Primer on Ensemble Modeling Systems

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National Severe Weather Workshop
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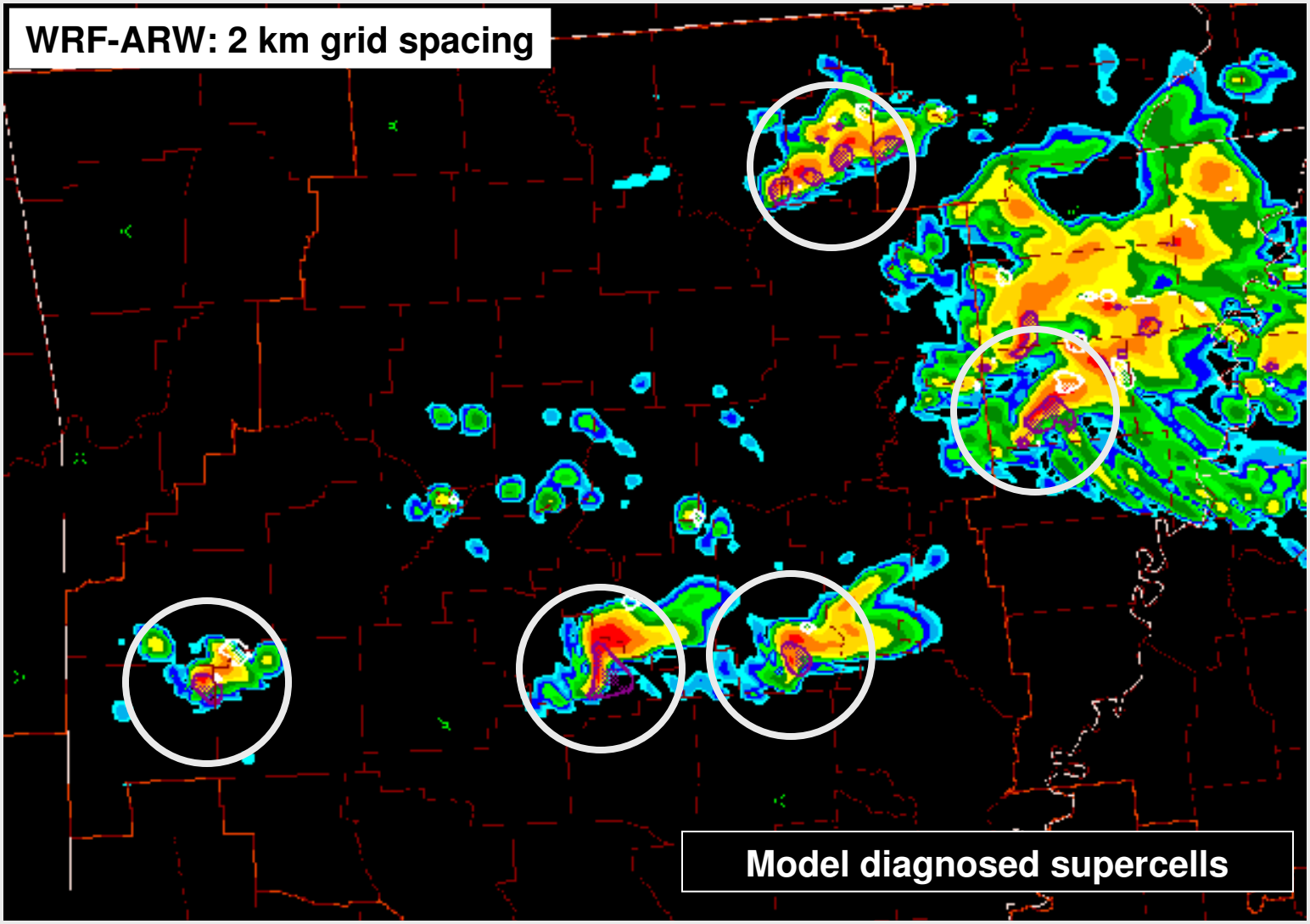
Norman, OK

Where Americas Climate and Weather Services Begin

Outline

- Introduction to Ensemble Forecasting
- NOAA/NWS Short-Range Ensemble System (SREF)
- Case Study: Predicting a Severe Convective Outbreak using the SREF
- Using the SREF in Decision Support
- The Future of Ensembles and High-Impact Forecasting
- Summary

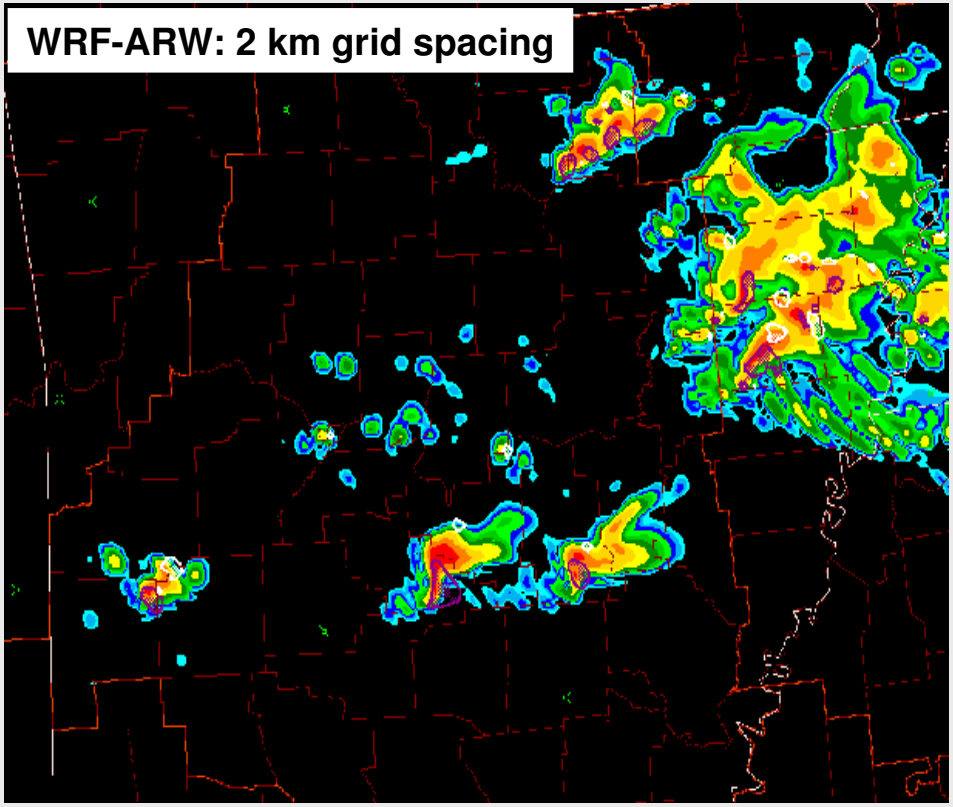
Example: One Model's Convective Forecast

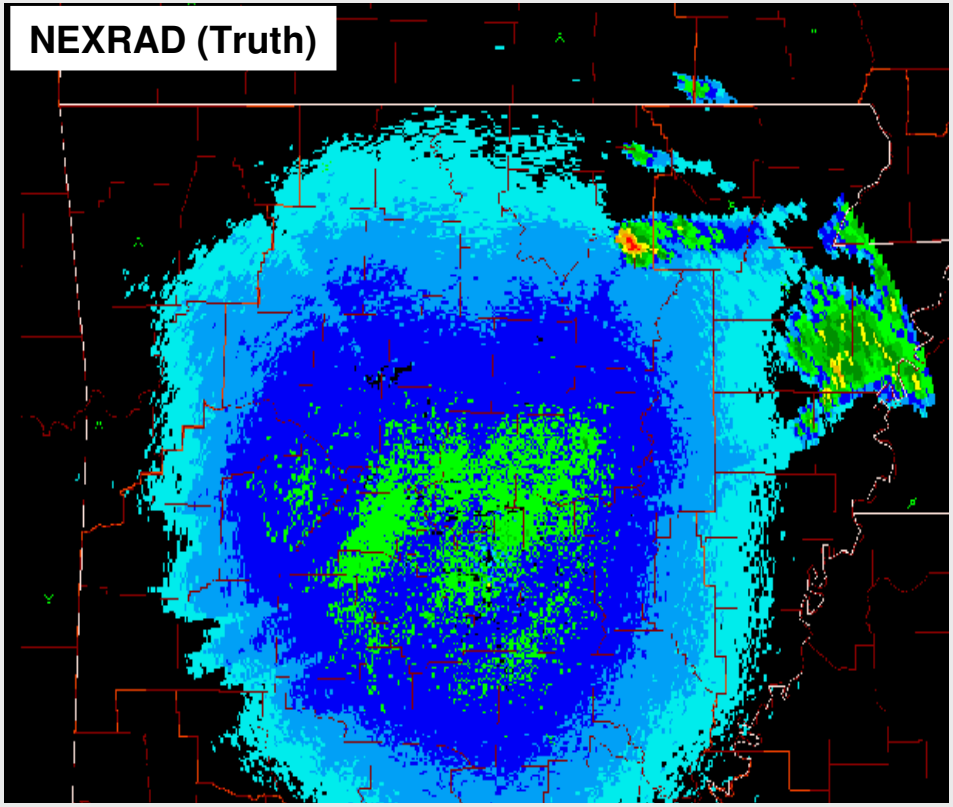


0500 UTC 29 April 2005: 29 hr model reflectivity

(Zoomed in over central Arkansas)

Example: One Model's Convective Forecast



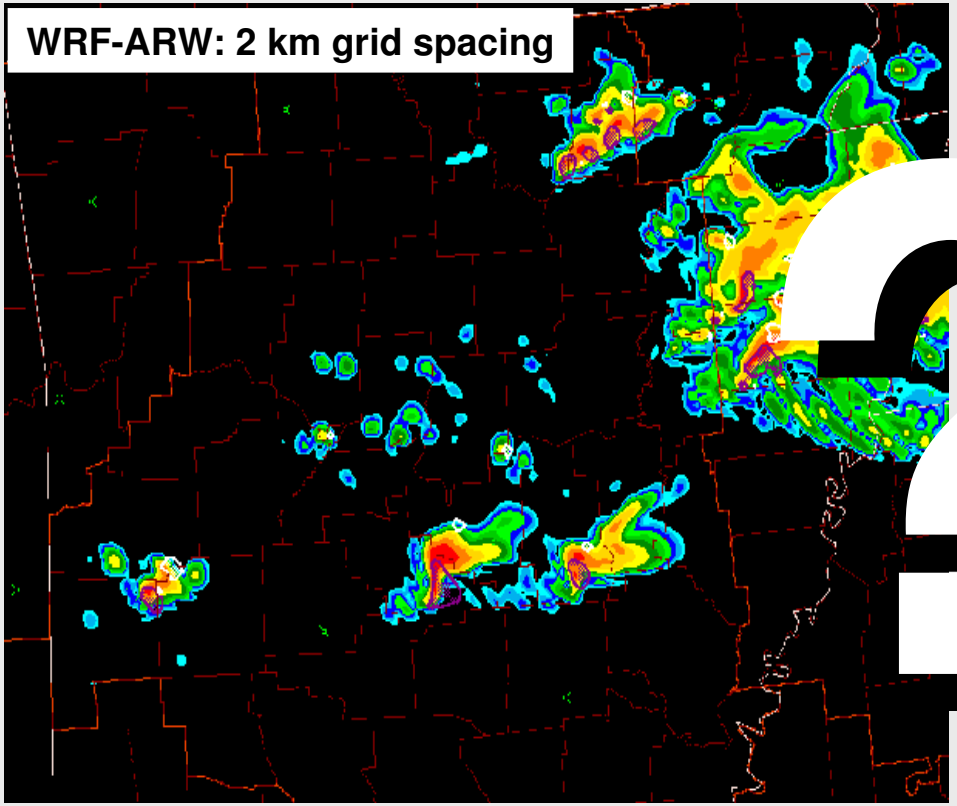


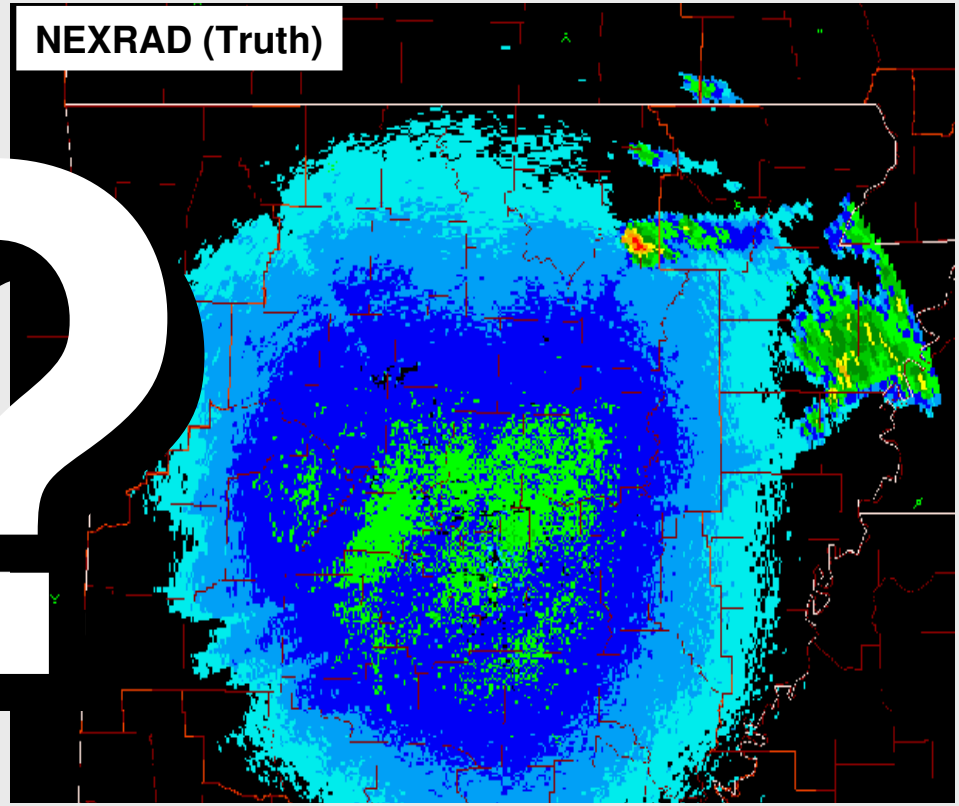
0500 UTC 29 April 2005:
29 hr model reflectivity

0500 UTC 29 April 2005:
Base Reflectivity

Example: One Model's Convective Forecast

Deterministic forecasts do not directly address questions of uncertainty





0500 UTC 29 April 2005:
29 hr model reflectivity

0500 UTC 29 April 2005:
Base Reflectivity (Truth)

- One forecast can be misleading and oversell forecast capability
- One forecast does not provide explicit information on uncertainty

What is an ensemble forecast?

