Ensemble Kalman Filter Assimilation of WSR-88D and CASA Radar Data for Prediction of a Tornadic Convective System

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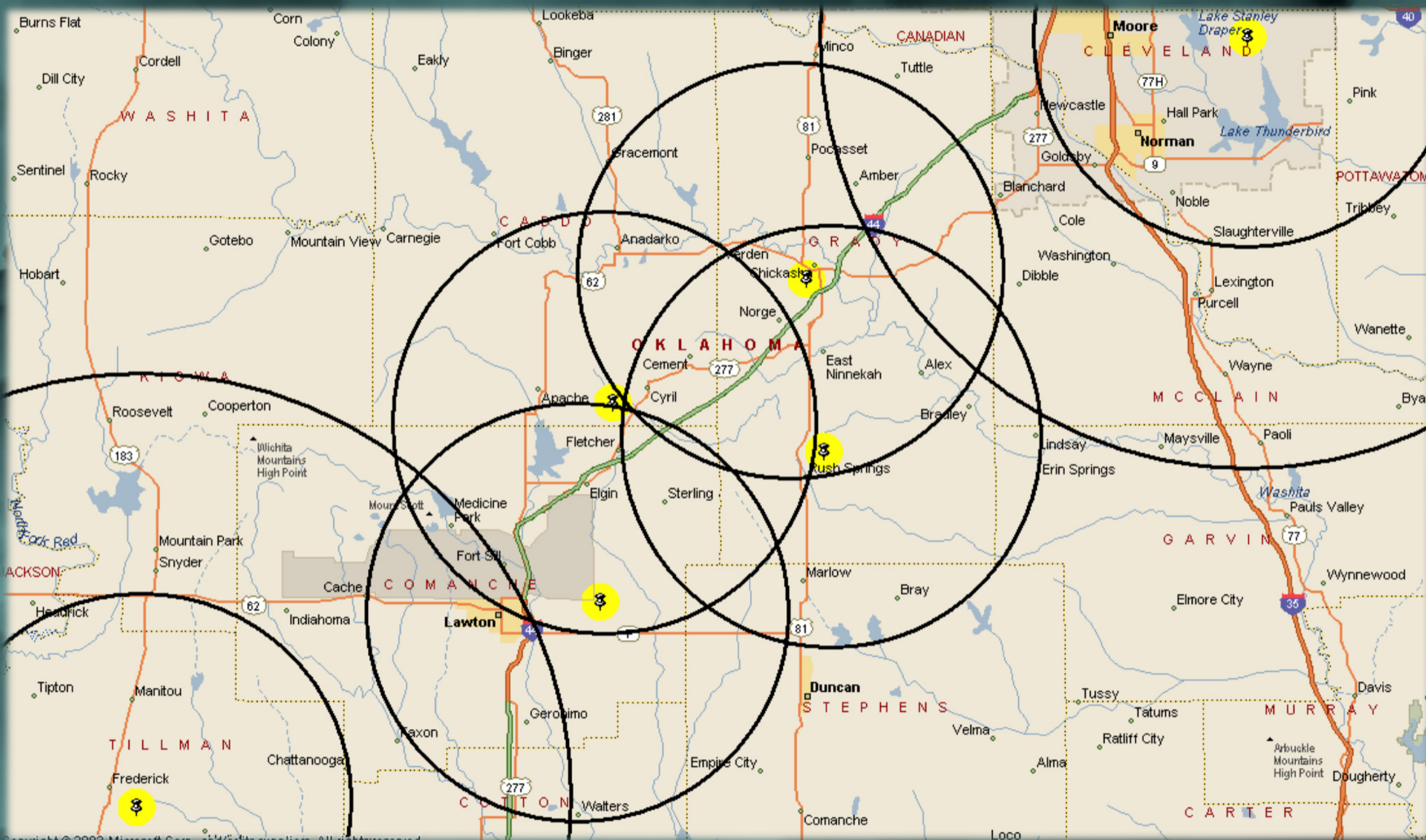
4th EnKF Workshop

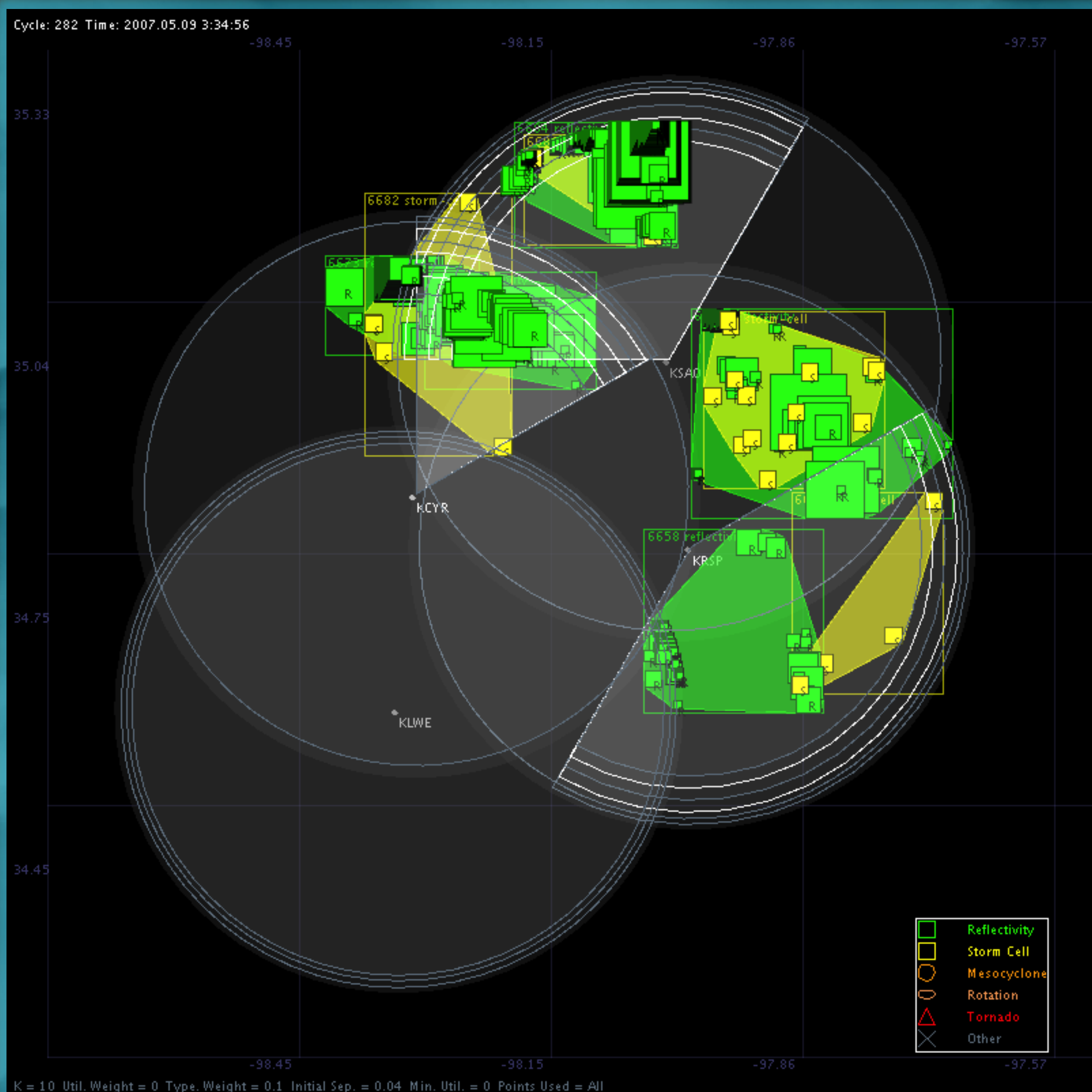
Presentation Outline

- Introduction
- 9 May 2007 Case Overview
  - Timeline of events
  - Model setup
- EnSRF Data Assimilation Results
- Deterministic and Probabilistic Forecast Results
- Conclusion and questions

CASA – A Brief Introduction



CASA – A Brief Introduction



- Adaptive Scanning:
  - Generate priorities (tasks) based on previous scan cycle.
  - Use these priorities to determine the scanning strategy for the next scan cycle.

CASA – A Brief Introduction

	CASA	WSR-88D
Wavelength	3.19 cm (X-band)	10.0 cm (S-band)
Maximum Peak Power	25 kW	750 kW
Pulse Repetition Frequency	Variable up to 3.33 kHZ	0.3 – 1.3 kHZ
3 dB Beamwidth	2.0 degrees	0.95 degrees
Polarization	Dual linear (V and H)	Horizontal only
Rotation Rate	Variable up to 120 deg./s	36 deg./s
Antenna Gain	38 dB	45 dB
Antenna Diameter	1.5 m	8.5 m
Maximum Range	40 km	459 km

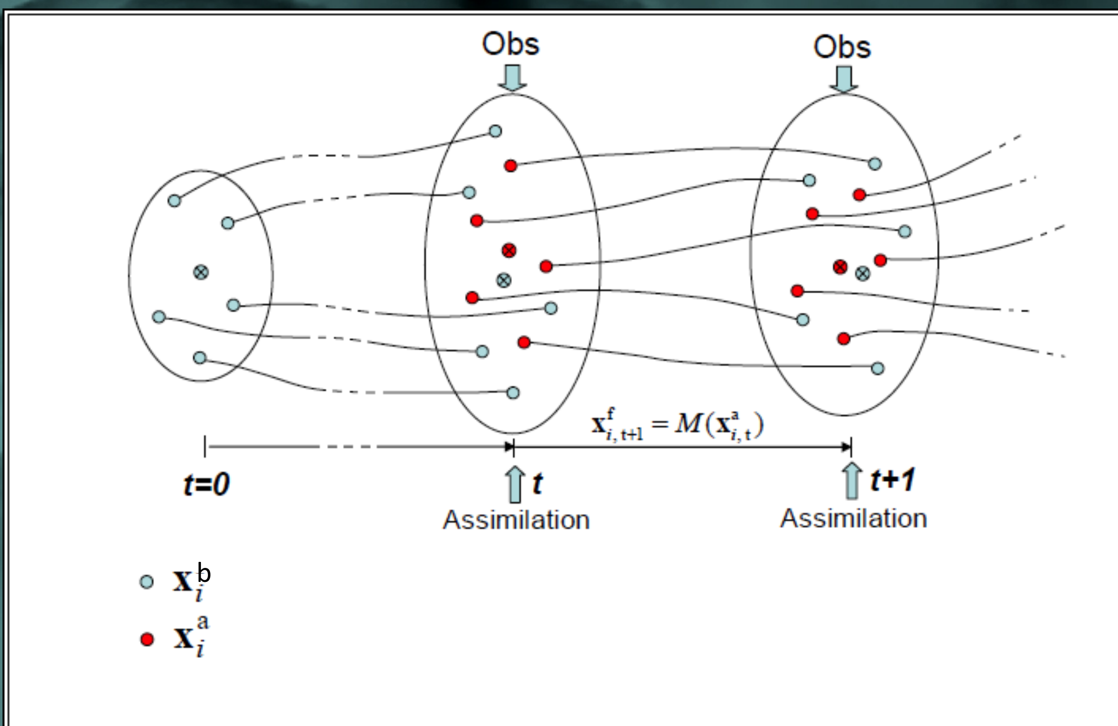
Project Overview and Goals

- Assimilate CASA and WSR-88D radar data using the ARPS EnKF system for tornadic convective storms.
  - Examine the impact of CASA data
  - Investigate methods for improving the analysis result (e.g. mixed-microphysics ensemble)

- Develop and test probabilistic forecast methods
  - Produce probabilistic forecasts for radar reflectivity and mesoscale circulations on a 0-3 hour timescale.
  - Examine impacts of ensemble microphysics and CASA data.

