Toward Developing a Storm-scale Prediction System for Hazardous Weather: An Upd

Moore OK Tornado 20 May 2013

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NOAA Warn-on-Forecast Project

NOAA's

National Severe Storms Laboratory

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Center for Analysis and Prediction of Storms
University of Oklahoma
CAPS

NSSL
National Severe Storms Laboratory

cimms

IMAGe

ESRL
Global Systems Division

National Weather Service

Storm Prediction Center
Norman, Oklahoma

SSWIM
Social Science woven into Meteorology

NCAR The Earth & Sun Systems Laboratory
ESSL

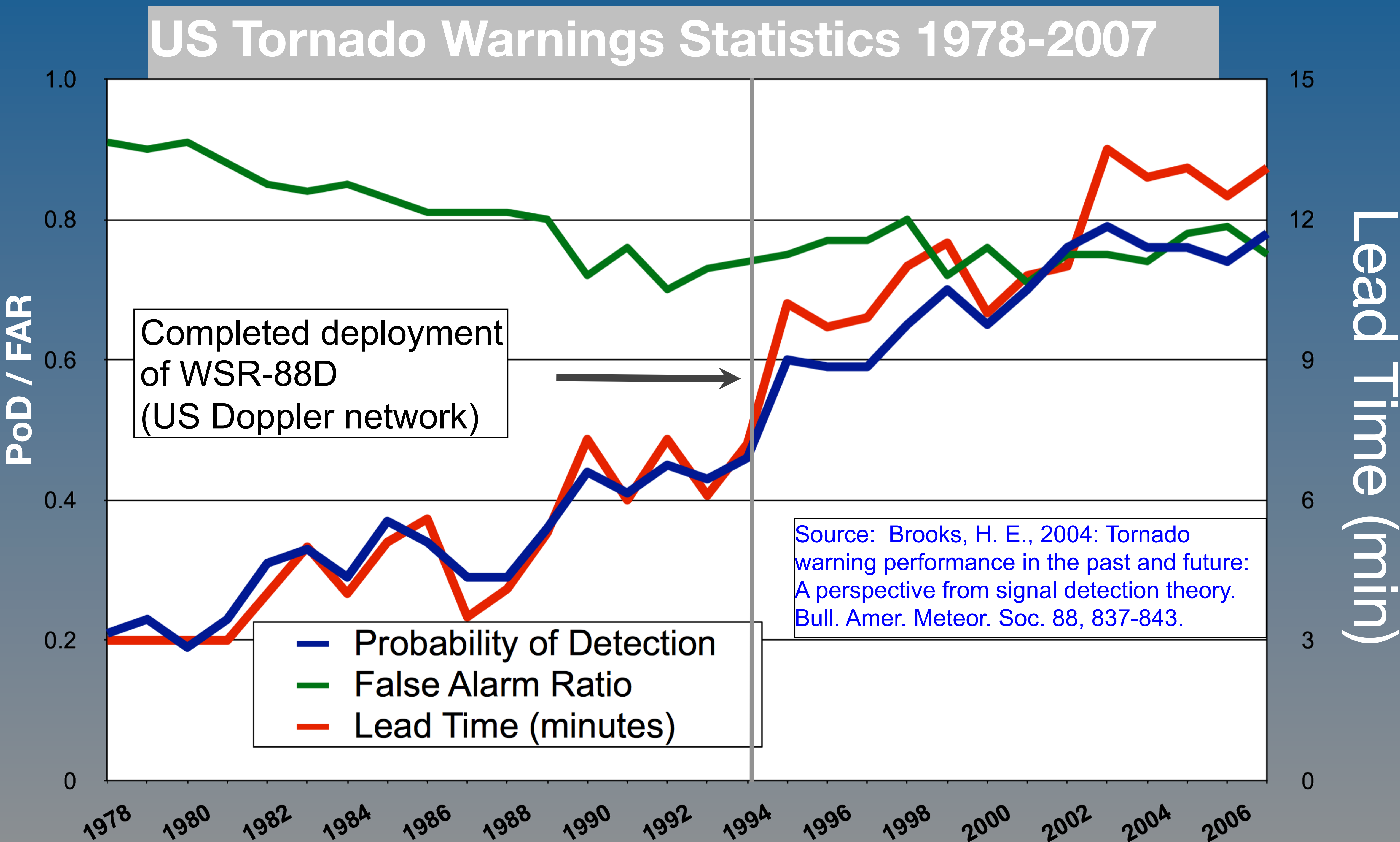
Earth Observing Laboratory
EOL

PENNSTATE
1855

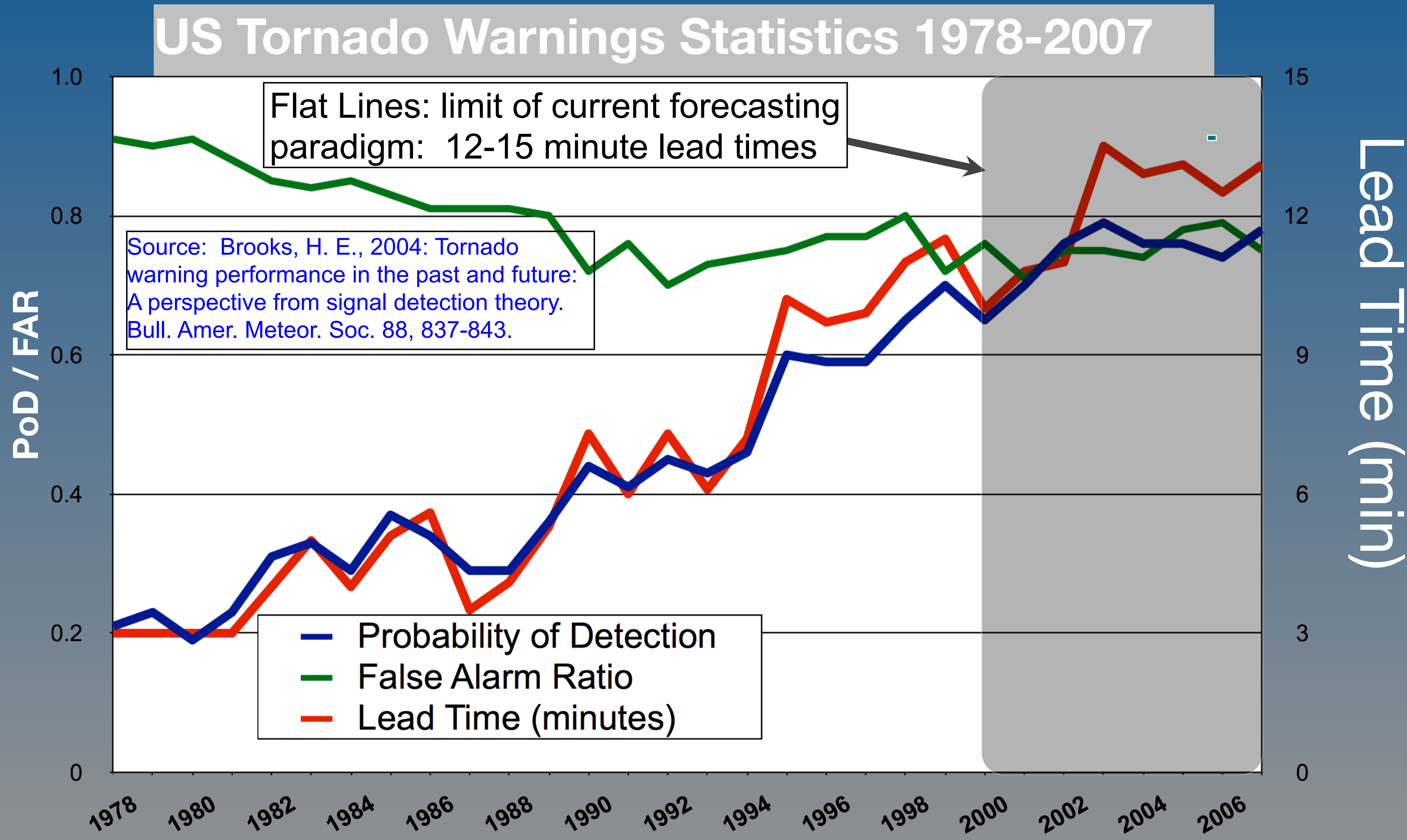
NCEP
National Centers for Environmental Prediction

GOES R
Geostationary Operational Environmental Satellite R-Series
NOAA ~ NASA

Since deployment of WSR-88D (Doppler) radar this paradigm has worked well!



But it appears we have reached the limit of the current warning paradigm...



New Warning Paradigm:

Storm-scale NWP or Warn on Forecast (WoF)

- NWP for individual convective storms using an ensemble of high-resolution model forecasts
- High-resolution synthesis of mesoscale, radar-scale, and in situ observational data via 4D data assimilation
- Quantitative prediction of internal storm dynamics
- Provides information on the type, severity, and probability of weather threat
- WoF is currently focused on 0-1 hour prediction AFTER convection is detected by the radar.....

Differences between Large-Scale and Storm-scale DA

- "Large-scale" data assimilation is an <u>analysis</u> problem:
  - The model state variables are similar to what you observe
  - STATE(P, T, T_d, U, V, ...) from OBS(P, T, T_d, U, V)
- "Storm-scale" data assimilation is a <u>retrieval</u> problem:
  - retrieval of the model state from mostly non-state observations
  - STATE (P, T, T_d, U, V, Qr, Qs, Qg,..) from OBS(dBZ, V_r ,Zdr, Kdp)
  - the problem is very underdetermined!
  - with ensemble data assimilation, model errors lead analysis uncertainty......
    - one can fit the observations very well
    - but retrieved <u>state</u> can be different depending on model error

Things we worry about.....

- Need an accurate mesoscale background (Dx ~ 10-20 km)
  - convective updrafts have time scales ~15 min.
  - 60 minute forecasts at least 4 eddy turnover cycles
  - getting the heterogeneities in the right place, at the right time!
- Need an accurate models at these scales
  - treatment of microphysics
  - turbulent transport of heat and momentum in lowest km
- Assimilation of radar and satellite data
  - Data QC! Data QC! DATA QC!
  - best techniques (EnKF, 3DVAR, 4DEnKF, Hybrid)
  - optimal forecasts: where uncertainty == forecast spread
- Use of NWP output by forecasters
  - forecasters remain a critical part of process
  - Longer lead times will provide opportunities to tailor warnings to various clients (hospitals, schools, sporting events, public).

With all these problems: will this work?

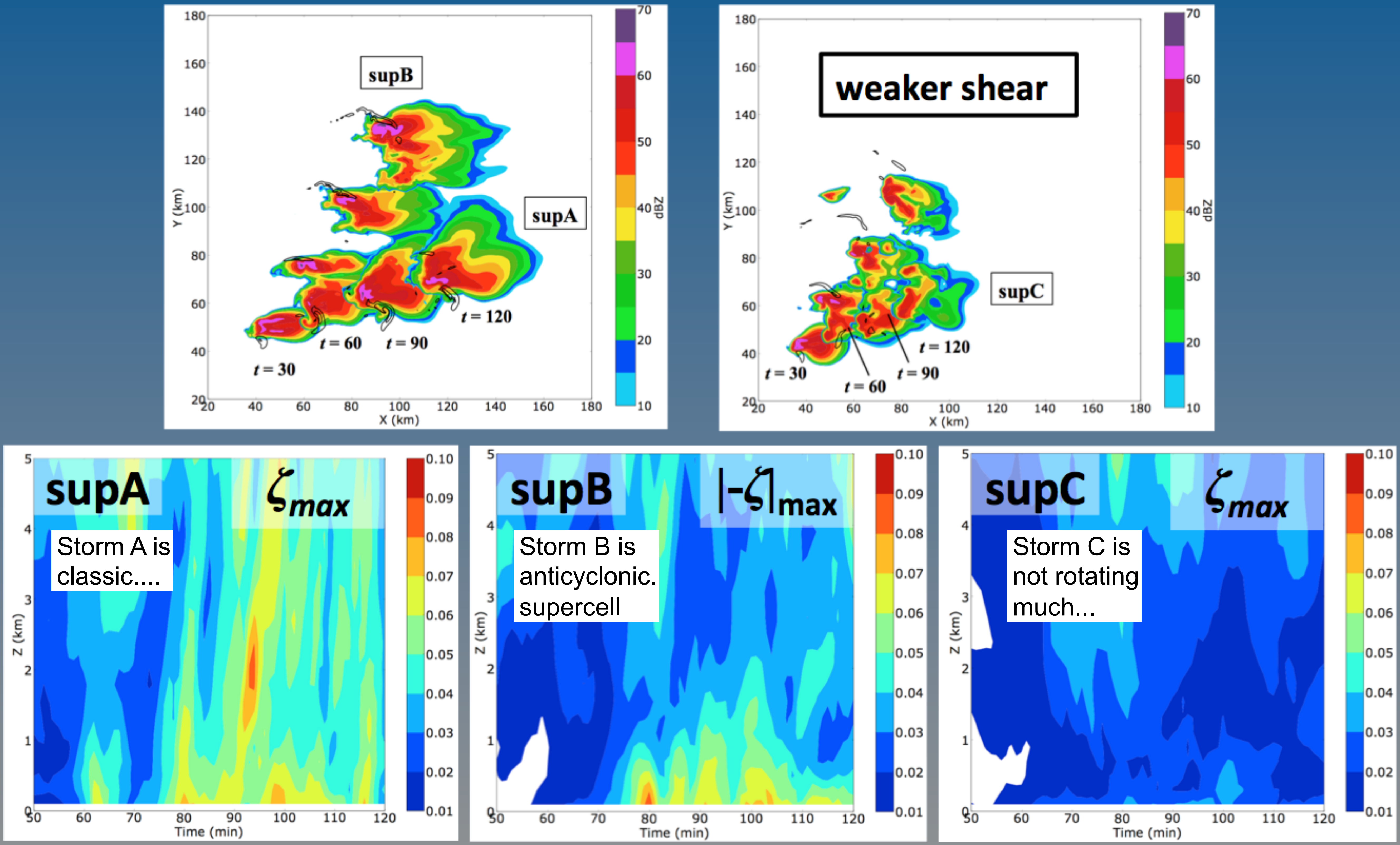
- Test ideas in simple forecast experiments
  - OSSE
  - homogeneous environments
  - perfect or in-perfect model experiments
- Can we estimate “best” possible forecasts using realistic complexity and radar locations

Predictability of Low Level Mesocyclones (LLM)

(Potvin and Wicker, *In press, Weather & Forecasting*)

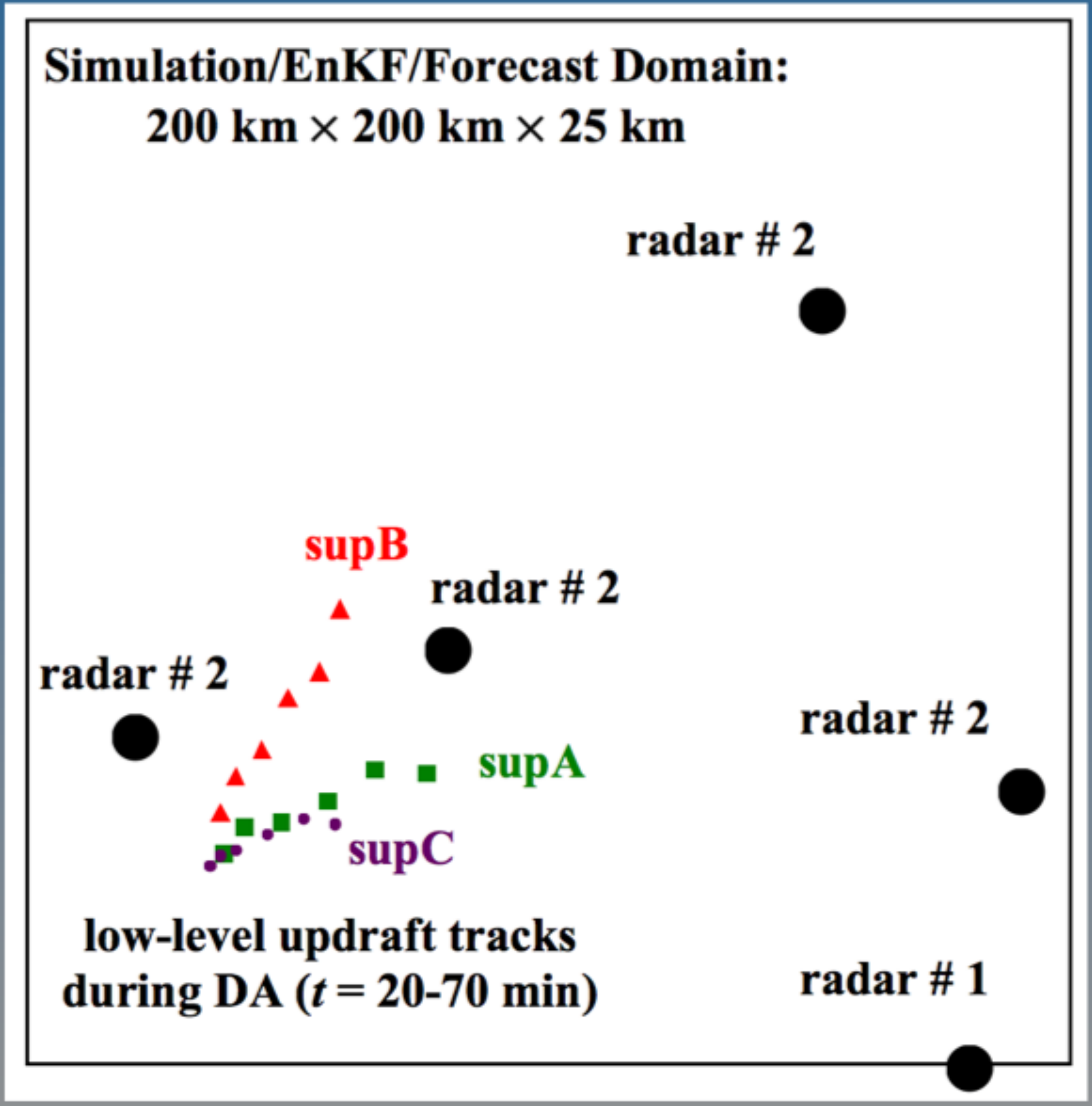
- Early WoF systems will not resolve tornadoes
- Δx = 1 km in ~5 years will partially resolve LLMs
- LLM much more likely than mid-level mesocyclone to be associated with tornadoes (Trapp et al. 2005)
- How well could early WoF systems predict LLMs?
- OSSE design
  - 3 supercells (weak, mod, strong low-level rotation)
  - assimilate using EnSRF
  - emulate WSR-88D observations and geometry

