Non-Supercell Tornadoes and the NST Parameter: Landspout Tornadoes June 16 2004

WFO La Crosse Research Series #11

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Objective

- Improve operational forecasts of nonsupercell tornadogenesis (NST) by increasing situational awareness of:
  - their behavior.
  - their meso- and misoscale (40m-4km) environment.
- How successful can a warning program be for NST?
  - At least 6 of our 18 tornadoes in 2004 were NST.

Outline

- Literature Review of NST
- Review 16 June 2004 NST case
- Situational Awareness for NST Events
  - The NST Parameter
  - The ESP Parameter

Literature Review

- 1978: discussion begins on a land mode of tornadogenesis where mesocyclones are not present.
- Cooley, 1978 “Cold-Air Funnels”
  - No indications of radar signatures which have a high correlation of severe weather (e.g., hooks, v-notches, echo-free vaults). No indication of rotation in the storm cells.

Literature Review

- Burgess and Donaldson, 1979
  - Several weak tornadoes with no mesocyclone.
  - All occurred during the developmental stages of the storms. One tornado formed five minutes prior to first echo.

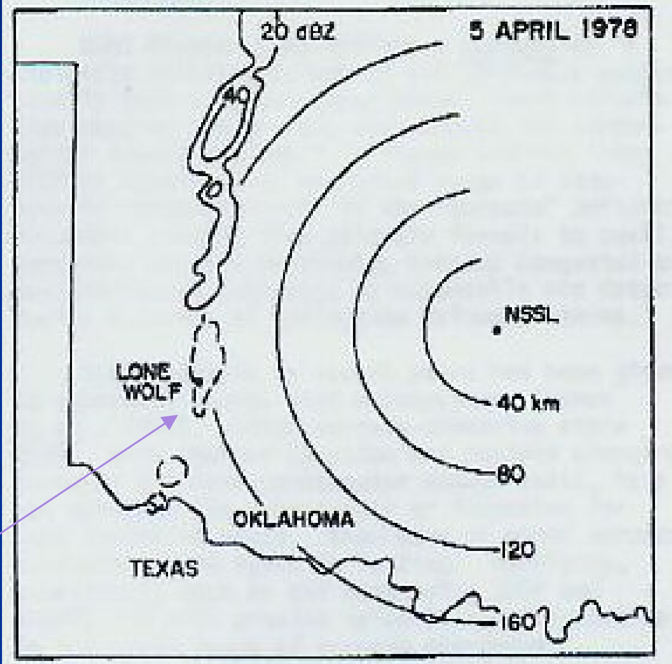
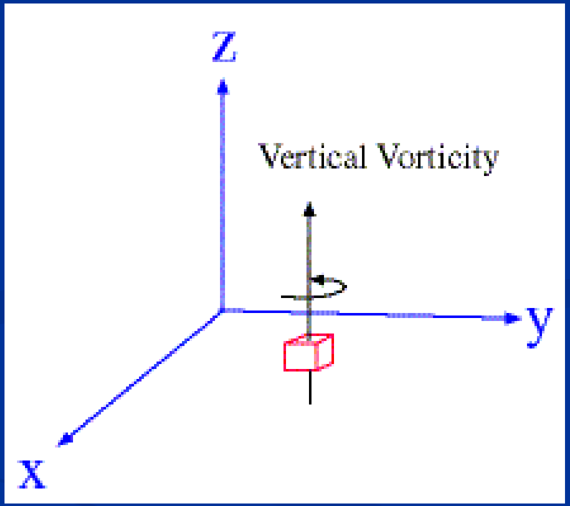


Figure 3. Radar echoes for 5 April 1978 at 1745 CST (solid lines) and new echoes at 1755 (dashed lines). Tornado was on the ground near Lone Wolf from 1746 until 1756 in conjunction with developing cell.

Literature Review

- Bluestein, 1985
  - "Landspout" term introduced.
  - Form within 30 min. of first radar echo.
  - Parent storm was not a supercell and no mesocyclone signatures were detected by radar.
  - Similar to waterspout formation where local vertical vorticity stretching is the source of the vortex at intersecting outflows.



Literature Review

- Wakimoto and Wilson, 1989 (WW89)
  - Inspected 27 visual vortices associated with non-supercell storms in the CINDE field project:

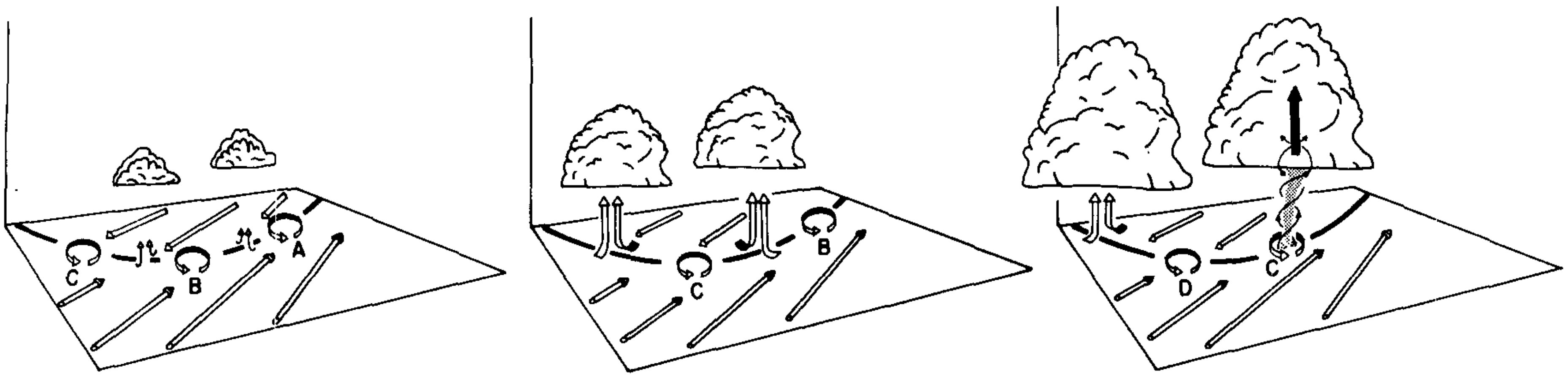


FIG. 20. Schematic model of the life cycle of the non-supercell tornado. The black line is the radar detectable convergence boundary. Low-level vortices are labeled with letters.

  - Boundaries having strong horizontal shears, possessing wavelike inflections indicative of 1-3km vertical vorticity circulations (misocyclones) with rapidly developing storms above.

Literature Review

- Brady and Szoke, 1989 (BS89):
  - Analysis of 26 July 1985 Erie, CO tornado.
  - Similar findings to WW89.
  - Misocyclones (<4 km diameter), traveled along the boundary and were stretched to produce the vortex.
  - Strong sub-cloud instability favors incipient circulations to grow in the vertical.
  - Large reflectivity increase of 30 dbZ in 5 mins.

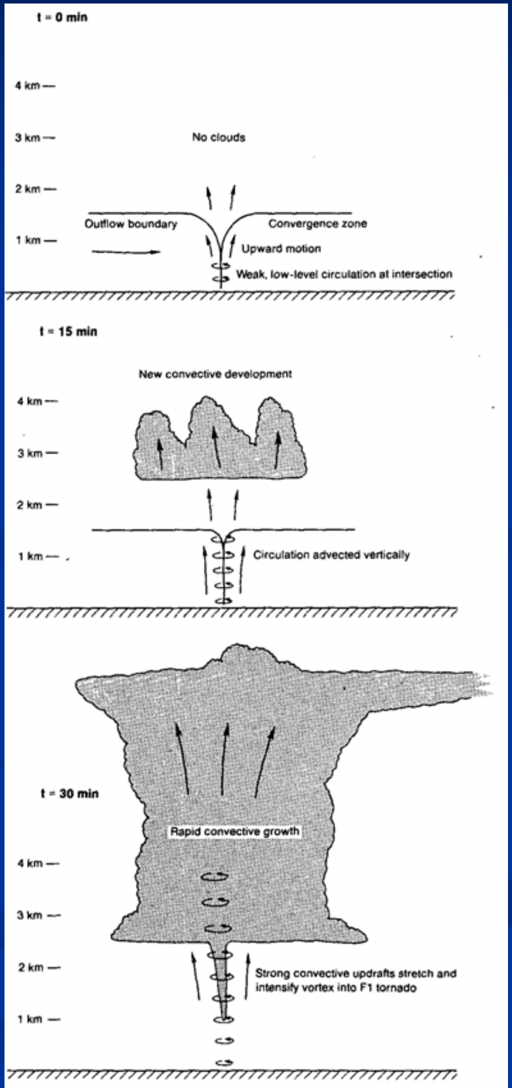
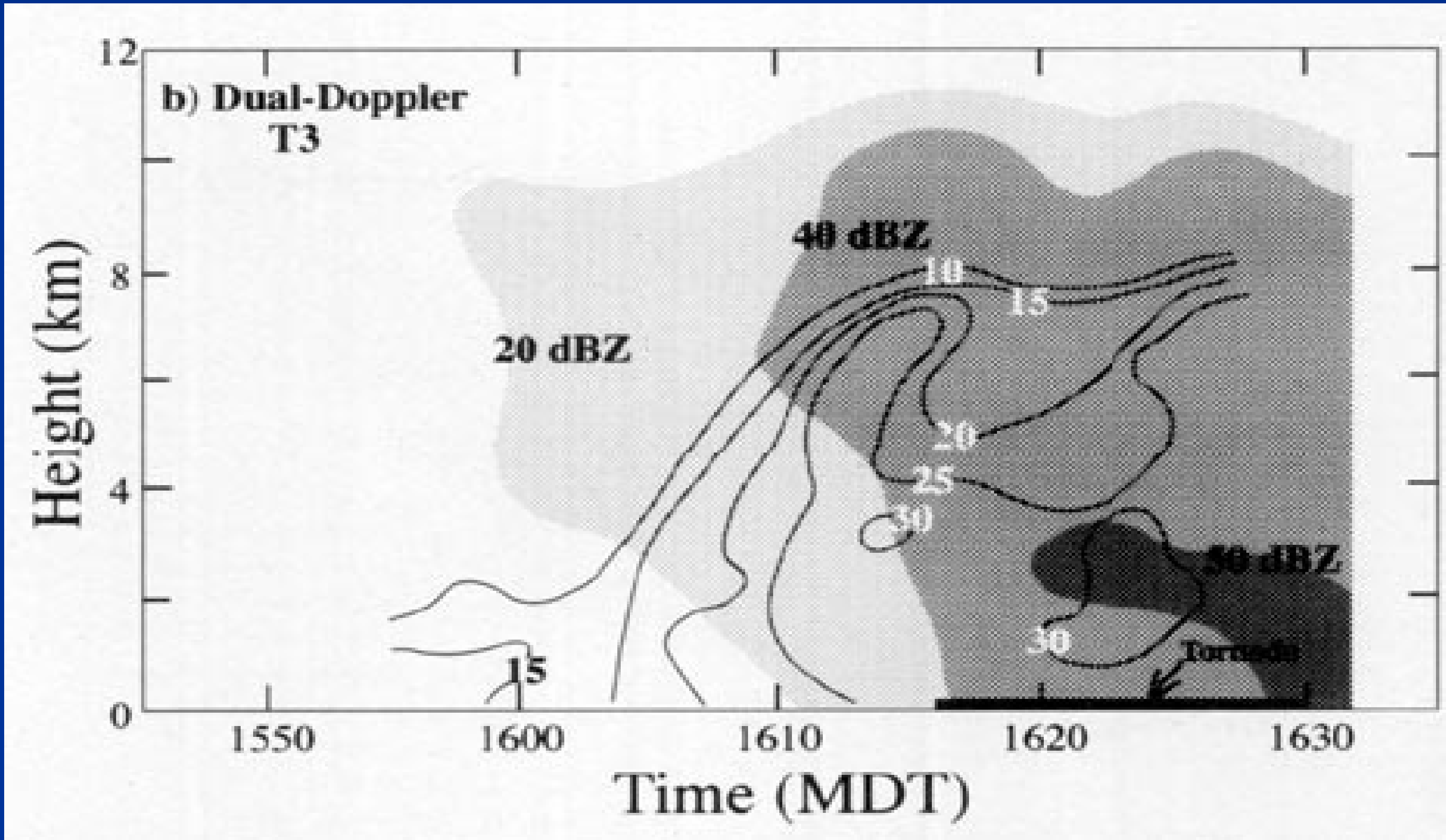


FIG. 9. Schematics illustrating the development of the Erie tornado. This basic scenario appears to be valid for most nonmesocyclone tornadoes.

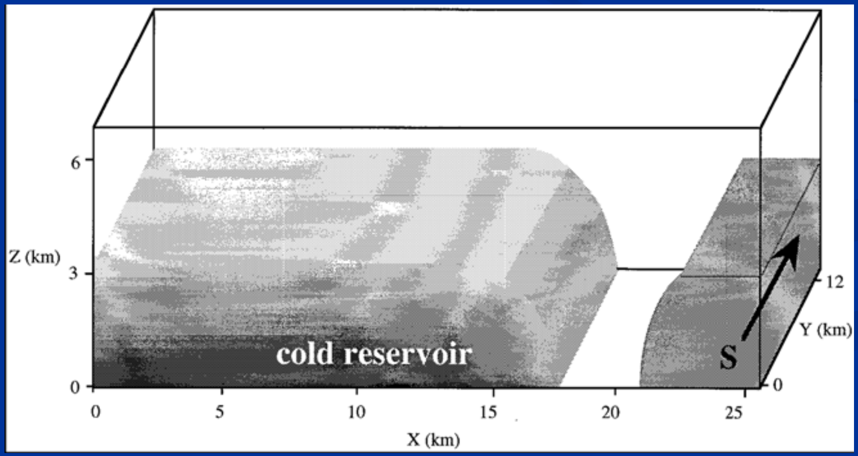
Literature Review

- Roberts and Wilson, 1995:



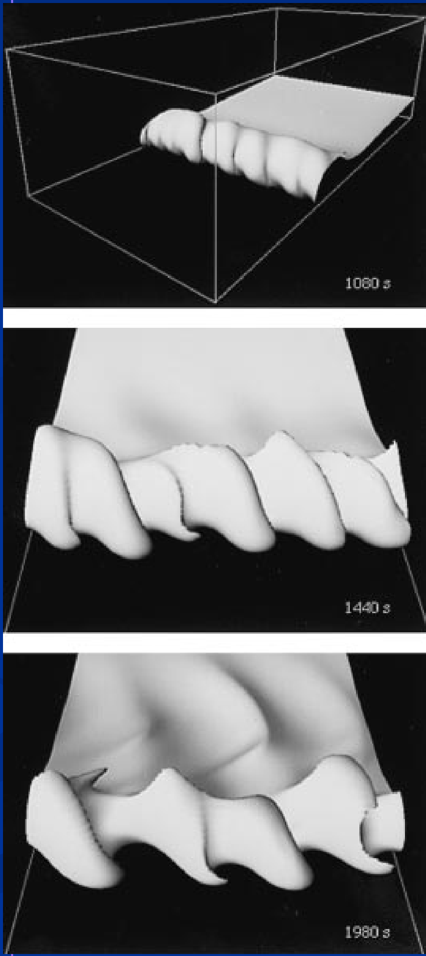
Literature Review

- Lee and Wilhelmson (1997, I):
- Investigated misocyclone development using a dry, high resolution, 3d numerical simulation independent of moist processes.
- Used a simulated outflow (-3K cooler) with southerly ambient flow ahead.



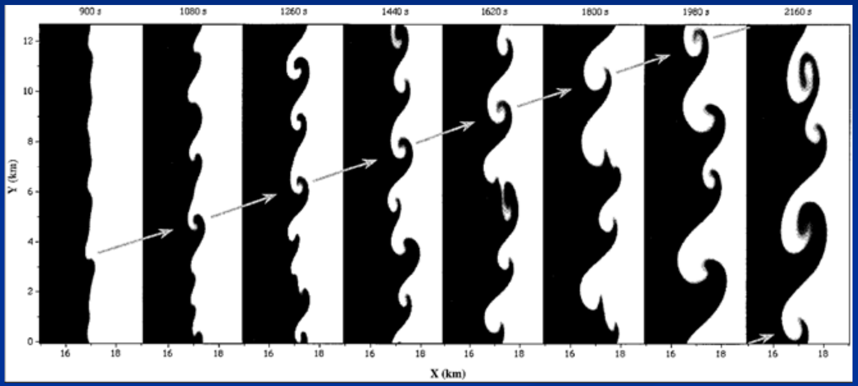
Literature Review

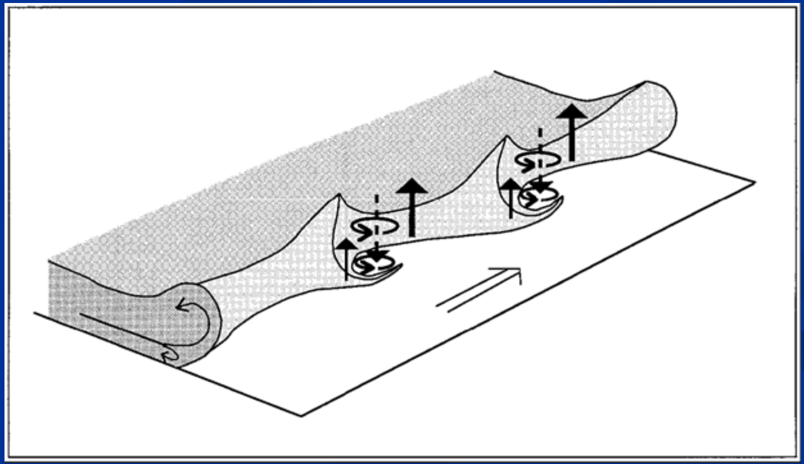
- Lee and Wilhelmson (1997, I):
- Simulations verified misocyclones exist.
- Theorized misocyclone-induced updrafts may have significantly contributed to convection initiation.
- Lobe and cleft response.
- Upscale consolidation of smaller misocyclones.



Literature Review

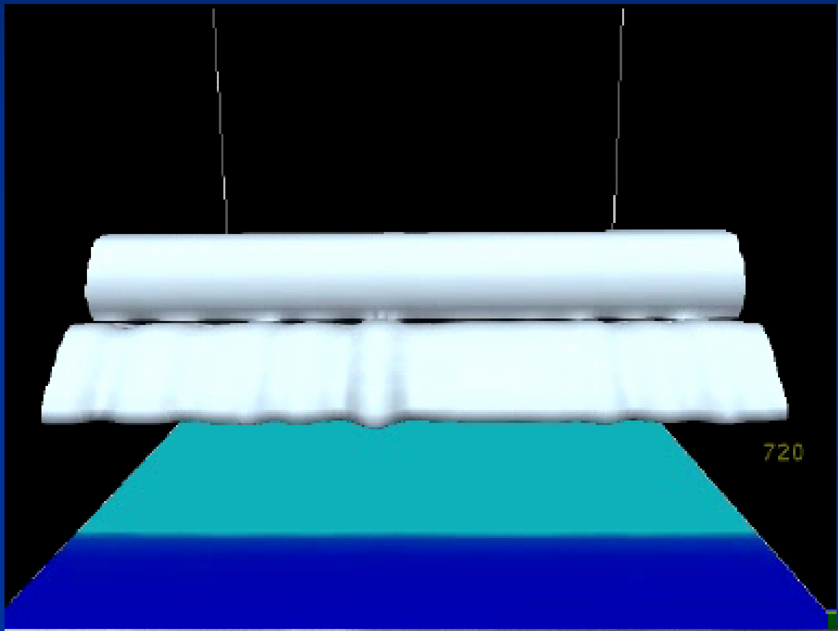
- Lee and Wilhelmson (1997, I):
- Traveling misocyclones along the boundary in the direction of the pre-boundary mean wind. Consolidation.
- 3-D conceptual model of misocyclone development along the boundary.





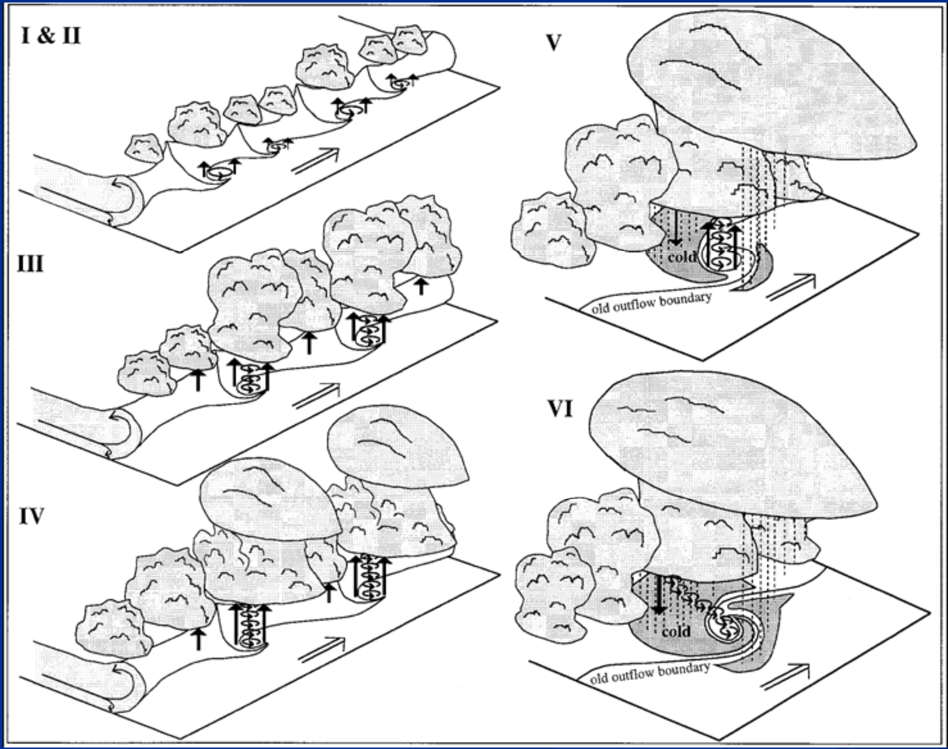
Literature Review

- Lee and Wilhelmson (1997, II):
- Simulations as in Part I but with moist processes.
- Confirmed:
  - Shearing instability creates misocyclones.
  - Tornadic origin near the surface.
  - Vertical vorticity stretching is primary source of vortex intensifications.
- Misocyclones influence the pattern of convective forcing along a boundary.



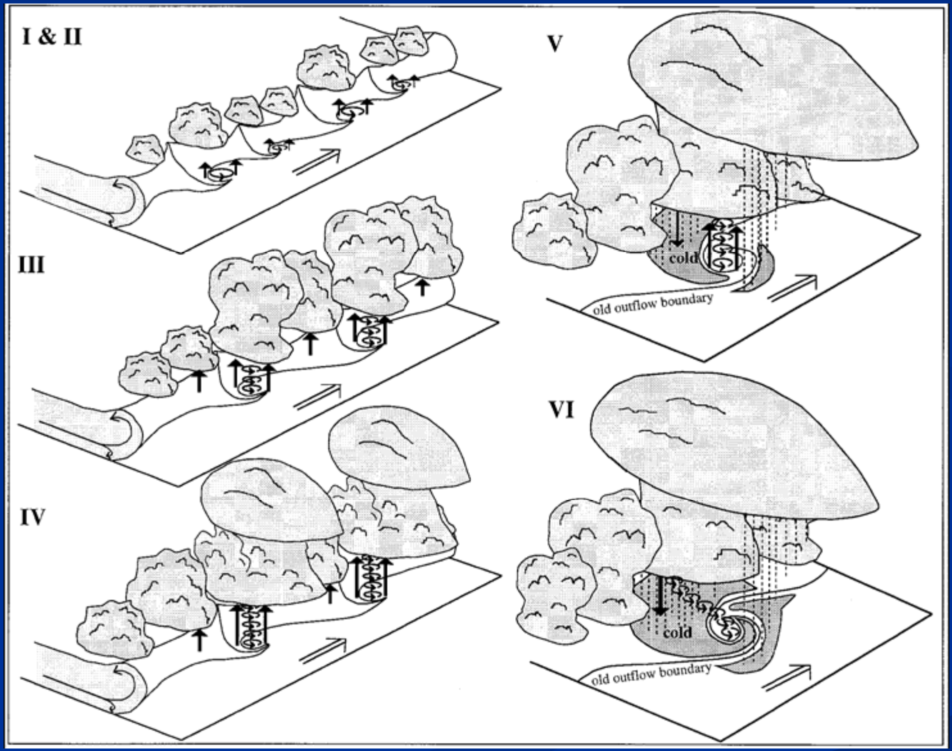
Literature Review

- Lee and Wilhelmson (1997, II):
- For a vortex sheet that breaks down into a number of vortices (later misocyclones) in conjunction with known favorable environmental conditions for convective development, one can expect not just one but a number of tornadoes that occur concurrently along a common boundary. A family of tornadoes.
- New storm outflow influences NST timing and intensity (25%+ delV).



