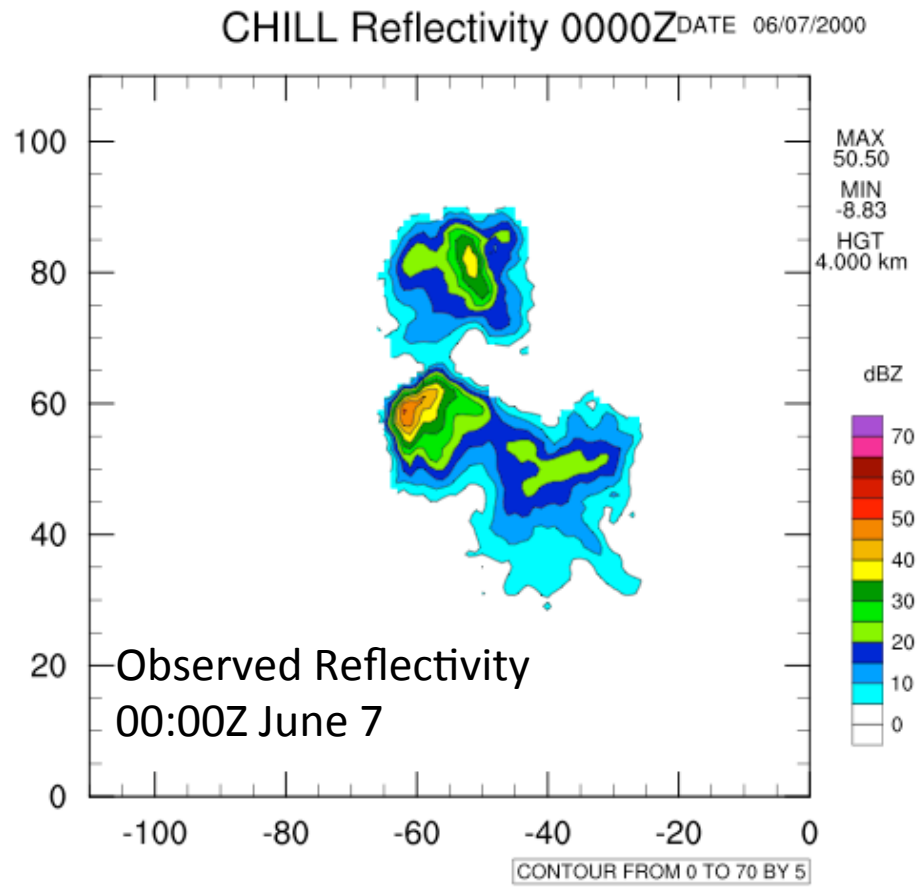
6 June 2000 Airmass Storm



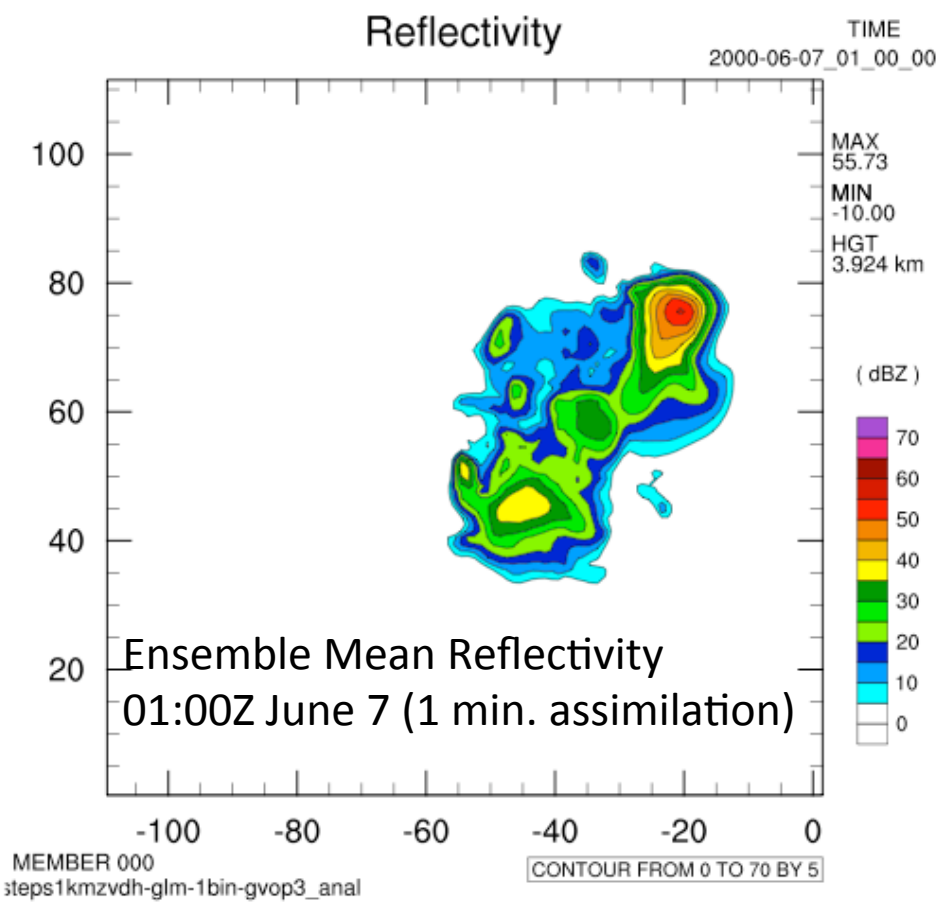


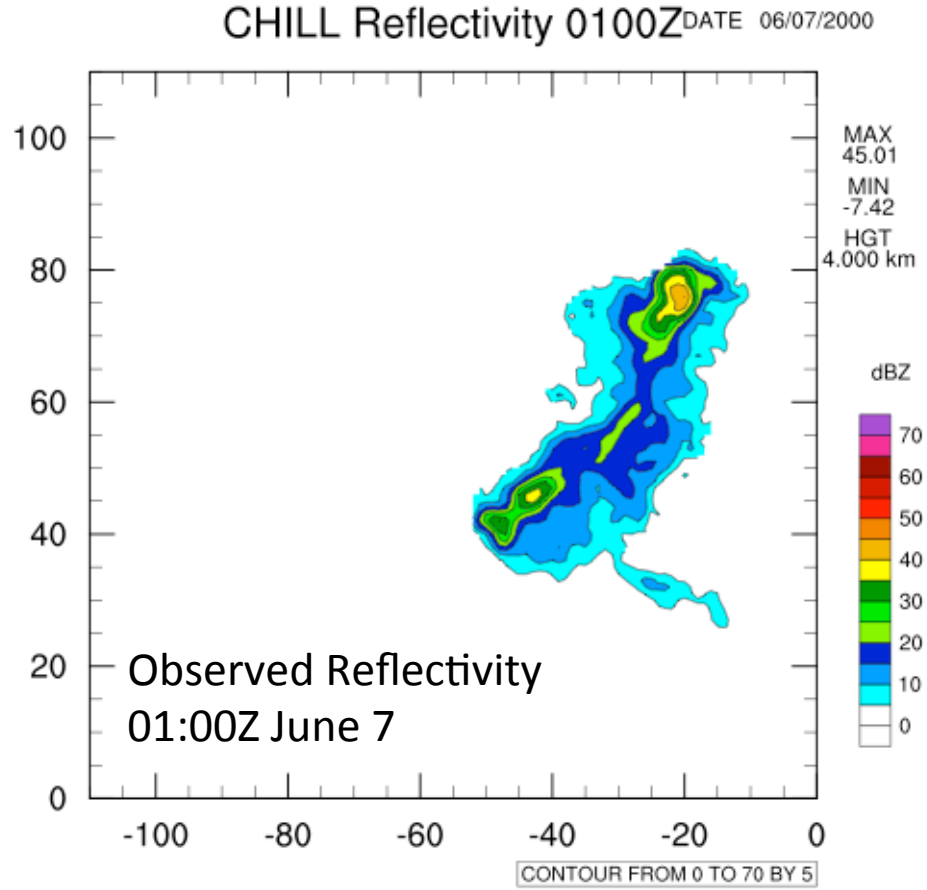
6 June 2000 Airmass Storm



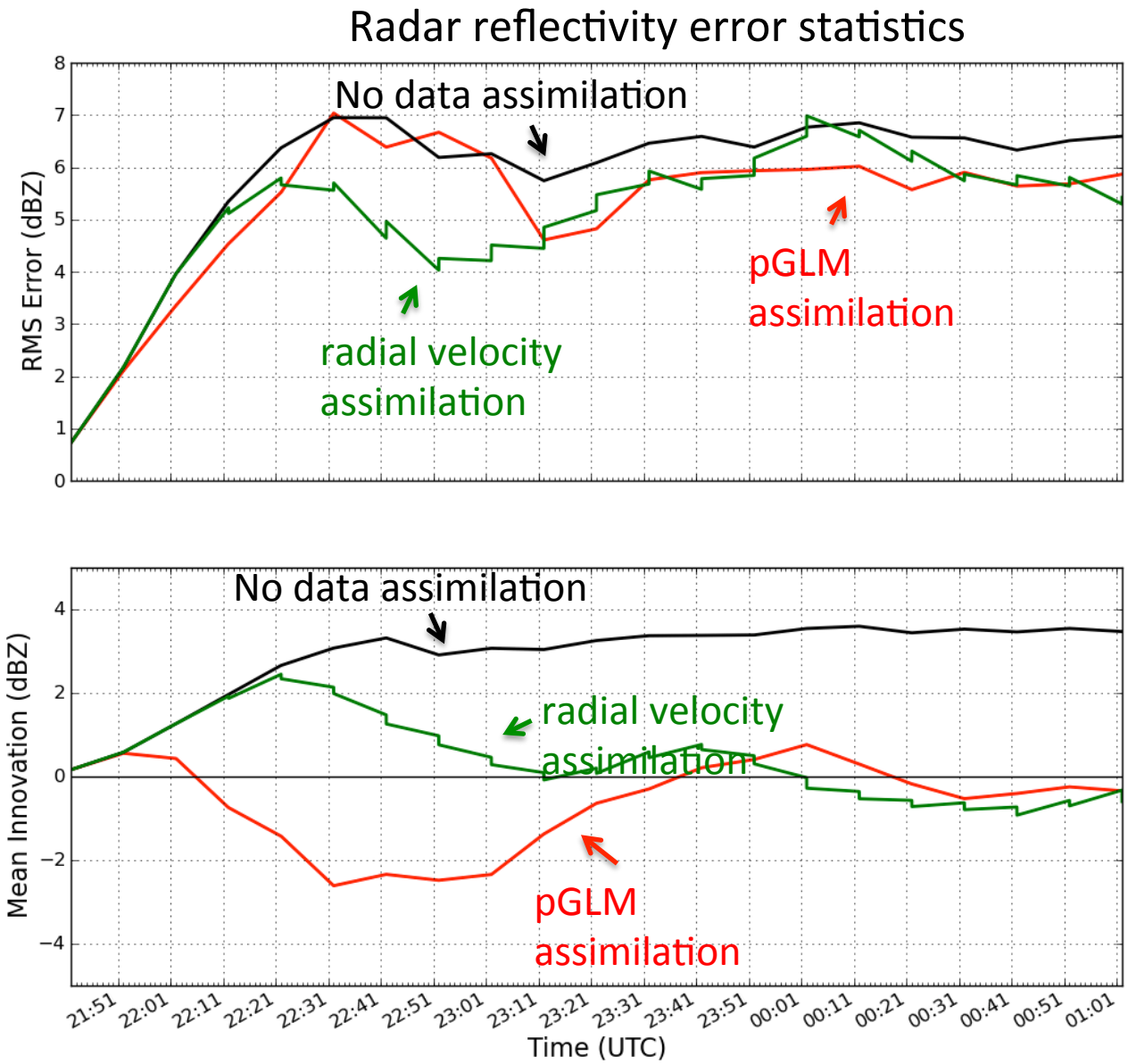