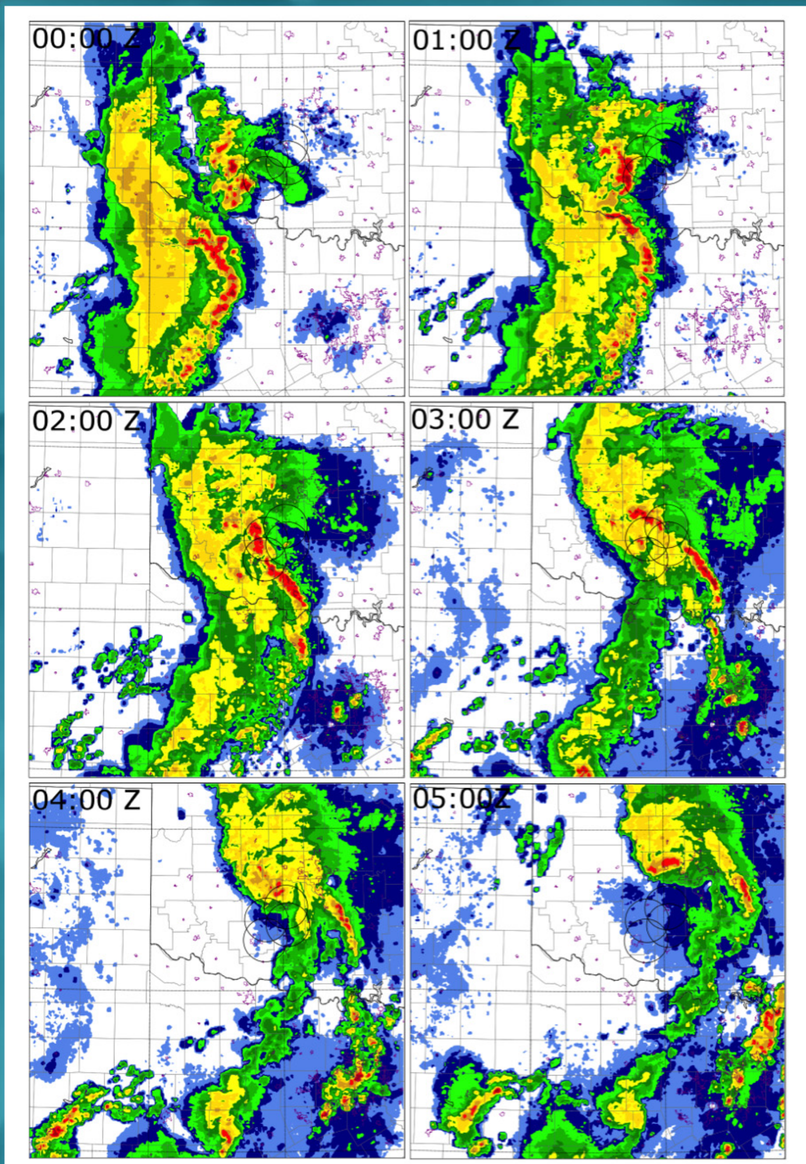
Data Assimilation Tools: ARPS EnSRF

- ARPS system uses a variant of EnKF known as the ensemble square root filter (EnSRF; Whitaker and Hamill 2002).

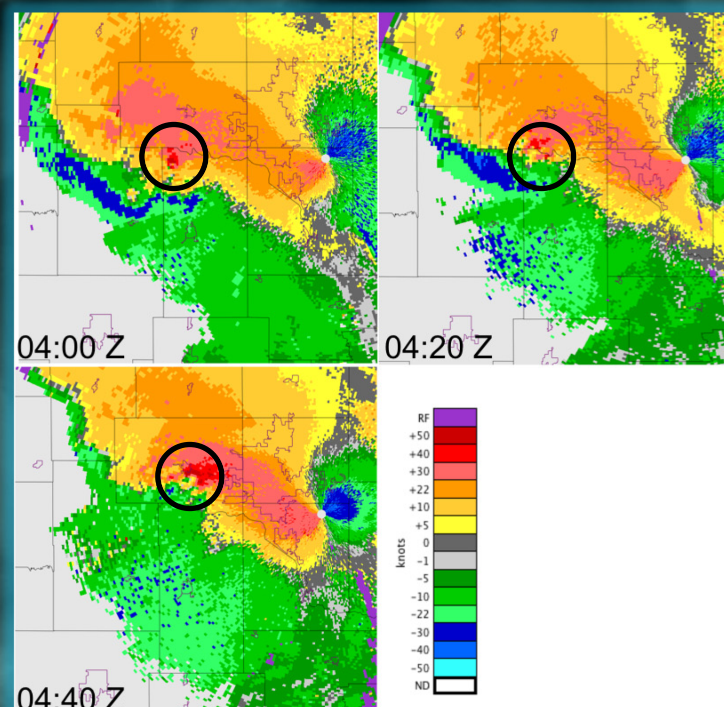


$$\begin{pmatrix} u^a \\ v^a \\ w^a \\ \theta^a \\ p^a \\ q_v^a \\ q_c^a \\ q_r^a \\ q_i^a \\ q_s^a \\ q_h^a \end{pmatrix} = \begin{pmatrix} u^f \\ v^f \\ w^f \\ \theta^f \\ p^f \\ q_v^f \\ q_c^f \\ q_r^f \\ q_i^f \\ q_s^f \\ q_h^f \end{pmatrix} + \alpha\mathbf{K}\left[\begin{pmatrix} V_r \\ Z \end{pmatrix} - \mathbf{H}\begin{pmatrix} u^f \\ v^f \\ w^f \\ \theta^f \\ p^f \\ q_v^f \\ q_c^f \\ q_r^f \\ q_i^f \\ q_s^f \\ q_h^f \end{pmatrix}\right]$$