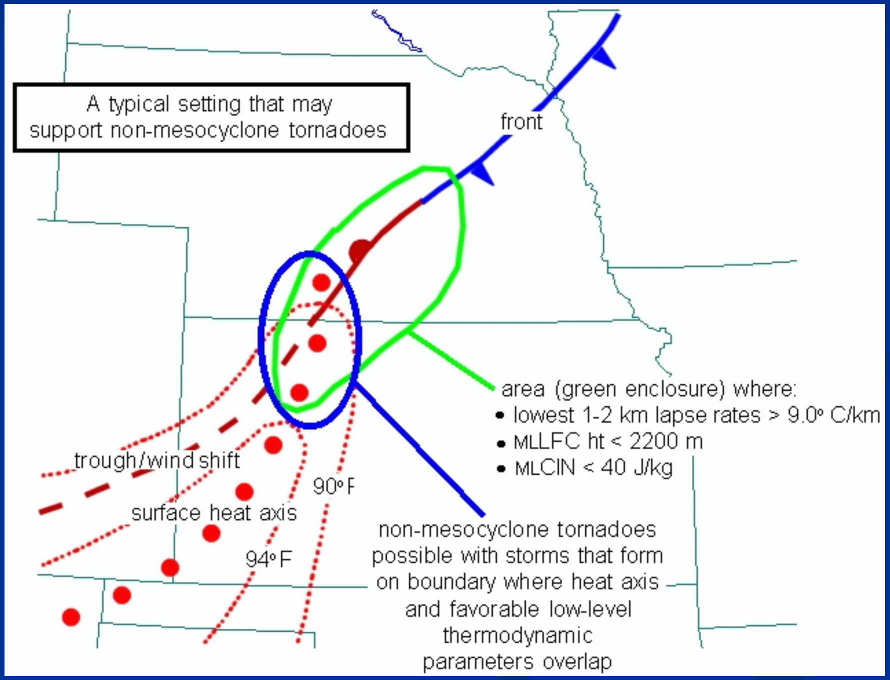
Literature Review

- Lee and Wilhelmson (2000, III):
- Continued numerical simulations with altered environments.
- As CAPE increased, NST vortex strength increased, vertical vorticity was stretched in shorter time periods.
- 10-20 kts of change in the line parallel wind field needed. Otherwise, NST less likely.
- The near-surface southerly winds correlated to misocyclone strength and progression along the boundary.



Literature Review

- Davies (2002, website):
- Environments supportive of NST:
  - A slow-moving or stationary wind shift boundary with pockets of vertical vorticity
  - Steep lapse rates (>9C/km) in the lowest 1 to 2 km
  - LFC heights that are relatively low (around 2200 m AGL or lower) and very close above the LCL height, with little CIN between the two levels.
  - Little CIN.



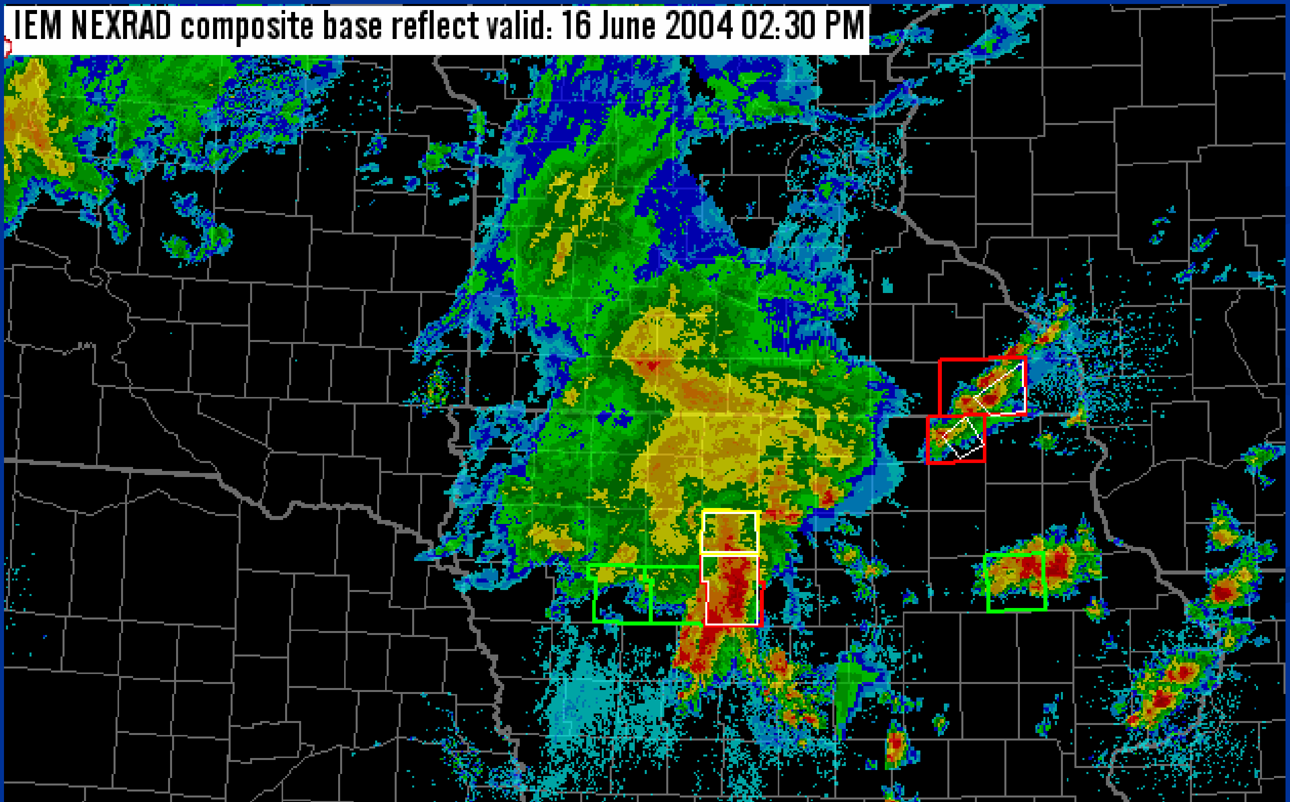
Jon M. Davies Web Site:
http://members.cox.net/jondavies1/tornado_fcsting/nonsprcll_tors.htm

Literature Review Summary

- Environments supportive of NST:
  - Convergent surface boundary with 10-20 kts of line-parallel shear across it. Misocyclones, slow-moving?
  - Larger 0-3km MLCAPE (>150 J/Kg), larger MUCAPE.
  - Steep sub-cloud lapse rates (>9C/km)
  - LFC heights that are relatively low (around 2200 m AGL or lower) and very close above the LCL height
  - Little CIN.
  - Non-supercell 0-6km bulk wind shear.
- Storm-scale NST:
  - Source vorticity originates from misocyclones traveling along the shear boundary.
  - Boundary temperature gradient of 3K seems to enhance forcing. Nearby outflow increases NST parent vortex strength.
  - Radar reflectivity of 0-30dbZ during tornado onset. Rapid reflectivity increase in minutes.
  - NST-type tornadoes occur in families. If one occurs, expect more!
  - Storm may produce supercell structures further into lifecycle.
  - Downdraft usually destroys tornado.

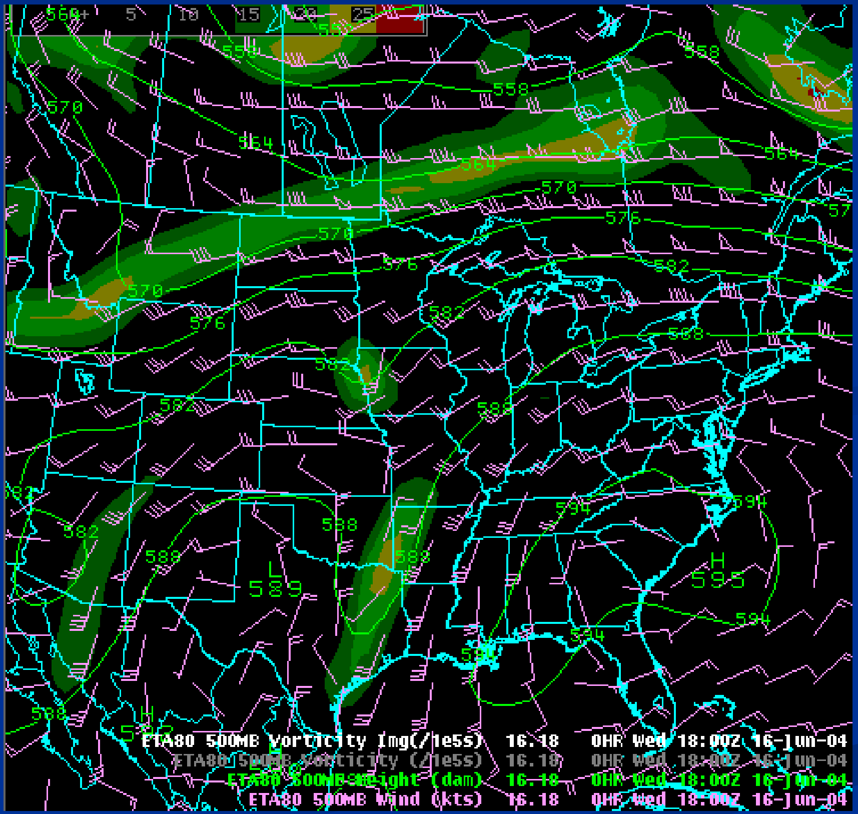
2004 June 16: Environment

- Weak stationary surface boundary convected at 1730Z.
- Convectively-enhanced deep cyclonic shortwave approaching.



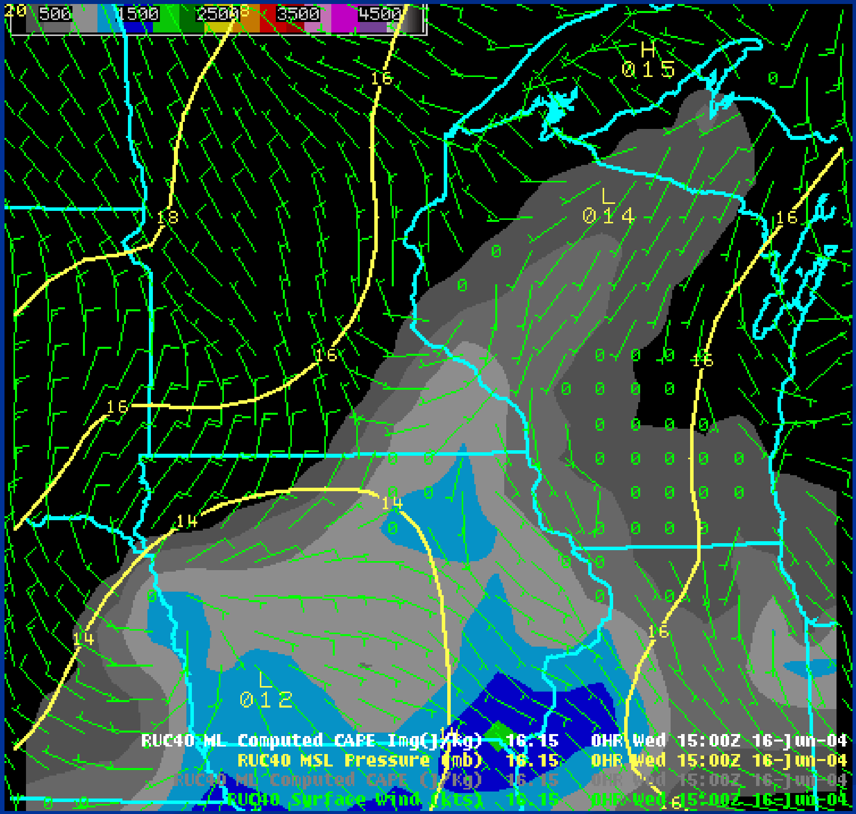
2004 June 16: Environment

- Eta 500mb 18z
- 20-25 knots
- Mean cloud bearing wind 230@20kts



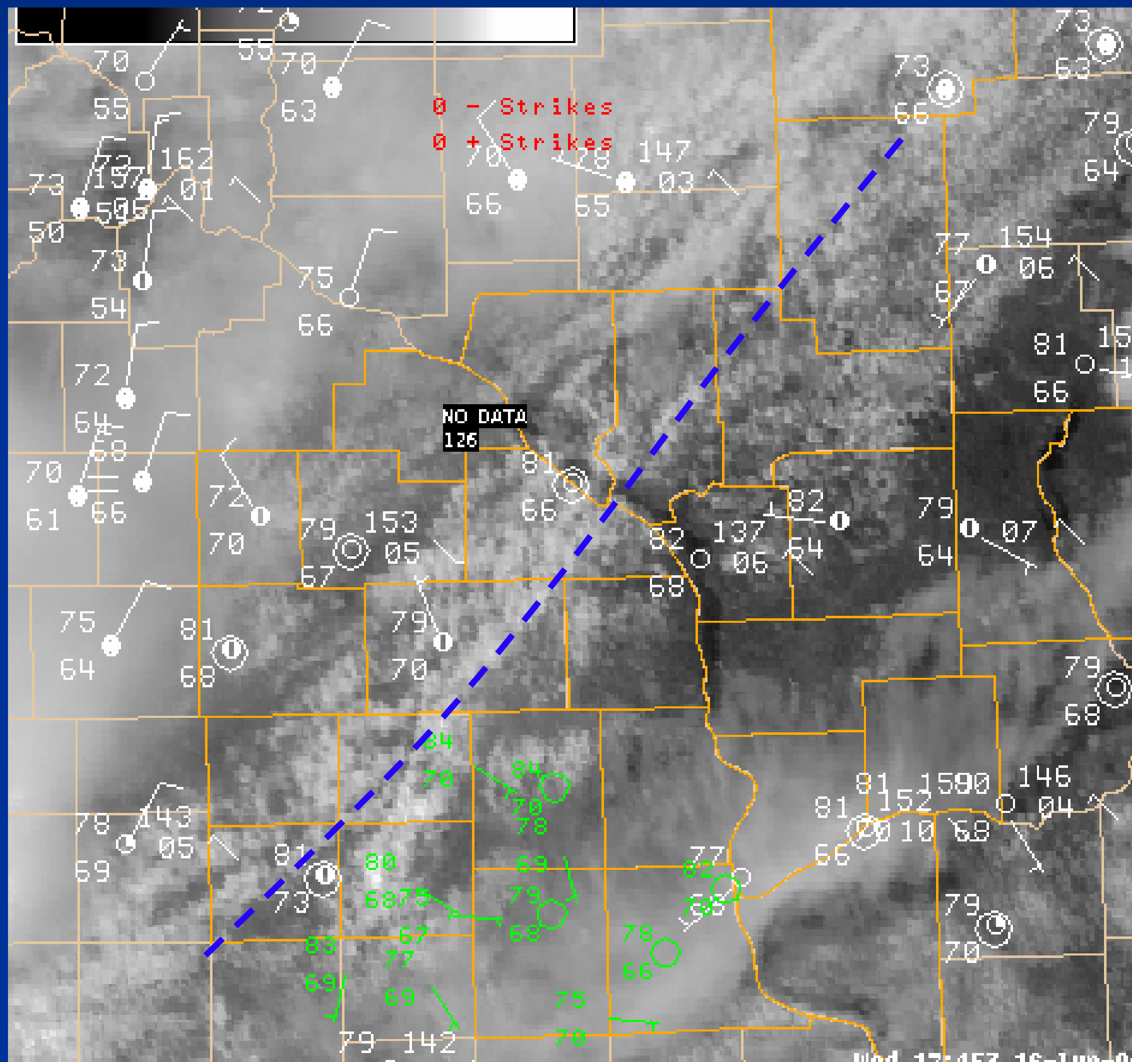
2004 June 16: Environment

- RUC Surface MSLP 15,18,21z
- Surface low center approaching.
- NE-SW surface boundary to become stationary over Iowa.



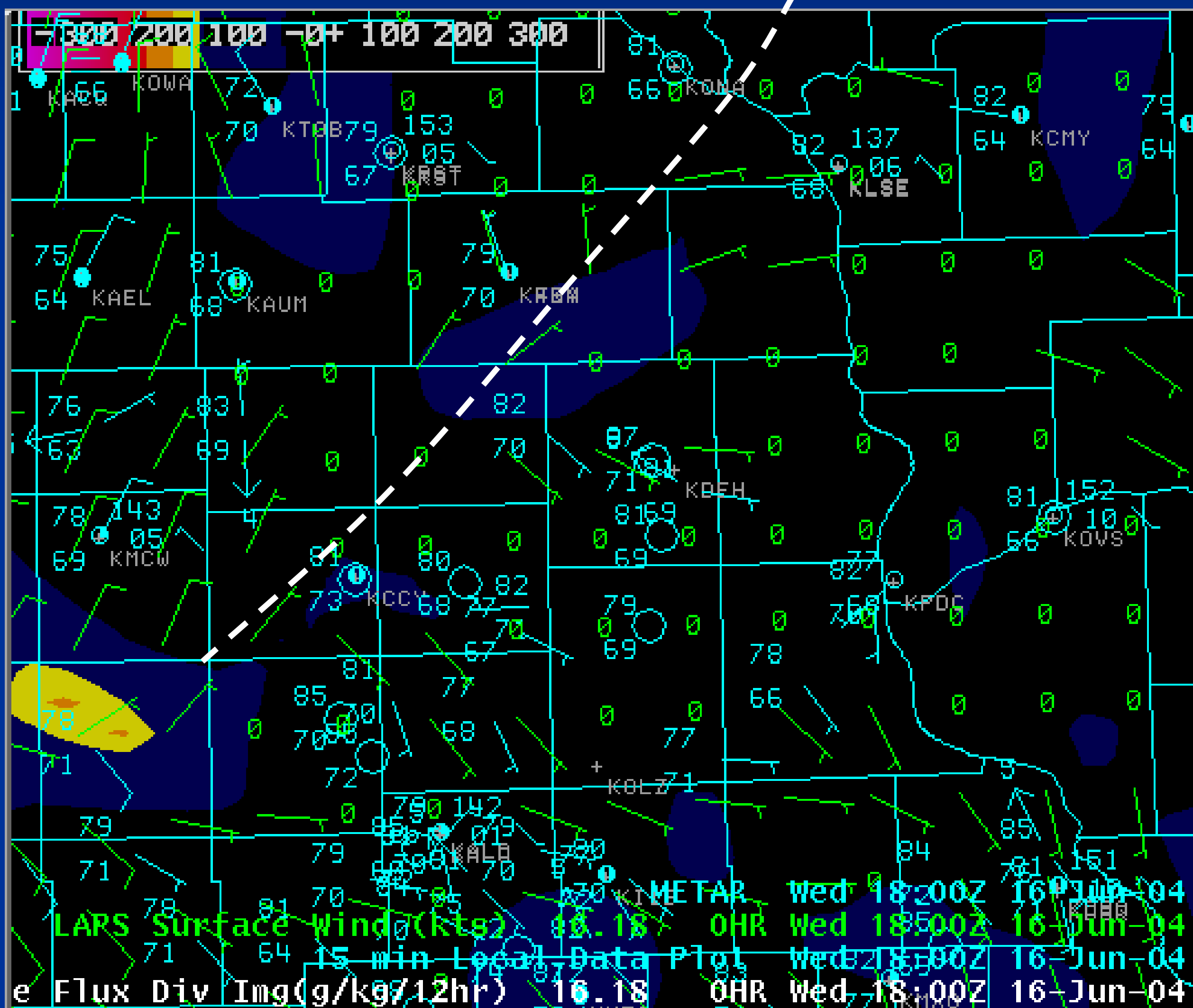
18z 2004 June 16: Environment

- First: echo 1730z, C-G strike 1830z, NST 1900z.



18z 2004 June 16: Environment

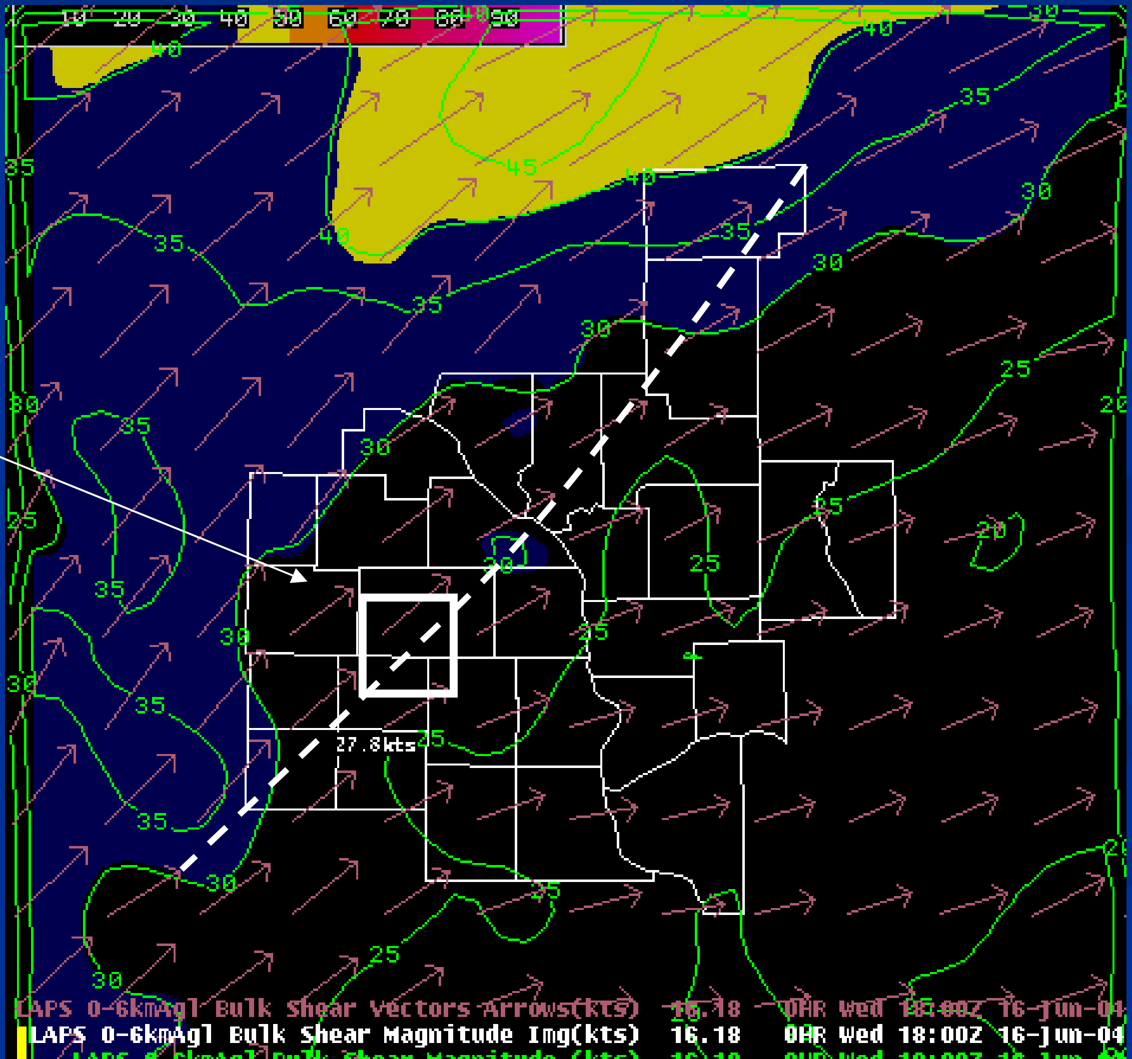
- Laps Surface Moisture Convergence, Wind, METAR



