# Welcome to the

## Technical Workshop on Numerical Guidance to Support NWS Warn-On-Forecast Capability

# Agenda for Tuesday

Session 1:  Warn-on-Forecast Vision and Customer Expectations

Session 2:  EMC needs and Expectations

**Lunch**

Session 3:  Warn-on-Forecast: CAPS Experiences and Challenges

Session 4: Warn-on-Forecast: New Observing Systems

Session 5: Discussion: WoF Vision and Requirements

***! ICE BREAKER !***

# Special Thanks

Linda McGuckin, NSSL

Tonia Rollins, NSSL

Dan Miles, NSSL

Session chairs: Ken Howard, Steve Goodman, Bill Lapenta

Discussion Moderator: Bill Lapenta and Steve Koch

# WiFi Access

"OUGuest"

# NSSL's WoF Project

**Lou Wicker**
**NSSL**

# NSSL's WoF Project

**Lou Wicker**
**NSSL**

Thanks to
Warn-on-Forecast partners
for their hard work and dedication!

# Talk Outline

- What is Warn on Forecast?
- WoF vision and evolution?
- Current research achievements
- Forecast/customer for an operational WoF-TTP system
- Challenges
- Components of a future system
    - Data requirements
    - Modeling systems and resolution requirements
    - Data assimilation
    - Initial testing

# What is Warn on Forecast?

# What is Warn on Forecast?

- **Why is this important?**

# What is Warn on Forecast?

- **Why is this important?**
  - WoF’s definition has broadened since first proposed by NSSL in 2008 within NOAA

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.
- **First:  Warn on Forecast is a concept:**

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.
- **First: Warn on Forecast is a <u>concept</u>:**
  - Use of state-of-the-art high-resolution numerical prediction models to warn the public of various weather threats.

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.
- **First: Warn on Forecast is a concept:**
  - Use of state-of-the-art high-resolution numerical prediction models to warn the public of various weather threats.
  - These include tornadoes, QPF, flash floods, lightning, fire, downbursts, severe winds, etc.

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.
- **First: Warn on Forecast is a <u>concept</u>:**
  - Use of state-of-the-art high-resolution numerical prediction models to warn the public of various weather threats.
  - These include tornadoes, QPF, flash floods, lightning, fire, downbursts, severe winds, etc.
  - WoF will be a set of enabling technologies for **FACETS** on a variety of space and time scales.

# What is Warn on Forecast?

- **Why is this important?**
  - WoF's definition has broadened since first proposed by NSSL in 2008 within NOAA
  - Some confusion as to what NSSL's program is and its deliverables.
- **First:  Warn on Forecast is a concept:**
  - Use of state-of-the-art high-resolution numerical prediction models to warn the public of various weather threats.
  - These include tornadoes, QPF, flash floods, lightning, fire, downbursts, severe winds, etc.
  - WoF will be a set of enabling technologies for **FACETS** on a variety of space and time scales.

**What is FACETS?**

Forecasting a Continuum

# FACETs

of Environmental Threats

**Thursday morning talk!**

**Idea: Coalesce the disparate watch and warning activities into a single vision for a new threat forecasting paradigm that is…**

- ***Modern***
- ***Effective***
- ***Scientifically robust***
- ***Holistic***
- ***Unifying***


Thursday morning talk!

Idea: Coalesce the disparate watch and warning activities into a single vision for a new threat forecasting paradigm that is…

- *Modern*
- *Effective*
- *Scientifically robust*
- *Holistic*
- *Unifying*

Lans Rothfusz

# What is Warn on Forecast?

# What is Warn on Forecast?

- **Second:  Warn on Forecast is a NOAA/OAR research project!**

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***
  - WoF Tornado Threat Prediction: WoF-TTP

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***
  - WoF Tornado Threat Prediction: WoF-TTP
- WoF-TTP will attempt to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***
  - WoF Tornado Threat Prediction: WoF-TTP
- WoF-TTP will attempt to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.
  - Current average lead time for tornado warnings via radar detection: 12-15 minutes

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***
  - WoF Tornado Threat Prediction: WoF-TTP
- WoF-TTP will attempt to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.
  - Current average lead time for tornado warnings via radar detection: 12-15 minutes
  - Future average lead time for tornado warnings via WoF-TTP: 40-60 minutes.

# What is Warn on Forecast?

- **Second: Warn on Forecast is a NOAA/OAR <u>research project</u>!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
  - *NSSL <u>led</u> Warn on Forecast project is to* ***<u>extend tornado warning lead times</u>***
  - WoF Tornado Threat Prediction: WoF-TTP
- WoF-TTP will attempt to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.
  - Current average lead time for tornado warnings via radar detection: 12-15 minutes
  - Future average lead time for tornado warnings via WoF-TTP: 40-60 minutes.
  - The technology and science developed to achieve the WoF-TTP goal will likely improve the prediction of other convective weather threats (e.g., large hail, severe winds).

# What is Warn on Forecast?

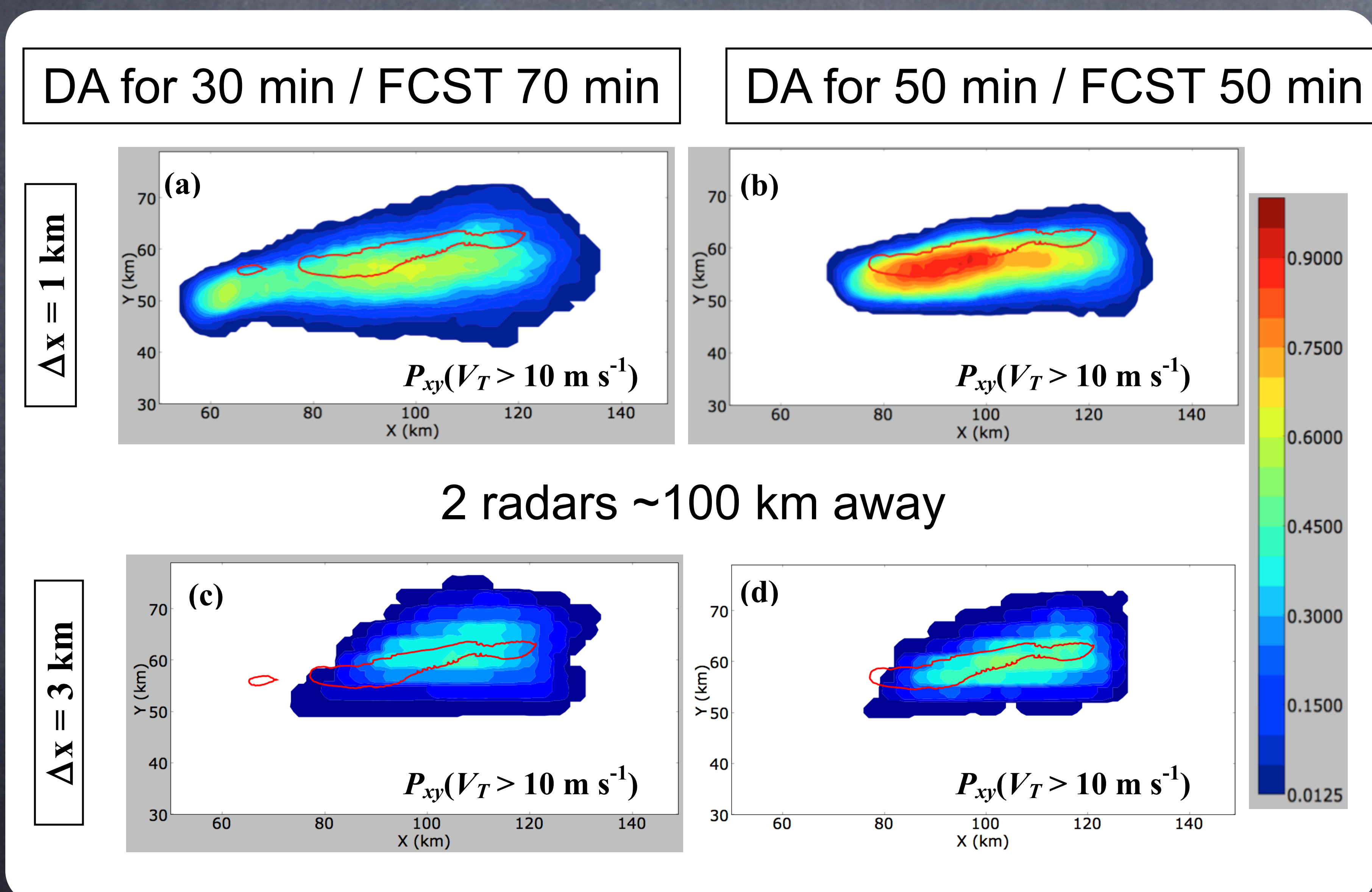
- **Second: Warn on Forecast is a NOAA/OAR research project!**
- **The 10 year (2010-2020) WoF research project funded by NOAA at NSSL**
    - *NSSL led Warn on Forecast project is to* ***extend tornado warning lead times***
    - WoF Tornado Threat Prediction: WoF-TTP
- WoF-TTP will attempt to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.
    - Current average lead time for tornado warnings via radar detection: 12-15 minutes
    - Future average lead time for tornado warnings via WoF-TTP: 40-60 minutes.
    - The technology and science developed to achieve the WoF-TTP goal will likely improve the prediction of other convective weather threats (e.g., large hail, severe winds).
    - WoF-TTP is a specific capability which will be integrated into **FACETS** tornado threat products

# Relationship between NSSL's WoF-TTP and other projects

- Example: High Resolution Rapid Refresh ensemble (HRRRe)
  - 3 km resolution ensemble of HRRRs
  - Forecasts produced every hour
  - full DA capability including radar, satellite, etc!
- Great Idea! We love this! We want to see this happen!
- But its **NOT** WoF-TTP! Cannot forecast tornadoes at these resolutions
- A 3 km grid is convection-permitting, but not convection-resolving!
- WoF-TTP will require grid resolution 3-10x higher than this to reliably predict the internal dynamics of convective entities.
- Think of a HRRRe as the initial background fields for a WoF-TTP system

*NSSL's WoF-TTP is a research project to develop a 0-1 hour, 1-km resolution ensemble-based NWP system to forecast individual convective storms and their tornadoes.*

# Grid Resolution
# 3 km vs 1 km




Potvin and Wicker 2013

OSSE EnKF DA Exp
Truth = 200m
Predict intensification of low-level rotation with realistic radar locations?

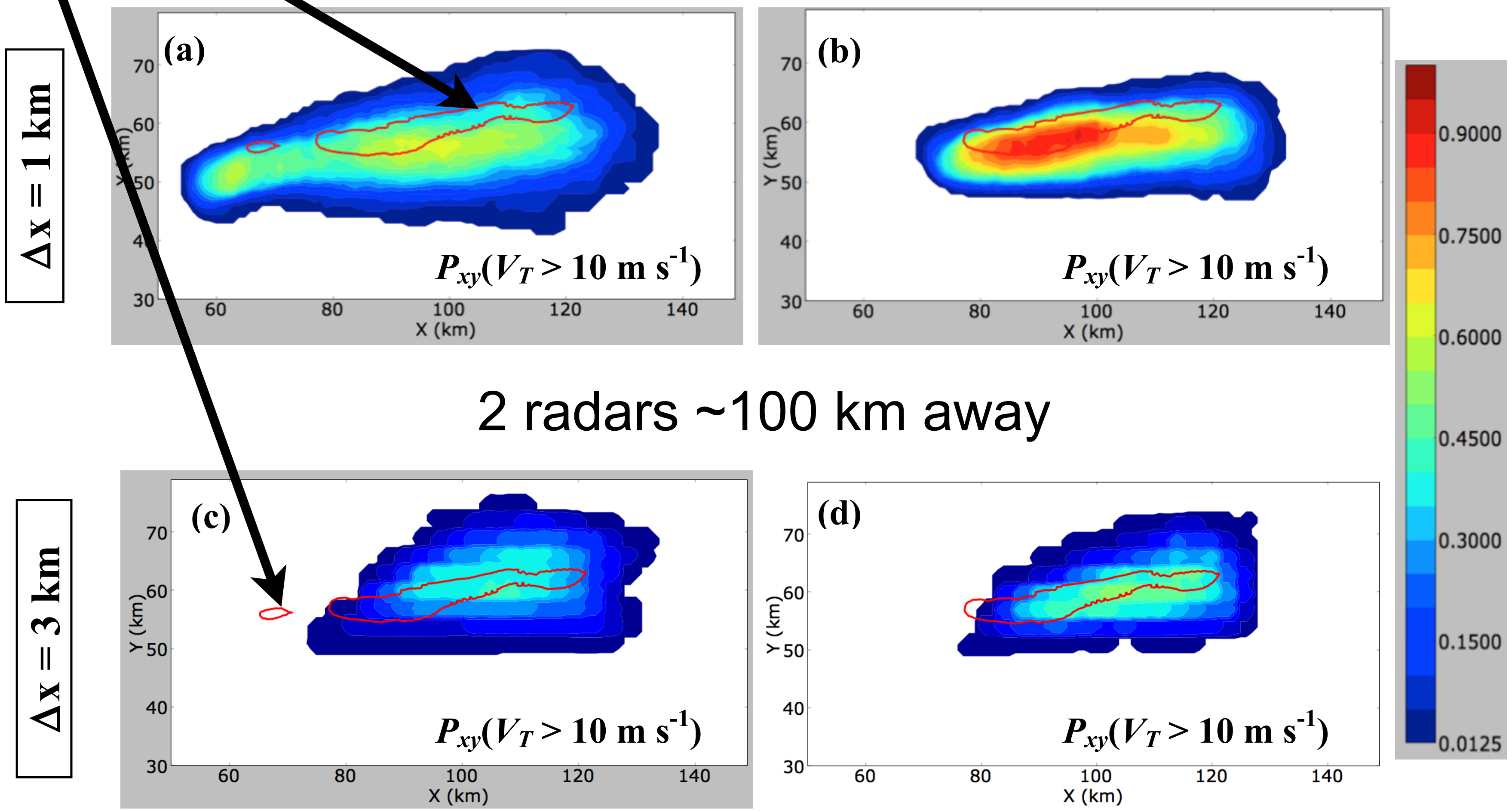
Here we show the change in probability of rotation greater than 10 m/s as a function of horizontal grid resolution

# Grid Resolution
# 3 km vs 1 km

Red contour is region where rotation > 10 m/s

DA for 30 min / FCST 70 min

DA for 50 min / FCST 50 min




2 radars ~100 km away

Potvin and Wicker 2013

OSSE EnKF DA Exp
Truth = 200m
Predict intensification of low-level rotation with realistic radar locations?

Here we show the change in probability of rotation greater than 10 m/s as a function of horizontal grid resolution

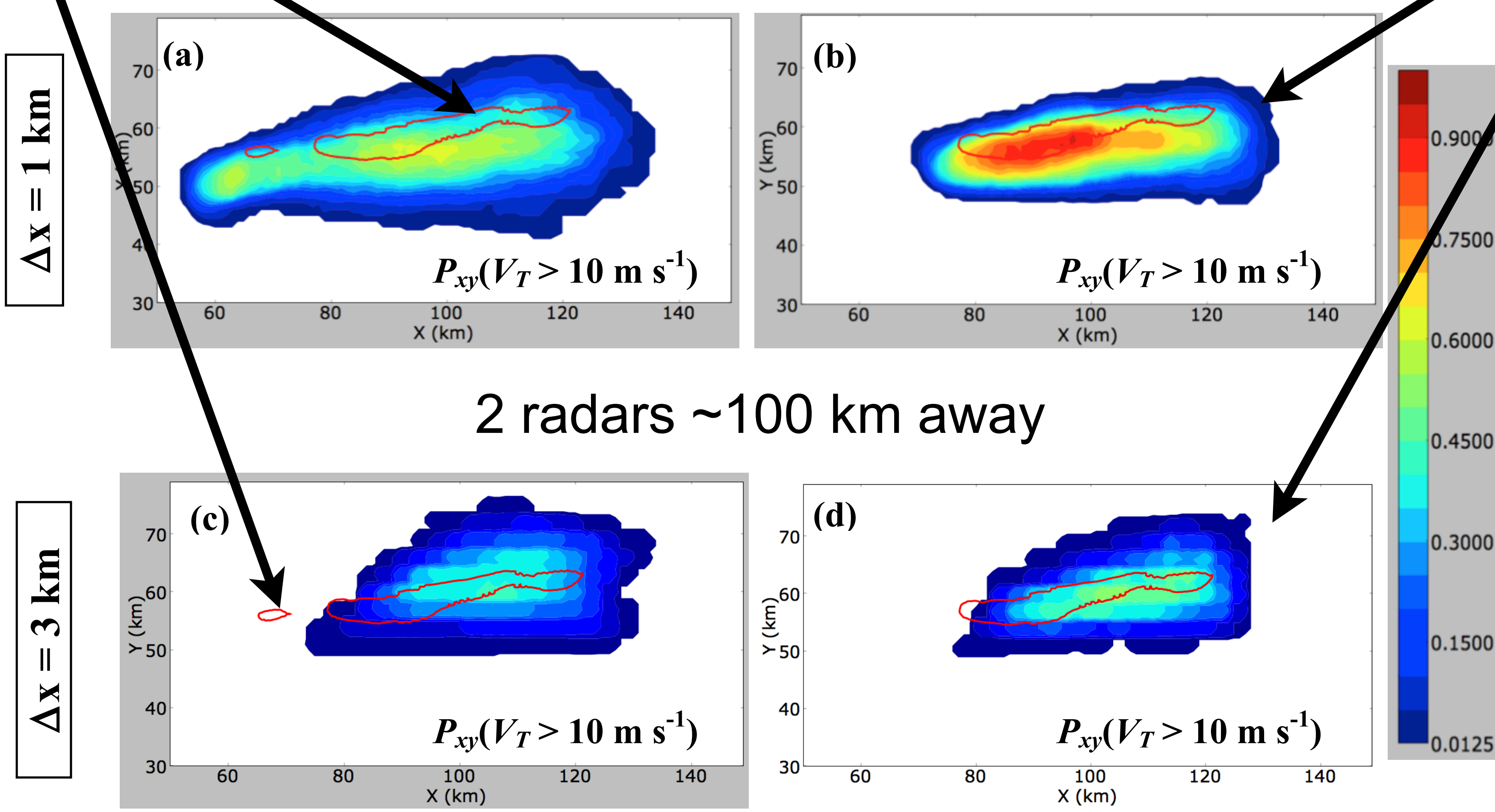
# Grid Resolution
# 3 km vs 1 km

Red contour is region where rotation > 10 m/s

Colored regions indicate locations and % of members having Rot > 10 m/s

DA for 30 min / FCST 70 min

DA for 50 min / FCST 50 min




Potvin and Wicker 2013

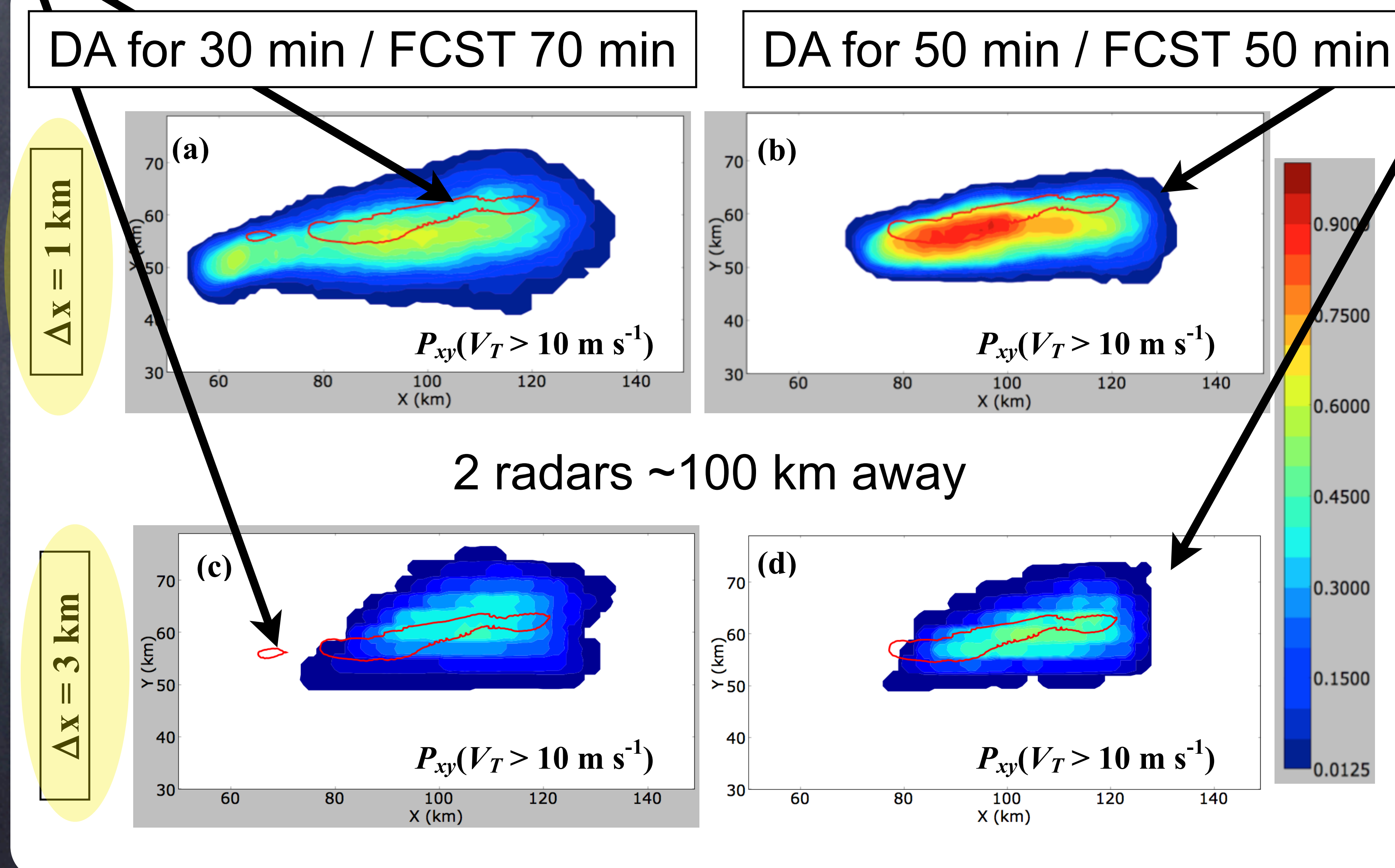
OSSE EnKF DA Exp
Truth = 200m
Predict intensification of low-level rotation with realistic radar locations?

Here we show the change in probability of rotation greater than 10 m/s as a function of horizontal grid resolution

# Grid Resolution
# 3 km vs 1 km

Red contour is region where rotation > 10 m/s

Colored regions indicate locations and % of members having Rot > 10 m/s



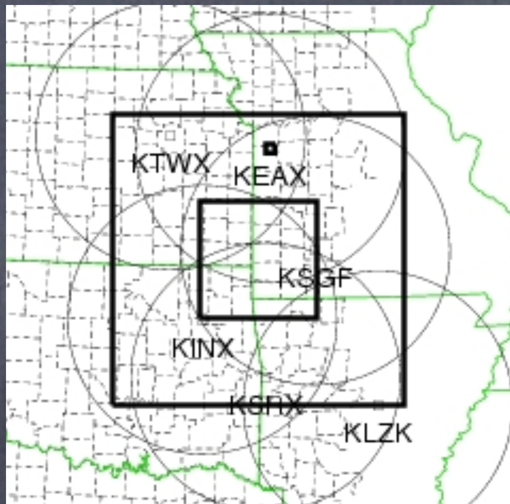

Potvin and Wicker 2013

OSSE EnKF DA Exp
Truth = 200m
Predict intensification of low-level rotation with realistic radar locations?