- A collection of forecasts valid at the same time
- These forecasts may be produced by humans or models
- As guidance, an ensemble is comprised of NWP models that may have slightly different initial conditions, boundary conditions, model physics or parameters, or be entirely different models
- Theoretically rooted in the work of Lorenz and chaos (late 1950s and 1960s)

Ensemble Forecast Systems

- Contribute to forecast confidence by:
  - Providing a range of possible solutions
  - Minimize forecast error (e.g., mean) and quantify uncertainty (e.g., spread)
  - Provide probabilistic information
- Ensemble systems aid in decision support
  - Particularly if calibrated (i.e., reliable probabilities)
- Extend Predictability

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NCEP

Storm Prediction Center
Norman, Oklahoma

NWP and Ensemble Systems

Weather forecasting: It's impossible to be certain all of the time!

- Numerical weather models...
  - All forecasts contain errors that increase with time
  - Doubling time of small initial errors ~1 to 2 days
  - Maximum large-scale (synoptic to planetary) predictability ~10 to 14 days
- Ensembles…
  - A collection of models that provide information on a range of plausible forecasts, statistical measures of confidence, and extend predictability
  - Scale to the problem of interest
  - Increasing in popularity
  - Requires "tools" to view a large number of models using a slightly different approach (statistical)

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Short Range Ensemble Forecast (SREF)

- NWS SREF system (21 members)
  - 87 hr forecasts four times daily (03, 09, 15, 21 UTC)
  - North American domain
  - Model grid lengths 32-45 km
  - Multi-model: Eta, RSM, WRF-NMM, WRF-ARW
  - Multi-analysis: NAM, GFS initial and boundary conditions
  - IC perturbations and physics diversity
  - SPC adds one time-lagged NAM to the mix (22 members)
  - Recently added bias-correction to some fields *(not covered and not available on the SPC webpage)*

Upgrade soon: 32-35 km grid spacing; latest model code; etc.

Global Ensemble Forecast (GEFS)

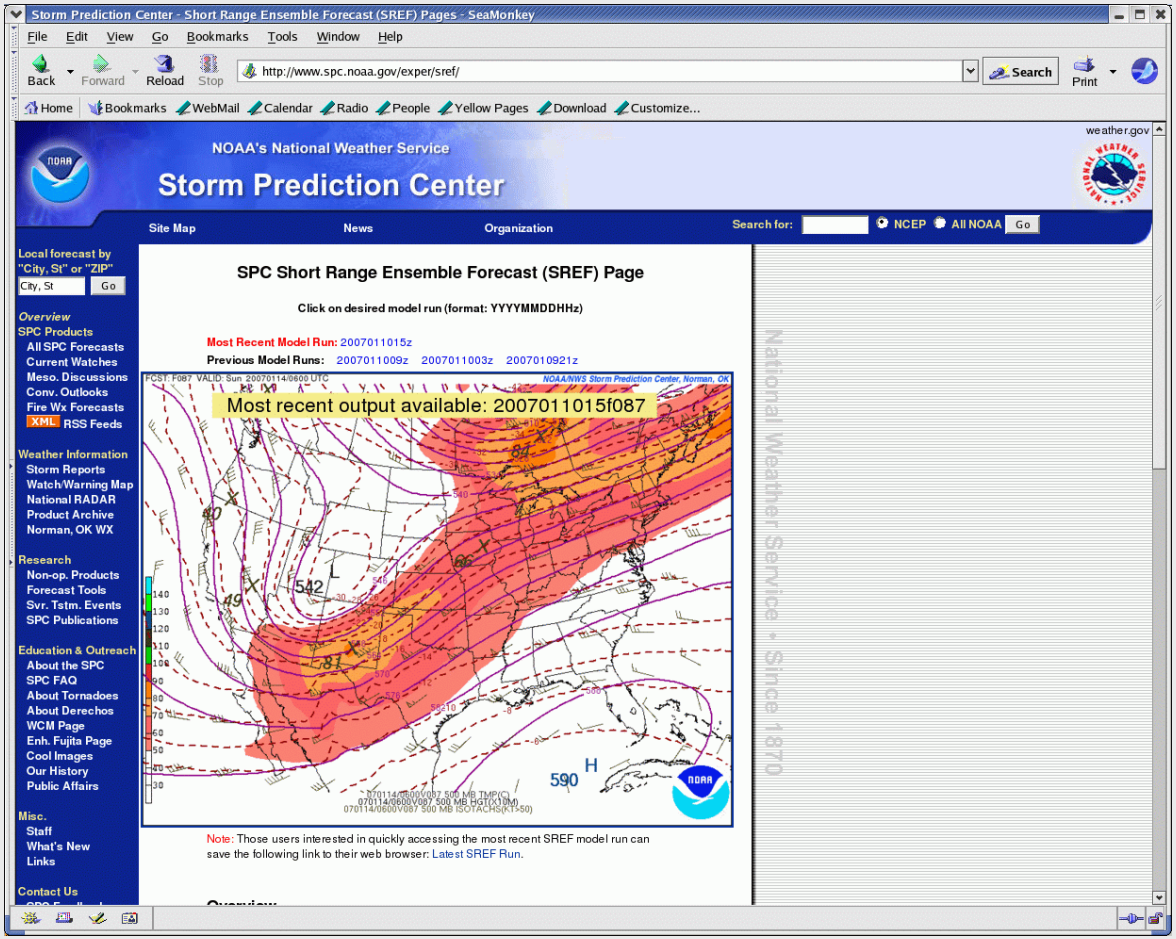
Model	*Res*	*Levels*	*Mems*	*Cld Physics*	*Convection*
GFS	**T126* (~ 105 km)**	**28**	**20****	**GFS physics**	**Simple A-S**

* *Same resolution as the operational GFS in 1998*

** ***20*** *statistically independent perturbations (using Ensemble Kalman filter method)*

Case Study: The following SREF products are available in real-time at the SPC website

http://www.spc.noaa.gov/exper/sref/



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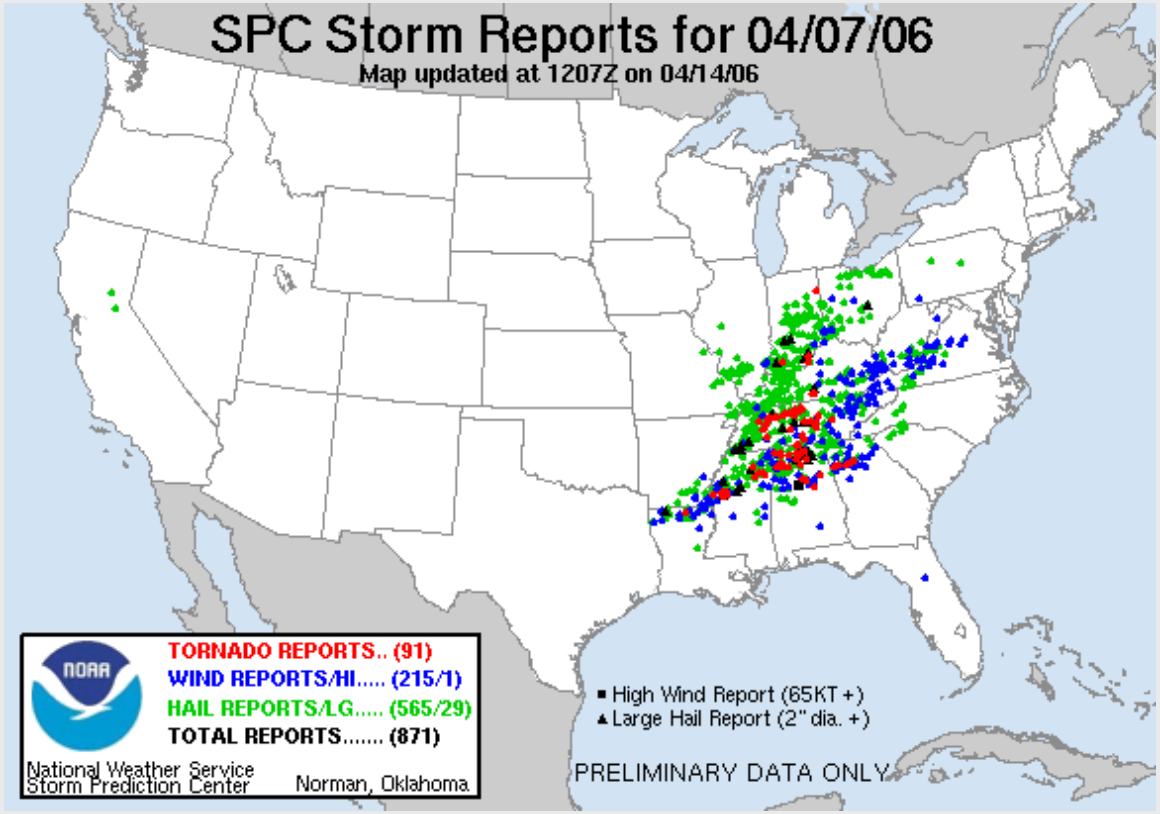
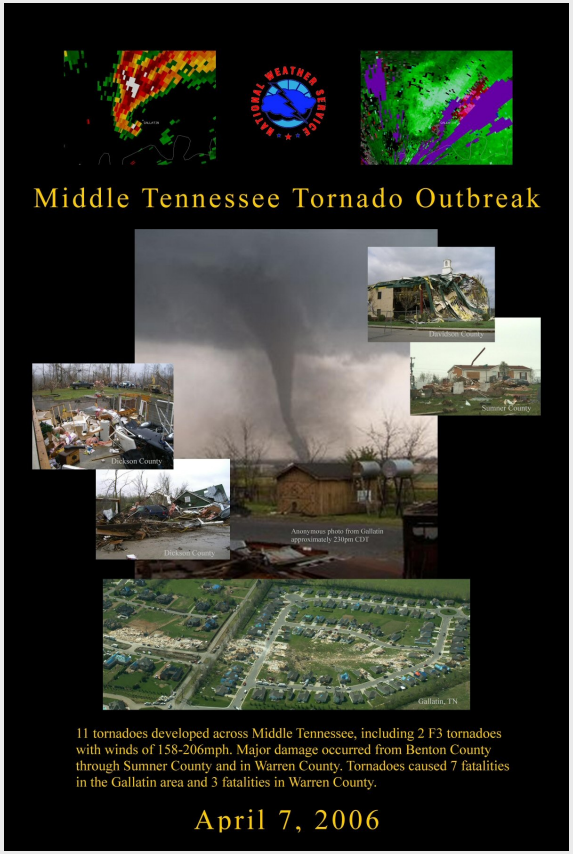
Storm Prediction Center, Norman, Oklahoma

Severe Weather Event of April 7, 2006

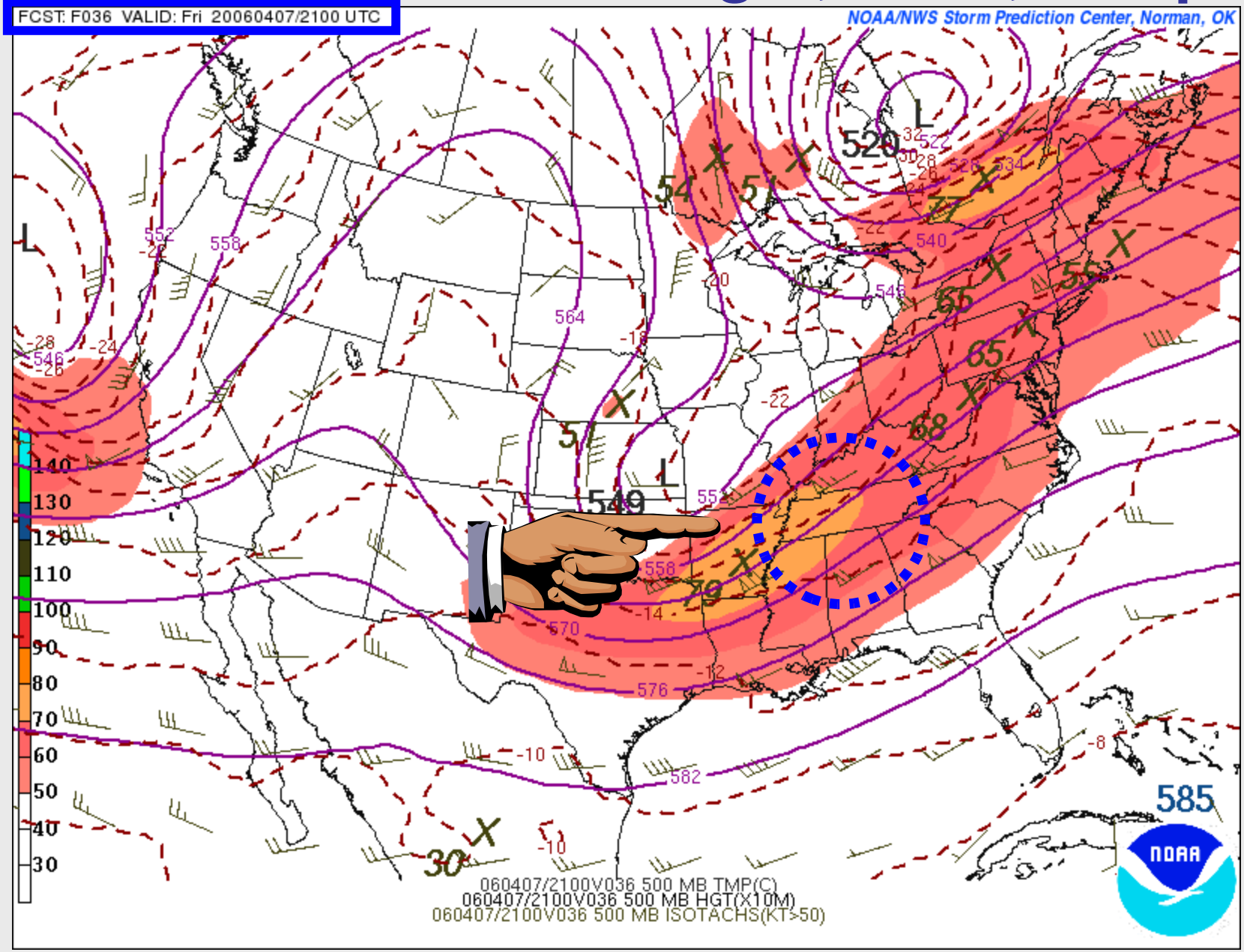
- More than 800 total severe reports
  - 3 killer tornadoes and 10 deaths