18z 2004 June 16: Environment

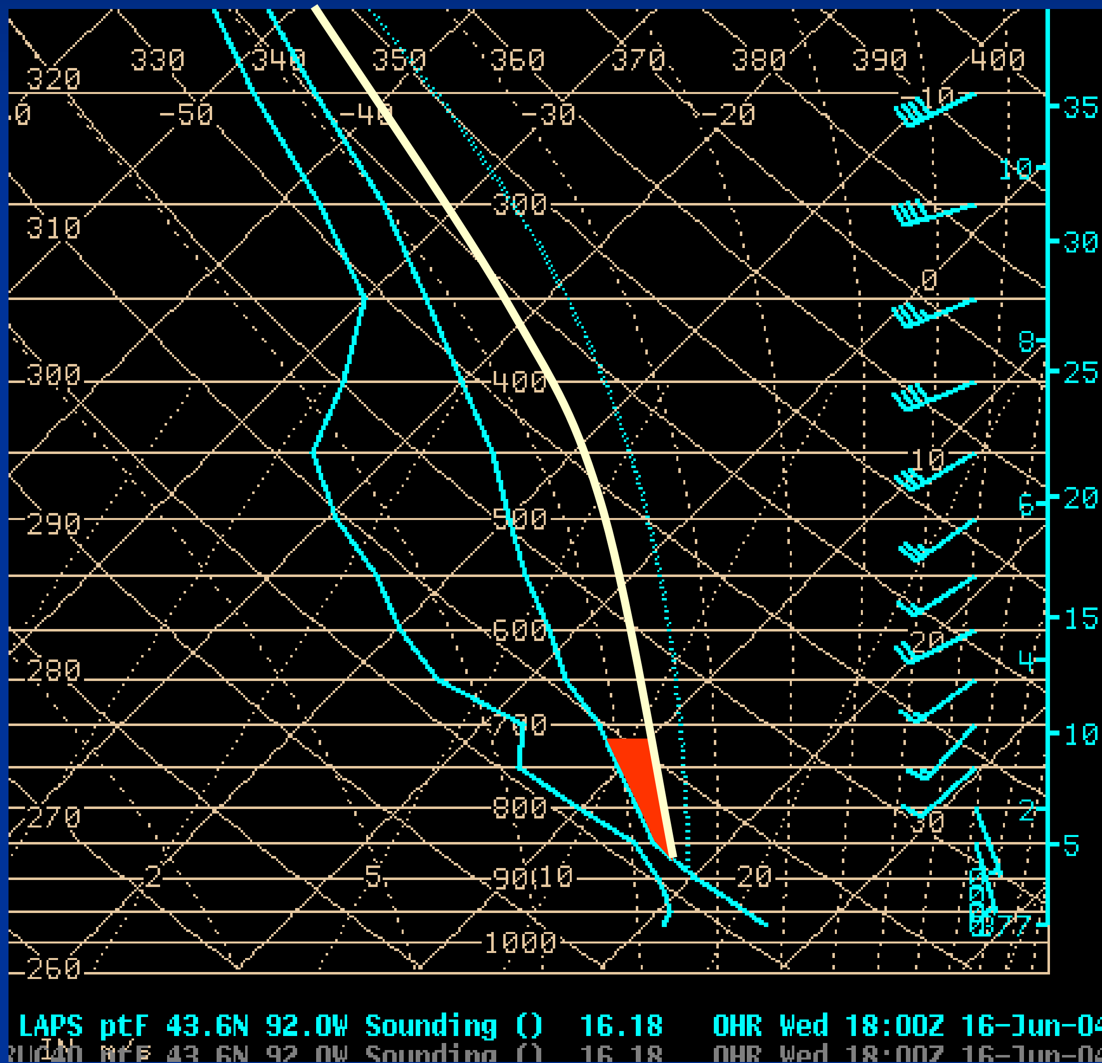
- Laps 0-6km Bulk Shear (kts)

LAPS Sounding taken here



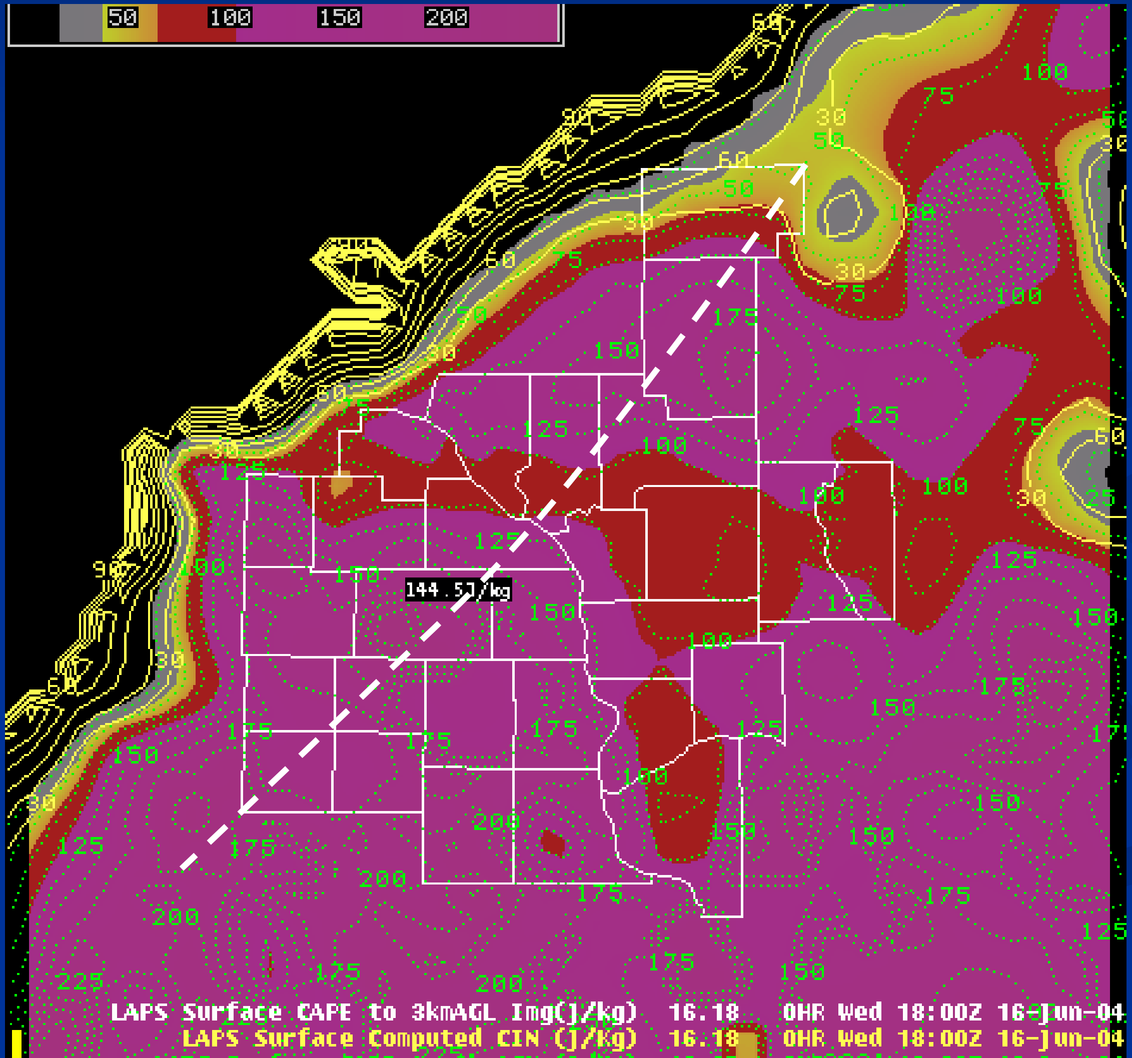
18z 2004 June 16: Environment

- Laps sounding on boundary (0-1km mean parcel)



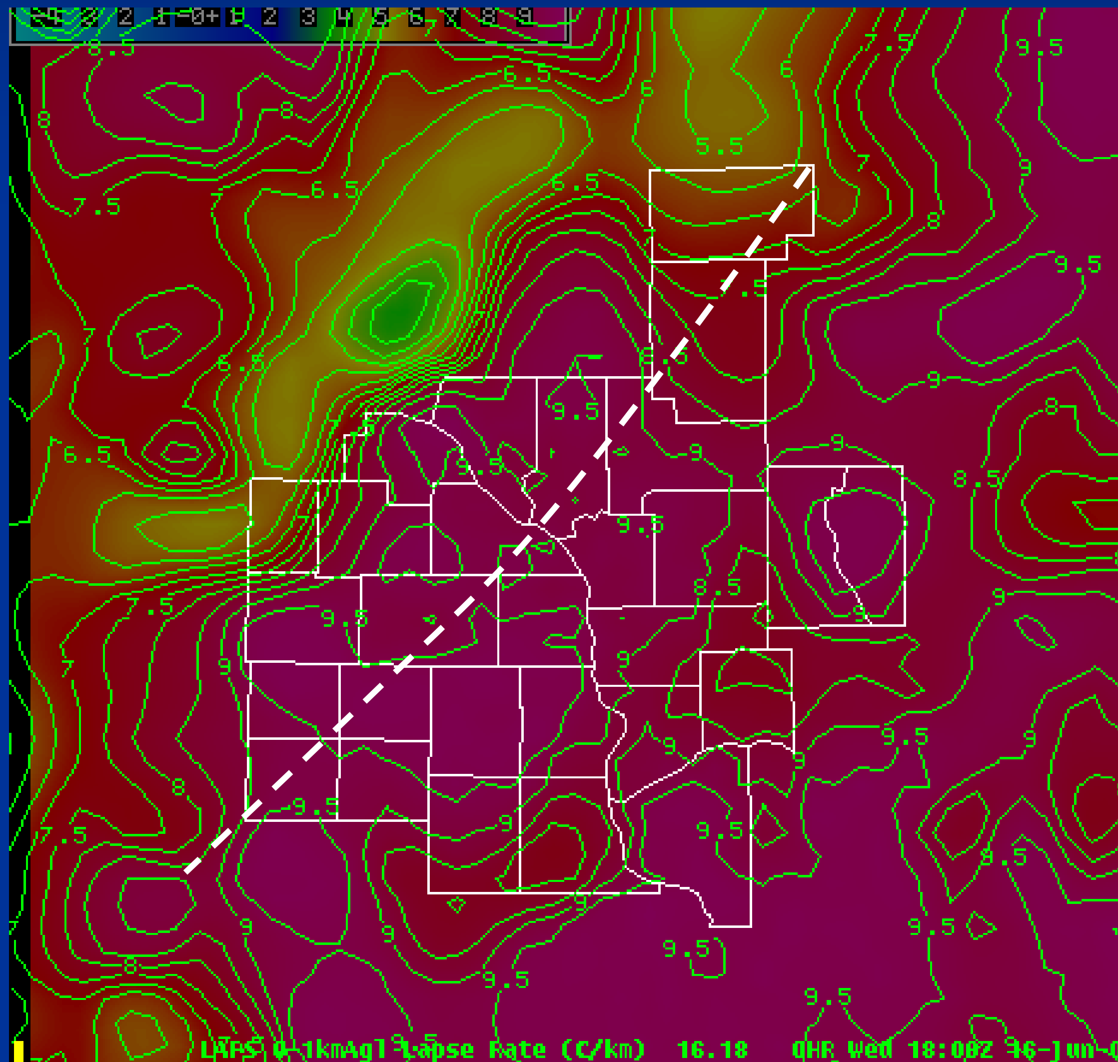
18z 2004 June 16: Environment

- Laps 0-3km ML CAPE



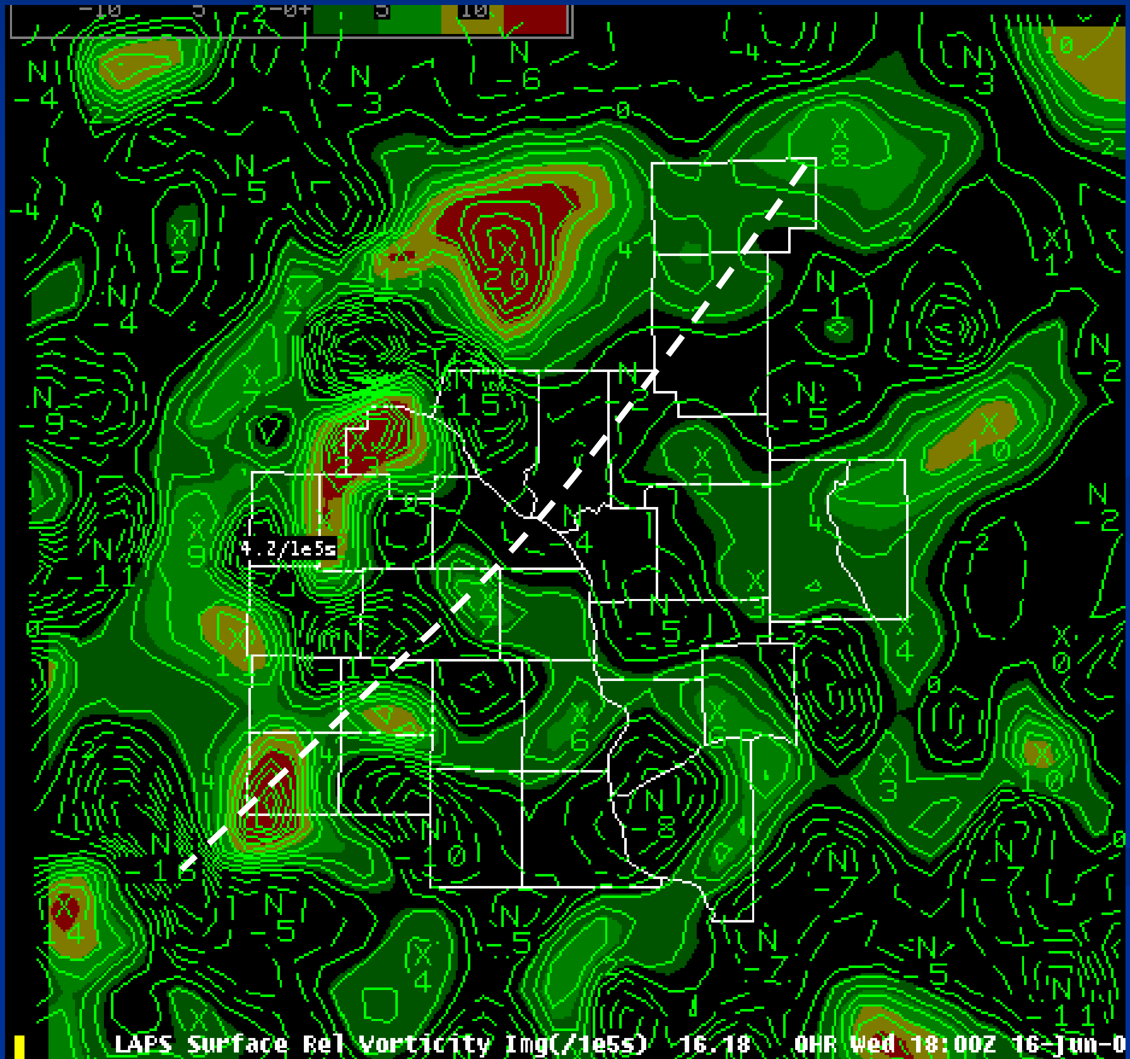
18z 2004 June 16: Environment

- Laps 0-1km Lapse Rate



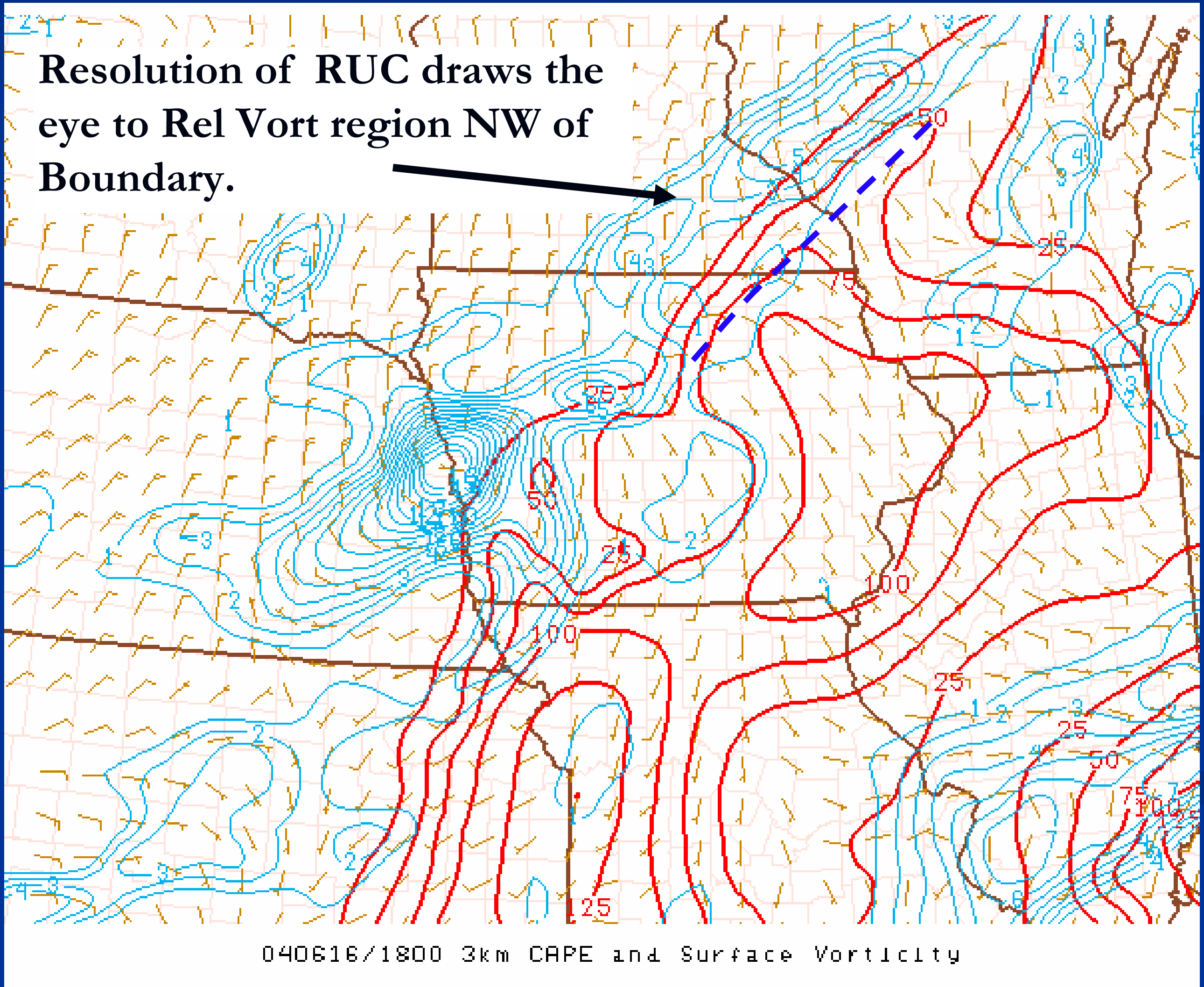
18z 2004 June 16: Environment

- Laps Surface Relative Vorticity



18z 2004 June 16: Environment

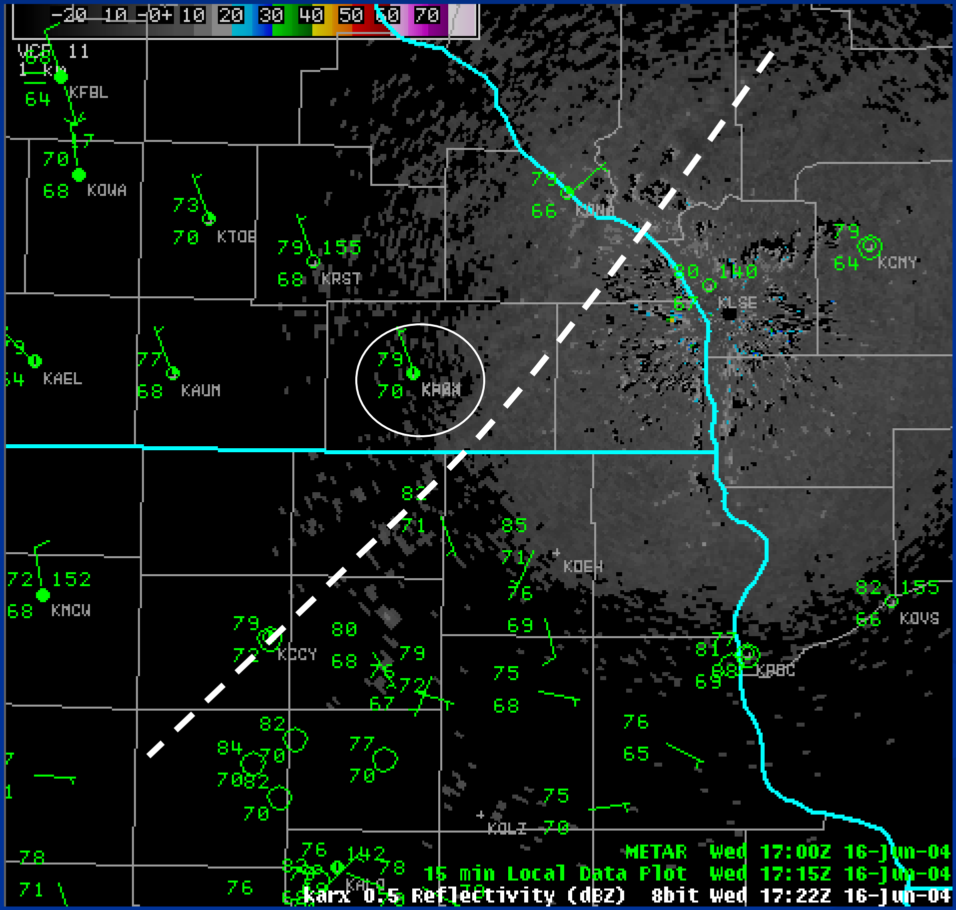
- SPC 0-3km CAPE and Surface Relative Vorticity



18z 2004 June 16: Environment

LAPS Environmental Parameter (On the Boundary)	18Z Value
0-6km Bulk Shear	25-30 kts
0-3km ML CAPE	175-200 J/Kg
ML CAPE	1500-1800 J/ Kg
ML CIN	0-20 J/Kg
0-1km Lapse Rate	9.5 C/Km
LCL/LFC Height	1000m
Surface Relative Vorticity (10km grid)	7-12 /1e-5

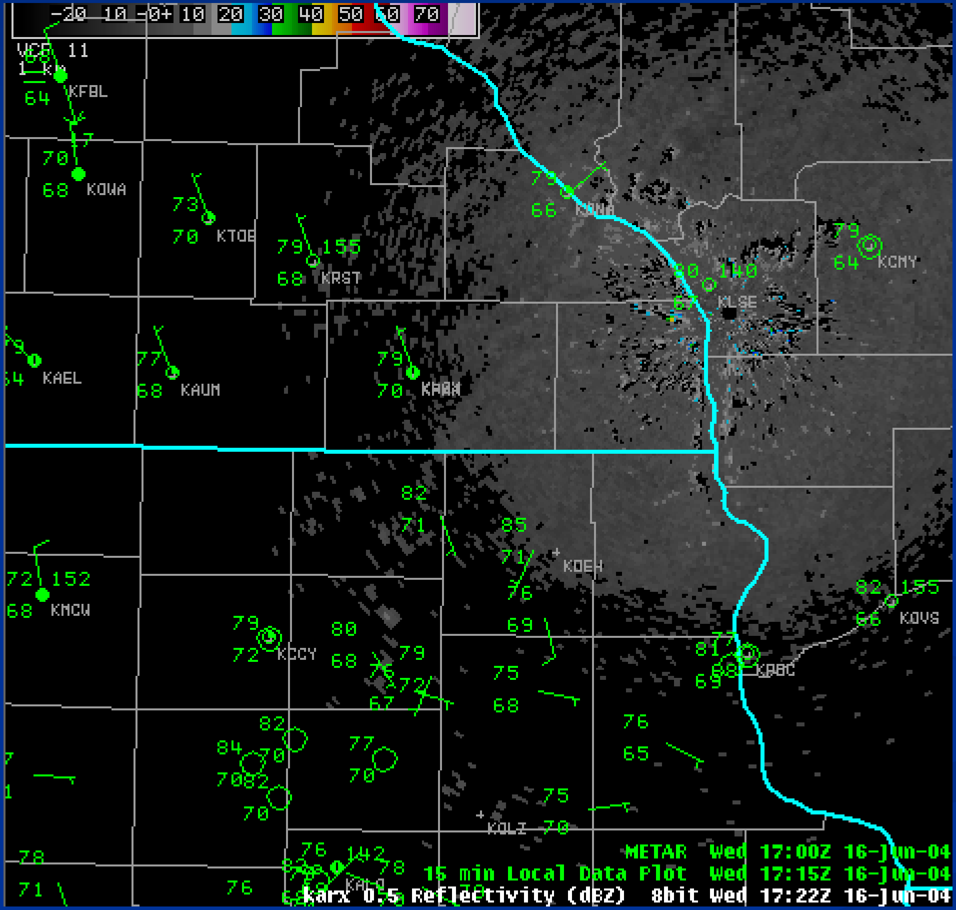
Radar Loop 1722z-2051z (fast)



- Cold pool sampled in Preston, MN (-3 deg C).