3 Supercells for our OSSE....



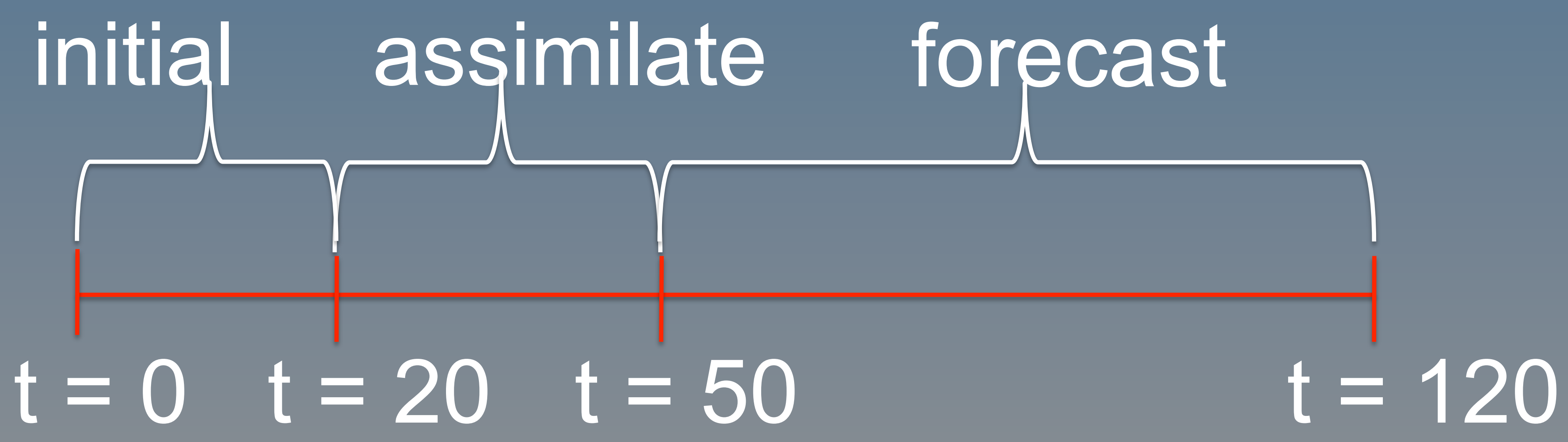
Realistic Radar Geometry and Sampling

- WSR-88D VCP-11
- Reflectivity, beam weighting
- Non-simultaneous obs
- Radar #1 fixed > 100 km away
- Radar #2 repositioned to vary radar-storm distance, cross-beam angles (CBAs)



Ensemble configuration

- Model identical to "truth" except Δ_H = 1000 m, not 333 m
- 80 members
- Perturb sounding u, v
- Additive noise through DA period
- Cook: 20 mins; assimilate: 30/50 mins; forecast: 70/50 mins



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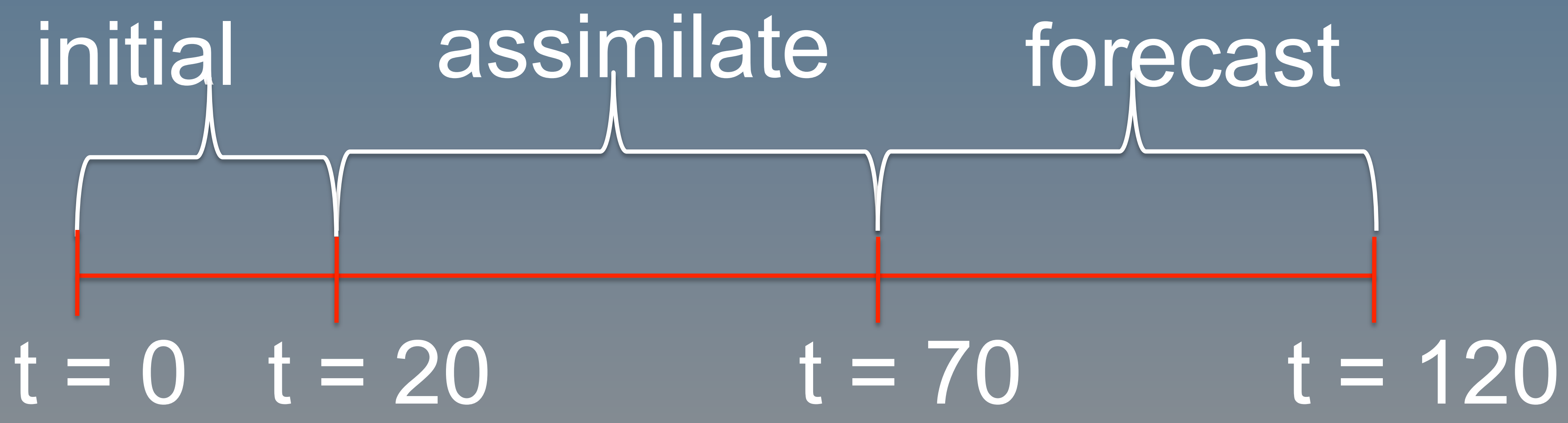
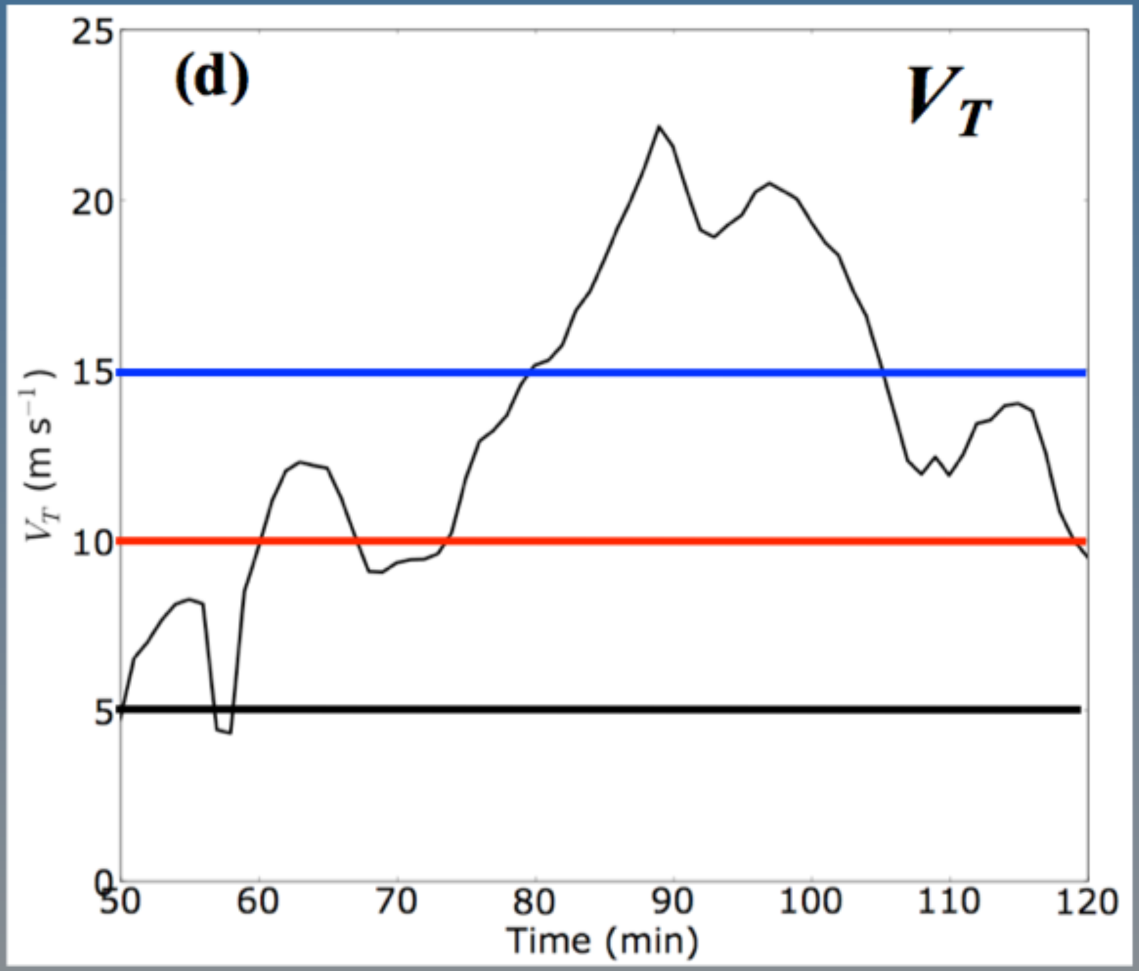


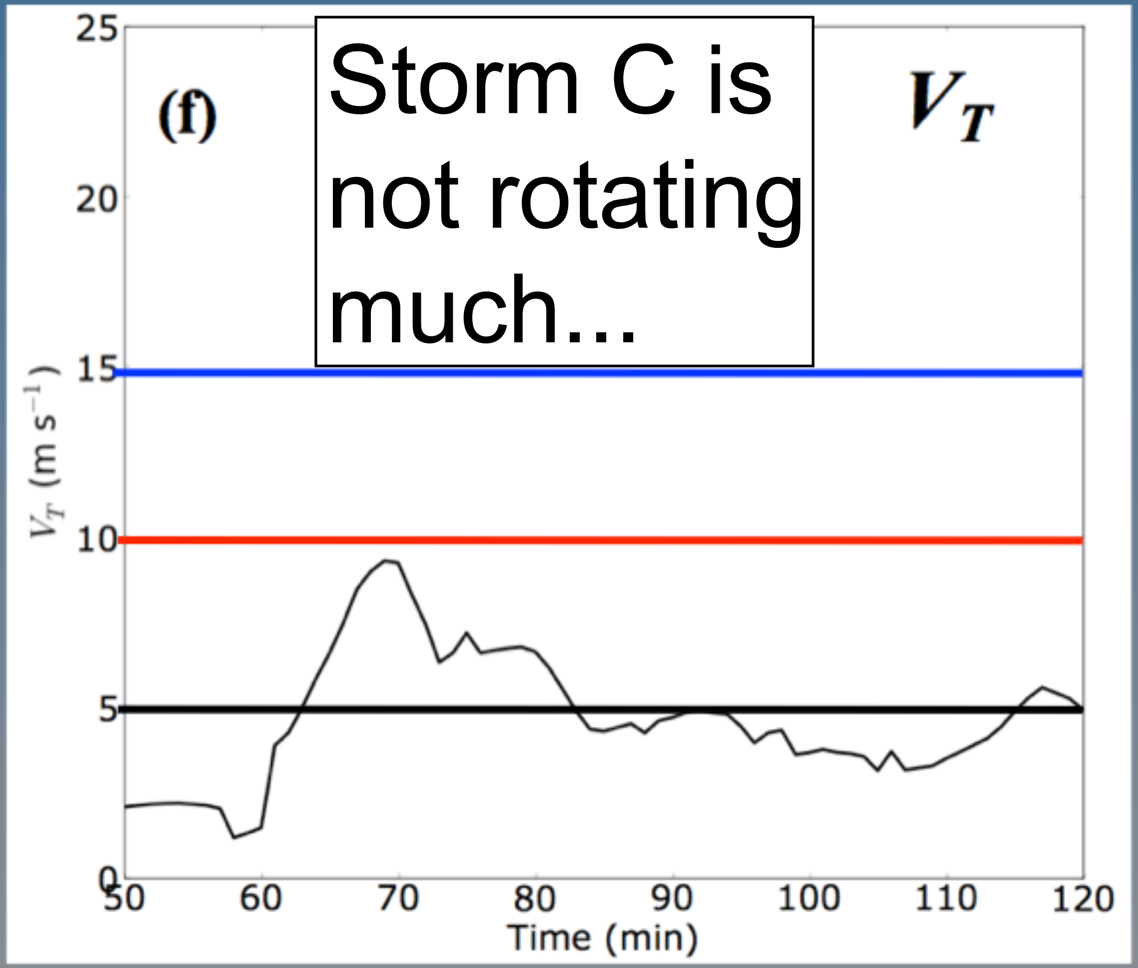
Forecast Verification

- V_T: peak azimuthal-mean vortex-maximum tangential velocity averaged over 0.5-1.5 km layer

Supercell A



Supercell C



Probablistic Rotation Swaths

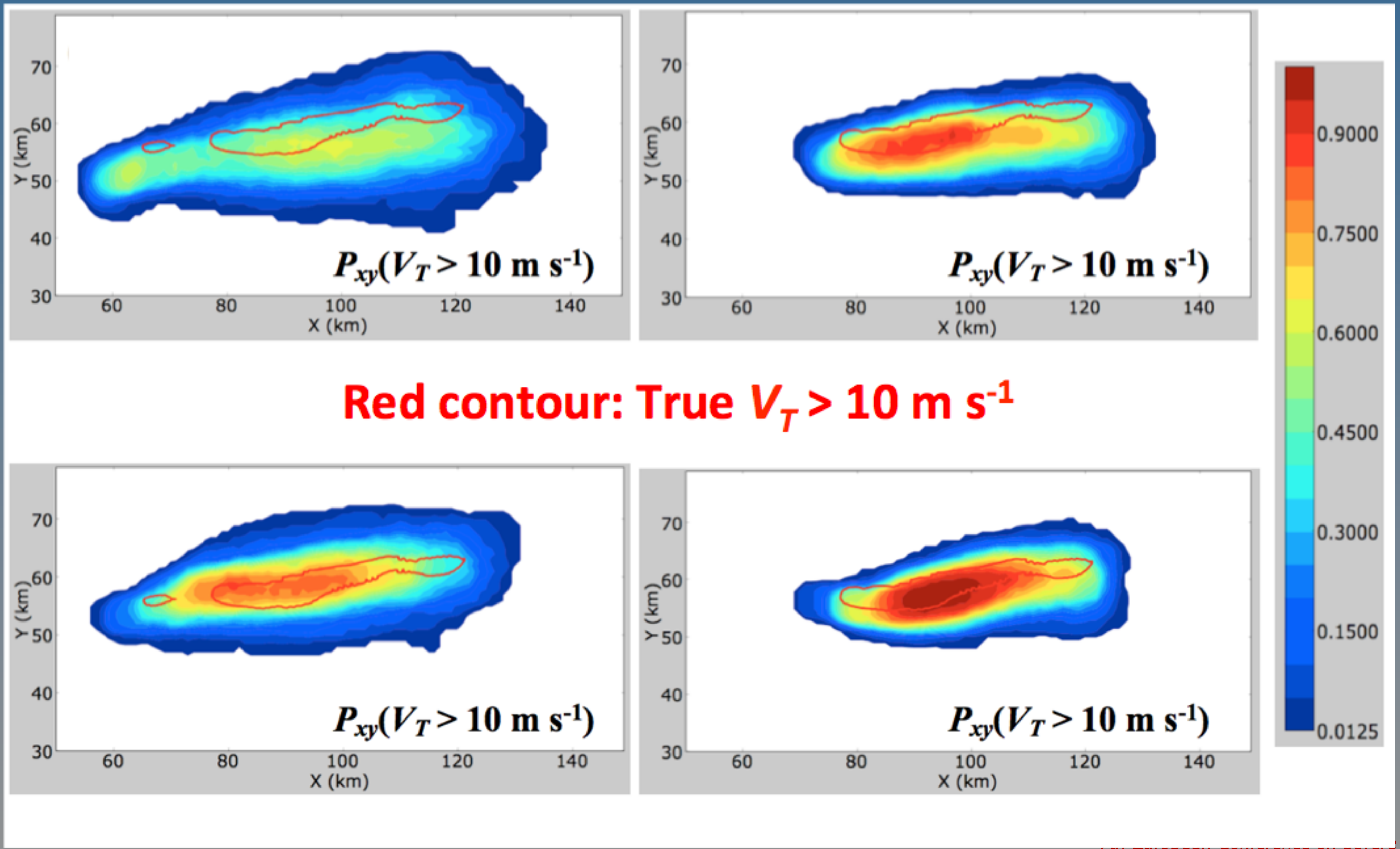
Supercell A – $P_{xy}(V_T > 10\ \mathrm{m\ s^{-1}})$