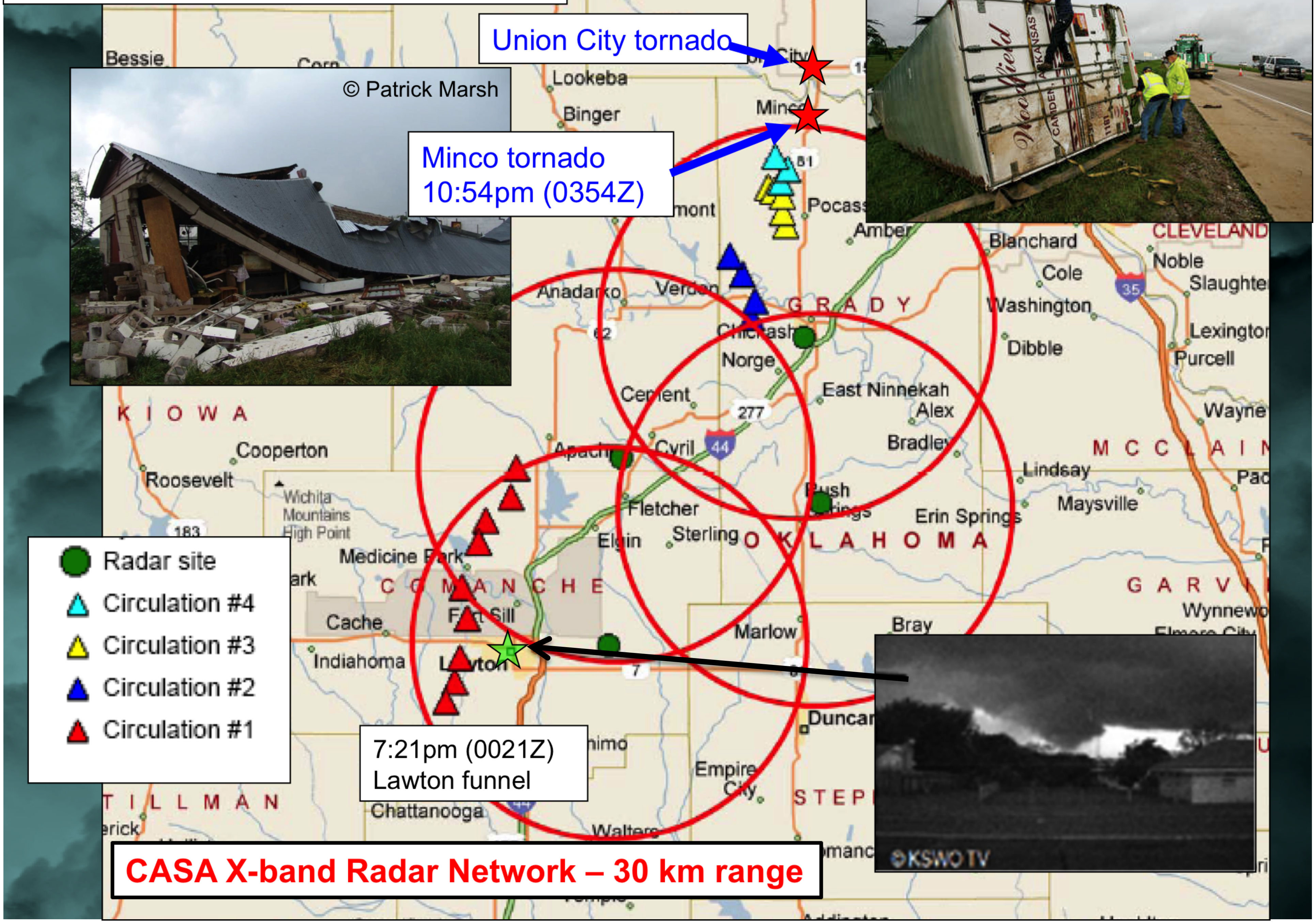
Case Overview: 9 May 2007



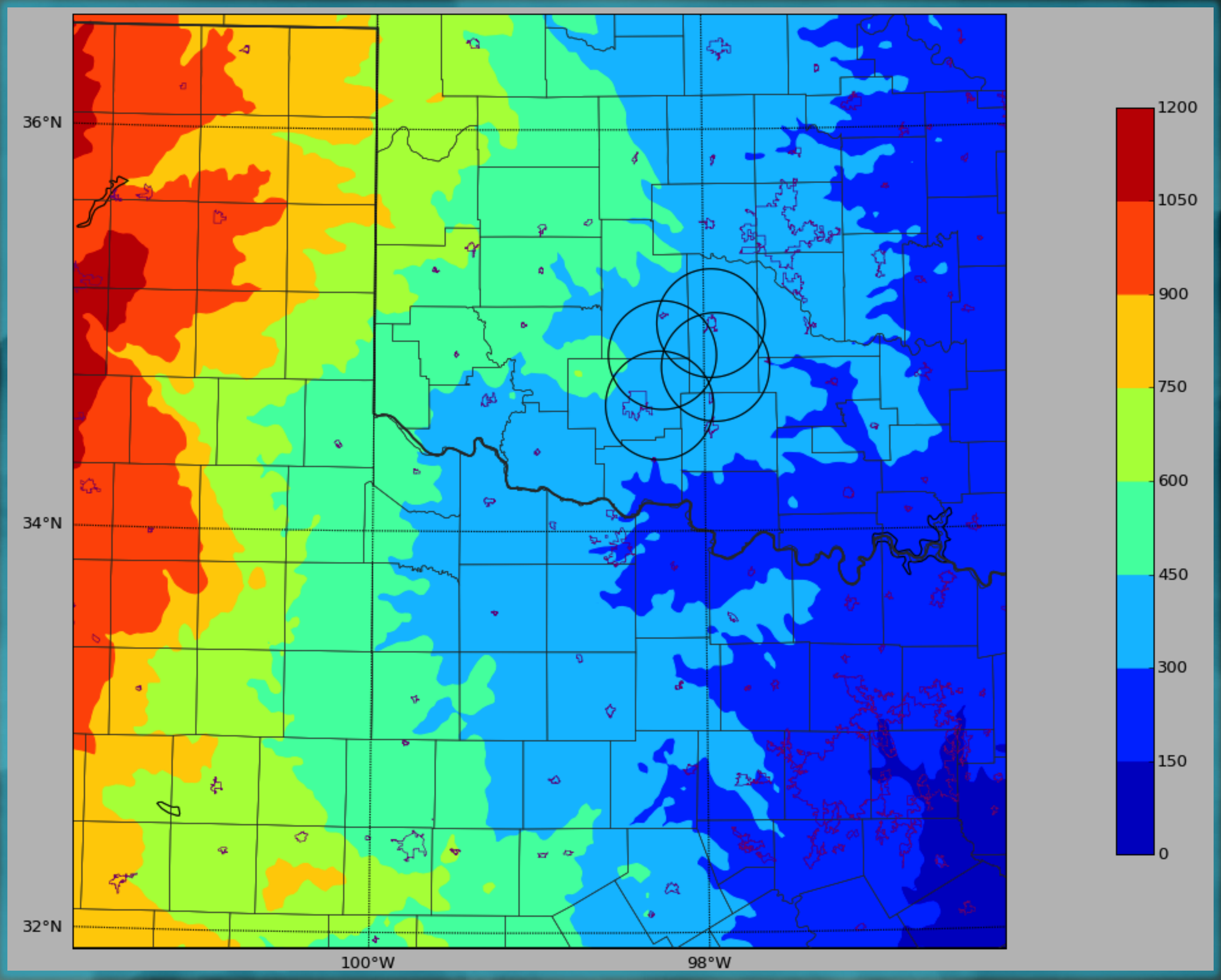
- Line-end vortex (LEV) developed within a larger mesoscale convective system (MCS).
- Tornadoes associated with smaller circulations within the LEV.



Tornadoes of 8-9 May 2007

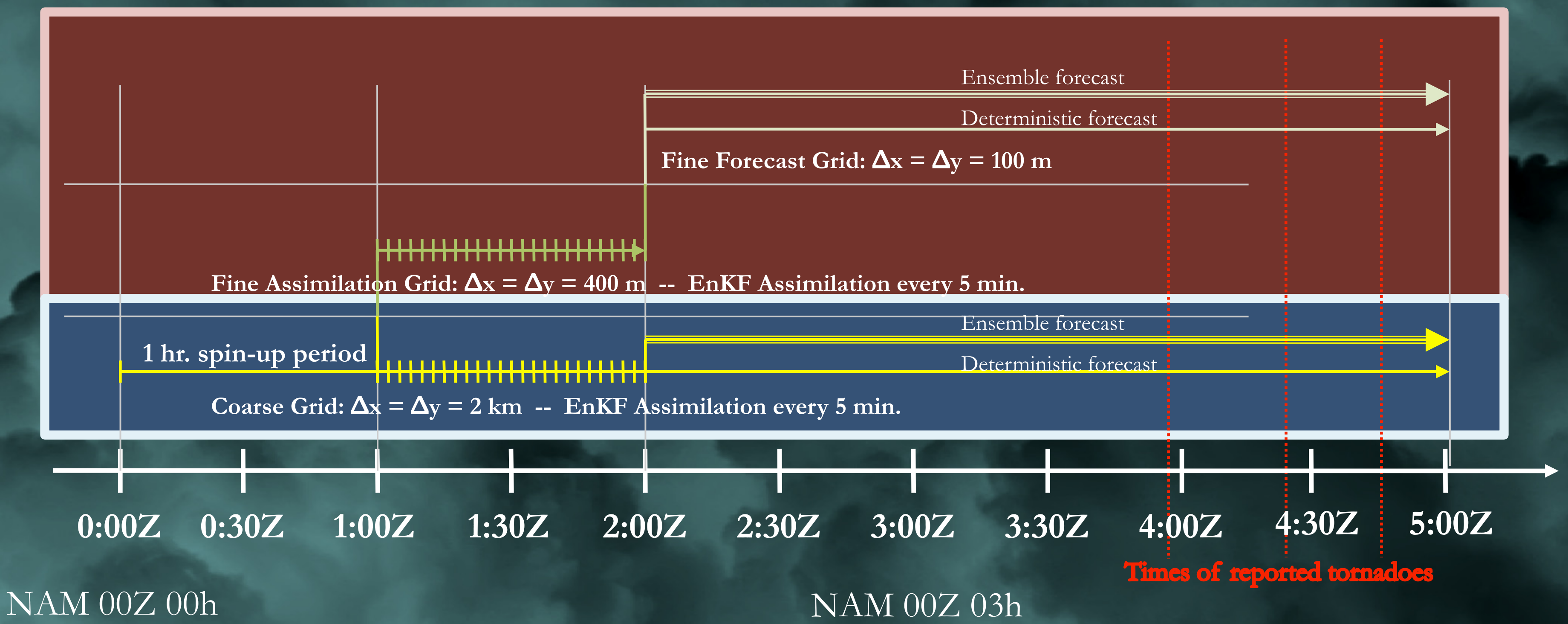


9 May 2007 – Experiment Setup



- $\Delta x = \Delta y = 2$ km
- $\Delta z_{min} = 100$ m
- Physical domain: $256 \times 256 \times 40$
- $N_{ens} = 40$

9 May 2007 – Experiment Setup



- Coarse grid experiments are presented here.
- Fine grid experiments are future work (currently in the preliminary stages).

9 May 2007 – Experiment Setup

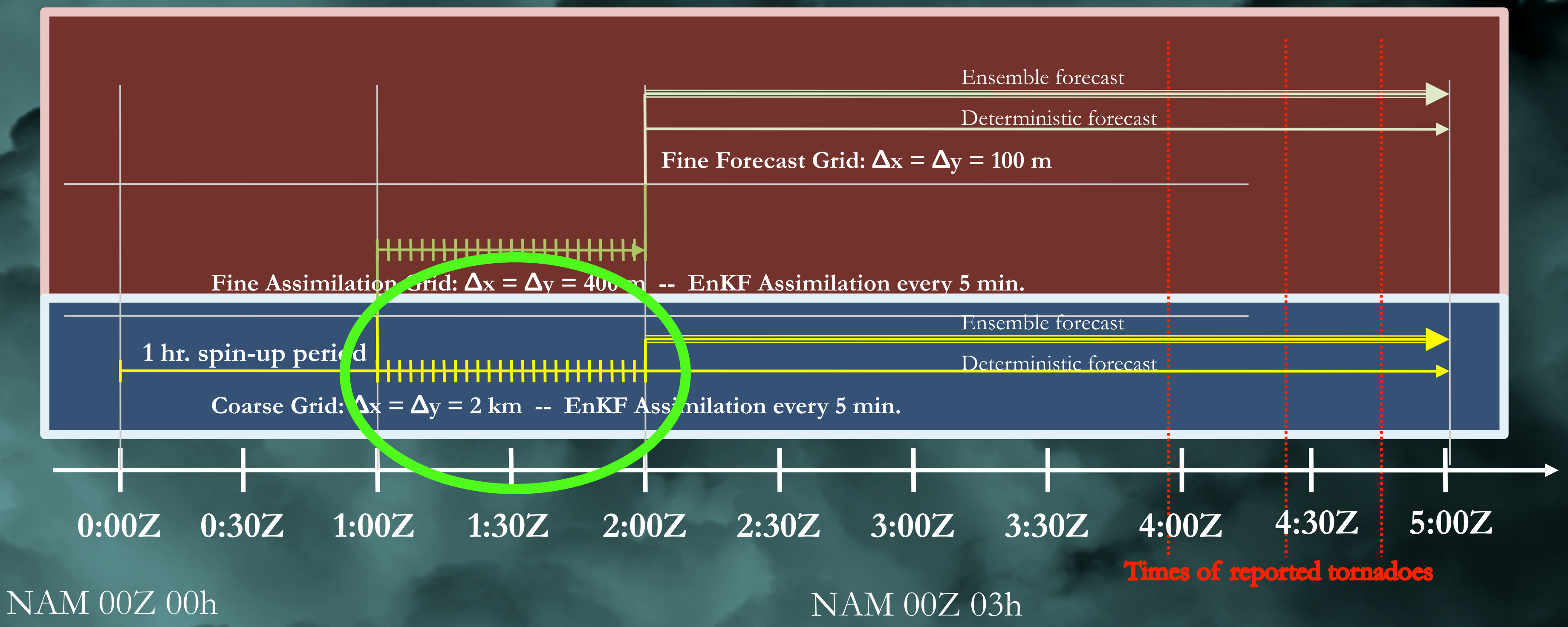
9 May 2007 -- 2 km Study	CNTL	88D	Lin
WSR-88D radar used?	Yes	Yes	Yes
CASA radar used?	Yes	No	Yes
Ensemble size	40	40	40
Number of Lin microphysics members	16	16	40
Number of WSM-6 microphysics members	16	16	0
Number of NEM microphysics members	8	8	0