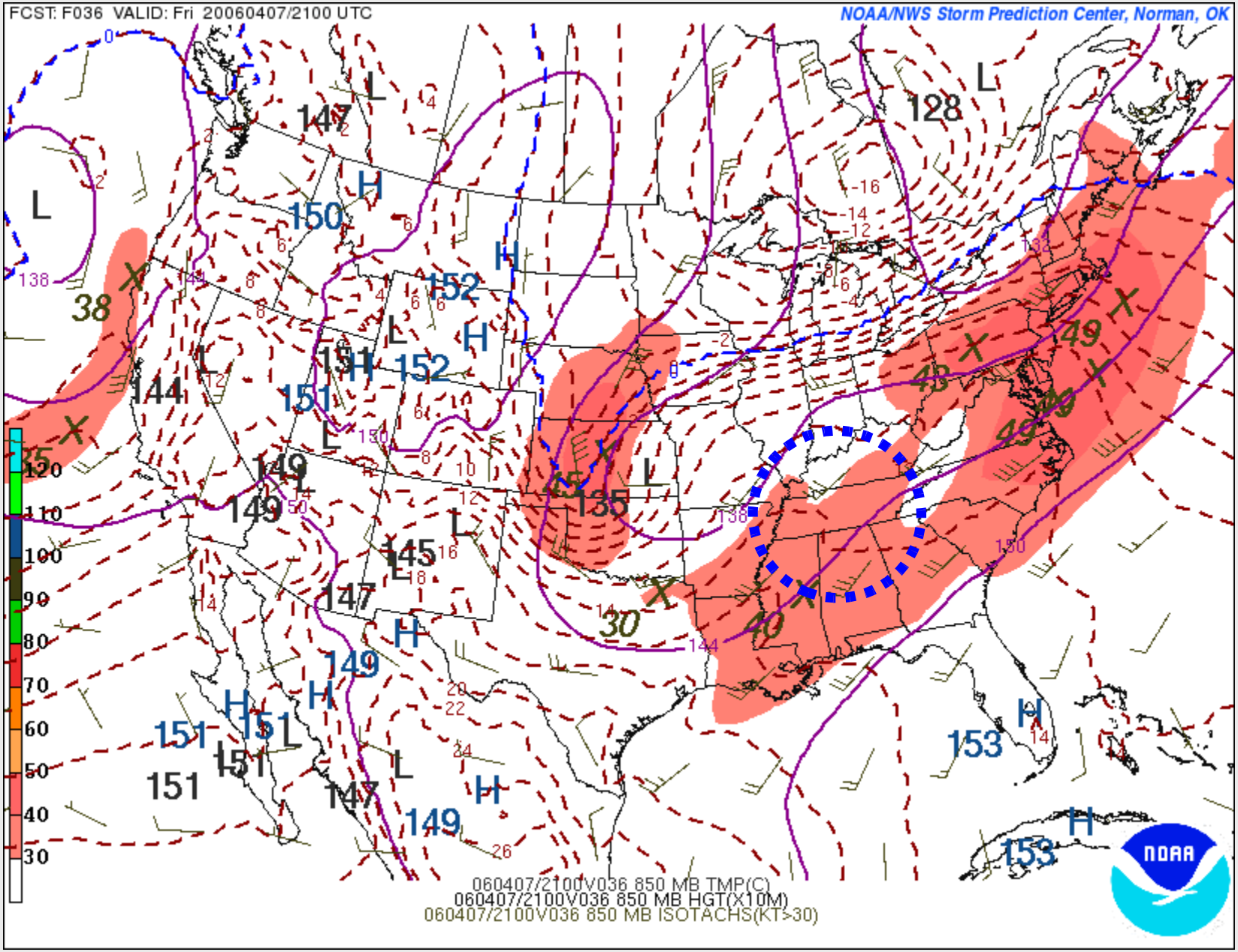


Poster from WFO Nashville, TN

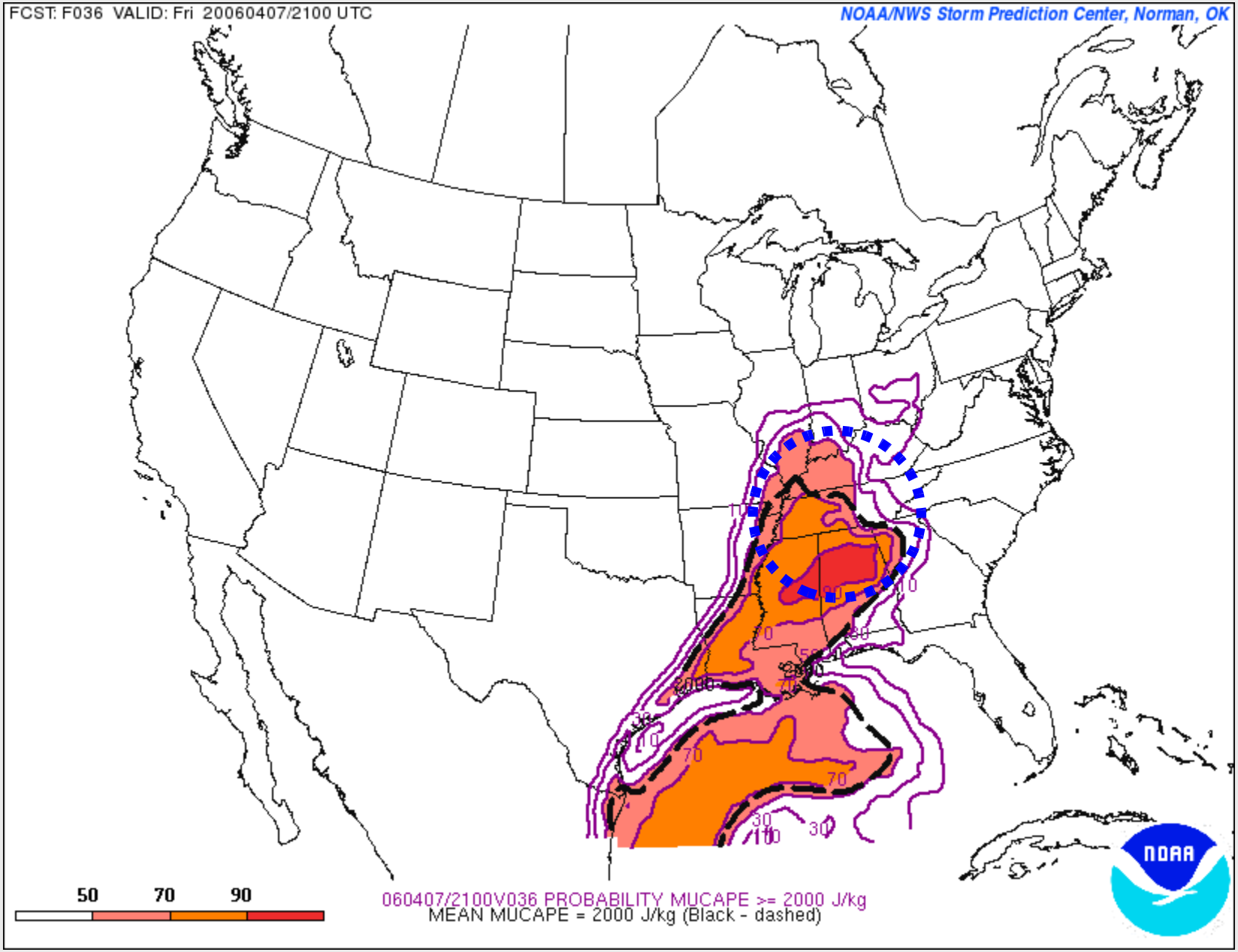
SREF 500 mb Mean Height, Wind, Temp



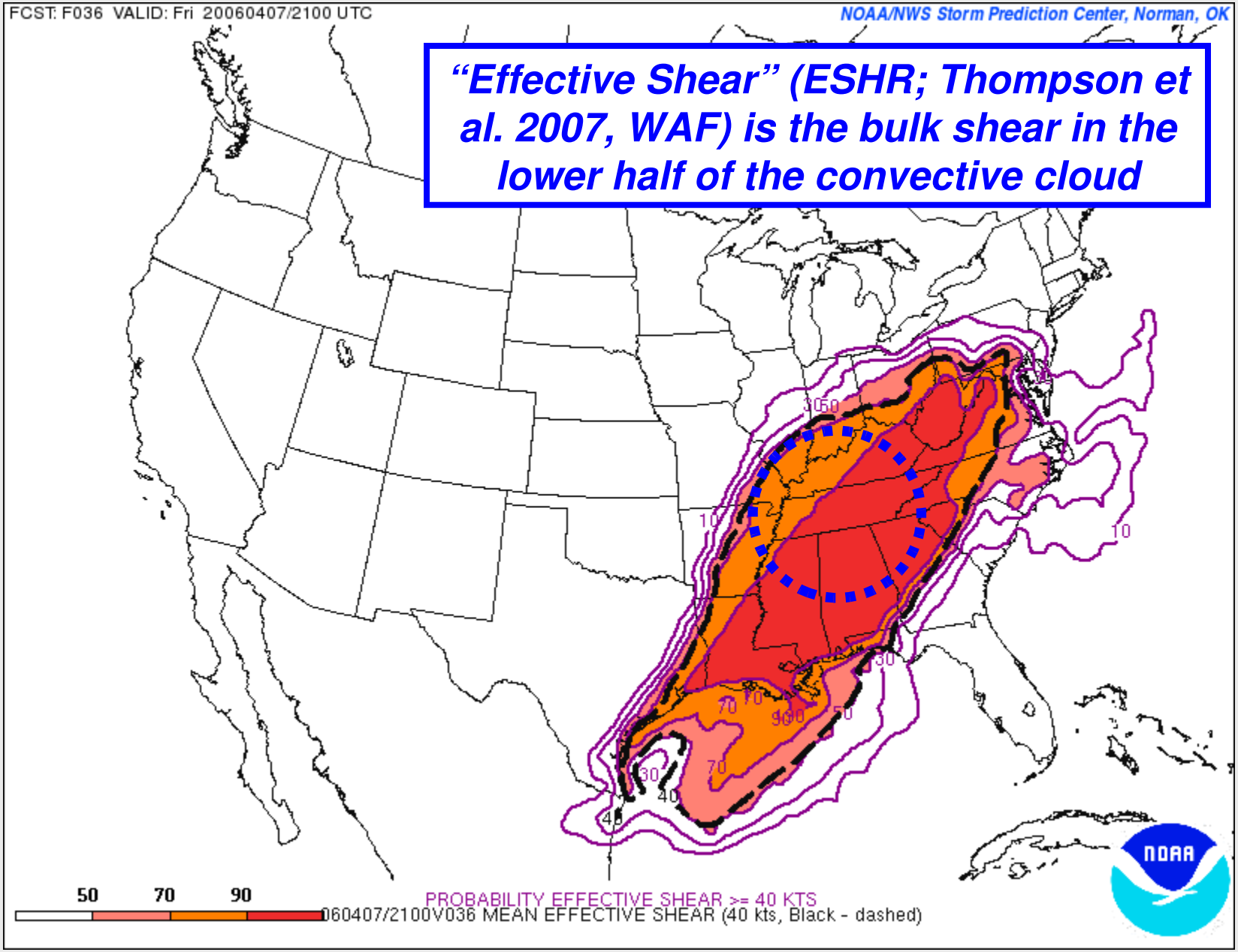
SREF 850 mb Mean Height, Wind, Temp



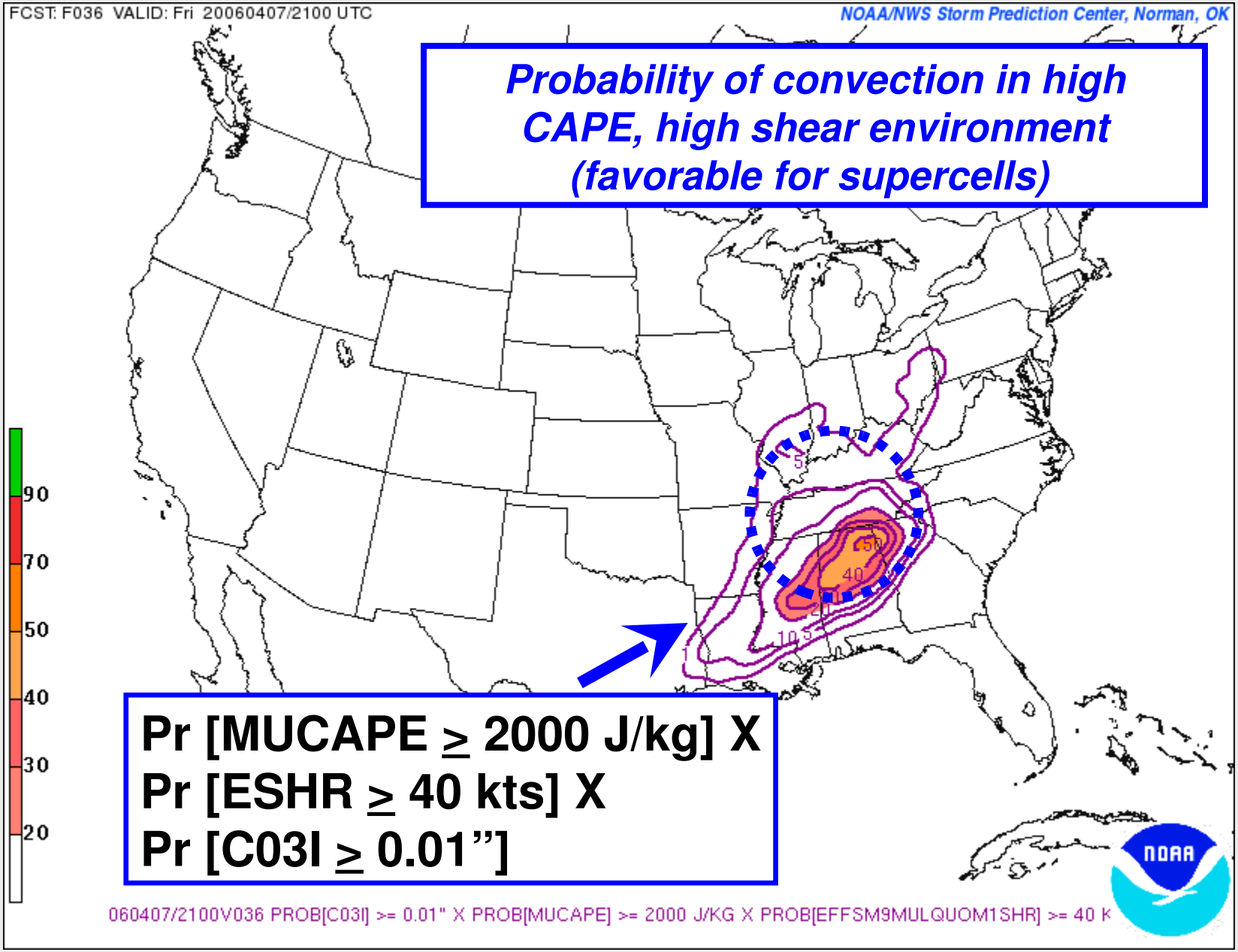
SREF Pr[MUCAPE ≥ 2000 J/kg] & Mean MUCAPE=2000 (dash)