6 June 2000 Airmass Storm

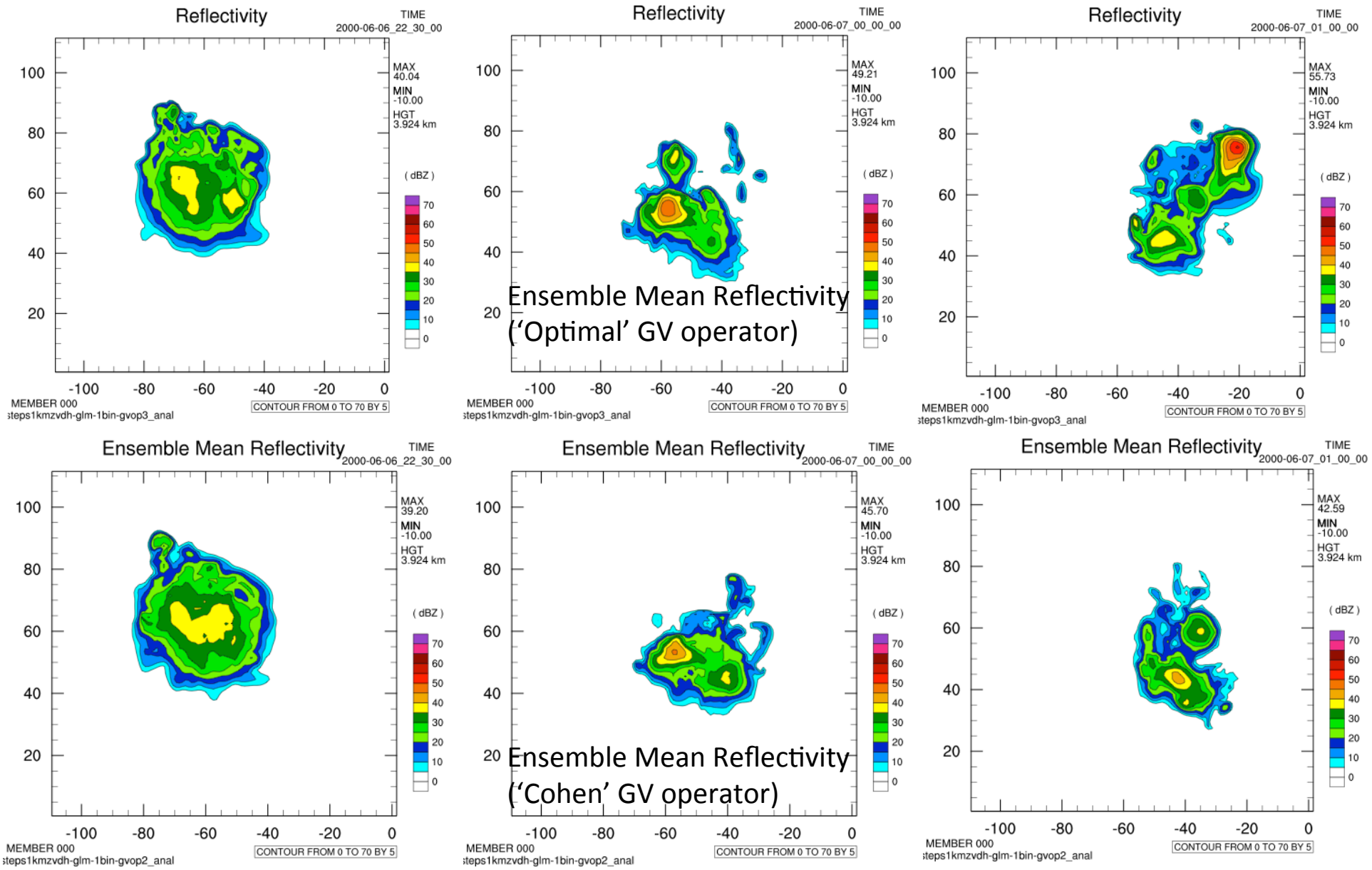




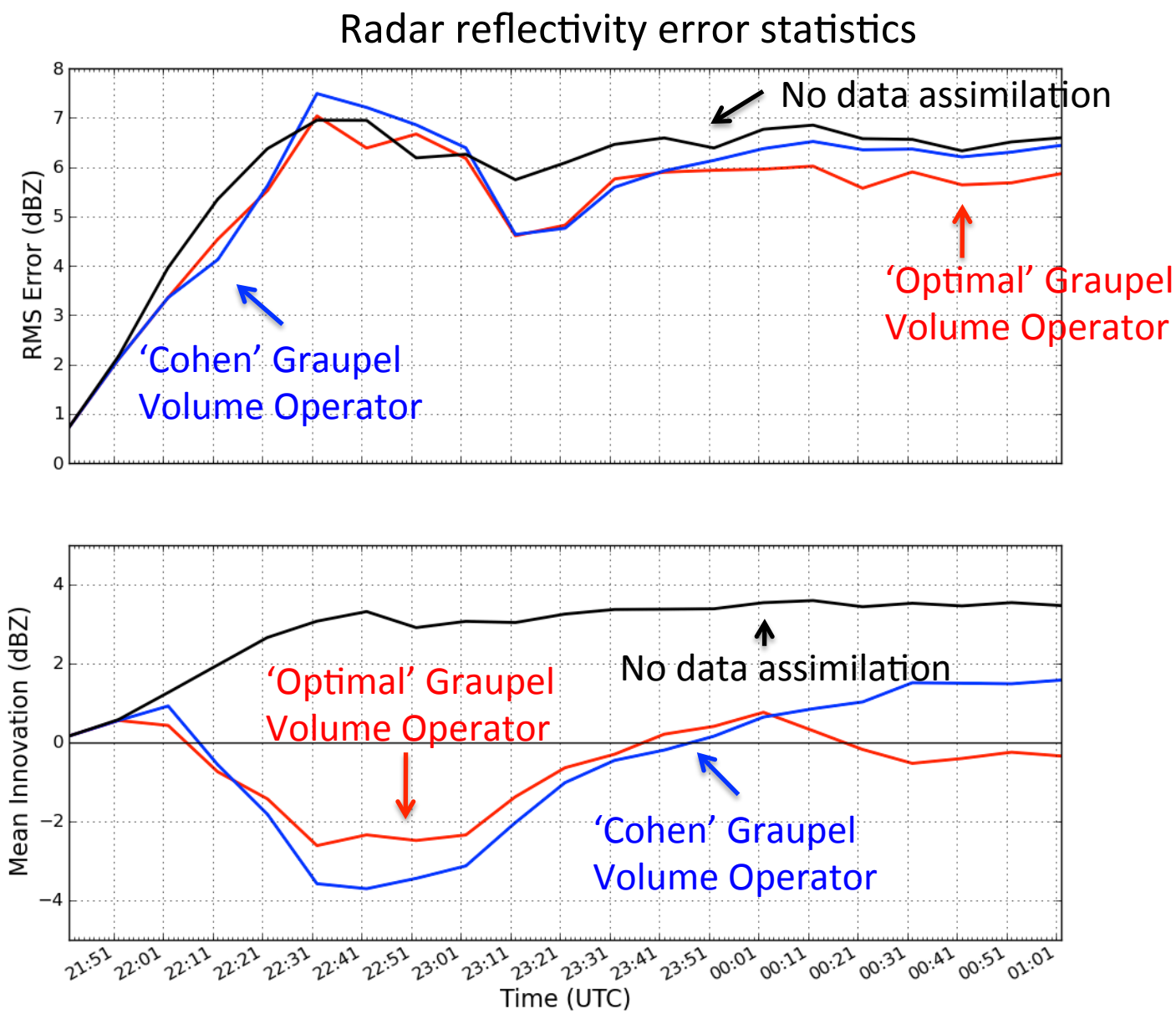
6 June 2000: 1 minute pGLM data assimilation using 'optimal' graupel volume observation operator vs. radial velocity data assimilation