Initialized t = 50 min

Initialized t = 70 min

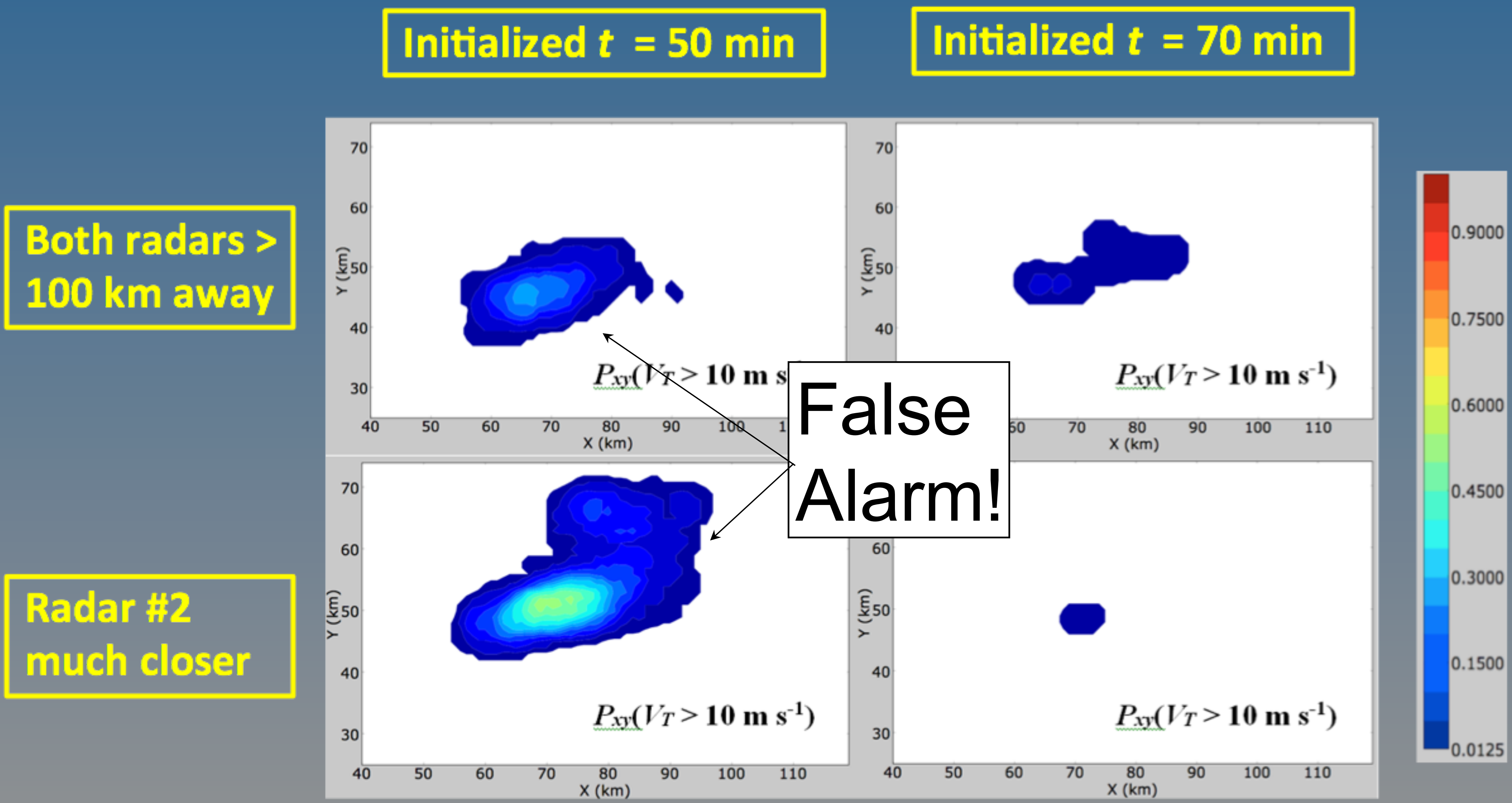
Both radars > 100 km away

Radar #2 30-50 km away



Probablistic Rotation Swaths

Supercell C – $P_{xy}(V_T > 10\ \mathrm{m\ s^{-1}})$



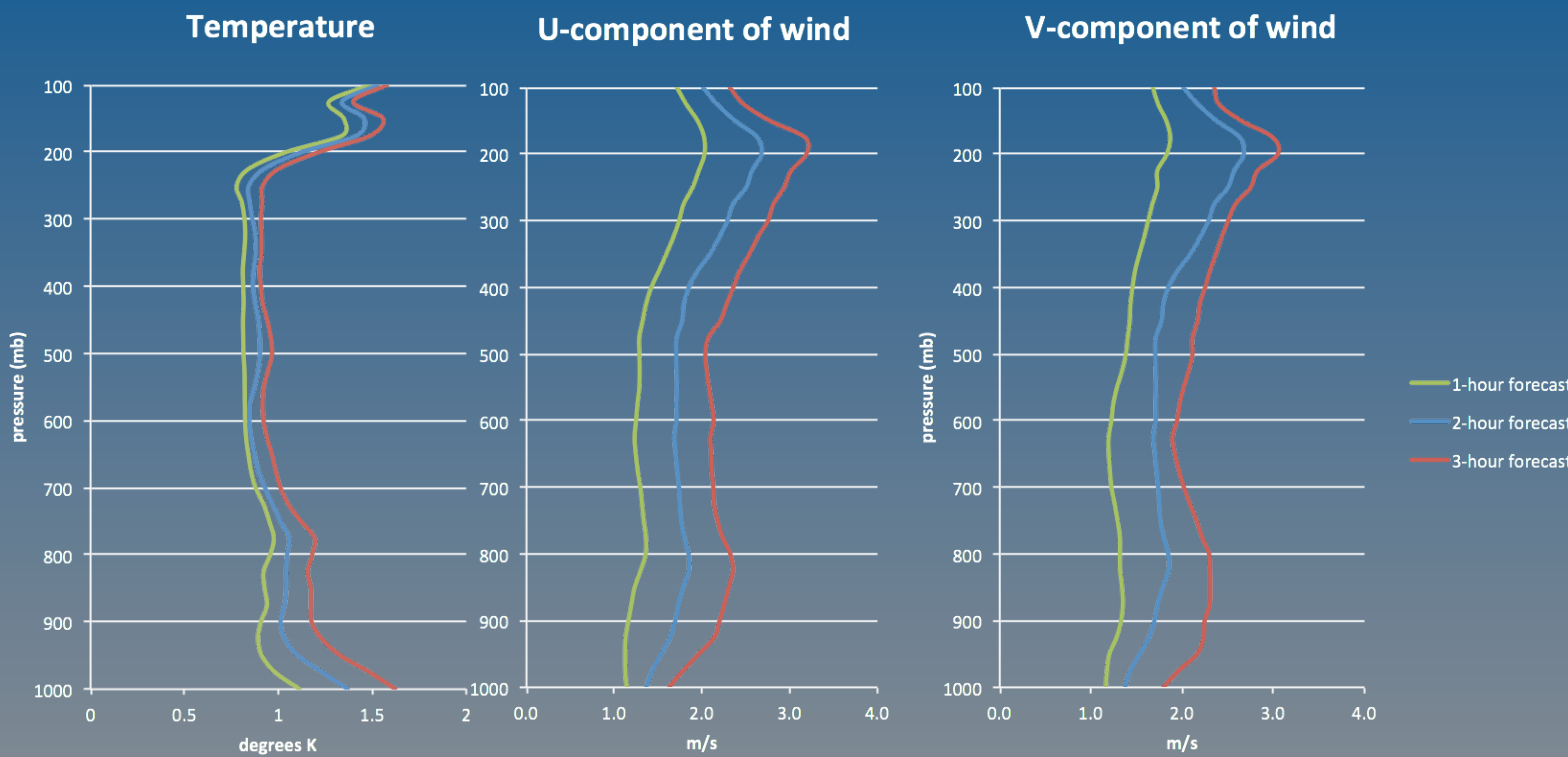
OSSE Summary

- It may be possible to predict storm “spin-up” at longer lead times than current warnings.
- Poor radar-storm geometry does not preclude useful low-level rotation forecasts
- May continue to be difficult to limit FAR
- Extra 20 mins of DA helps substantially
- More realistic OSSEs needed
  - explore impact of model error
  - environment errors
  - radar scanning strategies....

Impact from Environmental Uncertainty

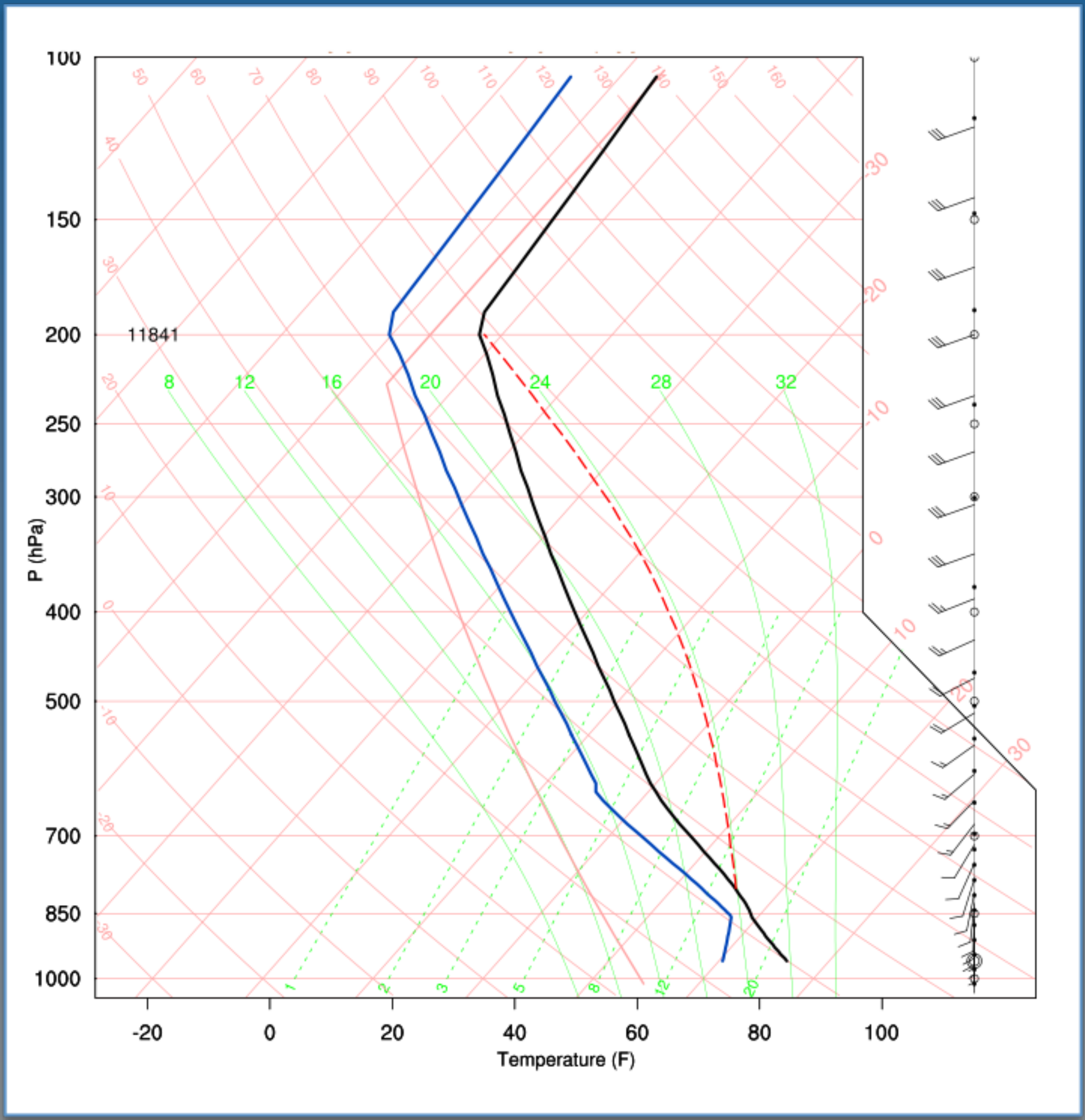
- How well do we need to know the mesoscale environment to accurately predict the 1 hour storm path?
- Cintineo and Stensrud, 2012: The predictability of supercells. *In press, J. Atmos. Sci.*
  - obtained typical forecast errors from mesoscale models soundings (U, V, T, RH)
  - generated an ensemble set of soundings based on errors
  - Using WRF model - input each sounding (a homogeneous environment) - initial convection - ensemble of supercells
  - examine the impacts from these uncertainties
  - this assumes convective scale model is perfect...

1/2/3 Hour Soundings Errors from Severe Weather Regions obtained from NCEP RUC Model



These vertical error structures are used to generate ensembles of soundings.....

Control Sounding



CAPE = 2315 Jkg^{-1}

CIN = -44 Jkg^{-1}

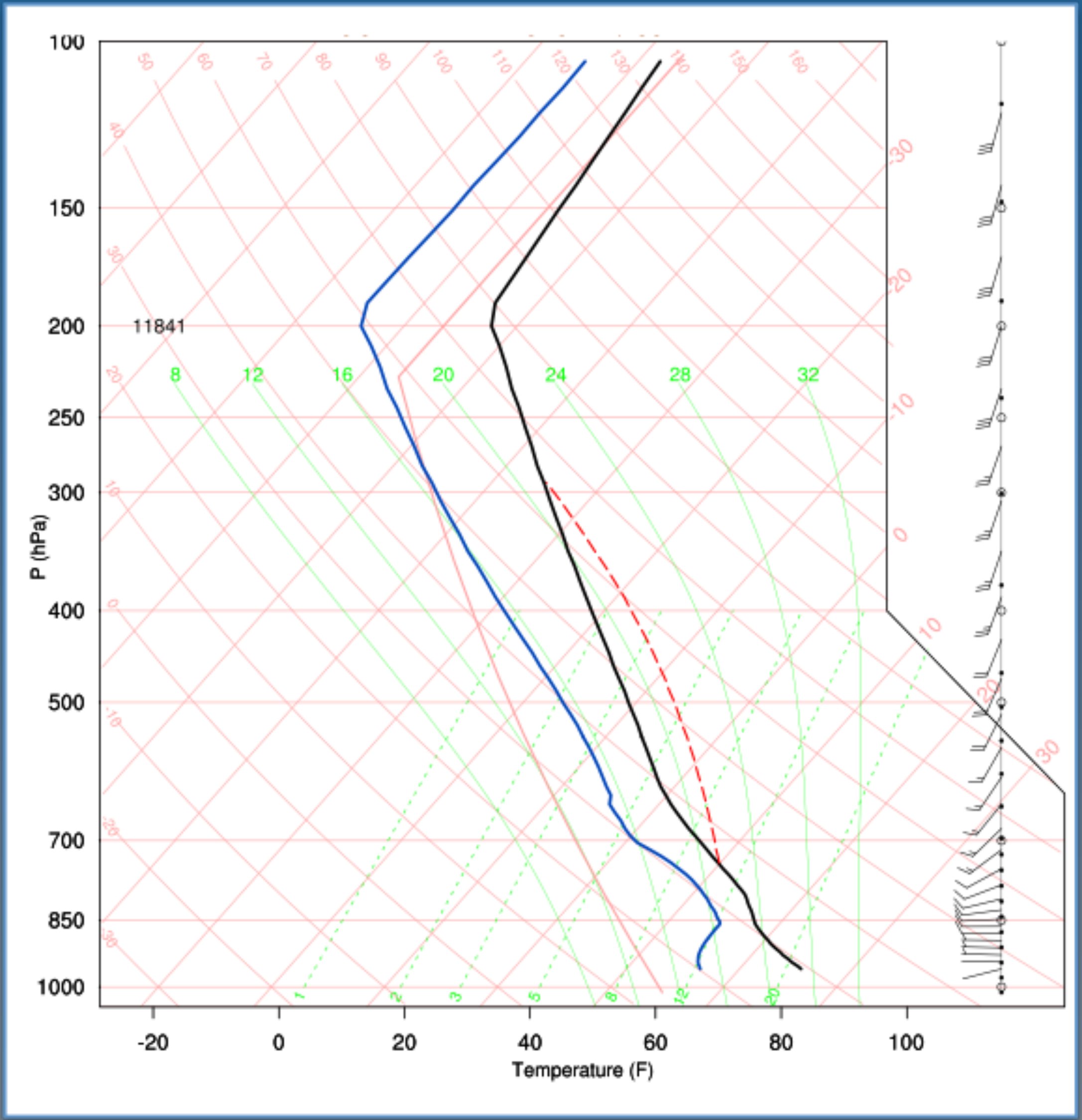
LCL pressure = 880 mb

LCL height = 741 m

0-6 km shear = 22 ms^{-1} (44 kts)