SREF Pr[ESHR ≥ 40 kts] & Mean ESHR=40 kts (dash)



SREF Combined or Joint Probability



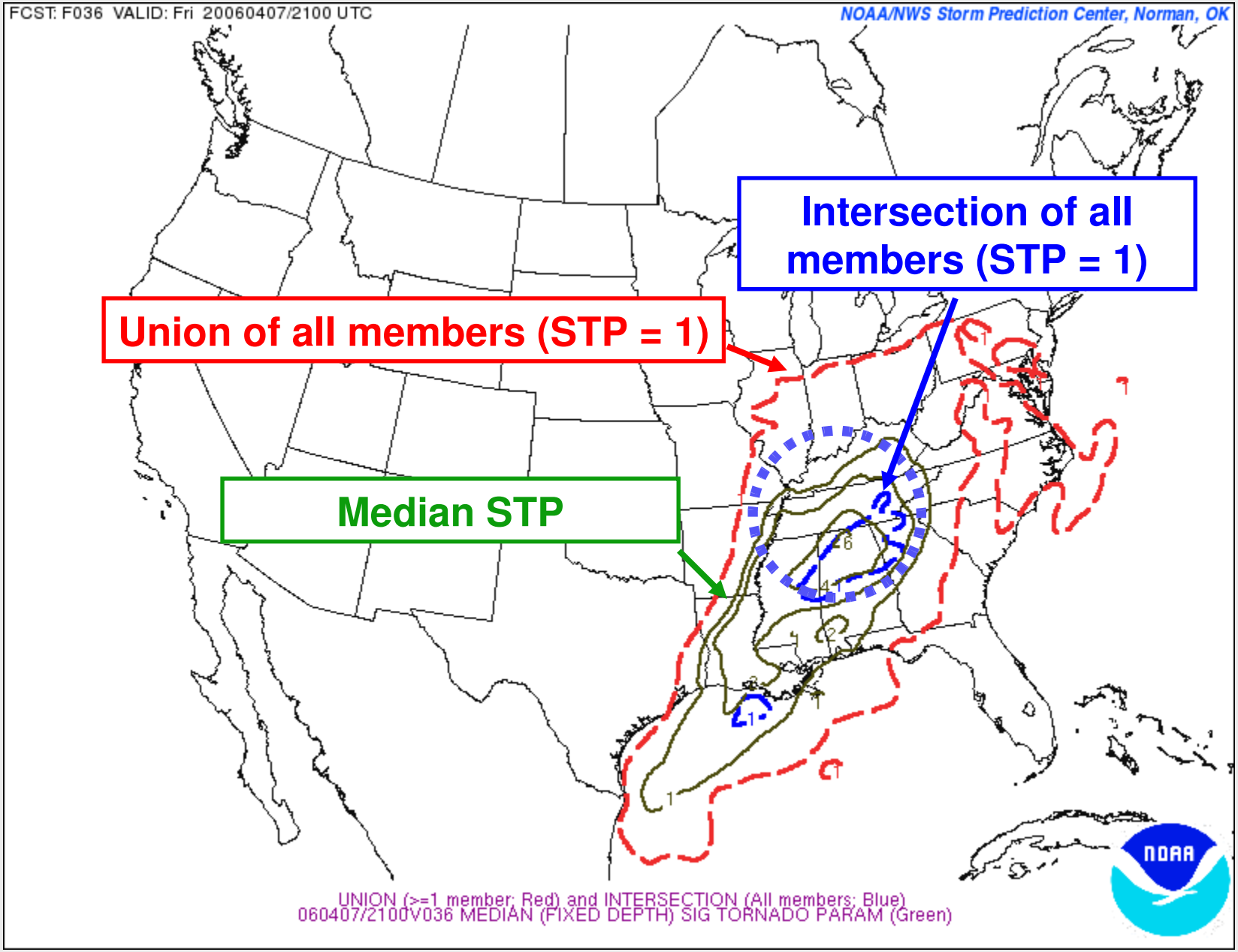
Diagnostics and Analysis

- Example: *Significant Tornado Parameter (STP)*
  - A parameter designed to help forecasters identify supercell environments capable of producing significant (≥ F2) tornadoes (Thompson et al. 2003)
- STP = **F**(MLCAPE, MLLCL, Helicity, Deep shear)*

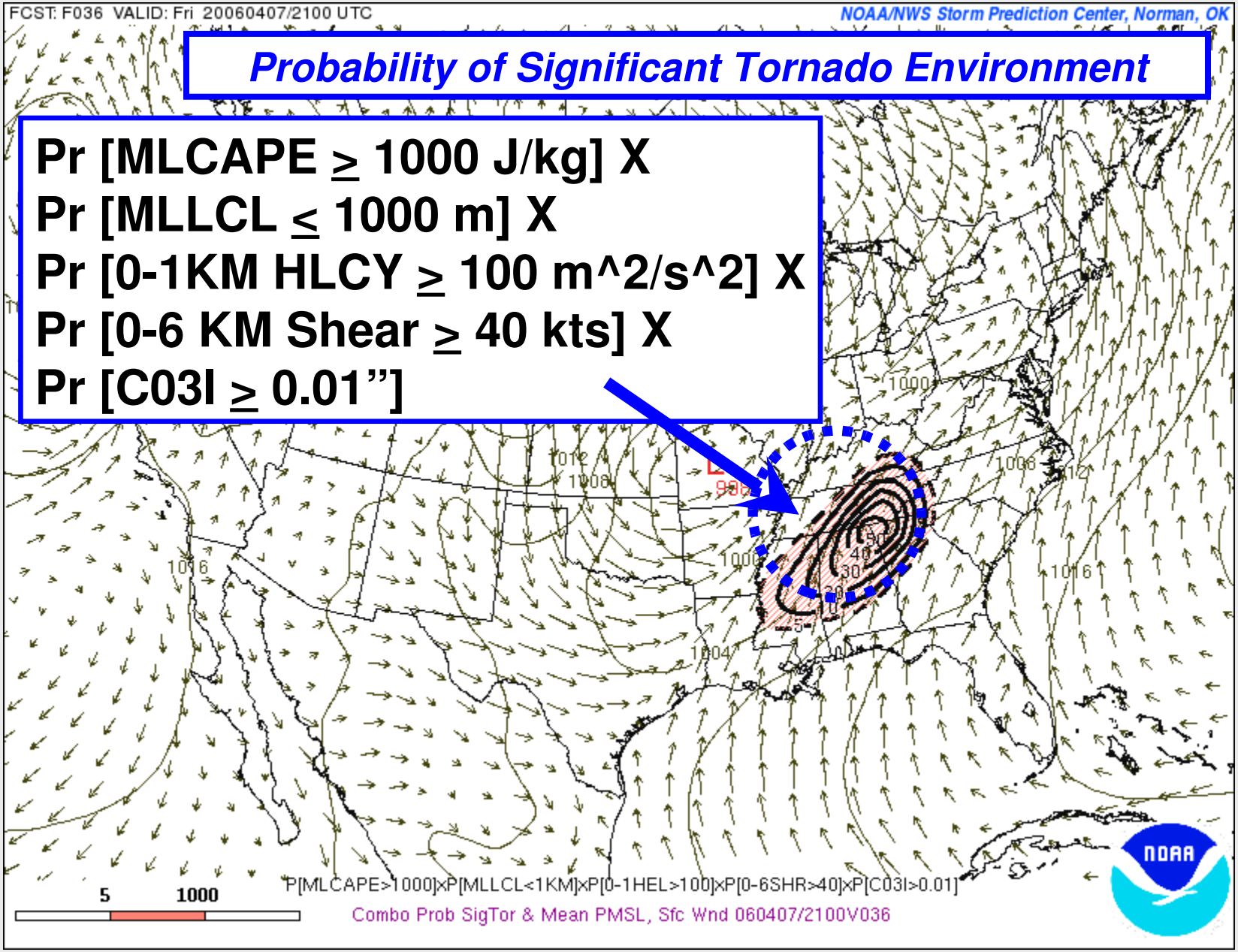
  → STP ≥ ~1 indicative of environments that may support strong or violent tornadoes (given that right moving supercells occur)

**** An updated version (not shown) includes CIN and effective depth***

SREF Median STP, Union (red), Intersection (blue)



SREF Combined or Joint Probability: STP Ingredients



SREF Probability of STP Ingredients: Time Trends

48 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

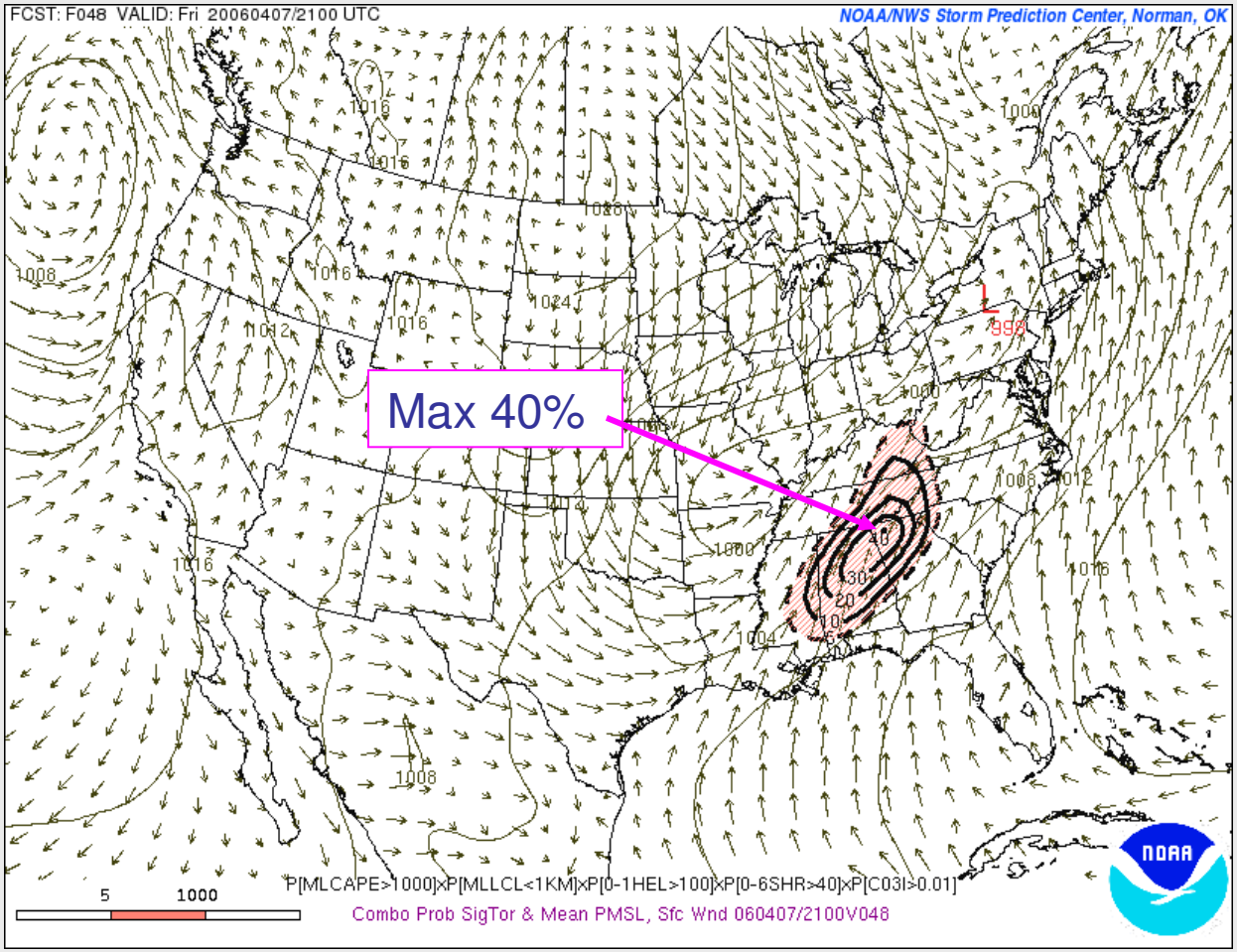
X

Prob (MLLCL ≤ 1000 m)

X

Prob (3h conv. Pcpn ≥ 0.01 in)