Radar Loop 1722z-1900z (slow)

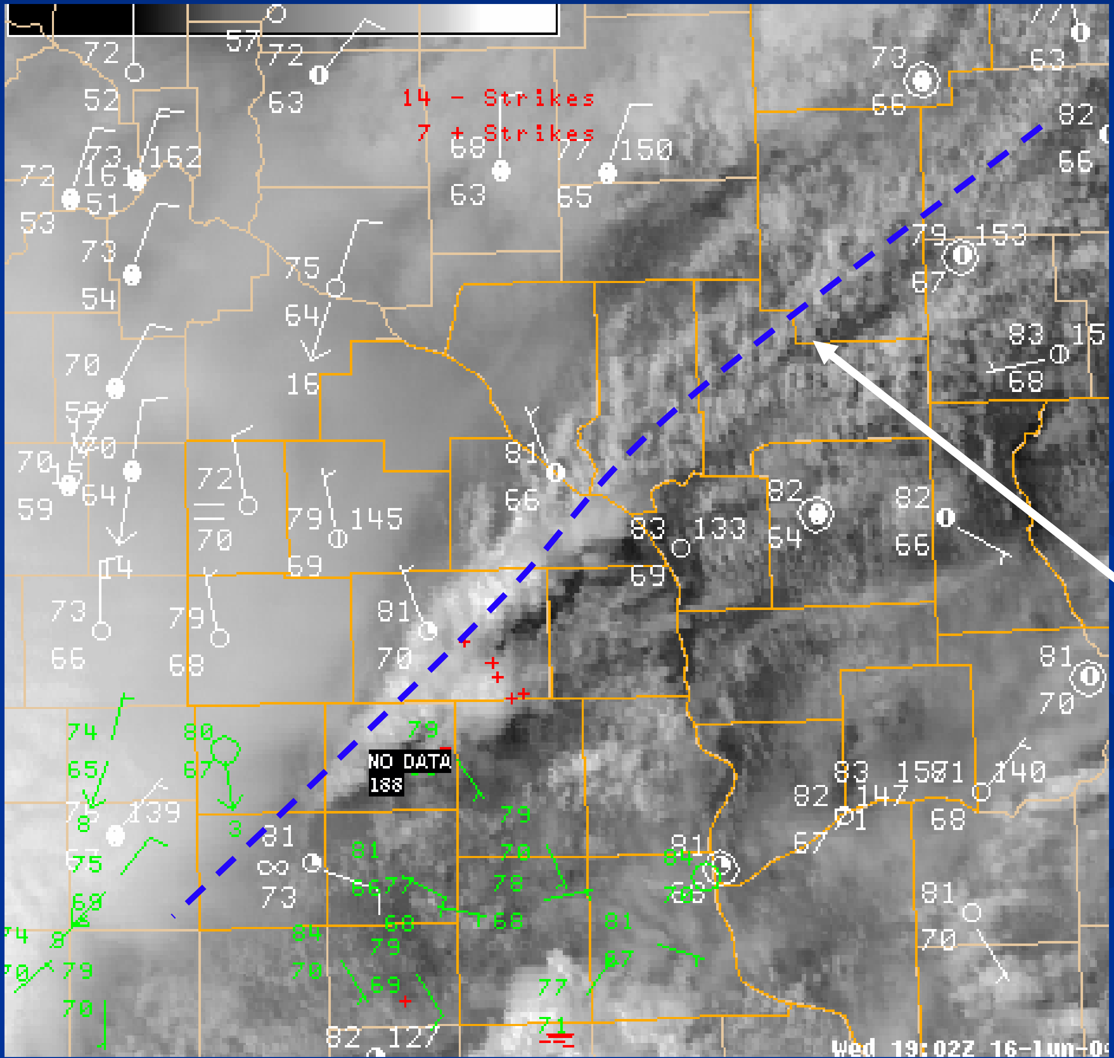
- NST theory would suggest TORs upon first echoes.



- Boundary not sufficient for NST alone, cold pool needed.

19z 2004 June 16: Environment

- Increasing northerly flow north of boundary.

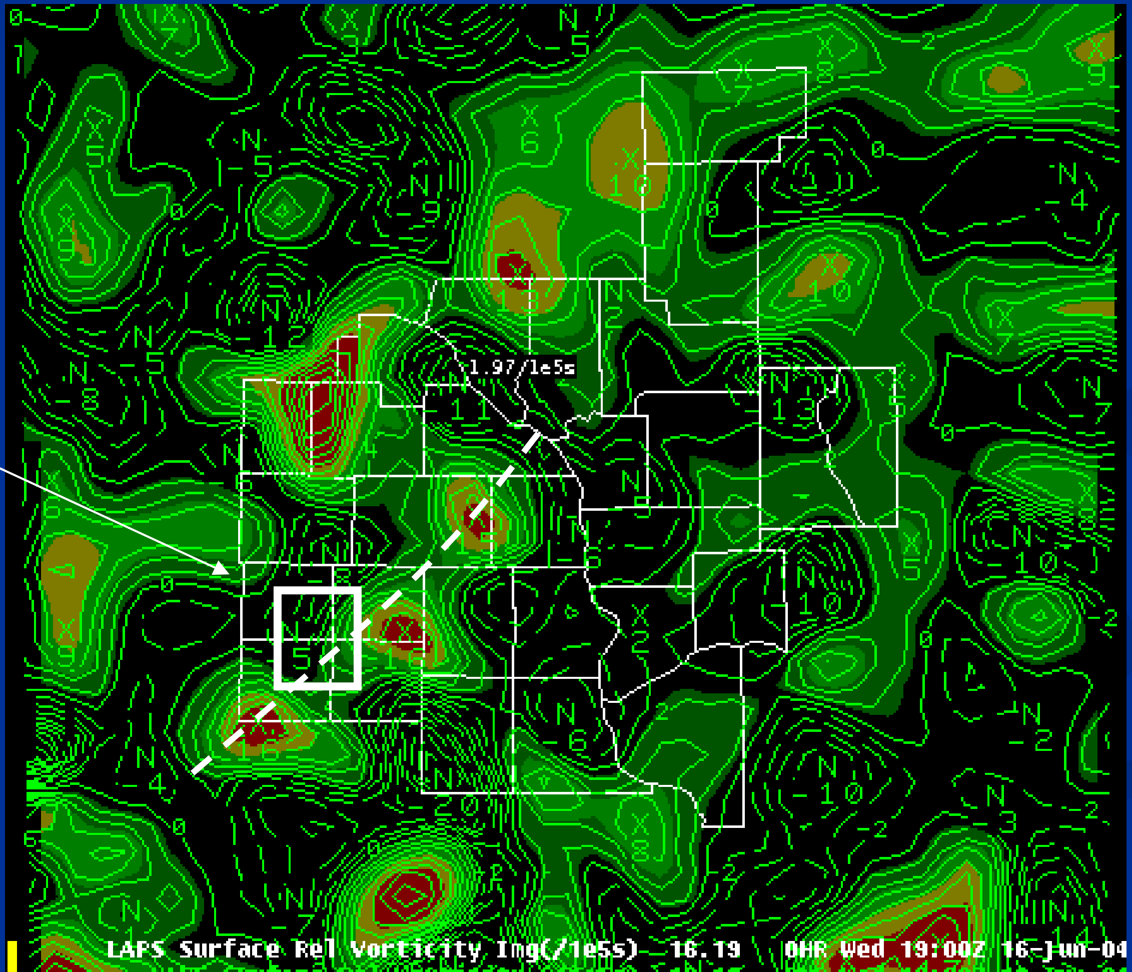


Boundary moving in WI.

19z 2004 June 16: Environment

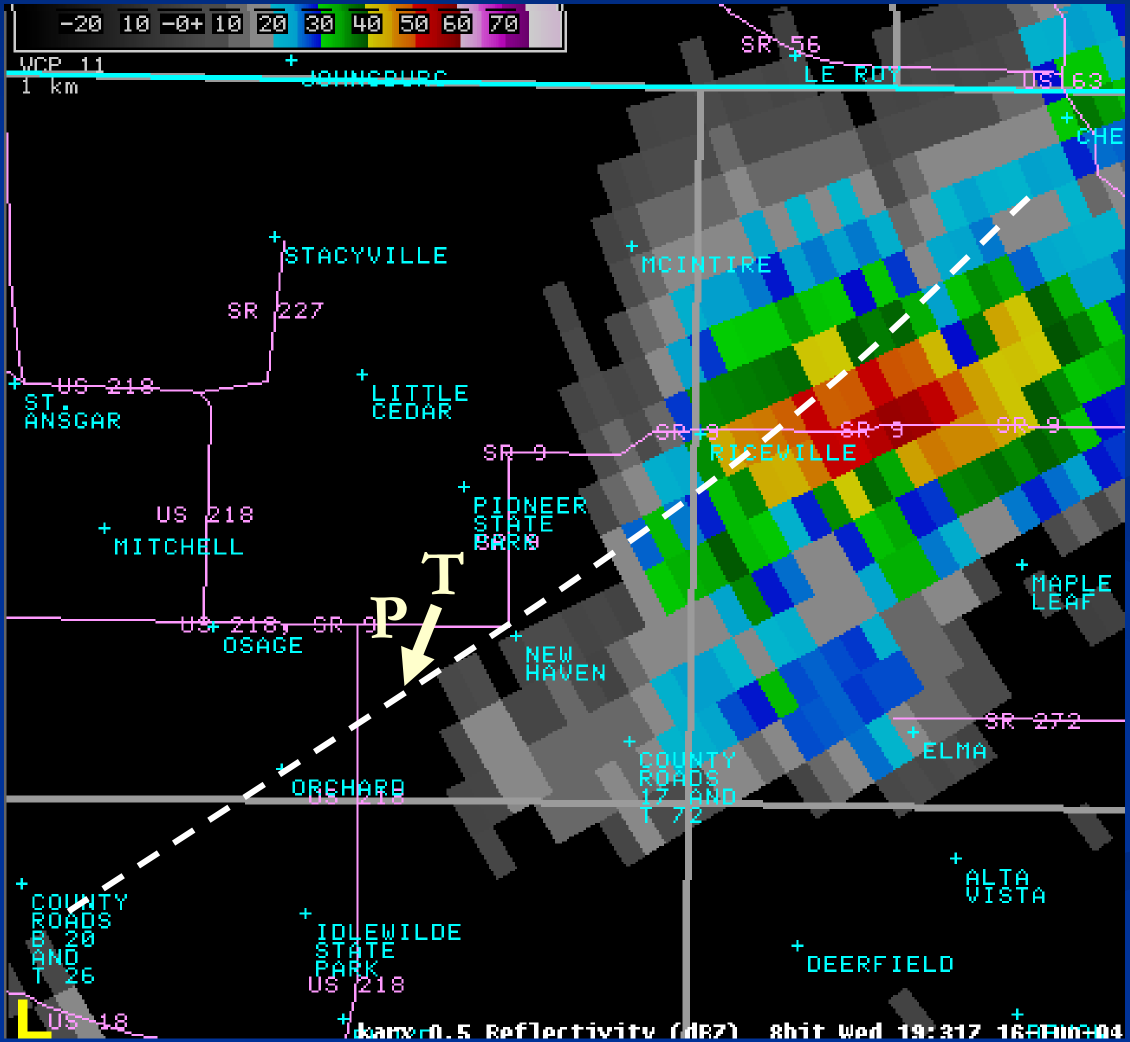
- Cold pool strengthens southeasterly flow, relative vorticity increases along boundary.

Zoom to a developing cell



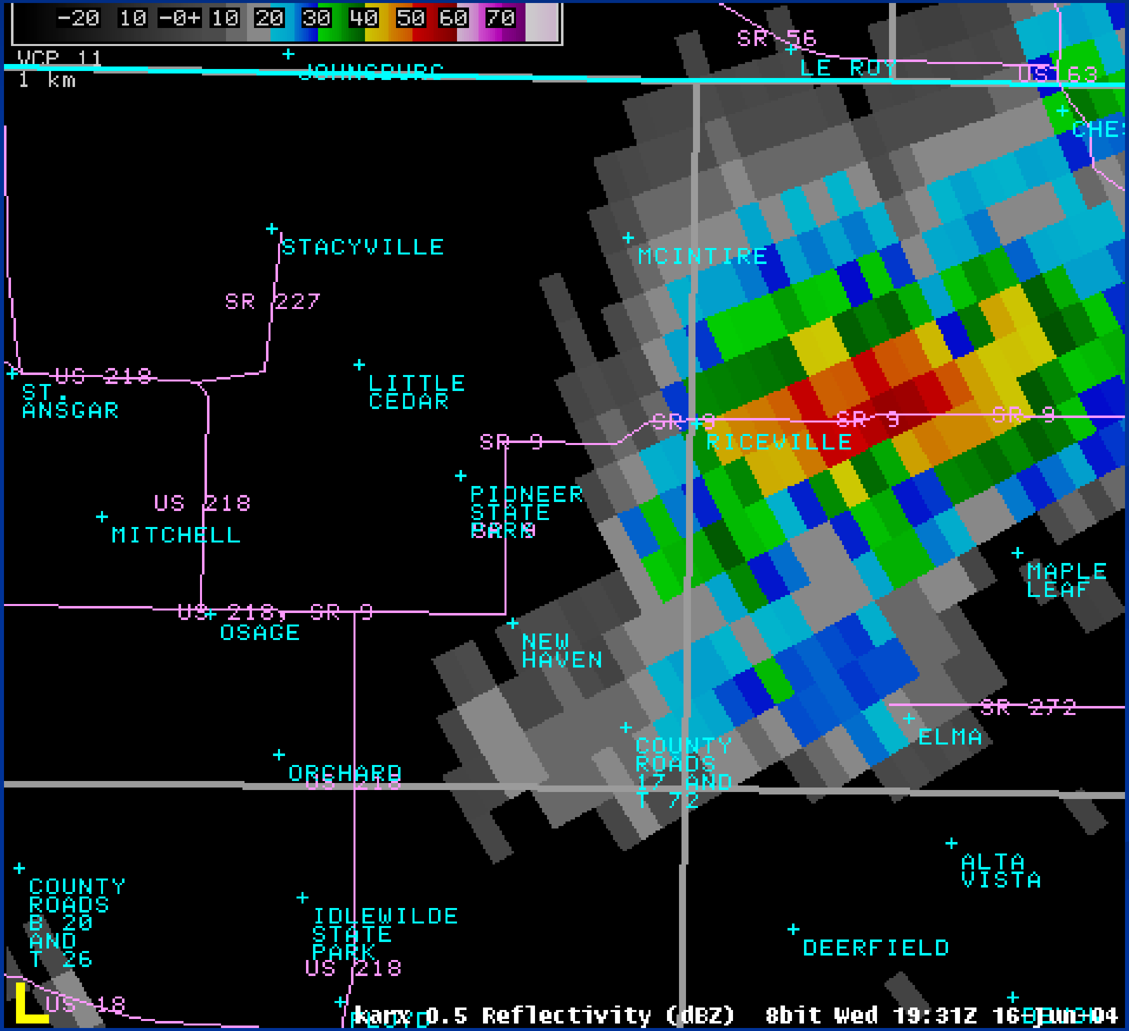
2004 June 16: Osage Cell

- NST occurs at 1947Z



2004 June 16: Osage Cell

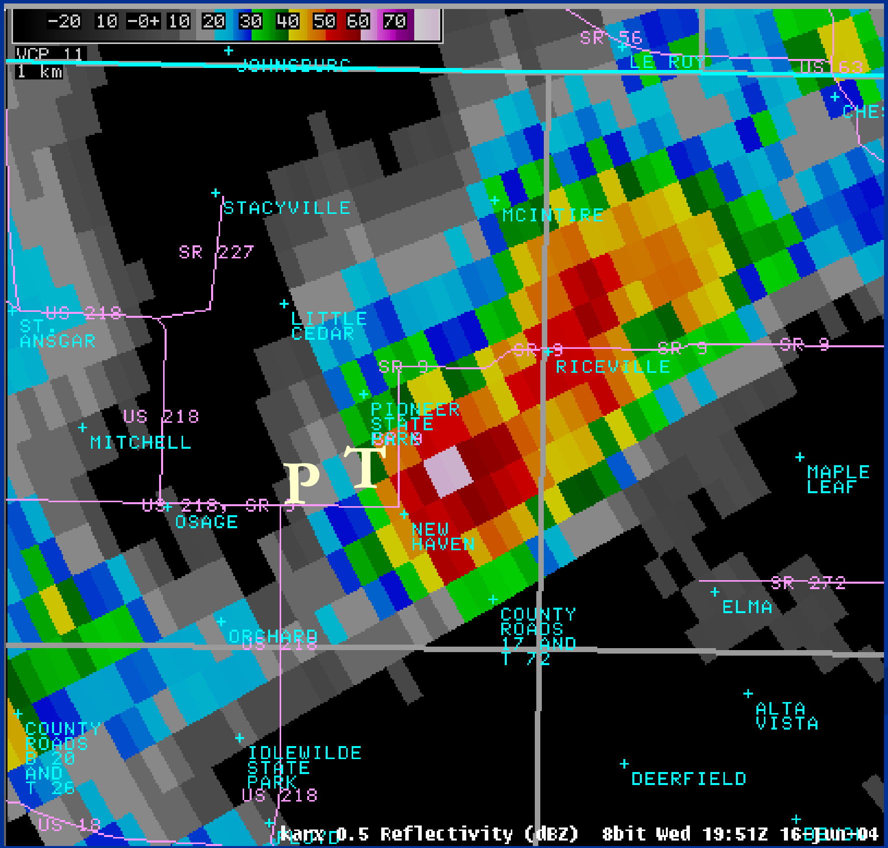
- 1931-2011z 0.5 deg ref loop. Tor from 1947-2005z.



2004 June 16: Osage Cell

- Tornado on updraft/downdraft gradient, misocyclone seen via proxy of cloud rotation?

Looking east, 1955z



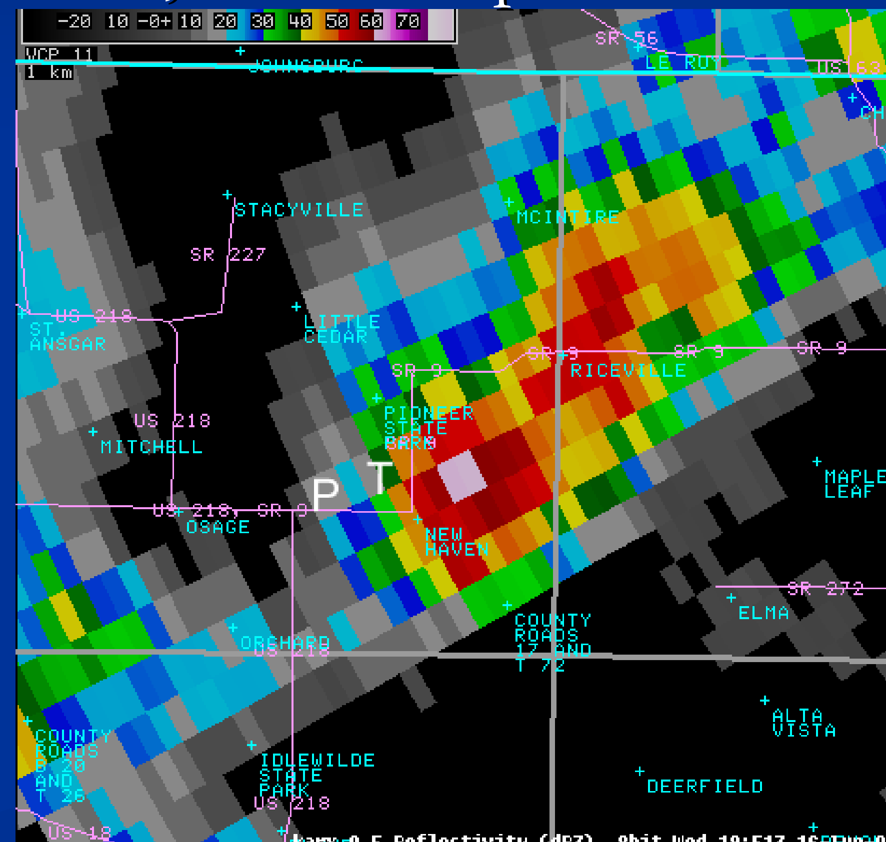
1951z 0.5 deg base Z
75nmi from radar, beam ~7500 ft AGL.

2004 June 16: Osage Cell

- TOR moves southwest under developing updraft, vortex strengthens. Precipitation on car, TOR dissipates.

Looking E, then S, then SW

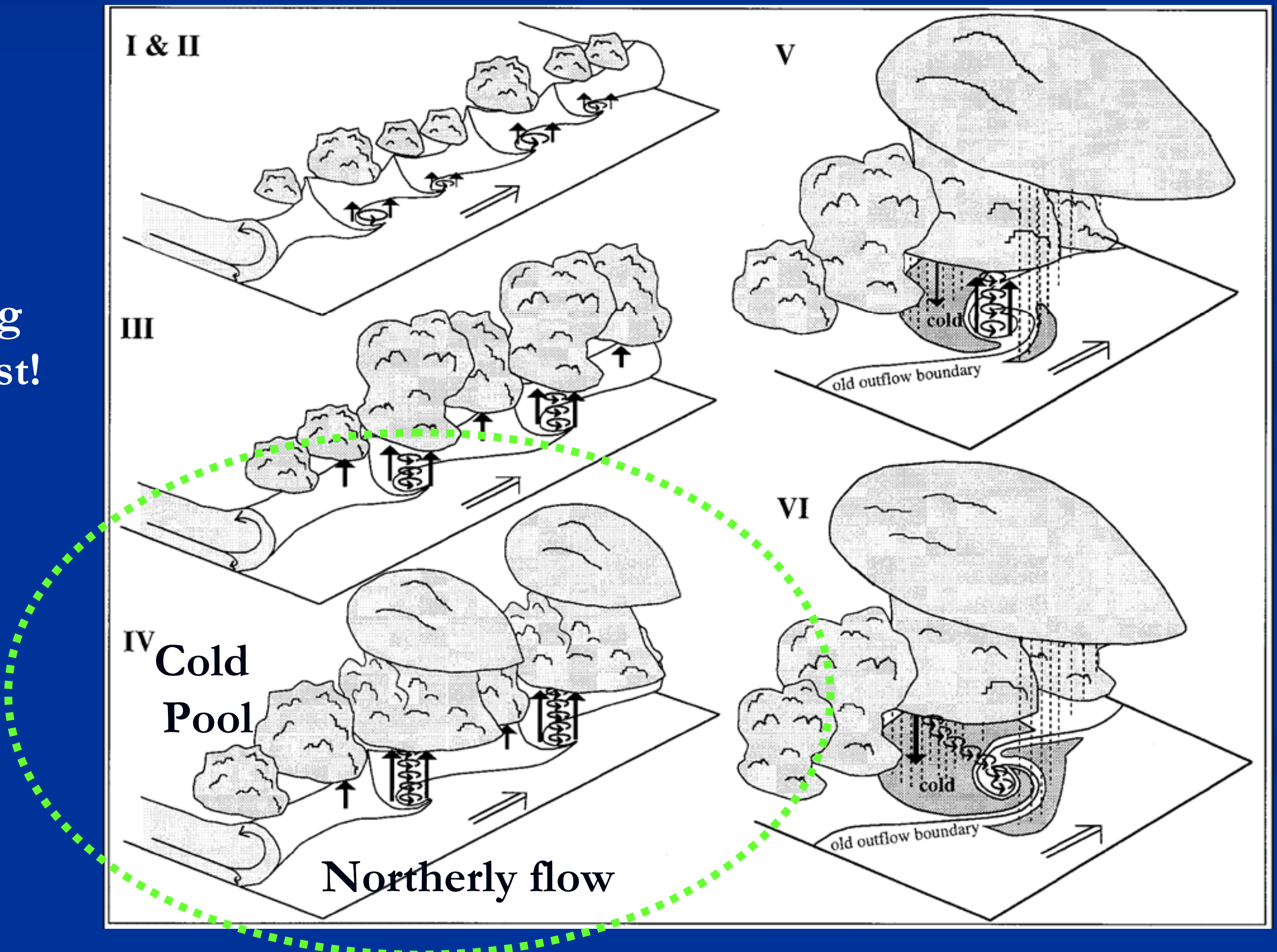
10x normal speed



2004 June 16: Osage Cell

- Misocyclone moving southwest along boundary while updrafts moved northeast with mean wind.

