Toward the Long-range Prediction of Severe Convective Windstorms

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Objectives

- Present background and results of literature review pertaining to severe convective windstorm (SCW) structure and evolution.

- Identify potential signatures for (SCW) forecasting using satellite, radar, and NWP resources.

- Apply SCW signatures to case studies of recent significant events.

- The results of this study will serve as a basis for the development of a long-range SCW prediction technique.

Background

- Severe windstorms resulting from mesoscale convective systems (MCS) cause major disruption to society, including widespread power outages, tree and structural damage, and transportation accidents that affect multi-state regions and metropolitan areas along their track.

- A derecho is defined as a long-lived, widespread severe convective windstorm (SCW) composed of numerous downbursts (intense localized storm downdrafts) that are organized into clusters and/or families of clusters (Fujita and Wakimoto 1981; Johns and Hirt 1987).

Background

- A convective downburst is the nucleus, or fundamental element, of a severe convective windstorm. Typically, SCWs are associated with deep, moist convective storms in which dry mid-tropospheric air interacts with elevated cores of heavy precipitation.

- Past studies of significant derecho events have employed Geostationary Operational Environmental Satellites (GOES), Doppler radar reflectivity and velocity imagery, and mesoscale numerical weather prediction model output to demonstrate the development and evolution of derecho-generated winds.

Fujita and Wakimoto Damaging Winds Scale

- **Family of downburst clusters (derecho)**
  - 1000 km (620 mi)
- **Downburst cluster**
  - 100 km (62 mi)
- **Downburst**
 - 10 km (6.2 mi)
- **Microburst**
  - 1 km (0.62 mi)
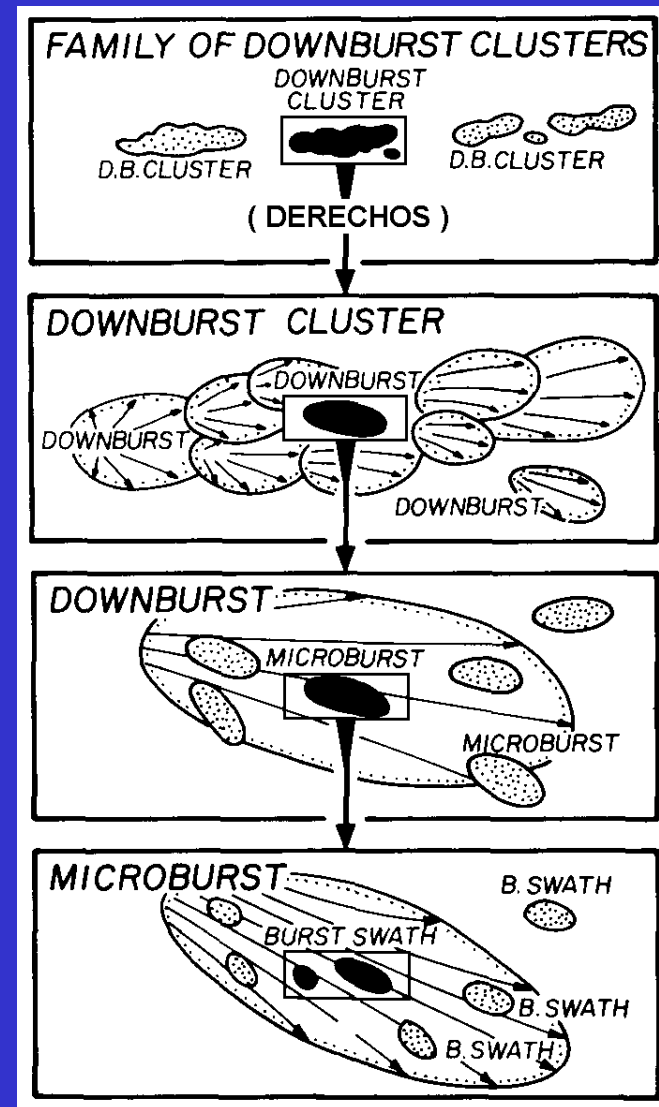
From Fujita and Wakimoto (1981)

# Convective Downburst Process

- Upon initiation of the storm downdraft by precipitation loading, lateral entrainment and channeling of drier mid-tropospheric air into the precipitation core often results in the following downburst process:

  - 1) sublimation and evaporation,

  - 2) cooling of the volume of precipitation-filled air,

  - 3) generation of negative buoyancy, and

  - 4) resultant acceleration of the downdraft.

- Melting of graupel and hail add an additional source of negative buoyancy.

- When the intense downdraft impinges on the surface, downward vertical momentum is converted to horizontal momentum, resulting in strong outflow winds.
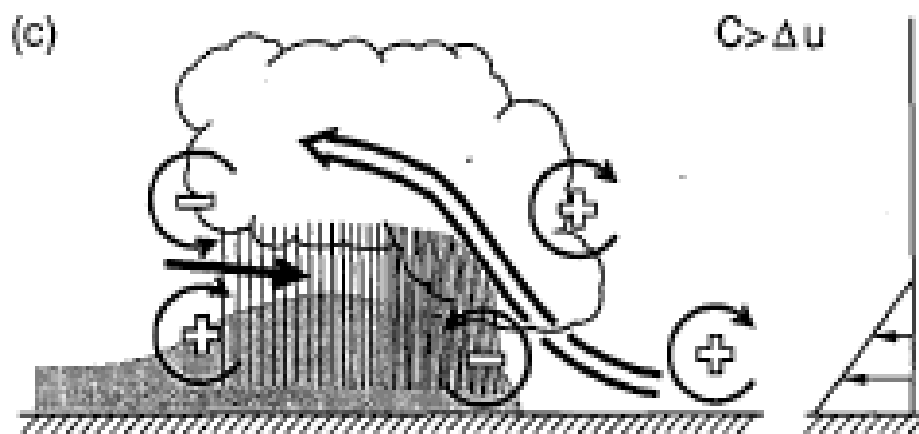
Bow Echo/Derecho Conceptual Models
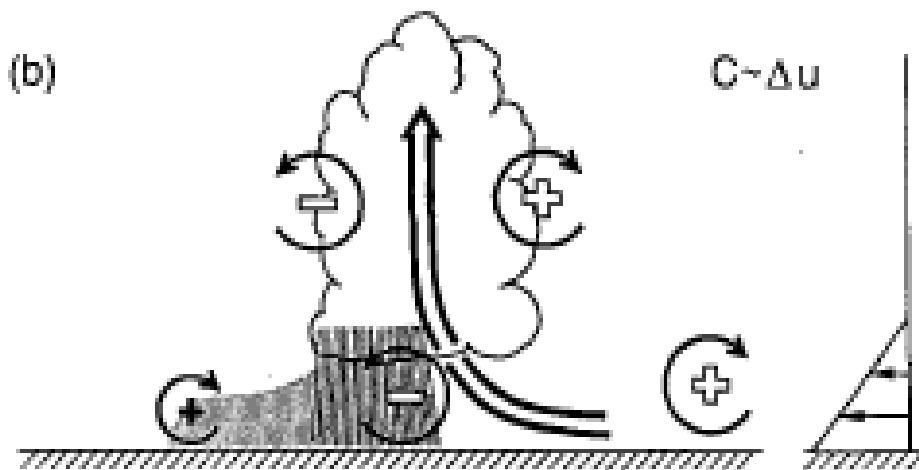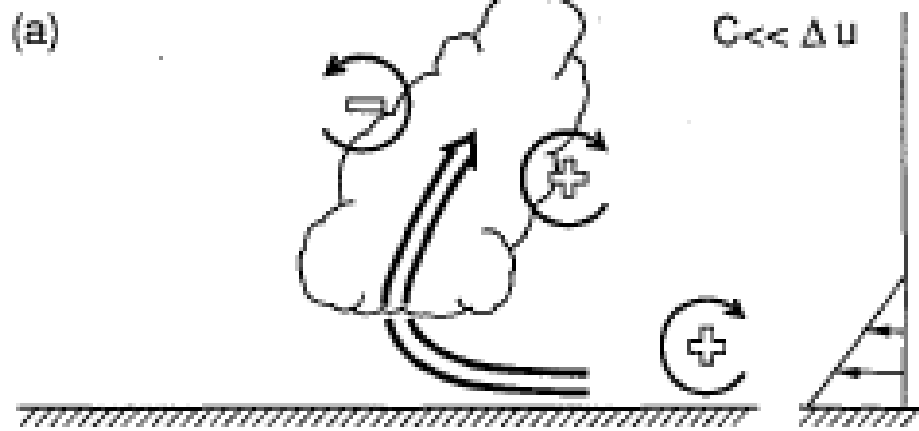