Here we show the change in probability of rotation greater than 10 m/s as a function of horizontal grid resolution

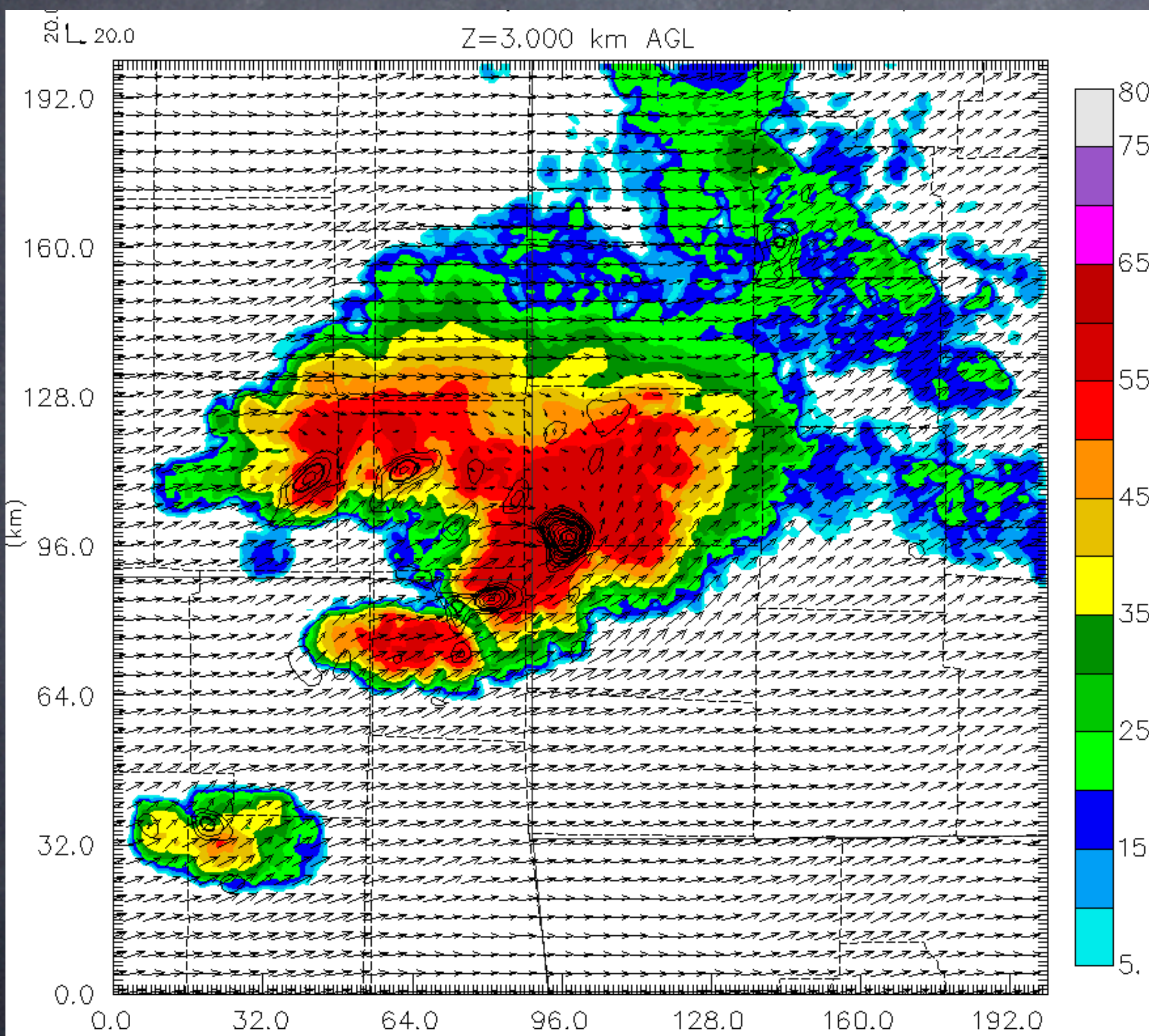
# Current research

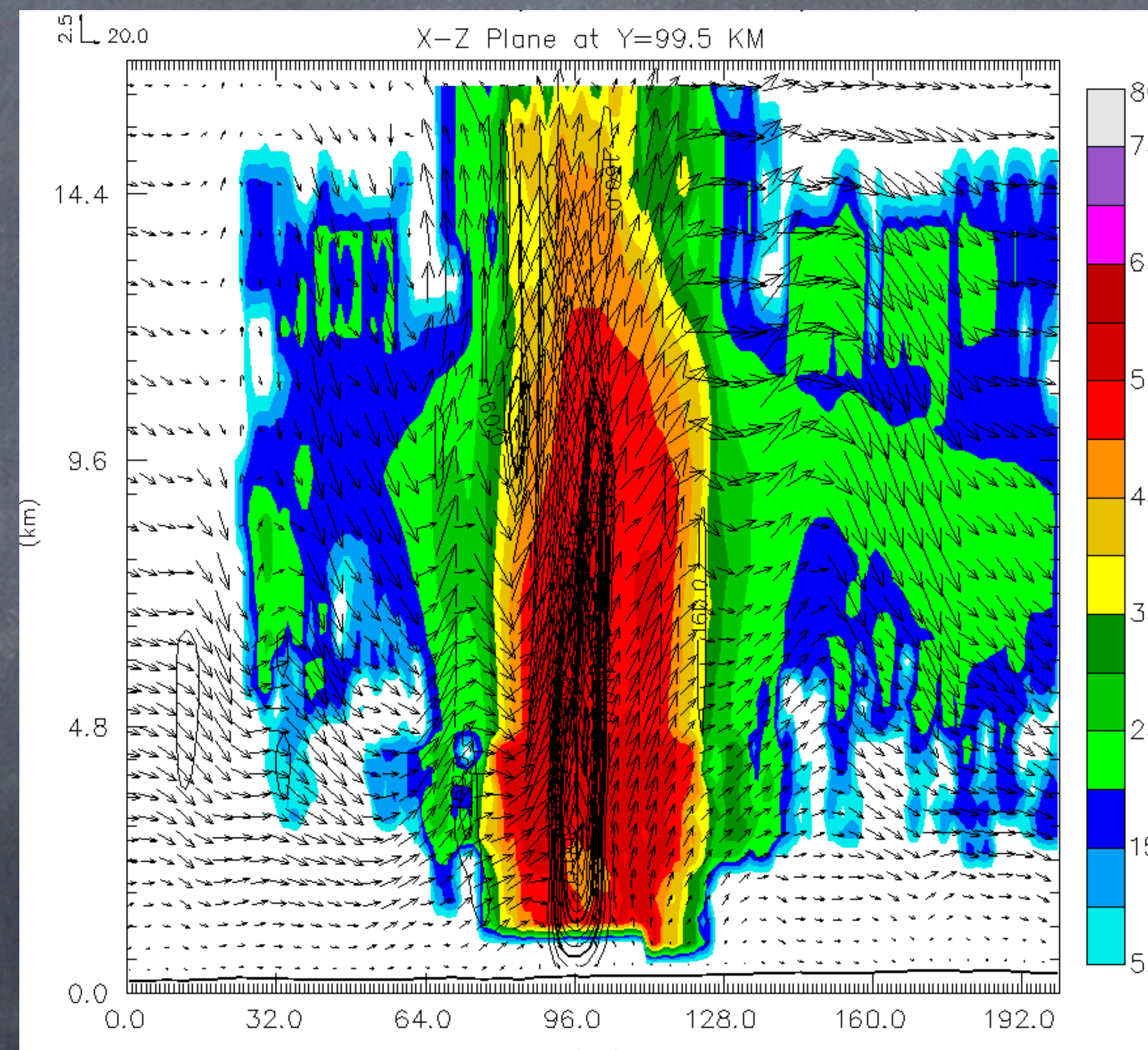
# achievements




# Realtime Analysis

## 3DVAR Analysis of Joplin Tornado (J. Gao)

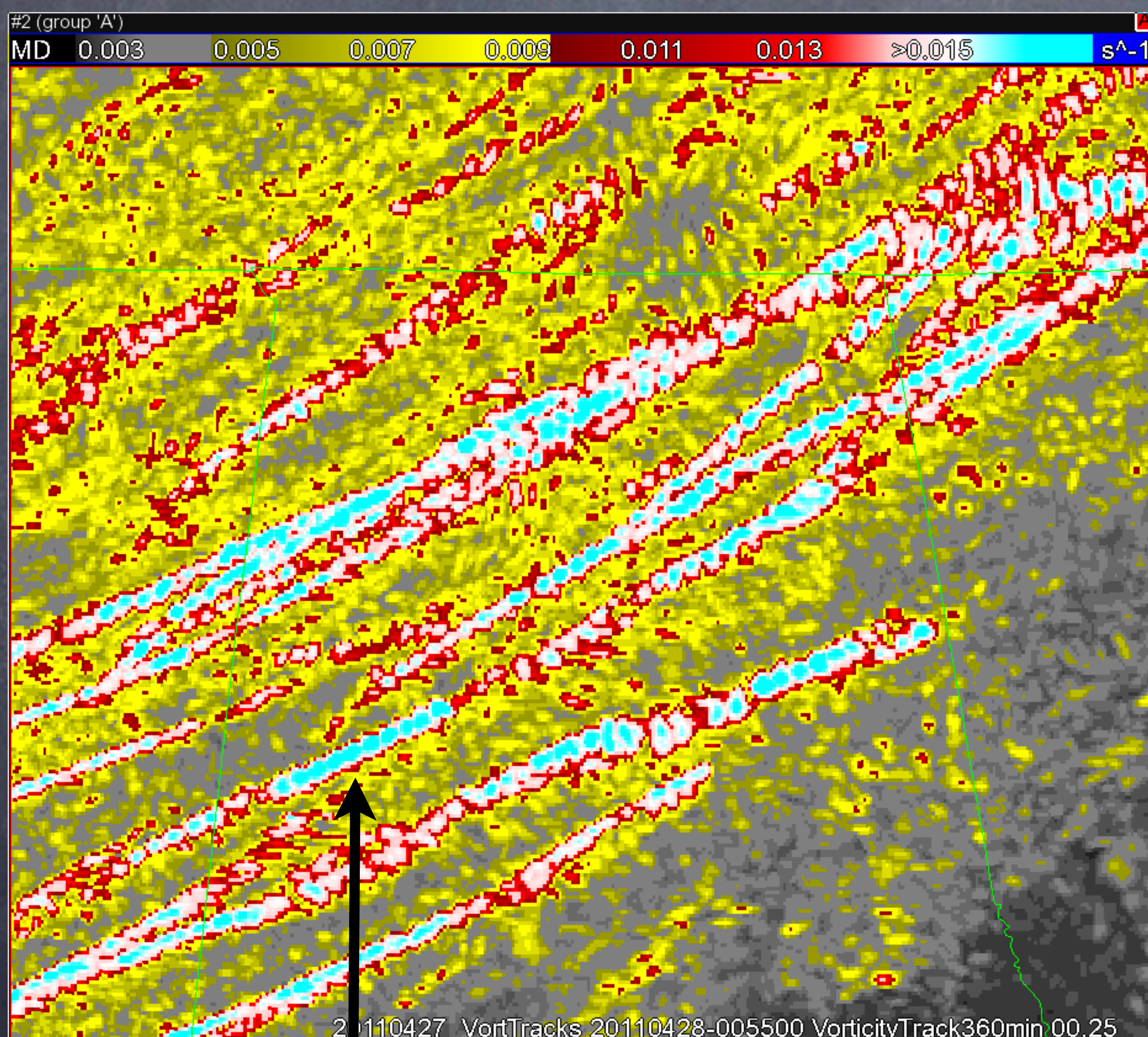


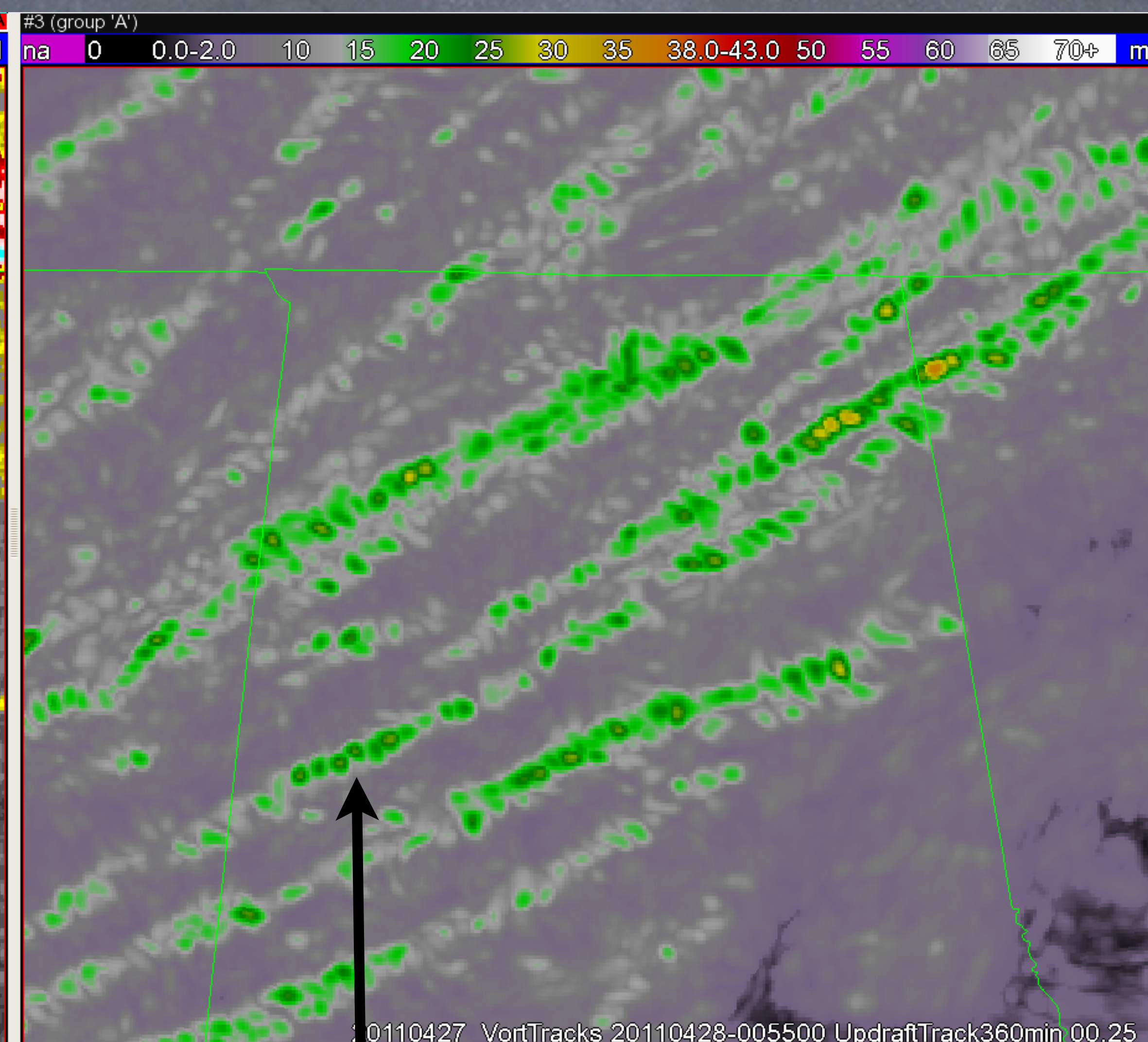




Domain is 200 x 200 km. 5 min latency

# Near RT:  Large-Domain 3DVAR  Analysis

## 3DVAR Analysis of Alabama Tornado Outbreak (J. Gao, T. Smith)

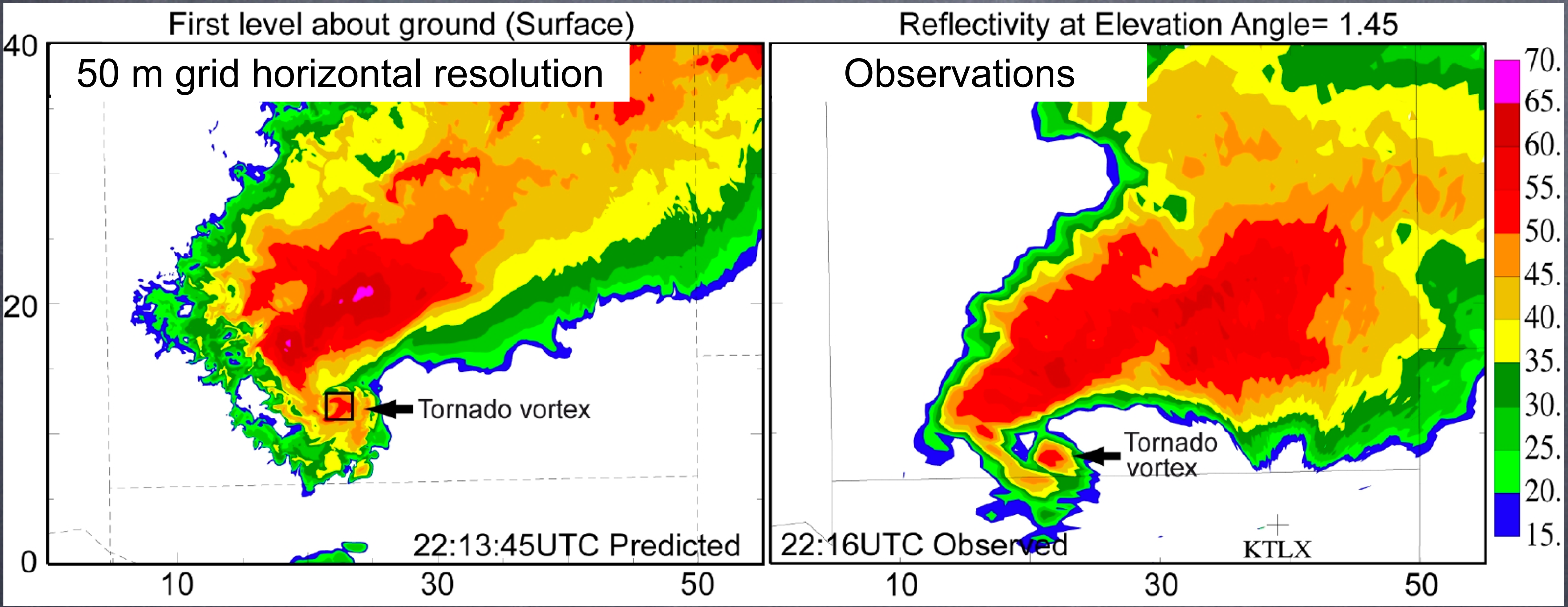



Tuscaloosa rotation track from Doppler radar

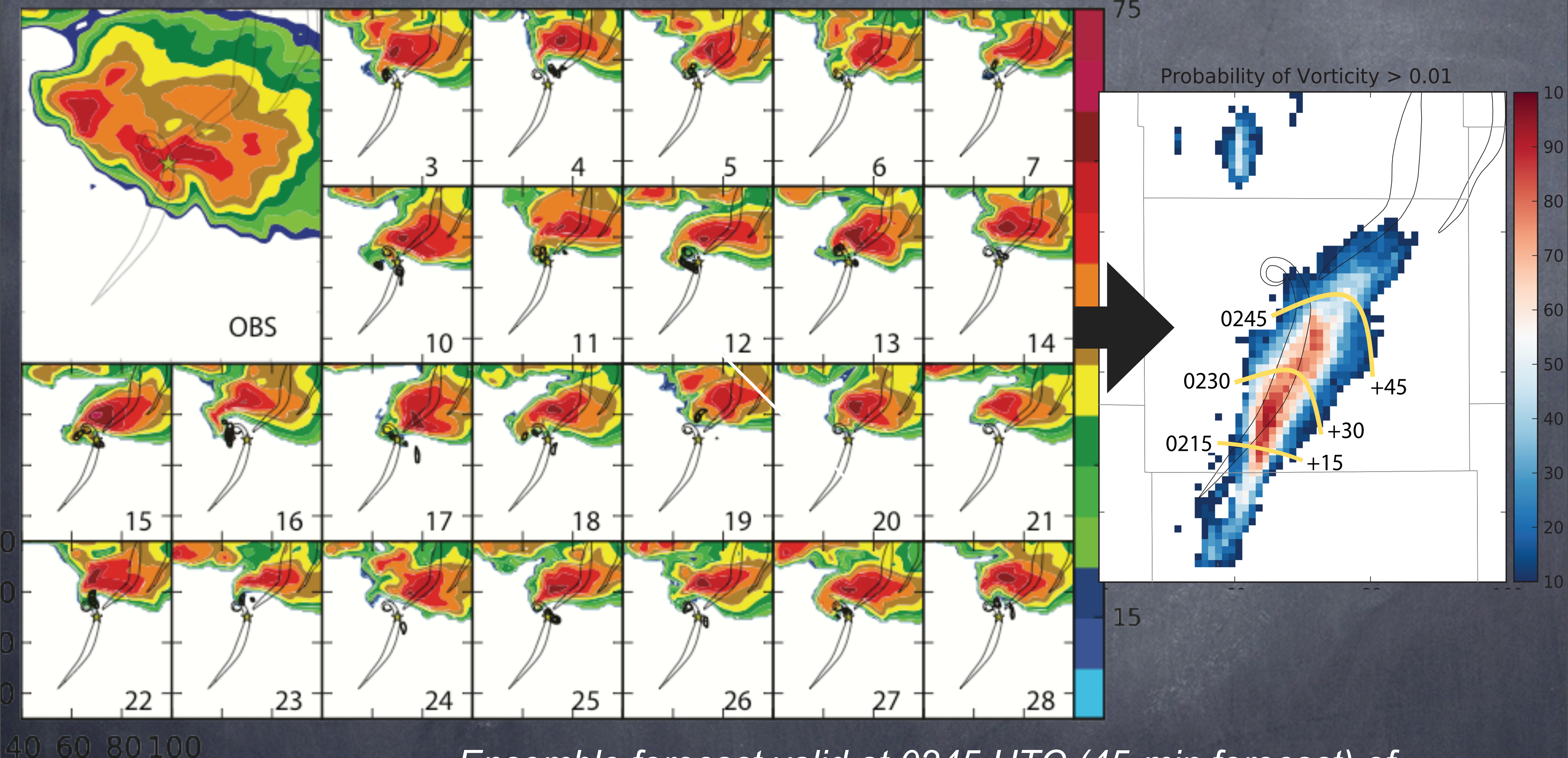
Tuscaloosa updraft track from 3DVAR analysis

# Research Mode: Deterministic Ultra-high Resolution Forecast




Deterministic 33 minute forecast of 8 May 2003 supercell/ tornado using radar observations and 50 m grid resolution Xue, Droegemeier and Weber (2007)

# Research Mode: EnKF DA
# Probabilistic Forecasts at 1 km




*Ensemble forecast valid at 0245 UTC (45-min forecast) of simulated reflectivity 24 of the 30 members shown*

**Synthesis of a lot of information!**

# Research Mode: Multiscale DA for MCS tornadoes using 0.4 km grid resolution

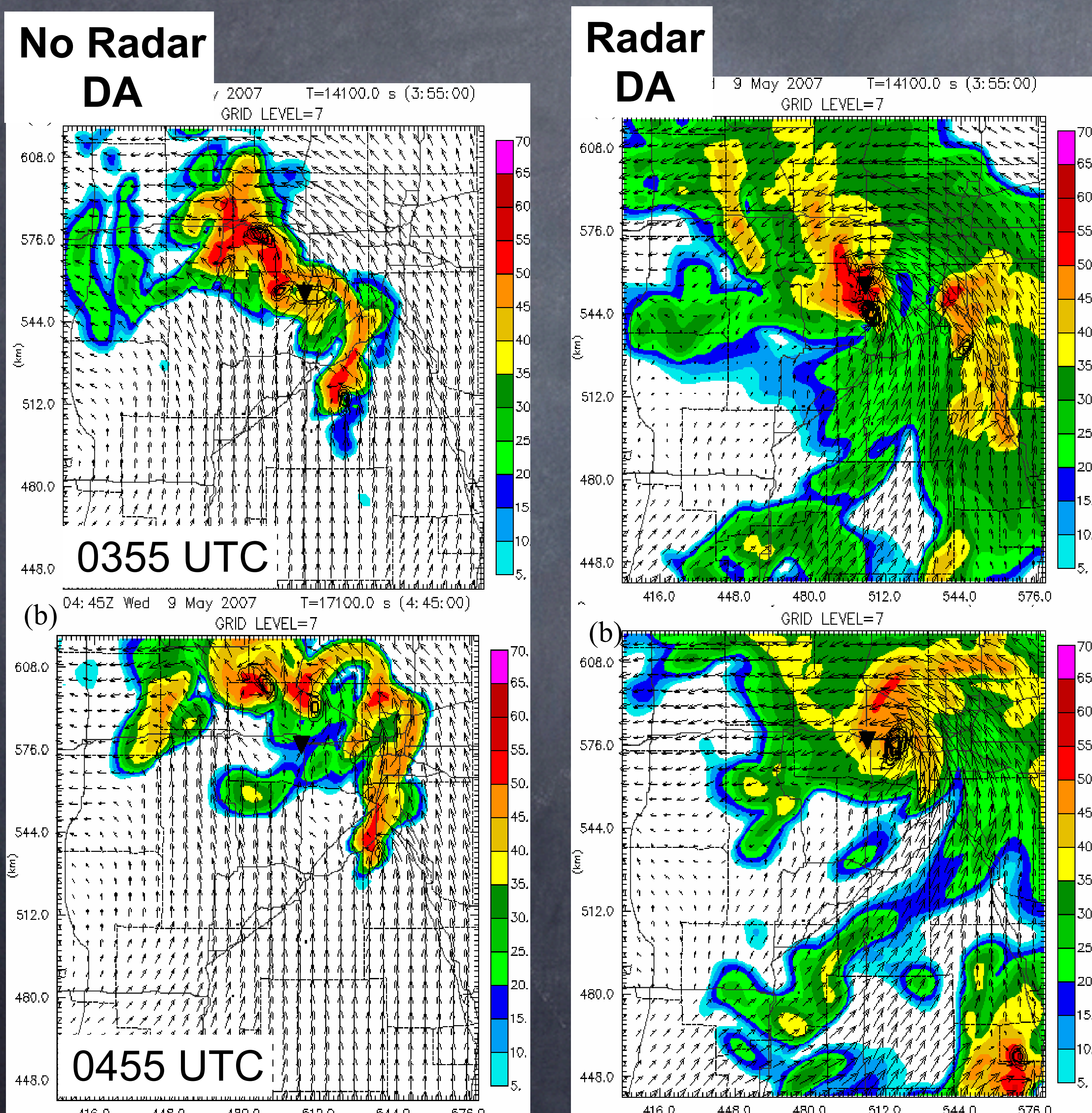



Fig. 5 As Fig. 4 but for EXP1.

**CAPS** has successfully forecasted the development of several tornadic vortices within the comma head of a central OK MCS with 40-60 min lead time.

- Schenkman, A. D., A. M. Shapiro, K. Brewster, M. Xue, J. Gao, and N. Snook, 2008a,b
- Schenkman, A., M. Xue, and A. Shapiro, 2011a,b.
- Snook, N., M. Xue, and J. Jung, 2012

See http://twister.ou.edu/vita.html

# Forecaster/Customer Requirements for a WoF-TTP system

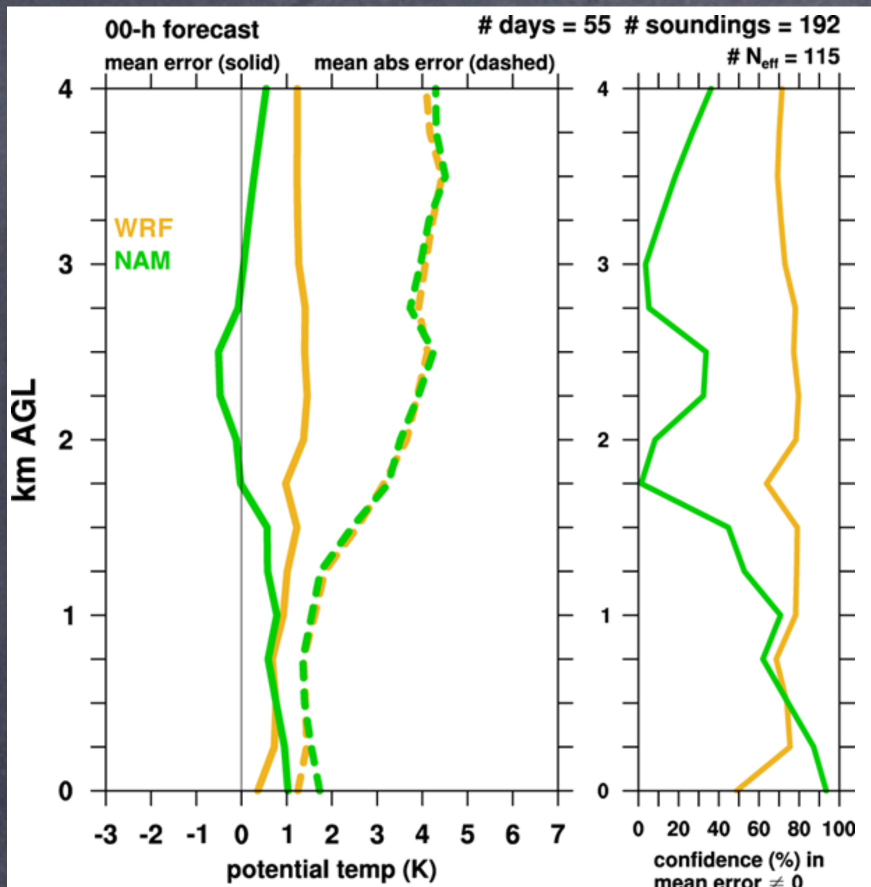
- Fast *(there when forecaster can best/most use it)*
  - Forecasters will continue to use radar, WoF-TTP will have be available multiple times per hour.
  - Assimilation/forecast cycle < 10-15 min latency, 1 hour forecasts needed
- Reliable *(earns forecaster trust)*
  - Output needs to be calibrated 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

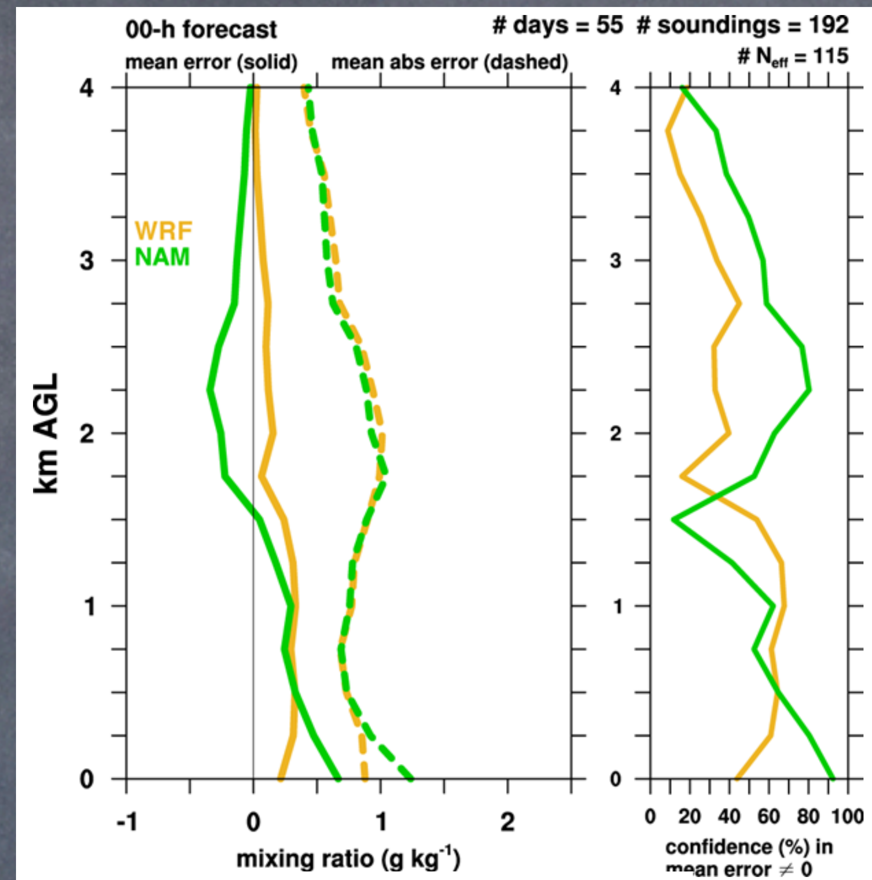
# Challenges

# Mesoscale Errors & Predictability

- Mesoscale forecast errors!
  - Impact of environmental heterogeneities on storm rotation
  - Relative roles of internal dynamics versus external environment in controlling evolution?
  - mesoscale can also enhance convective-scale predictability (e.g., terrain,fronts)