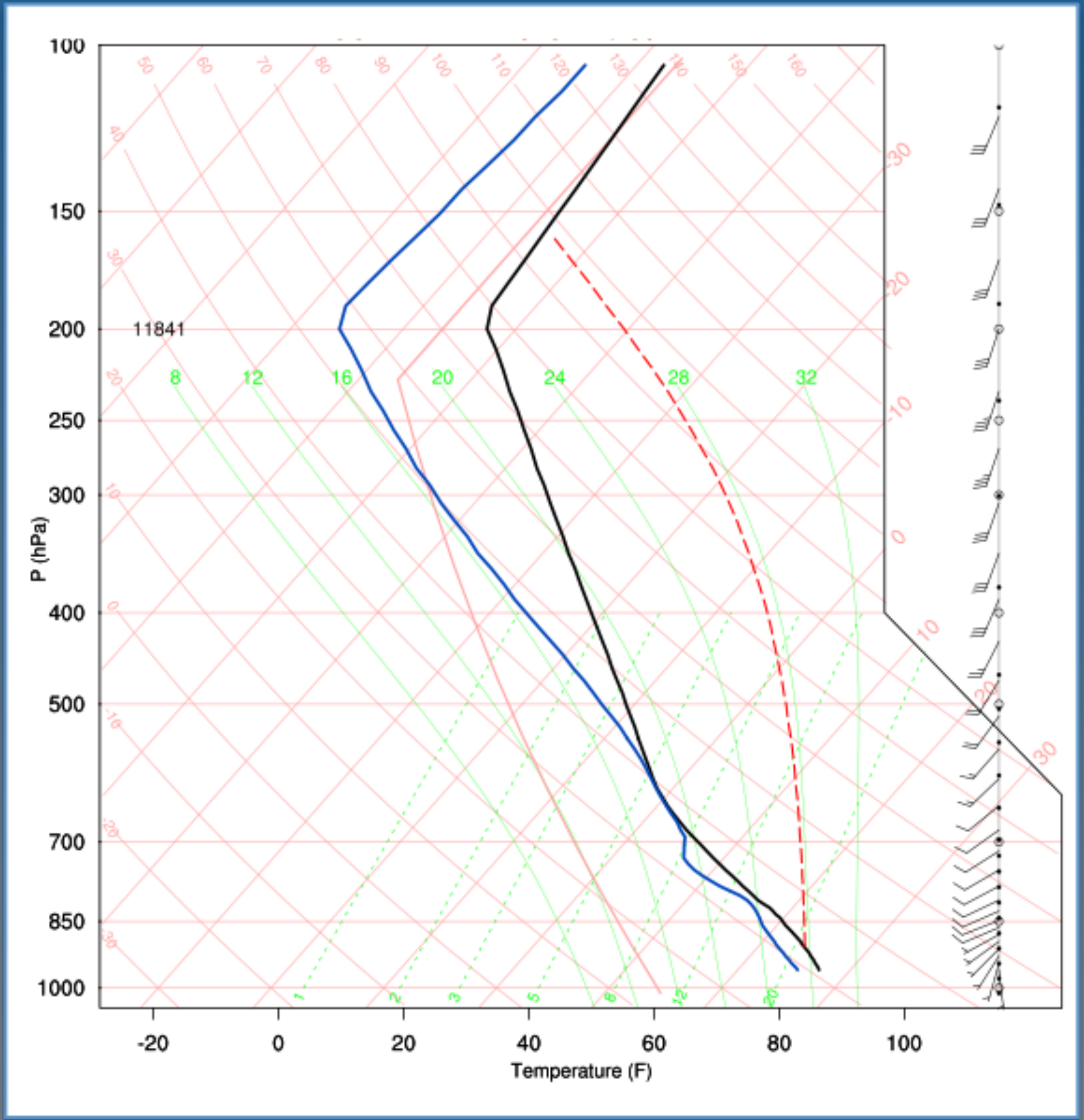
1-hr Error Perturbed Soundings - SBCAPE

mean = 2407 Jkg^{-1} standard deviation = 835 Jkg^{-1}



Minimum CAPE Sounding

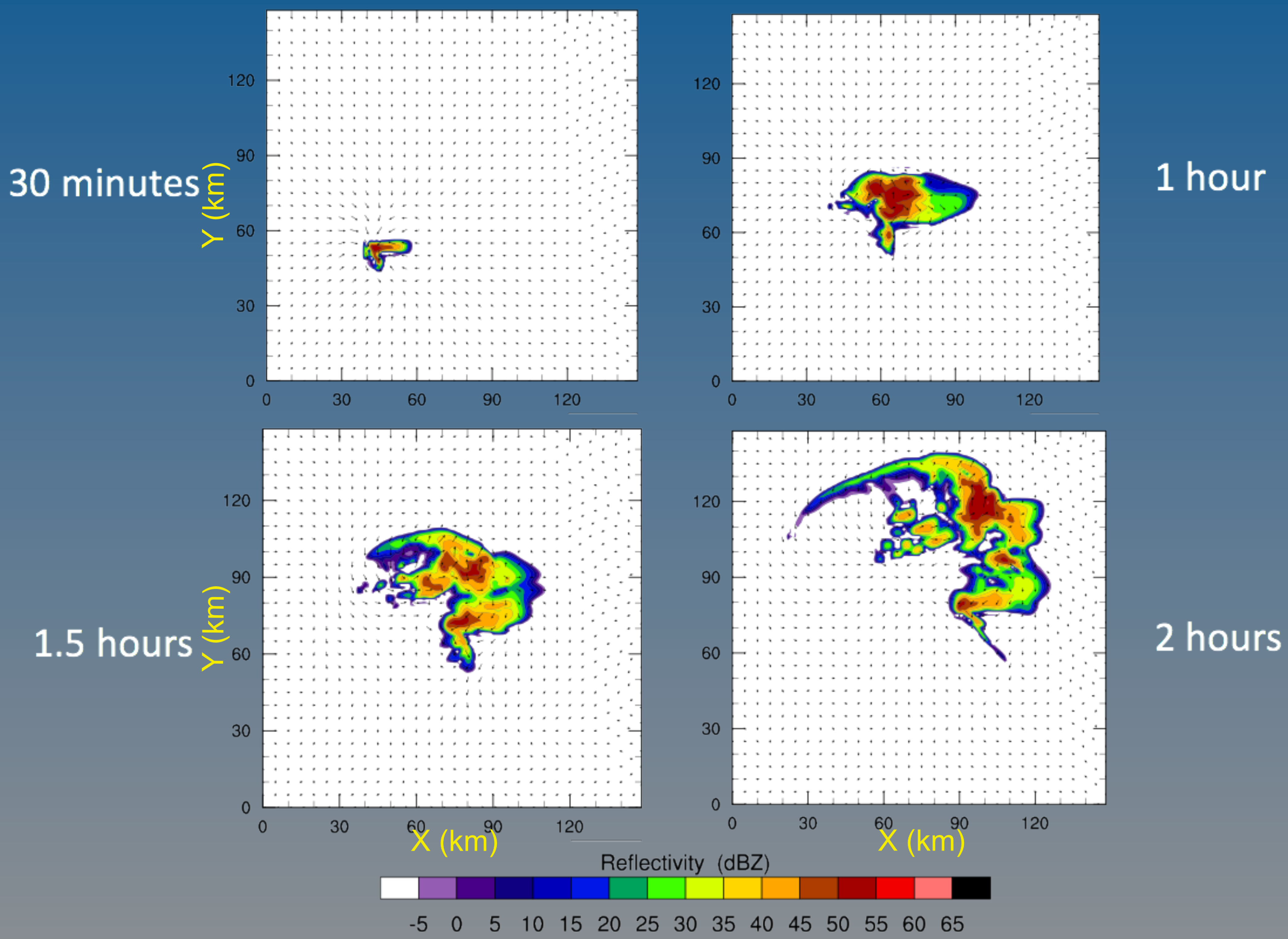
Surface Based CAPE = 780 Jkg^{-1}



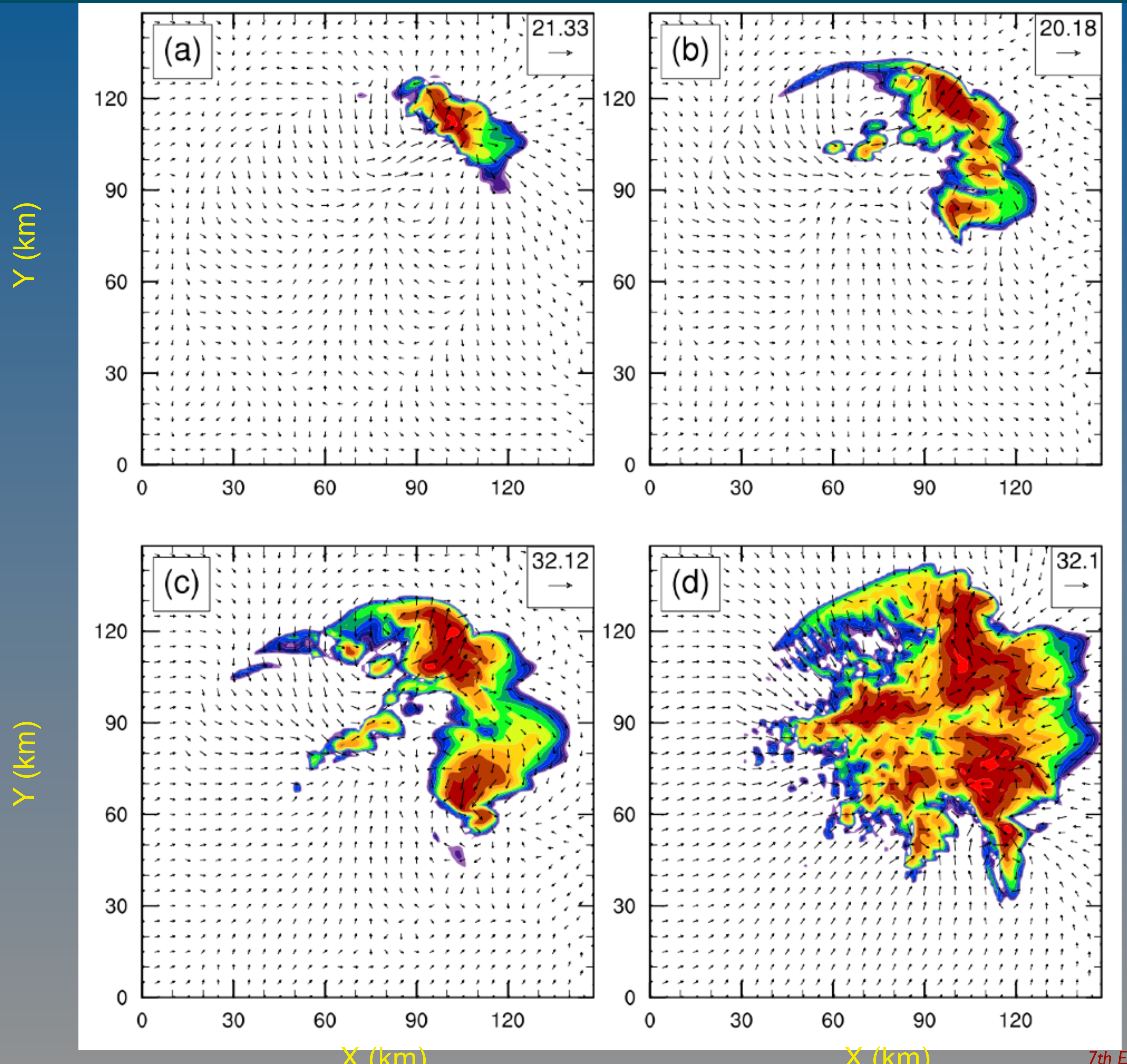
Maximum CAPE Sounding

Surface Based CAPE = 5907 Jkg^{-1}

Low Level Reflectivity from Control Run Storm



Reflectivity 1 km at 120 minutes from 4 individual ensemble members

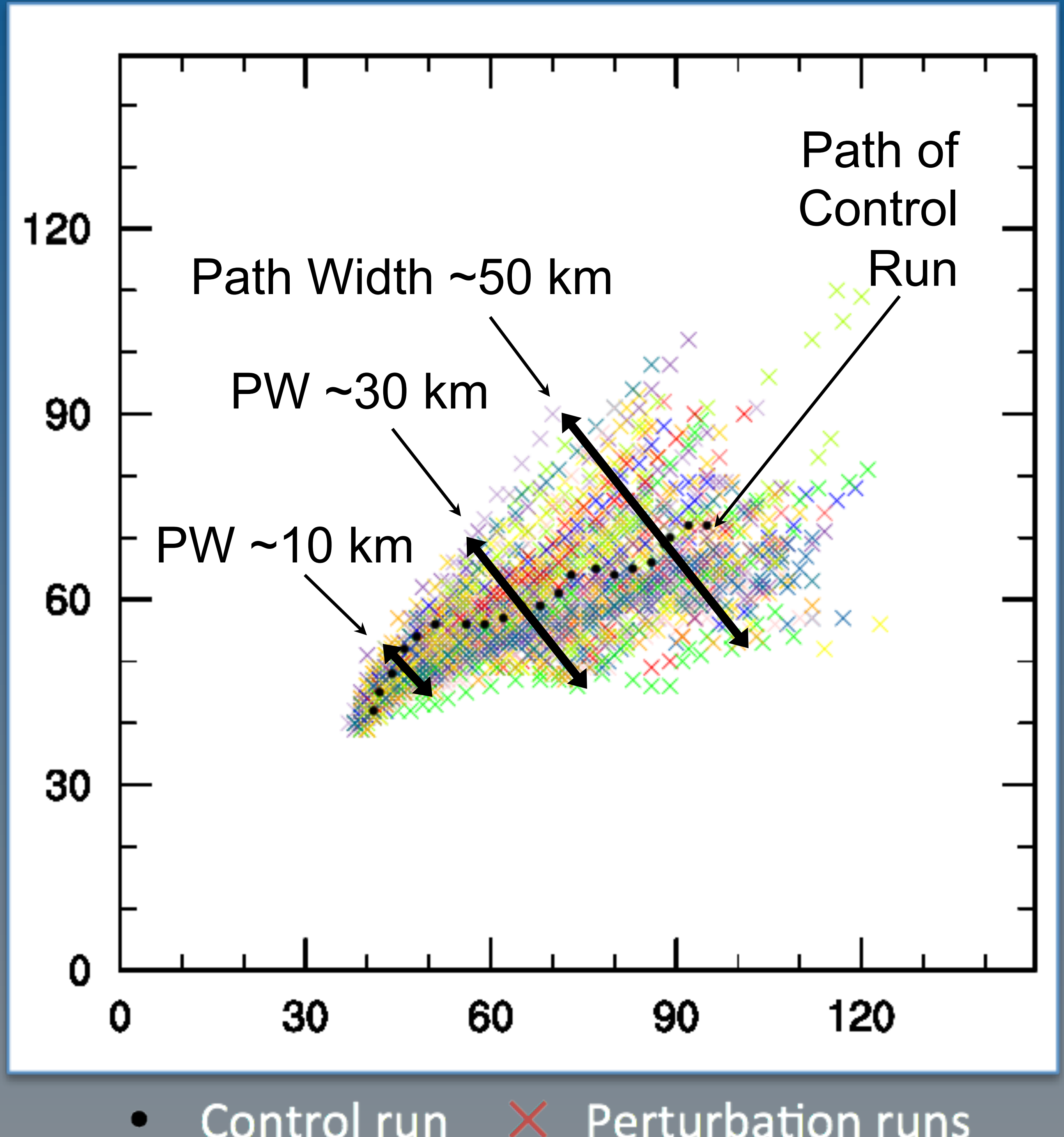


Updraft Helicity Paths

$$UH = \int_{z=2000m}^{z=5000m} w\zeta dz$$

Indicates cyclonically rotating updrafts in lower to middle troposphere

Plotted values are UH ≥ 50 m^2s^{-2}



Storm track errors from 3 hr simulations using 1-hour sounding errors

Takeway

1 hour forecast storm paths have 20-30 km spread

Real-Data Demonstration Cases

- 5 May 2007 – Greensburg KS EF-5
- 8 May 2003 – "2nd" Moore F4 tornado
- 4-5 June 2004 BAMEX severe MCS
- 27 April 2011 Alabama super outbreak
- Current cases being worked on…
  - 24 May 2011 central OK outbreak (El Reno EF-5)
  - 22 May 2011 Joplin tornado
  - 2013!