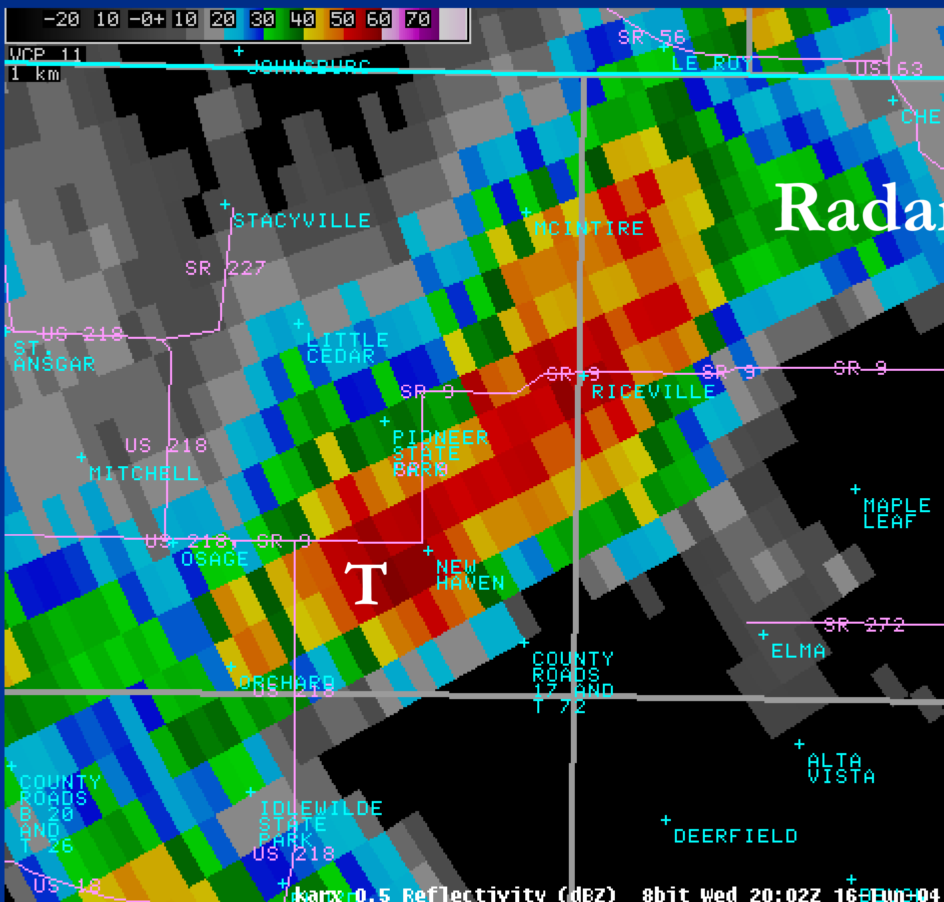
Looking Southeast!

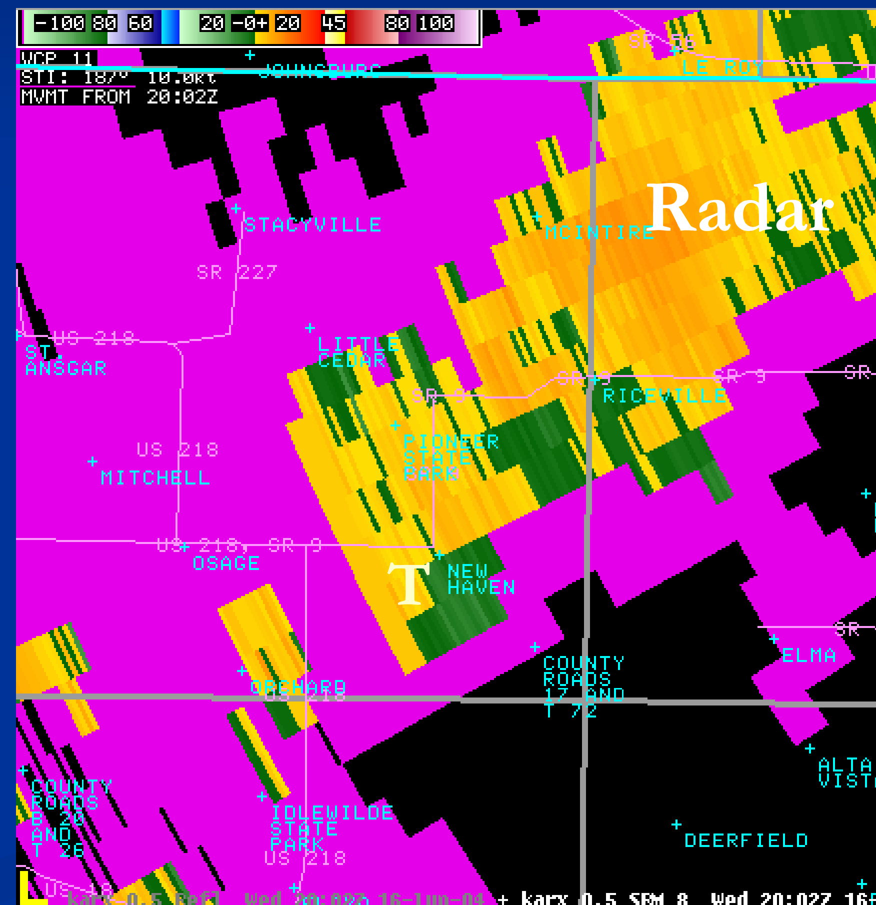


Lee and Wilhelmson, 2000.

2004 June 16: Osage Cell

- 0.5 deg base Z and SRM (10kt delV) at peak TOR time.





- 75nmi from radar, center of beam ~7500 ft AGL.

2004 June 16: Summary

- NST-type tornadoes observed with no mesocyclones present prior to formation. Strongest rotation typically around 10kts or less in radar velocity data.
- Environment favorable for NST but cold pool seemed to be key to misocyclone enhancement.
  - Steep 0-1km rates, 0-3km MLCAPE>150 J/Kg, non-supercellular 0-6km Bulk Shear, ML CAPE >1500 J/Kg all coincident on a stationary surface boundary.
  - Ambient line parallel wind shear not 10-20 kts (LW,2000).
  - Surface relative vorticity a diagnostic for the potential downscaling of vorticity and misocyclone presence?

2004 June 16: Summary

- New storms initiated, and tornadoes moved, southwest along the boundary while the mean wind was northeast. This seems to coincide with misocyclone movement along the boundary toward the southwest.
  - Rotated Lee and Wilhelmson (2000) conceptual model.
- Convective cell lifecycles were 50 minutes or less with tornadoes occurring in the first 20 minutes. Osage tornado confirmed to occur at or before first echo.
- Family of tornadoes observed. All were F0 and F1 (Osage).

Situational Awareness

- With current radar technology, sampling NST and non-supercell tornadoes is very limited due to time and space scales of the phenomena.
- Situation awareness of the environmental conditions that support NST are key.
  - Familiar with parameters discussed in this talk.
  - Higher resolution analysis is favored (10km or less: LAPS). Mesonet!
  - When environments for misocyclones are present along a boundary, after one non-supercellular tornado occurrence, expect more!
    - Focus on new updrafts expected provided the environment is similar or nearby.
    - Cold pool may enhance a boundary for misocyclone development.
  - Not all nonsupercell tornadoes are non-damaging!
- Lead time possible on the order of minutes.
  - ARX from negative lead times tors 1-3 to five minutes for tors 4-6.
  - SVS and HWO making the public aware.

Situational Awareness

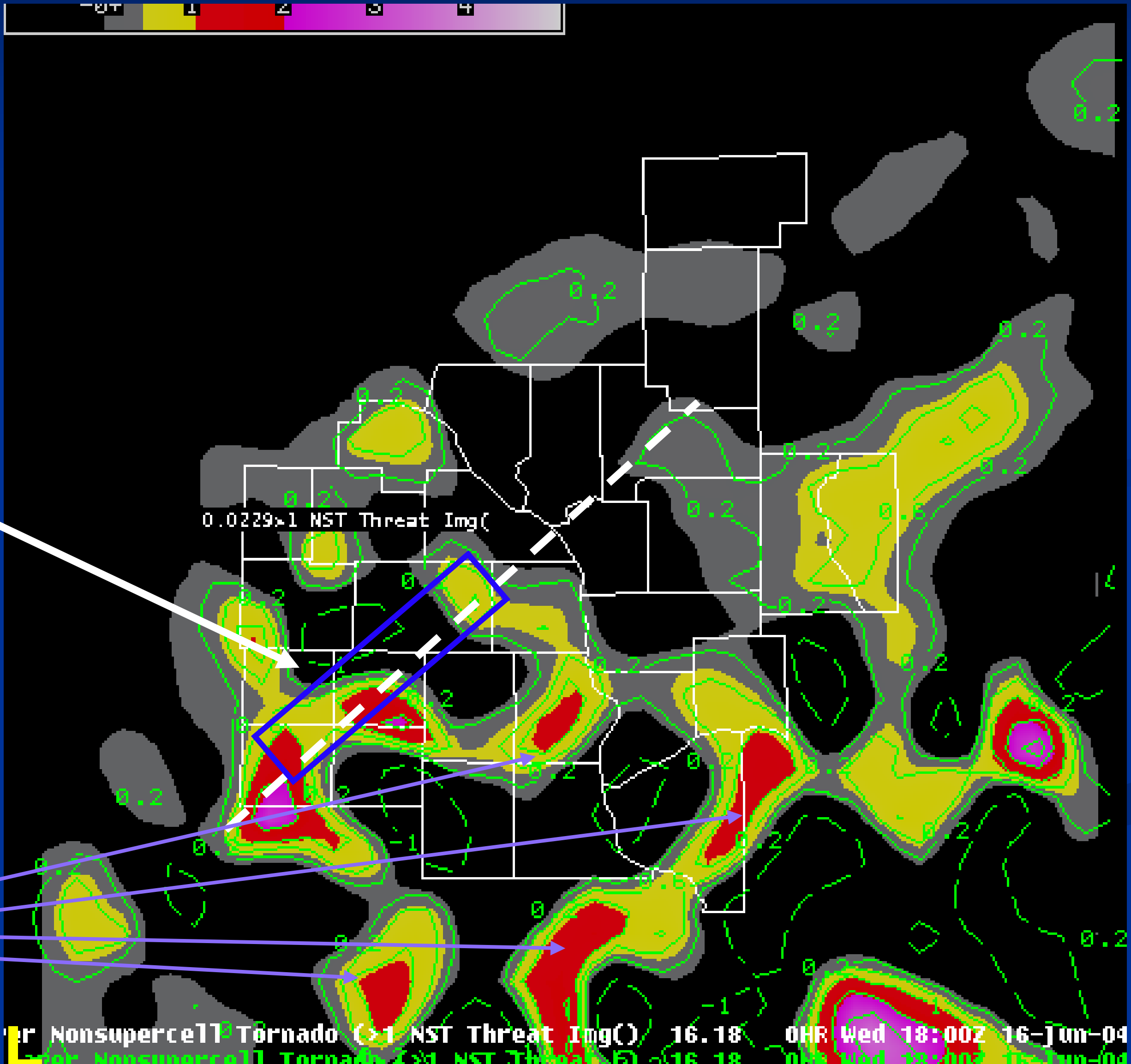
- NST Environment Parameter:
  - 0-1km Lapse Rate > 9C
  - 0-3km MLCAPE > 100 J/Kg
  - MLCIN < 25 J/Kg
  - 0-6km Bulk Shear < 26kts
  - Surface Relative Vorticity > 8 /1e5s

$$= \frac{\text{0-1km AGL Lapse Rate}}{\text{9 C/km}} \mathbf{x} \frac{\text{0-3km MLCAPE}}{\text{100J/Kg}} \mathbf{x} \frac{\text{(225 - MLCIN)}}{200} \mathbf{x} \frac{(36 - \text{BlkShr}_{\text{0-6km}})}{5} \mathbf{x} \frac{\text{Sfc Relative Vorticity}}{\text{8 /1e5s}}$$

- NST >= 1 then NST possible.
- Applying this with understanding!
  - Based on NST research you saw here.
  - Stationary boundary (or nearly stationary) with wind shift.

18z 2004 June 16: NST Parameter

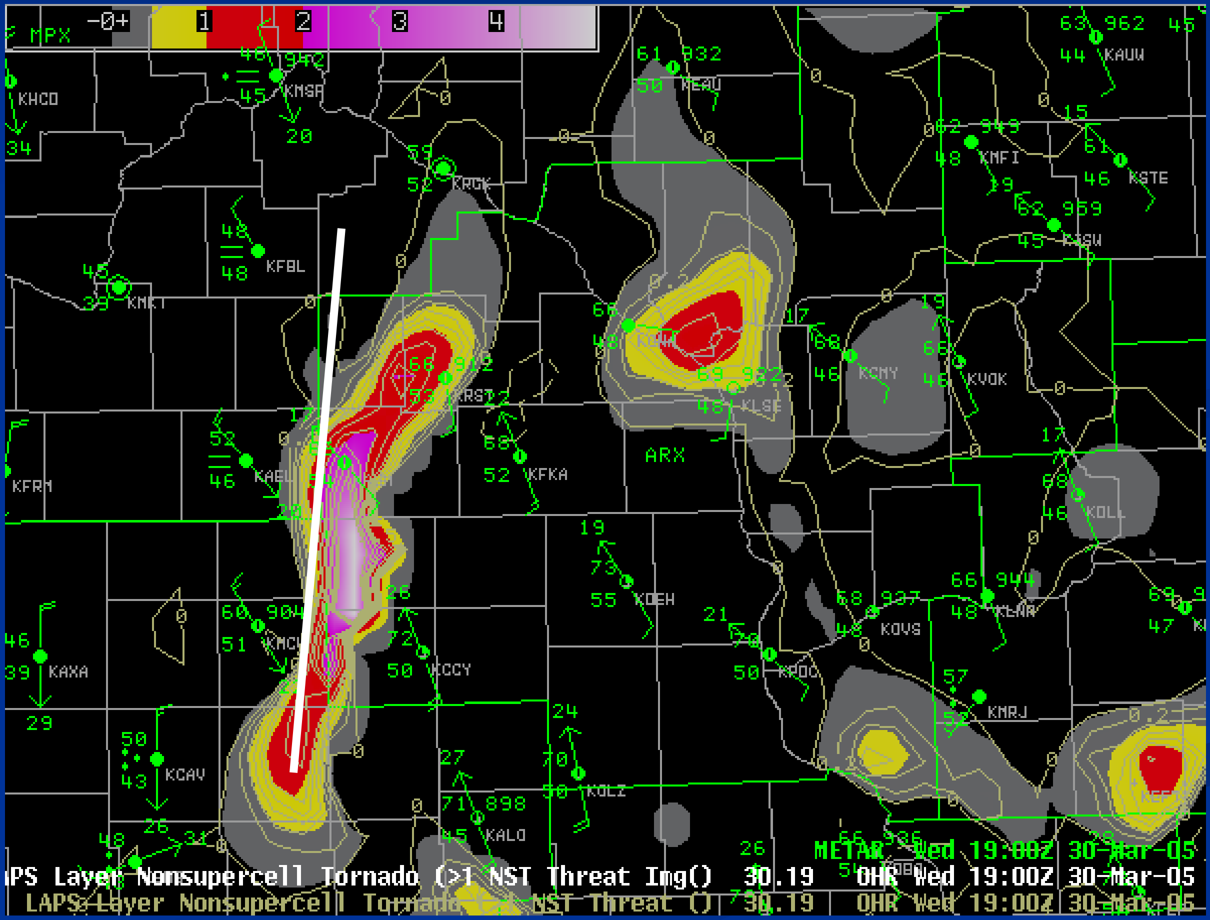
- NST >= 1 then NST possible (red, purple).
- Earliest TORs occurred here.



- False Alarms

19Z 30 March 2005: NST Parameter

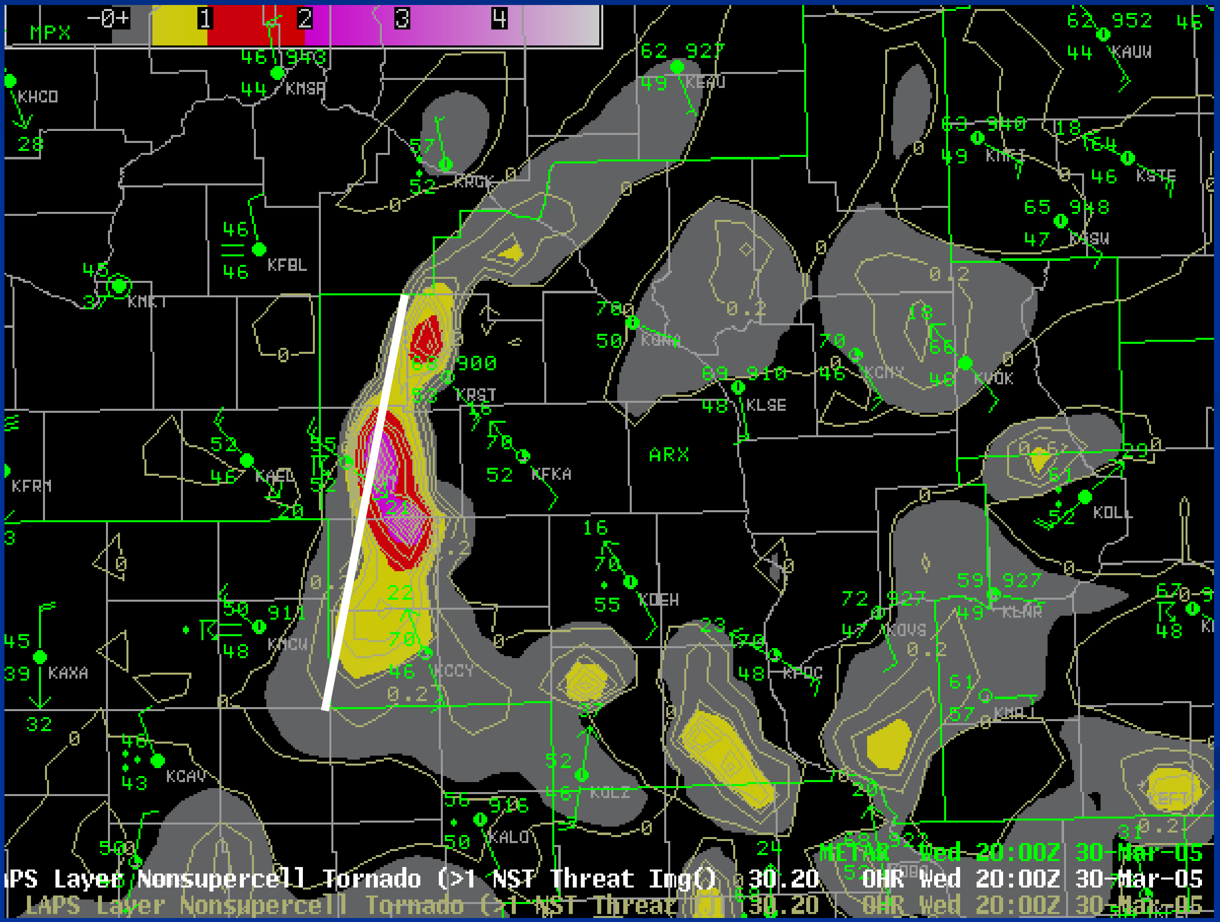
- Non-supercell deep shear.
- Stationary boundary with 0-3km CAPE.



- NST >= 1 then NST possible (red, purple).

20Z 30 March 2005: NST Parameter

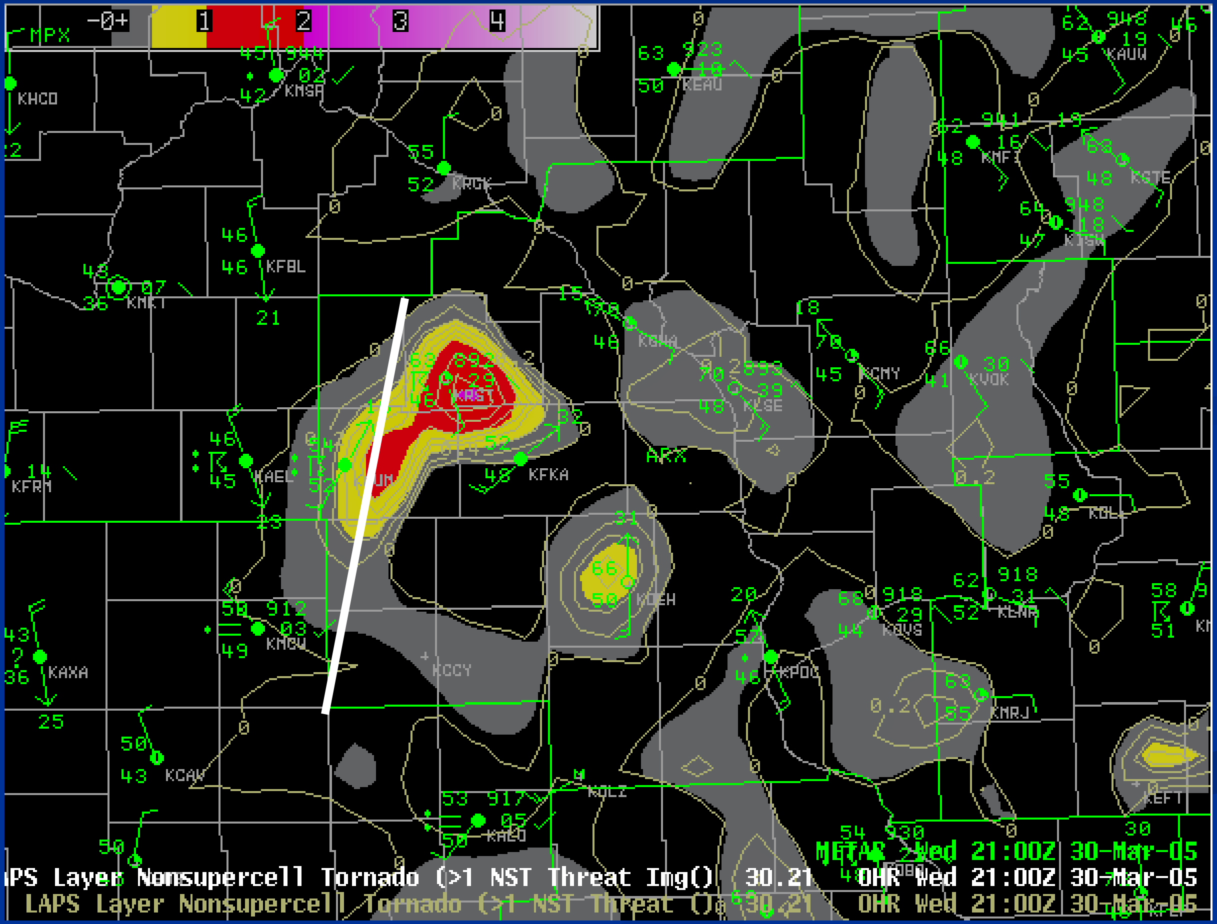
- Non-supercell deep shear.
- Stationary boundary with 0-3km CAPE.



- NST >= 1 then NST possible (red, purple).

21Z 30 March 2005: NST Parameter

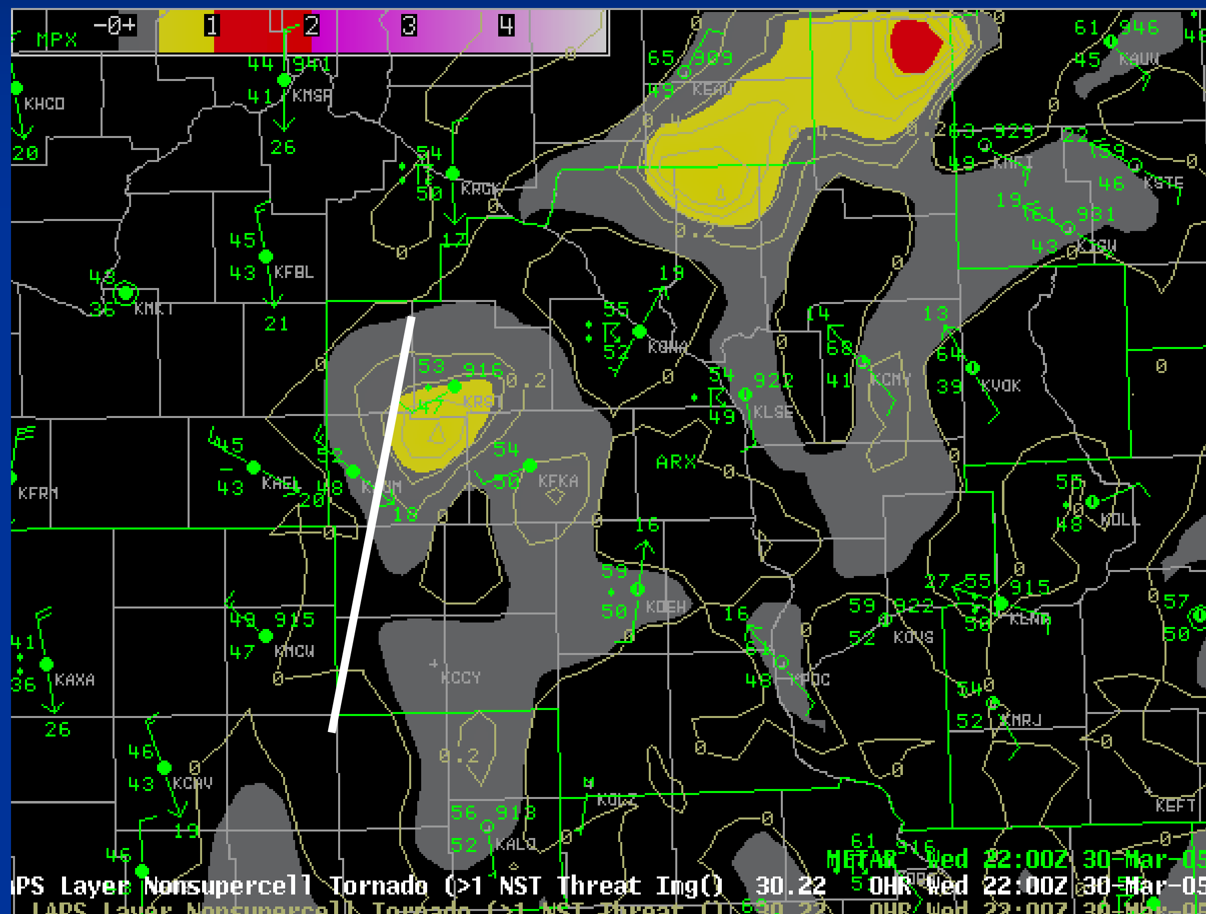
- Non-supercell deep shear.
- Stationary boundary with 0-3km CAPE.