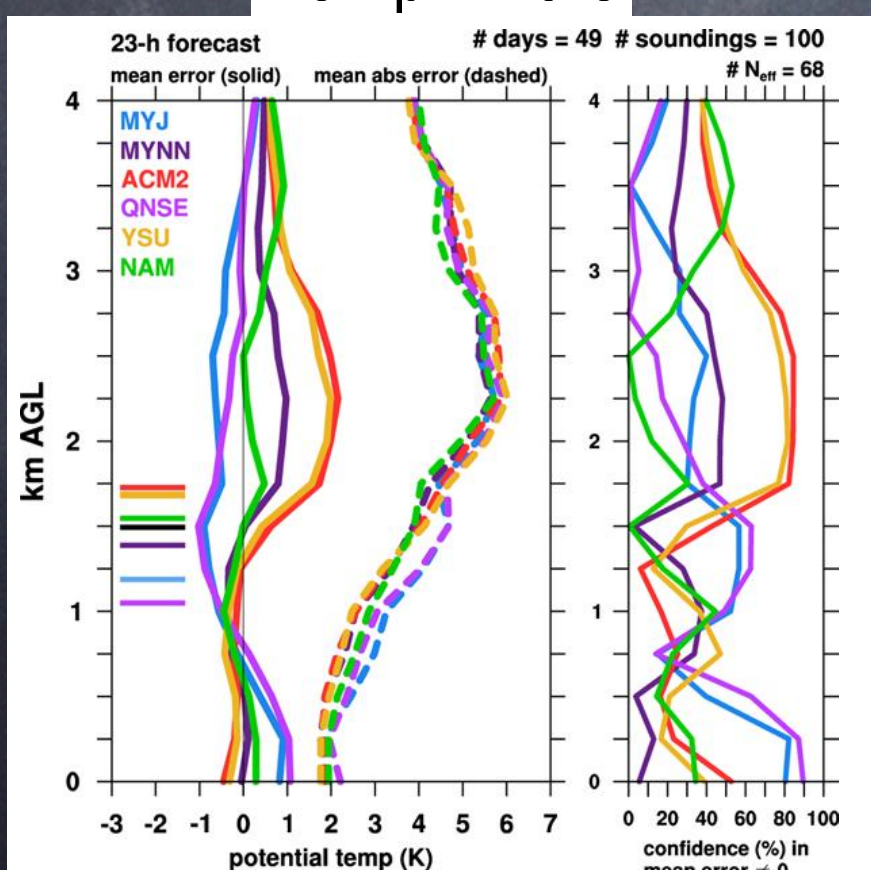
# PBL Error/Uncertainty (Coniglio et al 2013)

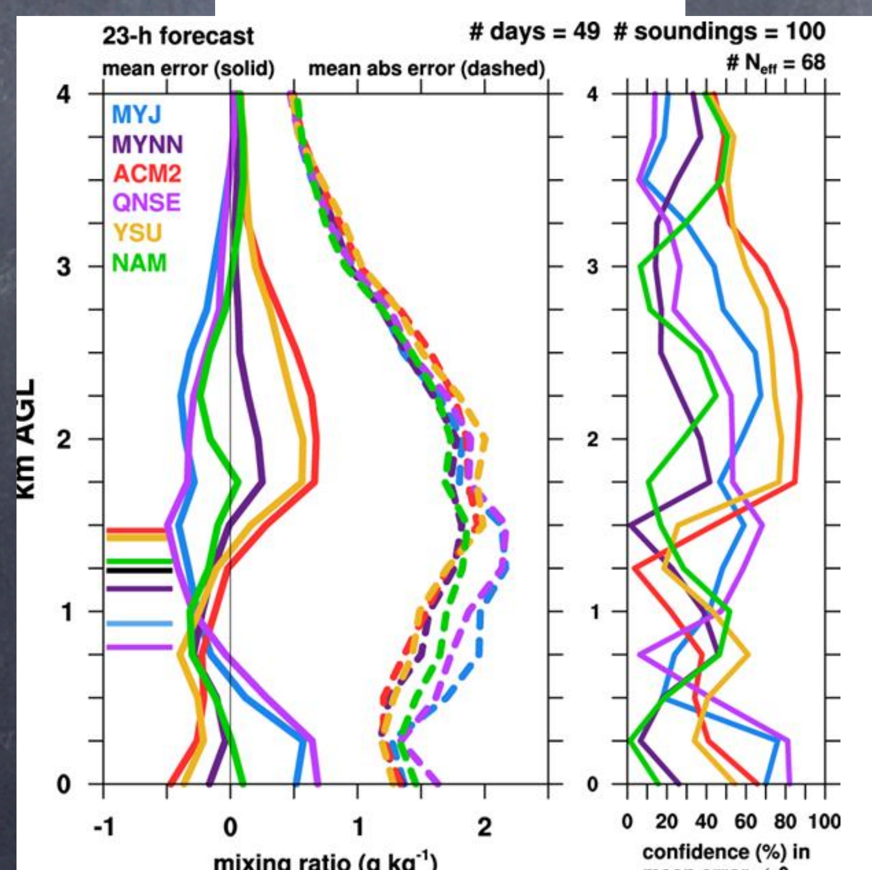



Temp Errors

Moisture Errors




**Sensitivity of Moist Convection Forced by Boundary Layer Processes to Low-Level Thermodynamic Fields**

N. Andrew Crook

*National Center for Atmospheric Research,* Boulder, Colorado*

(Manuscript received 21 August 1995, in final form 18 January 1996)

ABSTRACT

*..variations in boundary layer temperature and moisture that are within typical observational variability (1 C / 1 g/kg) can make the difference between no initiation and intense convection*

**The Impact of Spatial Variations of Low-Level Stability on the Life Cycle of a Simulated Supercell Storm**

Conrad L. Ziegler and Edward R. Mansell

*NOAA/National Severe Storms Laboratory, Norman, Oklahoma*

Jerry M. Straka

*School of Meteorology, University of Oklahoma, Norman, Oklahoma*

Donald R. MacGorman

*NOAA/National Severe Storms Laboratory, Norman, Oklahoma*

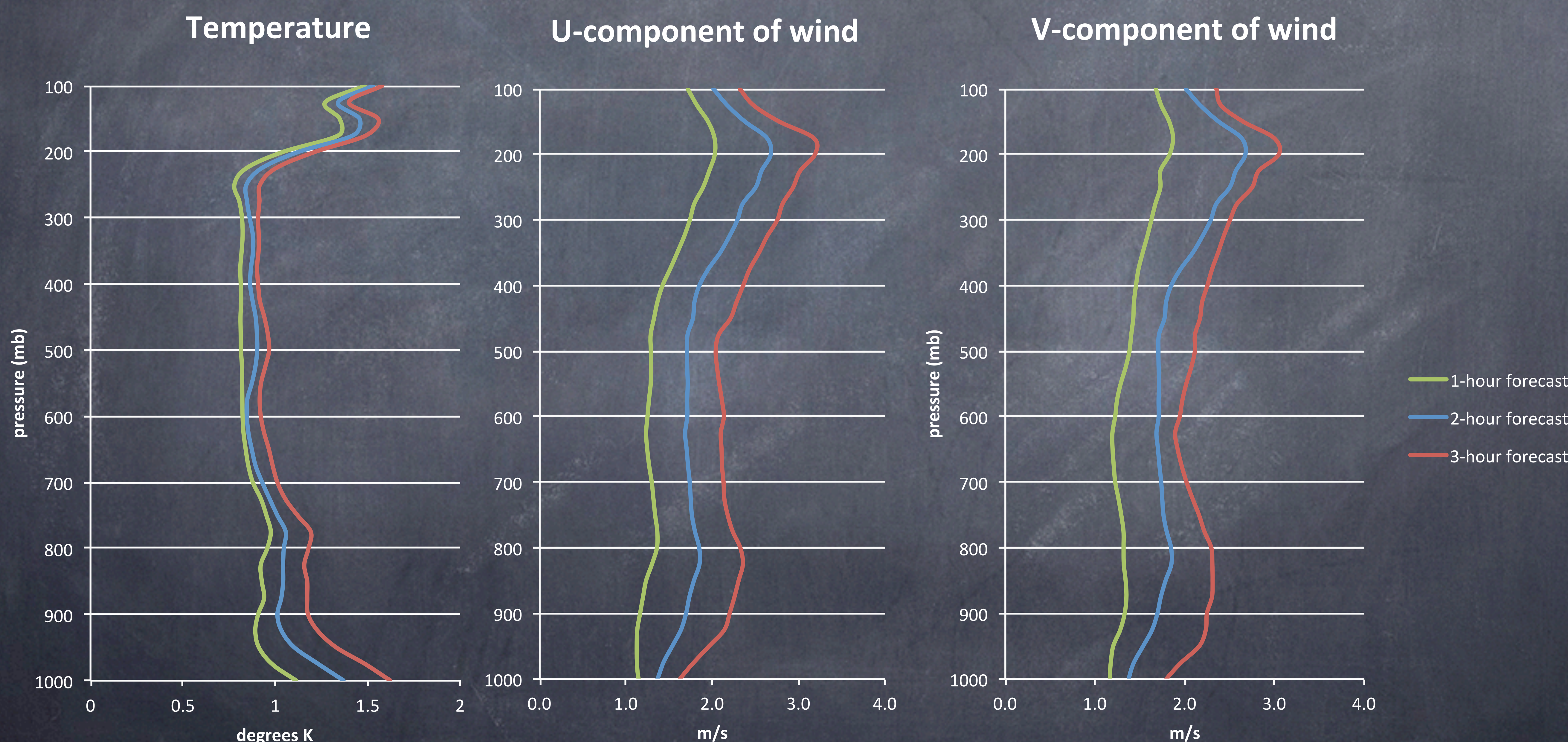
Donald W. Burgess

*Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, Oklahoma*

*...Despite the same levels of CAPE and shear supporting the observed and simulated severe convection....a significant sensitivity of supercell lifetime is noted even having moist BLs ...where the virtual temperature differences did not exceed 0.3 K and MLCIN differences of 5-10 J/kg..*

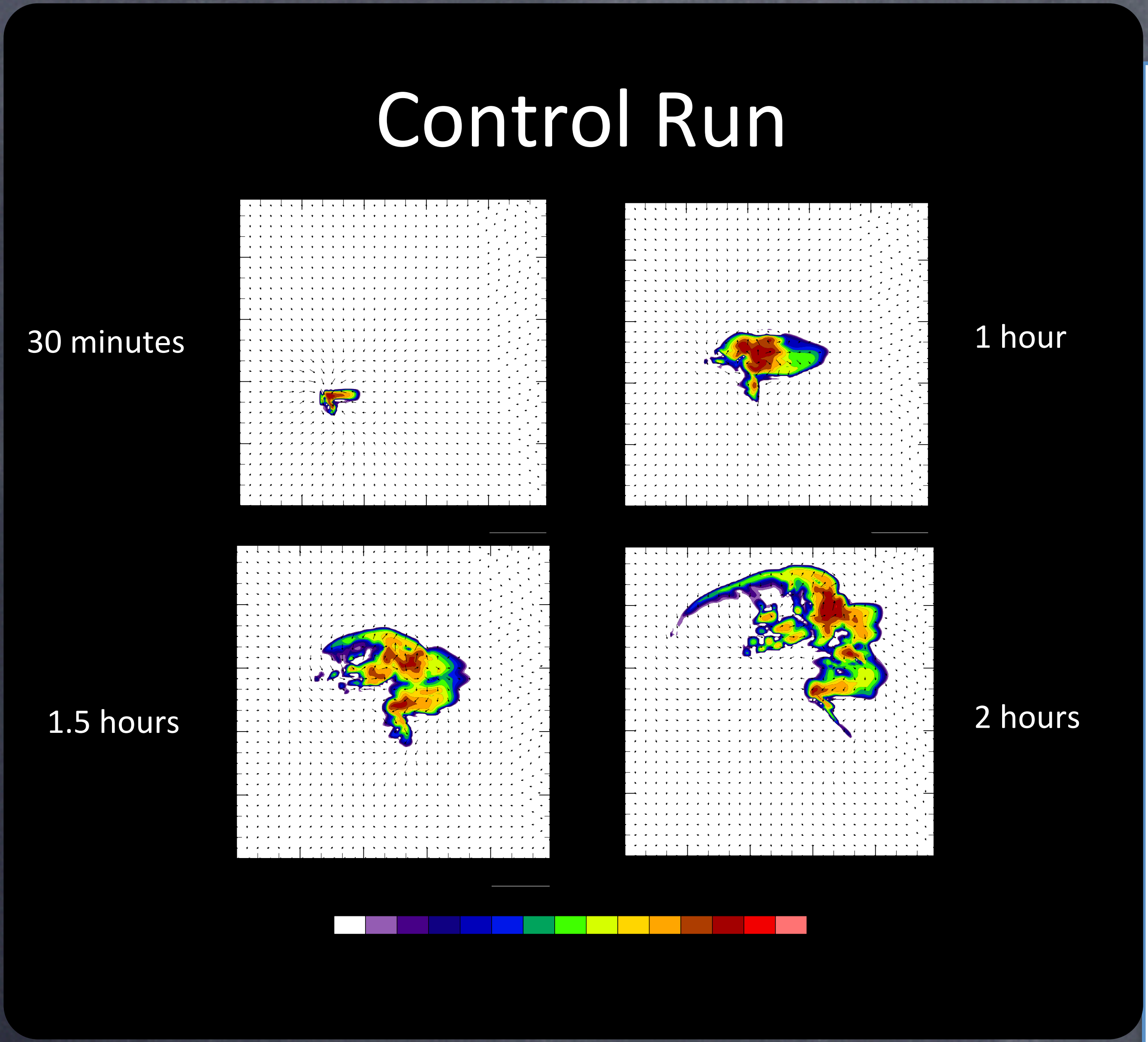
*All the mean errors for the model PBL schemes exceed these sensitivity levels*

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



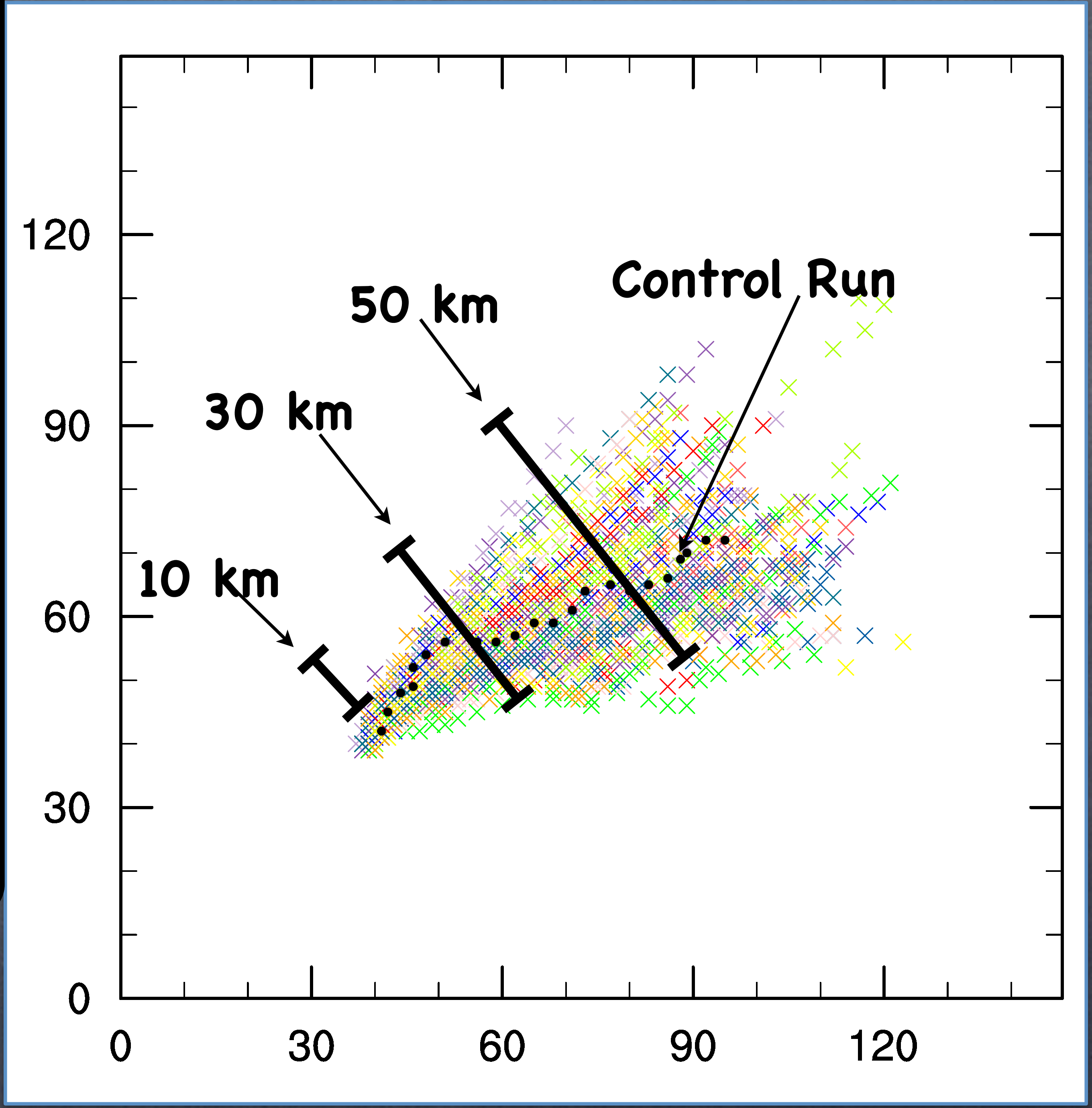

*Cintineo and Stensrud, JAS, 2012*

# Updraft Helicity Paths




Plotted values are UH ≥ 50 $m^2s^{-2}$

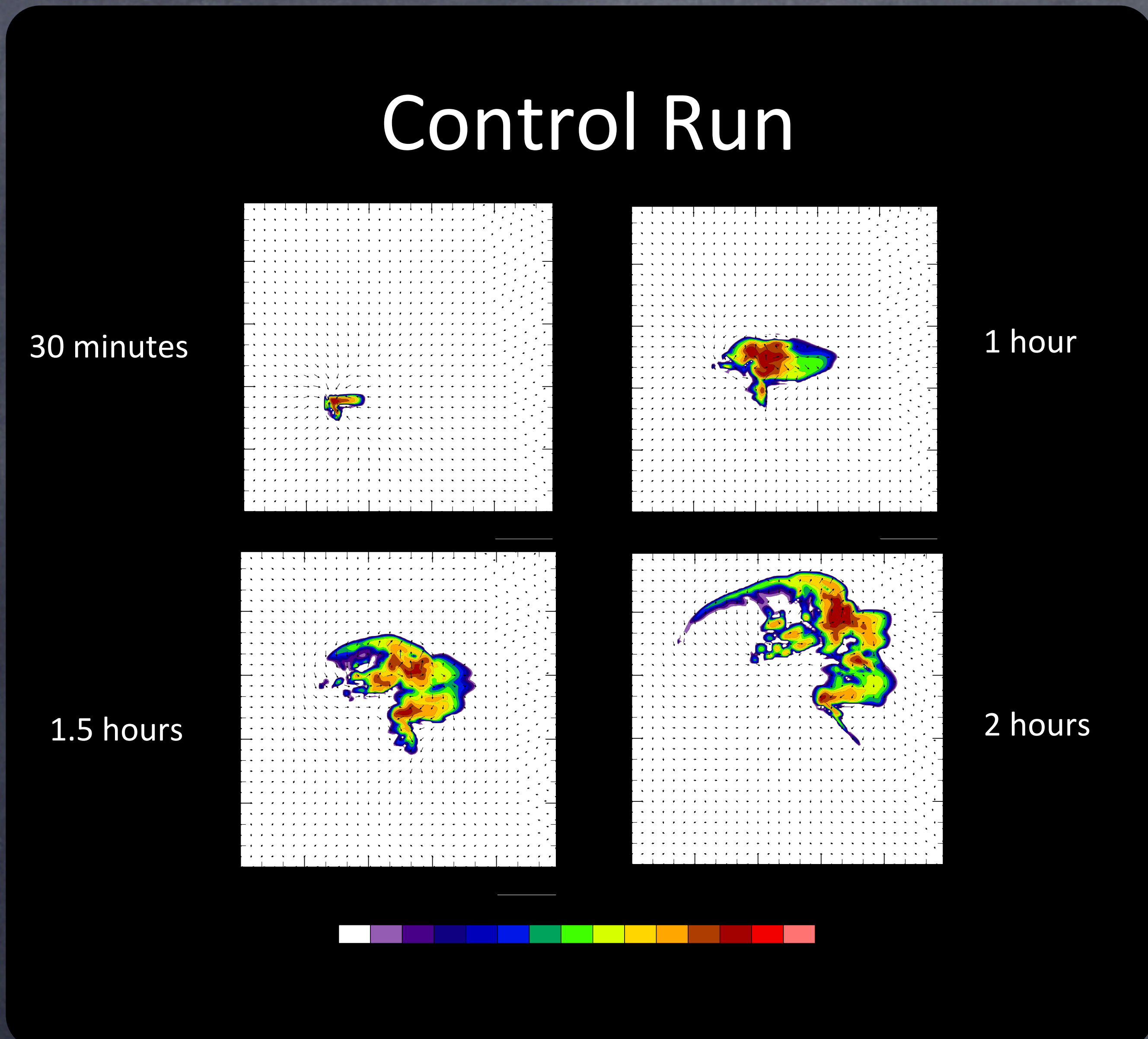
*Cintineo and Stensrud, JAS, 2012*




• Control run ✕ Perturbation runs

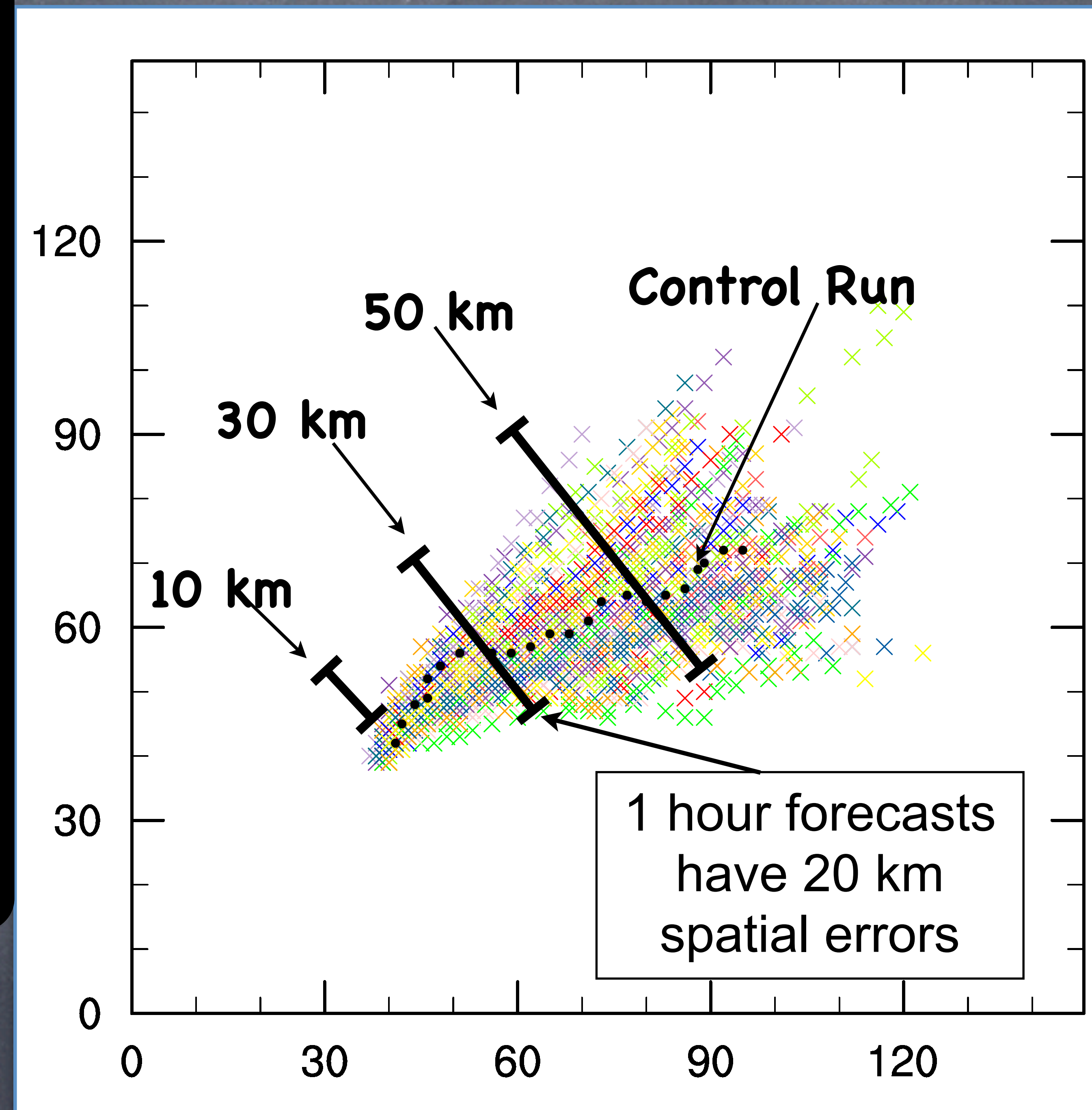
**Storm track errors from 3 hr simulations using 1-hour sounding errors!**