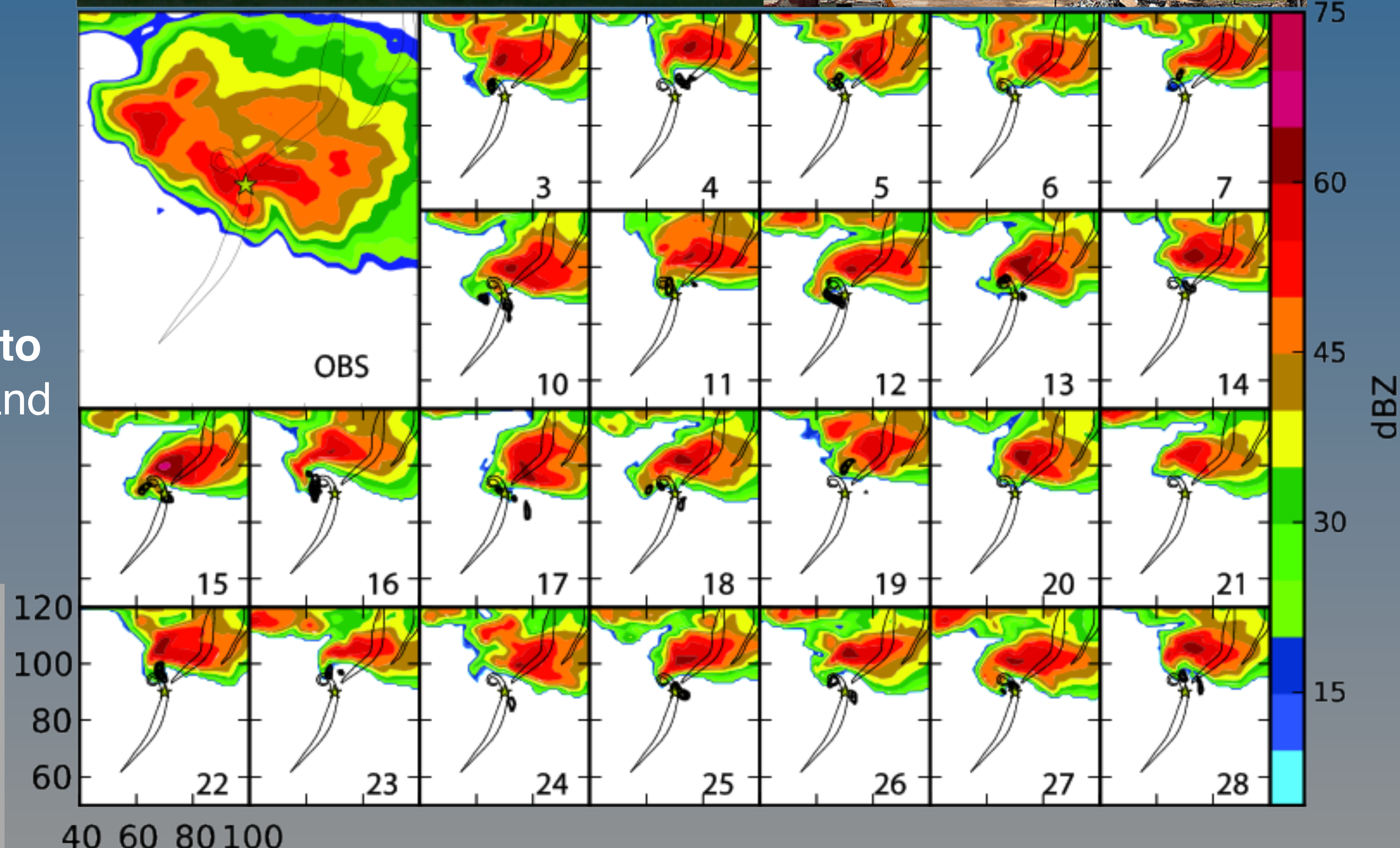
5 May 2007 Greensburg KS

- **EnKF analysis and prediction** of the EF5 tornadic storm on 5 May 2007 storm near Greensburg, KS

- **Single radar retrival** using DDC obs

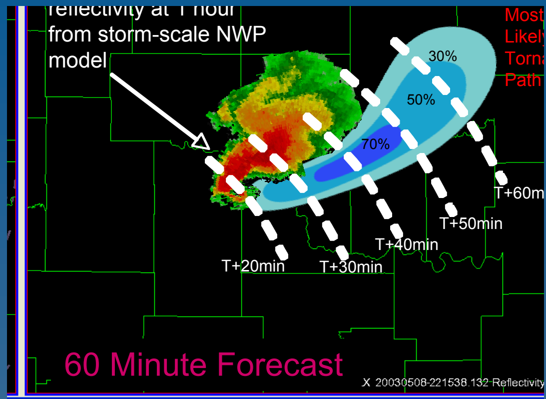
- **Homogeneous** initial environment

- Examined **sensitivity to low-level wind profile** and (to a lesser extent) microphysics



Dawson et al., 2012: Impact from the environmental wind profile on ensemble forecasts of the 4 May 2007 Greensburg tornado and its associated mesoscyclones. Mon. Wea. Rev. 140, 69

Probabilistic Vorticity Forecast



(All 9 experiments)

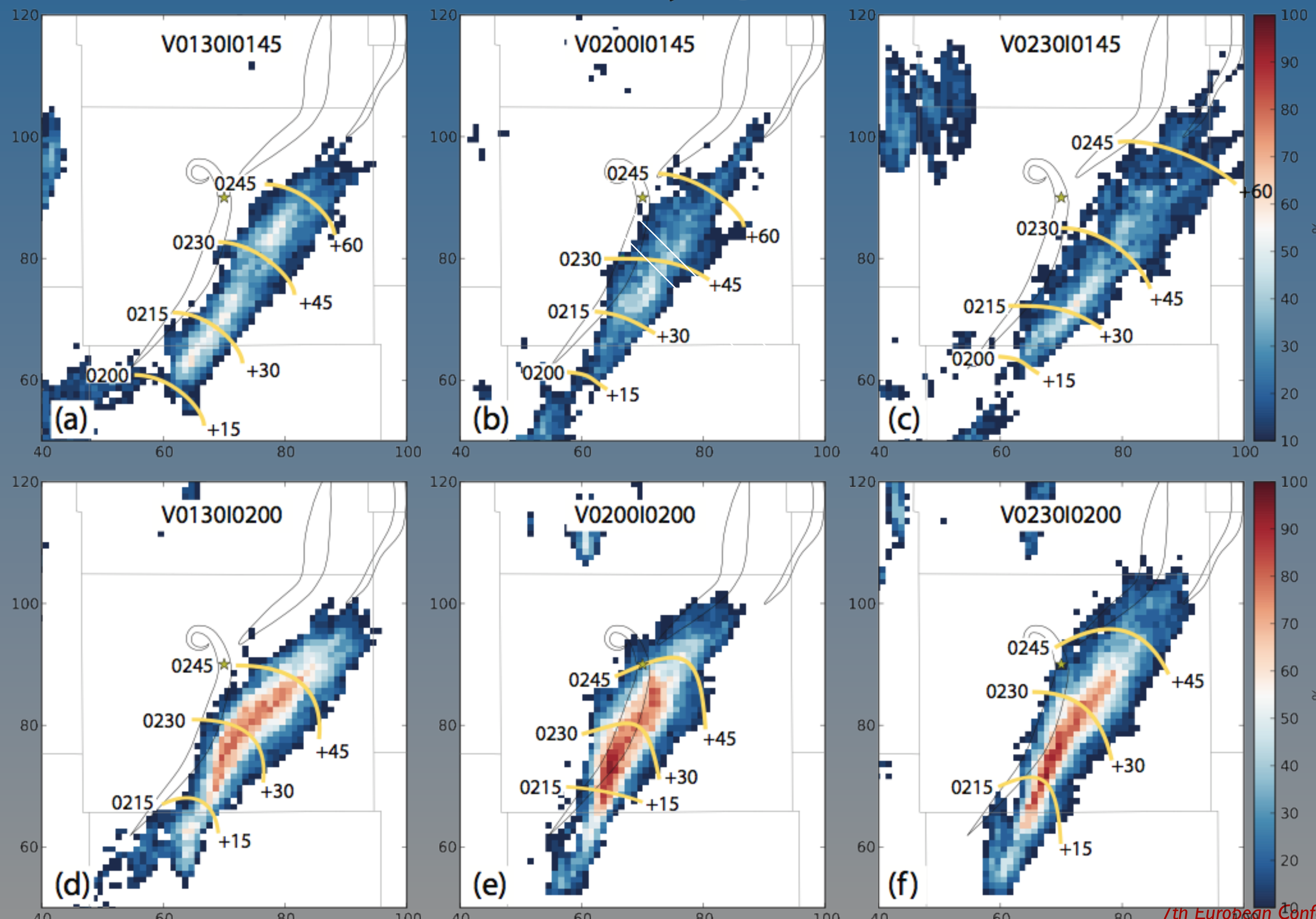
Initial Wind Profile (UTC)

0130 0200 0230

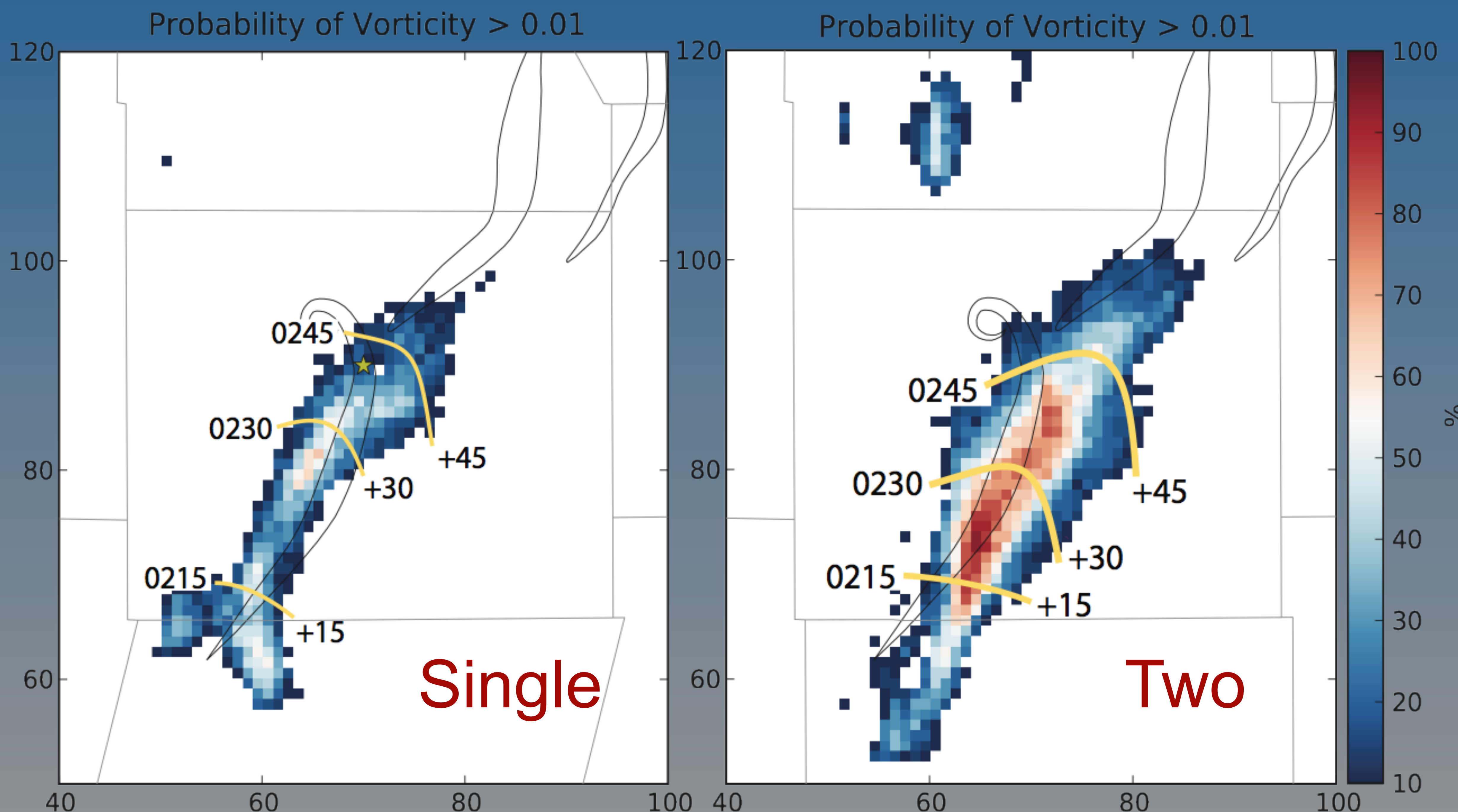
Ensemble Probability of $\zeta > 0.01\ s^{-1}$ (75 m AGL)

60 min forecasts

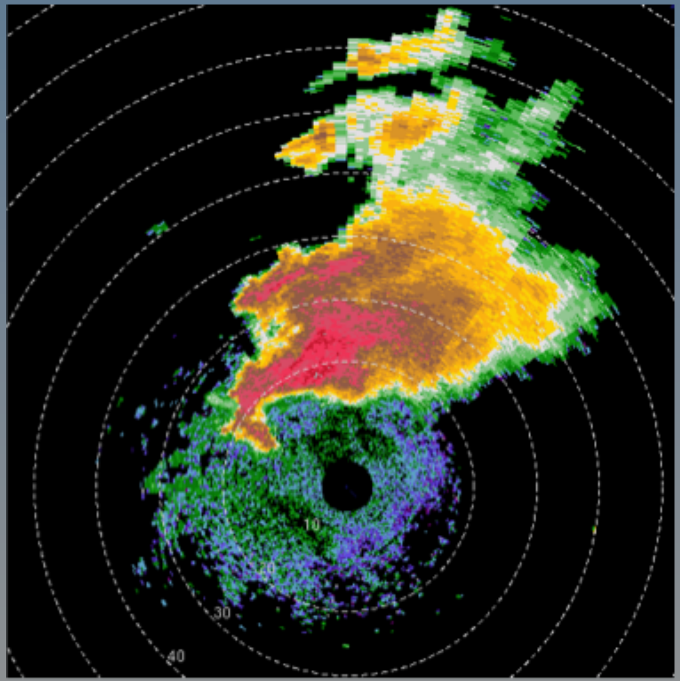
45 min forecasts

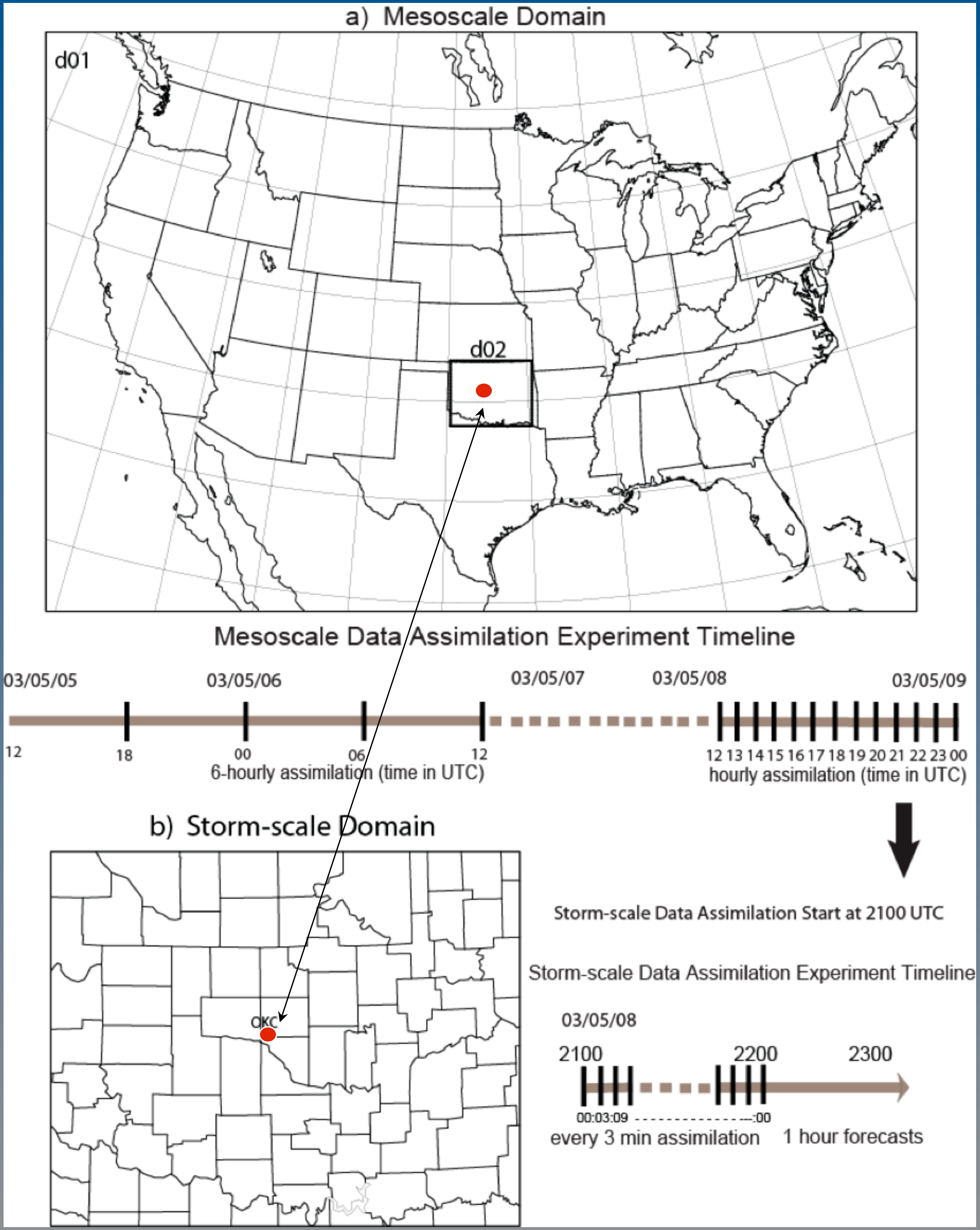


Is Microphysics Scheme Important? Greensburg KS Forecasts Single vs. Two Moment Microphysics