9 May 2007 Case Study: Data

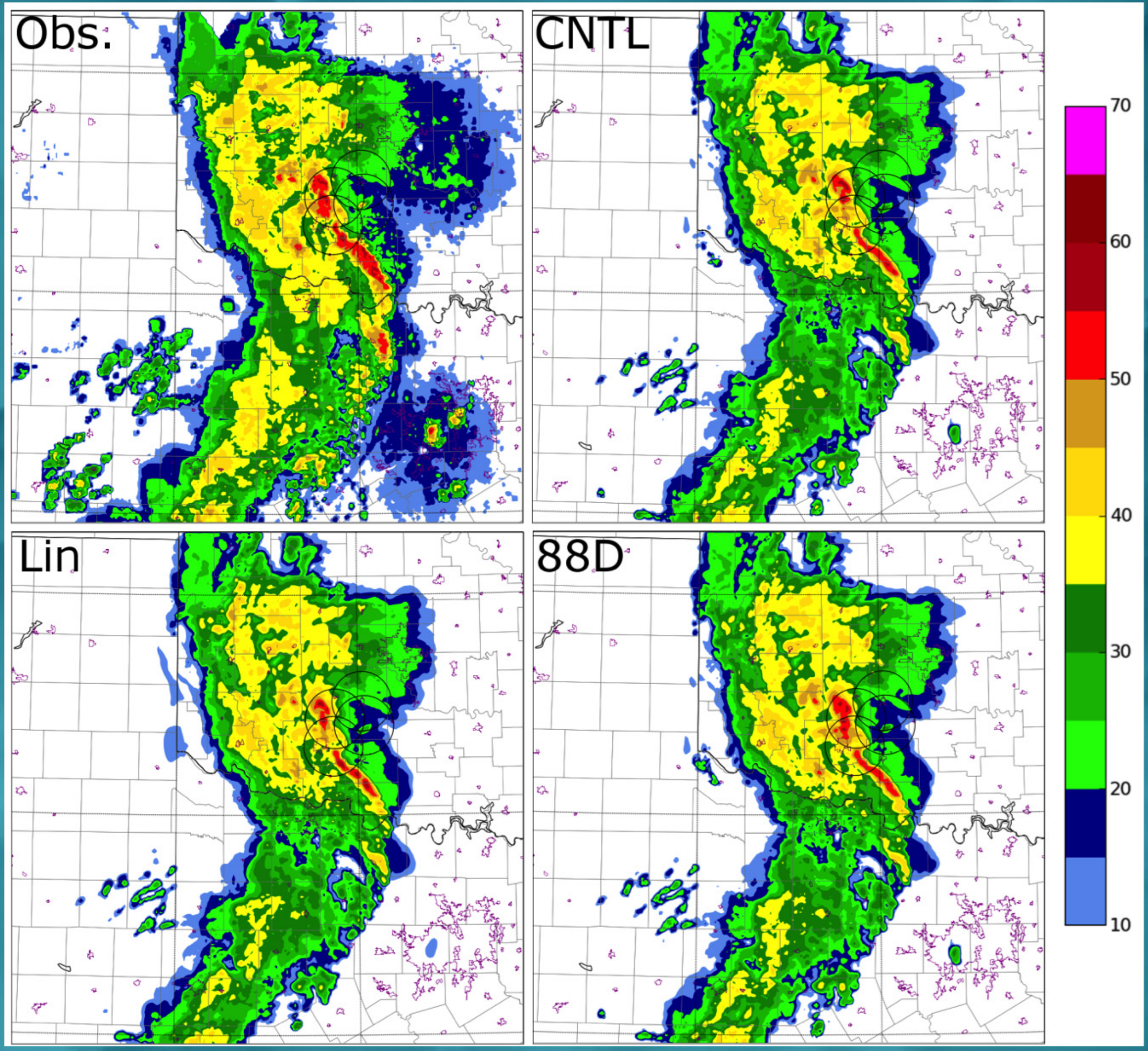
Radar Name	Radar Type
KAMA	WSR-88D
KDYX	WSR-88D
KLBB	WSR-88D
KTLX	WSR-88D
KVNX	WSR-88D
KCYR	CASA
KLWE	CASA
KRSP	CASA
KSAO	CASA

- Data from 9 radars assimilated:
  - 5 WSR-88D
  - 4 CASA
- WSR-88D radar KFDR *not used* because Level II data was unavailable during the assimilation period.

Assimilation Period -- Results



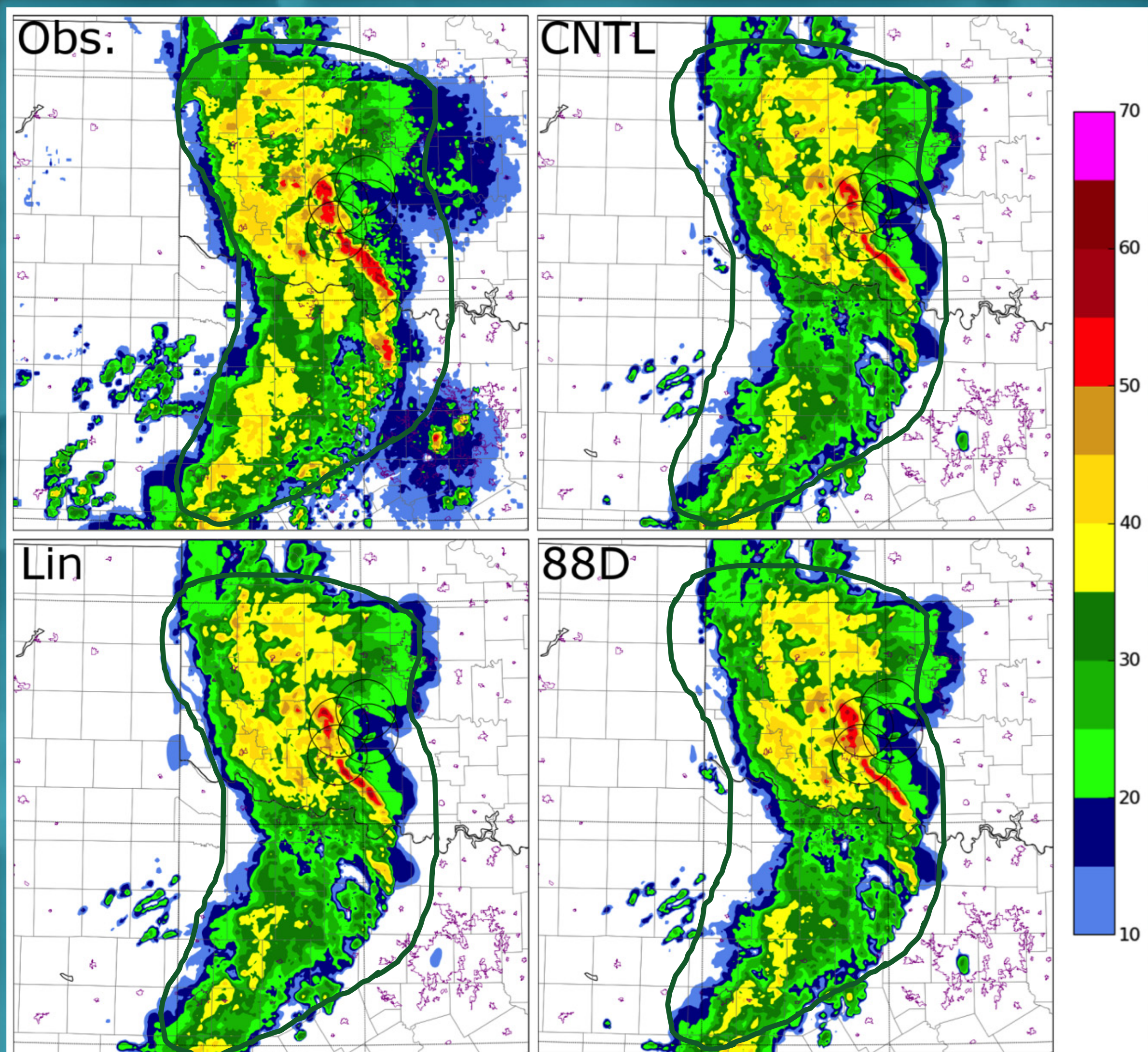
Assimilation Period – Results



- Main convective line and trailing stratiform region well represented.
- Cells in SW portion of domain too weak in the models.
- Models underestimated intensity of small individual cells ahead of the convective line.

Observed and simulated composite radar reflectivity, 02:00 UTC

Assimilation Period – Results



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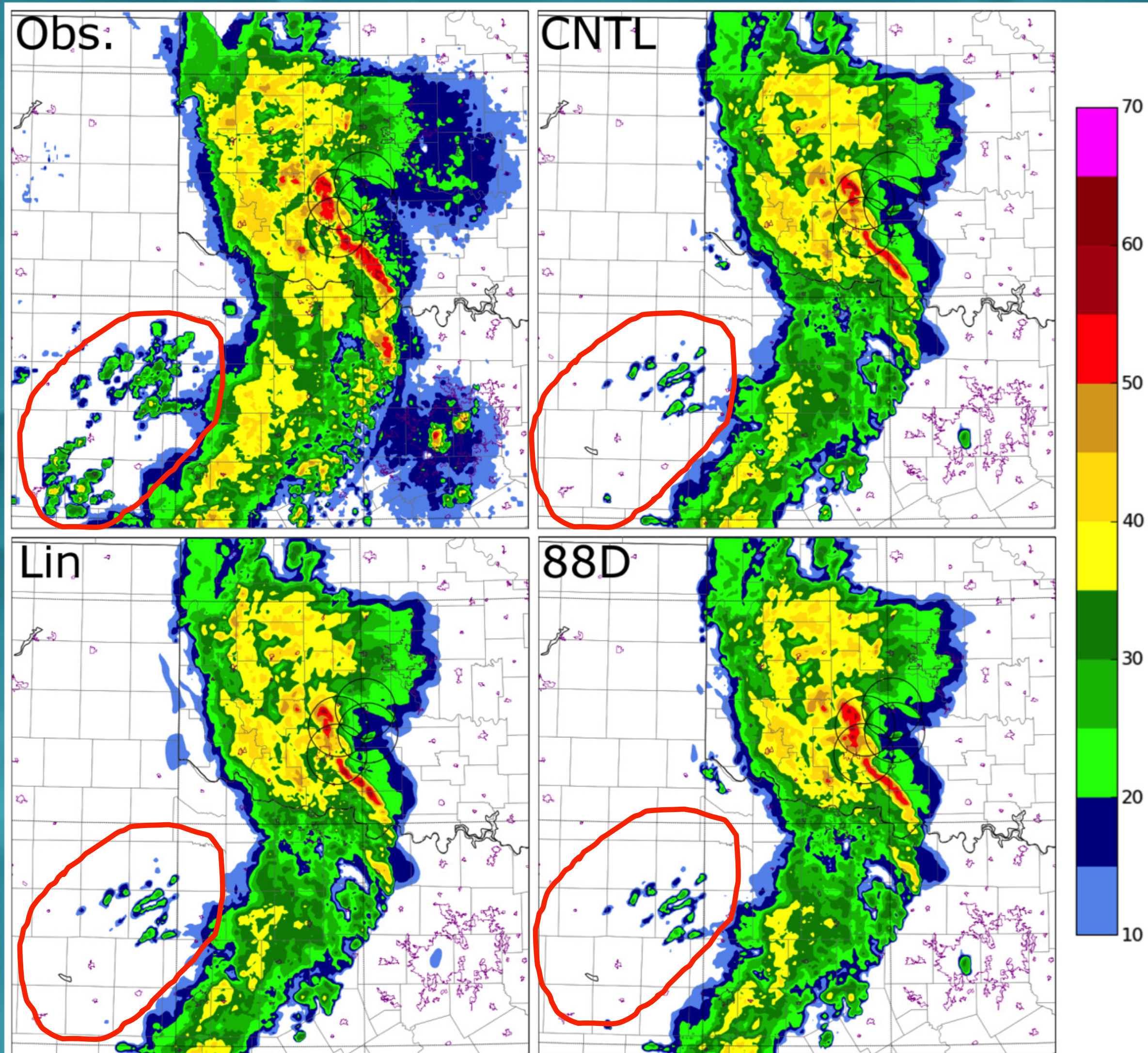