Shaded Area Prob ≥ 5%



SREF Probability of STP Ingredients: Time Trends

36 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

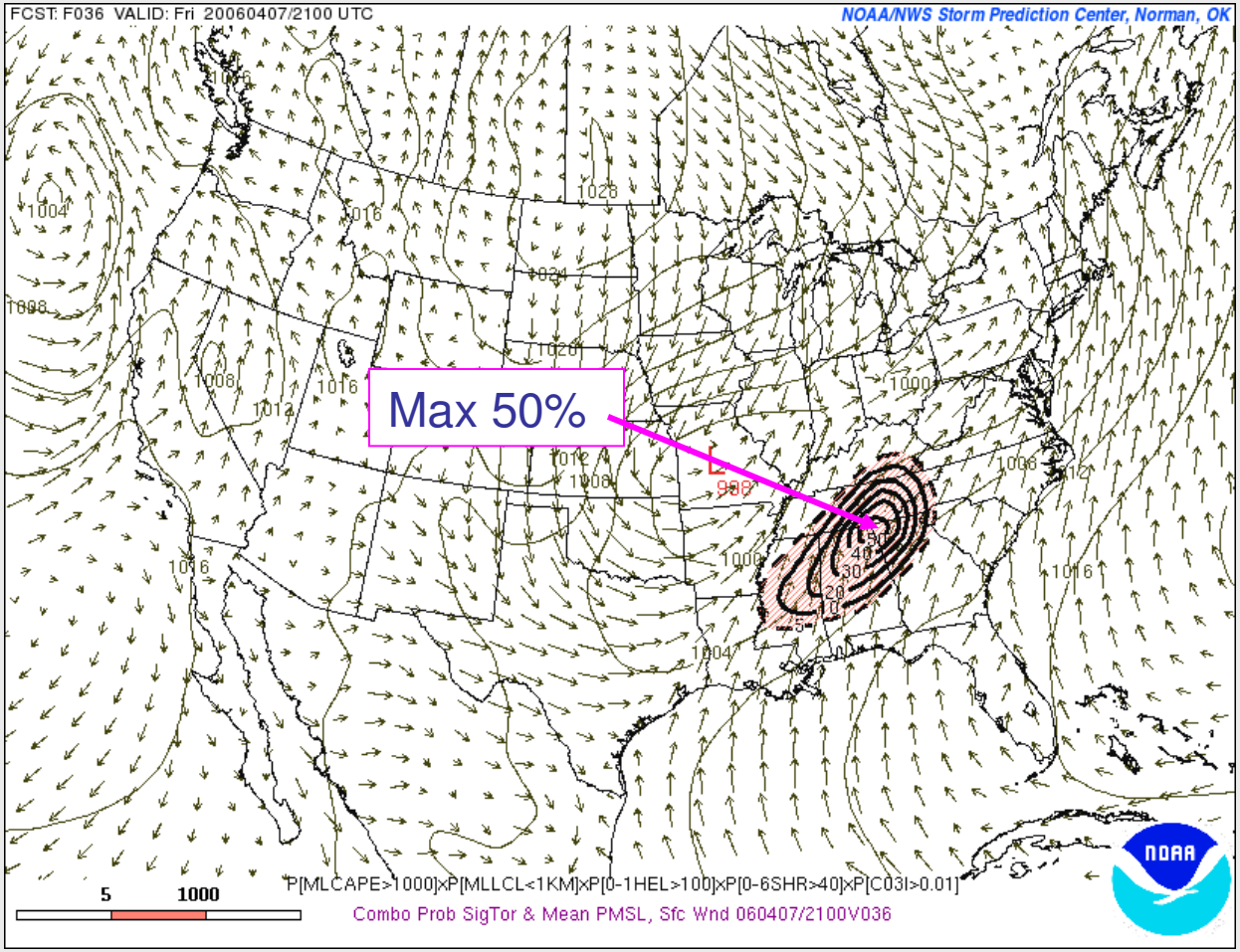
X

Prob (MLLCL ≤ 1000 m)

X

Prob (3h conv. Pcpn ≥ 0.01 in)

Shaded Area Prob ≥ 5%



SREF Probability of STP Ingredients: Time Trends

24 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

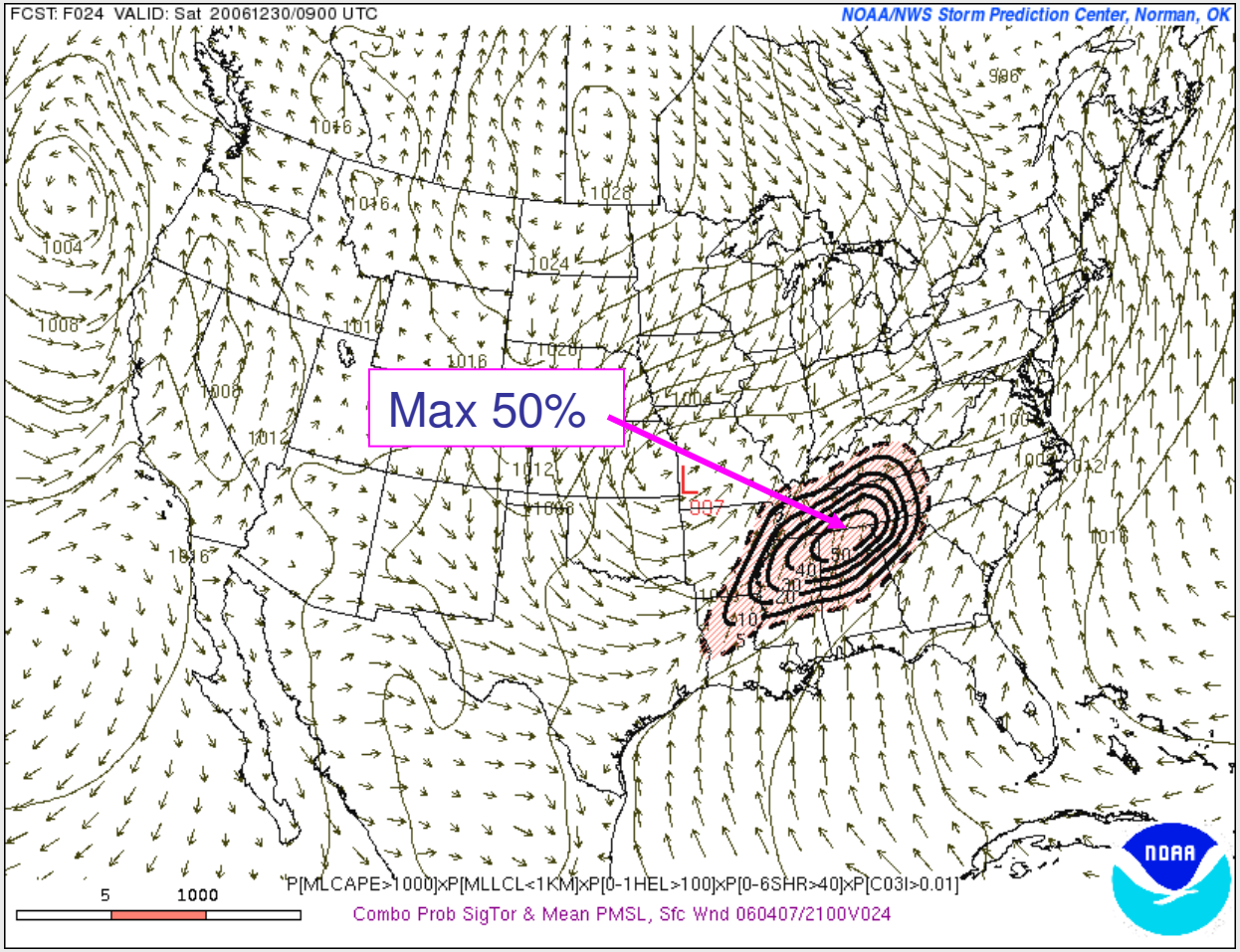
X

Prob (MLLCL ≤ 1000 m)

X

Prob (3h conv. Pcpn ≥ 0.01 in)

Shaded Area Prob ≥ 5%



SREF Probability of STP Ingredients: Time Trends

12 hr *SREF Forecast Valid 21 UTC 7 April 2006*

Prob (MLCAPE ≥ 1000 Jkg^{-1})

X

Prob (6 km Shear ≥ 40 kt)

X

Prob (0-1 km SRH ≥ 100 m^2s^{-2})

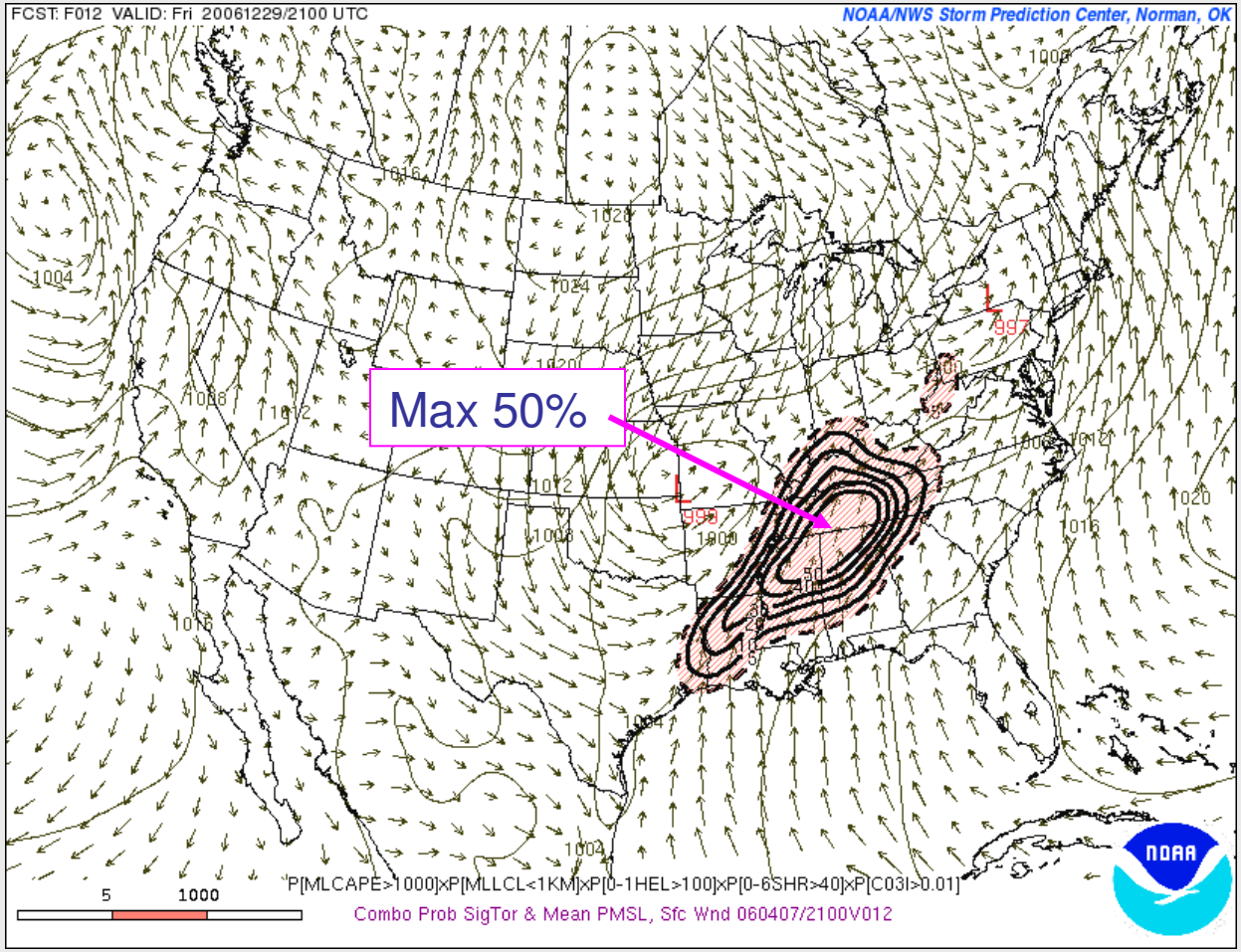
X

Prob (MLLCL ≤ 1000 m)

X

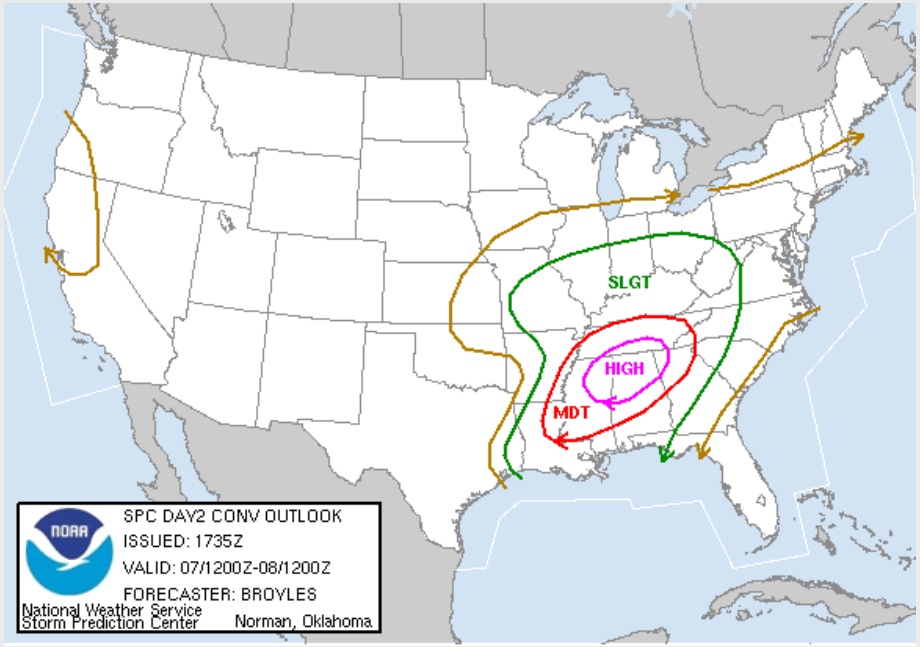
Prob (3h conv. Pcpn ≥ 0.01 in)

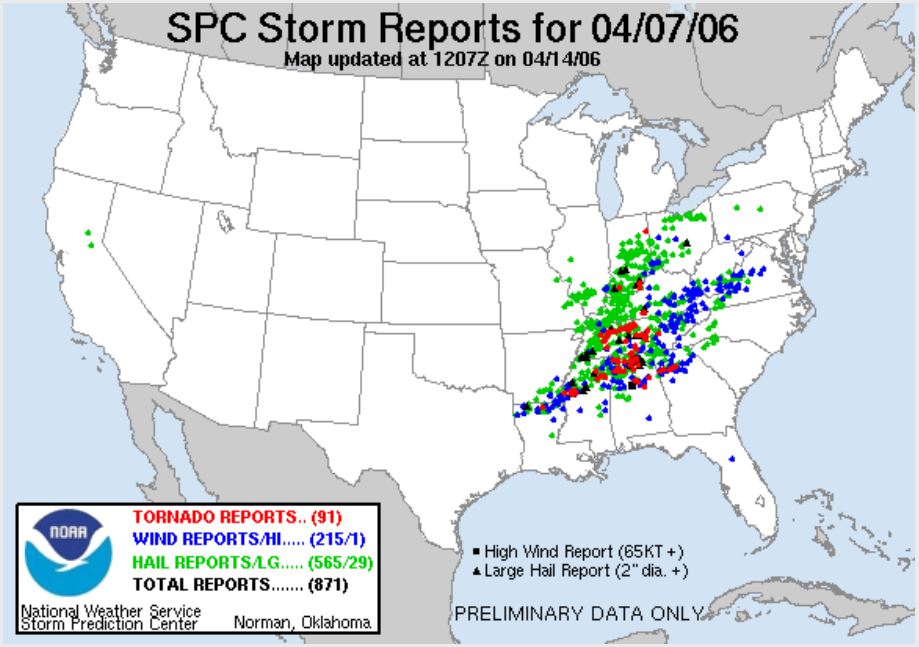
Shaded Area Prob ≥ 5%



Severe Event of April 7, 2006

- **First ever** Day 2 outlook High Risk issued by SPC
- More than 800 total severe reports
  - 3 killer tornadoes and 10 deaths
- SREF severe weather fields aided forecaster confidence