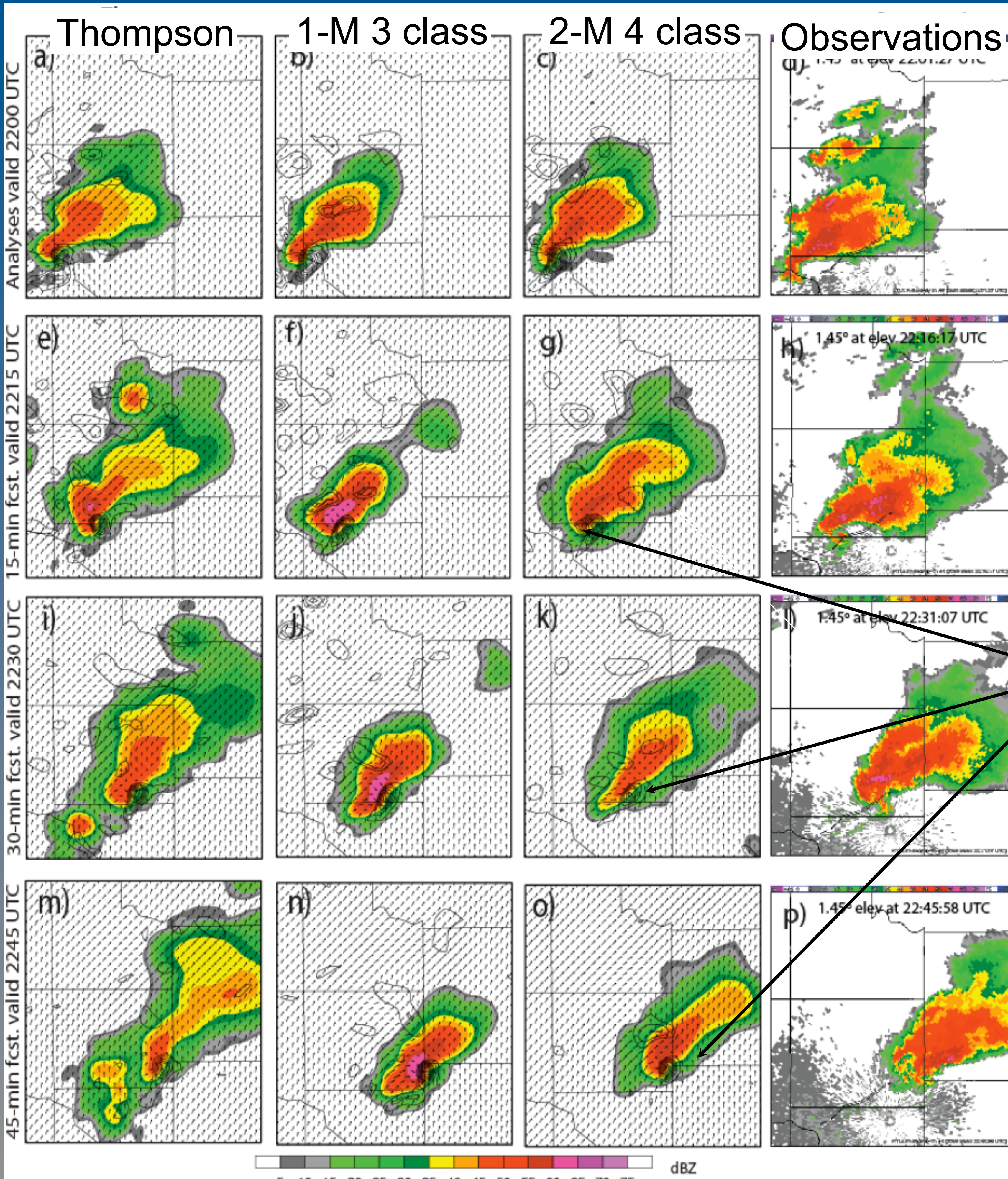


8 May 2003
Oklahoma City
Tornadic Supercell





Forecasts with 3 microphysics schemes dBZ and z @ z = 1 km



Analyses (2200 UTC)

15 min FCSTS

Contours are rotation maxima

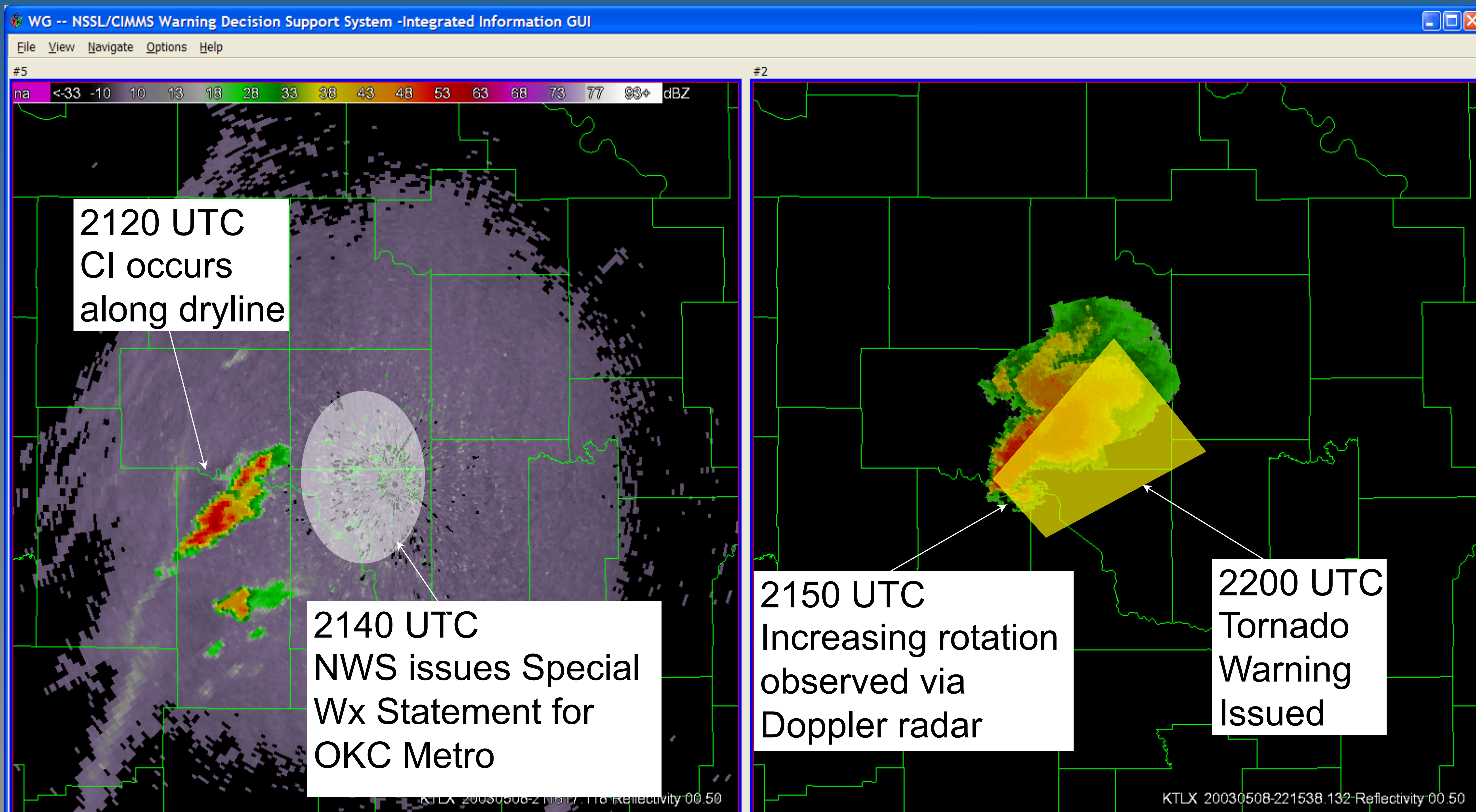
30 min FCSTS

45 min FCSTS

Summary

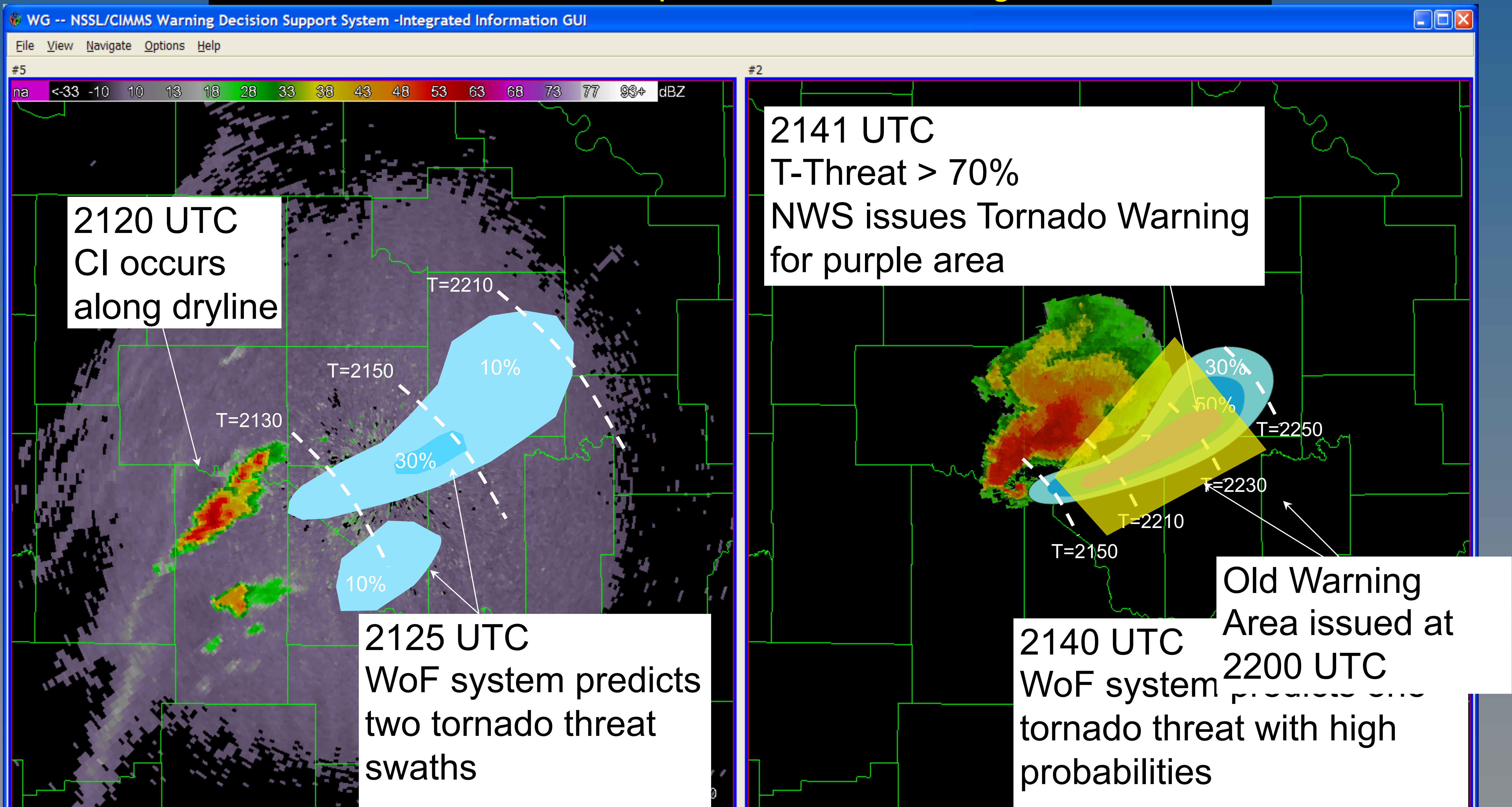
- Prediction of isolated severe convection shows promise
  - both OSSE and real-data studies demonstrate some ability to predict rotation on 30-60 minute time scale
  - Why? Getting the details right over a small area?
  - MCS's require getting the details right over a larger area...
- Challenges...
  - Real-time data QC
  - Internal and external predictability limitations for convection
  - Model error….

Tornado warning based on observations….



Tornado warnings based on NWP (~2020)

An ensemble of storm-scale NWP models predict the path of a potentially tornadic supercells during the next 40-60 min. The ensemble is used to create probabilistic tornado guidance.