- NST >= 1 then NST possible (red, purple).

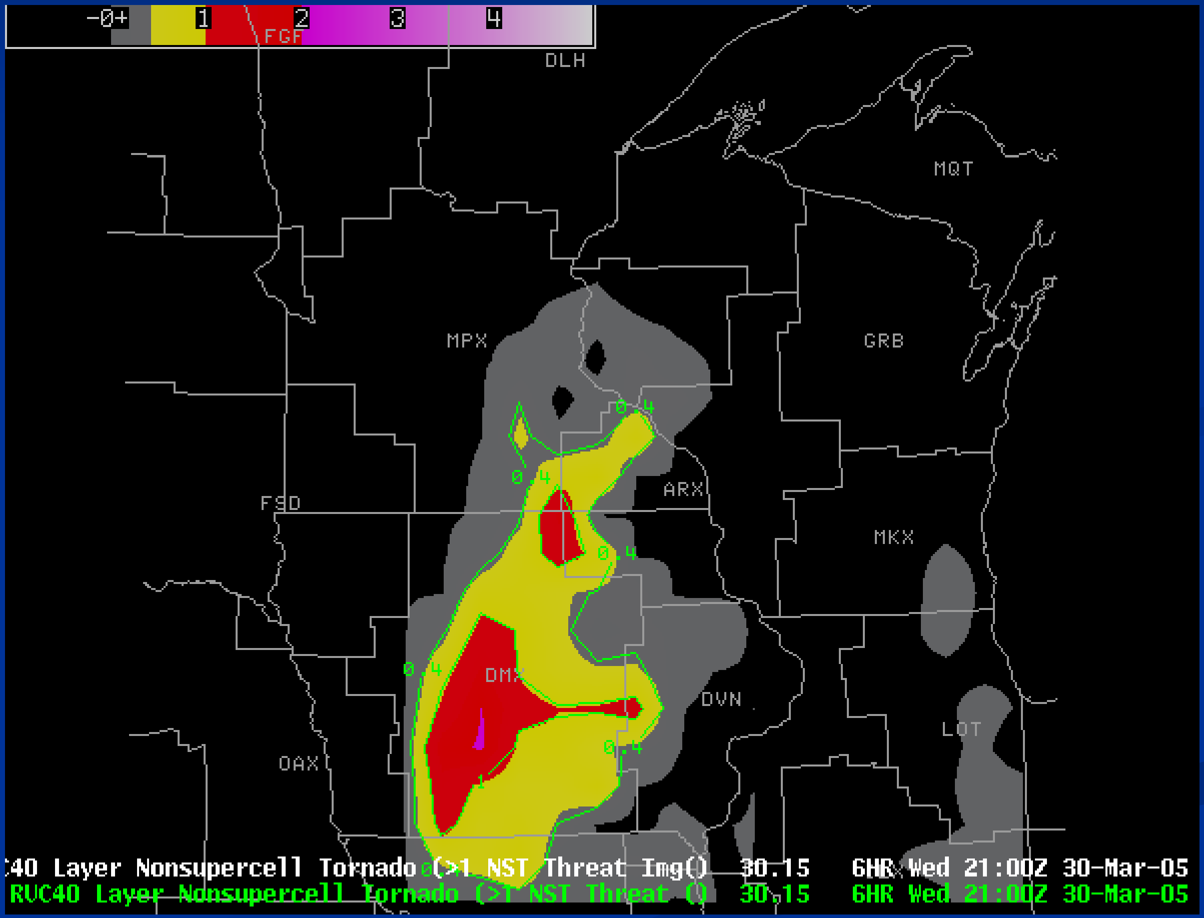
22Z 30 March 2005: NST Parameter

- Diminishing threat.
- NST >= 1 then NST possible (red, purple).

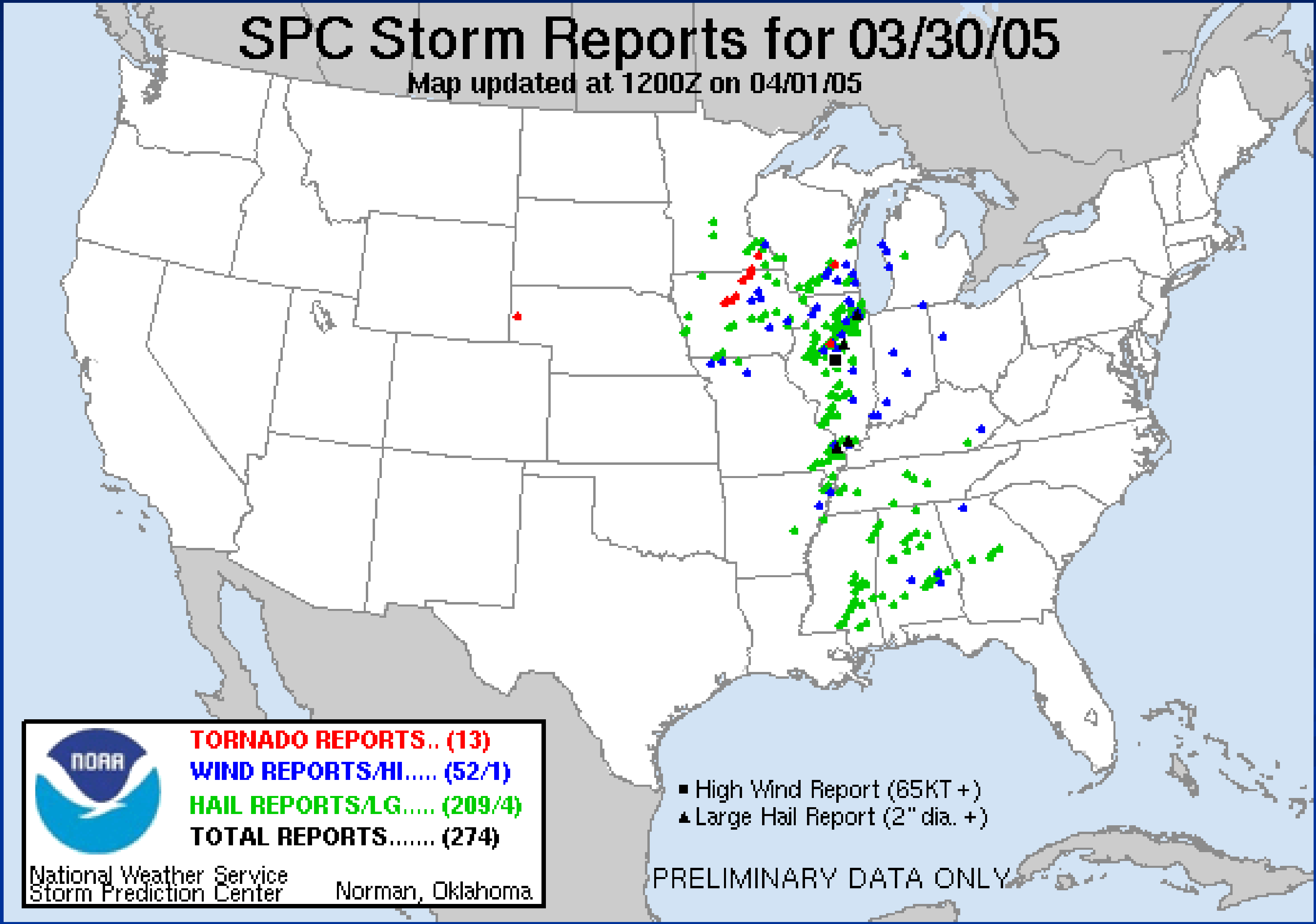


30 March 2005: NST Parameter

- 15Z RUC 6hour forecast valid 21Z.
- NST >= 1 then NST possible (red, purple).



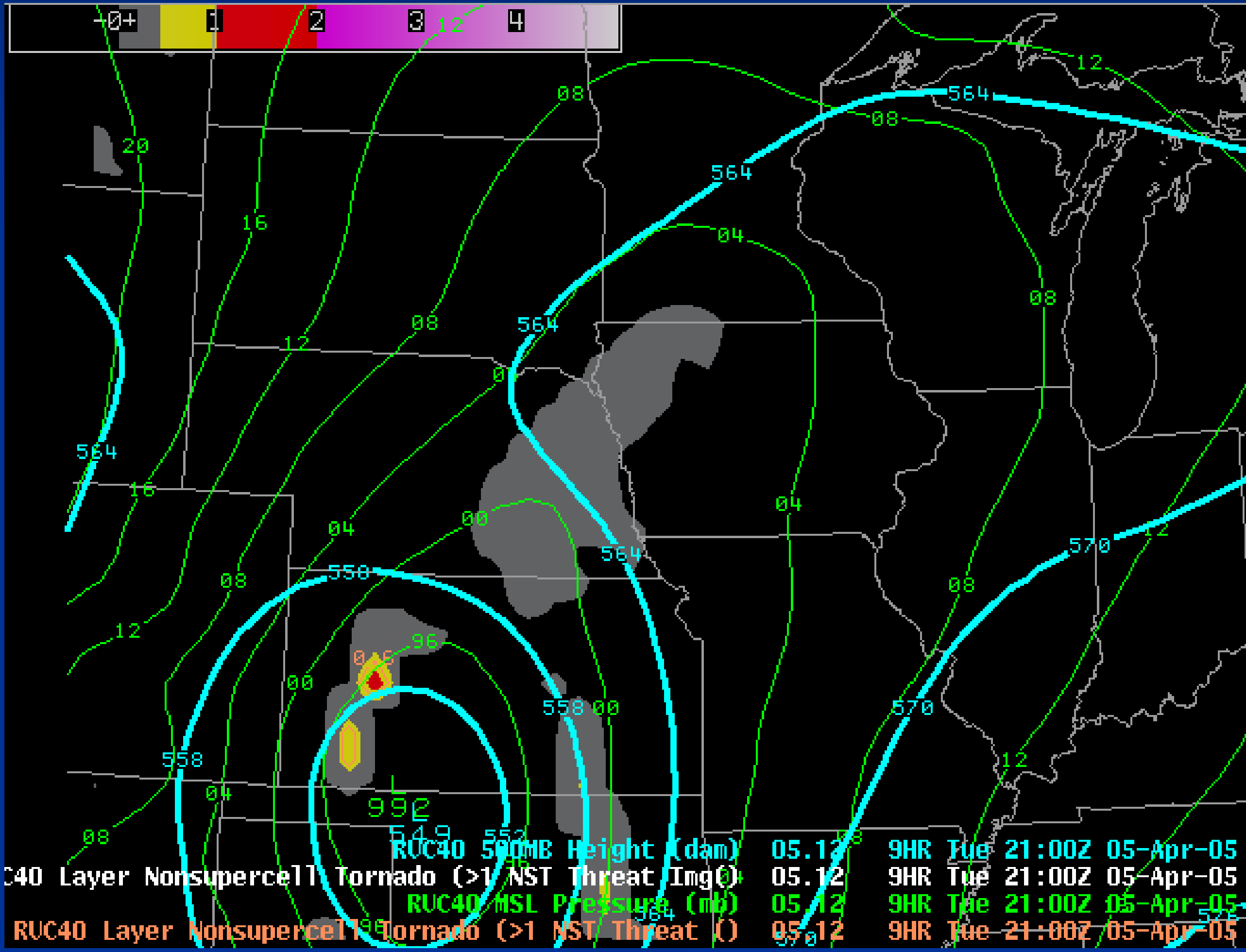
30 March 2005: NST Parameter



30 March 2005: NST Parameter

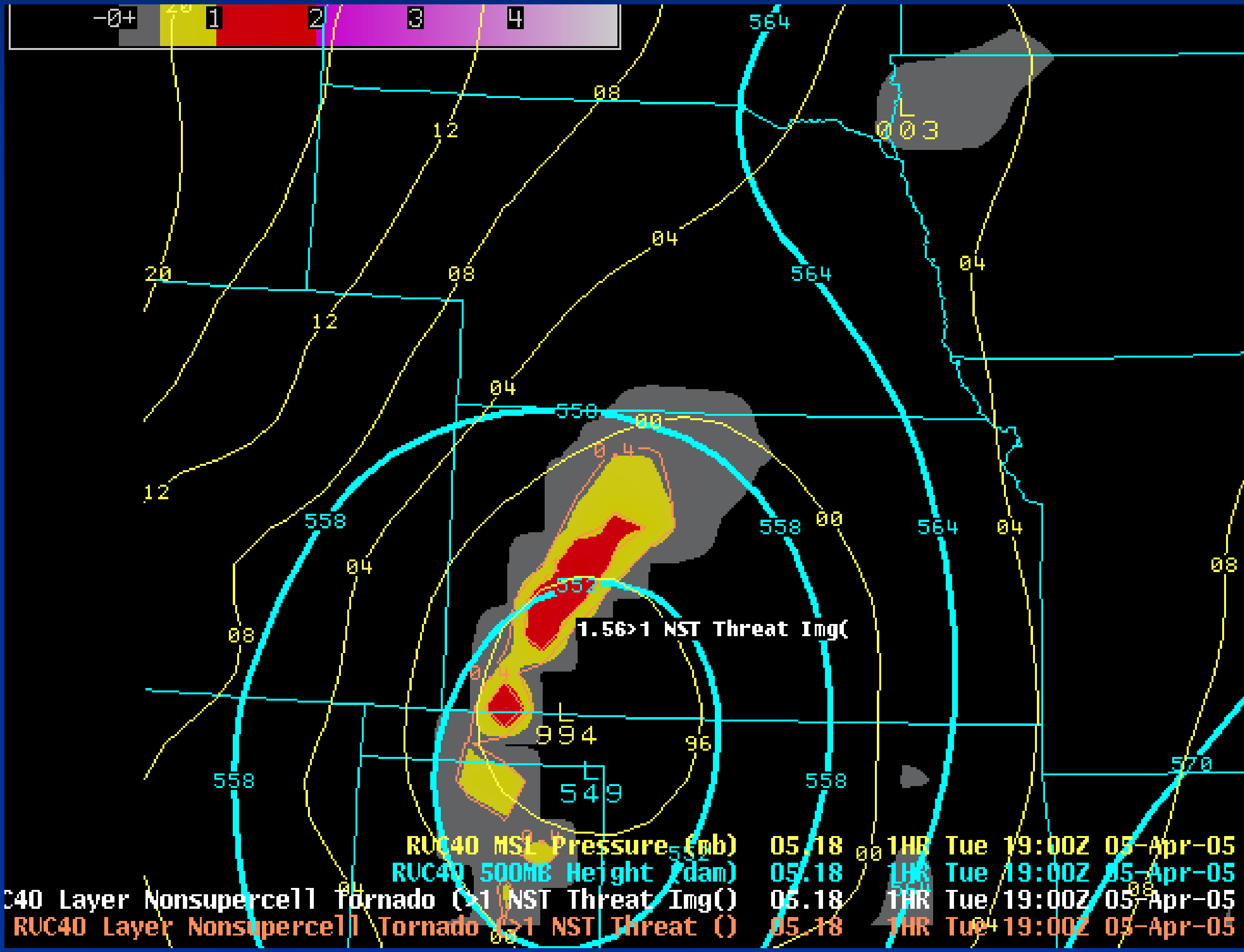
5 April 2005: NST Parameter

- 15Z RUC 9 hr forecast valid at 21Z.
- Occluded low with nearly stationary boundary.
- NST threat area near KDDC in afternoon.
- NST >= 1 then NST possible (red, purple).



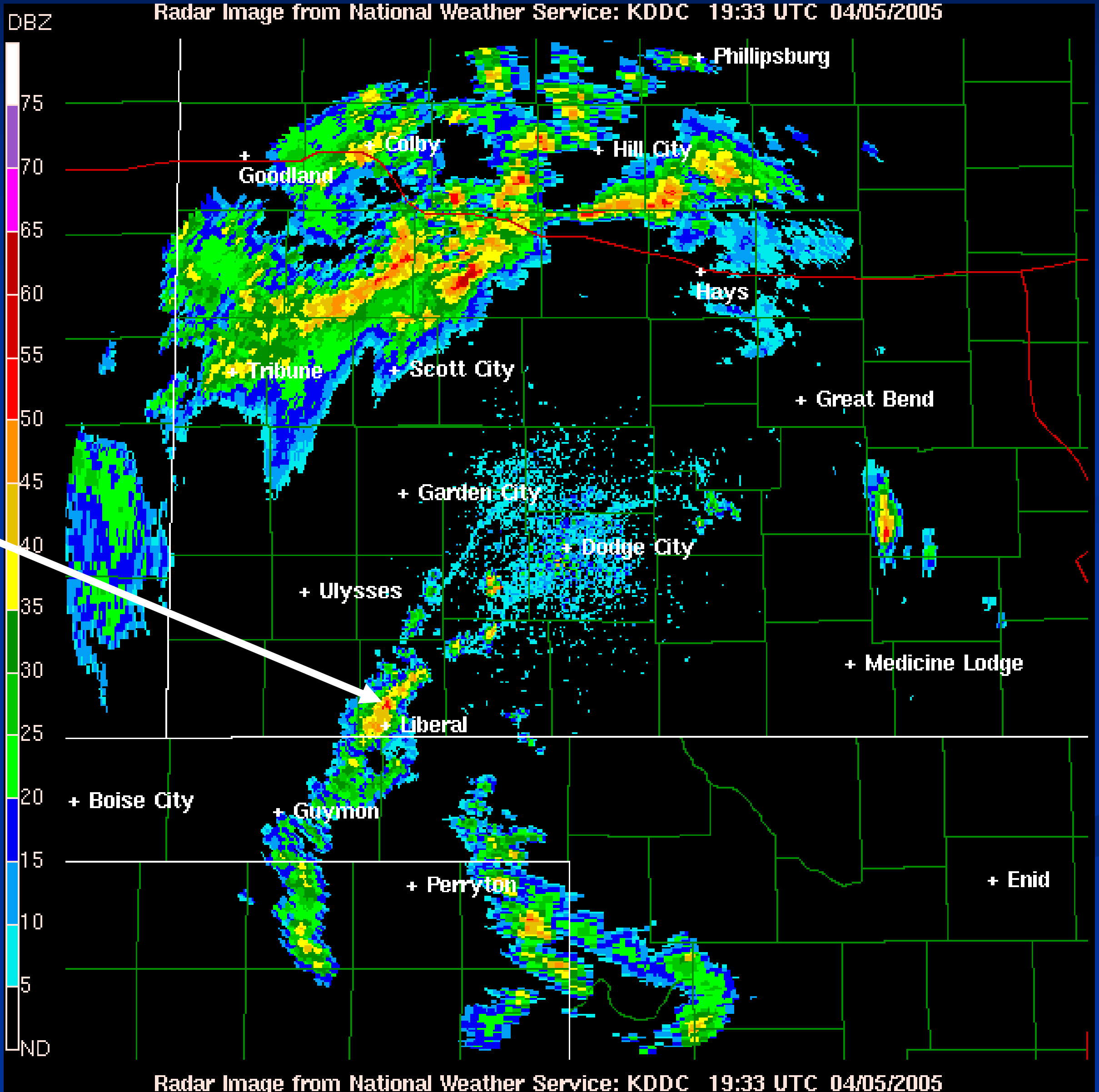
5 April 2005: NST Parameter

- 18Z RUC 1 hr forecast valid at 19Z.
- Slightly higher NST threat.
- NST >= 1 then NST possible (red, purple).



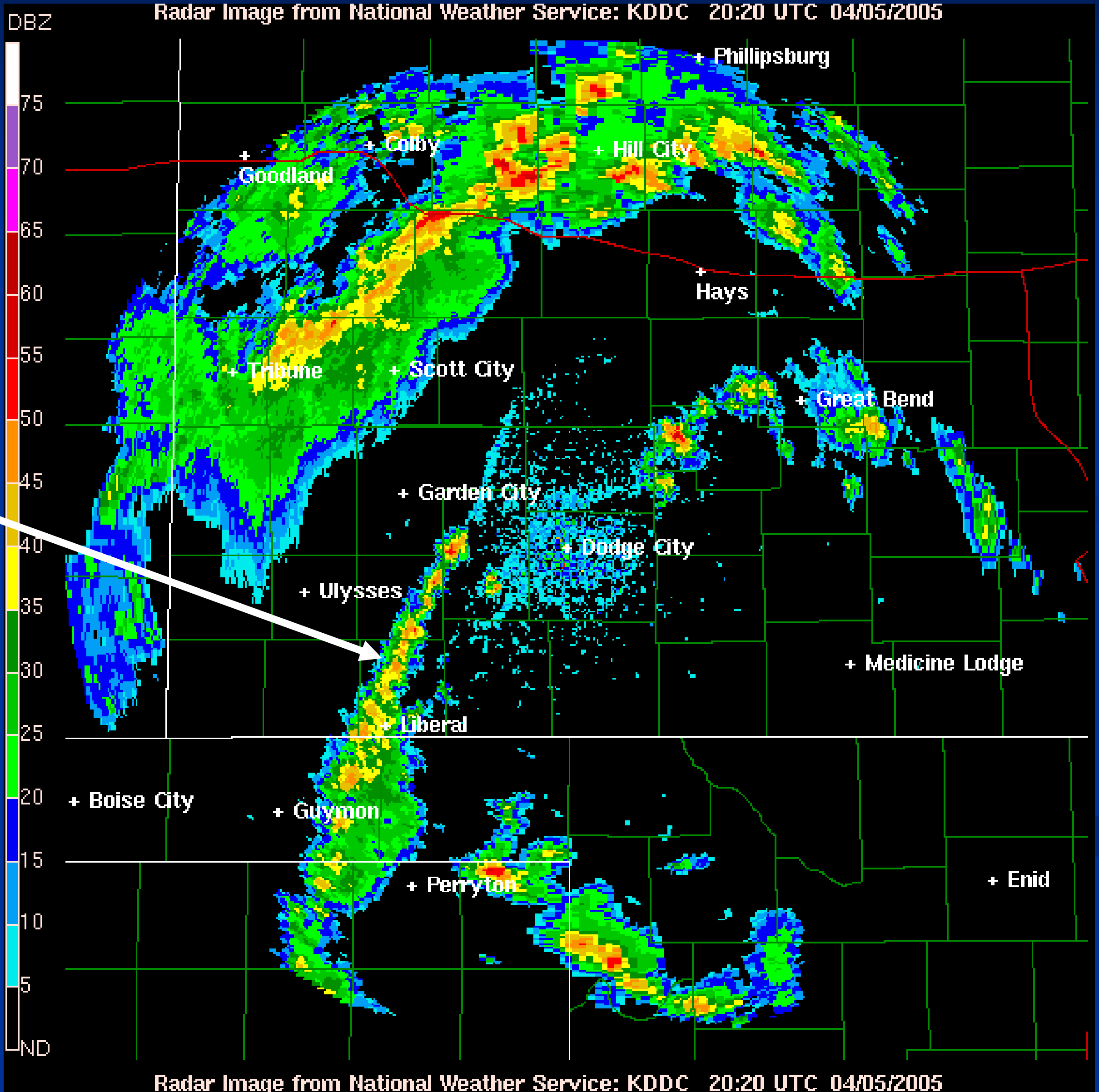
5 April 2005: NST Parameter

- 1933Z 0.5 deg bref from KDDC.
- Tornado
- NST >= 1 then NST possible (red, purple).