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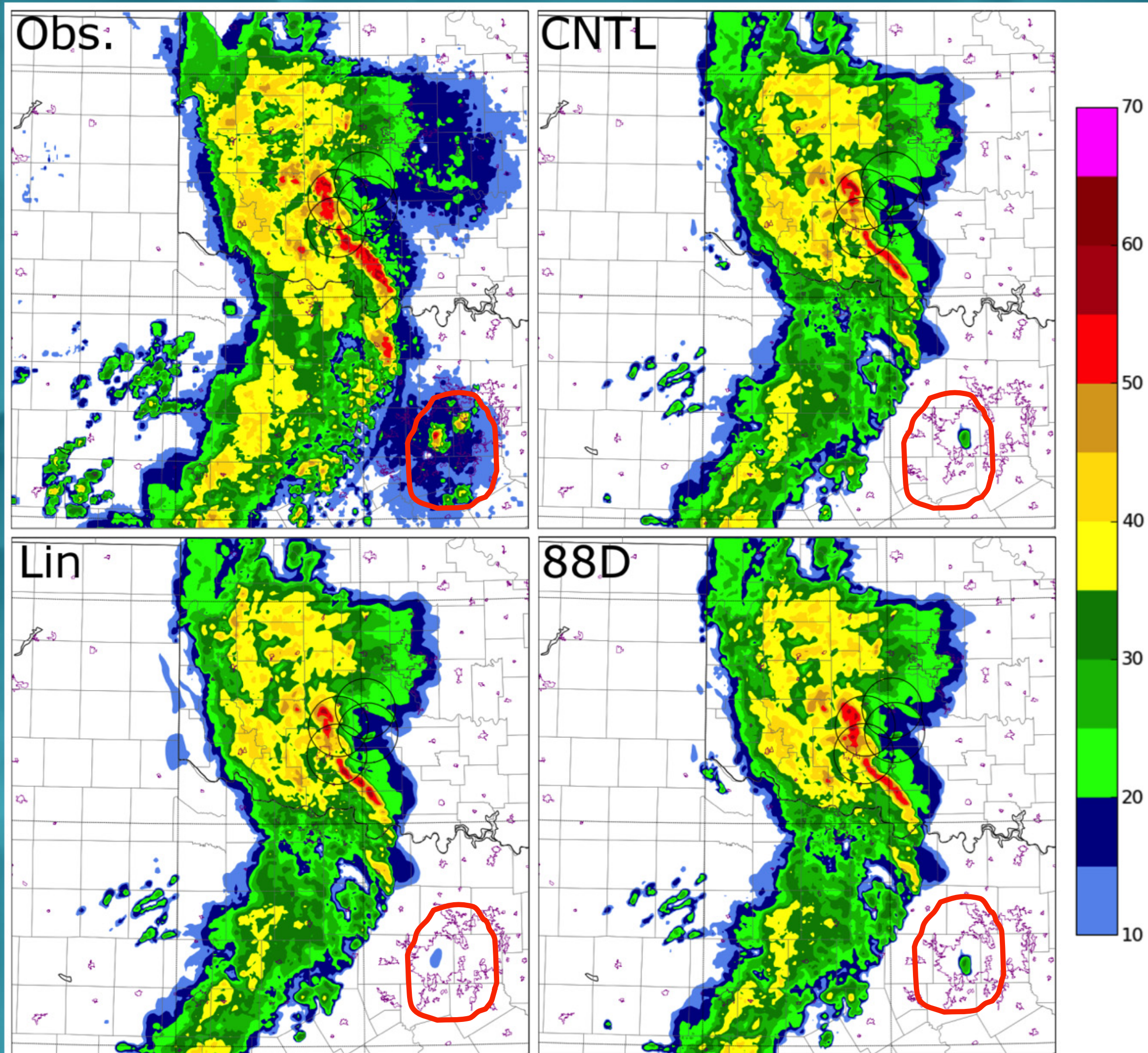

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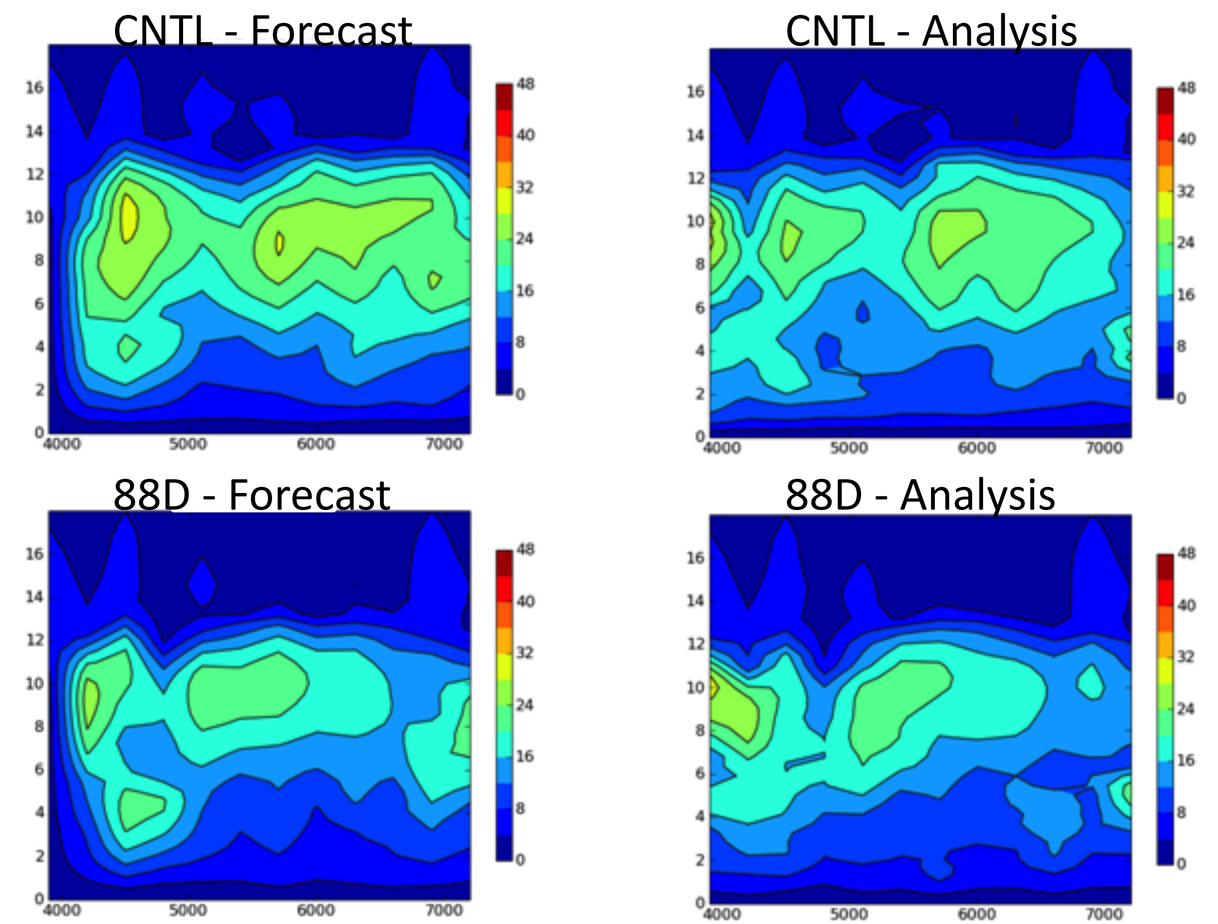
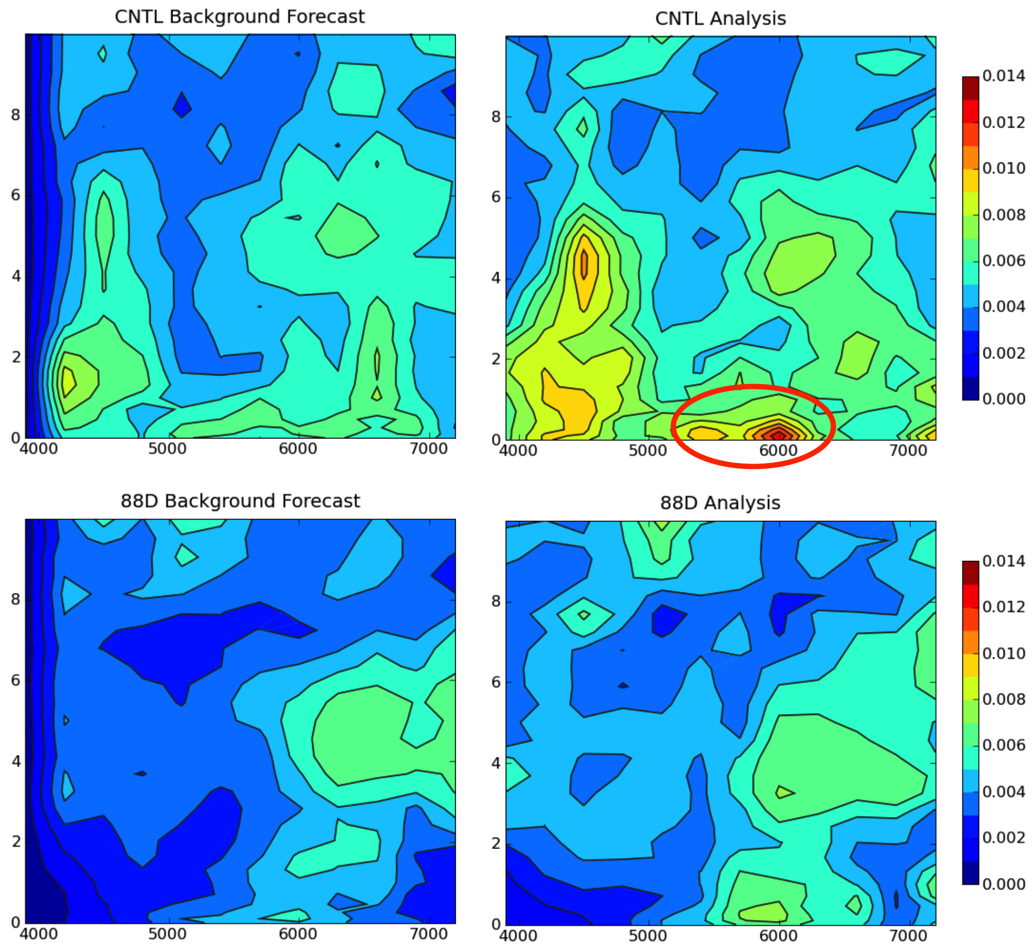
Assimilation Period – Effect of CASA Data



Time-height plot of maximum updraft speed (m/s) during the assimilation period

- Updraft is noticeably more intense when CASA data are used.