# Updraft Helicity Paths




Plotted values are UH ≥ 50 $m^2s^{-2}$

*Cintineo and Stensrud, JAS, 2012*

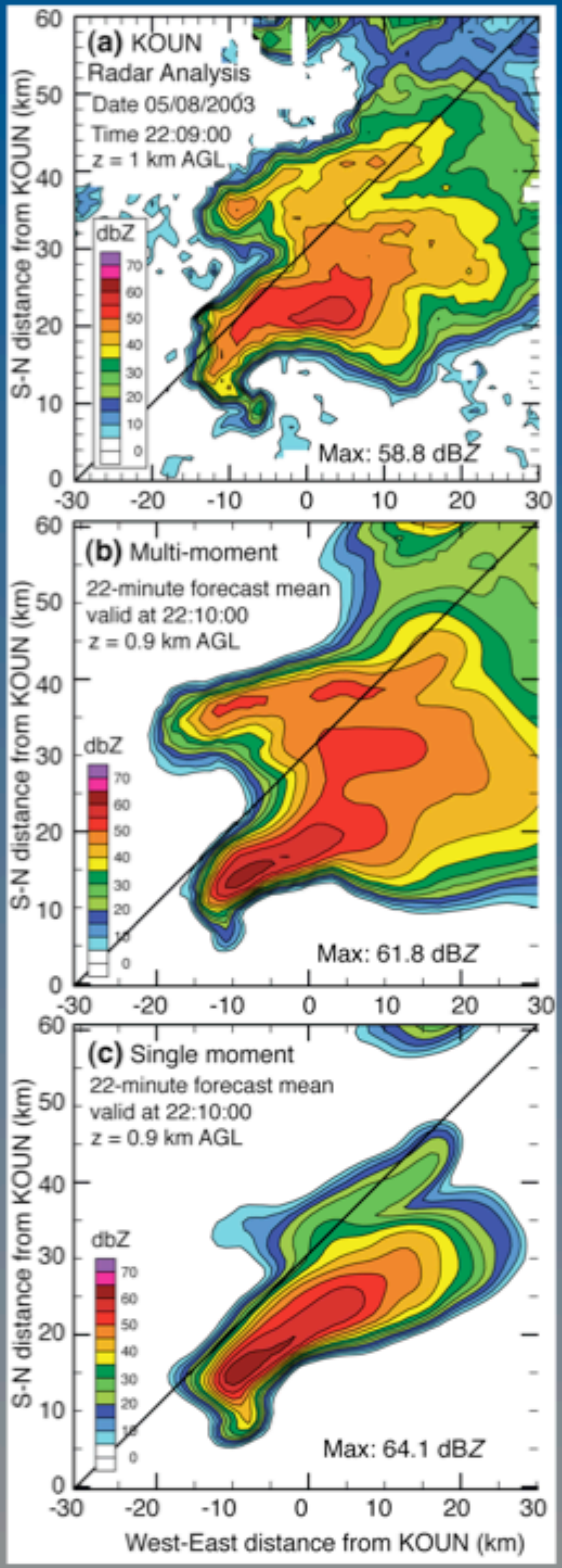



• Control run × Perturbation runs

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

# Convective Model Errors

- Convective-scale modeling errors?
  - Sensitivity to numerical grid choices (particular vertical grid spacing)
  - Sensitivity to numerical dissipation
- Parameterizations
  - **Microphysics** *(Observations confined to Polarimetric radar?)*
  - Turbulence and entrainment *(Few direct observations)*
  - Surface fluxes *(Few observations)*
  - Radiation *(only top of cloud observations)*



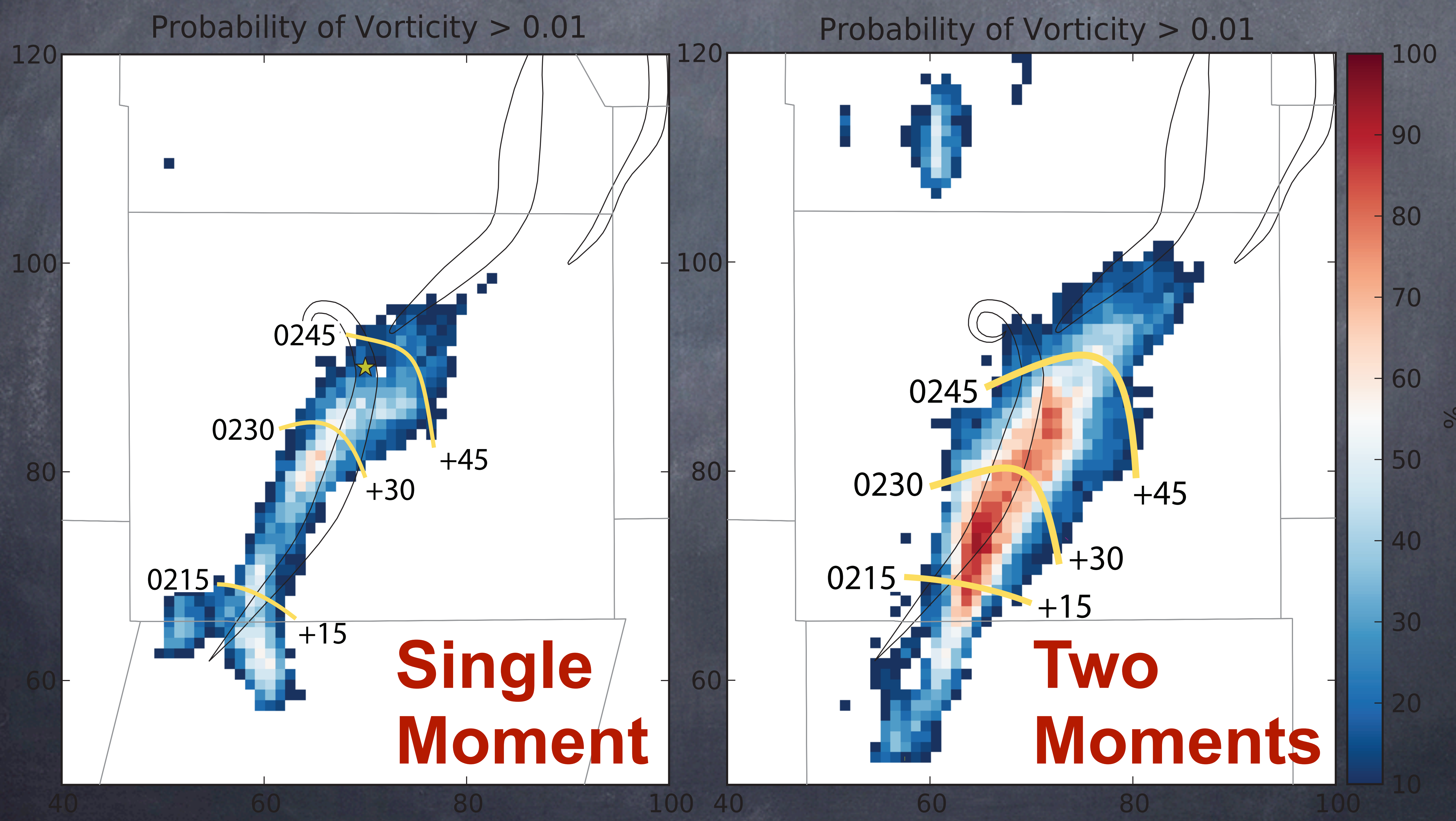

# Microphysical Sensitivity

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

# Microphysics Sensitivity
## Greensburg KS Storm Forecasts:
## Single vs. Two Moment Microphysics

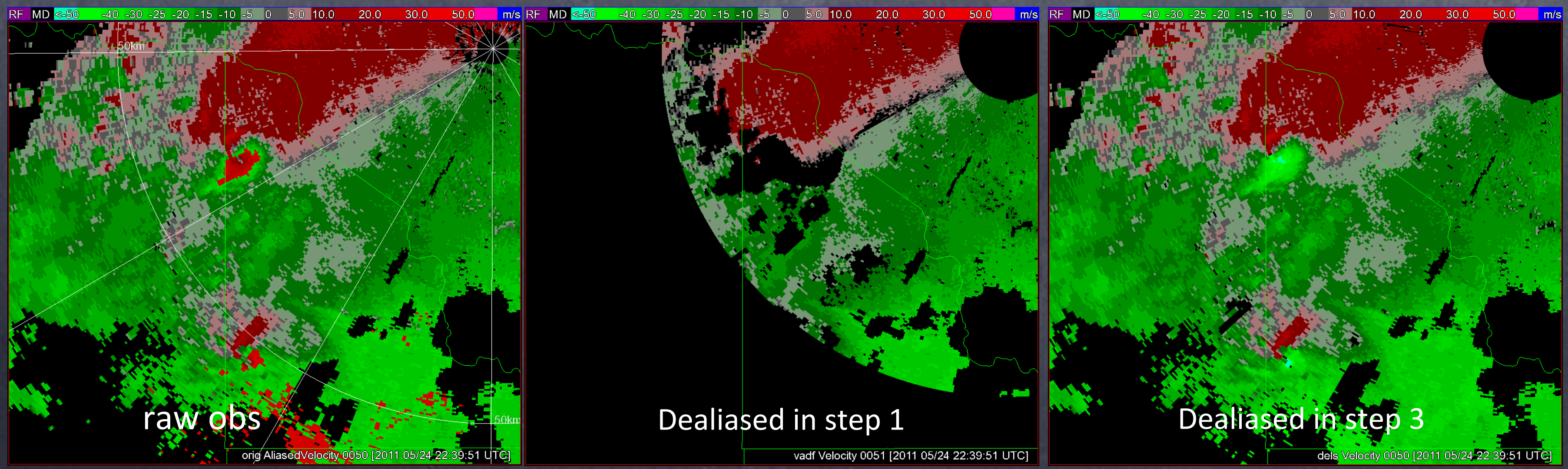


# Technical Requirements for a WoF-TTP

- Data QC
- Grid & Computer
- Modeling approaches
- Data assimilation approaches
- Getting there from here....

# Radar Data QC

- Quality control of data from WSR-88D
  - velocity dealiasing/clutter/clear air cleanup can be difficult on storm-scale
  - Velocity folding occurs on both small (storm) AND large (meso) scales
  - <u>time-sensitive processing </u>– need QC data within minutes
  - After two decades - cannot automate QC for Doppler velocity/reflectivity at storm-scales
  - Polarimetric variables help characterize the echo better - but they are noisier than Vr and dBZ



# Grid vs Computer....

# Grid vs Computer....

- **1 km CONUS grid**

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer
  - *by power I mean speed, although electricity may be another matter!*

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer
  - *by power I mean speed, although electricity may be another matter!*
- **I/O will be the problem**

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer
  - *by power I mean speed, although electricity may be another matter!*
- **I/O will be the problem**
  - $10^5$-$10^6$ cores:  how fast can they write to a parallel file system?

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer
  - *by power I mean speed, although electricity may be another matter!*
- **I/O will be the problem**
  - $10^5$-$10^6$ cores:  how fast can they write to a parallel file system?
  - seen this with NCSA's Bluewater system

# Grid vs Computer....

- **1 km CONUS grid**
  - 5600 x 3000 x 100 grid
  - 25-30 state variables  (need at least two moment microphysics)
  - 50 ensemble members
  - Ensemble State:  5600 x 3000 x 100 x 20 x 50 = 2-3 TB of memory = 16-48 TB per restart image


- **2023:  CPU power will not be NOT the problem!**
  - you will need essentially a dedicated computer
  - *by power I mean speed, although electricity may be another matter!*
- **I/O will be the problem**
  - $10^5$-$10^6$ cores:  how fast can they write to a parallel file system?
  - seen this with NCSA's Bluewater system
  - IMHO:  This has big implications

# Software & Model?

# Software & Model?

- **Hardware solution**

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model: Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model: Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly
- **Other thoughts**

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model: Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly
- **Other thoughts**
  - models forecasts need to be more accurate than today

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model: Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly
- **Other thoughts**
  - models forecasts need to be more accurate than today
  - for convective forecasts: need to address systematic errors WRT boundary layer profiles

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly
- **Other thoughts**
  - models forecasts need to be more accurate than today
  - for convective forecasts:  need to address systematic errors WRT boundary layer profiles
  - time/state dependent vertical coordinates introduce errors into the ensemble DA

# Software & Model?

- **Hardware solution**
  - Buy a computer than can read/write 16-48 TB of data every few seconds off to/from disk
  - Model system can then be similar to current approaches
  - Ensemble state is constructed from a set of individual model forecasts
  - Data assimilation is done outside of the model code (separate code)
- **Software solution**
  - The Ensemble **IS** the model:  Ensemble state never leaves computer memory....
  - NEVER do I/O except to dump output for forecasters
  - Higher level of parallel efficiency may be able to found via this approach
    - Now have 50x more stuff to do per tile (momentum advection, mixing, turbulence..)
    - May facilitate hybrid parallelization strategies (MPI / OpenMP / GPU / ??)
    - Data assimilation must be built into the ensemble code directly
- **Other thoughts**
  - models forecasts need to be more accurate than today
  - for convective forecasts:  need to address systematic errors WRT boundary layer profiles
  - time/state dependent vertical coordinates introduce errors into the ensemble DA
  - IMHO:  the model needed to run accurate convective-permitting/resolving IS NOT YET BUILT

# Data Assimilation

# Data Assimilation

- “Large-scale” DA is essentially an analysis problem:

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There is little or no balance between analysis variables within the equations

# Data Assimilation

- "Large-scale" DA is essentially an <u>analysis</u> problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a <u>retrieval</u> problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There <u>is little or no</u> balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There is little or no balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!
- Model error + retrieval uncertainty

# Data Assimilation

- "Large-scale" DA is essentially an <u>analysis</u> problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a <u>retrieval</u> problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There <u>is little or no</u> balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!
- Model error + retrieval uncertainty
  - Data assimilation method + the bias and errors within BECs are critical

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There is little or no balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!
- Model error + retrieval uncertainty
  - Data assimilation method + the bias and errors within BECs are critical
  - One can fit the observations very well....but the inherent uncertainties imply...

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There is little or no balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!
- Model error + retrieval uncertainty
  - Data assimilation method + the bias and errors within BECs are critical
  - One can fit the observations very well....but the inherent uncertainties imply...
    - the retrieved state can be different depending on model errors

# Data Assimilation

- "Large-scale" DA is essentially an analysis problem:
  - The analysis variables are similar to those you observe
  - STATE(P, T, $T_d$, U, V, .....) from OBS(P, T, $T_d$, U, V)
  - There exist balances between analysis variables within the equations
- "Convective-scale" DA is mostly a retrieval problem:
  - Retrieval of the state from mostly non-state obs, e.g., **RADAR & SATELLITE**
  - STATE (P, T, $T_d$, U, V, Qr, Qs, Qg,..) from OBS(dBZ, $V_r$ ,Zdr, Kdp)
  - There is little or no balance between analysis variables within the equations
  - BECs specified from an ensemble of convective-scale forecasts!
- Model error + retrieval uncertainty
  - Data assimilation method + the bias and errors within BECs are critical
  - One can fit the observations very well....but the inherent uncertainties imply...
    - the retrieved state can be different depending on model errors
    - no guarantee that a "better" analysis yields a better forecast

# So Which Data Assimilation Approach?

# So Which Data Assimilation Approach?

- 3DVAR
  - good success where flow balance can be approximated...
  - getting hydrometeers parameters (Q's, N's) from reflectivity (maybe polarimetric data?)
  - cross-variable covariances either not well known, or simply unknown (very situation dependent)

# So Which Data Assimilation Approach?

- 3DVAR
  - good success where flow balance can be approximated...
  - getting hydrometeers parameters (Q's, N's) from reflectivity (maybe polarimetric data?)
  - cross-variable covariances either not well known, or simply unknown (very situation dependent)
- Ensemble approaches
  - good success across a wide variety of scales, relatively simple implementation
  - ensemble methods provide measures of uncertainty
  - reliability of B.E.C?
  - localizations for non-local data (satellite, GPM?)

# So Which Data Assimilation Approach?

- 3DVAR
  - good success where flow balance can be approximated...
  - getting hydrometeters parameters (Q's, N's) from reflectivity (maybe polarimetric data?)
  - cross-variable covariances either not well known, or simply unknown (very situation dependent)
- Ensemble approaches
  - good success across a wide variety of scales, relatively simple implementation
  - ensemble methods provide measures of uncertainty
  - reliability of B.E.C?
  - localizations for non-local data (satellite, GPM?)
- Hybrid
  - attractive...but are they the best of both?
  - need scale-dependent weights for static/ensemble BECs? (Vetra-Carvalho et al. QJRMS, 2012)
  - how to do variable dependent localization?

# So Which Data Assimilation Approach?

- 3DVAR
  - good success where flow balance can be approximated...
  - getting hydrometeers parameters (Q's, N's) from reflectivity (maybe polarimetric data?)
  - cross-variable covariances either not well known, or simply unknown (very situation dependent)
- Ensemble approaches
  - good success across a wide variety of scales, relatively simple implementation
  - ensemble methods provide measures of uncertainty
  - reliability of B.E.C?
  - localizations for non-local data (satellite, GPM?)
- Hybrid
  - attractive...but are they the best of both?
  - need scale-dependent weights for static/ensemble BECs? (Vetra-Carvalho et al. QJRMS, 2012)
  - how to do variable dependent localization?
- Multiple scales/Multiple passes?
  - 3DVAR/Hybrid at larger scales, ensemble DA at convective scales
  - fully-in-core ensemble lowers cost barrier to multi-pass methods: No I/O cost.
  - may make sense to do some DA at coarser resolutions (Ancell MWR 2012)

# Summary

- Sufficient progress has been made by CAPS, NCAR, GSD, and NSSL etc to continue supporting WoF-TTP research.
- An operational WoF-TTP is ~decade away
- Significant issues remain with RT radar data QC, NextGen radar systems must QC at hardware level
- For convective scales - DA requires ensemble approach for BECs
- CONUS deployment of monolithic 1 km ensemble may have significant technical hurdles
- Adaptive NWP approach is needed for foreseeable future
- Initial WoF-TTP system should be deployed first to SPC
    - possible to test in 5-7 years.

# Thank You

# Questions?

# Overall Approaches

- That was the Monolithic Version of WoF-TTP
  - Could it work?  Eh...High-risk? Probably!
- Adaptive Approaches
  - Limited region, on-demand WoF-TTP modeling
  - EMC does this already:  GFDL model, HWRF, NMMB Fire-Wx
- Other Adaptive
  - Dynamic Grid adaption
  - Spectral Element / DG block adaptive
  - Berger-Oliger adaptive gridding

# Dynamic Grid Adaption

**A Fast Dynamic Grid Adaption Scheme for Meteorological Flows**

BRIAN H. FIEDLER AND R. JEFFREY TRAPP

*School of Meteorology, University of Oklahoma, Norman, Oklahoma*

(Manuscript received 5 October 1992, in final form 27 April 1993)

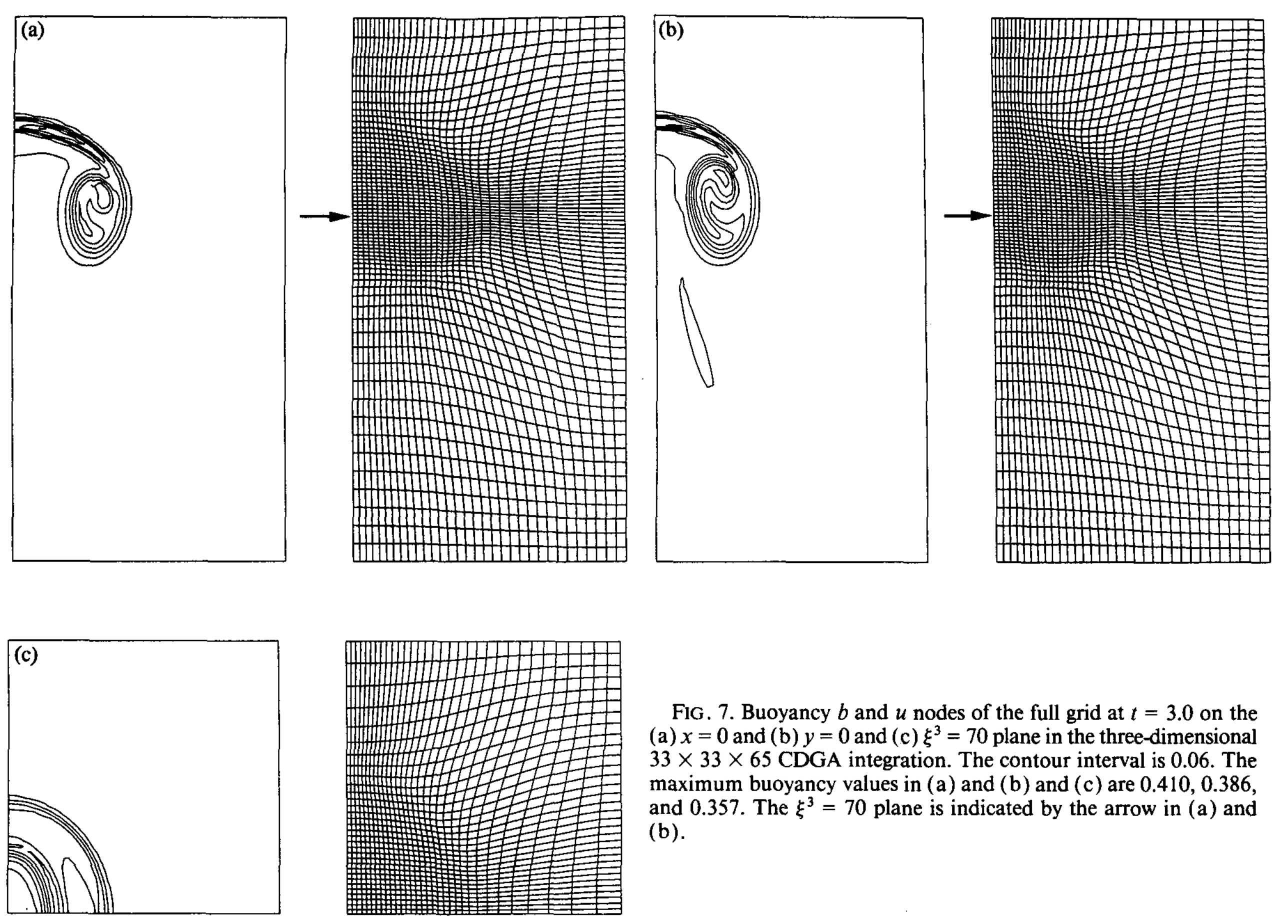


FIG. 7. Buoyancy $b$ and $u$ nodes of the full grid at $t = 3.0$ on the (a) $x = 0$ and (b) $y = 0$ and (c) $\xi^3 = 70$ plane in the three-dimensional $33 \times 33 \times 65$ CDGA integration. The contour interval is 0.06. The maximum buoyancy values in (a) and (b) and (c) are 0.410, 0.386, and 0.357. The $\xi^3 = 70$ plane is indicated by the arrow in (a) and (b).

**Application of Continuous Dynamic Grid Adaption Techniques to Meteorological Modeling. Part II: Efficiency**

GARY S. DIETACHMAYER

*Bureau of Meteorology Research Centre, Melbourne, Australia*

(Manuscript received 11 November 1990, in final form 27 August 1991)

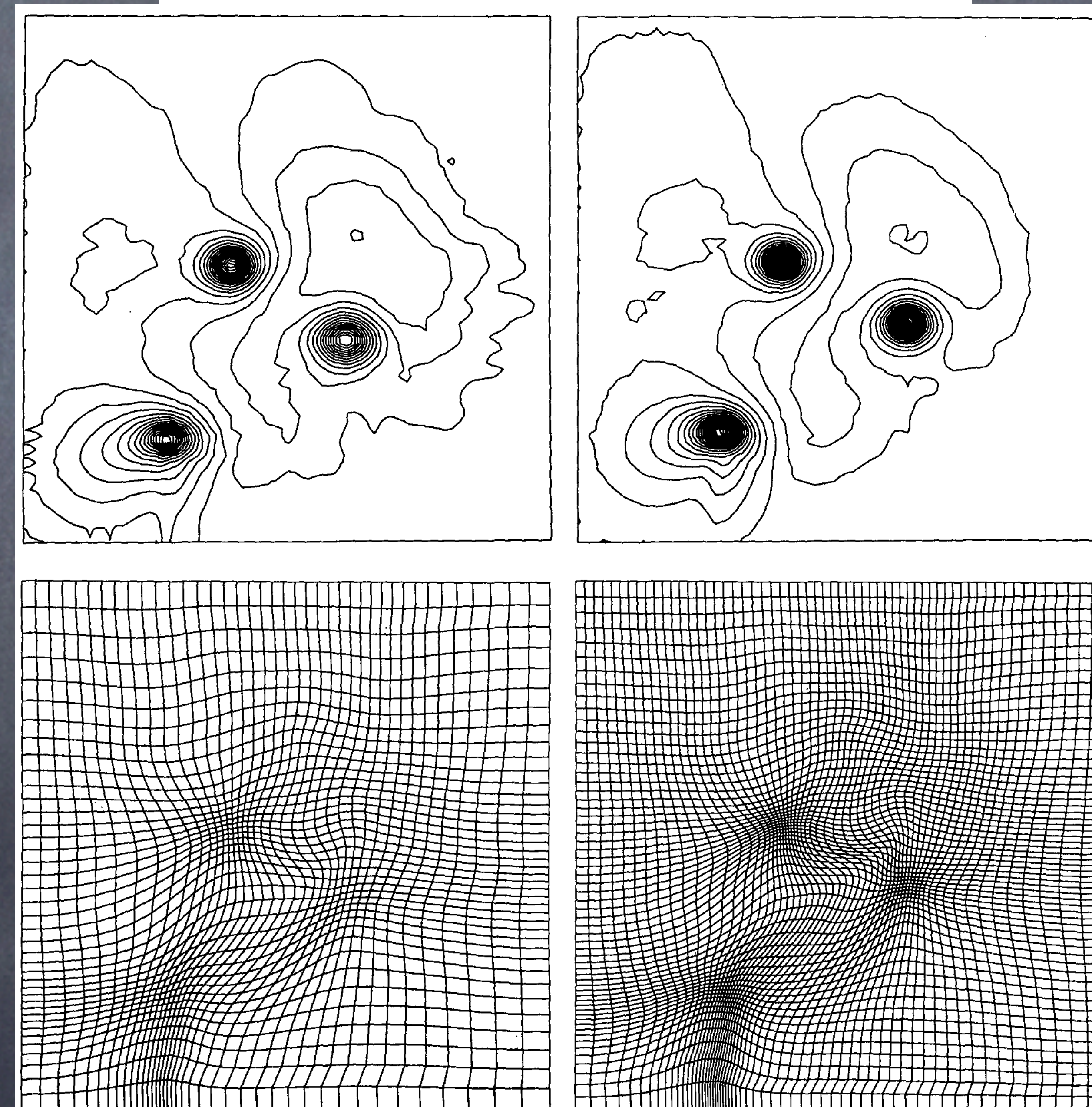
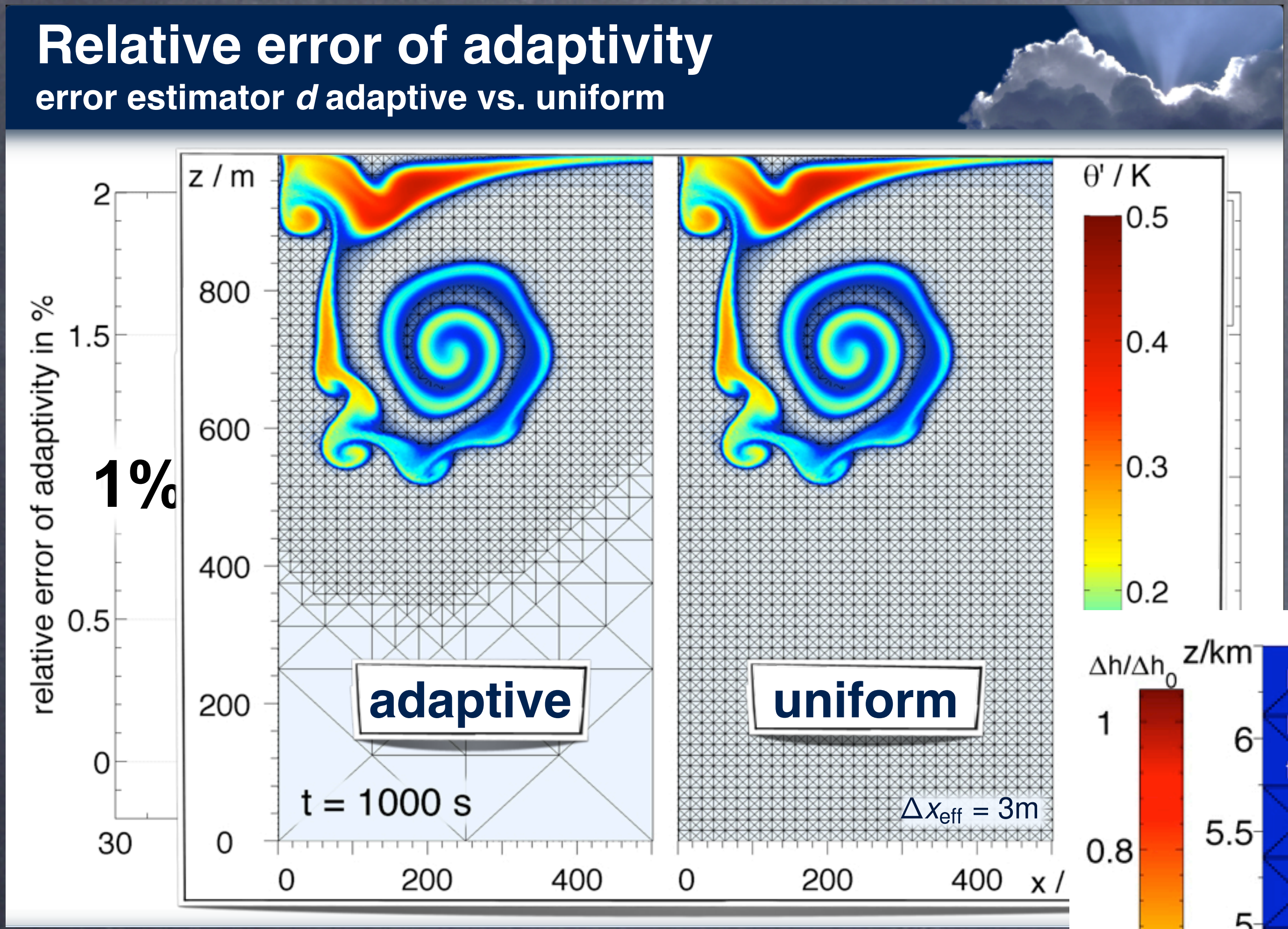


FIG. 4. Height field and associated gridpoint distribution at 72 h for the adaptive primary experiments of section 4a. Contour interval is 20 m. Specific experiments: [(a) and (b)] A $41^2$, [(c) and (d)] A $61^2$, and [(e) and (f)] A $81^2$. Maximum and minimum height values (m): (a) 4280, 3865, (c) 4265, 3743, and (e) 4263, 3709.