From Fujita (1978)

From Johns and Hirt (1987)
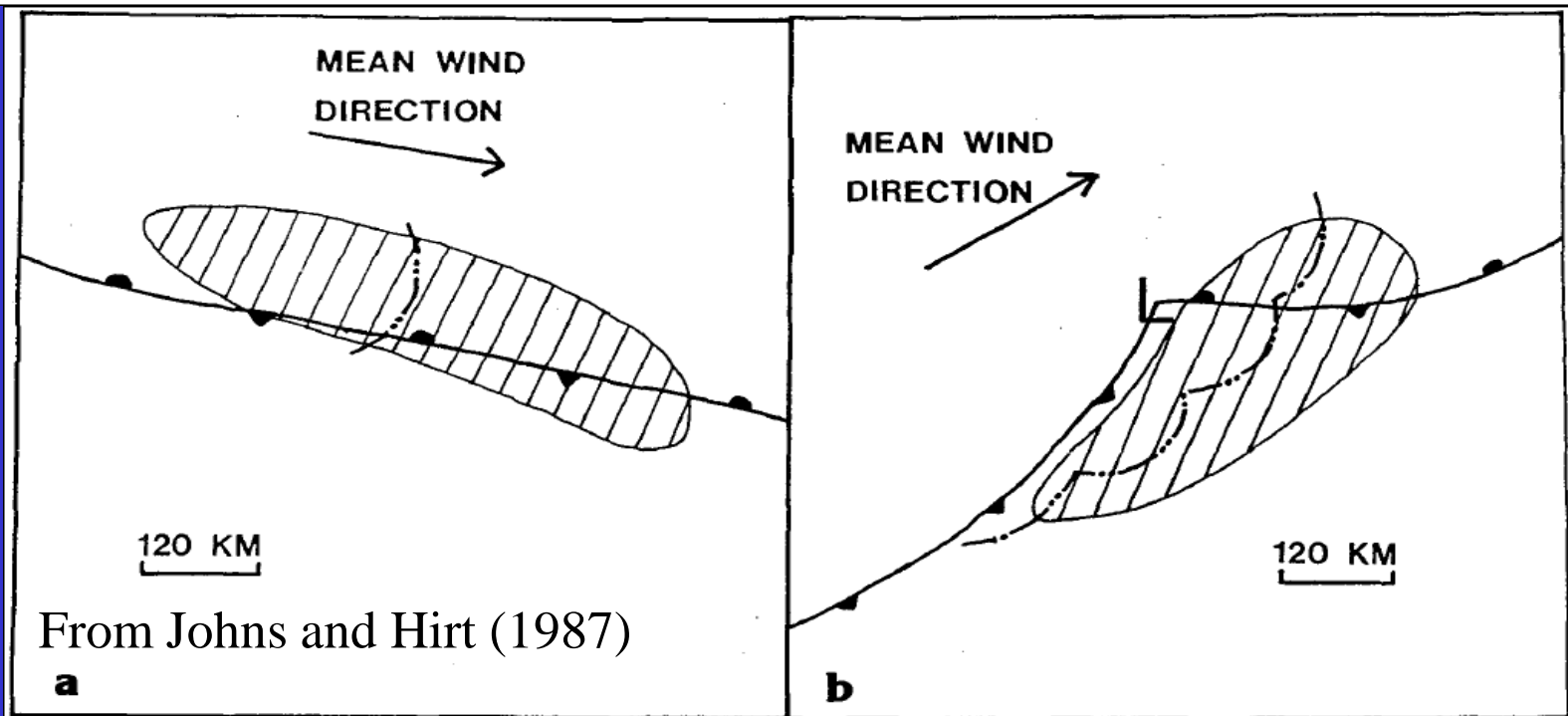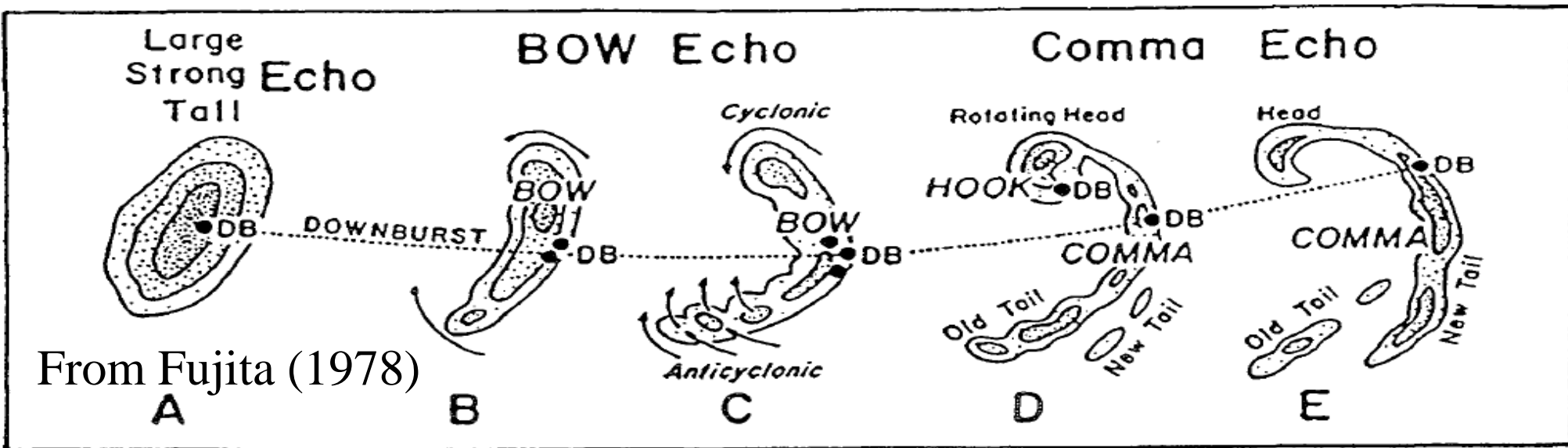
Squall Line Conceptual Model
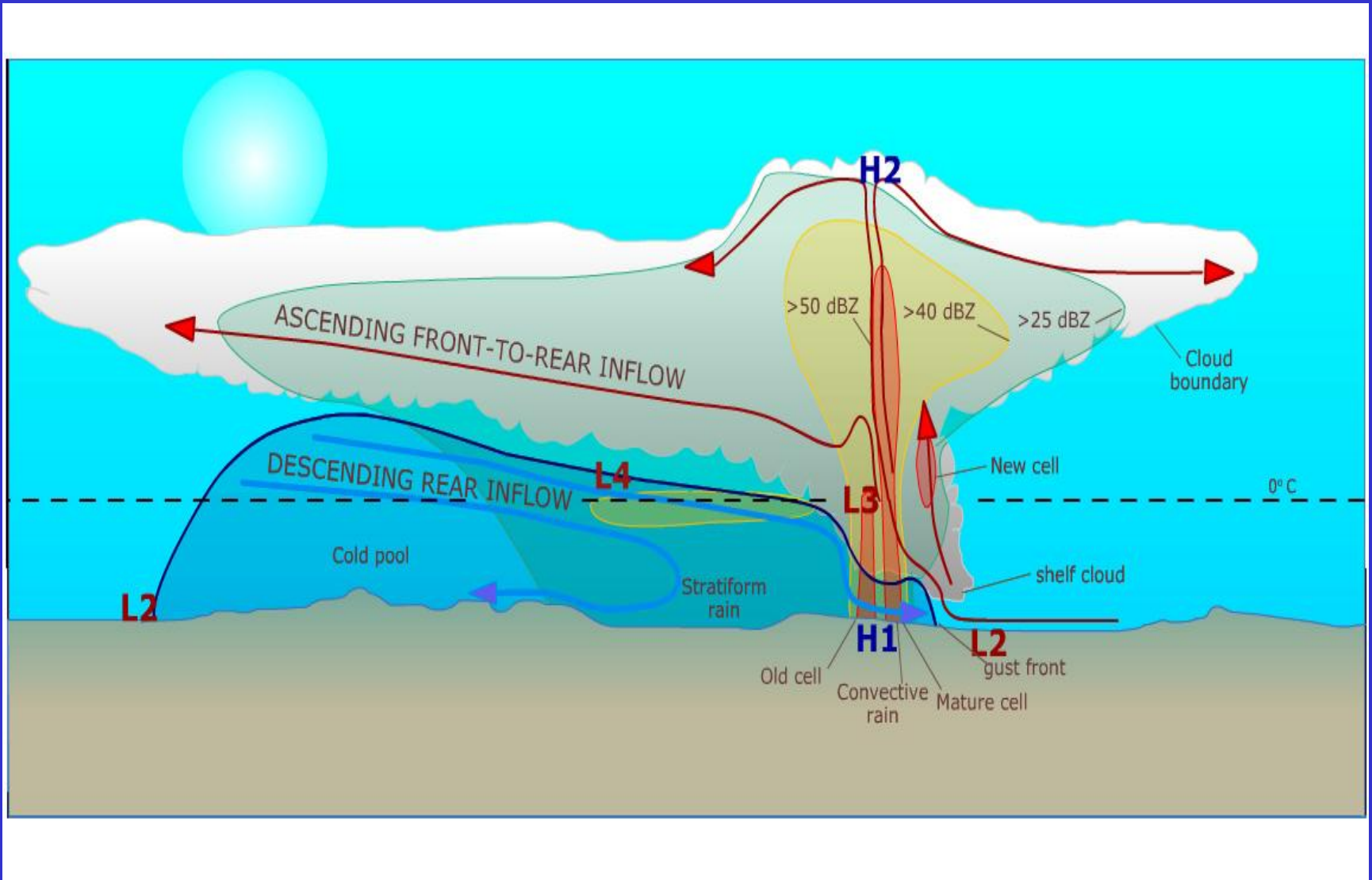
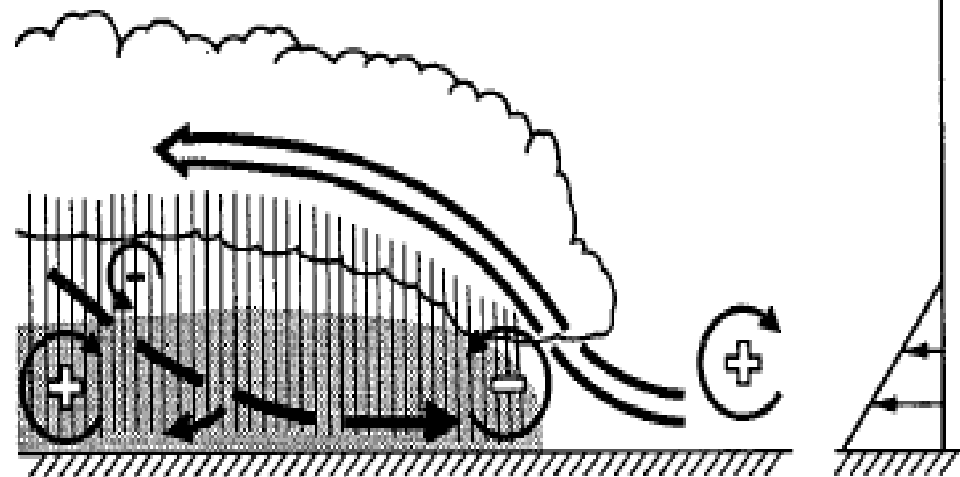From Smull and Houze (1987)