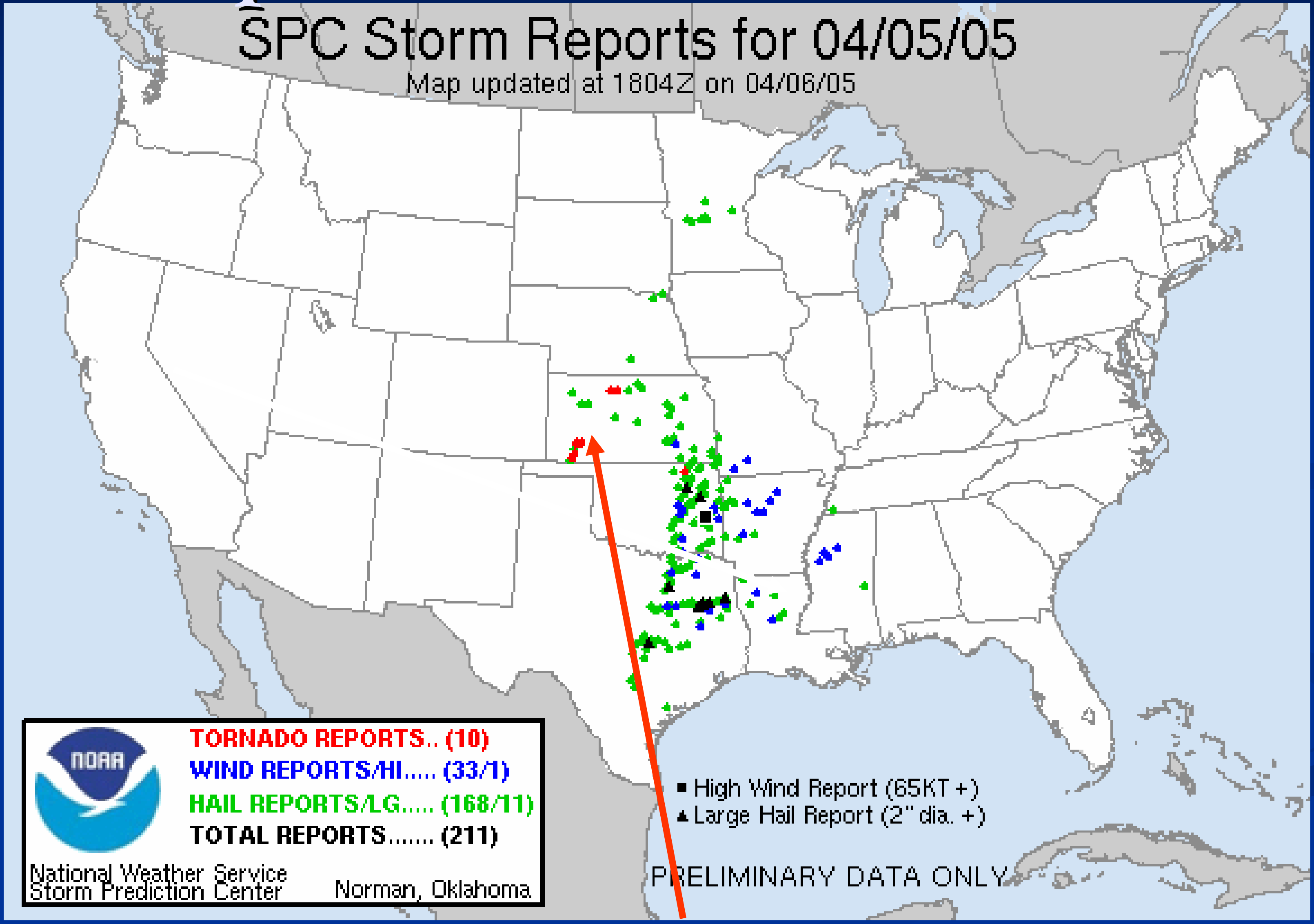


5 April 2005: NST Parameter

- 2020Z 0.5 deg bref from KDDC.
- Tornado
- NST >= 1 then NST possible (red, purple).



5 April 2005: NST Parameter



The only tornadoes occurred only along the max NST axis.

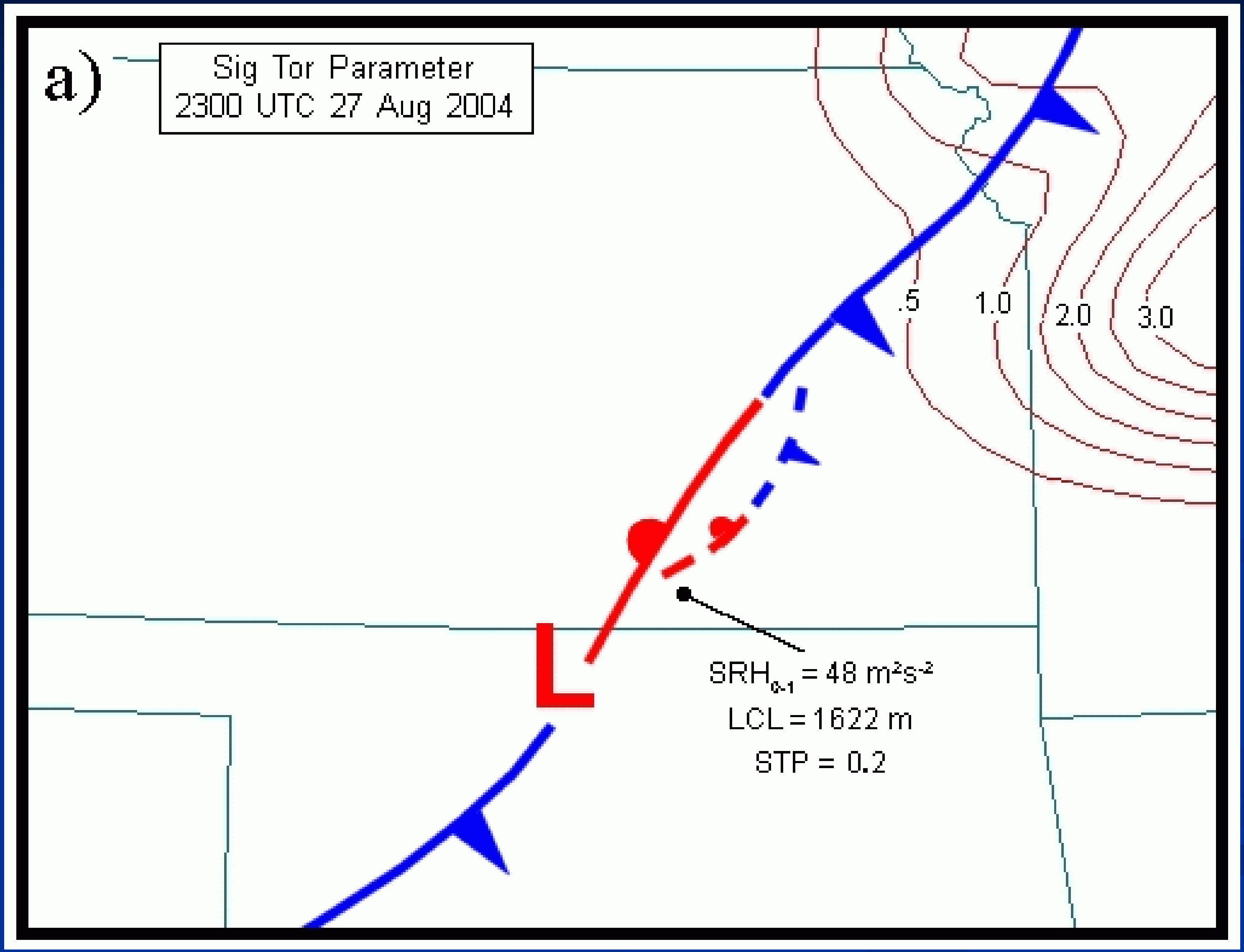
Enhanced Stretching Potential?

A way to combine low-level lapse rate and low-level CAPE to suggest increased potential for low-level stretching?

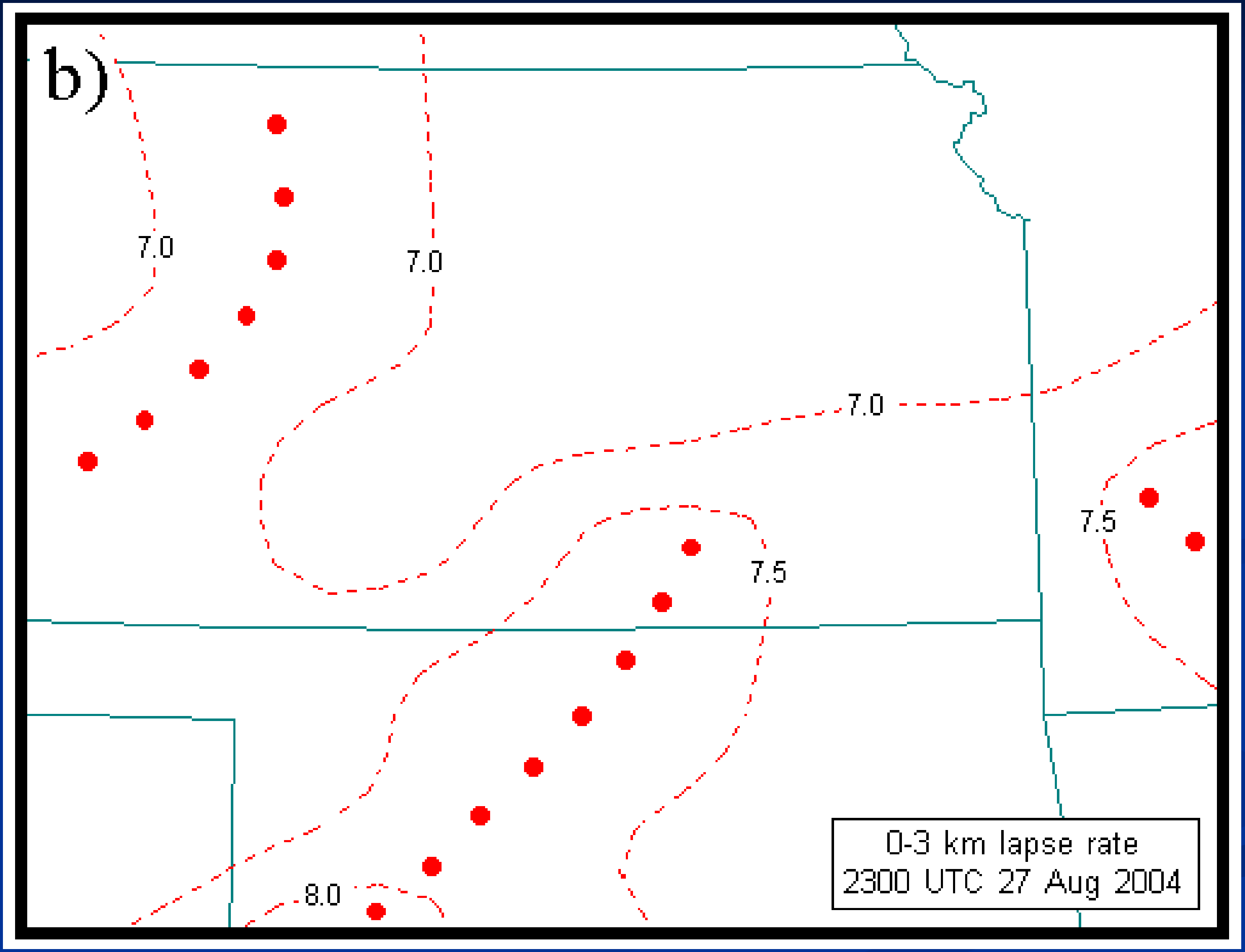
$$ESP = (LR_{0\text{-}2 \text{ or } 0\text{-}3} - 7.0) \times CAPE_{0\text{-}3}$$

(Set negative values to 0;
limit $CAPE_{0\text{-}3}$ to 100 J kg^{-1})