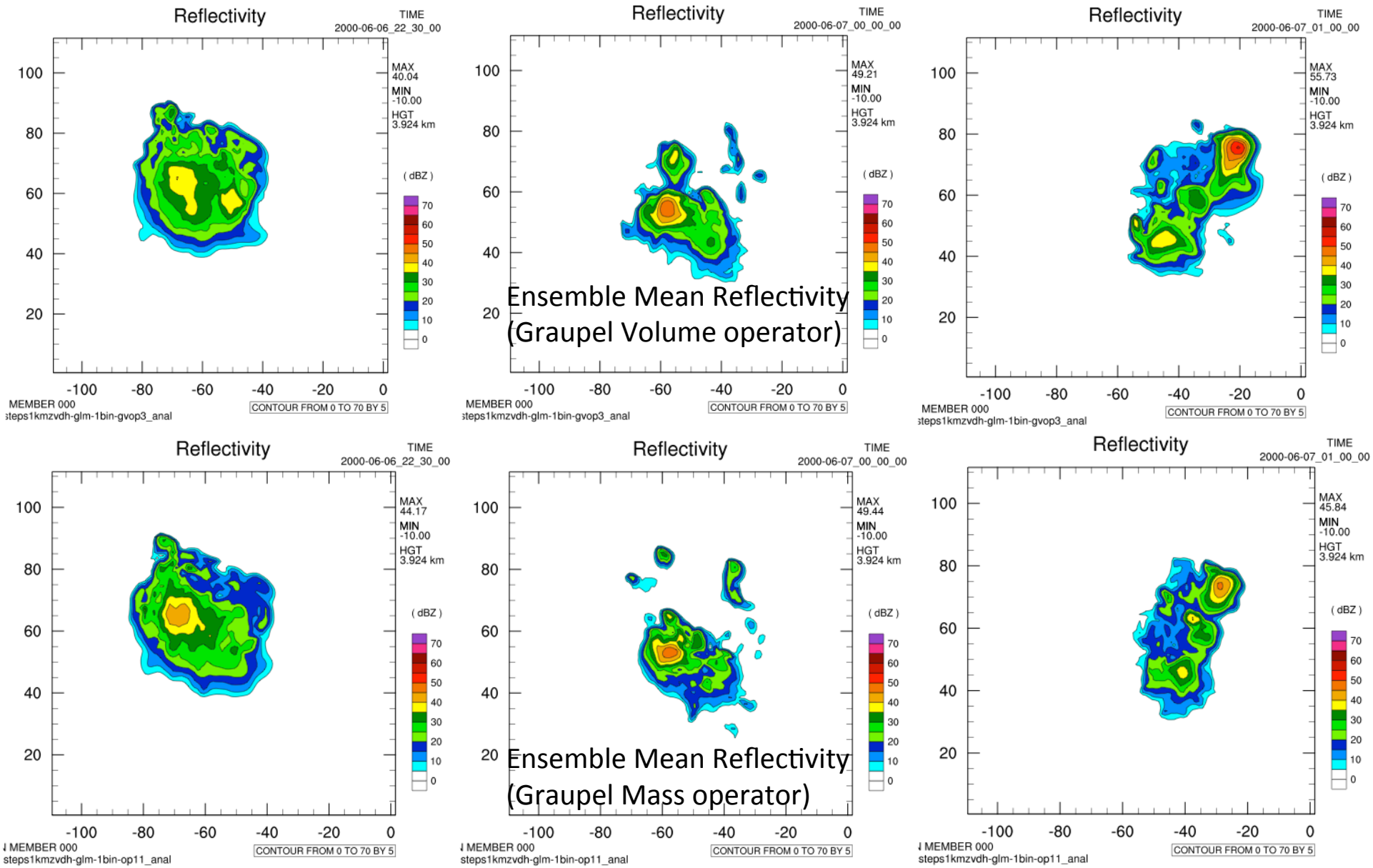
6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)



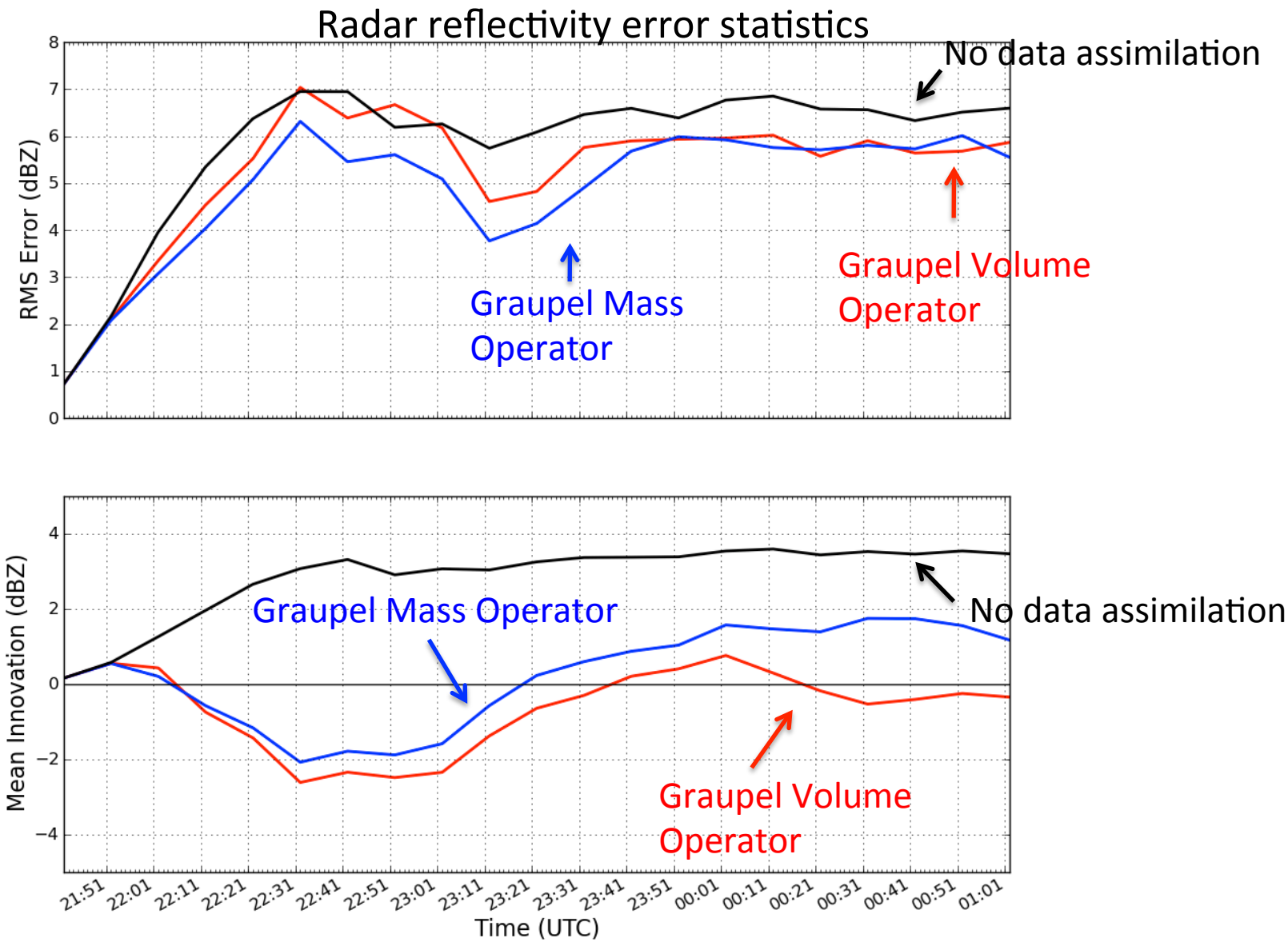
6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)



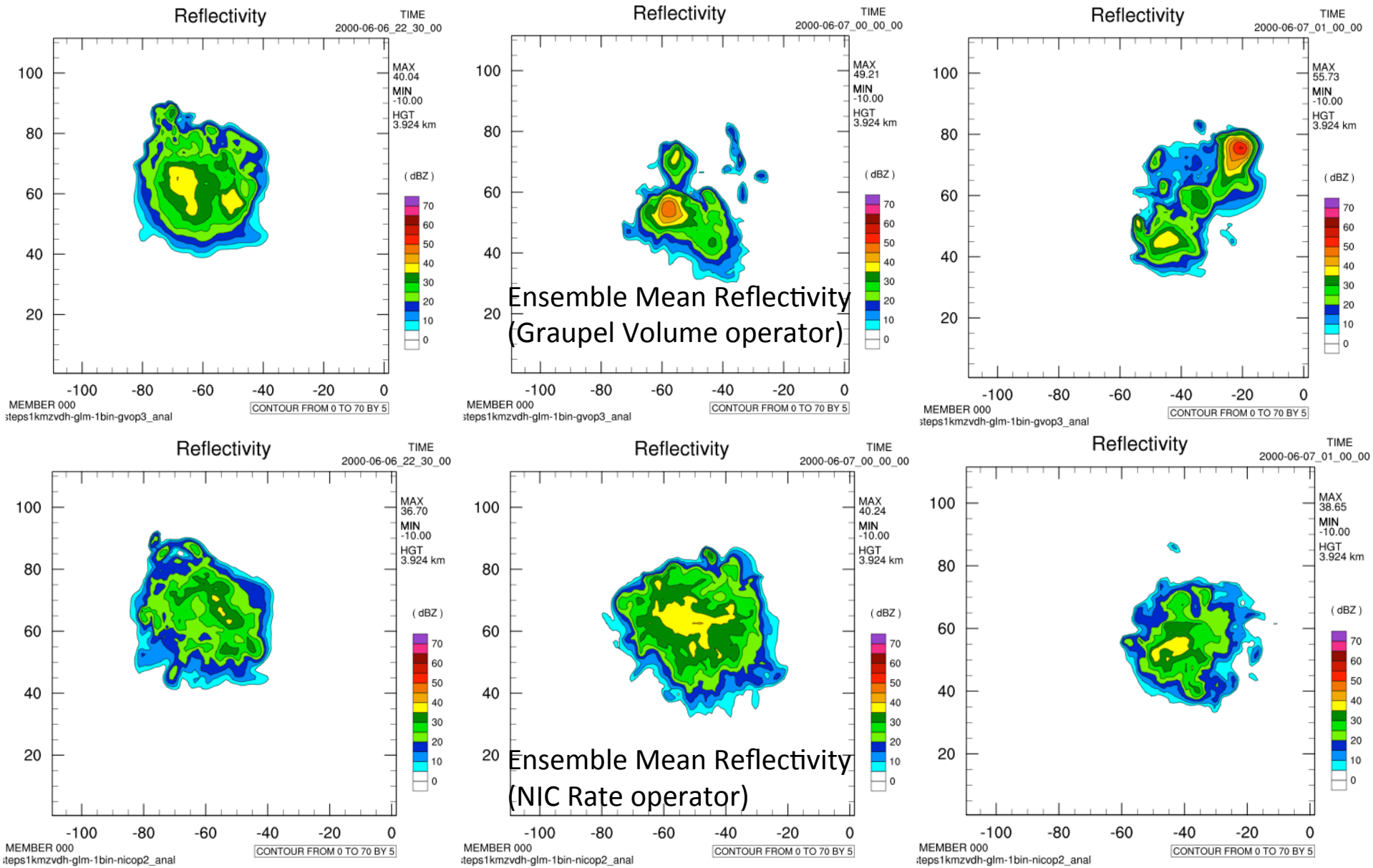
6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)