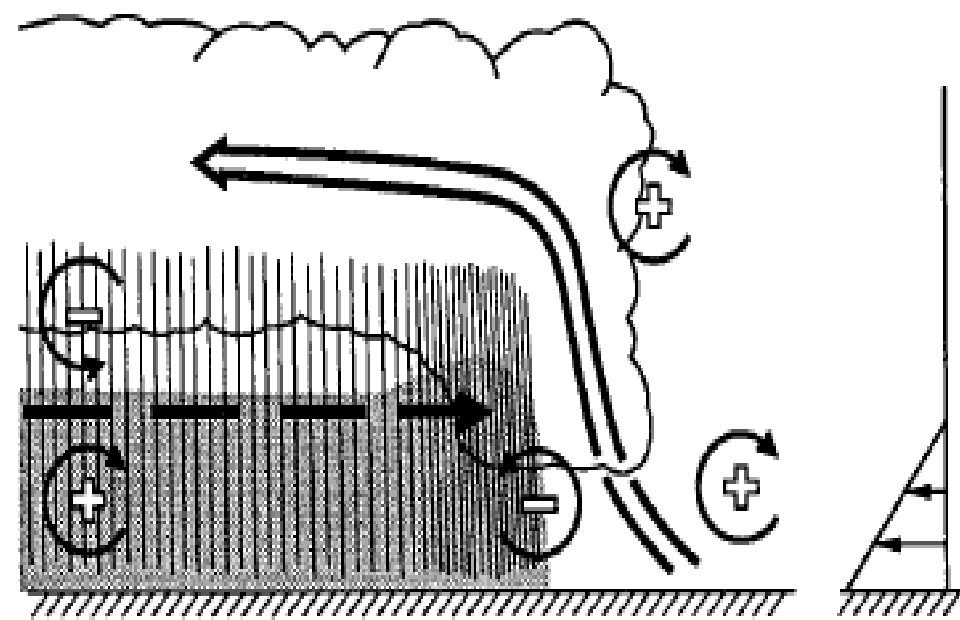(a)   C << Δu

(b)   C ~ Δu

(c)   C > Δu

(a) Descending Rear-Inflow

(b) Elevated Rear-Inflow

Candidate SCW Predictors

- Upper and lower-tropospheric vertical velocity (VV) and the vertical velocity difference (ΔVV) between these fields:
  - Found to correspond to the presence of elevated rearward ascending flow and the presence of a cold pool, respectively.

- Theta-e advection ($\mathbf{V} \cdot \nabla \theta_e$):
  - Shows effectiveness as a prognostic parameter for SCW generation based on the premise that mid-tropospheric negative theta-e advection, where cooler and drier air aloft is being transported into an MCS environment and is interacting with the trailing stratiform precipitation and leading convective storms, serves as a major forcing mechanism for intense downdrafts.

- Incorporated into a numerical weather prediction (NWP) model or a satellite hyperspectral sounder profile, the combined use of these parameters could serve to indicate the presence of a mature convective system with a rear inflow jet that has the potential to generate widespread severe winds.

Vertical Velocity Difference (ΔVV)

RAP model-derived 850-300-mb vertical velocity difference with overlying radar reflectivity at 2000 UTC 17 November 2013