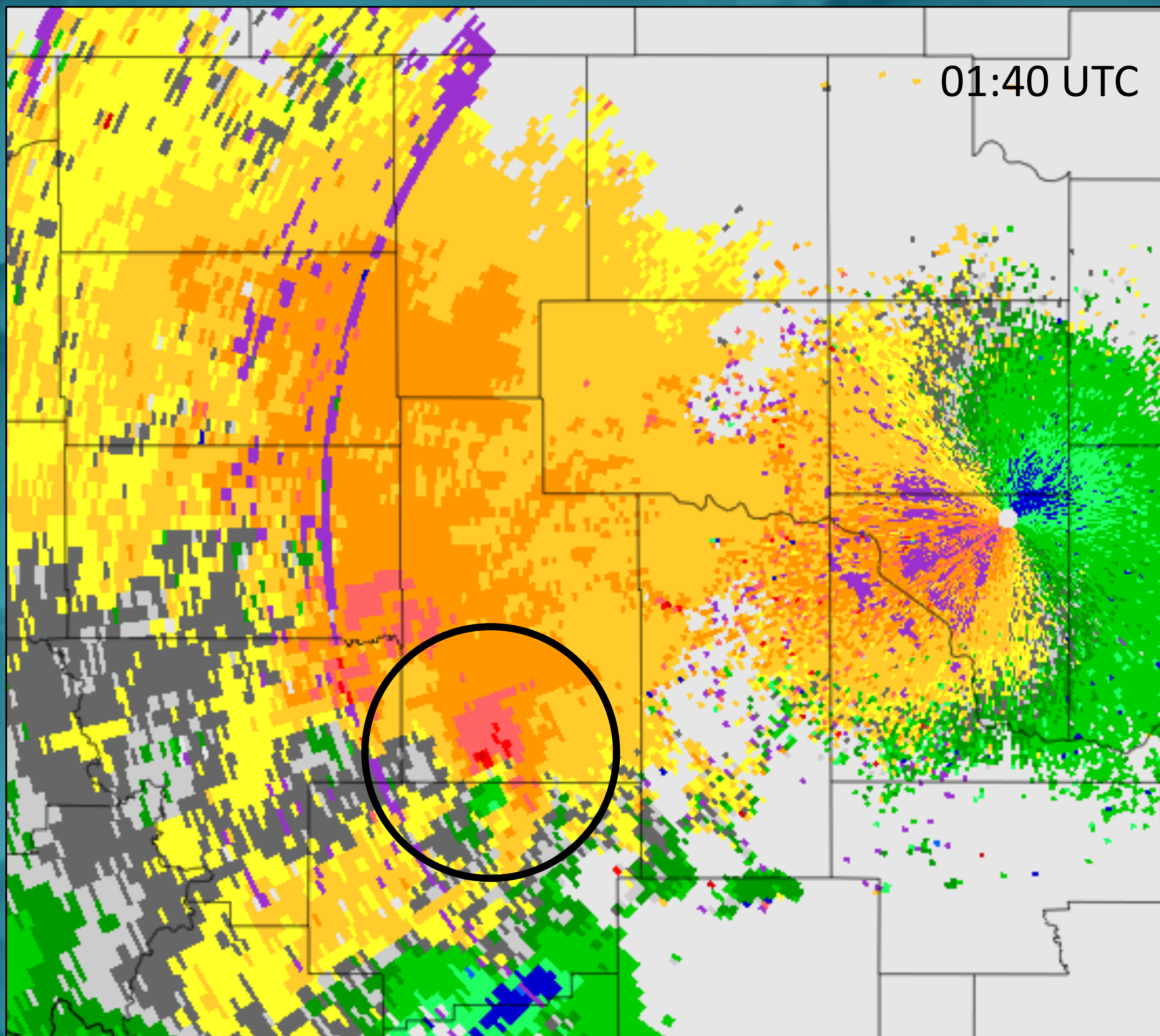
Assimilation Period – Effect of CASA Data



Time-height plot of maximum vertical vorticity (s^{-1}) during the assimilation period

- Addition of CASA data increases low-level vorticity in both forecast and analysis.

Assimilation Period – Effect of CASA Data



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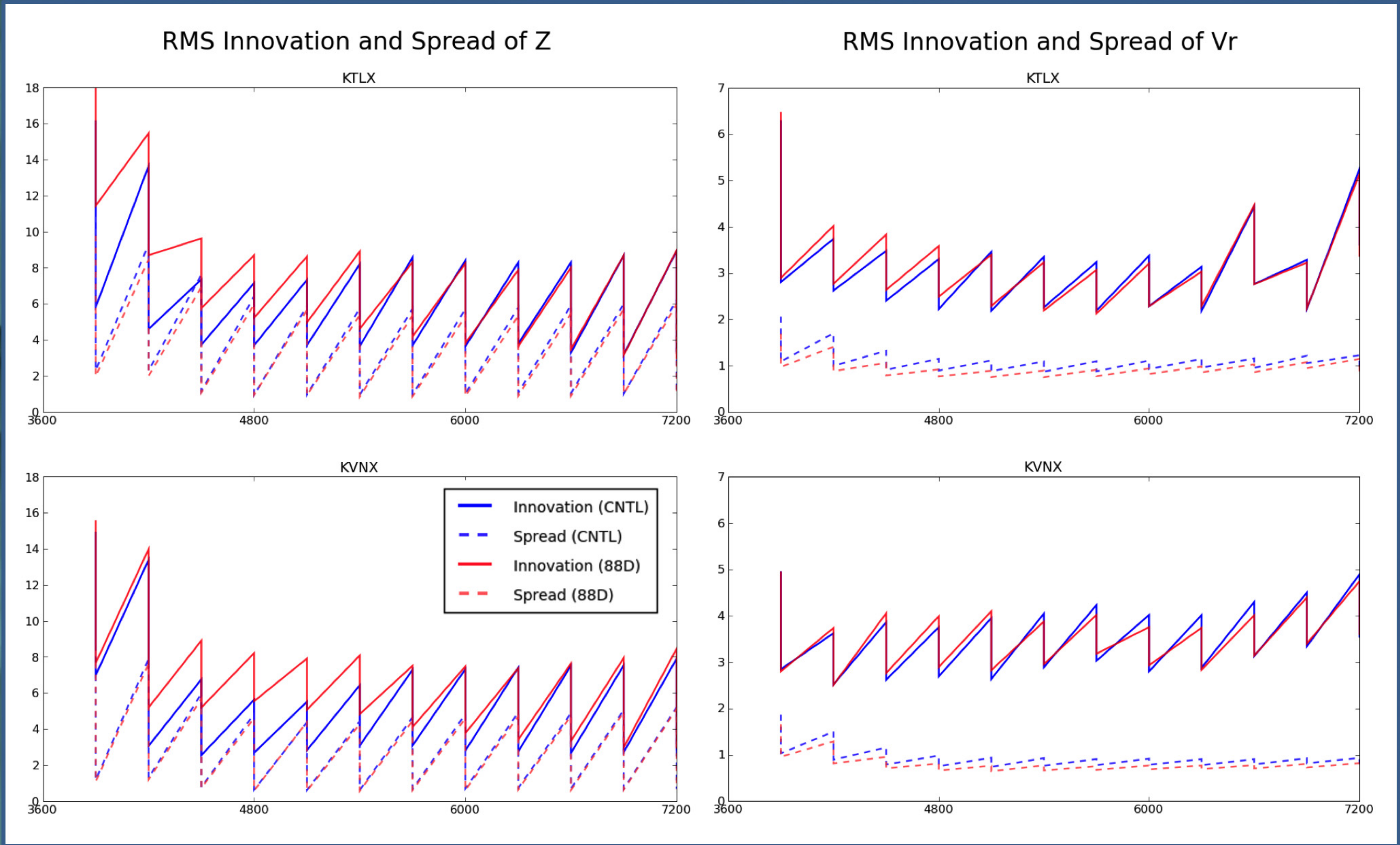
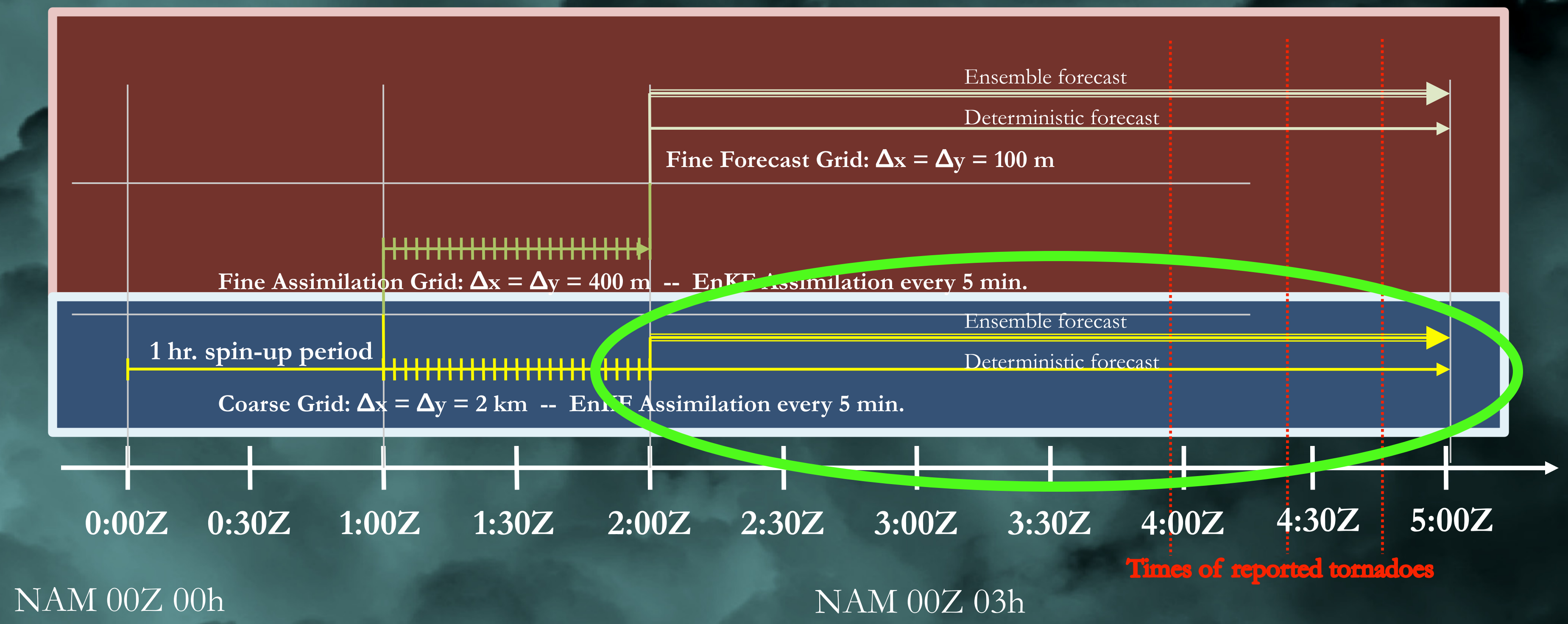