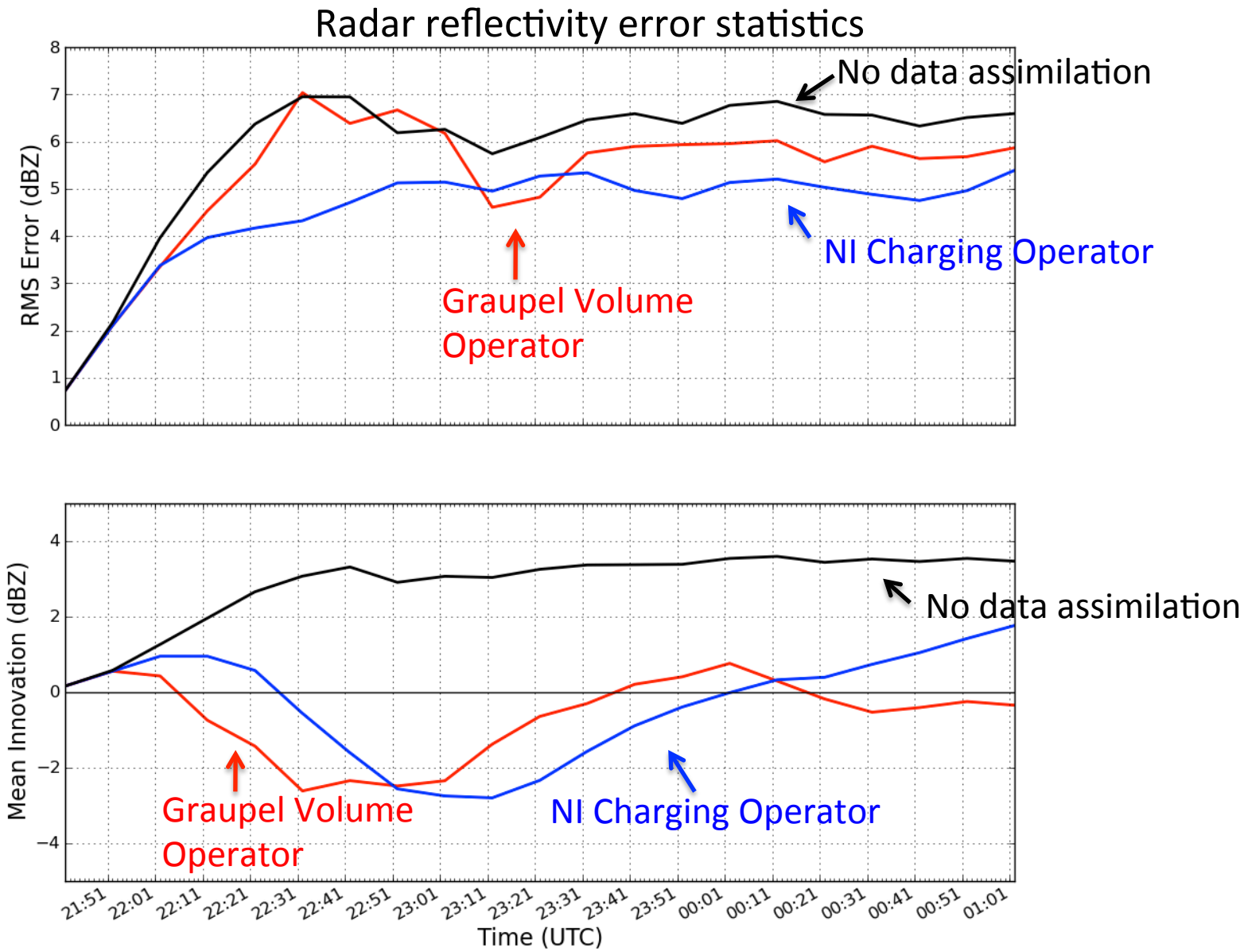
6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)



6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)

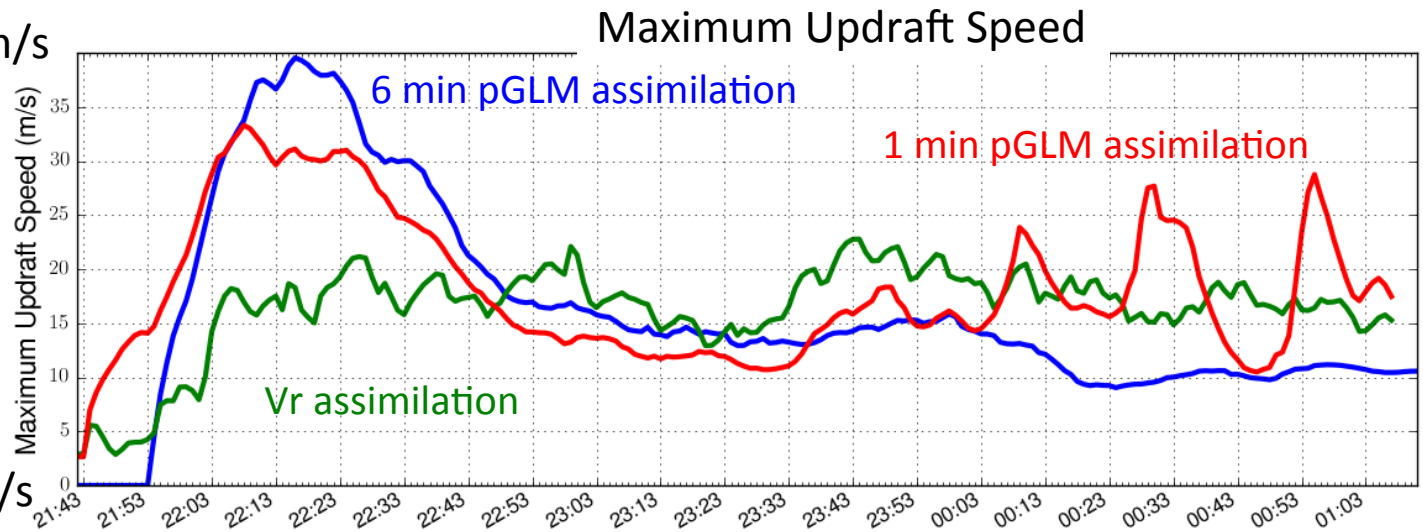


6 June 2000: Obs Operator Comparisons (with 1 minute data and 1km grid)



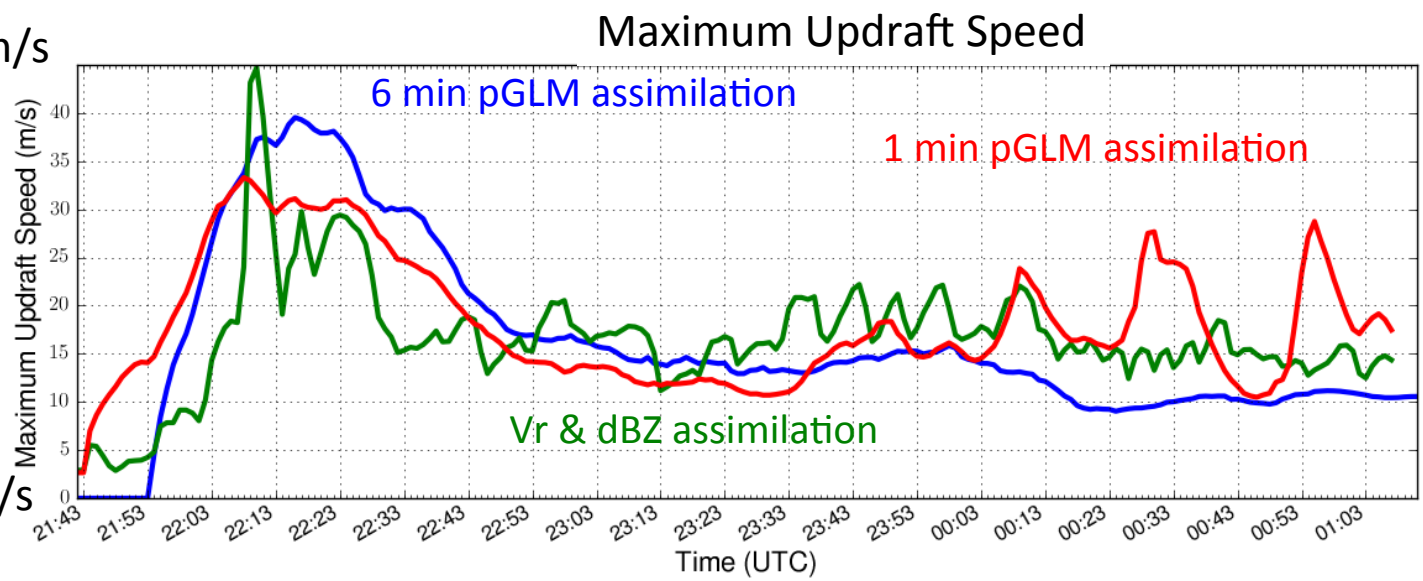
6 June 2000 Airmass Storm

Max = 40 m/s



Min = 0 m/s

Max = 45 m/s



Min = 0 m/s

8 May 2003 Supercell

Moved through an area well-sampled by the Oklahoma LMA

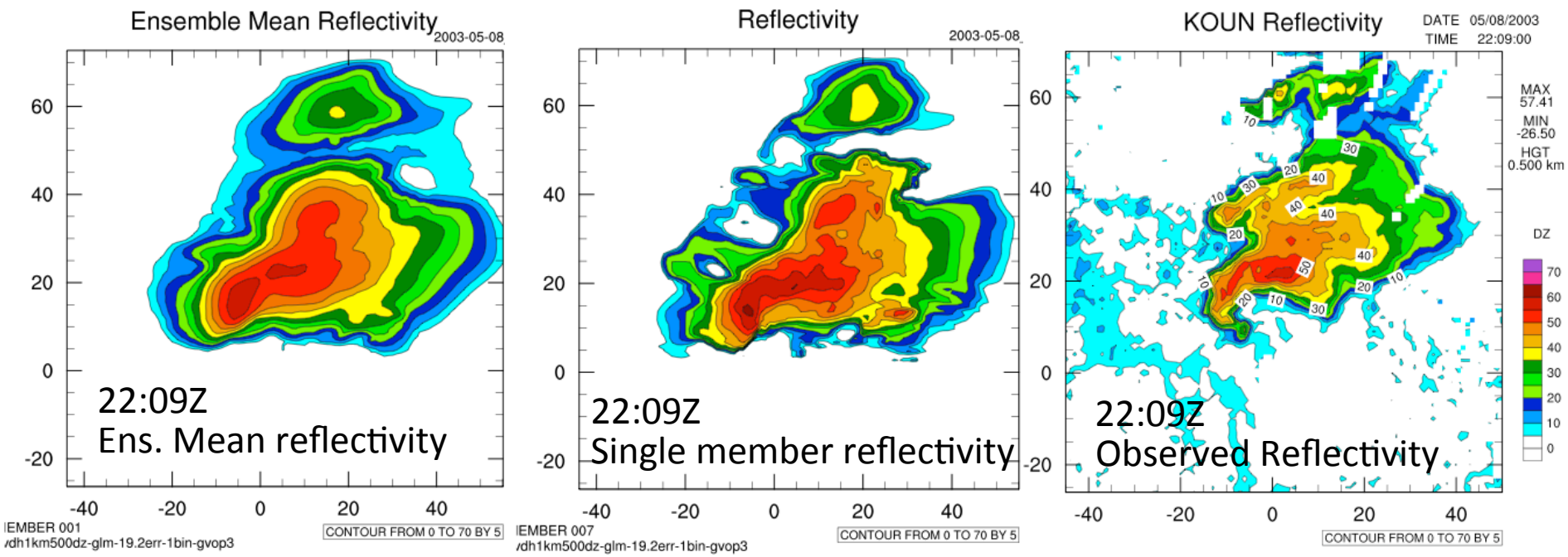
Radar data available from KOUN and KTLX, and previous work has been done using the storm as a test case for assimilation of radar velocity and reflectivity data (Dowell et al 2010, many others referenced therein).