Could a 2 km CONUS grid do a large convective outbreak at 1 km?
(do you have enough degrees of freedom?)

# Block Adaptive DG

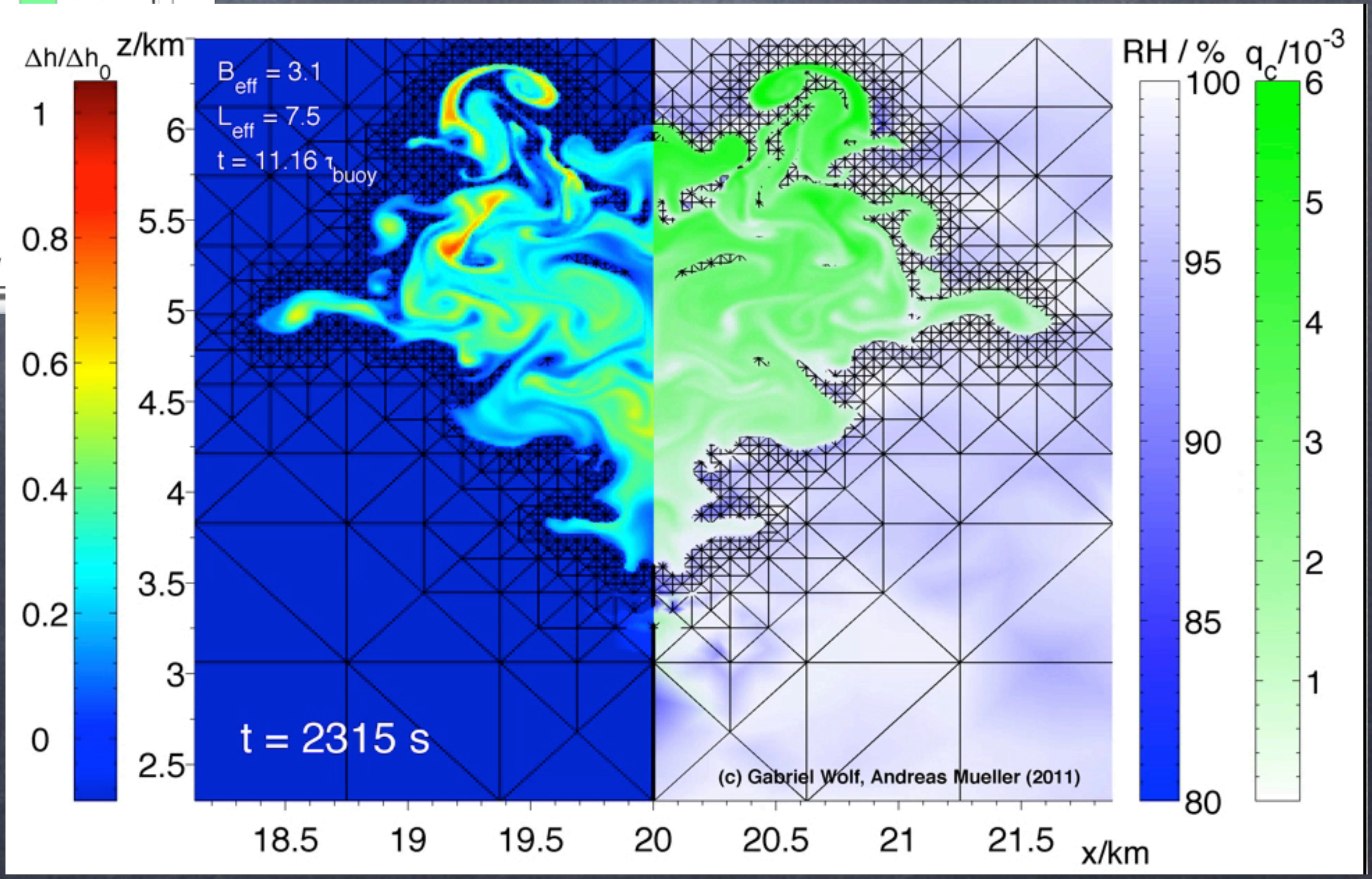
## F. Giraldo, NUMA Model, etc.




Credit: A. Muller, NPS
From: http://www.newton.ac.uk/programmes/AMM/seminars/2012082313301.pdf

Moist Cloud

Dry Thermal



# Berger-Oliger Adaption

**Adaptive Grid Refinement for Two-Dimensional and Three-Dimensional Nonhydrostatic Atmospheric Flow**

WILLIAM C. SKAMAROCK AND JOSEPH B. KLEMP

*National Center for Atmospheric Research,* Boulder, Colorado*

(Manuscript received 7 February 1992, in final form 19 July 1992)

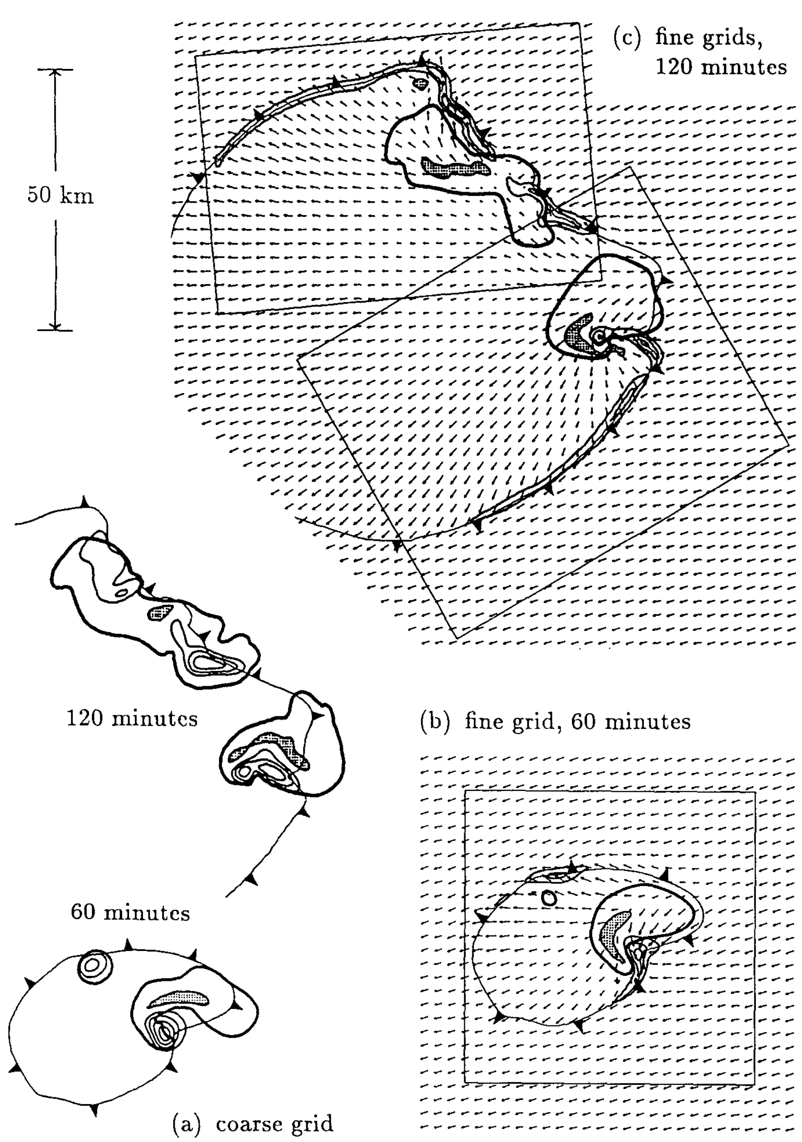



FIG. 6. Adaptive simulation of 20 May Del City supercell storm with $\Delta x_c = 3$ km, $\Delta x_f = 1$ km: (a) at $z = 3150$ m on the stationary coarse grid at 60 and 120 min, (b) at $z = 250$ m on the fine grid at 60 min, and (c) on the two fine grids at 120 min. The cold-frontal boundary in all figures is at $z = 250$ m and denotes the $-1°C$ potential temperature perturbation. The heavy solid lines represent the 0.5 g $kg^{-1}$ rainwater contour. Velocity vectors are for storm relative winds with storm velocities $U_s = 3$ m $s^{-1}$ and $V_s = 14.6$ m $s^{-1}$. Vertical velocity is contoured at 1 m $s^{-1}$ in (b) and (c) and at 5 m $s^{-1}$ in (a) with the negative regions being stippled and zero contours removed.

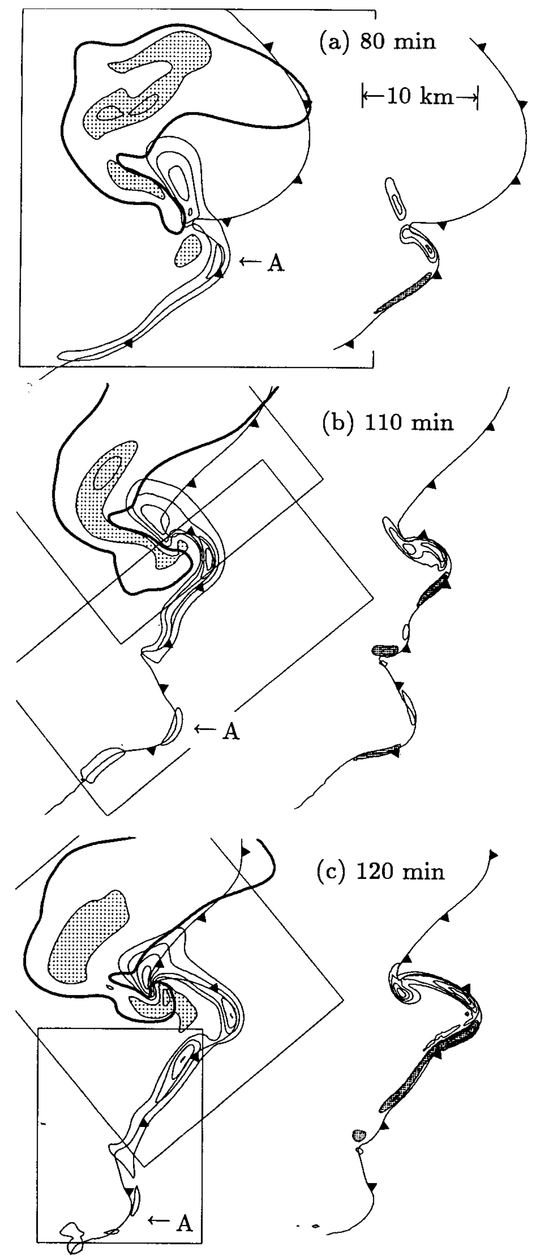



FIG. 9. Fields and vorticity at $z = 250$ m for the fine grids at (a) 80 min, (b) 110 min, and (c) 120 min. The vorticity is plotted to the right of the flow fields. Plotting is as in Figs. 7 and 8.

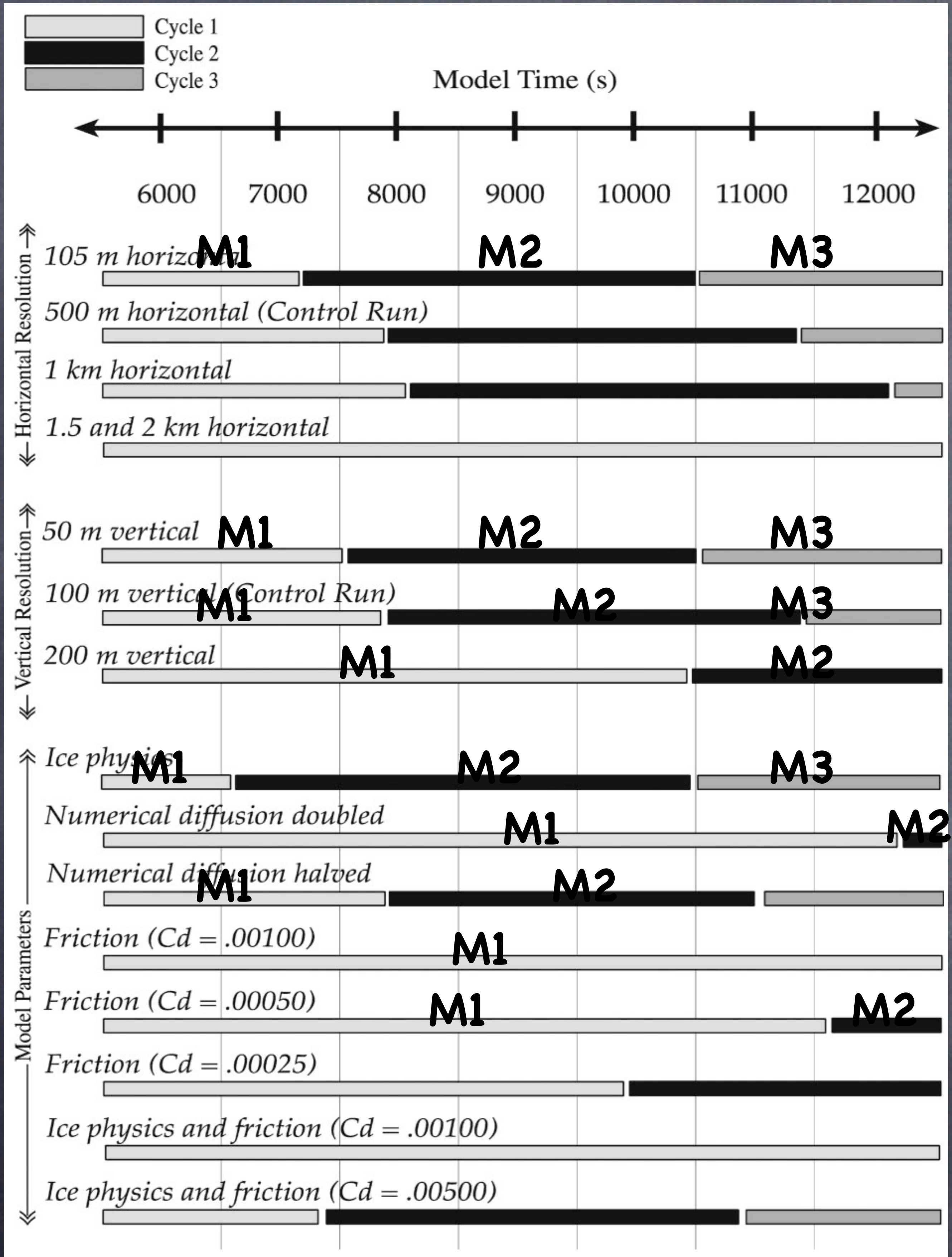
**Three-Dimensional Evolution of Simulated Long-Lived Squall Lines**

WILLIAM C. SKAMAROCK, MORRIS L. WEISMAN, AND JOSEPH B. KLEMP

*National Center for Atmospheric Research,* Boulder, Colorado*

(Manuscript received 17 May 1993, in final form 2 February 1994)


FIG. 11. Horizontal cross sections from the Coriolis simulations at 3000 m plotted in ground-relative coordinates at 2, 6, and 10 h. Plotted as in Fig. 4. Note the strong system growth and migration toward the southeast. The finest-resolution grids are included at the three times.




Timing of sequential mesoscylone circulations in supercell

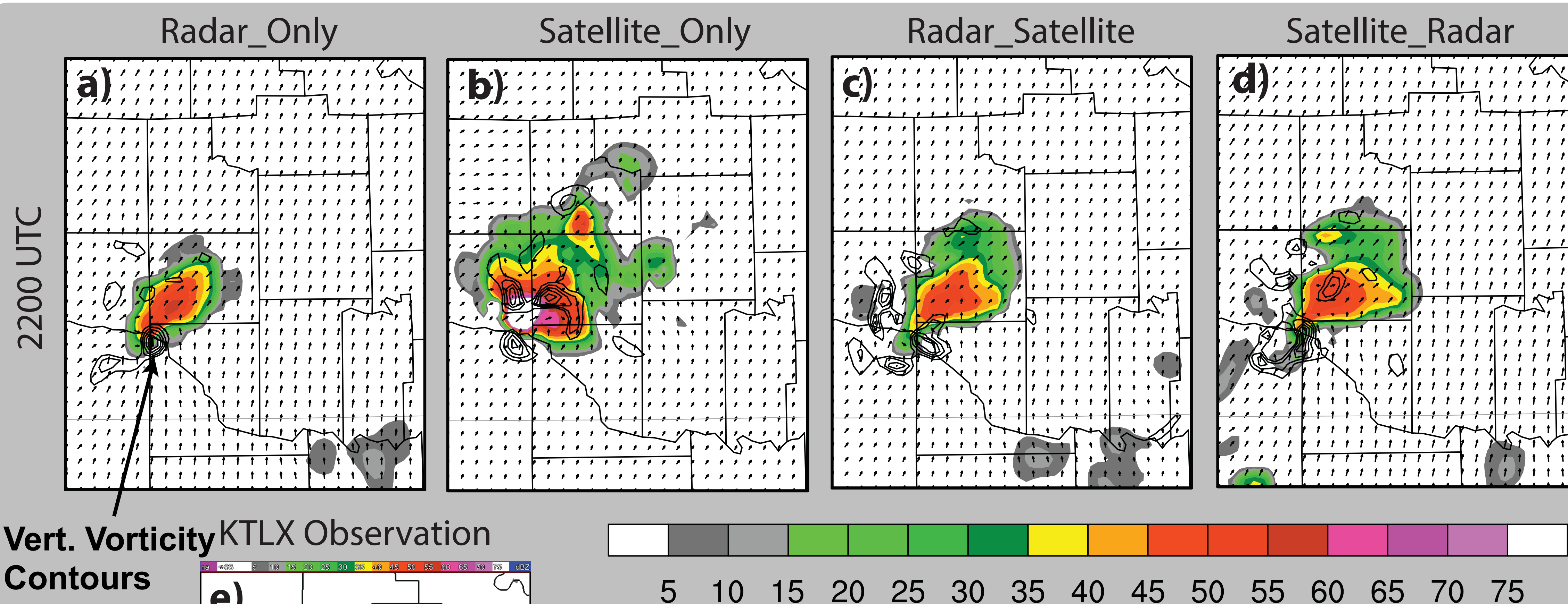
# Model Uncertainty?

- Importance of current convective scale model errors need to more carefully studied
- Models have a number of parameters, parameterizations, and choices which can greatly impact the internal evolution of the storm.

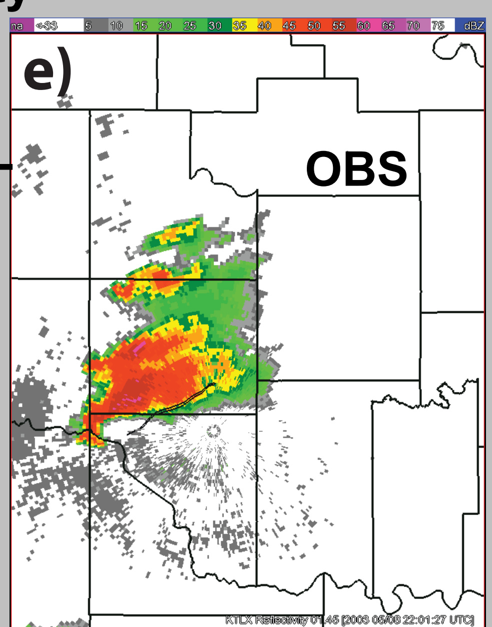
from Adlerman and Droegemeier MWR 2002

# Research Mode: Multiscale EnKF using both Radar and Satellite Data

M. Vaughn, T. Jones, N. Yussouf




KTLX Observation




## 2200 UTC Analysis

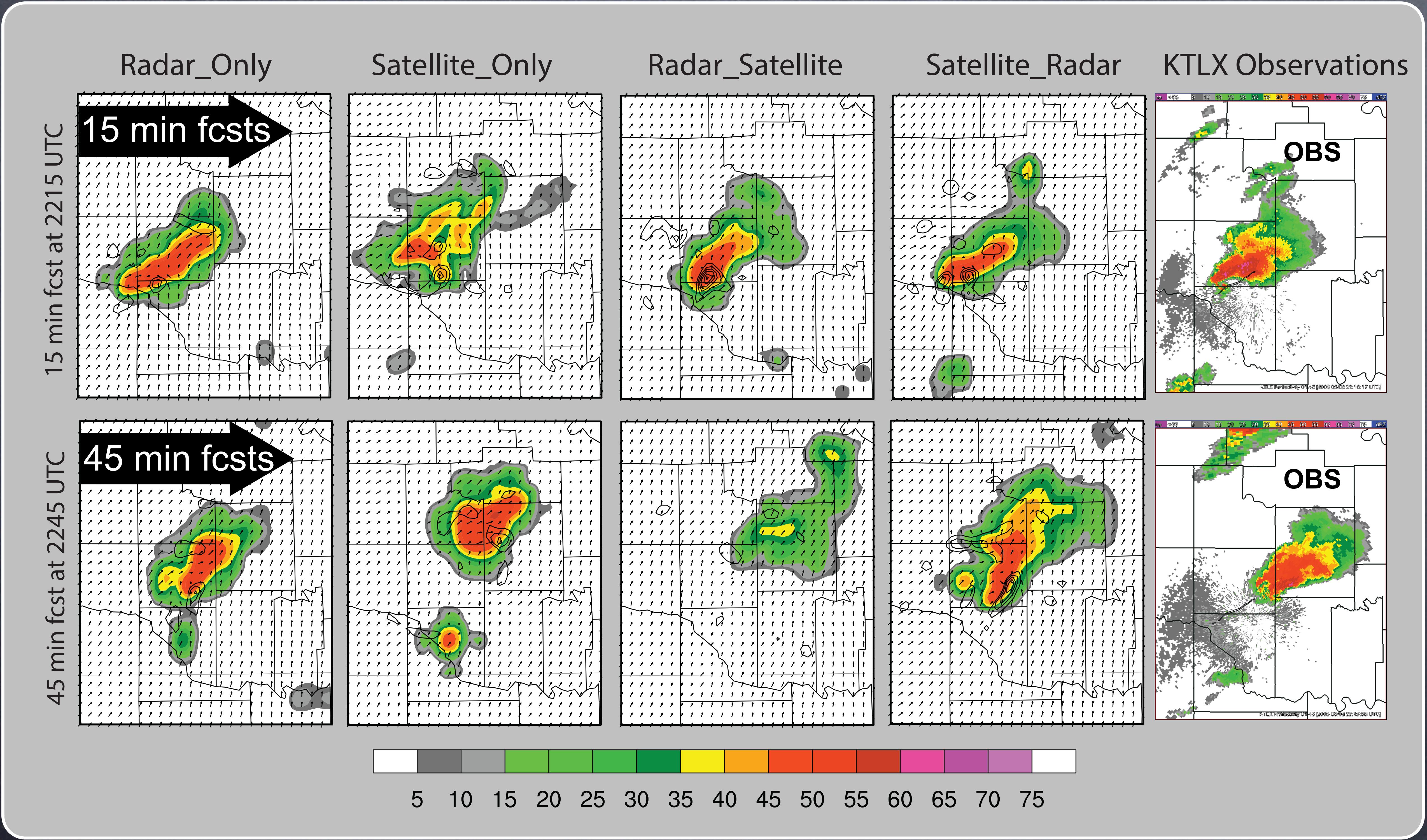
Radar_Satellite = DA radar then CLWP

Radar_Satellite: Assim radar then Cloud Liq Water Path

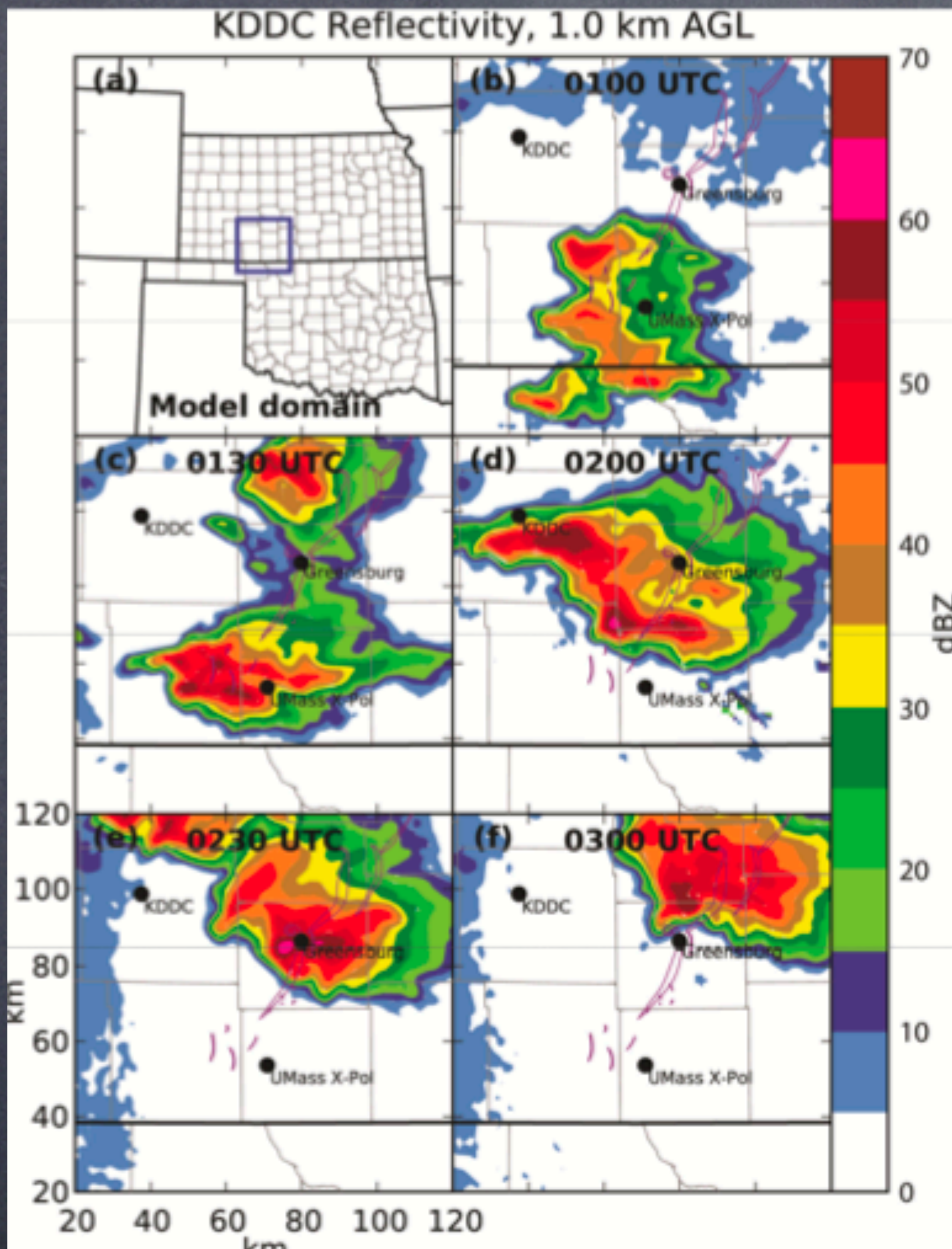
Satellite_Radar: Assim Cloud Liq Water Path then radar