Vertical velocity profile in maximum difference region over northeastern Illinois
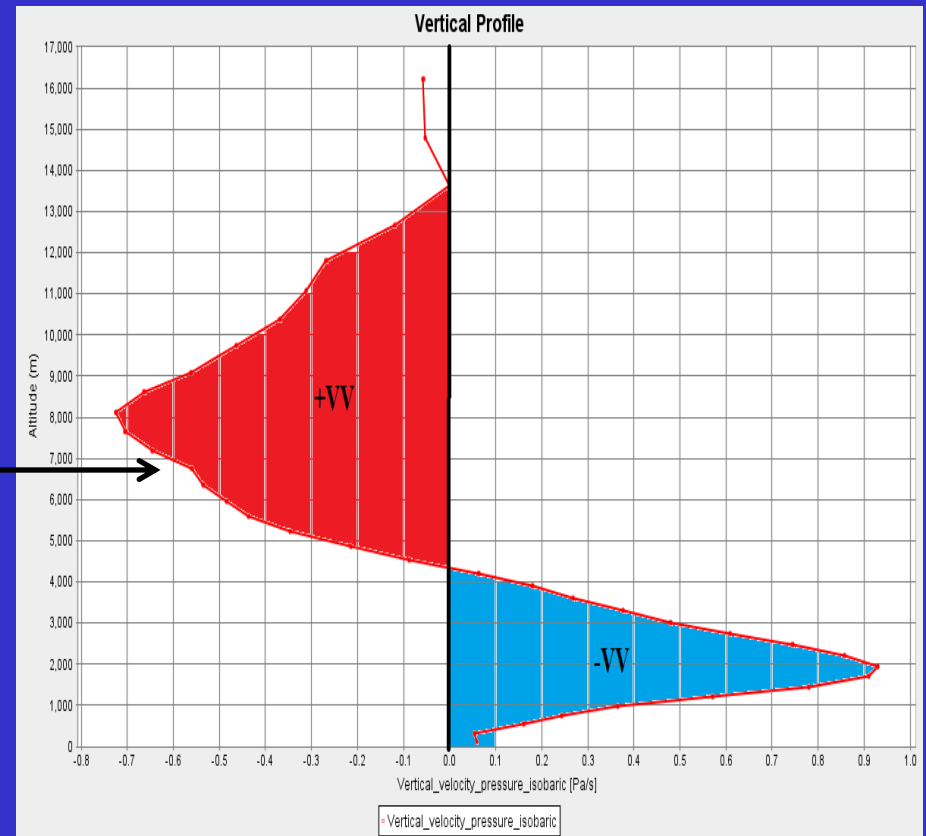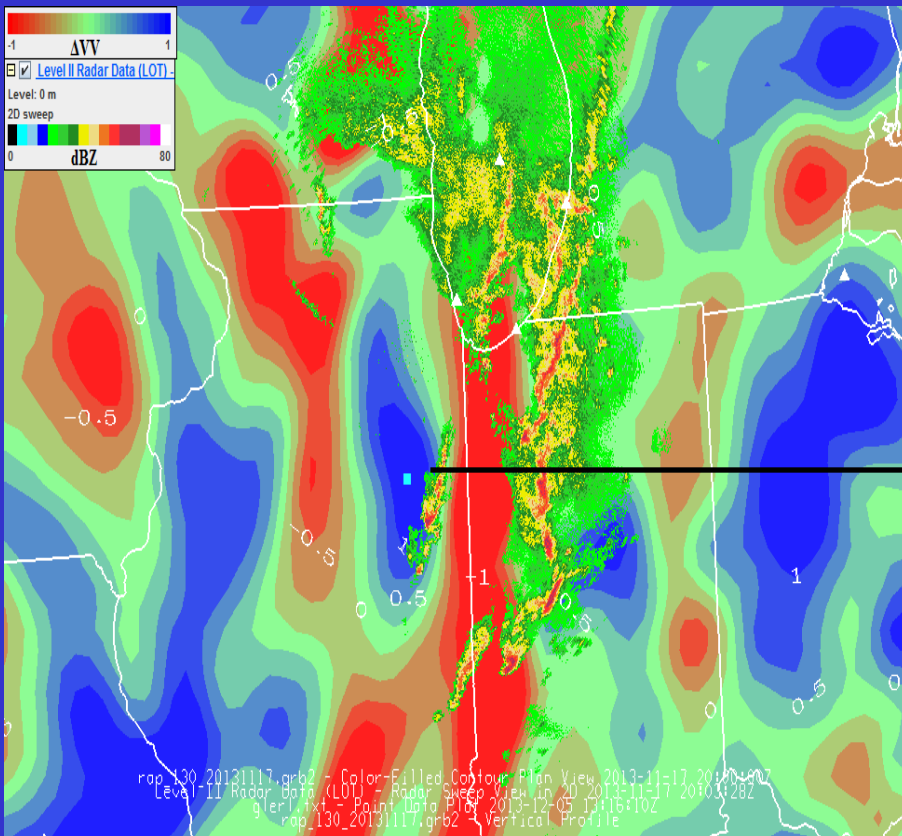
GOES-East Imager Product

- Enhanced band 3 – 4 BTD image showing well-defined dry air notches.

WV BT   -   IR BT   =   BTD

http://www.star.nesdis.noaa.gov/smcd/opdb/kpryor/mburst/mbimg.html
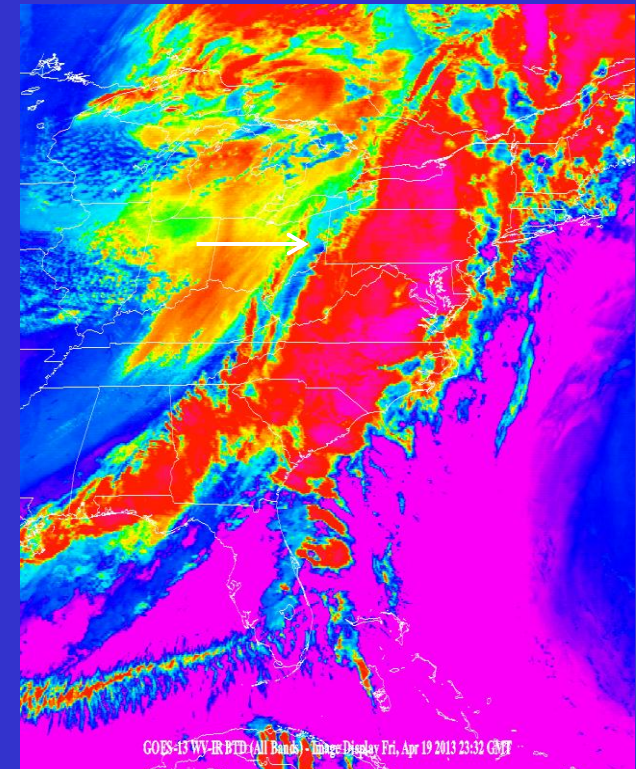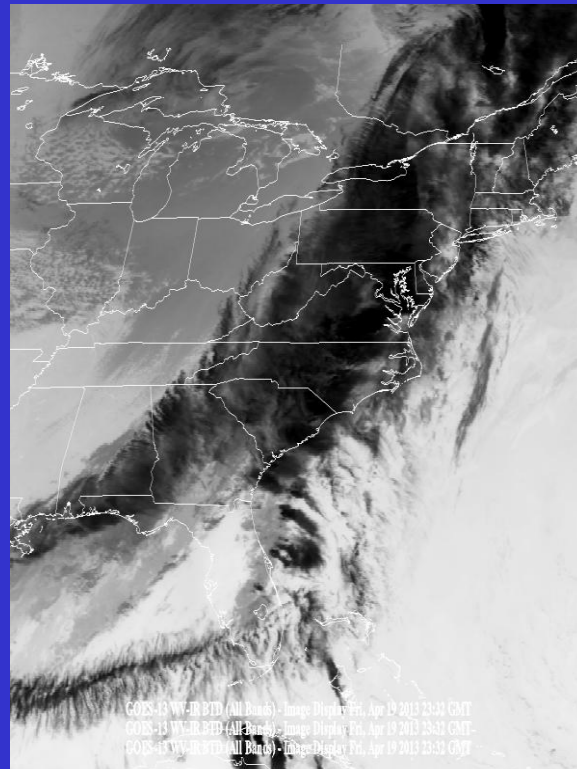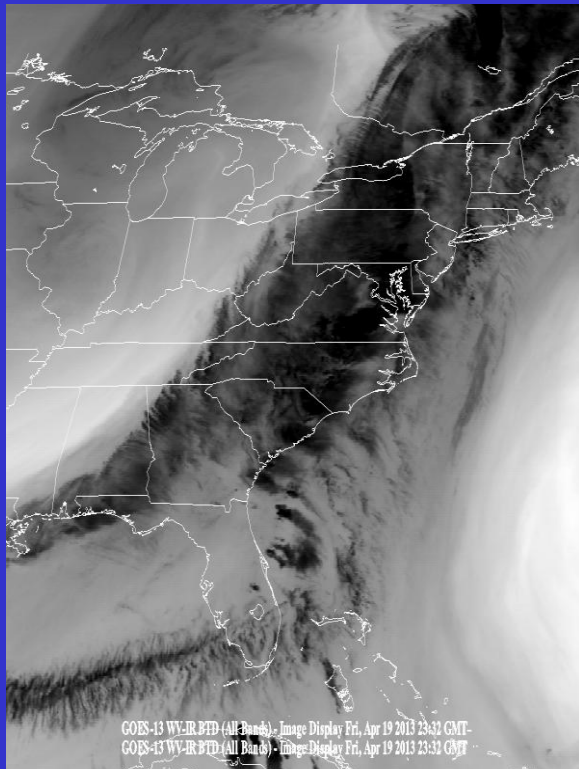
Theta-e advection ($\mathbf{V} \cdot \nabla\theta_e$)