High-shear, high-CAPE environment

Produced multiple tornadoes, including a long-tracked F4 that struck Moore OK and other parts of the Oklahoma City metro area.

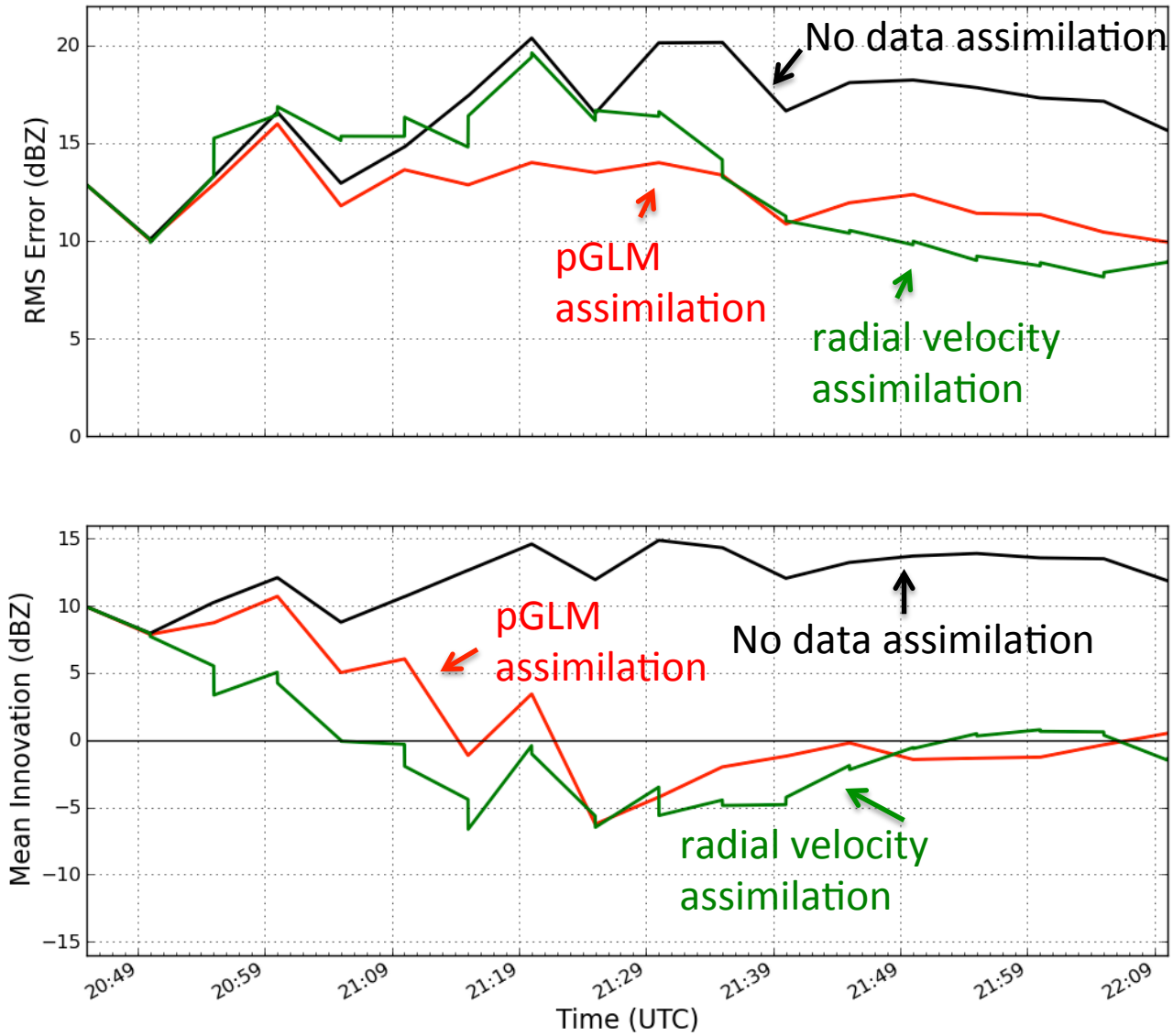
8 May 2003 Supercell

Near-surface radar reflectivity around the time of the first tornado

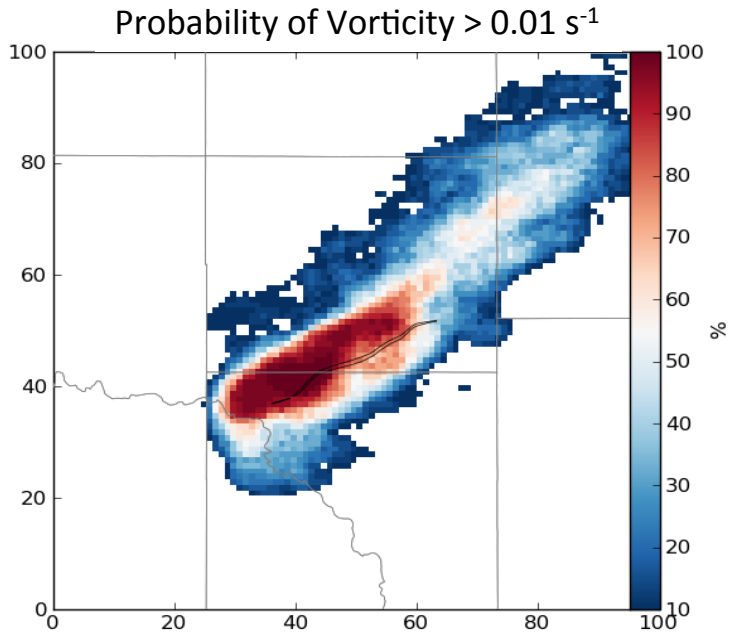


8 May 2003: 1 minute pGLM data assimilation using 'optimal' graupel volume observation operator vs. radial velocity data assimilation

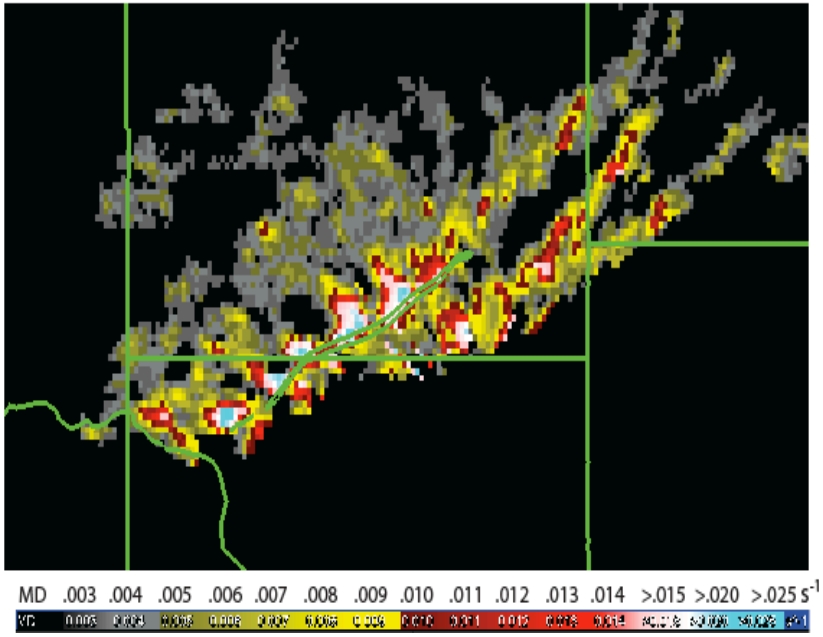
Radar reflectivity error statistics



8 May 2003 Supercell

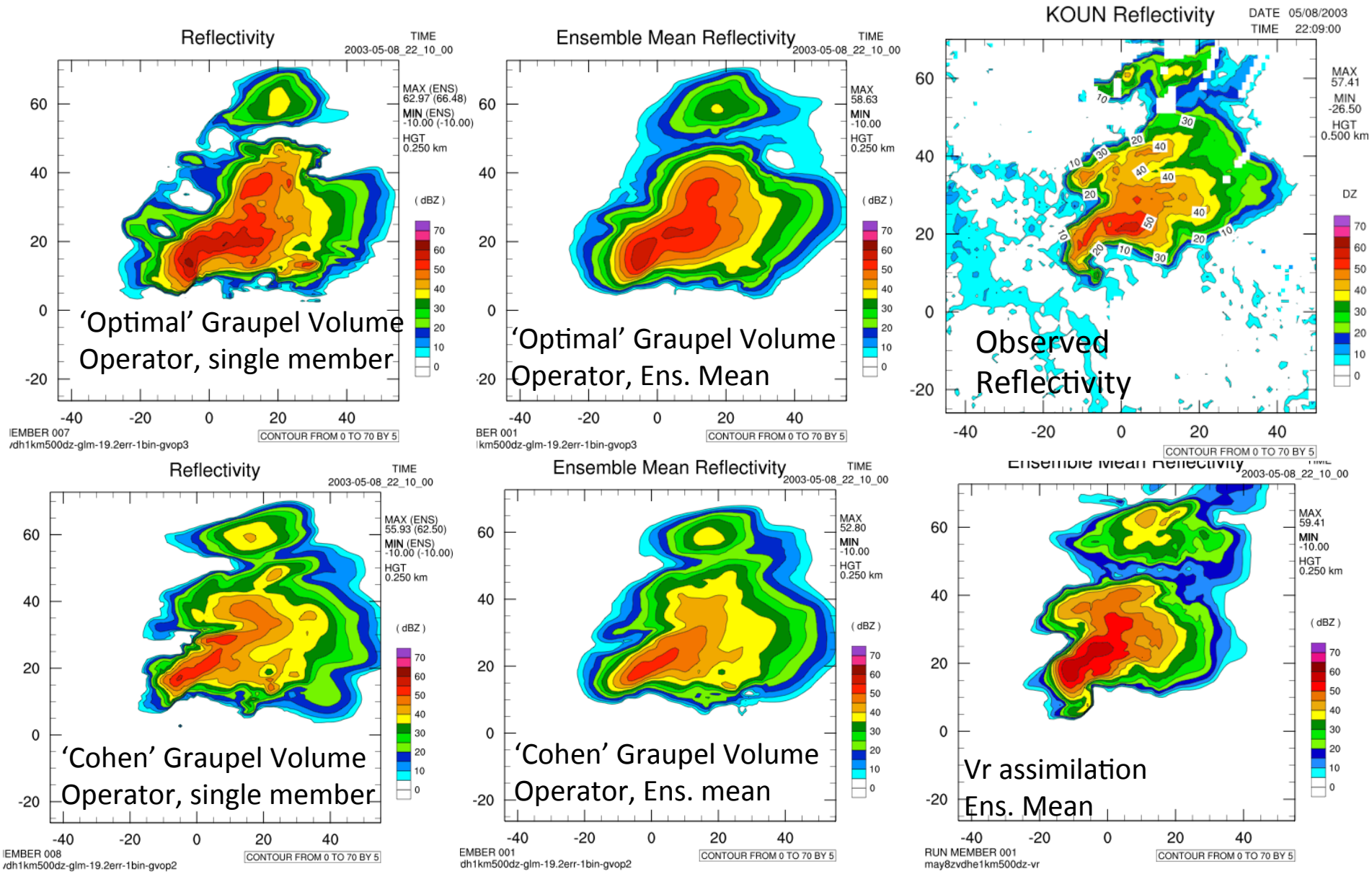


Ensemble probability of vorticity > 0.01 s^{-1} at 1.25 km AGL from 2200 UTC to 2300 UTC, assimilating 1 minute pGLM data with graupel volume observation operator. Tornado track is given by thin black outline near center of plot.