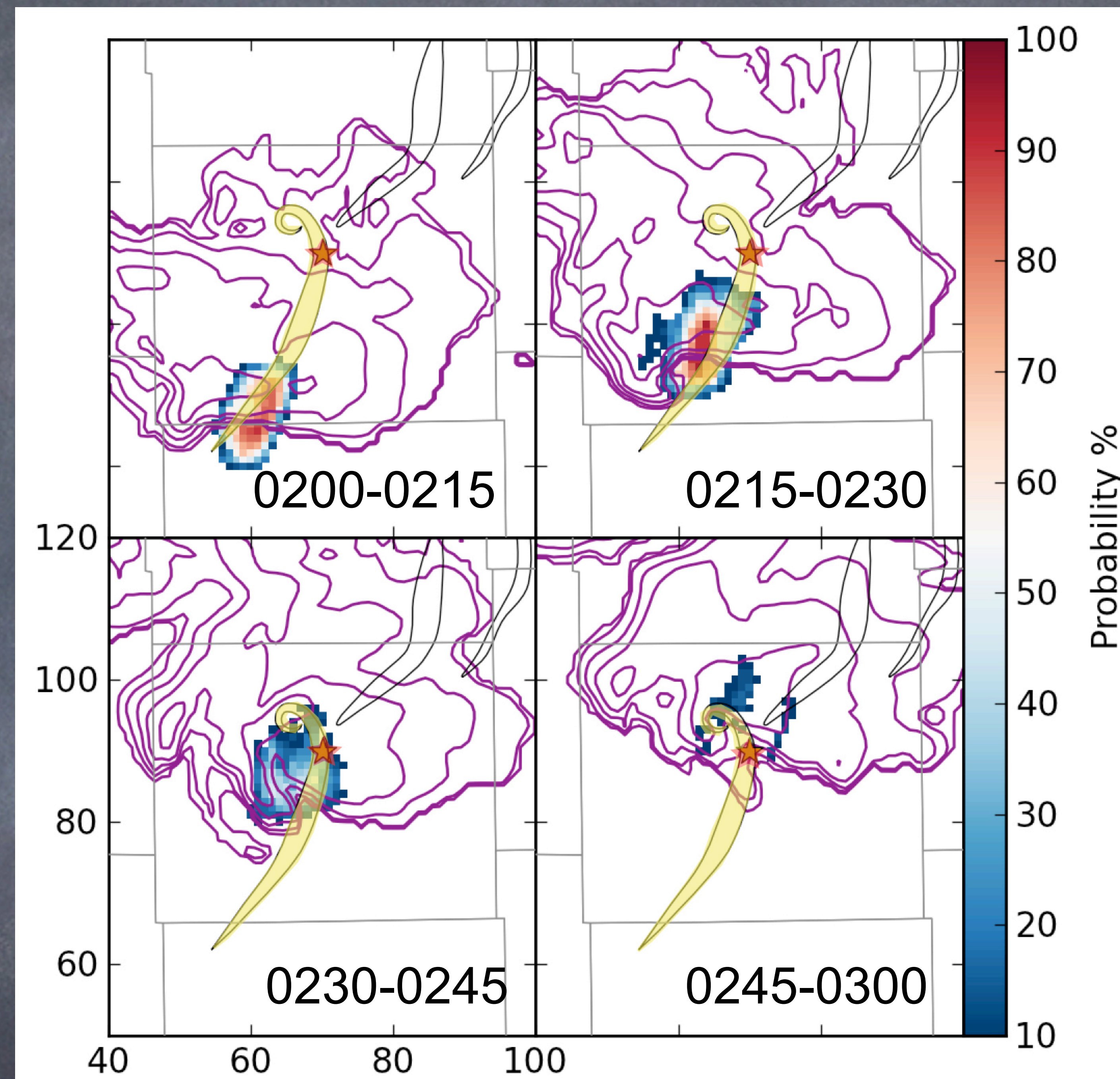
# Research Mode: Multiscale EnKF using both Radar and Satellite Data

M. Vaughn, T. Jones, N. Yussouf



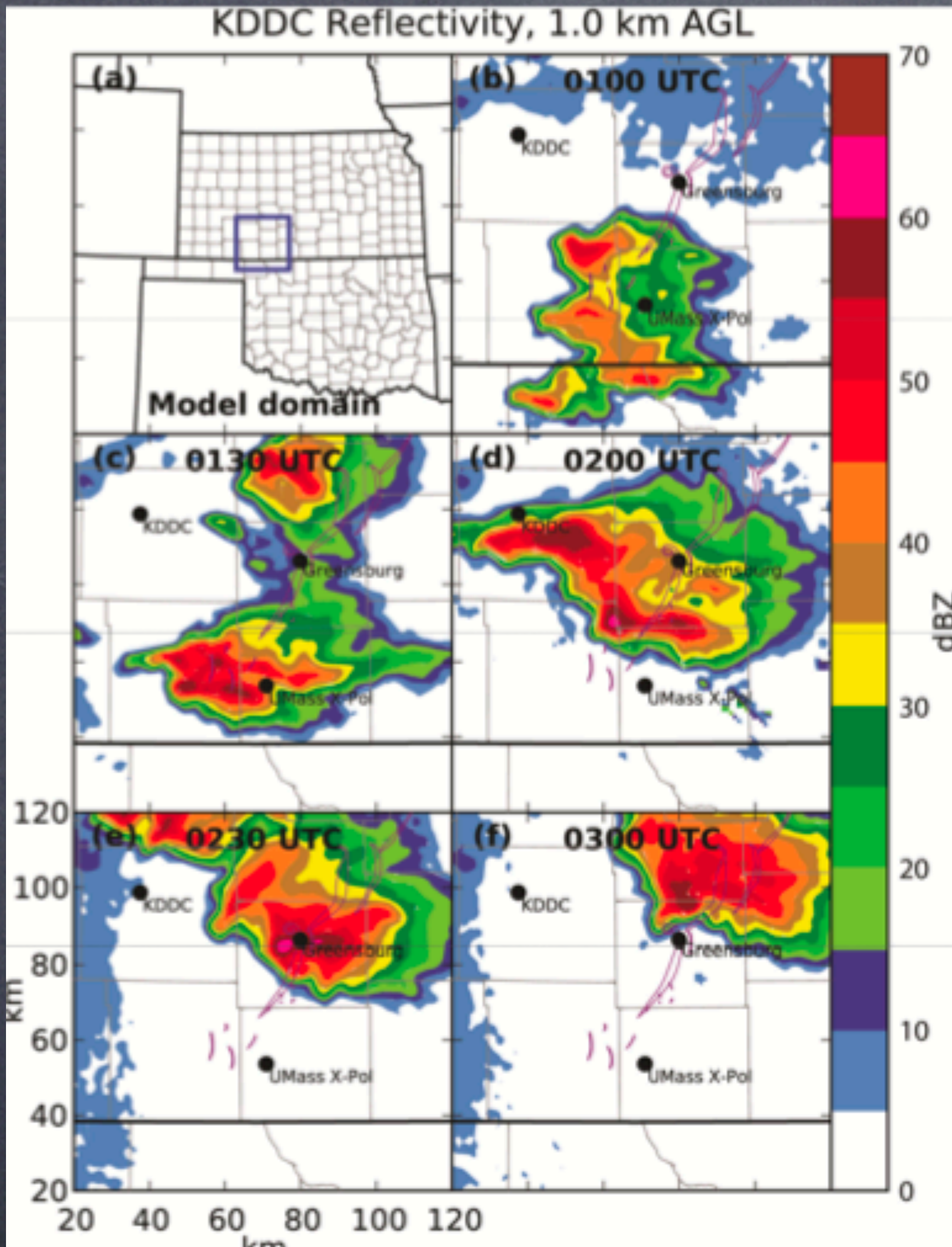
# Research Mode: EnKF DA Probabilistic Forecasts at 1 km

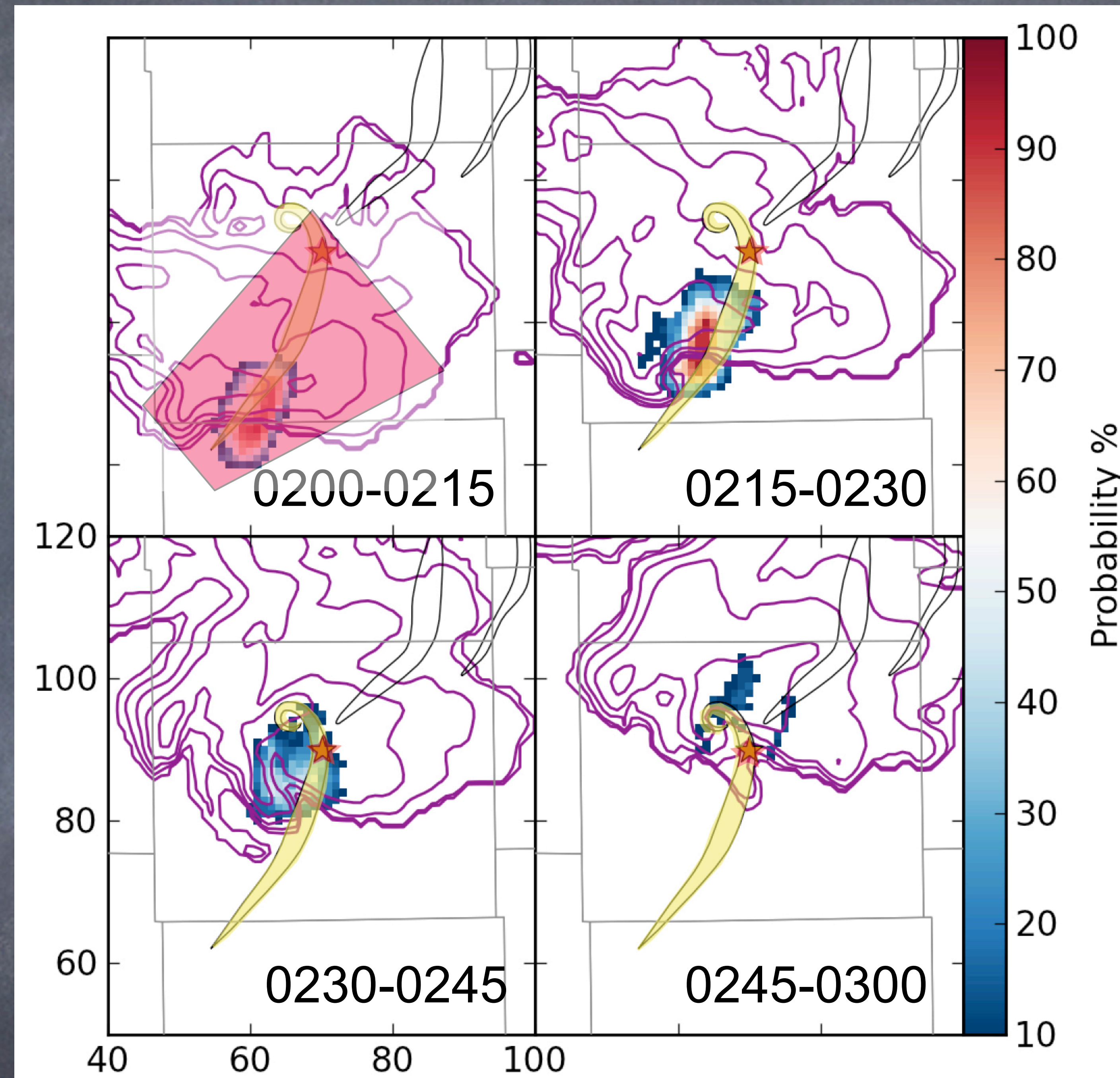



- Greensburg KS 4 May 2007 EF5 tornado
- Probability of strong low-level rotation over 15-minute forecast intervals
- Greensburg tornado track is shaded yellow, other tornadoes only black lines.
- Model-derived mean radar reflectivity by purple lines.
- Location of Greensburg KS indicated by the star.

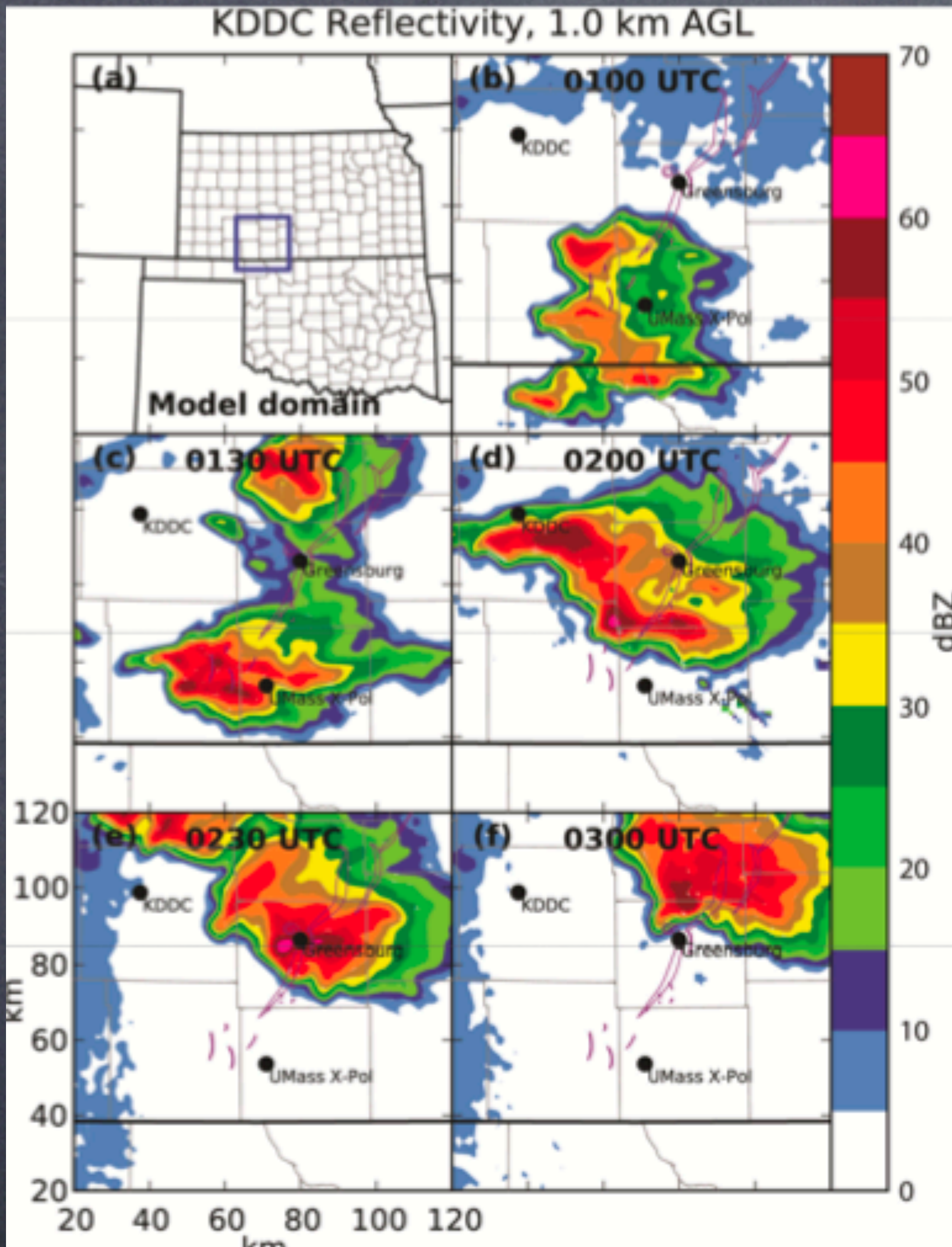
# Research Mode: EnKF DA Probabilistic Forecasts at 1 km

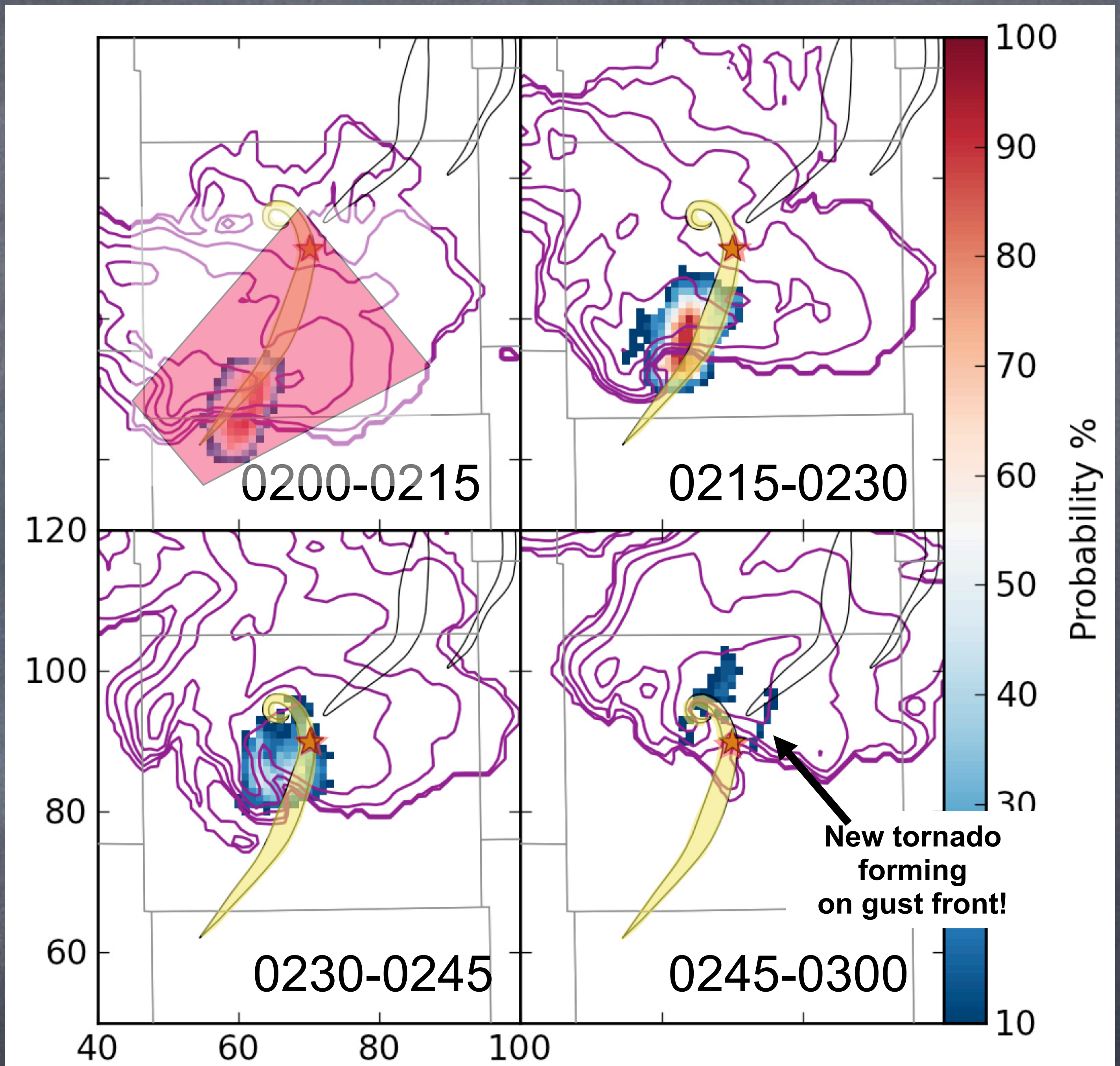



- Greensburg KS 4 May 2007 EF5 tornado
- Probability of strong low-level rotation over 15-minute forecast intervals
- Greensburg tornado track is shaded yellow, other tornadoes only black lines.
- Model-derived mean radar reflectivity by purple lines.
- Location of Greensburg KS indicated by the star.

# Research Mode: EnKF DA Probabilistic Forecasts at 1 km




- Greensburg KS 4 May 2007 EF5 tornado
- Probability of strong low-level rotation over 15-minute forecast intervals
- Greensburg tornado track is shaded yellow, other tornadoes only black lines.
- Model-derived mean radar reflectivity by purple lines.
- Location of Greensburg KS indicated by the star.

Warn on Forecast

Radar Data QC Improvements

Case Studies: Where are we now?

Environmental Sensitivity, Improved Mesoscale Prediction

Development of Data Assimilation Methods, Linkages to RR/HRRR

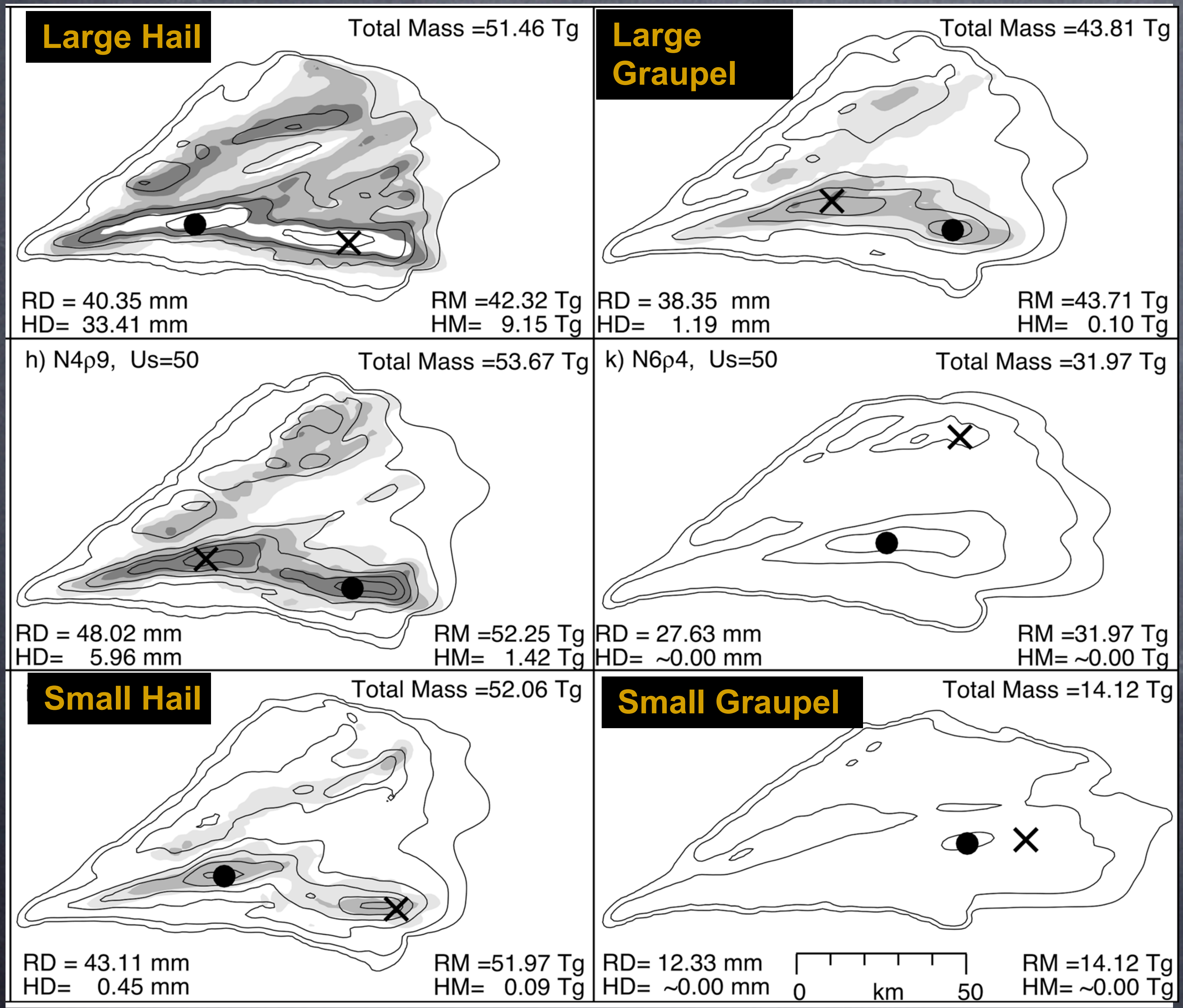
How to best use probabilistic information: HWT, SDPG and SSWIM