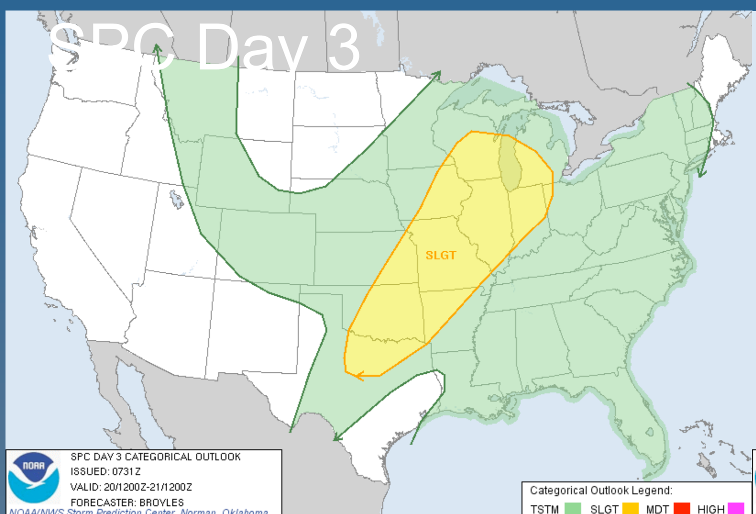
Remembering Tim Samaras and Carl Young

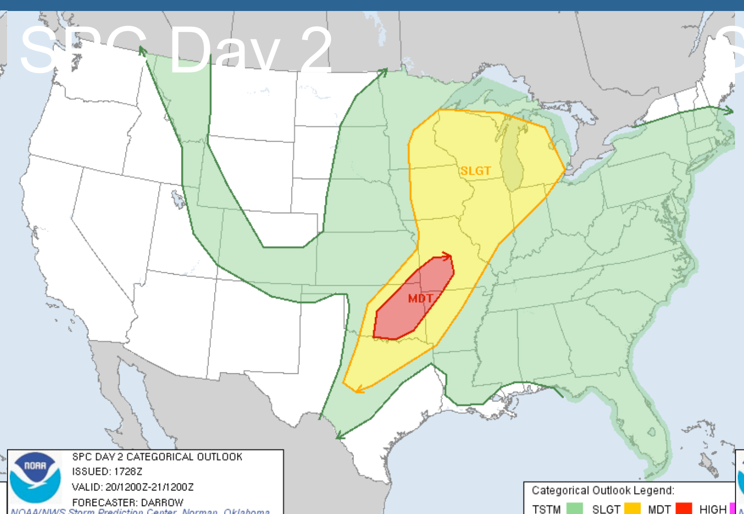
Tim

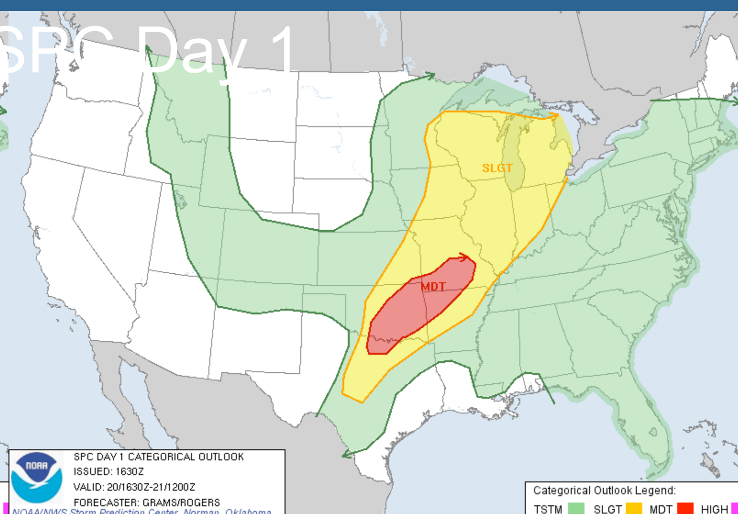
Carl

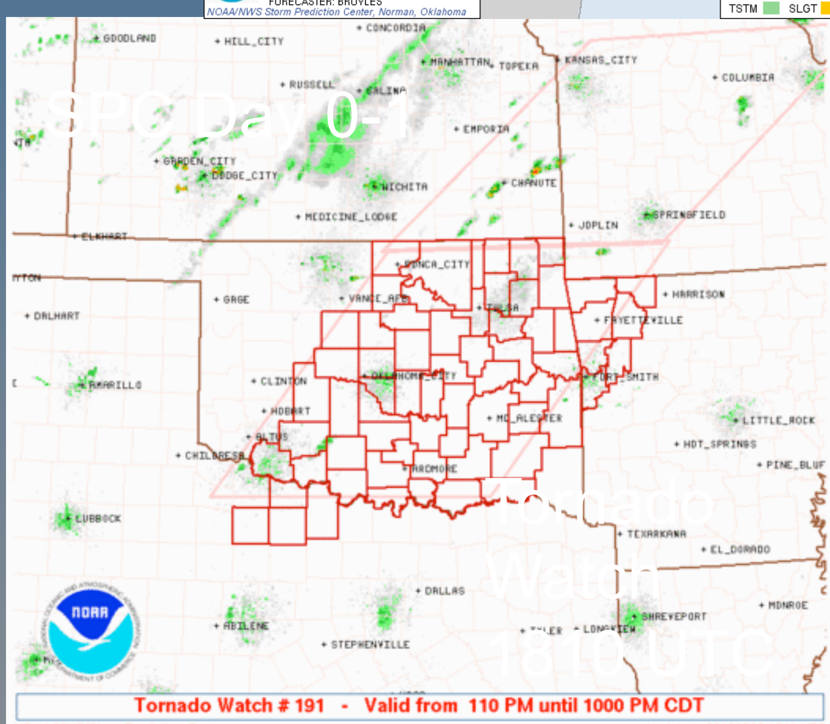
Current US Severe Weather Warning Paradigm

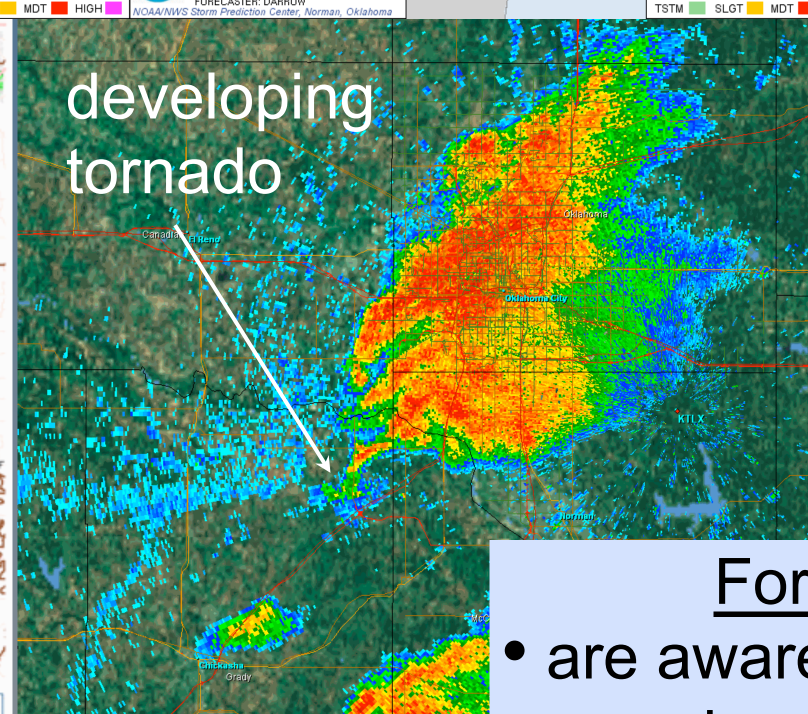
Warnings are a natural culmination of weather information generated and distributed over a period of several days...

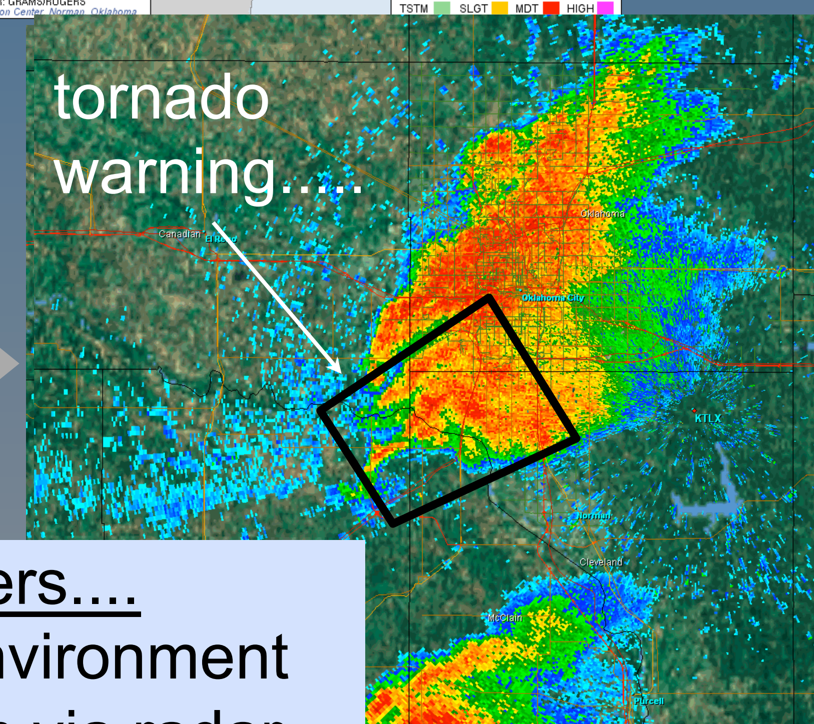












<u>Forecasters....</u>

- are aware of environment
- examines storm via radar
- sees developing rotation...
- issues warning....

Current US Severe Weather Warning Paradigm

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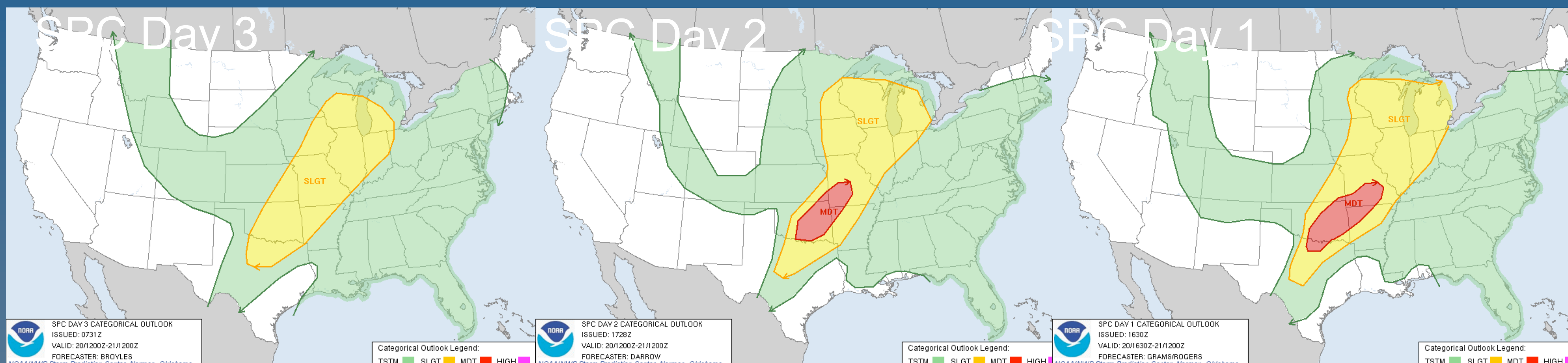

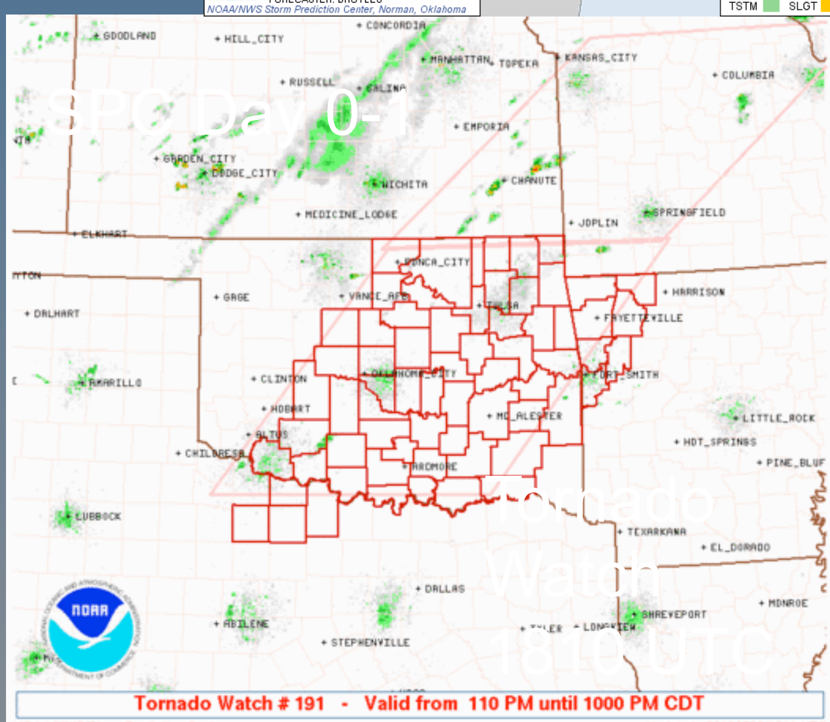

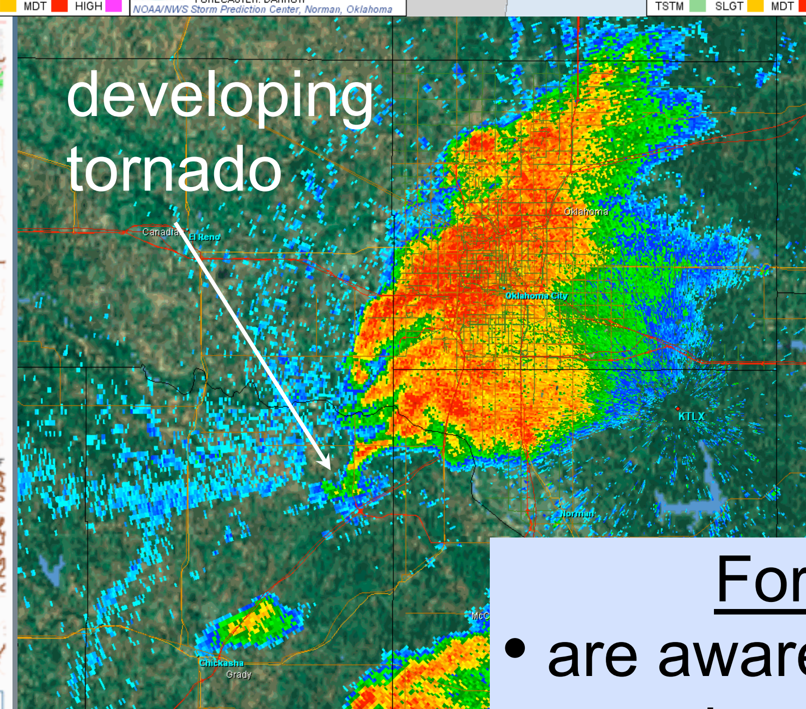

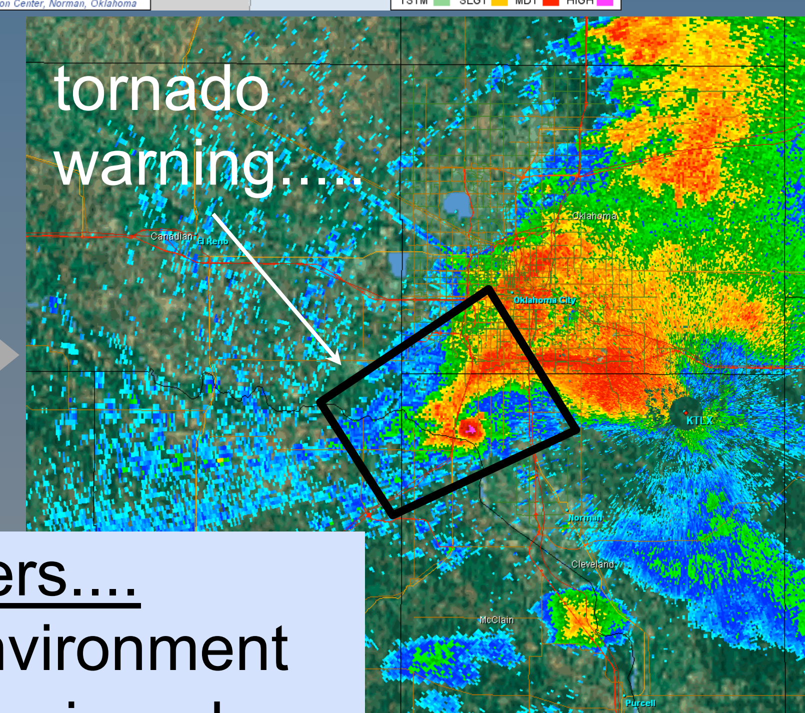

Forecasters....