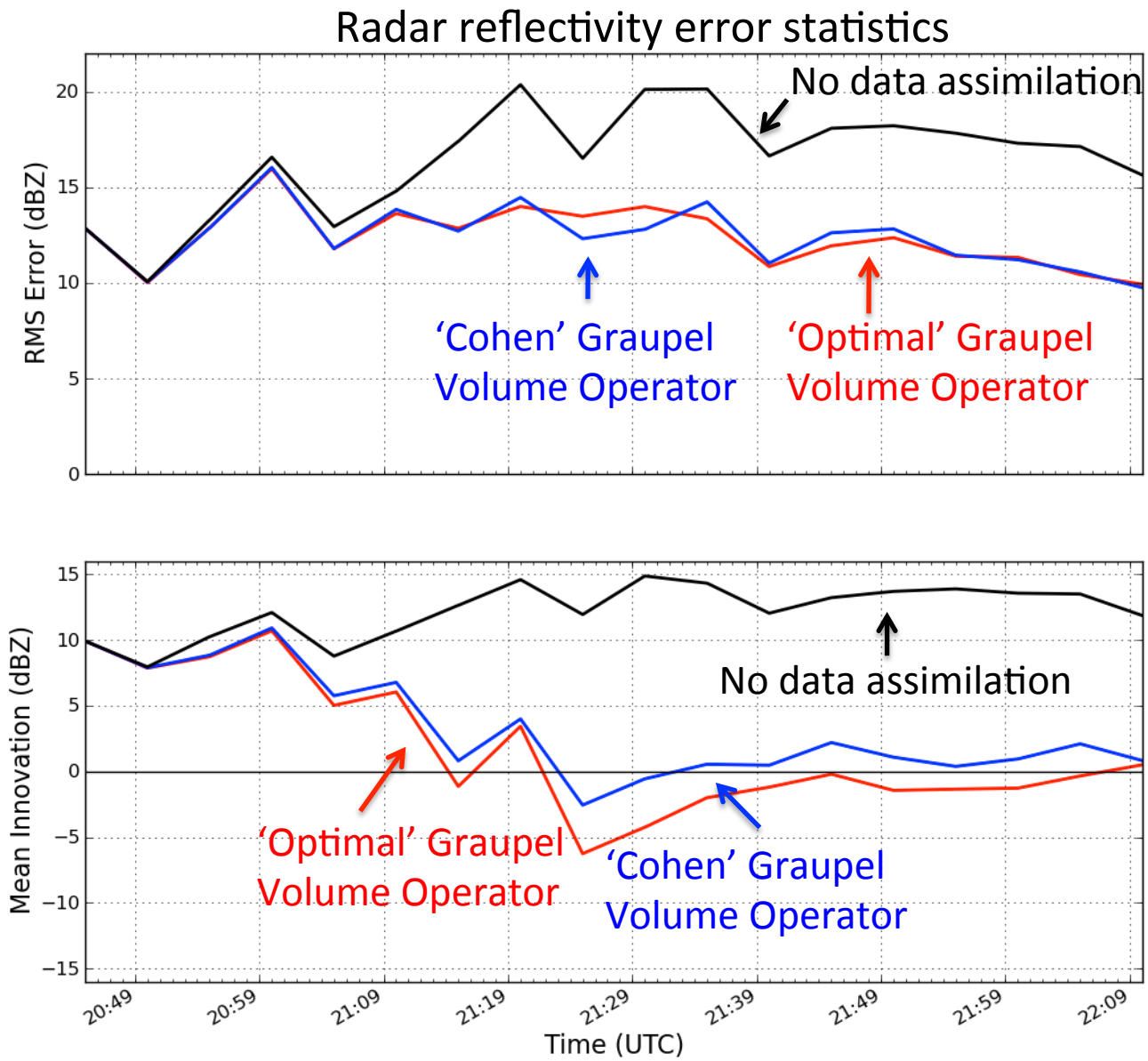


WDSS-II 0-2 km rotation track derived from KTLX radial velocity data from 2200 UTC to 2300 UTC. Tornado track given by green outline near center of plot. (From Yussouf et al. 2013)

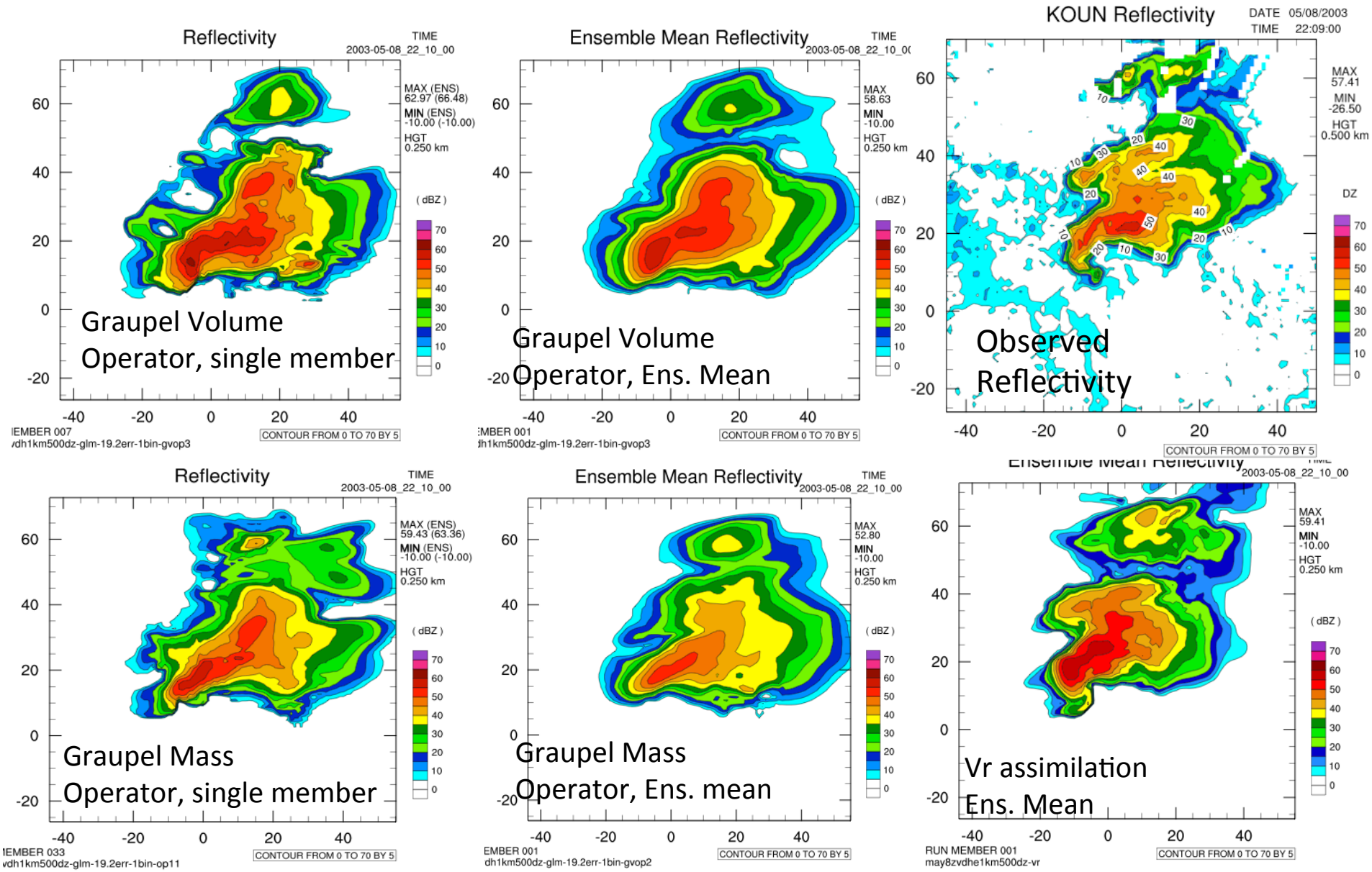
8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)



8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)