Great Lakes regional WV-IR BTD image 1945 UTC 17 November 2013
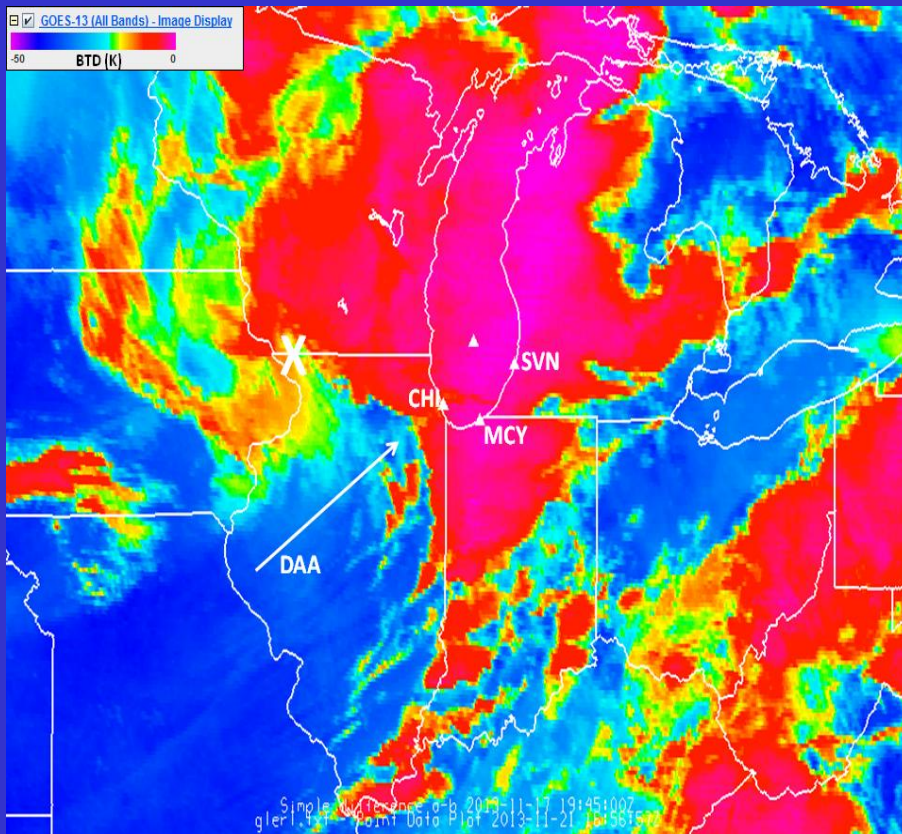
Rapid Refresh (RAP) model-derived 500-mb ($\mathbf{V} \cdot \nabla\theta_e$) at 2000 UTC (bottom) 17 November 2013
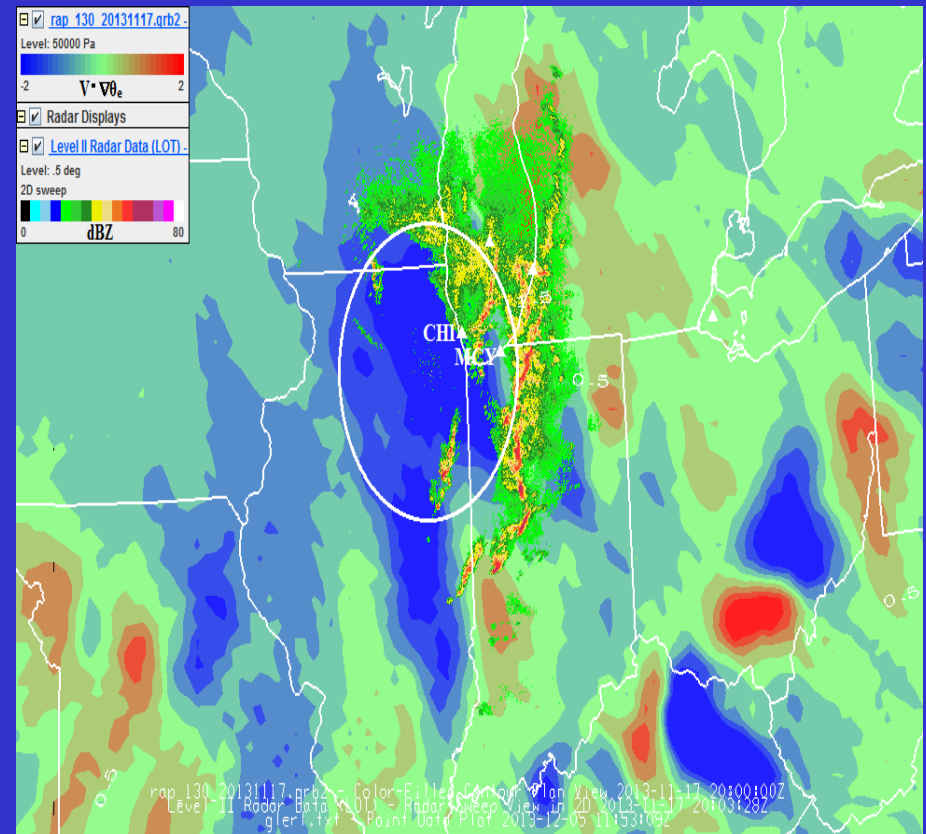
Case 1: The June 2012 North American Derecho

- During the morning of 29 June 2012, an area of convective storms over Iowa organized into a quasi-linear convective system (QLCS) as it tracked into northern Illinois. The system then evolved into a bow echo (Fujita 1978; Przybylinski 1995) during the afternoon and tracked southeastward over the Ohio Valley to the Mid-Atlantic coast by late evening.

- What would eventually become the 29 June 2012 "North American" Derecho, this QLCS produced its first significant severe downburst, with winds measured over 65 knots, at Michigan City, Indiana during the early afternoon.

Case 1: The June 2012 North American Derecho

- This extraordinary derecho-producing convective system (DCS) event resulted in 22 deaths and nearly a thousand severe wind reports from northern Illinois to the Atlantic Coast.

- This system was more typical of a warm-season progressive derecho, associated with a major heat wave and an elevated mixed layer (EML)(Banacos and Ekster 2010, Corfidi et al. 2014).

RAP Model Sounding Profiles

Dayton, Ohio
2000 UTC 29 June

Reston, Virginia
0200 UTC 30 June
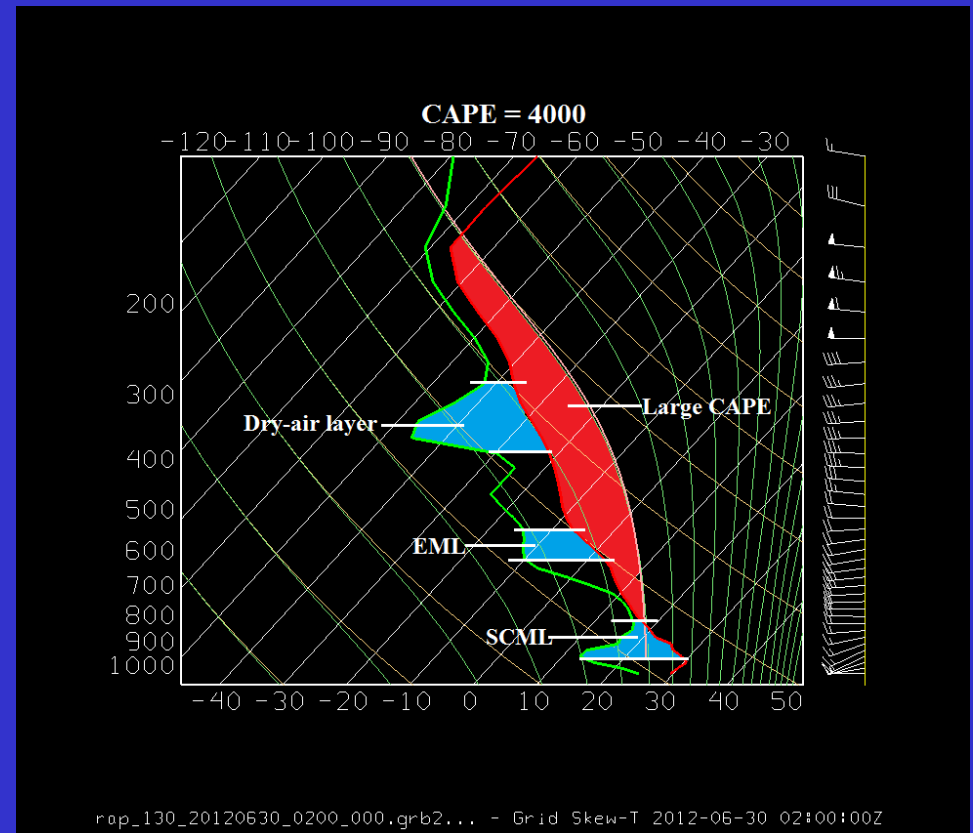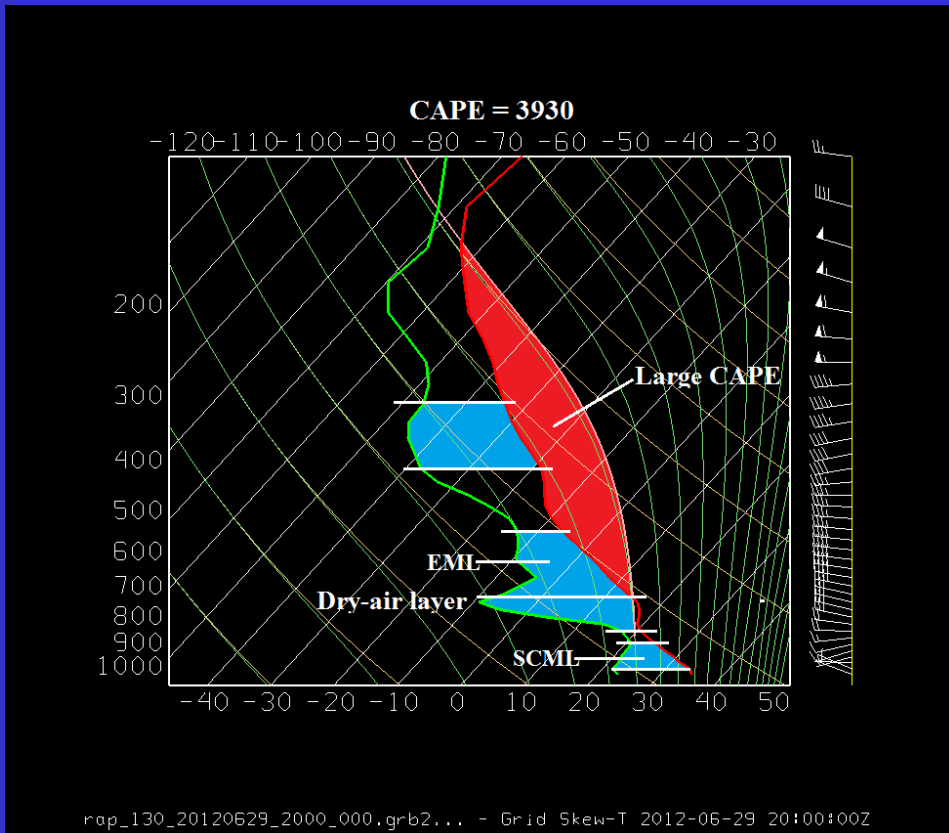
RAP model sounding profiles echo the favorable environment for severe downbursts with very large convective available potential energy (CAPE) and a prominent EML between the 500 and 700-mb levels.