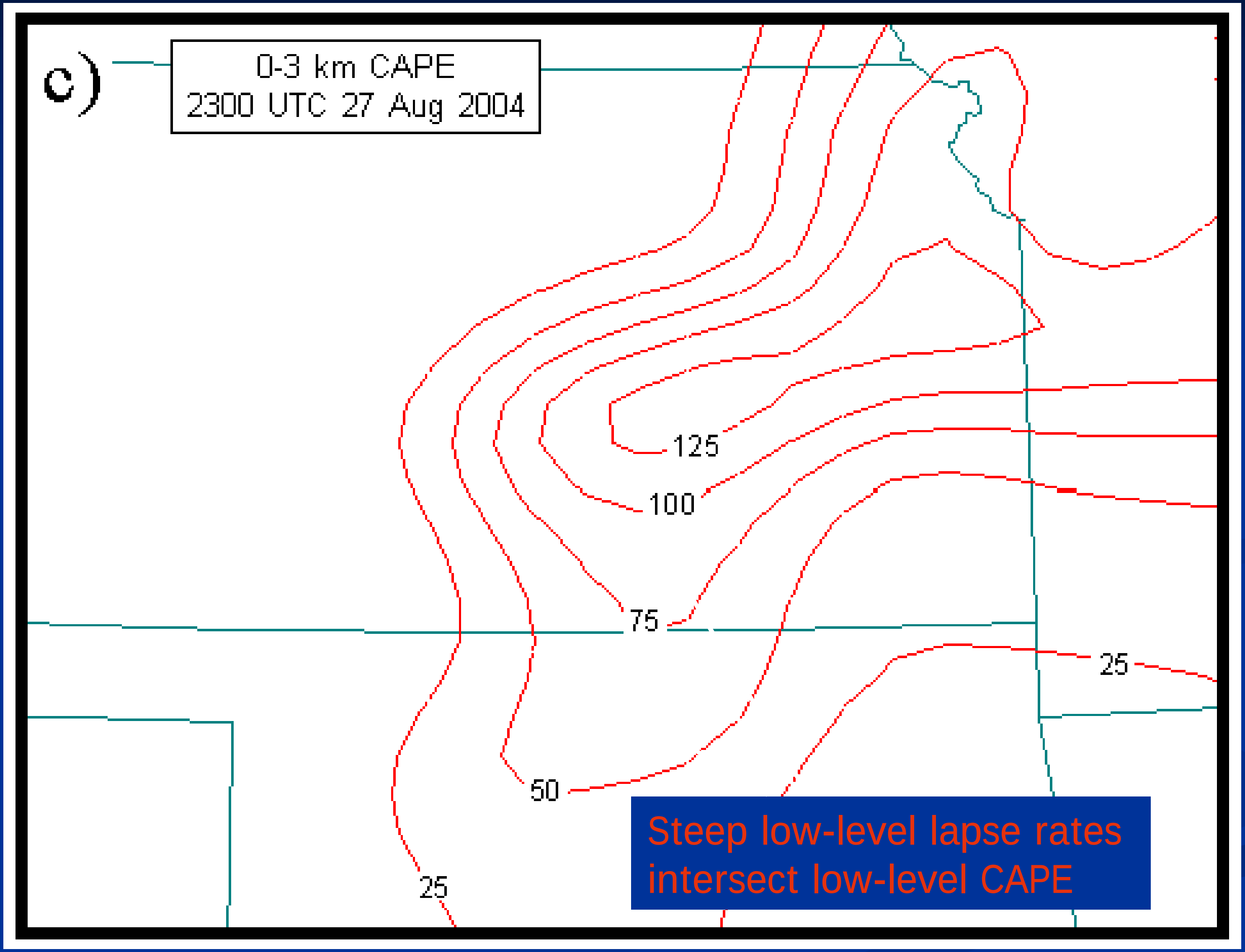
Slide courtesy Jon Davies



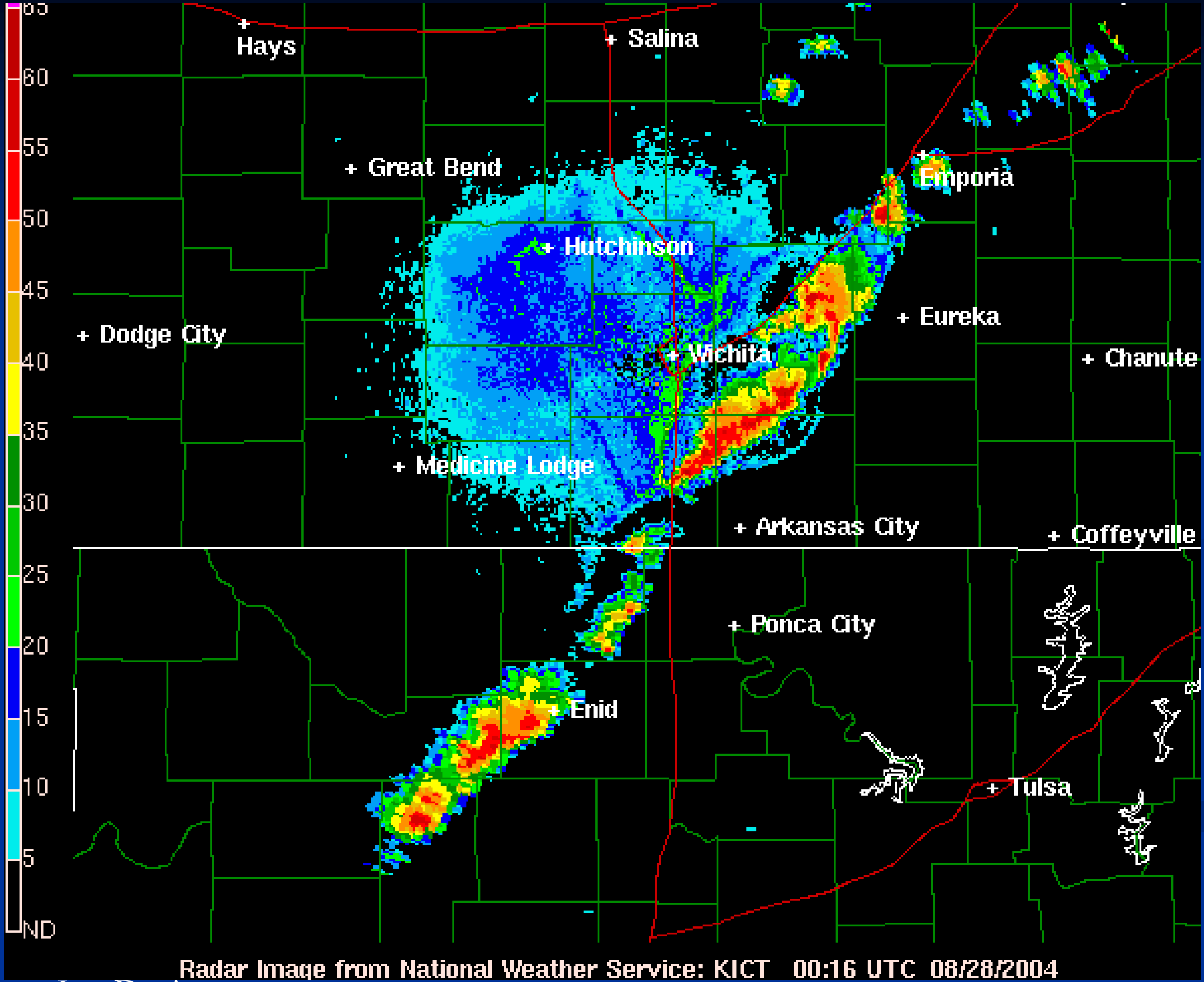
Slide courtesy Jon Davies



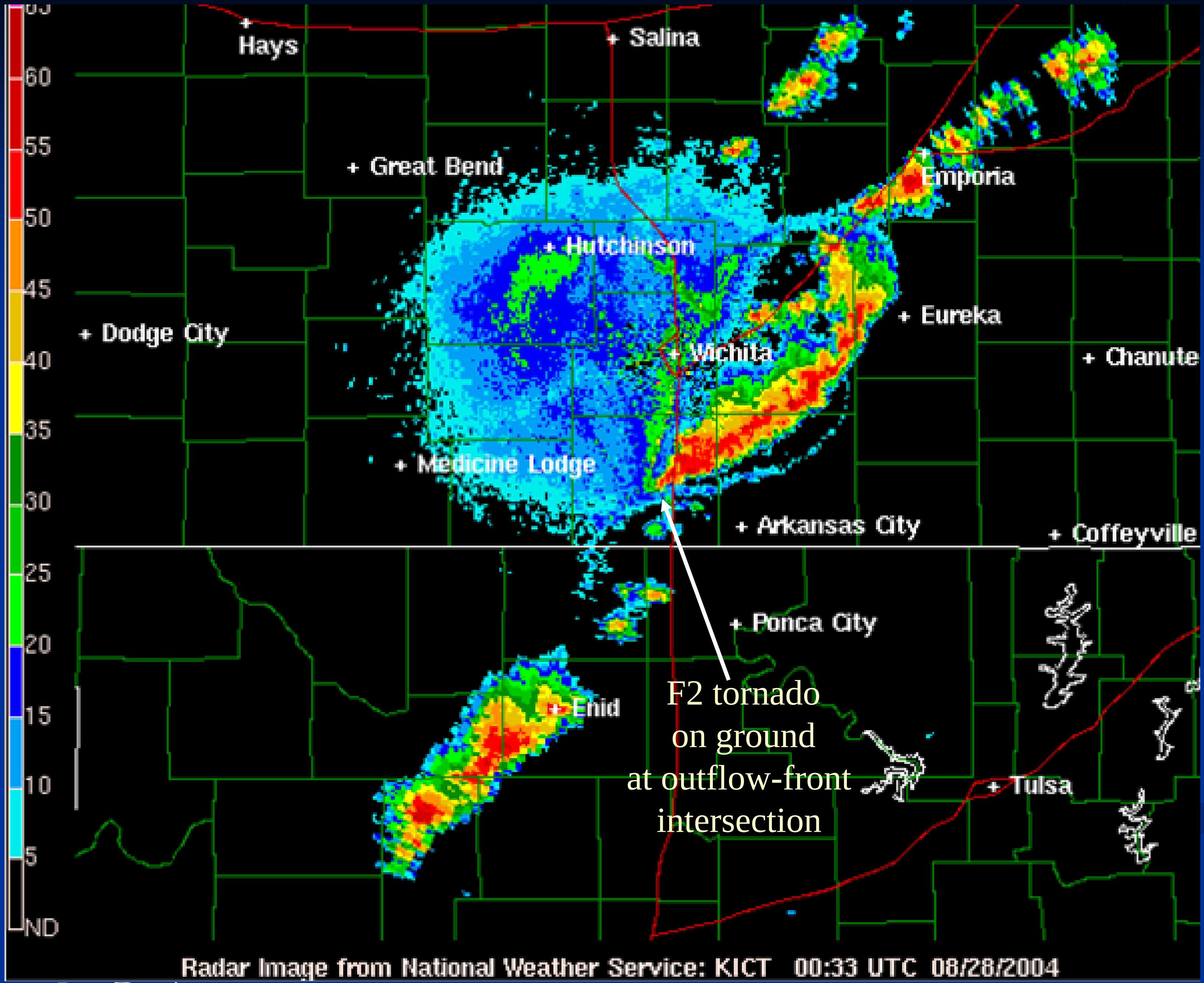
Slide courtesy Jon Davies



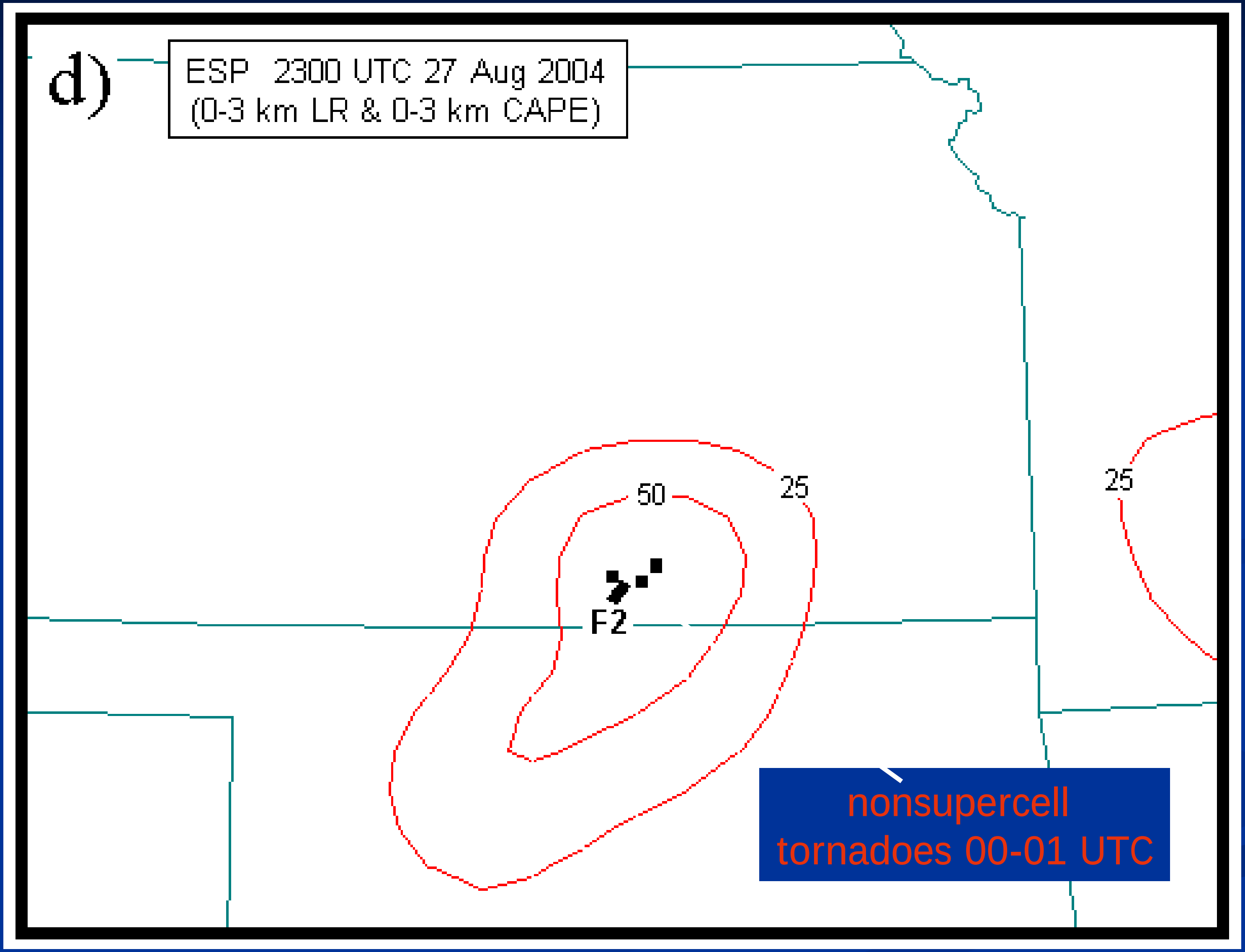
Slide courtesy Jon Davies



Slide courtesy Jon Davies

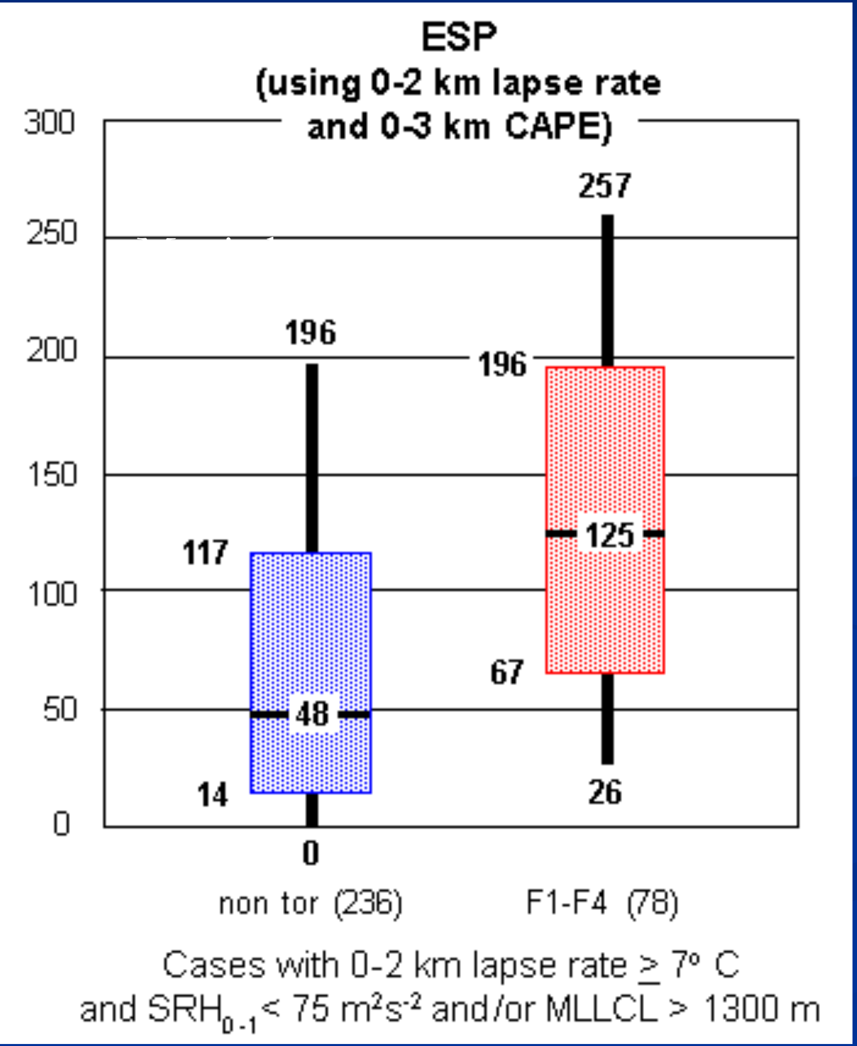


Slide courtesy Jon Davies



Slide courtesy Jon Davies

314 cases with steep low-level lapse rates non-tornadic and tornadic (RUC proximity analysis soundings)

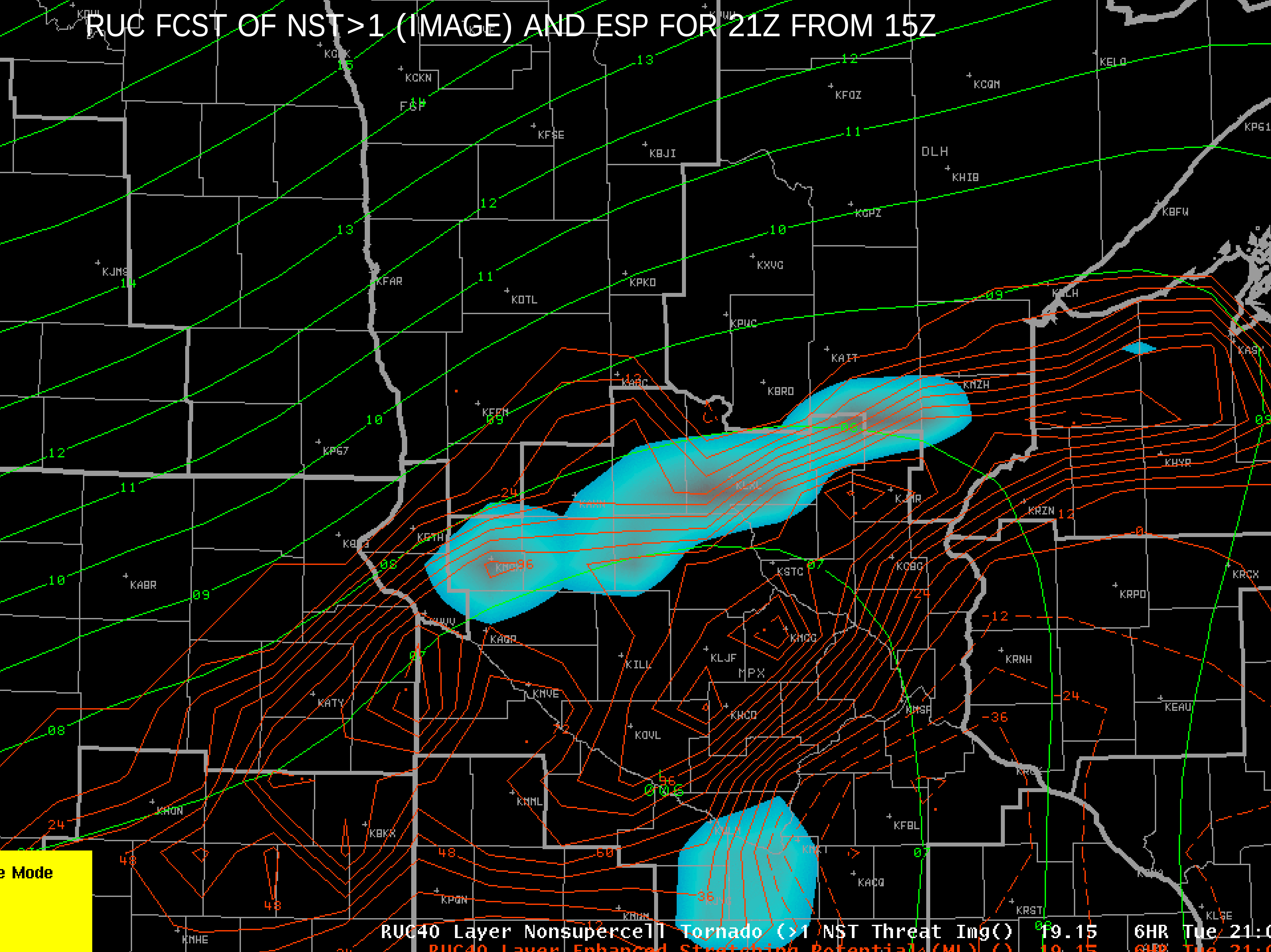


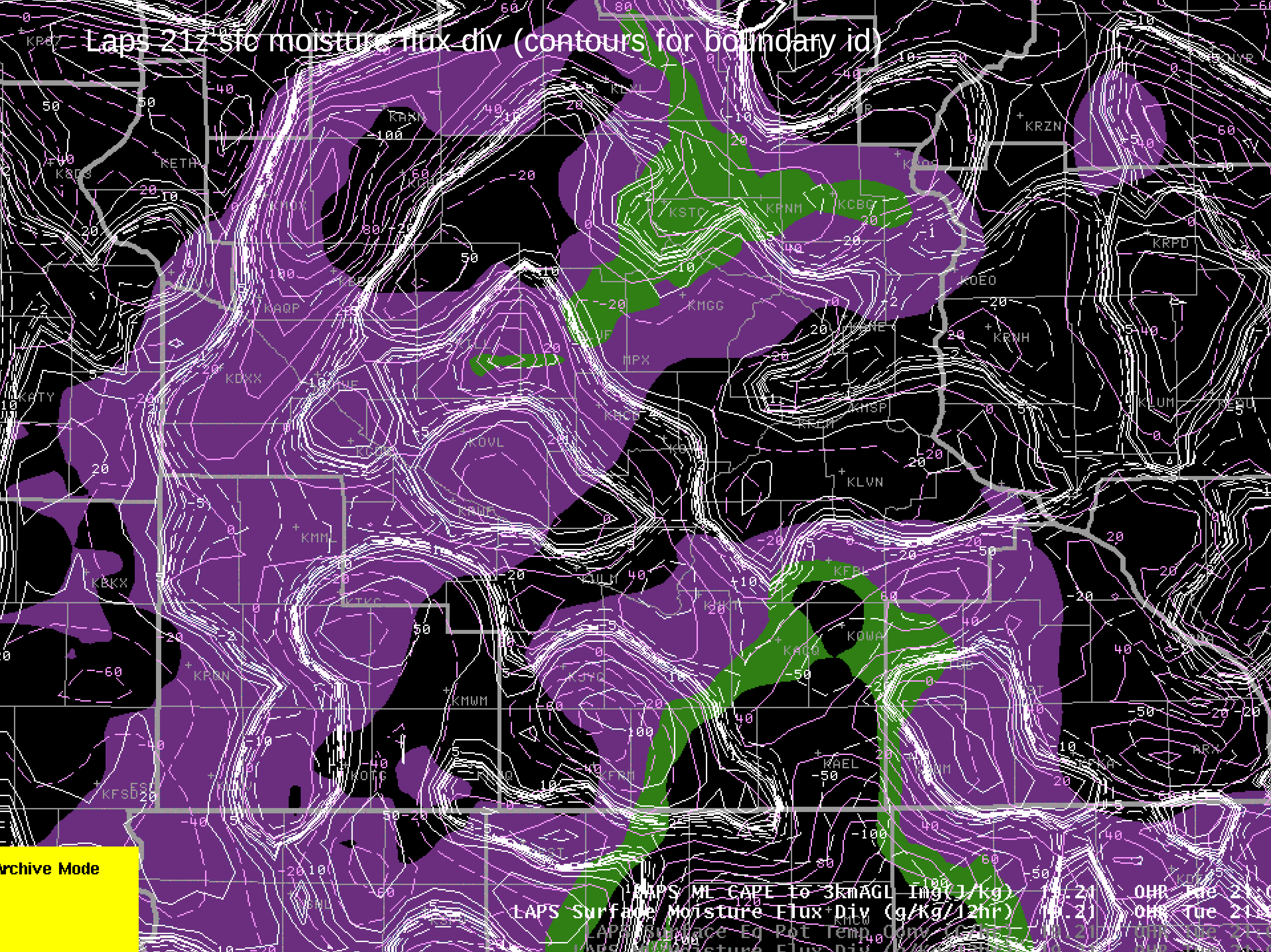
Small SRH/high LCL tornado cases (nonsupercell?) tend toward larger ESP values?

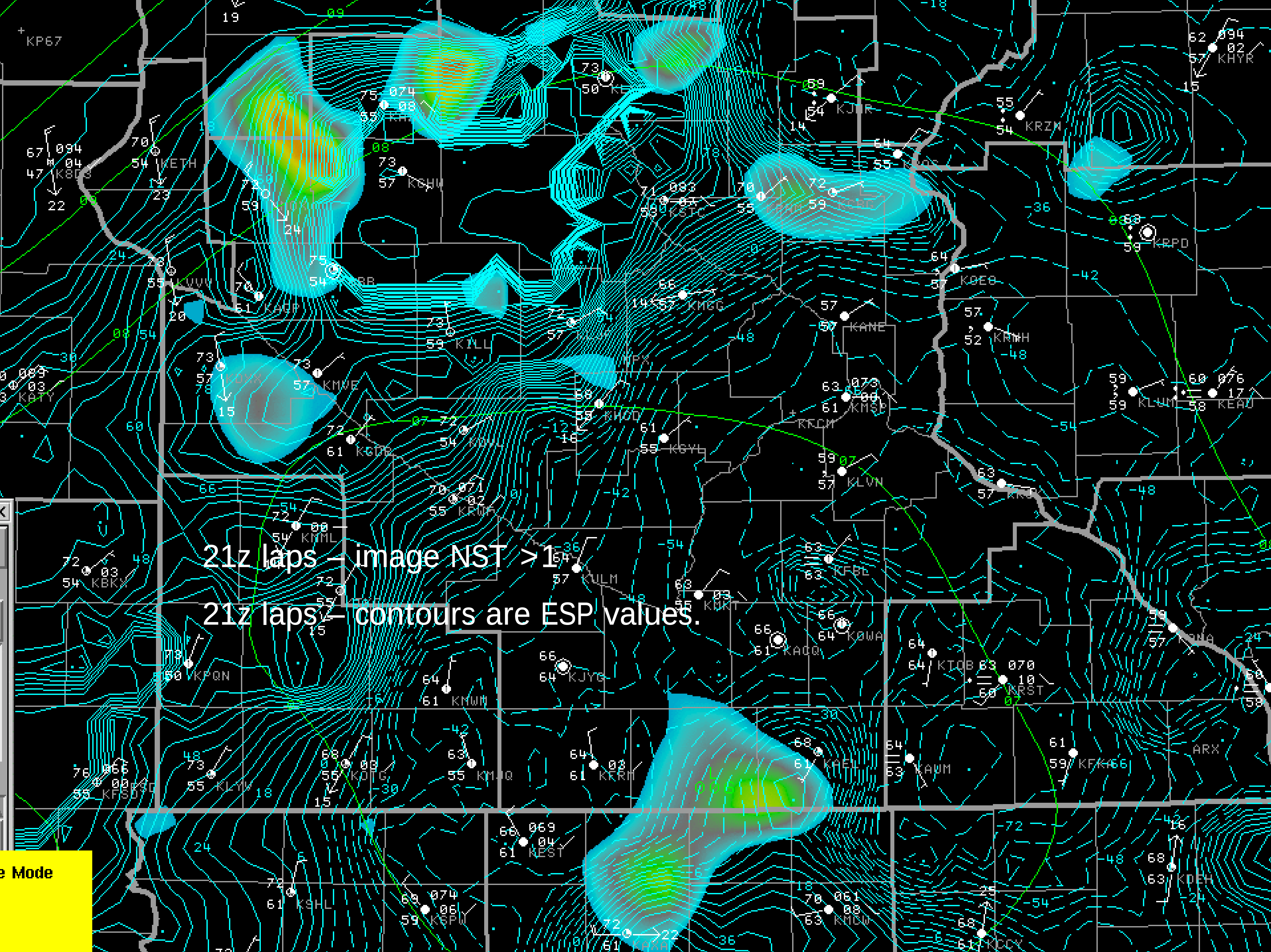
Slide courtesy Jon Davies

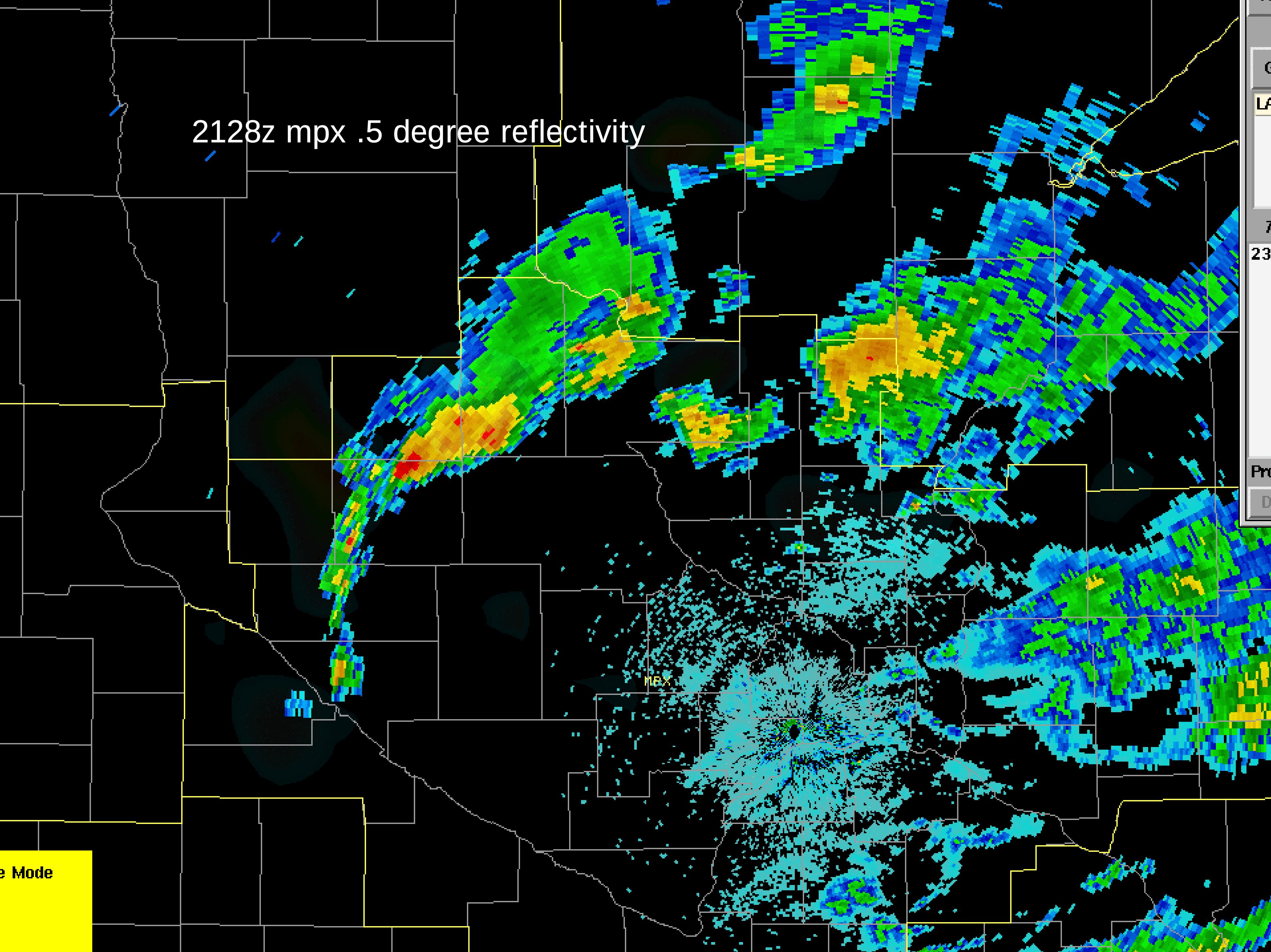
19 April 2005: NST Parameter

- Slides courtesy Rich Naistat SOO MPX.


RUC FCST OF NST>1 (IMAGE) AND ESP FOR 21Z FROM 15Z
RUC40 Layer Nonsupercell Tornado (>1 NST Threat Img()
e Mode

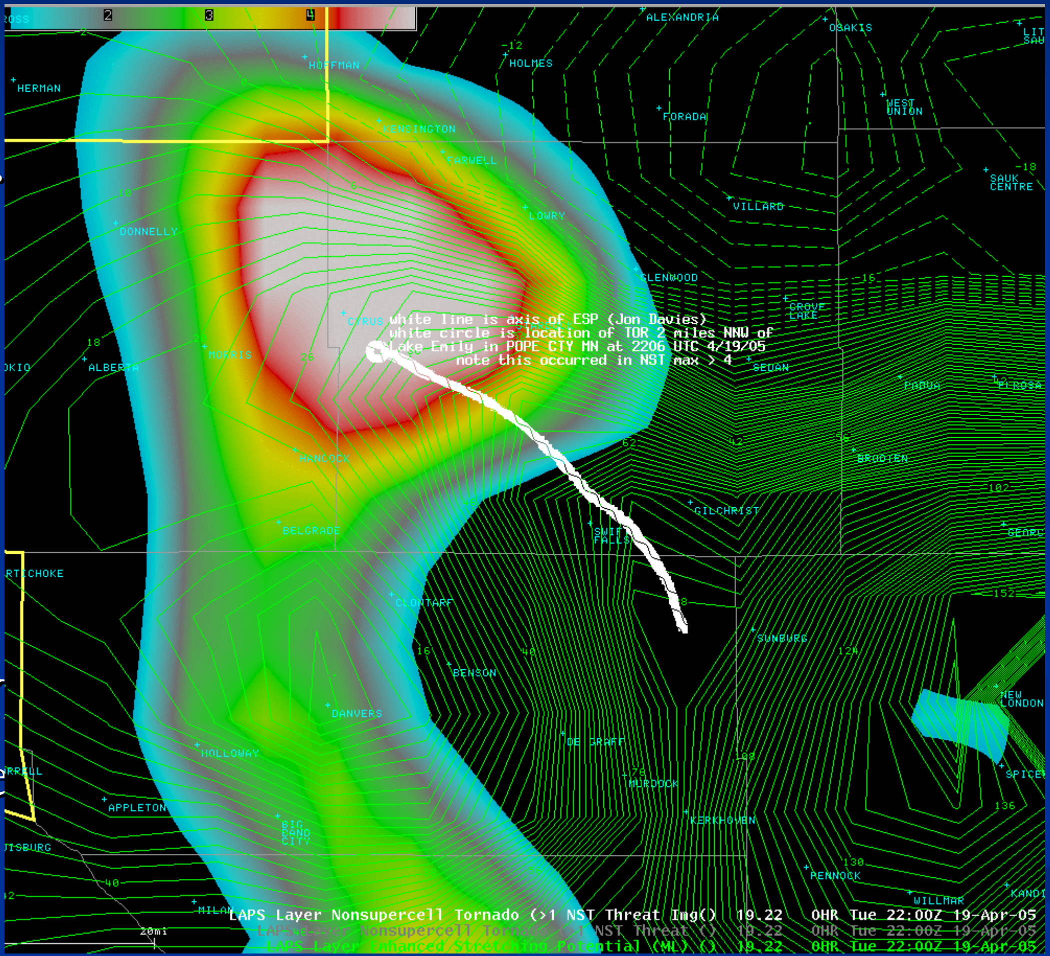

Laps 21z sfc moisture flux div (contours for boundary id)
rchive Mode
LAPS Surface Moisture Flux Div (g/Kg/12hr)


21z laps – image NST >1
21z laps – contours are ESP values.


2128z mpx .5 degree reflectivity
MPX

19 April 2005: NST Parameter

- 38 minute lead time on an NST tornado.
- WELL North of an occluding low.



- NST >= 1 then NS
possible (red, purple

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