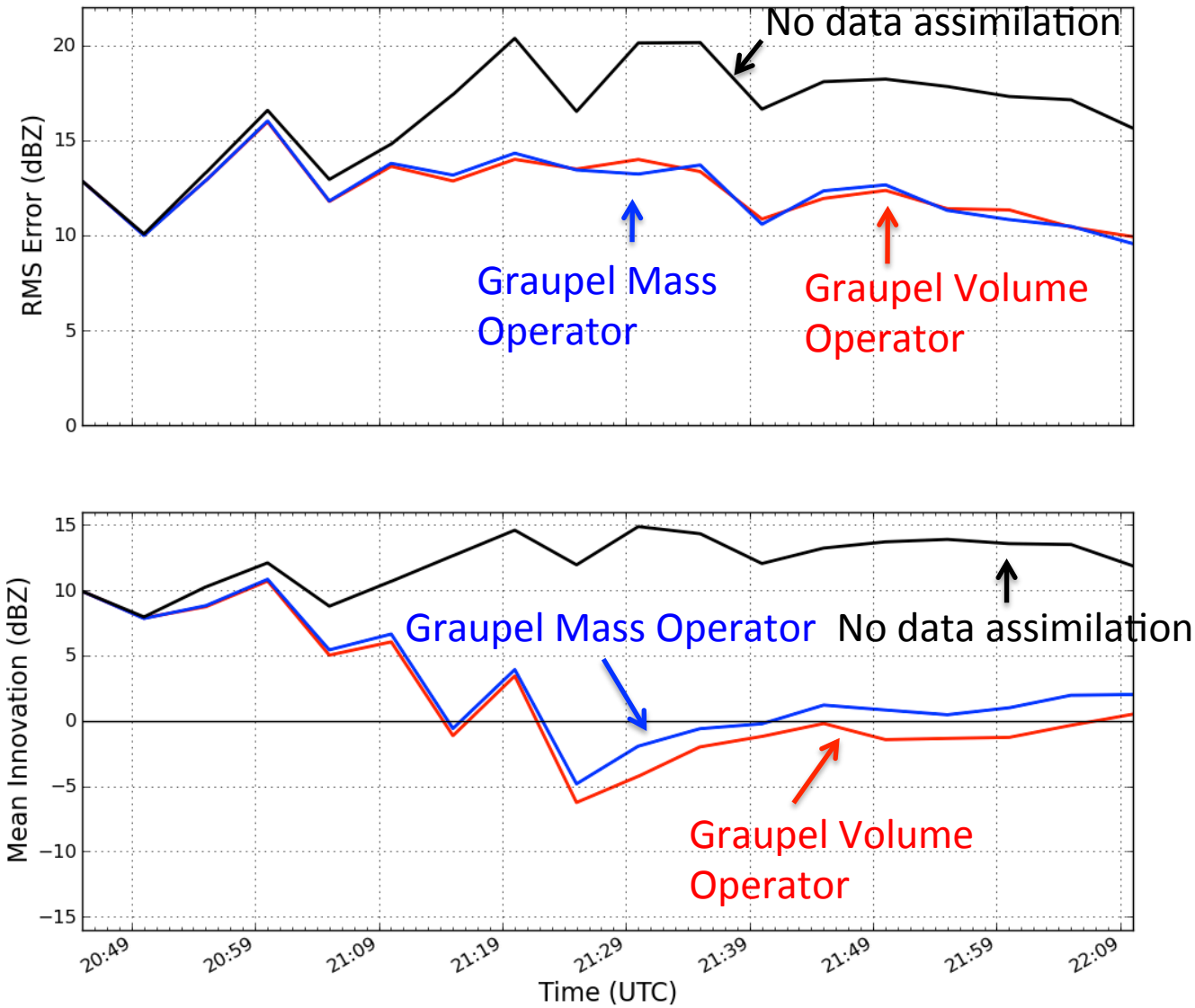


8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)

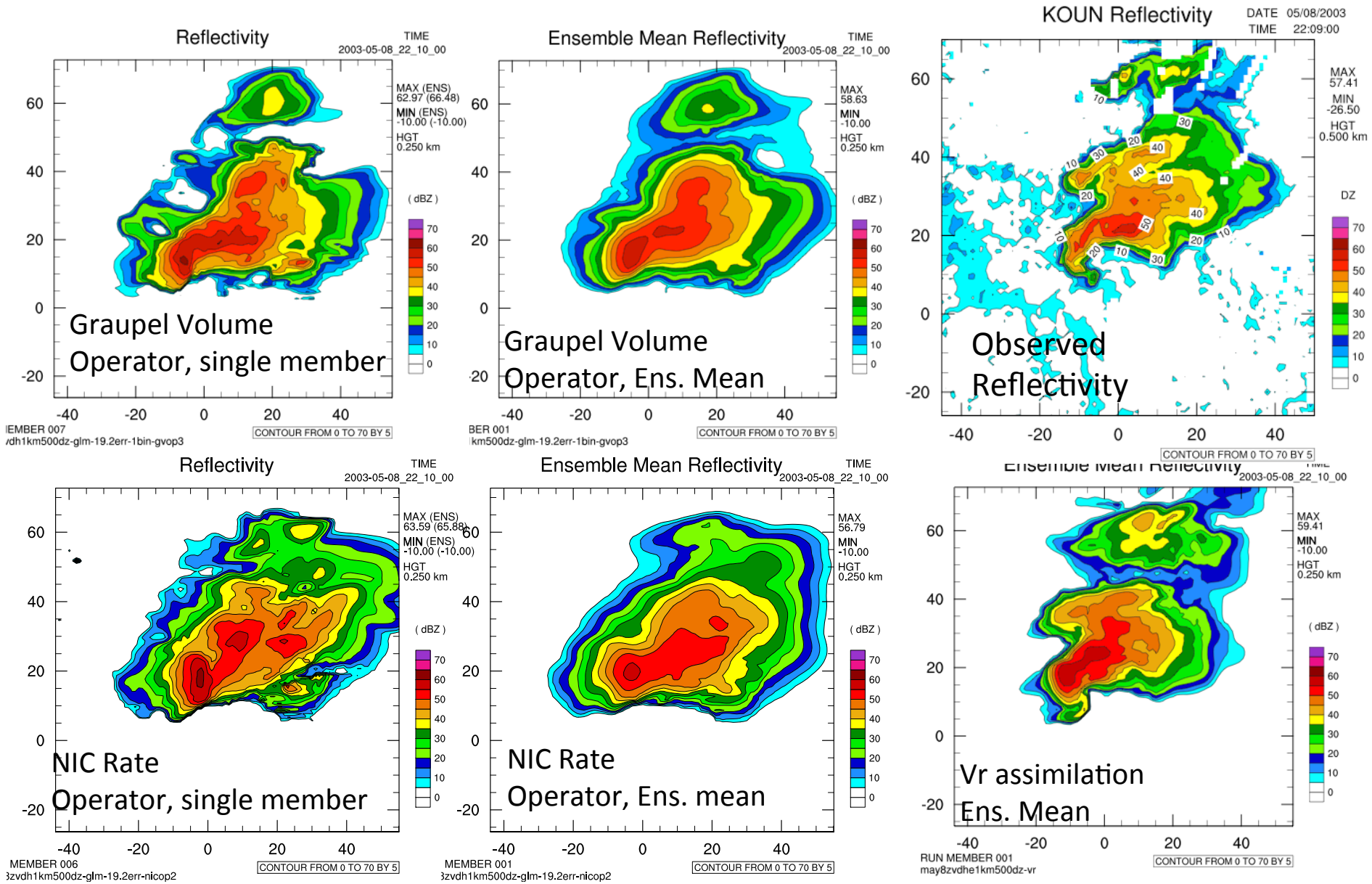


8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)

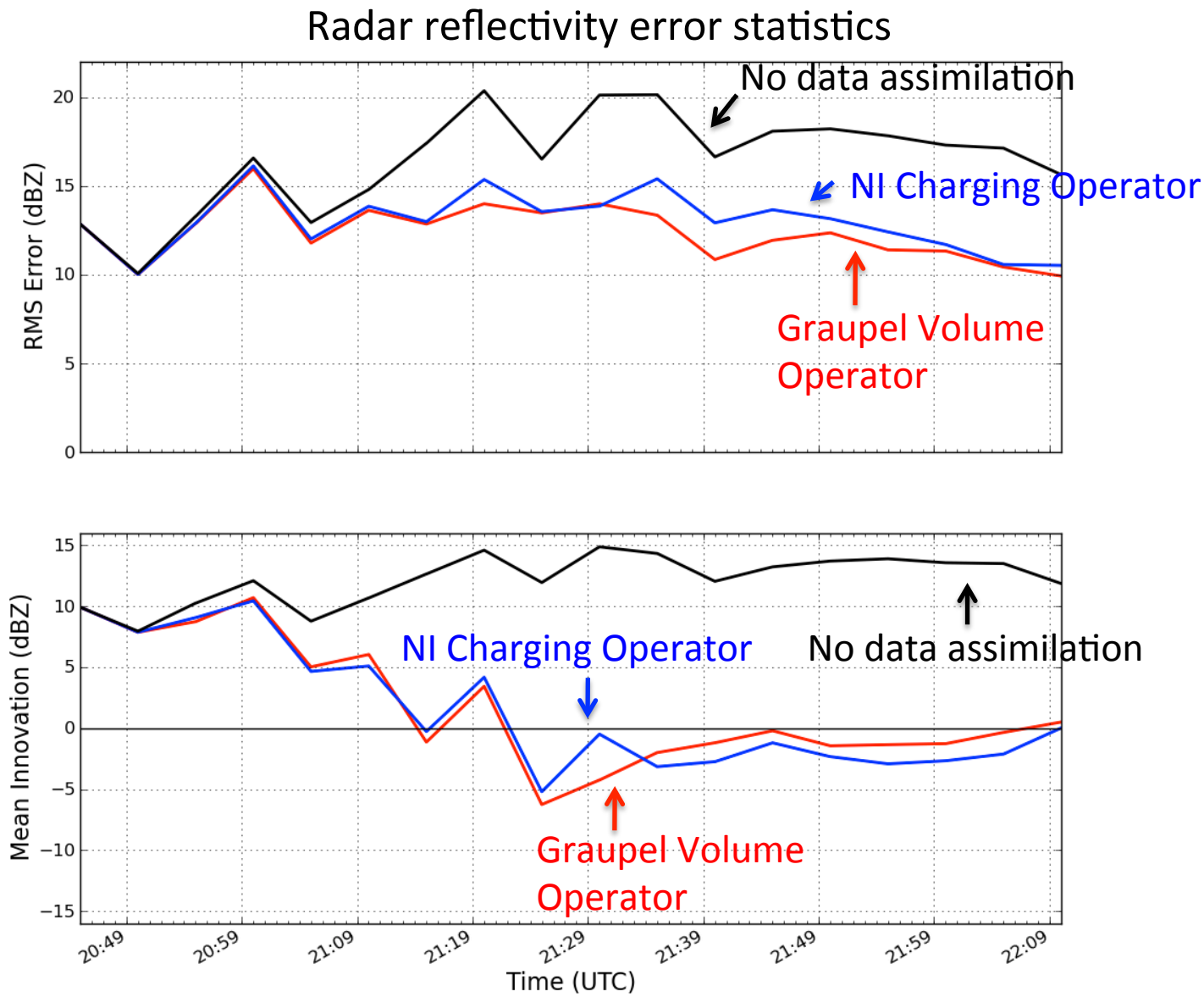
Radar reflectivity error statistics



8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)