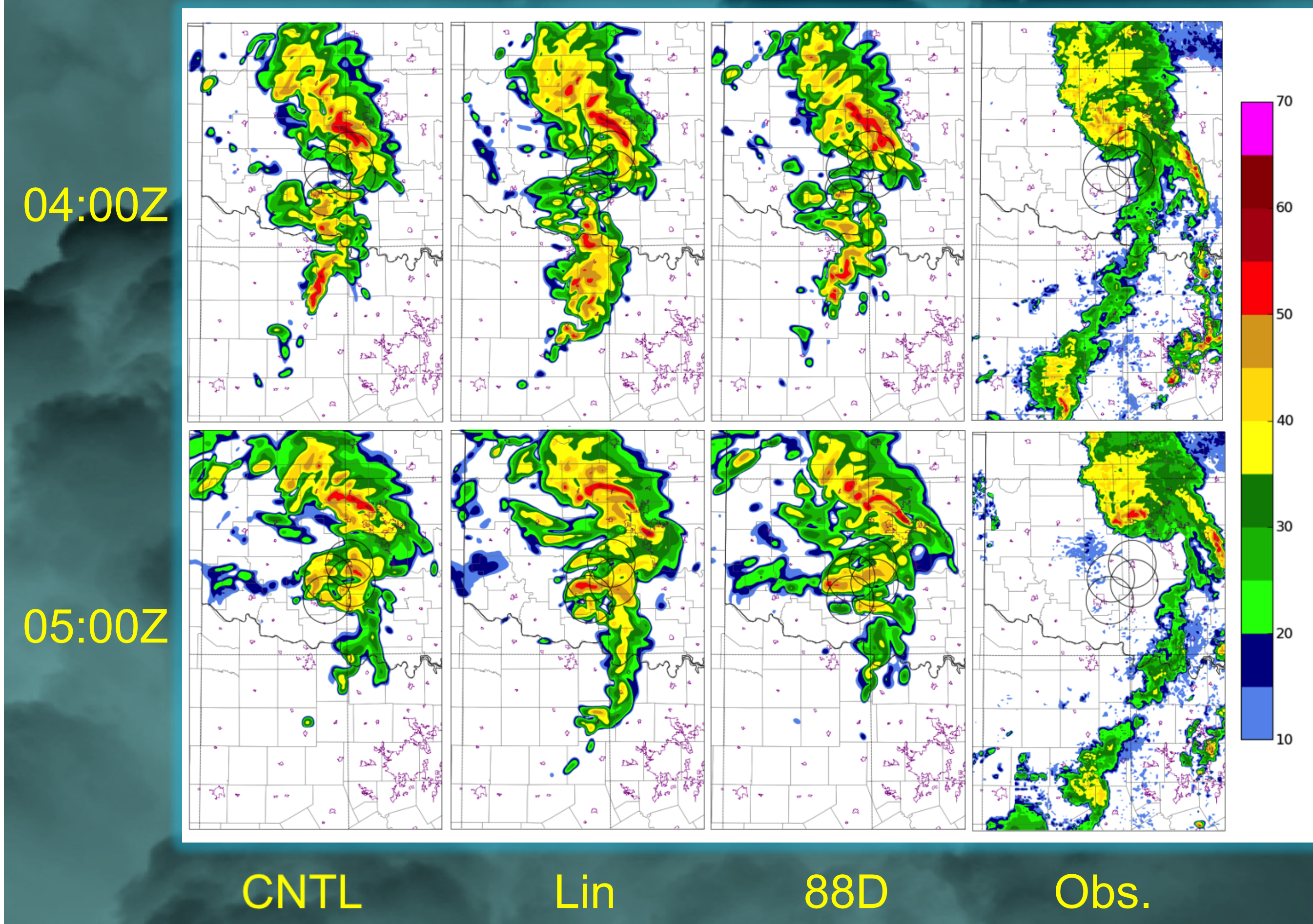
Assimilation Period – Summary / Conclusions

- Structure of the MCS well represented after radar data assimilation using EnSRF.
- Assimilation of CASA data increased low-level vorticity in analysis and forecast at the time of observed strong near-surface rotation.
- Inclusion of CASA data improved fit of Z analysis to 88-D observations.
- Significant under-dispersion noted in the ensemble; mixed-microphysics reduced under-dispersion in Z (not shown).

Forecast Period -- Results

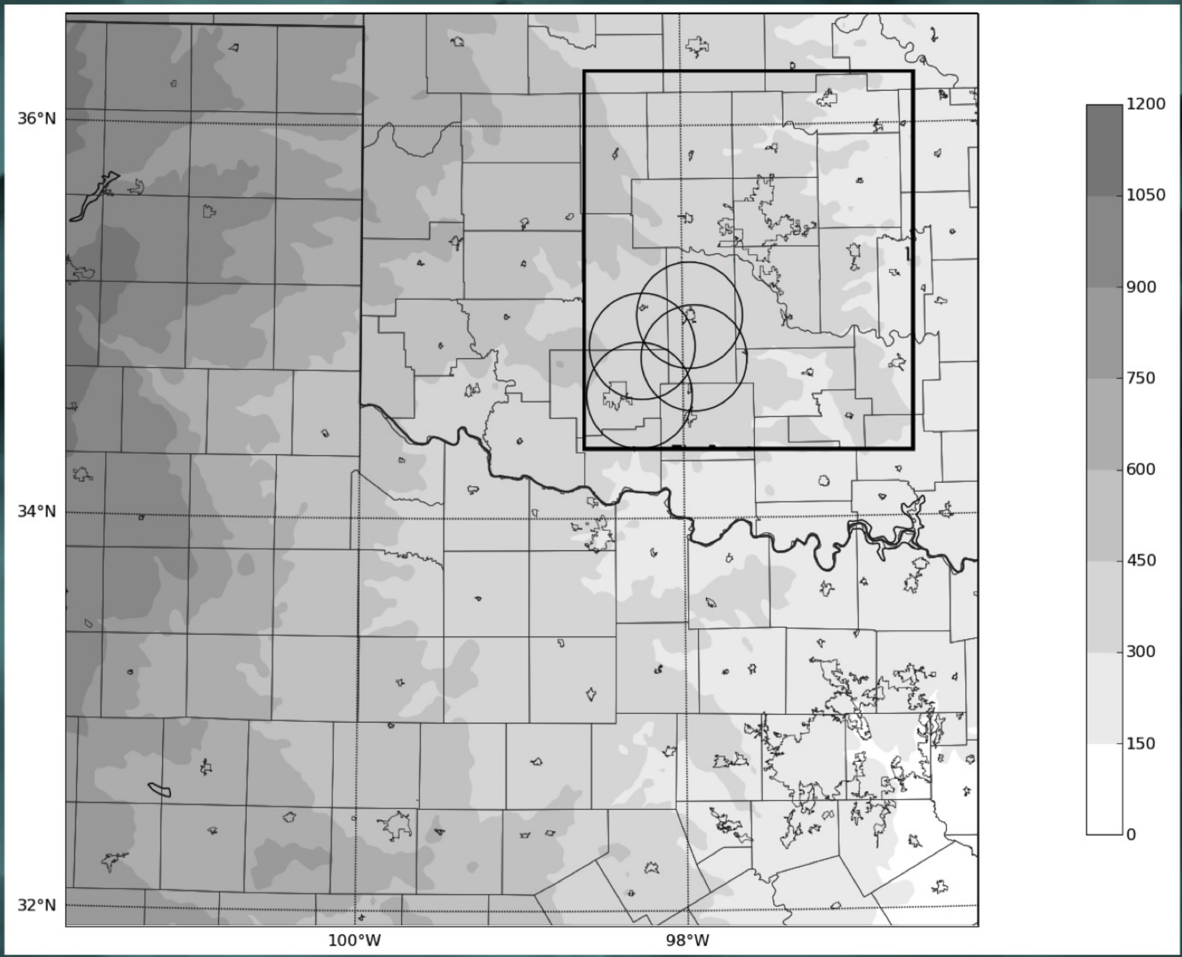


Deterministic Forecasts



- Z at grid level k = 10 (≈ 2 km AGL)
- Motion of LEV and north end of system agree well with obs.
- Convective lines too weak in forecasts
- Greatest similarity between CNTL and 88D