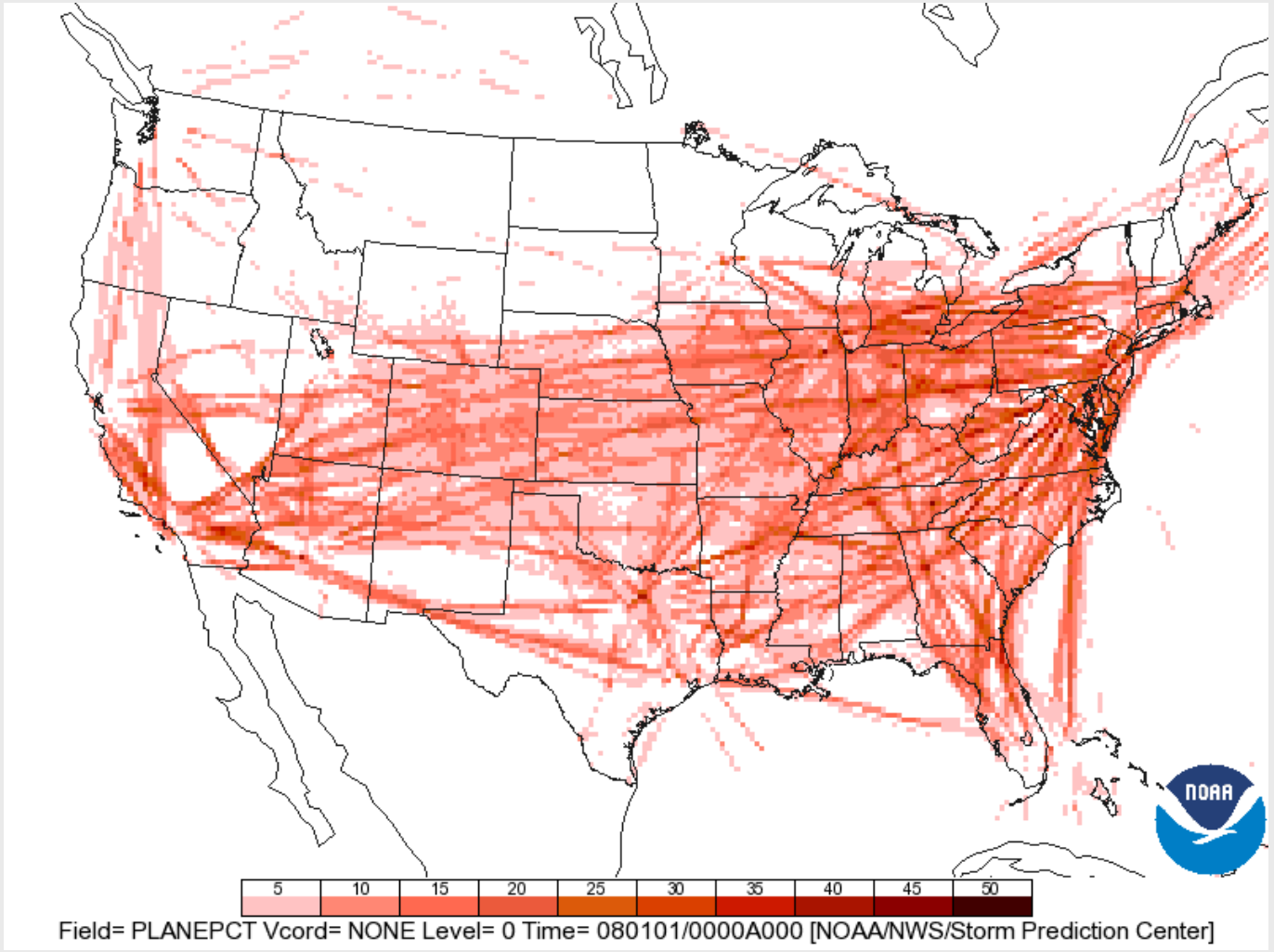
Ensembles and Decision Support

- **Example: En Route Aviation Impacts**
  - Convection cloud tops ≥ 37,000 feet obstacles to aviation
  - Consider probability of cloud tops *and* probability of en route aircraft position

Gridded Flight Composites (20 km Grid) at 00 UTC

January 1, 2004 to December 31, 2008

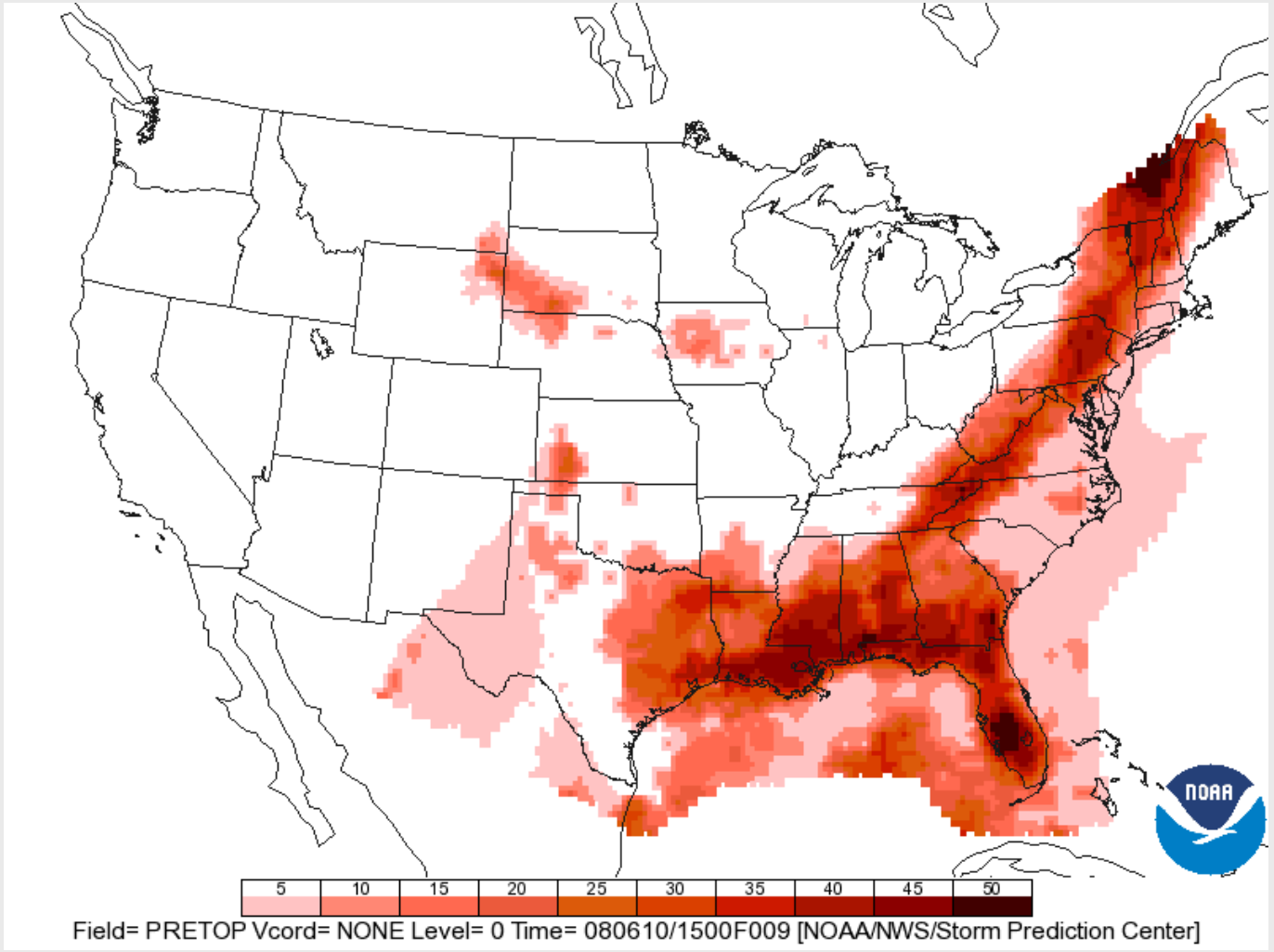
Snapshot probability of an aircraft inside the 20 km (AWIPS 215) grid box
All Flights ≥ 25,000 Feet



SREF Guidance 15 UTC 10 June 2008

F009 valid at 00 UTC 11 June 2008

Probability of Convective Cloud Tops ≥ 37,000 Feet

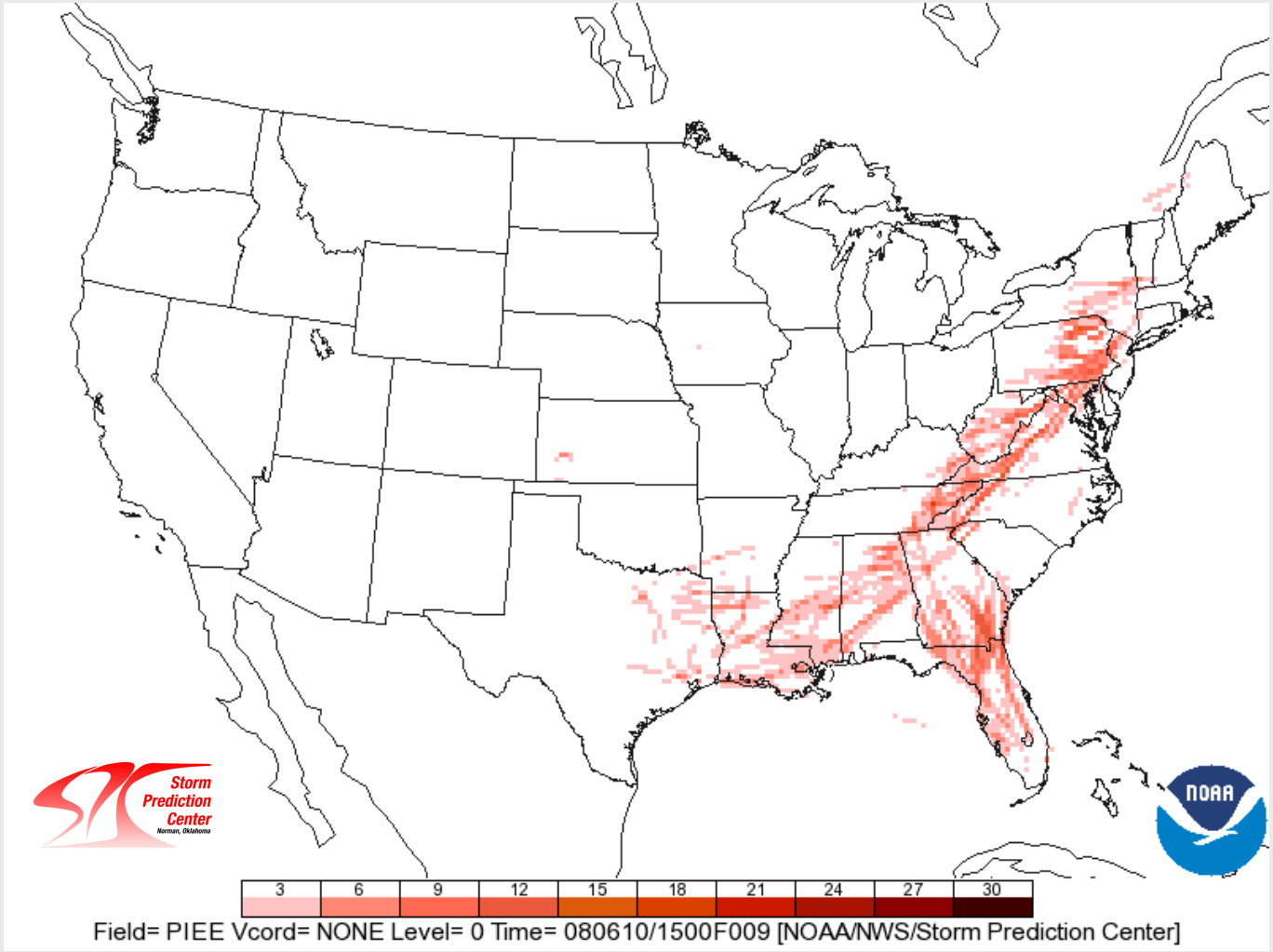


SREF Impact Guidance 15 UTC 10 June 2008

F009 valid at 00 UTC 11 June 2008

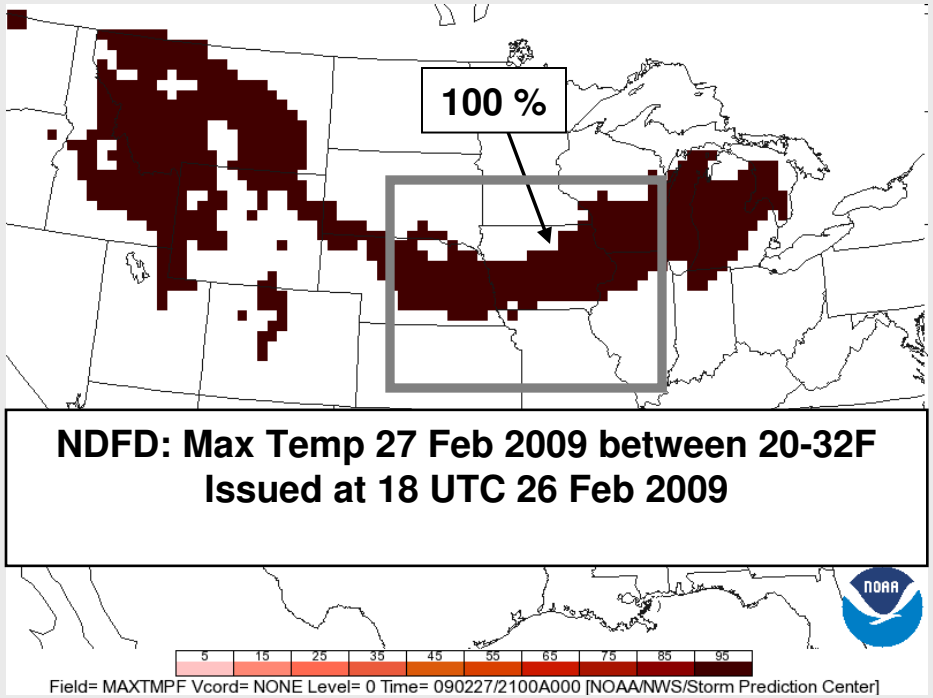
Probability cloud tops ≥ 37,000 feet AGL *AND* aircraft > 25,000 feet AGL