June 2012 Derecho Overview
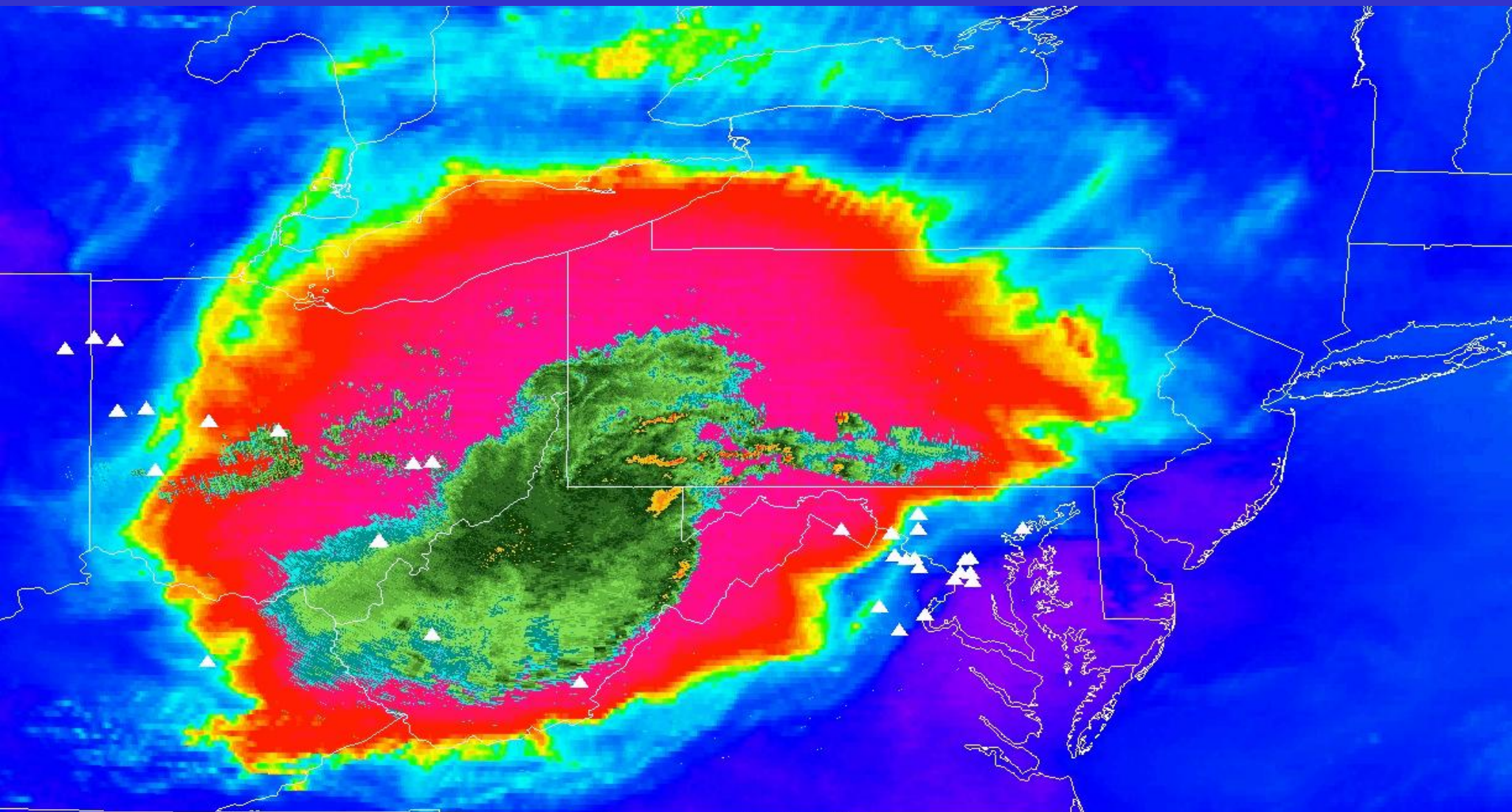
GOES-13 WV-IR BTD (All Bands) - Image Display Sat, Jun 30 2012 00:15 GMT
Level III Radar Data (DCA) - Radar Sweep View in 2D Sat, Jun 30 2012 00:19 GMT
reportplot.txt - Point Data Plot Tue, Apr 09 2013 19:24 GMT

June 2012 Derecho Overview

SPC Storm Reports for 06/29/12

Map updated at 1213Z on 07/09/12

TORNADO REPORTS.. (2)
WIND REPORTS/HI..... (1195/37)
HAIL REPORTS/LG..... (67/5)
TOTAL REPORTS....... (1264)

National Weather Service
Storm Prediction Center   Norman, Oklahoma

■ High Wind Report (65KT +)
▲ Large Hail Report (2" dia. +)

PRELIMINARY DATA ONLY

Photo: NASA

Derecho Initiation

Level: 70000 Pa
MBI
0   20
Level: 85000 Pa
VV (Pa/s)
-2   2

MBI maximum

Cold pool

SE

QLCS

rap_130_20120629_15_17.grb2 - Image Display Fri, Jun 29 2012 17:00 GMT
mcy.txt - Point Data Plot Fri, Aug 02 2013 15:49 GMT
rap_130_20120629_15_17.grb2 - Image Display Fri, Jun 29 2012 17:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 17:06 GMT
rap_130_20120629_15_17.grb2 - Contour Plan View Fri, Jun 29 2012 17:00 GMT

Derecho Initiation

Level: 70000 Pa

0   MBI   20

Level: 85000 Pa

-2   VV (Pa/s)   2

Cold pool

Velocity > 50 kt

RIJ

rap_130_20120629_15_17.grb2 - Image Display Fri, Jun 29 2012 17:00 GMT
mcy.txt - Point Data Plot Fri, Aug 02 2013 15:49 GMT
rap_130_20120629_15_17.grb2 - Image Display Fri, Jun 29 2012 17:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 17:06 GMT
rap_130_20120629_15_17.grb2 - Contour Plan View Fri, Jun 29 2012 17:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 17:06 GMT

Derecho Initiation

RIJ

QLCS

rap_130_20120629_15_17.grb2 - Color-Filled Contour Plan View Fri, Jun 29 2012 17:00 GMT
rap_130_20120629_15_17.grb2 - Contour Plan View Fri, Jun 29 2012 17:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 17:01 GMT
mcy.txt - Point Data Plot Thu, Aug 01 2013 19:50 GMT