VORTEX2 Studies

Model Physics Improvements

2010 2015 2020

# Microphysics Sensitivity:
## Accumulated Precip affected by Hail/Graupel Density and No. Concentration parameters



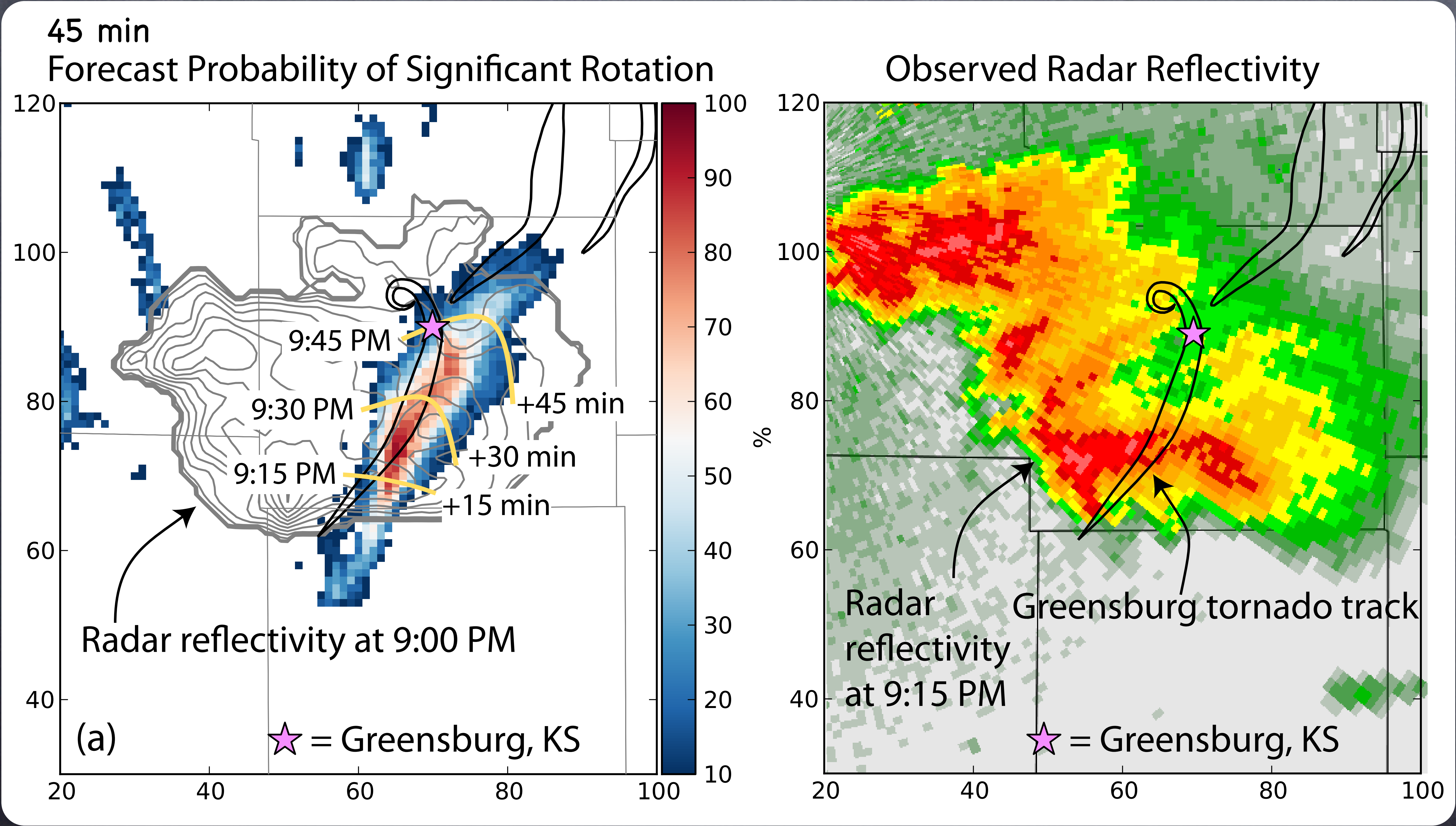

Single moment microphysics...
3 hour integration

**from Gilmore et al. MWR, 2004b**

**Large Sensitivity!**

Parameter variations over observed ranges of changes total precip by factor of ~4

# But if things were so bleak...



# Impact of Mesoscale Forecast Errors on convective forecasts

- *Cintineo and Stensrud, JAS, 2012*
  - obtained typical forecast errors from mesoscale models soundings (U, V, T, RH)
  - generated ensemble forecasts in simple homogeneous environments for supercells using these errors
  - examine the impacts from these uncertainties
  - perfect model assumption

# Radar Data QC

## Velocity QC

| DIFFERENCE | N | hit | Gate missed for dealias | Gate used wrong Nyquist |
|---|---|---|---|---|
| 2D-Raw | 62,898,616 | 61,036,300 | 1,697,813 | 164,503 |
| Legacy-Raw | 62,898,616 | 61,039,078 | 1,696,103 | 163,435 |
| Truth-2D | 62,899,323 | 62,881,353 | 6,754 | 8,587 |
| Truth-Legacy | 62,899,323 | 62,873,003 | 10,982 | 12,675 |
| Truth-Raw | 62,899,323 | 61,033,726 | 1,698,514 | 167,063 |

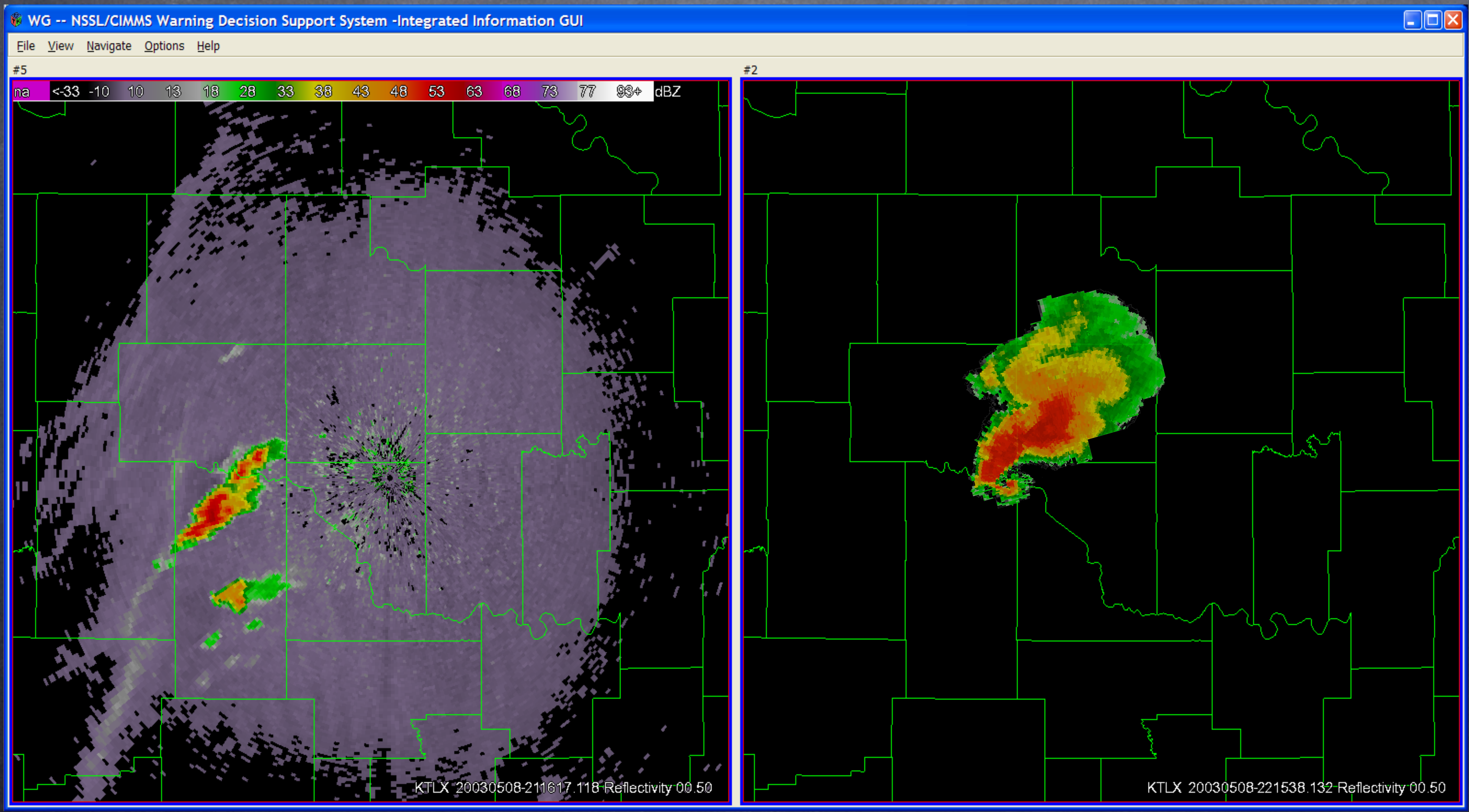
# Radar Data QC

Errors ~4%
Problem: Many errors occur in regions of high velocity gradient from storm dynamics

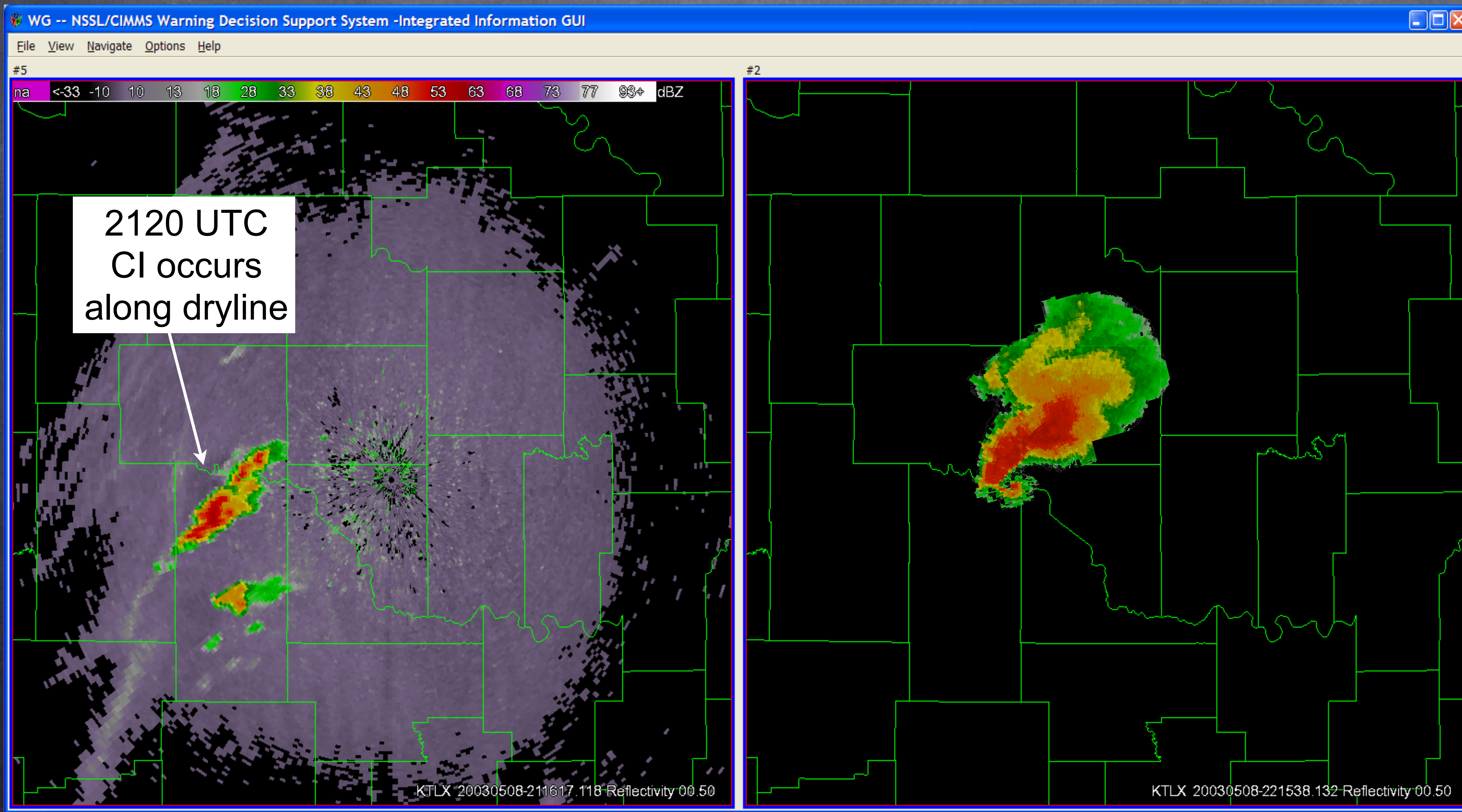
## Velocity QC

| DIFFERENCE | N | hit | Gate missed for dealias | Gate used wrong Nyquist |
|---|---|---|---|---|
| 2D-Raw | 62,898,616 | 61,036,300 | 1,697,813 | 164,503 |
| Legacy-Raw | 62,898,616 | 61,039,078 | 1,696,103 | 163,435 |
| Truth-2D | 62,899,323 | 62,881,353 | 6,754 | 8,587 |
| Truth-Legacy | 62,899,323 | 62,873,003 | 10,982 | 12,675 |
| Truth-Raw | 62,899,323 | 61,033,726 | 1,698,514 | 167,063 |

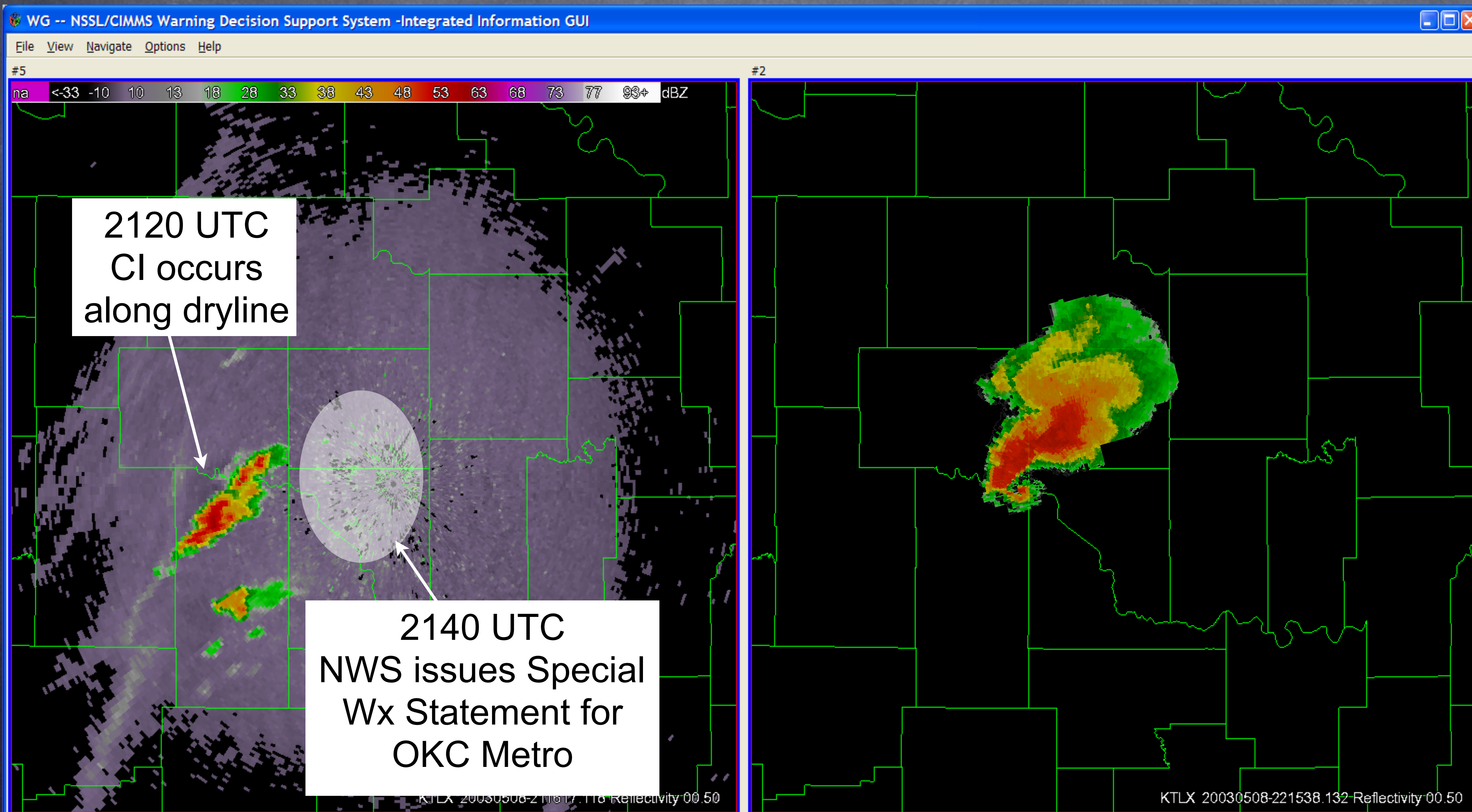
# Current T-Warning Process



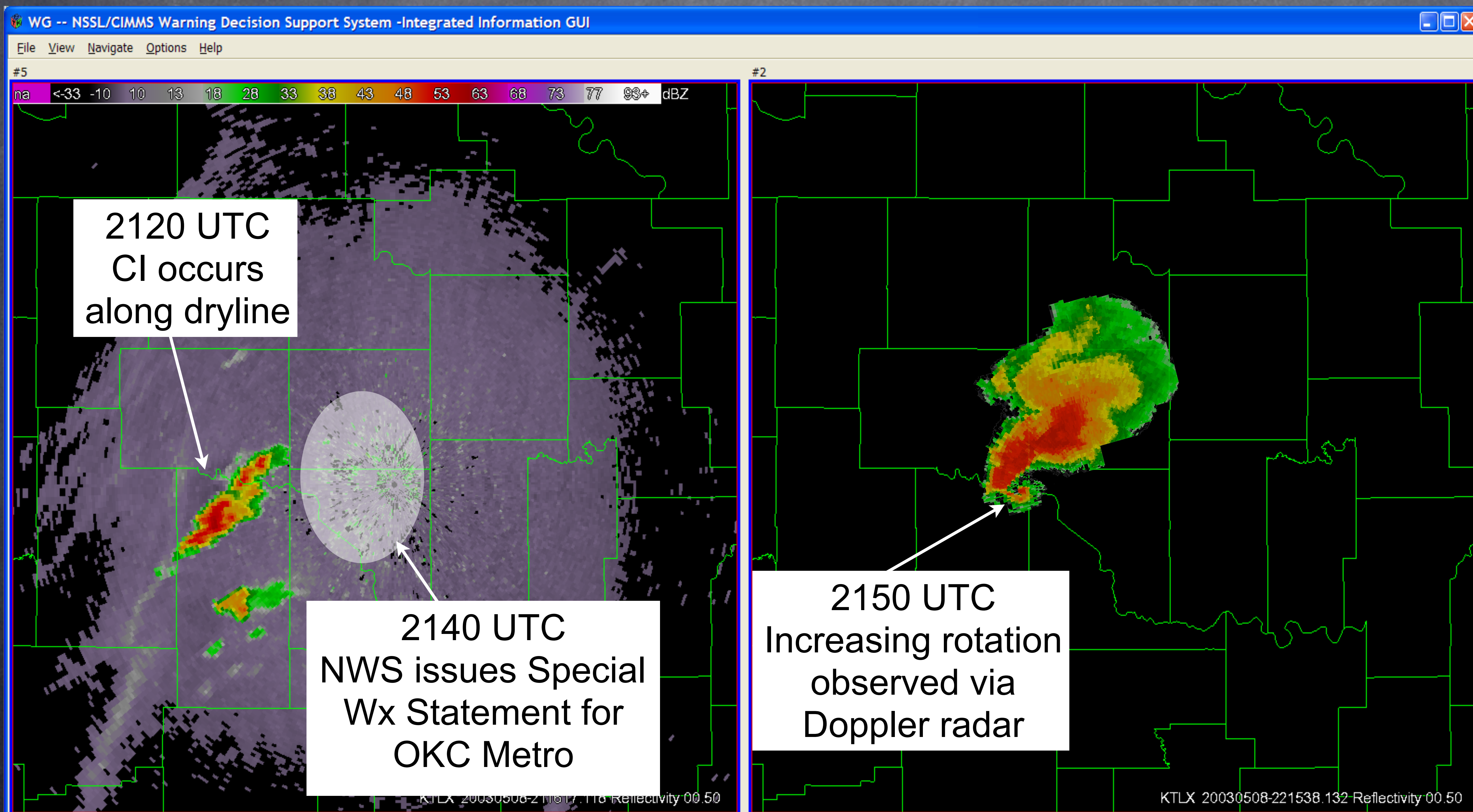
# Current T-Warning Process



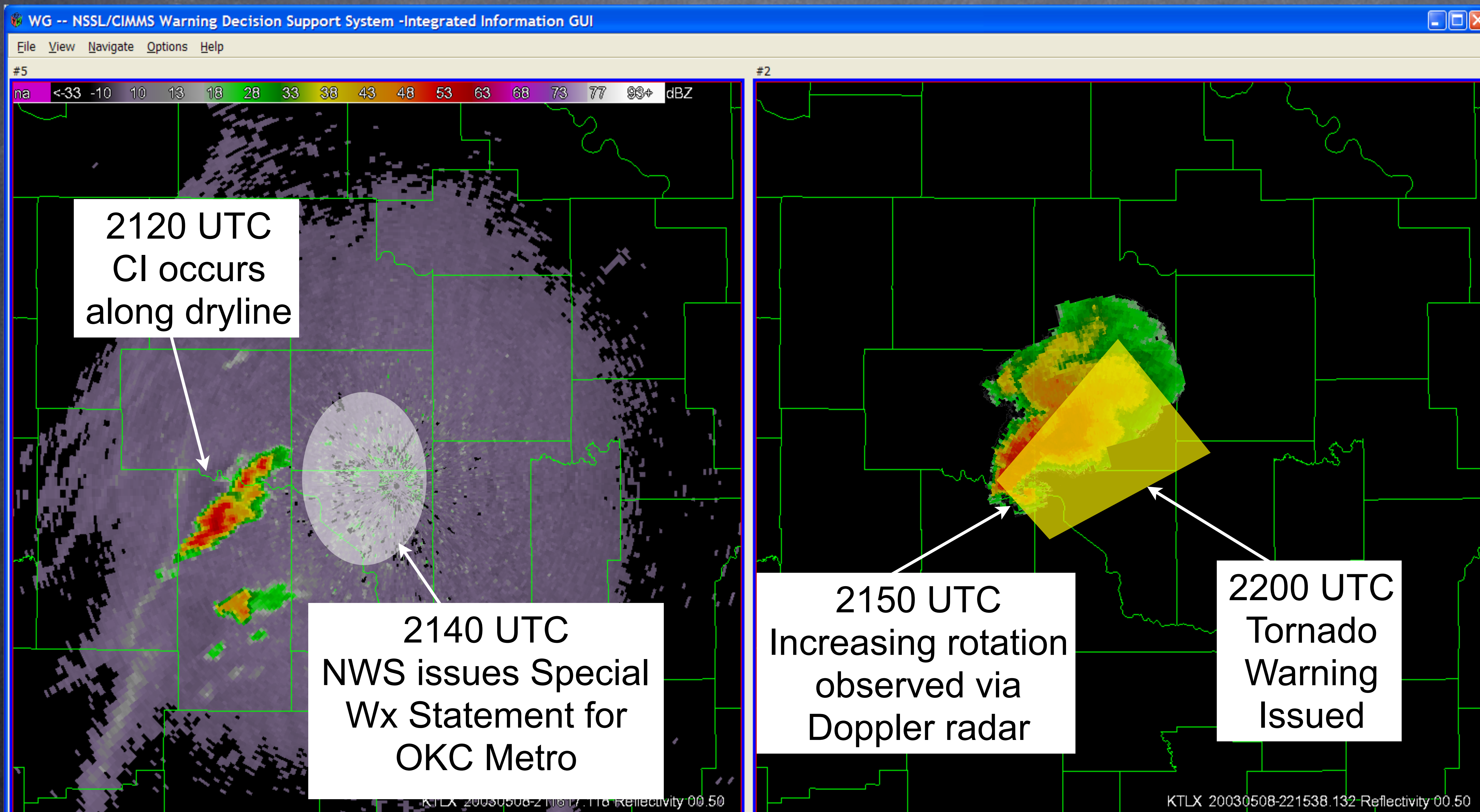
# Current T-Warning Process



# Current T-Warning Process

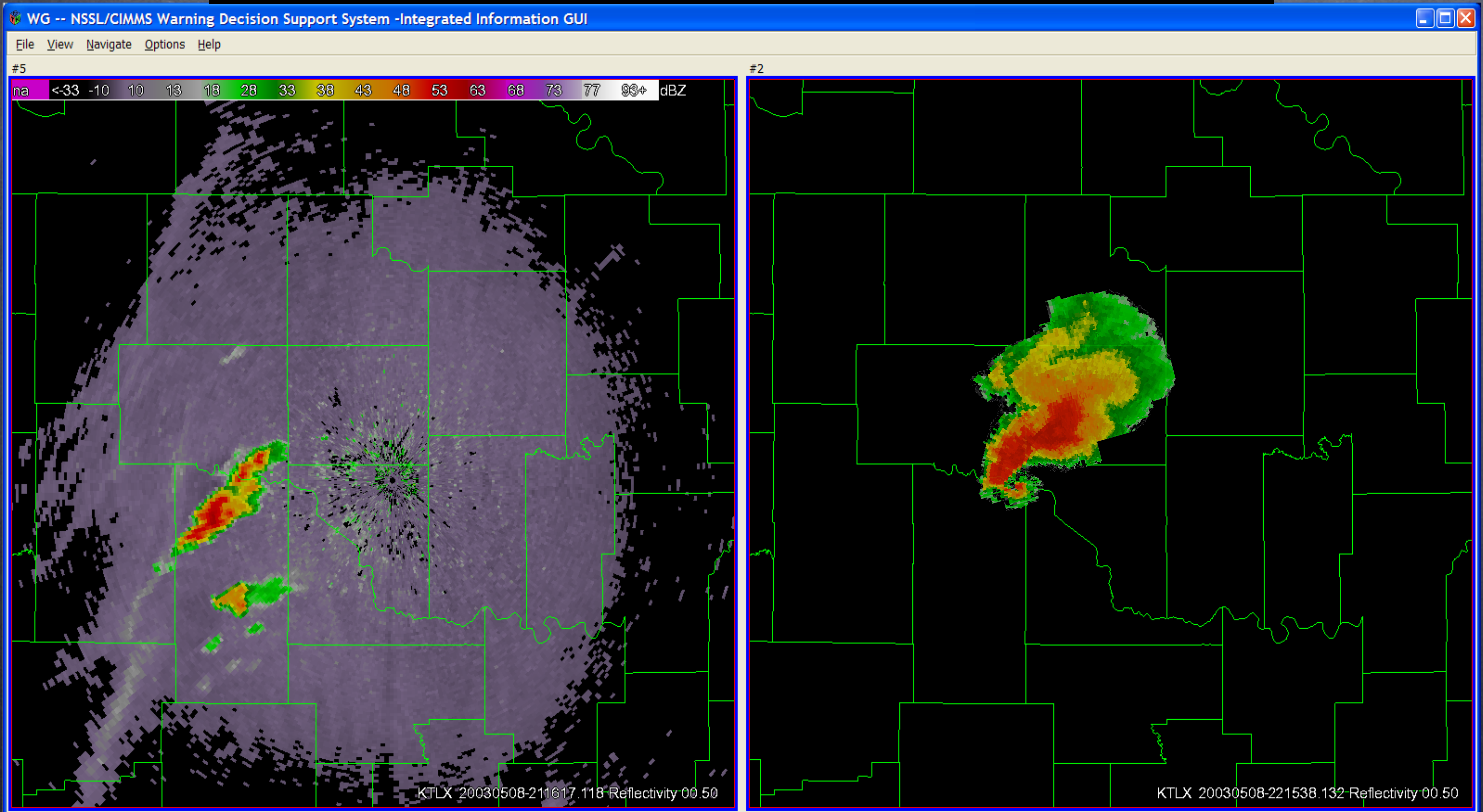


# Current T-Warning Process



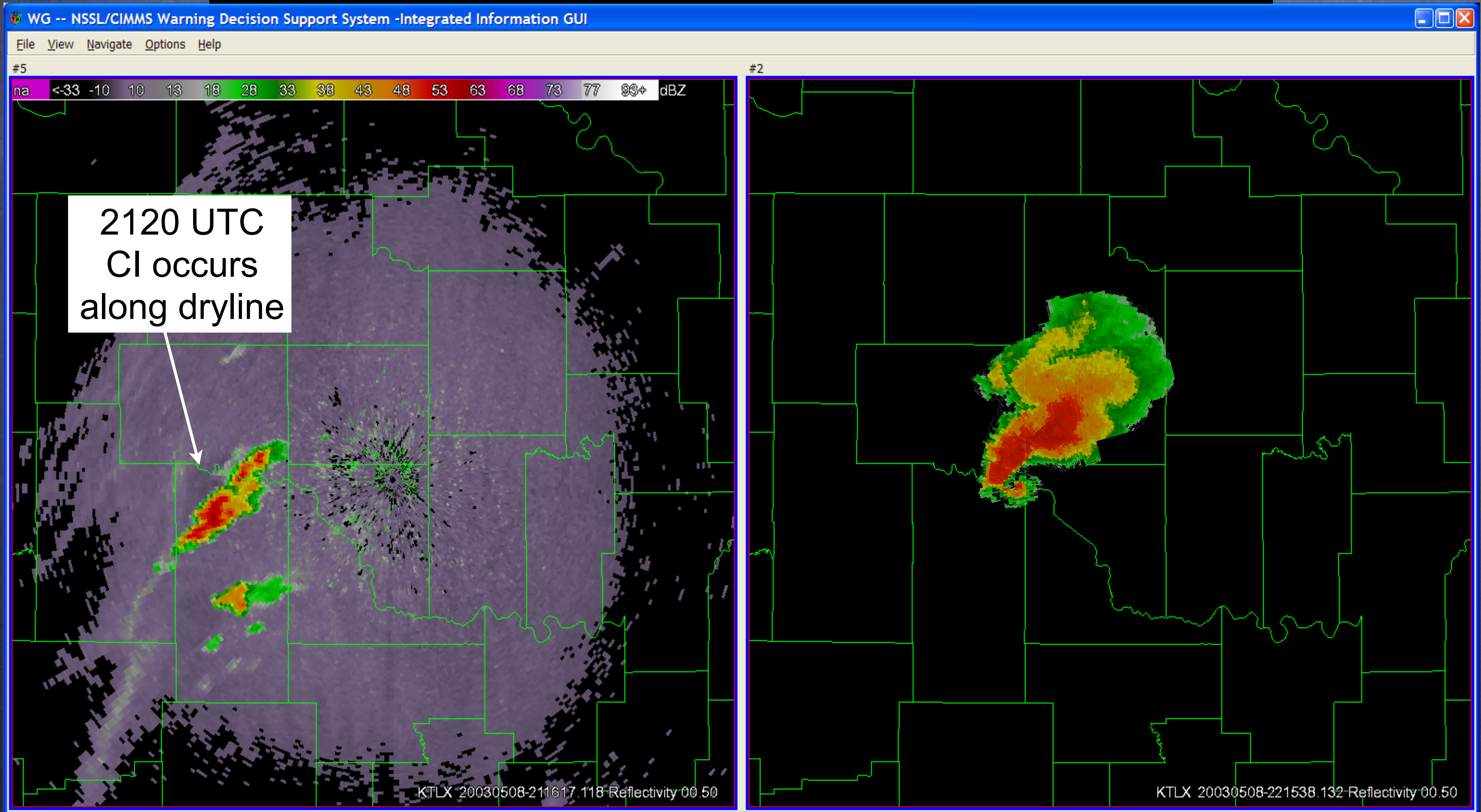
# WoF-TTP Process

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.