Equitable Threat Score Analysis



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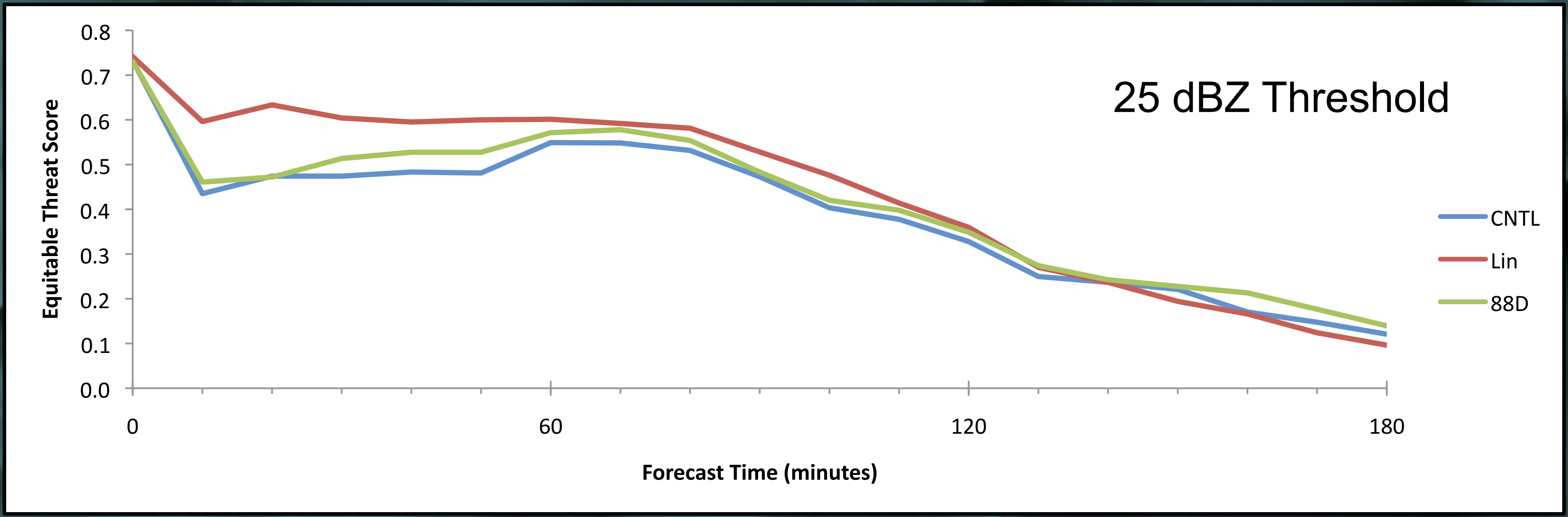
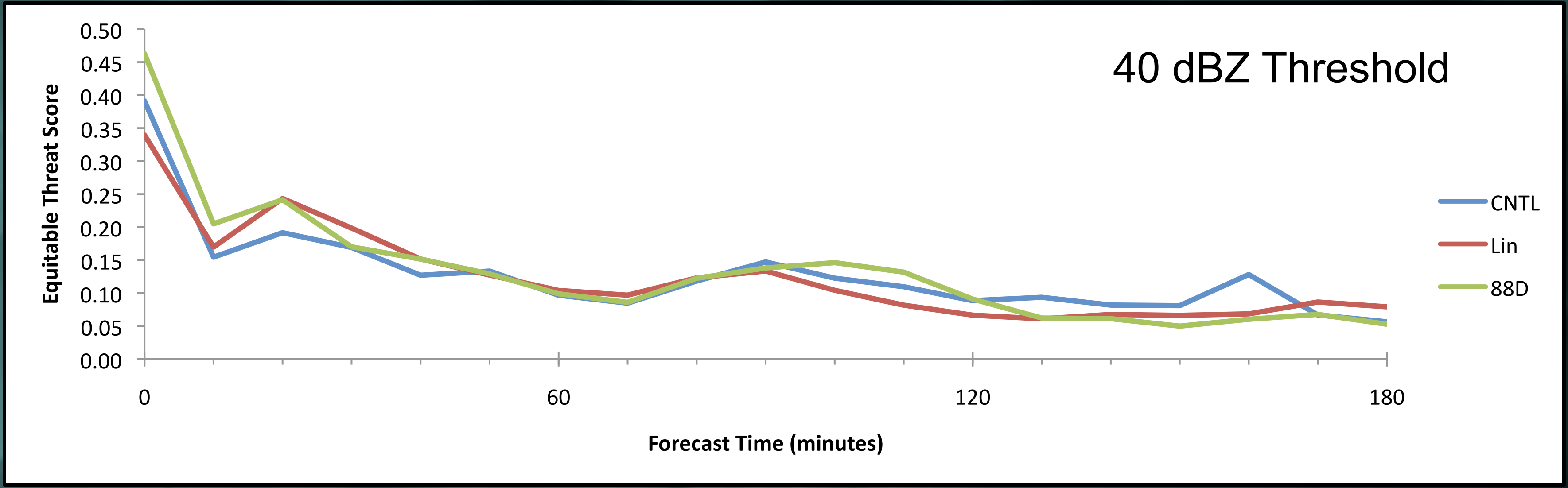
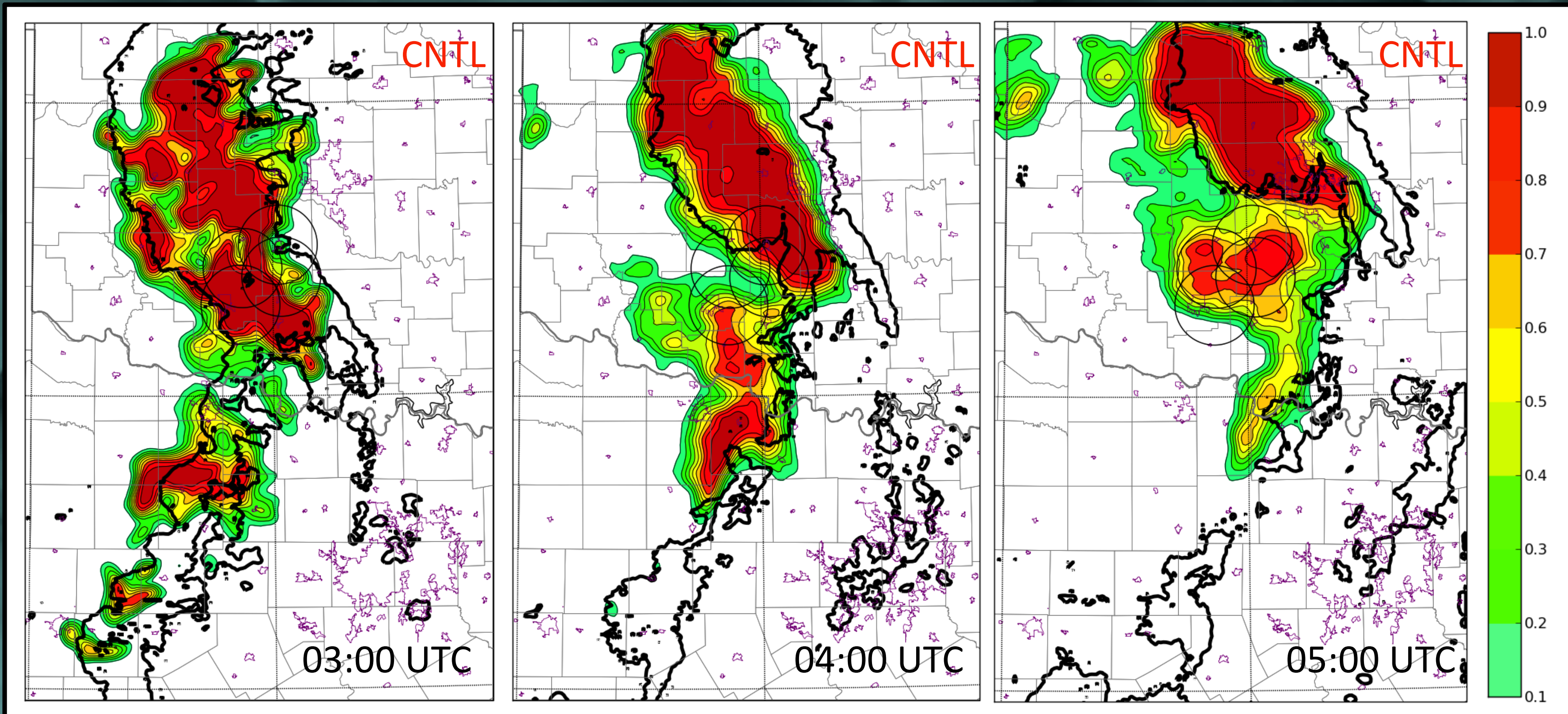




Ensemble Forecasts

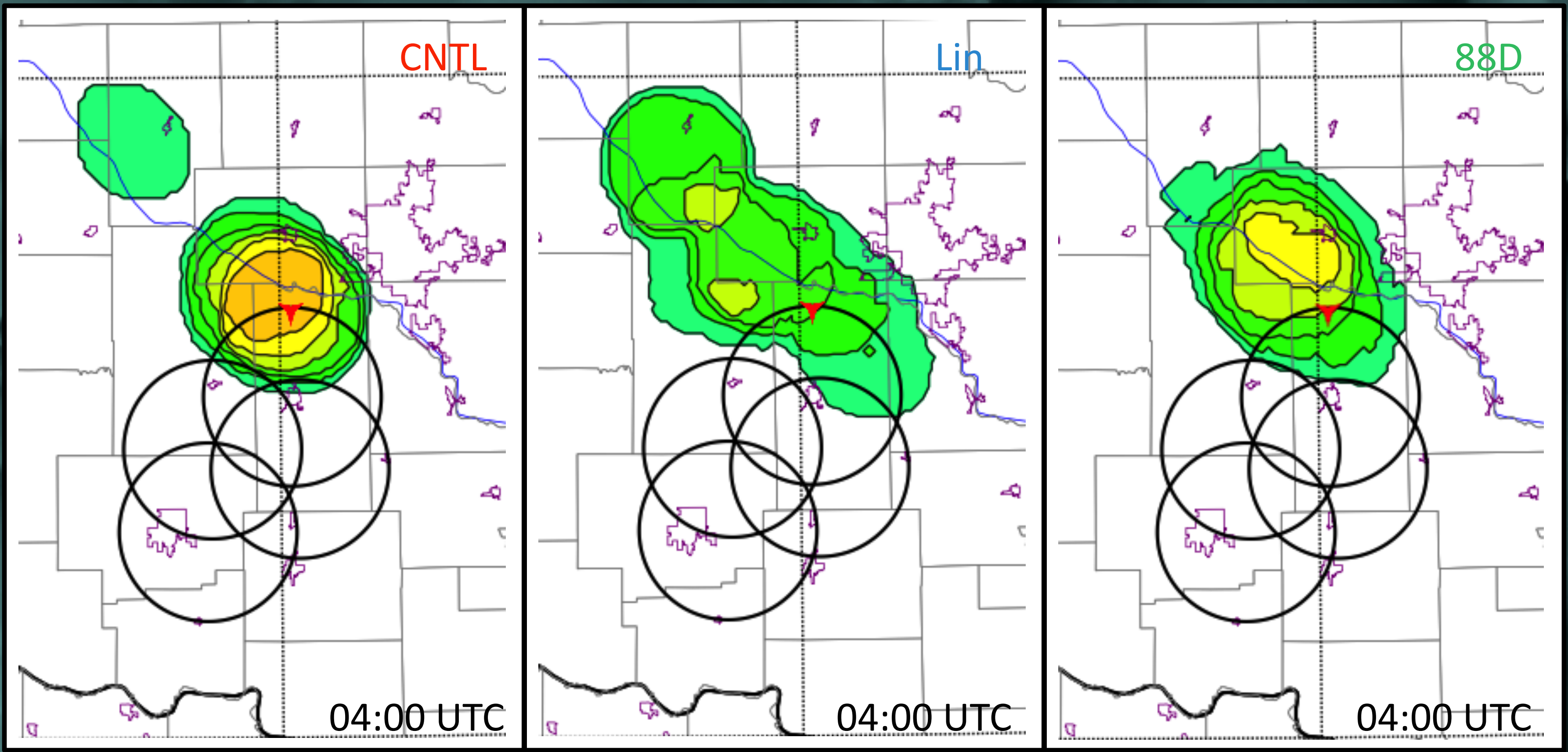
- 40 member ensemble initialized from 02:00 UTC analyses of individual ensemble members.
- Forecast verification focused on radar reflectivity (Z) and mesoscale circulations.
- Probabilistic calculations based on occurrence of events within the ensemble and within a fixed radius from a grid point; a method similar to that of Schwartz et al. (2009).

Ensemble Forecasts – 25 dBZ Threshold



- Highest probabilities match well with observations in placement and motion.
- As in deterministic forecasts, leading line absent and trailing line decays too quickly, with spurious convection after 04:00 UTC near the CASA domain.

Ensemble Forecasts: Tornadic Mesocyclones



- Probability of significant low-level vortex at tornado location:

CNTL: 0.65	Lin: 0.35	88D: 0.43

Forecast Period – Summary / Conclusions

- Highest values of probability for radar reflectivity and mesoscale circulations matched well with observations on the 1-3 hour timescale.

- Both assimilated CASA data and a mixed-microphysics ensemble showed positive impact on probabilistic mesoscale circulation predictions.

- Greater sensitivity during forecast period to use of a mixed-microphysics ensemble than assimilated CASA data.
    - Previous studies (e.g. Snook and Xue 2008) show great sensitivity of convective dynamics to microphysical parameters.
    - CASA IP1 domain is quite small compared to the MCS simulated.