Potential En Route Impacts

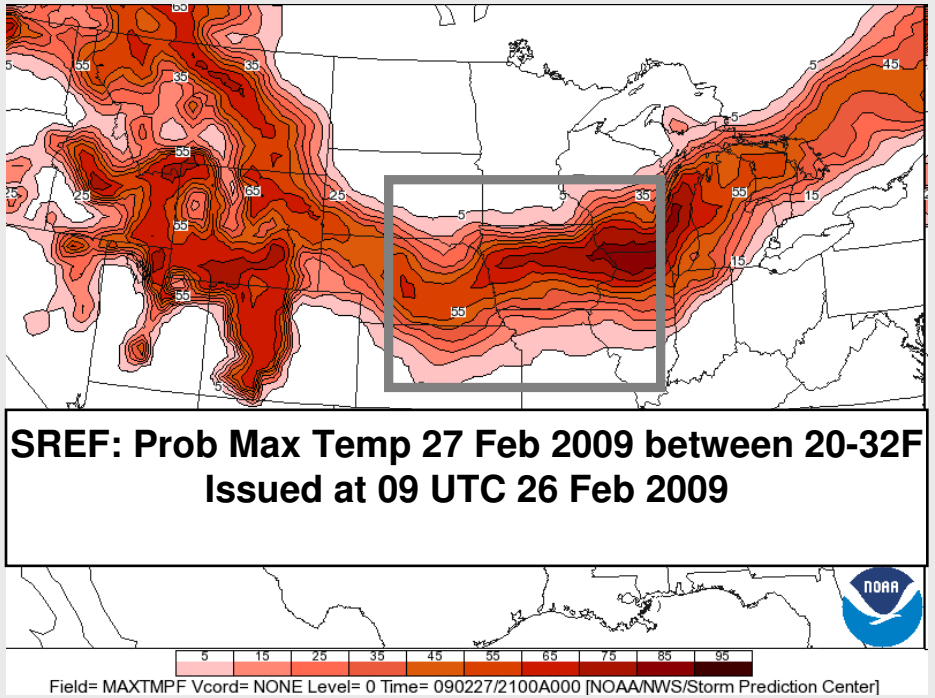


Ensembles and Decision Support

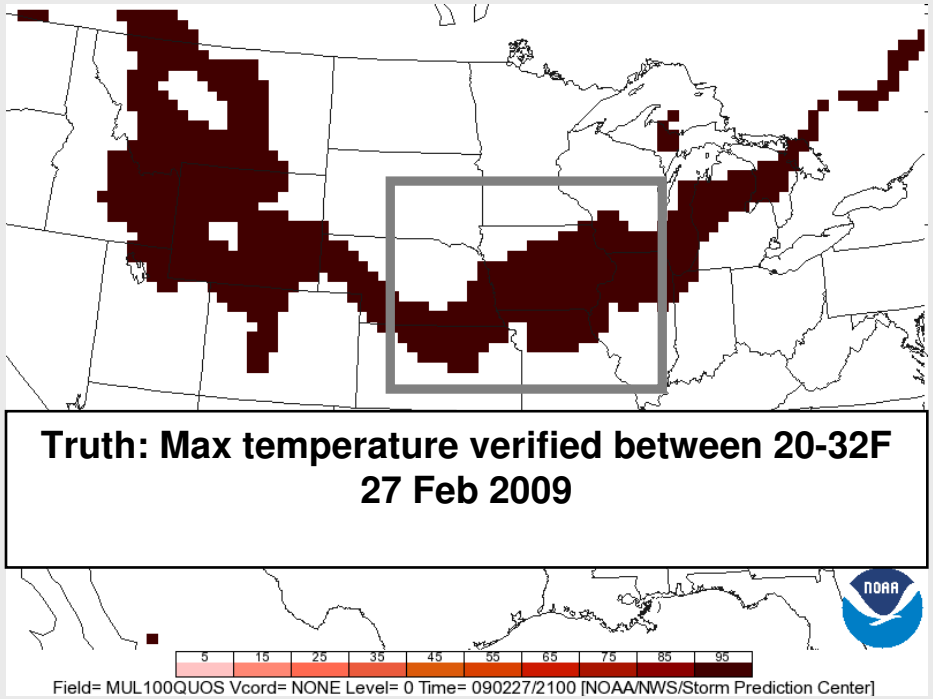
- **Example: Temperature forecasting**
  - Salt road treatment about 10% of cost of chemical road treatment
  - Salt most effective between 20F and 32F
  - Limited resources; therefore want to optimize decision making



NDFD: Max Temp 27 Feb 2009 between 20-32F
Issued at 18 UTC 26 Feb 2009



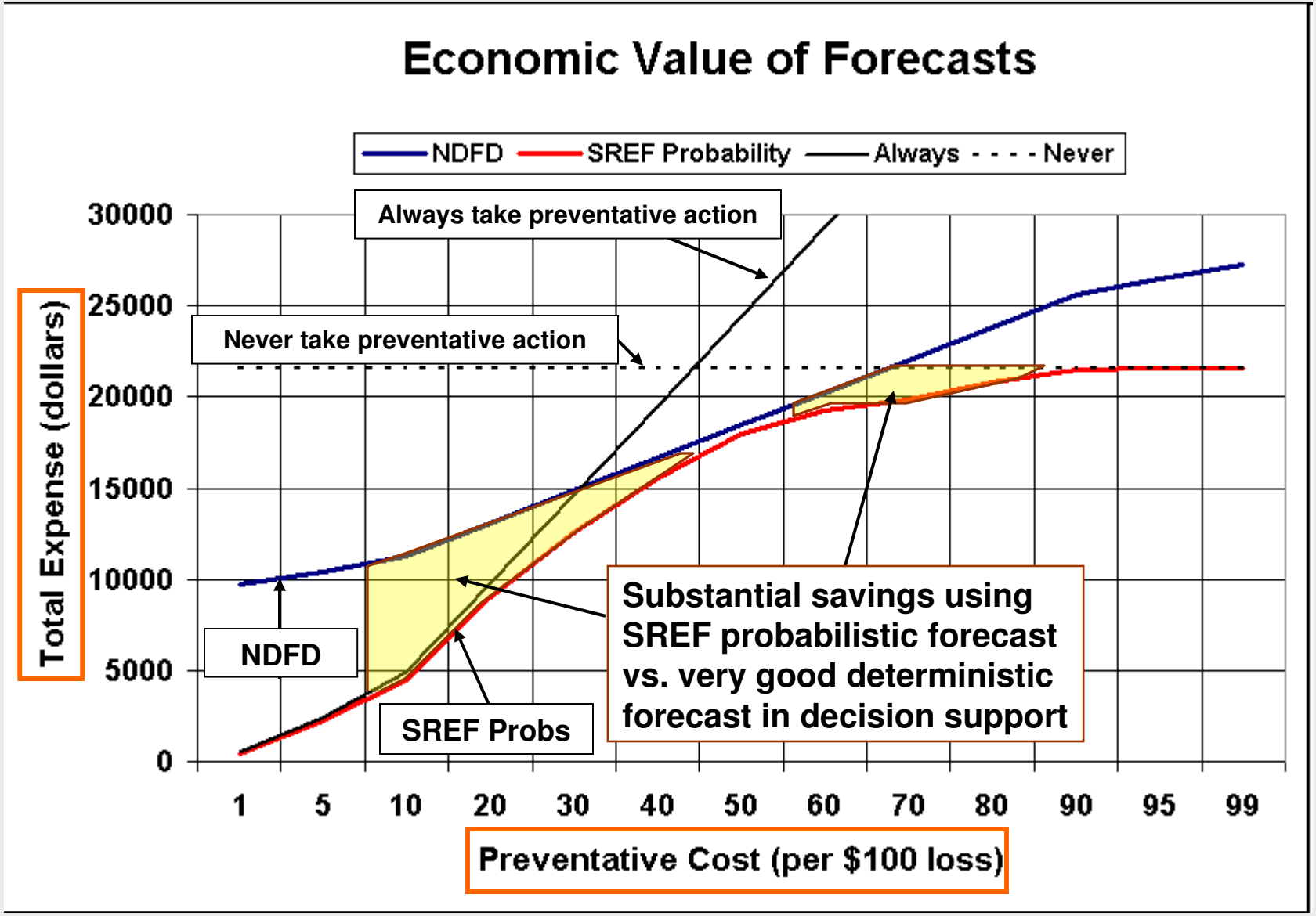
SREF: Prob Max Temp 27 Feb 2009 between 20-32F
Issued at 09 UTC 26 Feb 2009



Truth: Max temperature verified between 20-32F
27 Feb 2009

Verify the decision support guidance at every 40 kmx40 km grid point within the domain shown

Ensembles and Decision Support



Looking to the Future…

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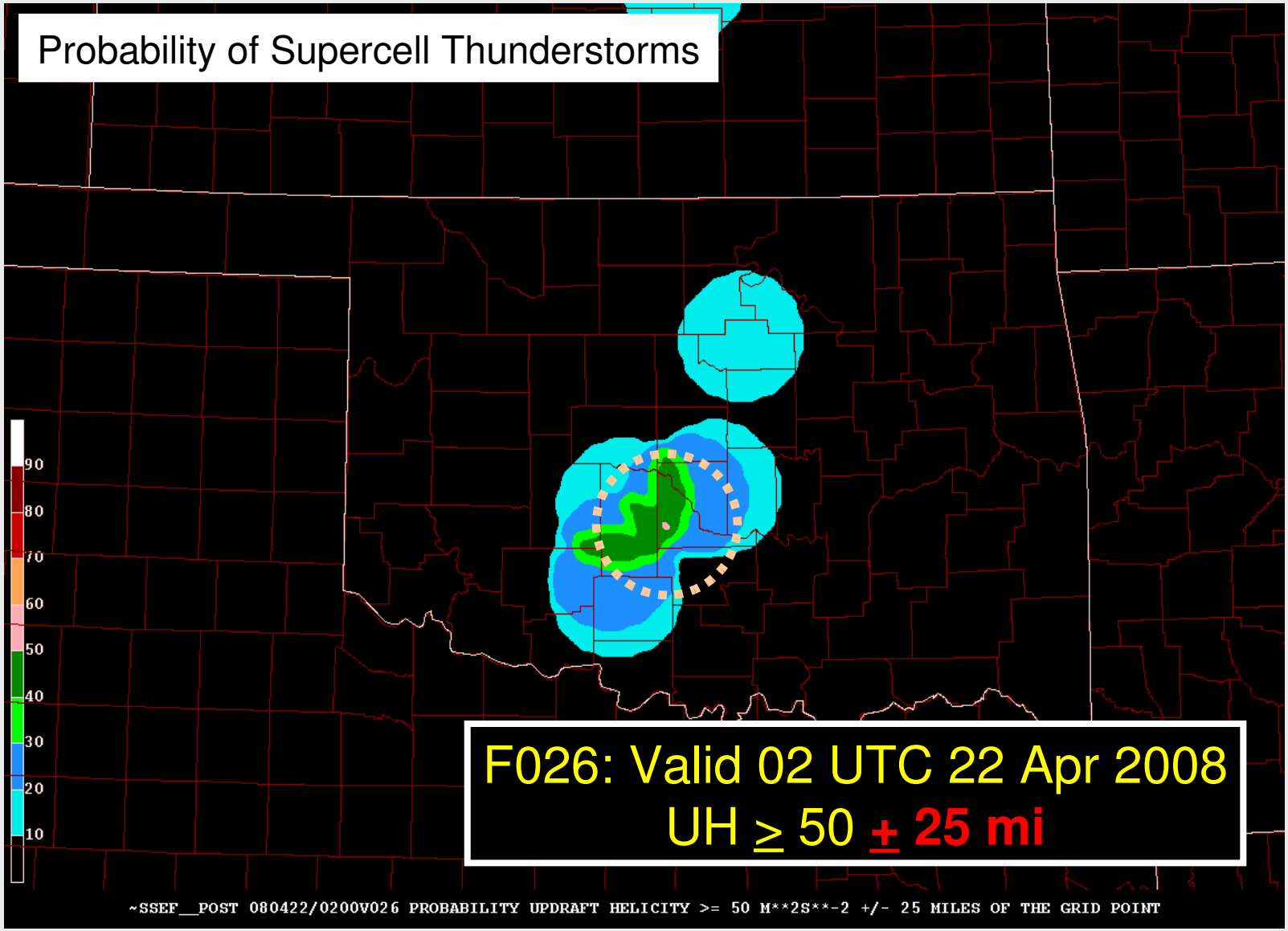
Future Applications: Convection and Severe Weather Resolving Ensembles

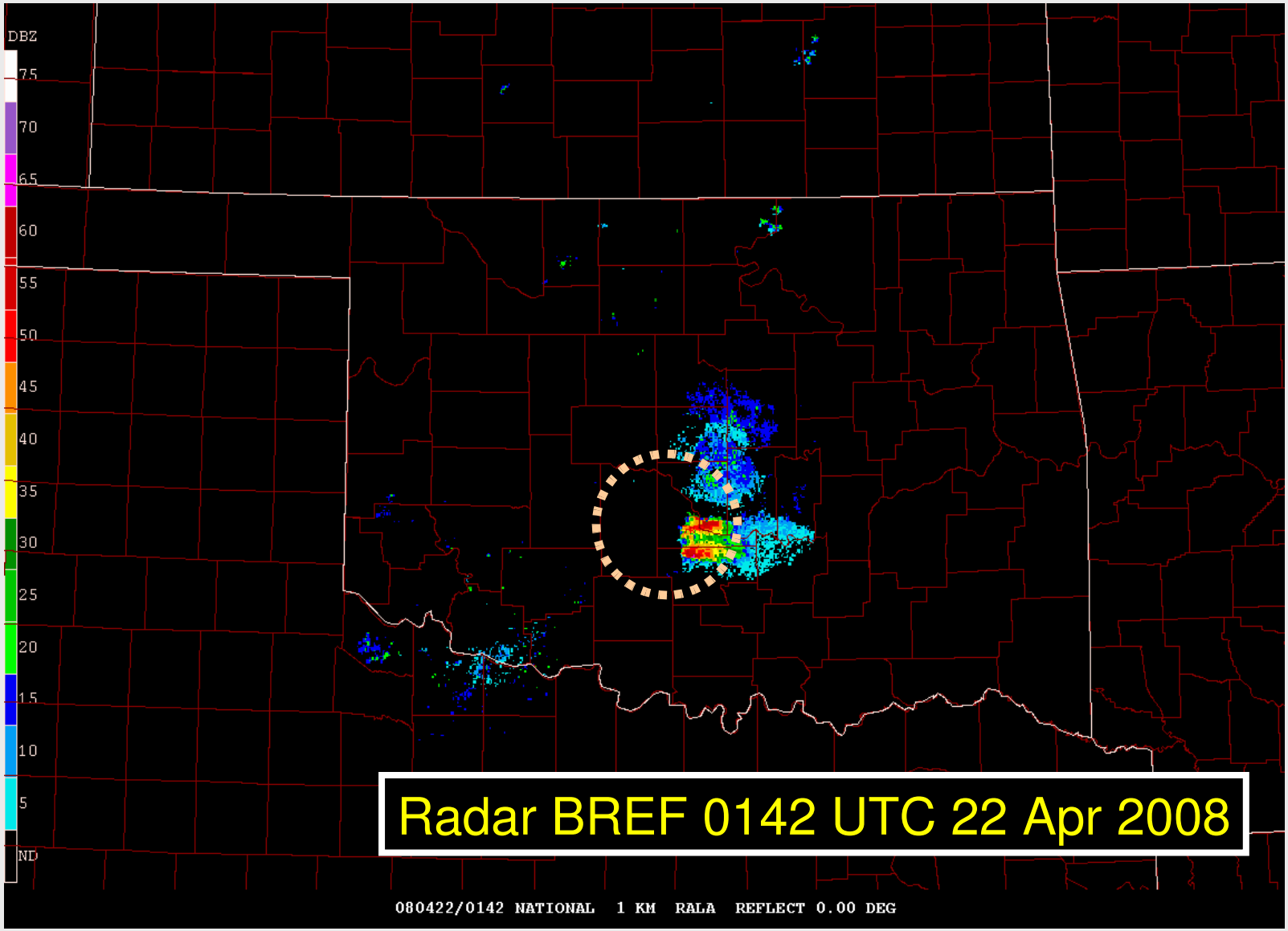
- NOAA Hazardous Weather Testbed (HWT)
- HWT Spring Experiment
- Convection allowing ensemble forecasts (2007-2009) to address uncertainty
  - 10 WRF members
  - 4 km grid length over 3/4 CONUS
  - Major contributions from: SPC, NSSL, OU/CAPS, EMC, NCAR
- Evaluate the ability of convection allowing ensembles to predict:
  - Convective mode (i.e., type of severe wx)
  - Magnitude of severe type (e.g., peak wind)
  - Aviation impacts (e.g., convective lines/tops)
  - QPF/Excessive precipitation