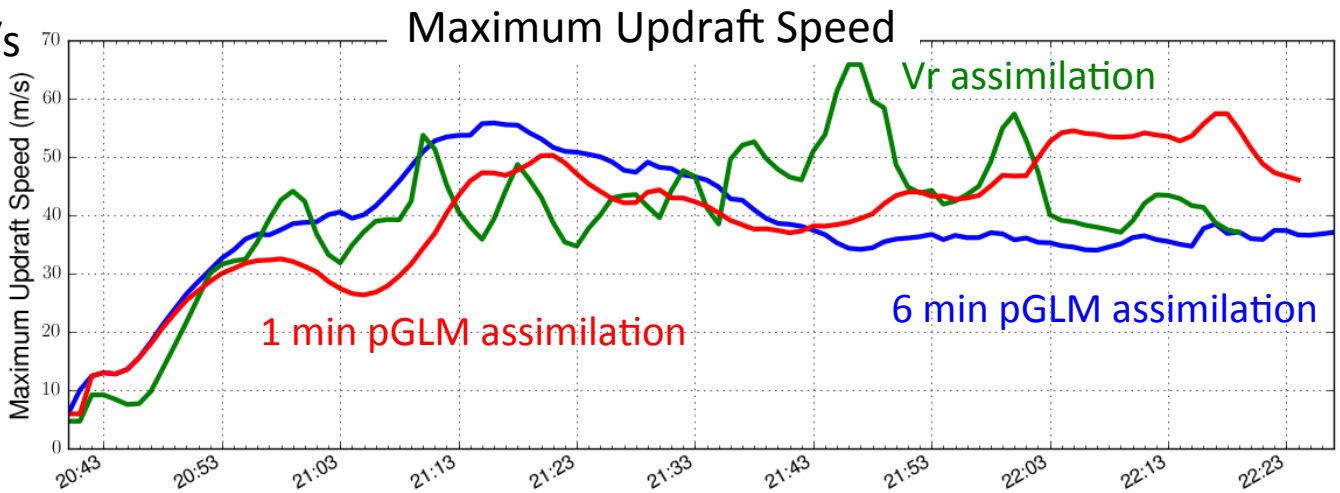


8 May 2003: Obs Operator Comparisons (with 1 minute data and 1km grid)



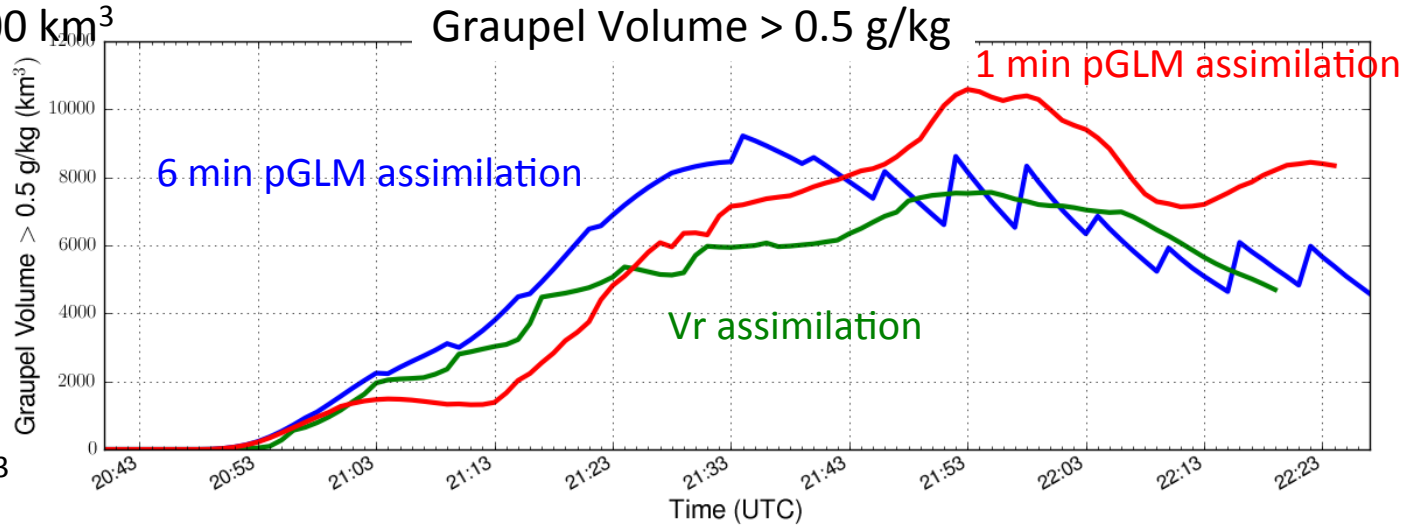
8 May 2003: Assimilation Frequency Comparisons (with optimal obs operator)

Max = 70 m/s



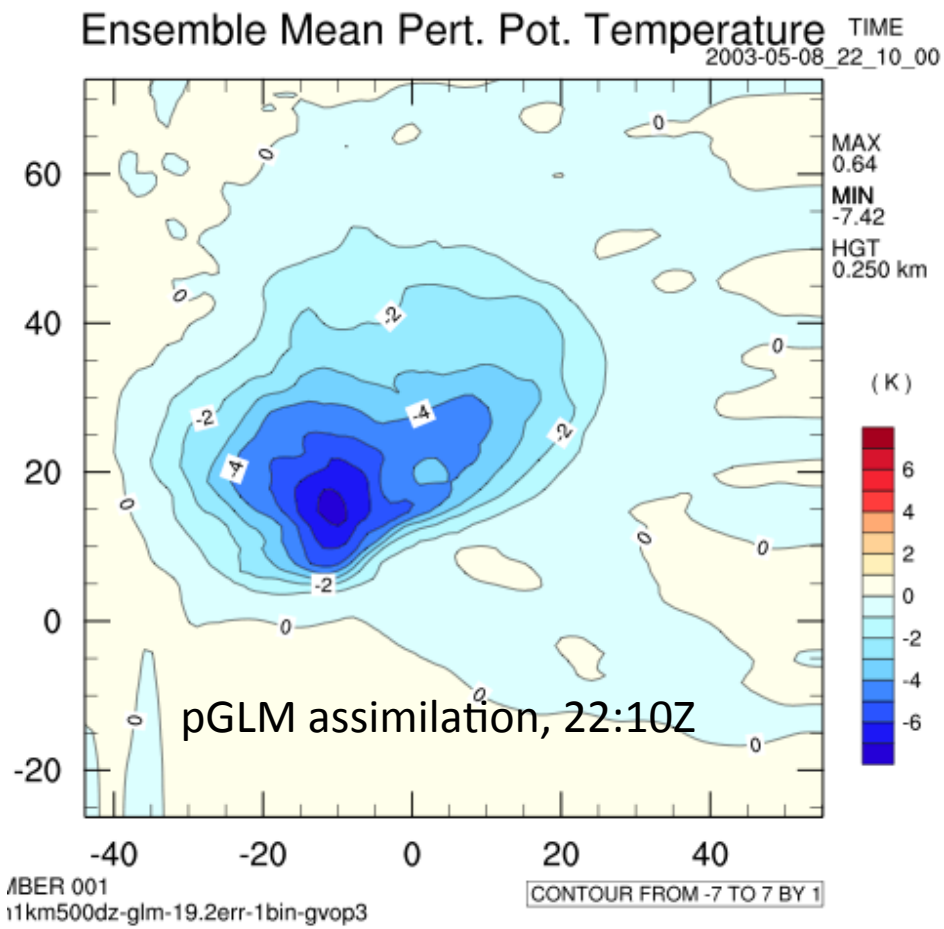
Min = 0 m/s

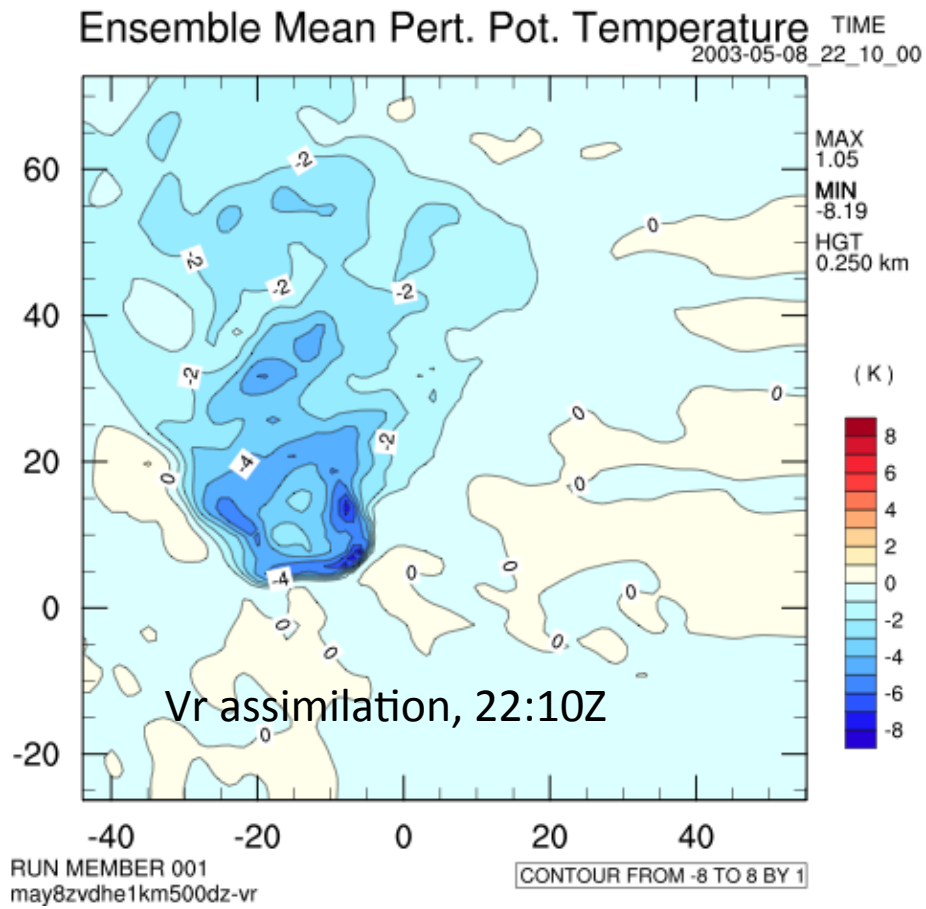
Max = 12000 km^3



Min = 0 km^3

8 May 2003: Cold Pool Comparison





Summary / Conclusions

1.) EnKF assimilation of pseudo-GLM data, using a single observation operator, can produce analyses that capture the basic reflectivity structure of multiple storm types, and can produce maximum updraft speeds comparable to those obtained when assimilating Doppler radar radial velocity.

2.) The best results across both cases came from an observation operator based on graupel volume.

3.) In the tornadic supercell case, the development of the low-level mesocyclone was captured well.

4.) Since the GLM will produce observations over a much larger area than radar observations are available, these results show promise that EnKF assimilation of GLM data can be useful stand-in for assimilation of radial velocity data in areas where radar data is lacking or of poor quality.

Questions?

Acknowledgements

Thank you to Kristin Calhoun for converting LMA data to pseudo-GLM observations, and to David Dowell for providing radar data for the 6 June and 5 July cases.

Funding Provided by NOAA-NESDIS/JCSDA