Derecho Initiation

Ascending front-rear flow

Cold pool

Leading convective storm line

rap_130_20120629_15_17.grb2 - Color-Filled Contour Plan View Fri, Jun 29 2012 16:00 GMT
rap_130_20120629_15_17.grb2 - Contour Plan View Fri, Jun 29 2012 16:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 16:01 GMT
mcy.txt - Point Data Plot Mon, Aug 05 2013 19:50 GMT
rap_130_20120629_15_17.grb2 - Color-Filled Contour Cross Section Fri, Jun 29 2012 16:00 GMT
Level II Radar Data (LOT) - Radar Cross Section Fri, Jun 29 2012 16:01 GMT

Derecho Initiation

Ascending front-rear flow

Heavy stratiform precipitation

Cold pool

Leading convective storm line

rap_130_20120629_15_17.grb2 - Color-Filled Contour Plan View Fri, Jun 29 2012 17:00 GMT
rap_130_20120629_15_17.grb2 - Contour Plan View Fri, Jun 29 2012 17:00 GMT
Level II Radar Data (LOT) - Radar Sweep View in 2D Fri, Jun 29 2012 17:01 GMT
mcy.txt - Point Data Plot Mon, Aug 05 2013 19:50 GMT
rap_130_20120629_15_17.grb2 - Color-Filled Contour Cross Section Fri, Jun 29 2012 17:00 GMT
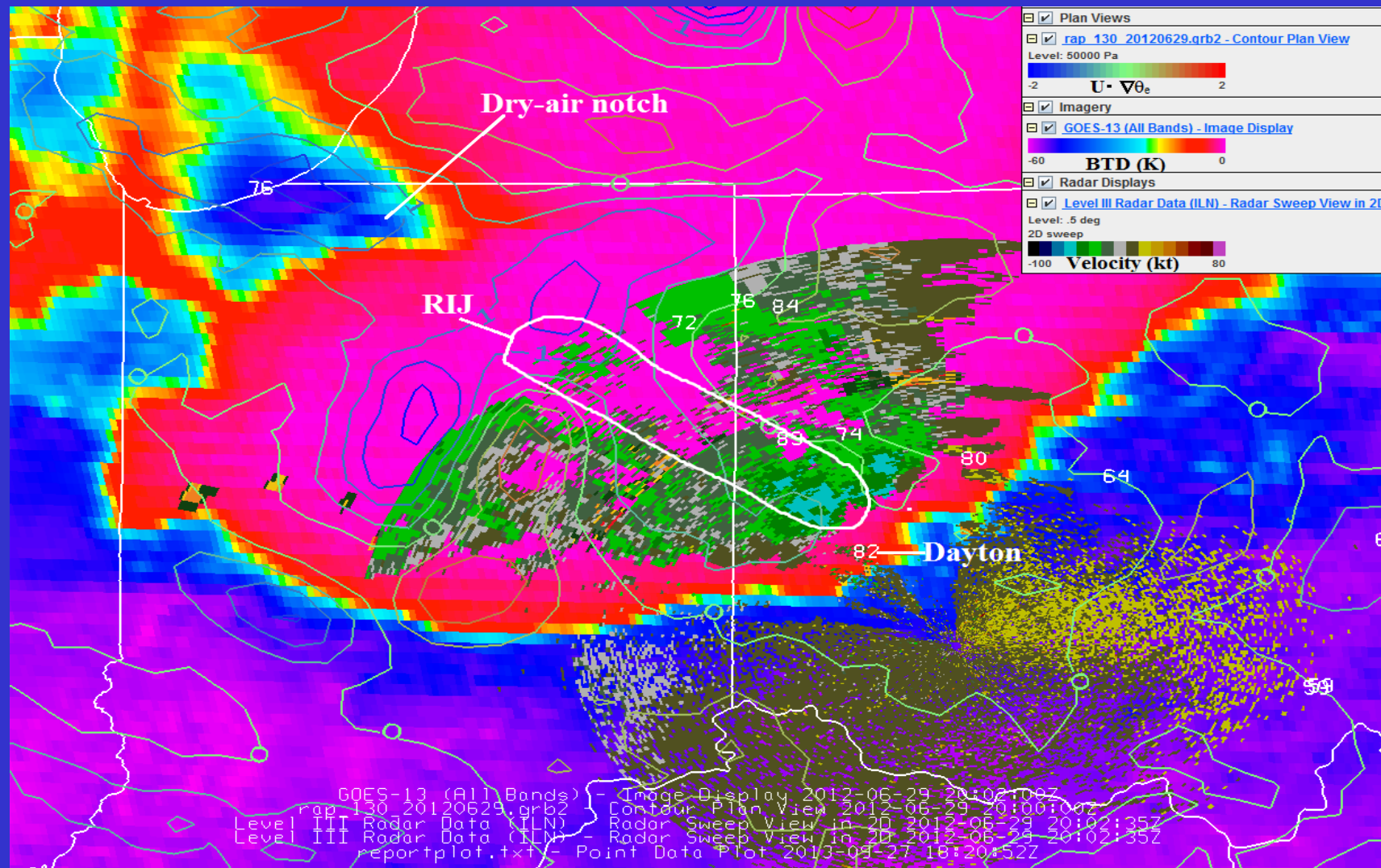Level II Radar Data (LOT) - Radar Cross Section Fri, Jun 29 2012 17:01 GMT
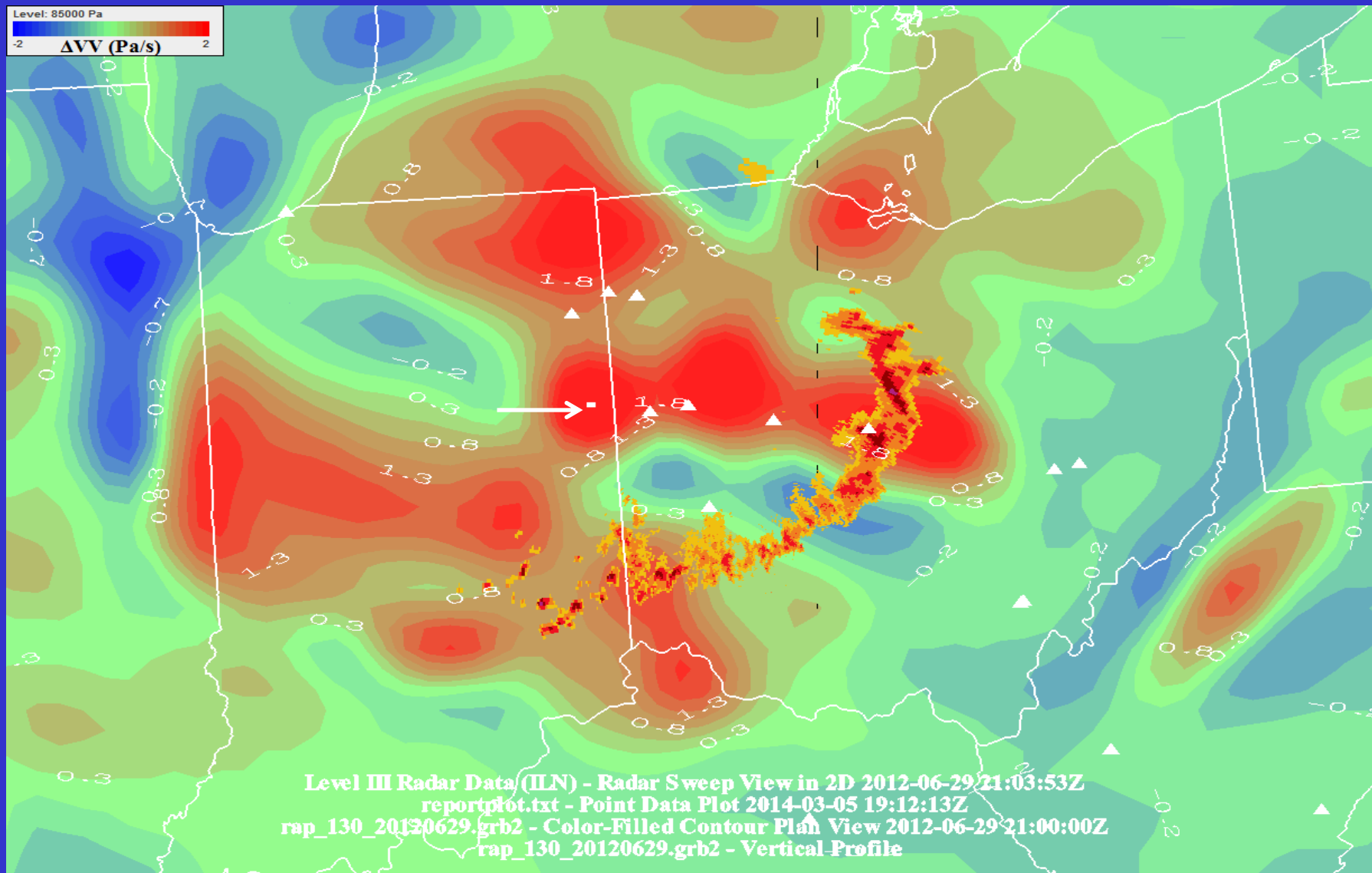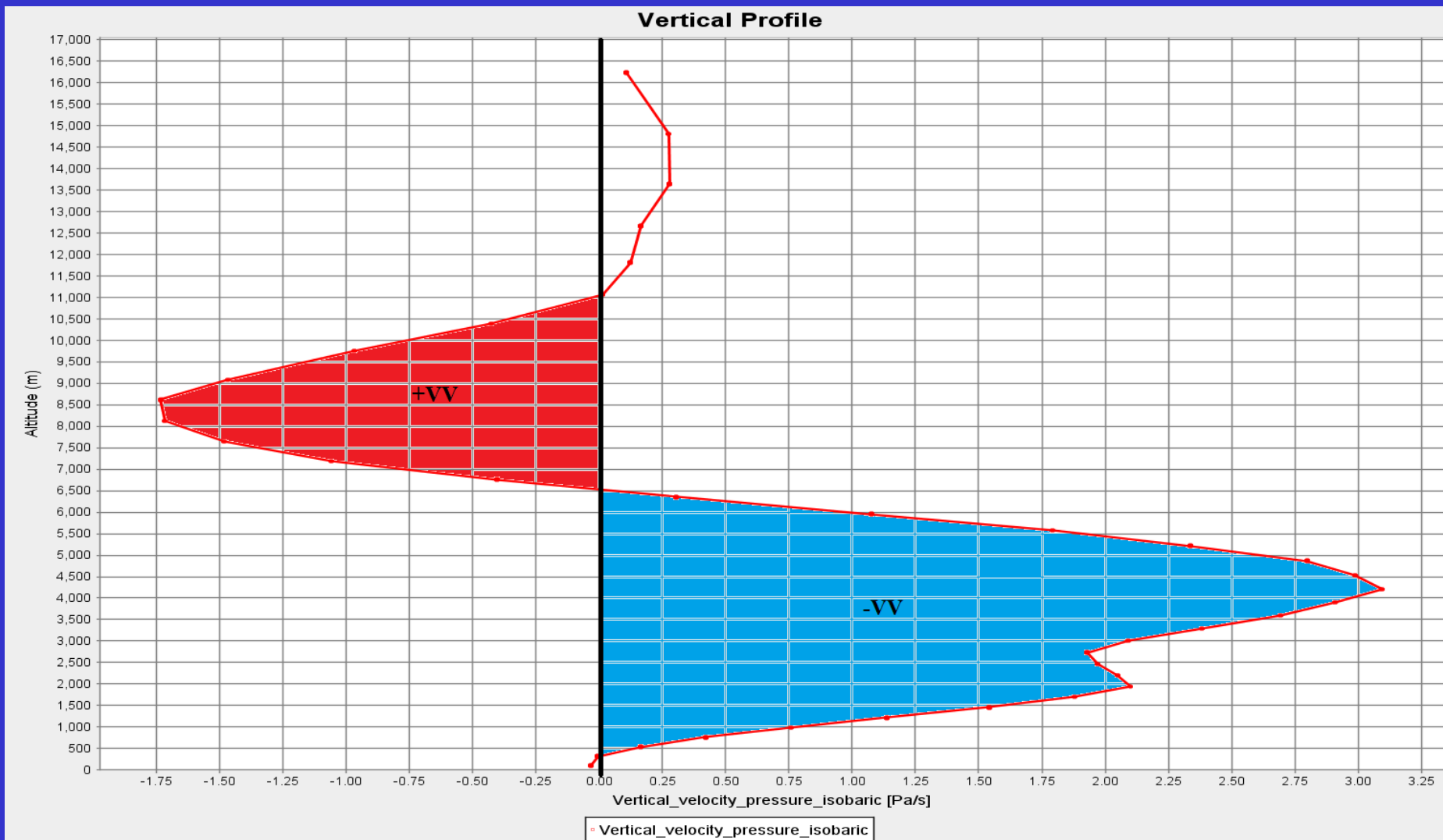
Theta-e Advection