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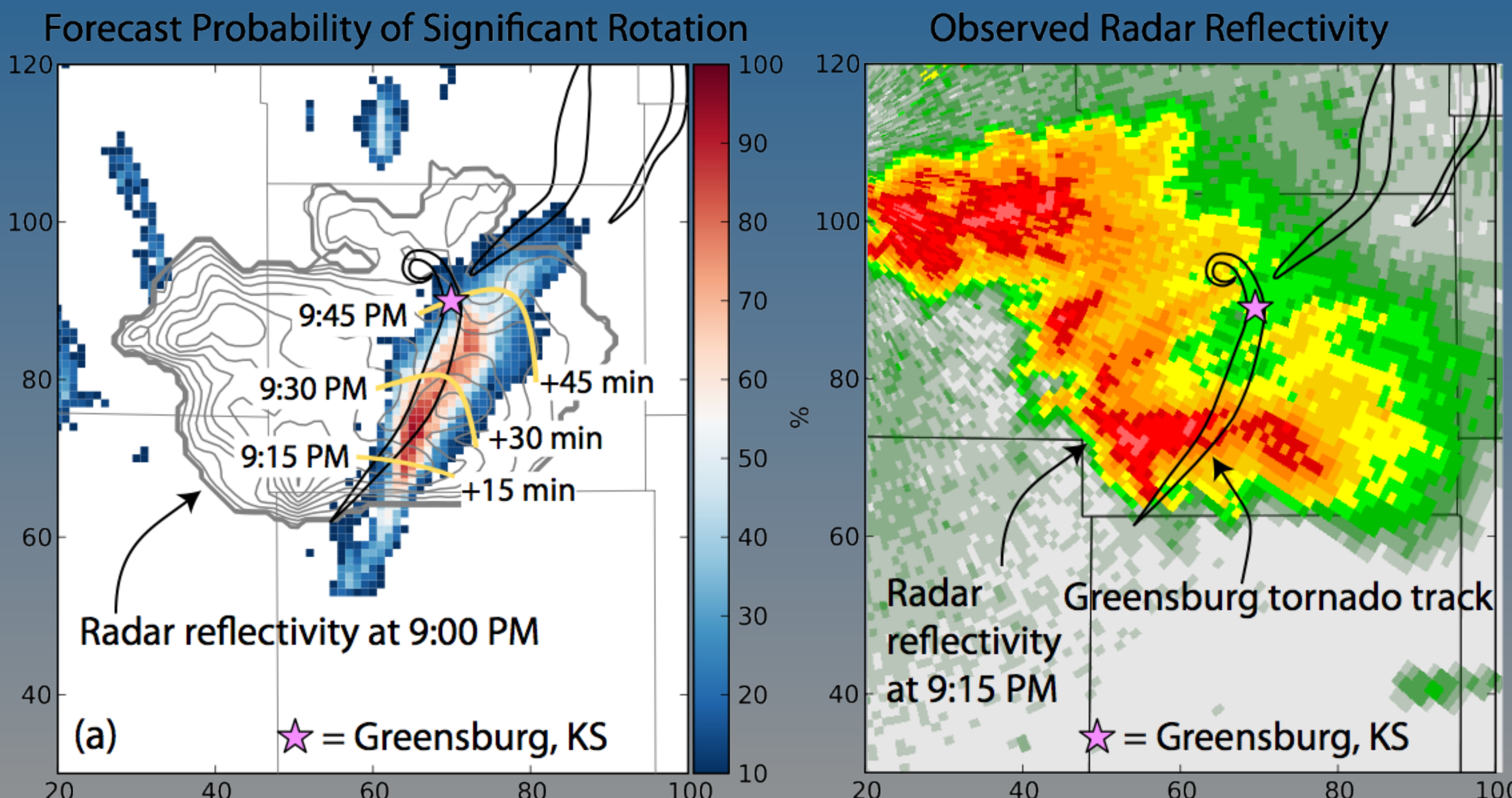
Prediction of Greensburg KS storm prediction

45 min



Forecaster Requirements for a SS-NWP system

- Fast (there when forecaster can best/most use it)
  - Forecasters will continue to use radar, WoF will have be available multiple times per hour.
  - Assimilation/forecast cycle < 10-15 min latency, 1 hour forecasts needed
- Reliable (earns forecaster trust)
  - Output needs to be calibrated and consistent across a variety of situations
  - For 30-60 min, this means at least providing threat information at our current PoD and FAR values from radar
- Effective (adds value forecaster recognizes)
  - Adds value relative to radar, satellite and other high resolution observations
  - Helps increase warning lead times (any reduction in FAR alone would present a significant advance)
- Probabilistic (communication to public from forecaster can be more precise)
  - Nature of phenomena being predicted (intermittent and highly nonlinear) requires uncertainty information
  - Future weather threat dissemination will be centered around providing uncertainty information for various users

Dual-Pol Radar Data

- In Principal:
  - Current multi-moment microphysical parameterizations (MMMP) should be able to use dual-pol radar data.
  - single moment schemes cannot be used
- Reality:
  - most MMMP have never been "tested" via the application of a forward operator and then compared to observations (for convective storms)
  - Within convection, the MMMPs do not generate the correct signatures
  - the errors are in the scheme itself, its parameters, as well as the forward operator algorithm!
- Best use of dual-pol data for a while....:
  - to tune microphysical schemes
  - to quality control the radar data
- Papers

  - Kumjian, M., and A. Ryzhkov, 2010: The Impact of Evaporation on Polarimetric Characteristics of Rain. Theoretical Model and Practical Implications, Journal of Applied Meteorology and Climatology, 49, 1247-1267.
  - Jung, Y., M. Xue, and M. Tong, 2011: Ensemble Kalman filter analyses of the 29-30 May 2004 Oklahoma tornadic thunderstorm using one-and two-moment bulk microphysics schemes. Mon. Wea. Rev.,140, 1457-1475.
  - Dawson II, D. T., E. R. Mansell, Y. Jung, L. J. Wicker, M. Kumjian, and M. Xue, 2012: Low-level Z_{dr} signatures in supercell forward flanks: The role of size sorting and melting of hail. Submitted to J. Atmos. Sci., 1 October 2012.

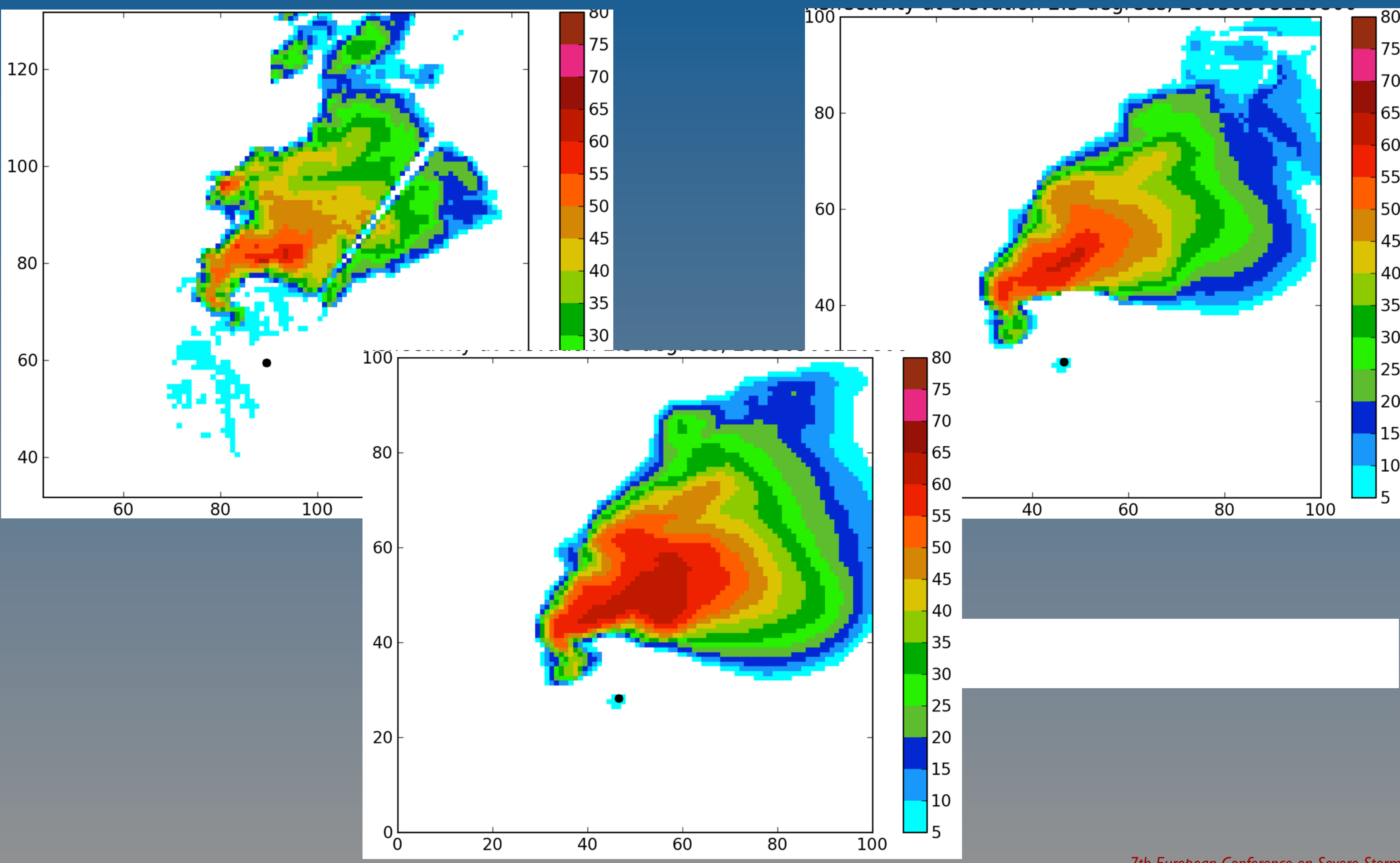
Improving Numerical Models!

Using D-Pol Data to Improve Microphysics

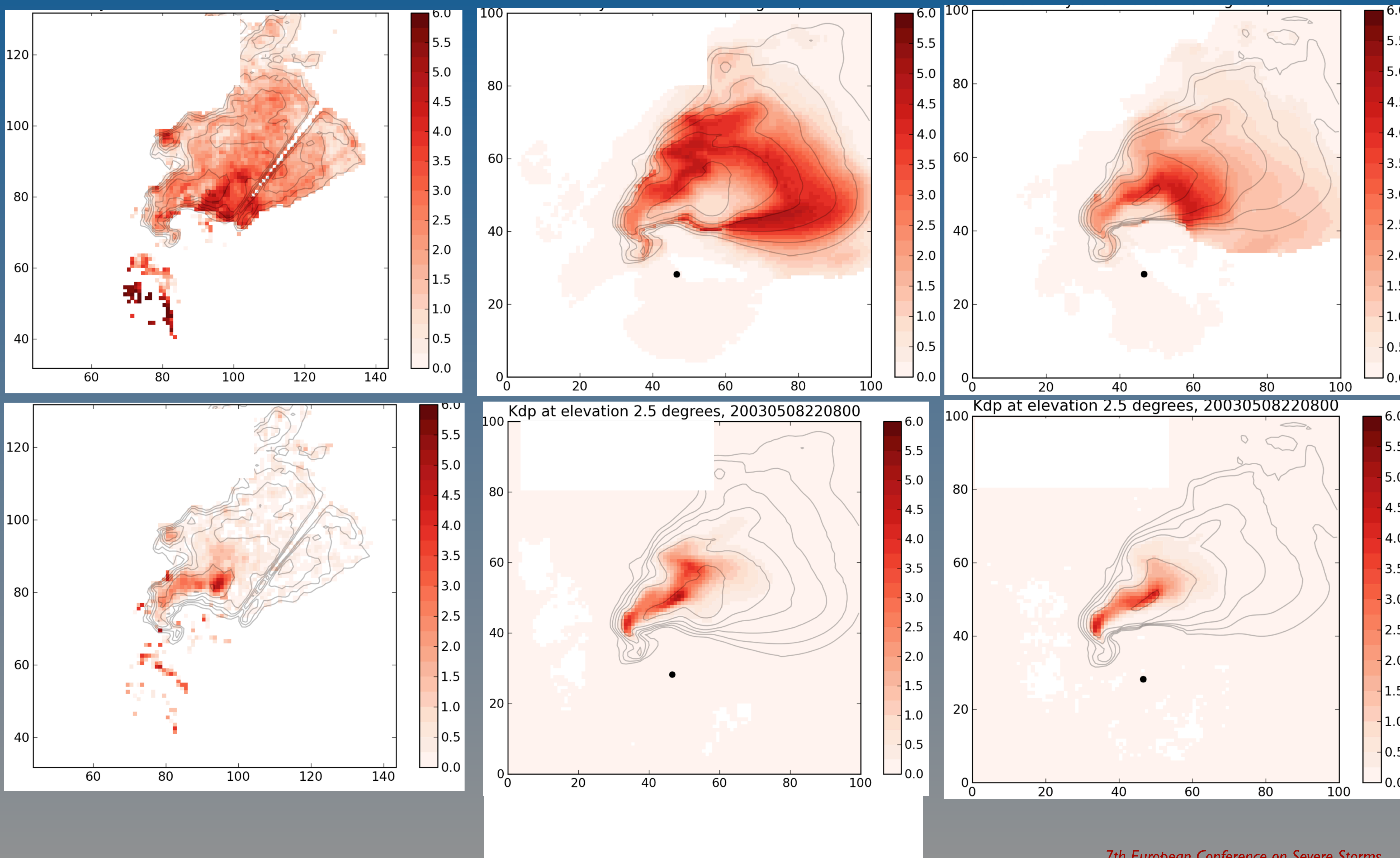
Dawson et al (2013) (submitted to special issue of Advances in Meteorology)

- Use dual-pol observations (Zdr, Kdp, RhoHV) to assess and improve microphysical parameterizations in cloud models
- The algorithm to convert model data into dual-polarimetric variables (a.ka. forward operator) is complicated
  - also microphysics scheme dependent !
- Compares the DP representation between 2-moment and 3-moment microphysical schemes
- 40 member EnKF analysis
- Real data case: 8 May 2003 OKC tornadic storm

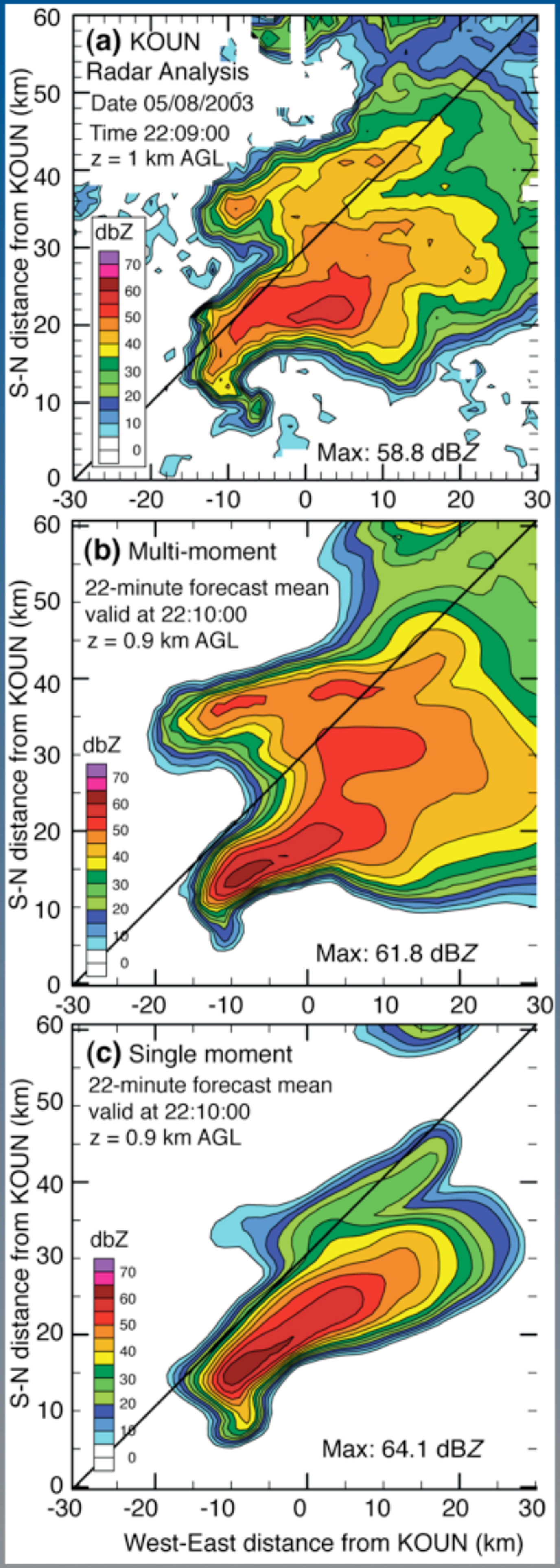
Dual-Pol Evaluation/Improvement of Microphysical Schemes (8 May 03 case)



Dual-Pol Evaluation/Improvement of Microphysical Schemes (8 May 03 case)



Microphysical Sensitivity



Observations 8 May 2003
22:10 (tornadogenesis)

22 minute ensemble mean forecast
with multi-moment microphysics
valid 22:10

22 minute ensemble mean forecast
with single-moment microphysics
valid 22:10

Predictability

"The largest obstacles in realizing the potential predictability of weather and climate are inaccurate models and insufficient observations, rather than an intrinsic limit of predictability.

In the last 30 years, most improvements in weather forecast skill have arisen due to improvements in models and assimilation techniques"

from J. Shukla, George Mason Univ., "Have we reached the limit of weather predictability?"

8 May 2003: Multiscale prediction including storm-scale WRF-DART system used for multiple scales

Mesoscale Ensemble

- 45 member WRF mesoscale ensemble at 18 km horizontal grid spacing
  over CONUS initialized from GFS
- 3 day cycling with assimilation of routinely available observations from
  metar, marine, radiosondes and ACARS using DART system
- Physics options used: MYJ, Thompson, Kain-Fritsch, Noah, Dudhia and RRTM

Storm-scale Ensemble

- 45 member storm-scale ensemble nested down from
the 45 member mesoscale ensemble data system
- 2-km horizontal grid spacing, 225 x 180 x 50 grid points
- Assimilates KTLX radar radial velocity and reflectivity observations every 3-min for a one-hour period
- Test multi-moment vs single moment microphysics