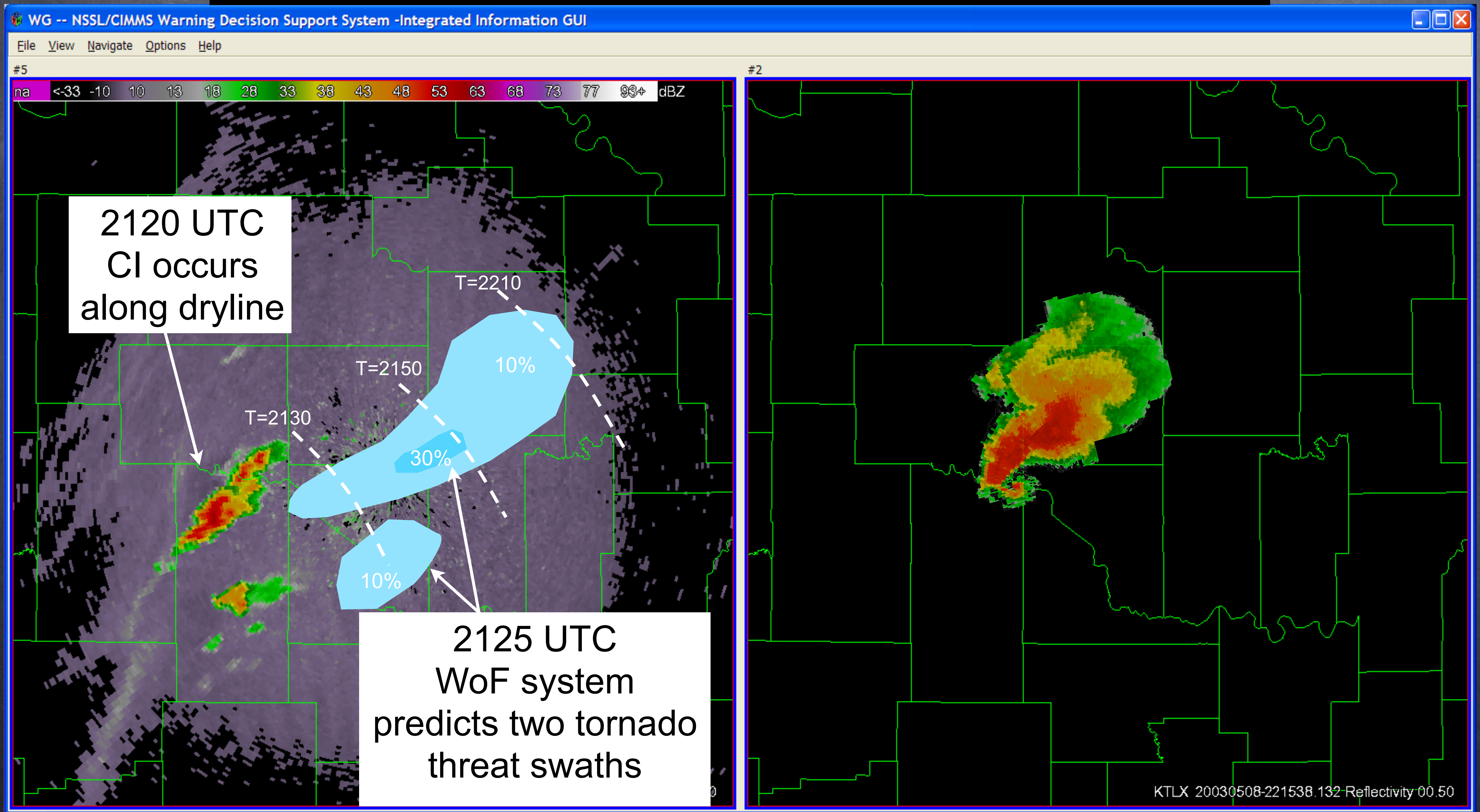
# WoF-TTP Process

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.



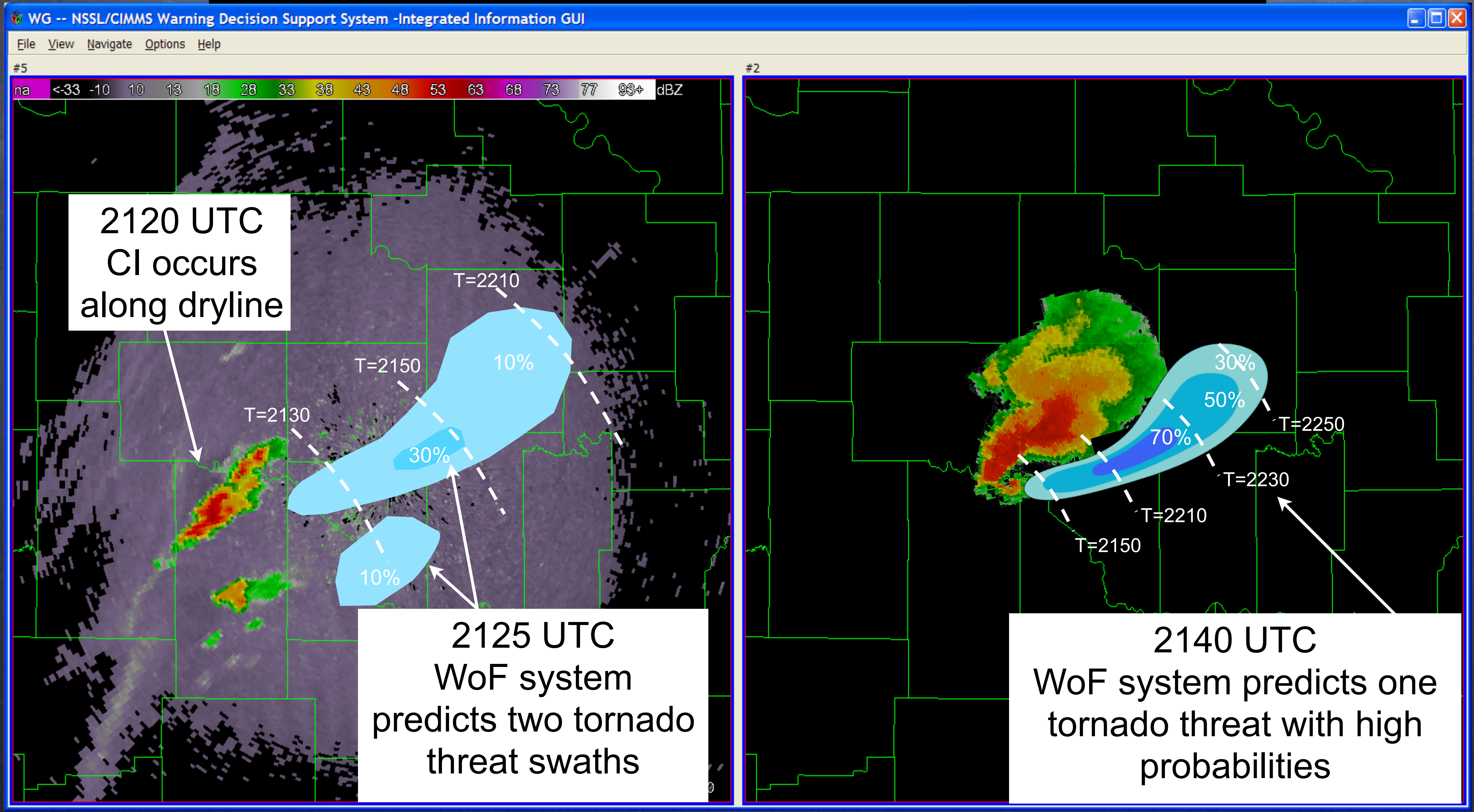
# WoF-TTP Process

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.



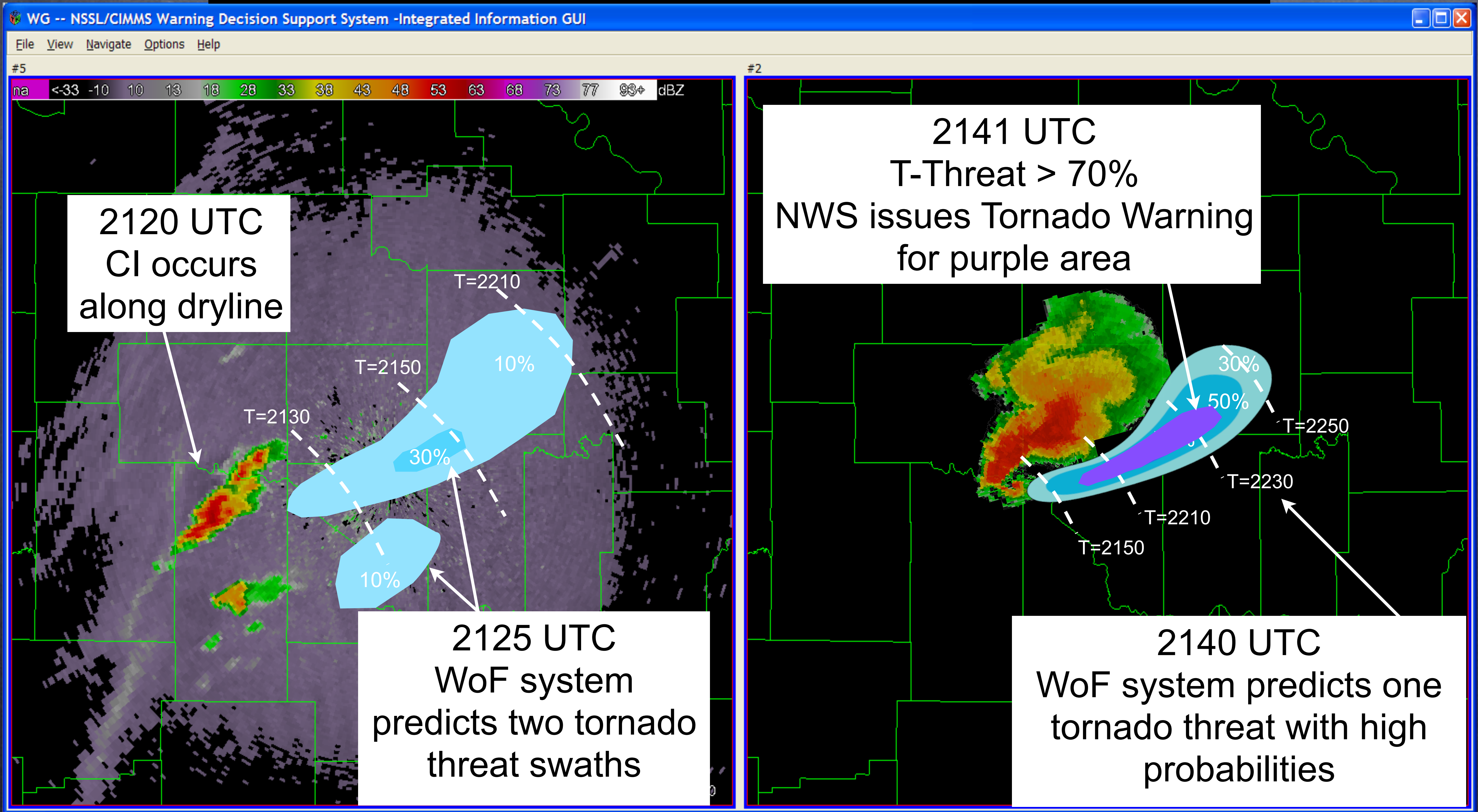
# WoF-TTP Process

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.



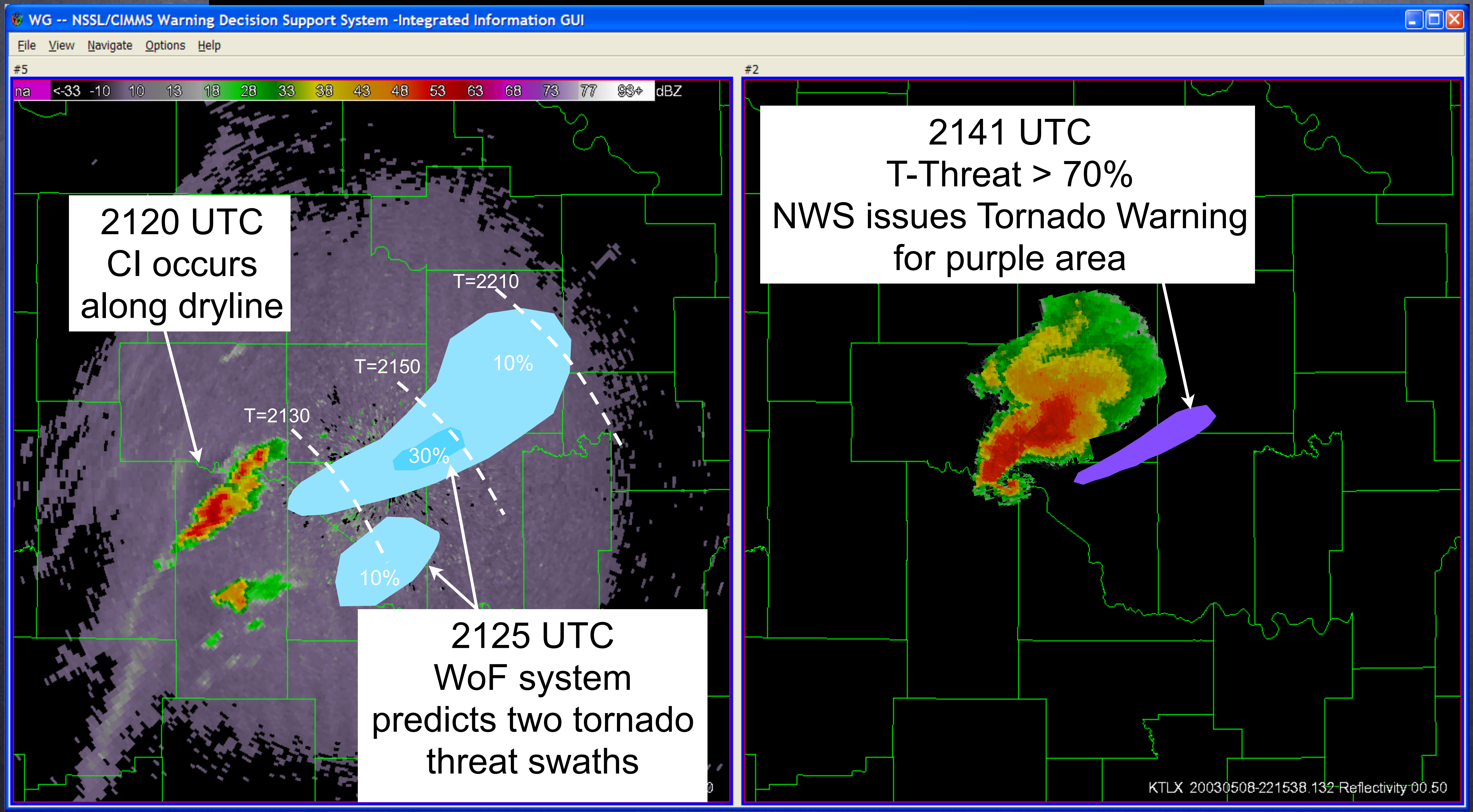
# WoF-TTP Process

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.



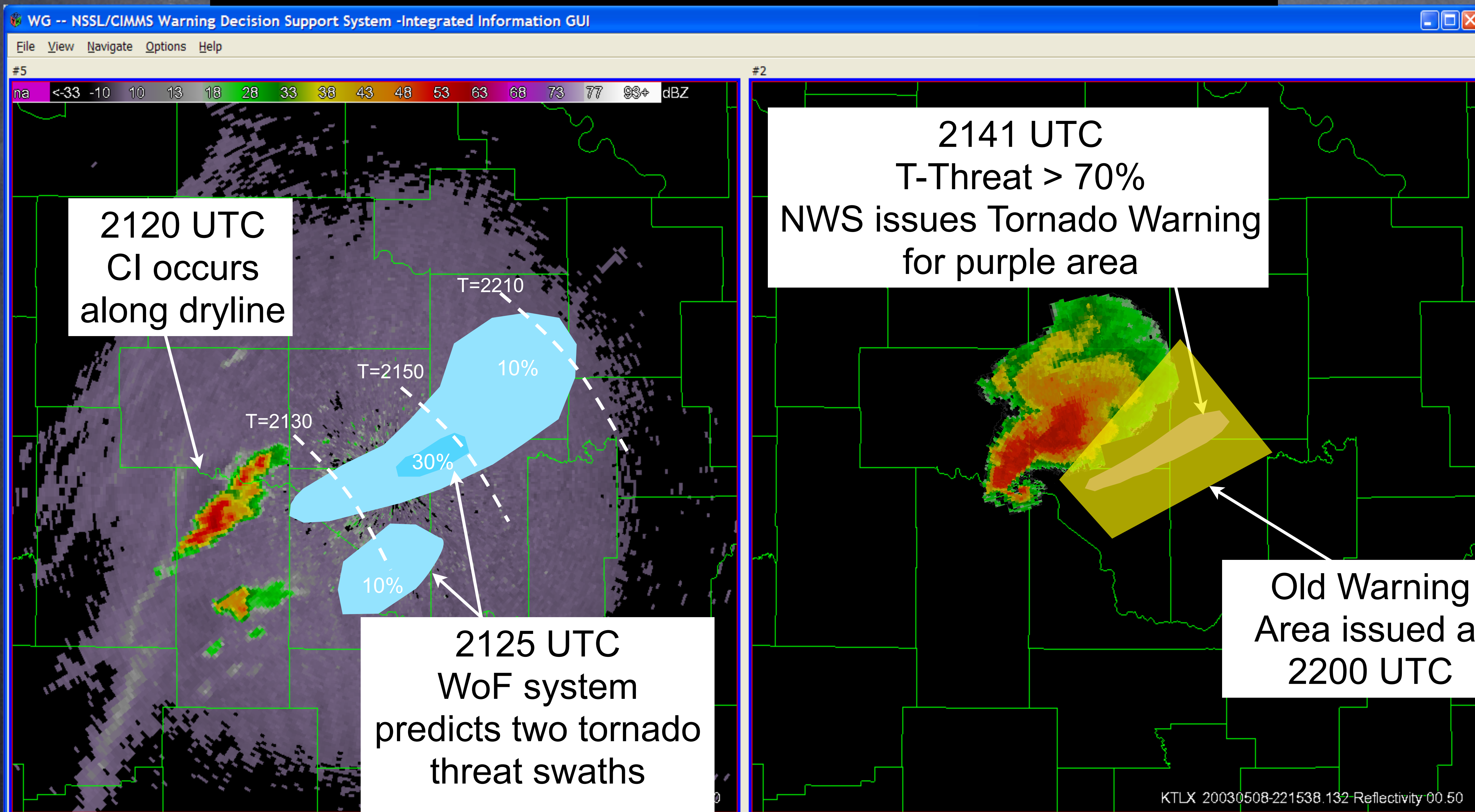
# WoF-TTP Process

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.



# WoF-TTP Process

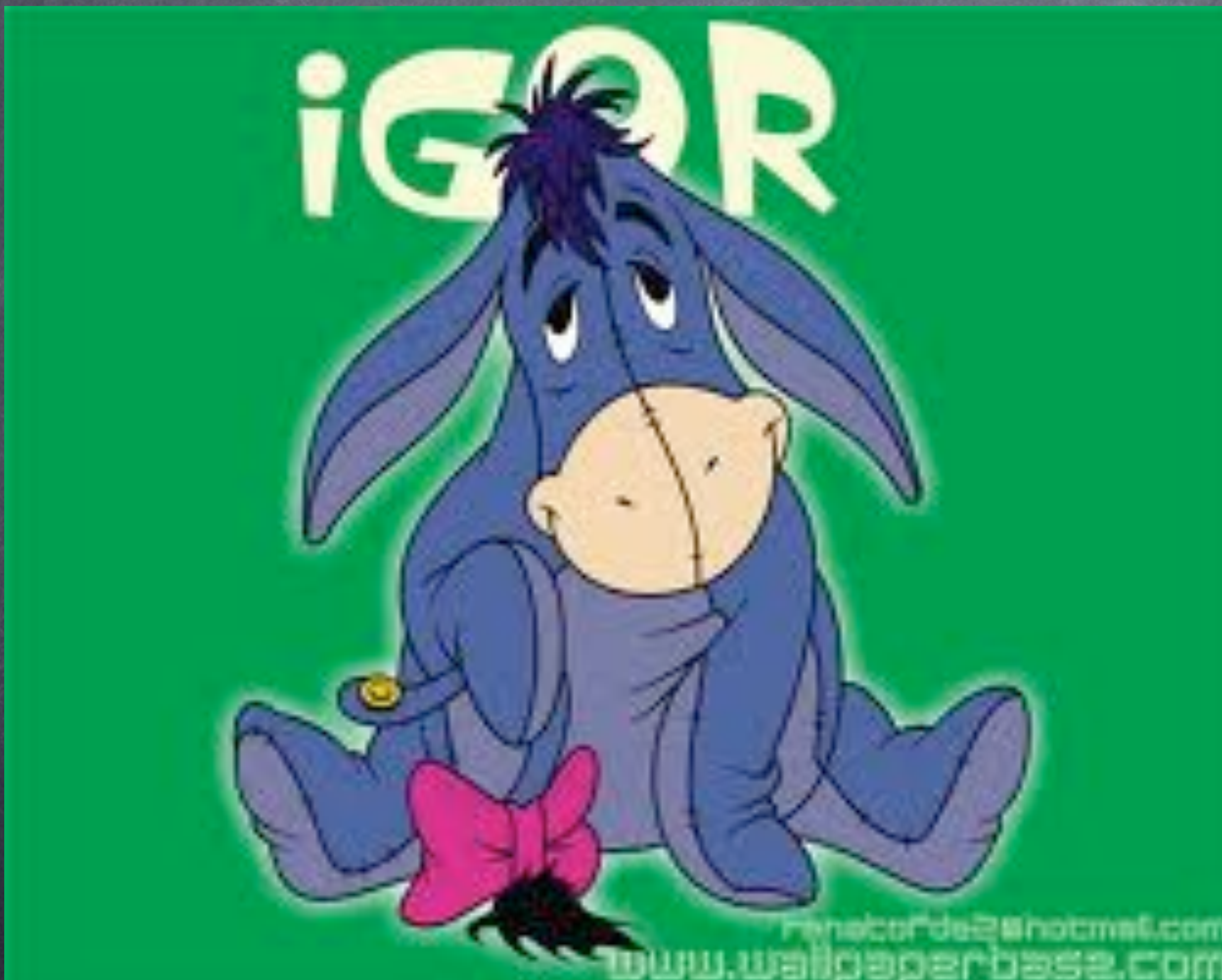
An ensemble of storm-scale NWP models predict the path of a potentially tornadic supercells during the next 40-60 min. The ensemble is used to create probabilistic tornado guidance.



# Mesoscale Errors & Predictability

- Mesoscale forecast errors!
  - Impact of environmental heterogeneities on storm rotation
  - Relative roles of internal dynamics versus external environment in controlling evolution?
  - mesoscale can also enhance convective-scale predictability (e.g., terrain,fronts)
- Convective-scale forecast errors?
  - How do these feedback up scale?
  - Storm-storm interactions are <u>very poorly</u> understood
  - Convective scale errors saturate within 6 hours (Zhang et al., 2007)
  - Large-scale errors begin to saturate by 24 hours (Zhang et al., 2007)
- Intrinsic limit to cycling a coupled system (< 18 hours?)

# So, is this ever going to be possible?




Story behind this: Ken Johnson, SSD chief for Eastern Region told me I was Eor'in on a WoF conference call recently...

# How to Test WoF-TTP System?

- Proposal: If a storm-scale numerical weather prediction is to be…
  - an on-demand, regionally placed enhanced NWP capability similar to HWRF
  - SPC would be the analogous place to disseminate WoF-TTP forecasts to offices
- Advantages of deploying an initial WoF-TTP system through SPC?:
  - Initial products will require sophisticated user interaction
  - Initial products will not replace radar interrogation @ offices
  - Initial products will likely only be available 3-4x times / hour
- Initial WoF-TTP impact via SPC?
  - Generates sub-watch scale / super-warning scale set of products for dissemination
  - Leverages EMC/GSD plans for HRRR ensemble as background
  - Presents a more manageable vision of a WoF capability
  - Does not preclude more capability running regionally/locally in future.

# Initial WoF-TTP System?

- **2020?**
  - Initial operational WoF system much like current GFDL/HWRF
  - Background may be from HRRRe, or an adaptive HRRRe system
  - WoF model resolution is ~ 1.0 km
  - 50-100 member ensemble forecasts produced 2-4x hourly
  - Ensemble probabilities of rotation tracks will be the primary products created and disseminated by SPC
- **2030?**
  - WoF model resolution ~ 0.1-0.3 km nationally
  - Detailed model output available to local offices
  - Local offices generate 3DVAR convective storm analyses using local radar over small domain every few minutes (using WoF-TTP as background)