2003 Spring Experiment

Probability Updraft Helicity ≥ 50 m²/s²



Observed Radar



Probability Updraft Helicity ≥ 50 m²/s²

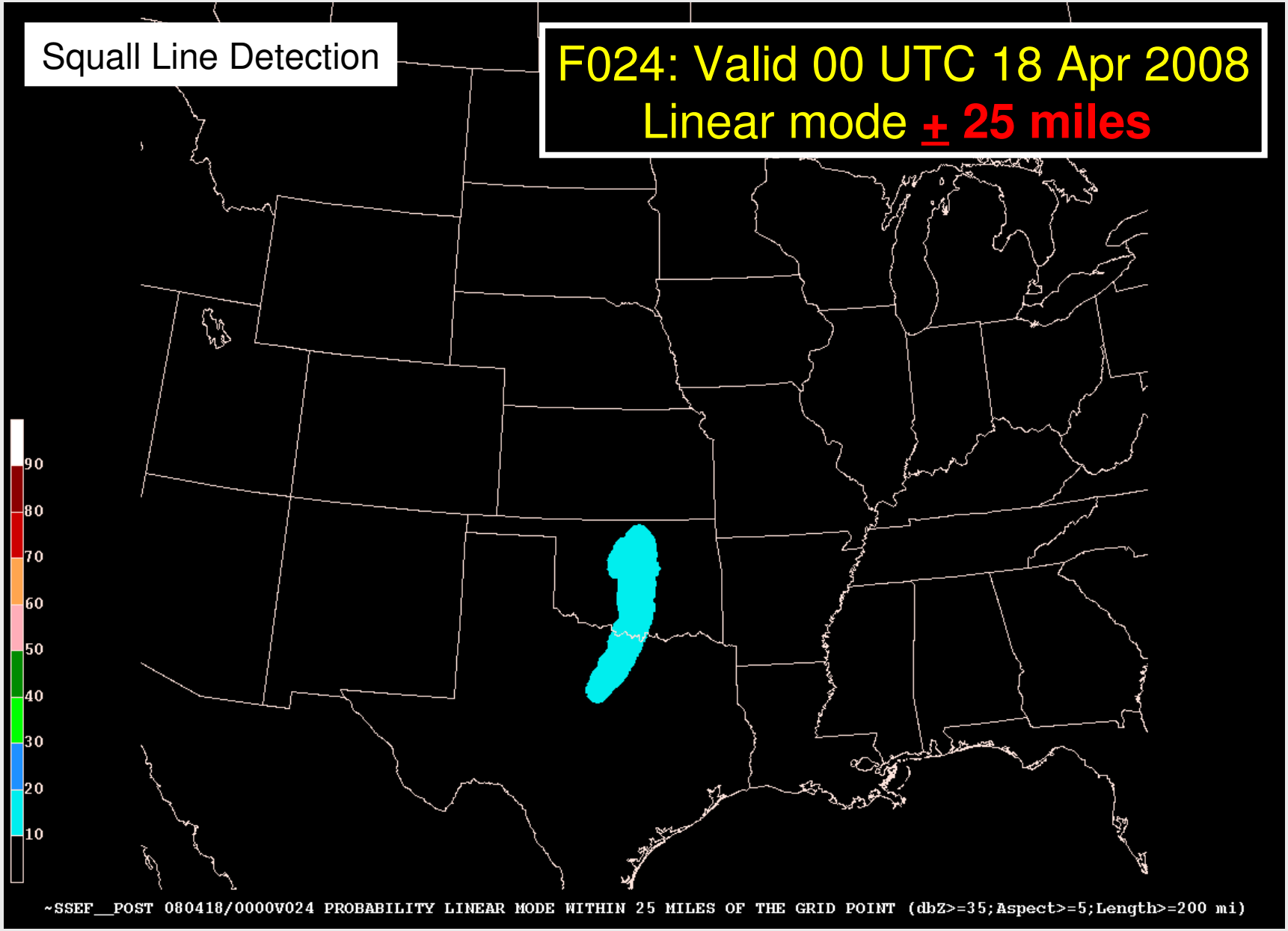
View of the left split looking south from Norman, OK (0145 UTC 22 Apr 2008)

(Numerous large hail reports up to 2.25")

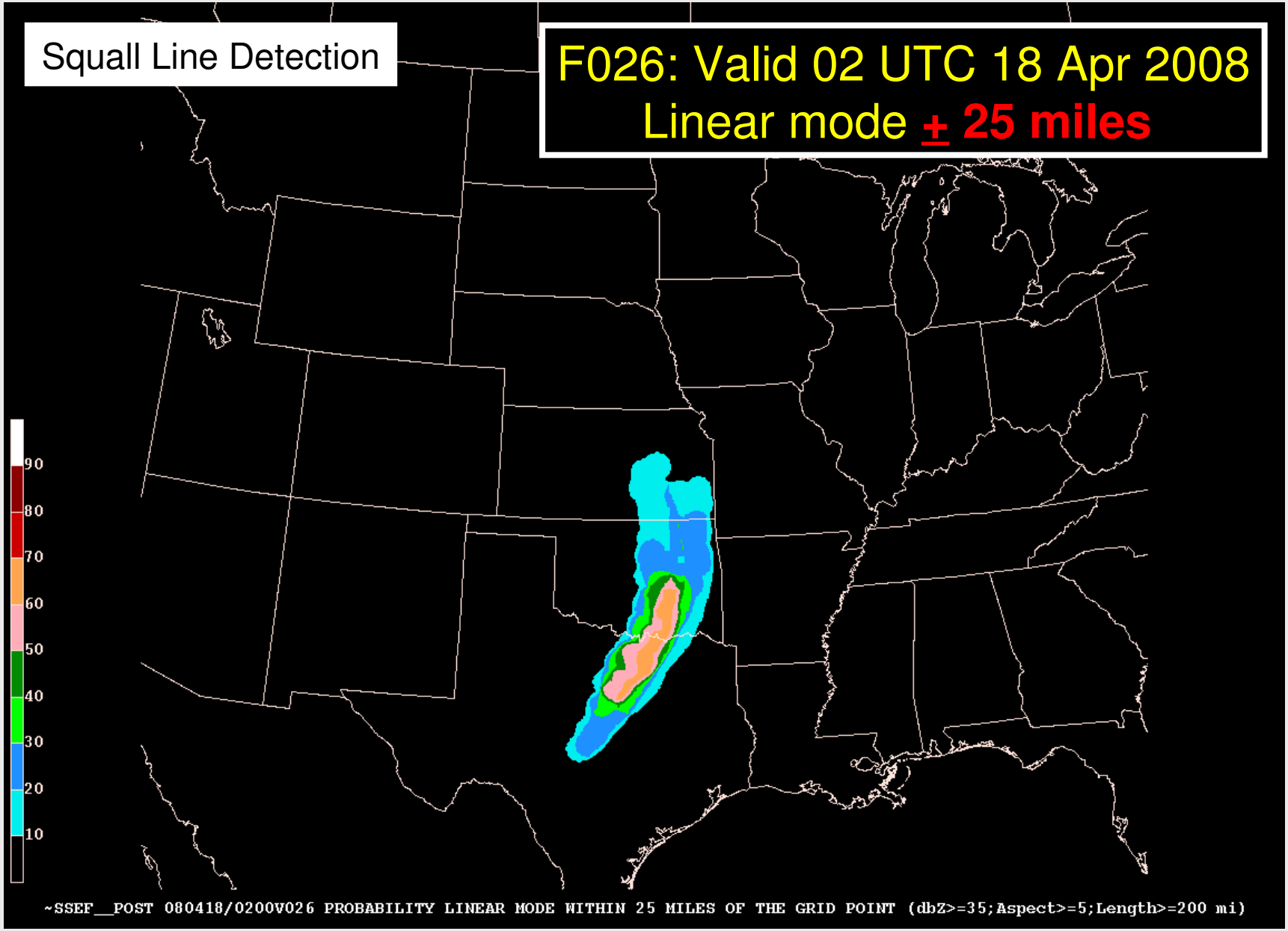
Convective Mode: Linear Detection

- Determine contiguous areas exceeding 35 dbZ
- Estimate mean length-to-width ratio of the contiguous area; search for ratios ≥ 5:1
- Flag grid point if the length exceeds:
  - 200 miles

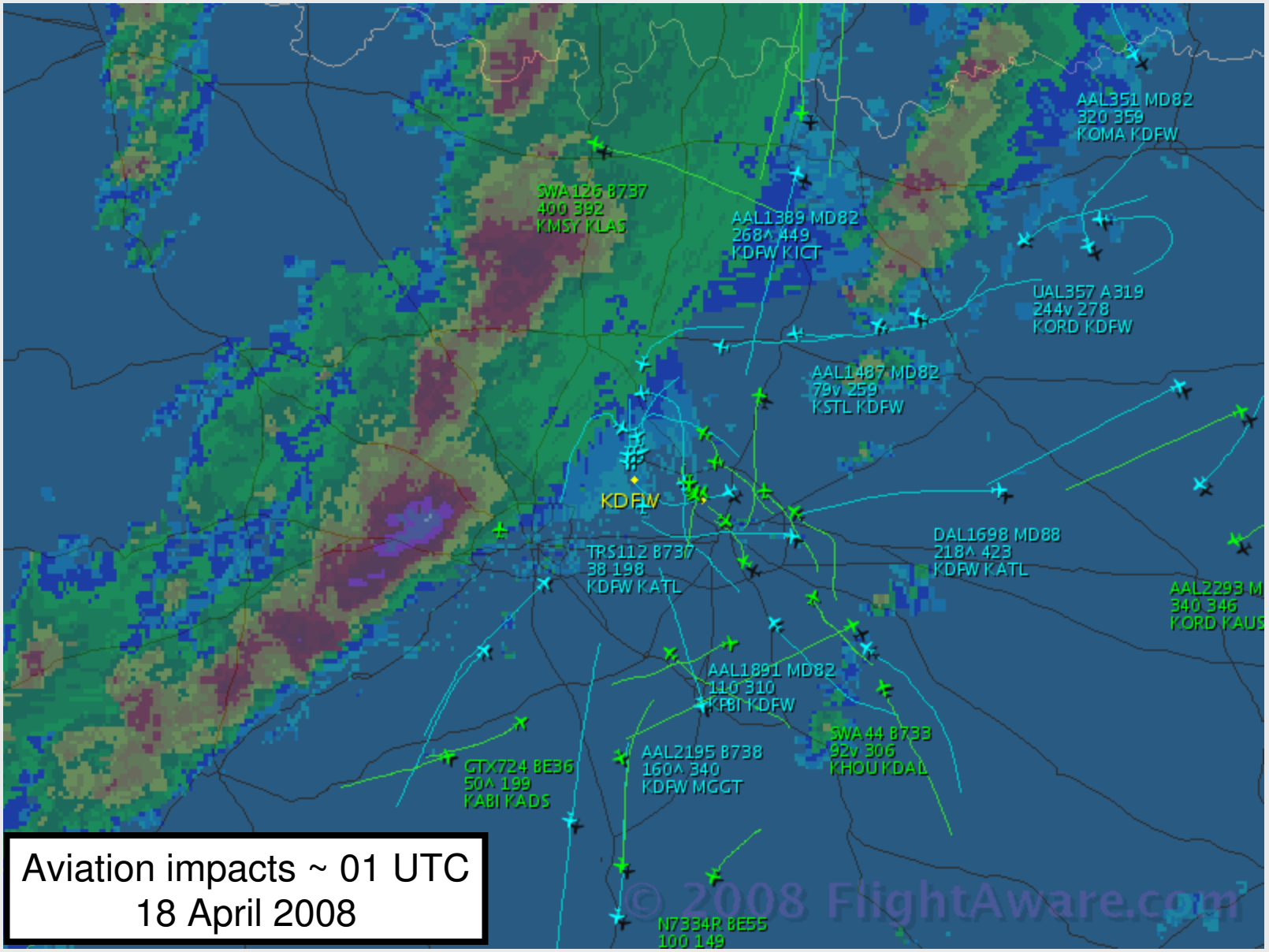
Probability Linear Mode Exceeding 200 miles



Probability Linear Mode Exceeding 200 miles



Linear Convective Mode: Impacts



Aviation impacts ~ 01 UTC
18 April 2008

Image provided by Jon Racy

Summary

- Ensembles are a collection of models valid at the same time
  - Contribute confidence to the forecast process
  - Provide a range of possible scenarios
  - Lend themselves to probabilistic forecasting and decision support
- Output can be tailored to many specialty applications or forecast problems
- High-resolution ensembles show tremendous promise for severe convective storm forecasting and decision support

Questions/Comments…
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