Theta-e Advection

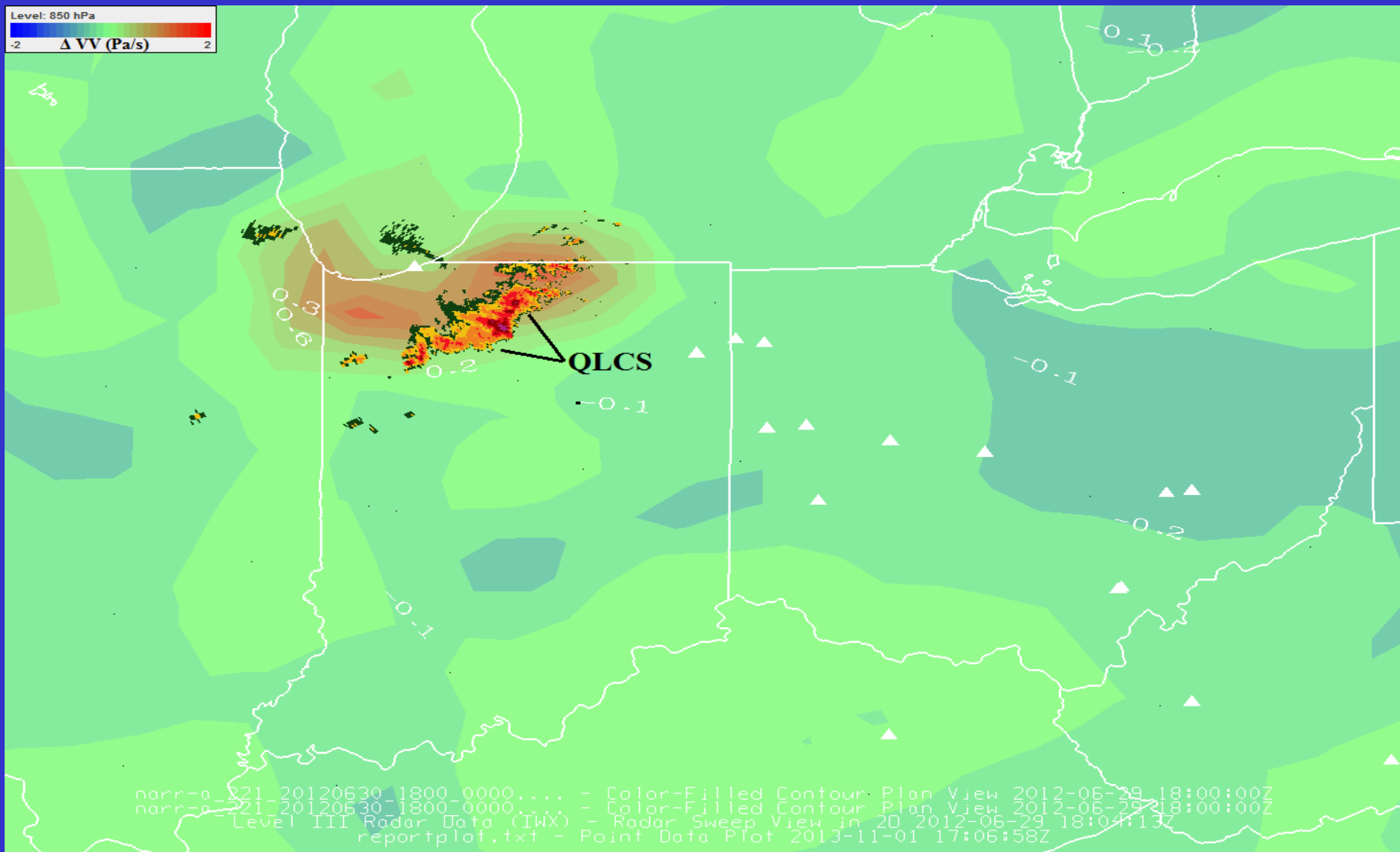# June 2012 Derecho: Mature Phase
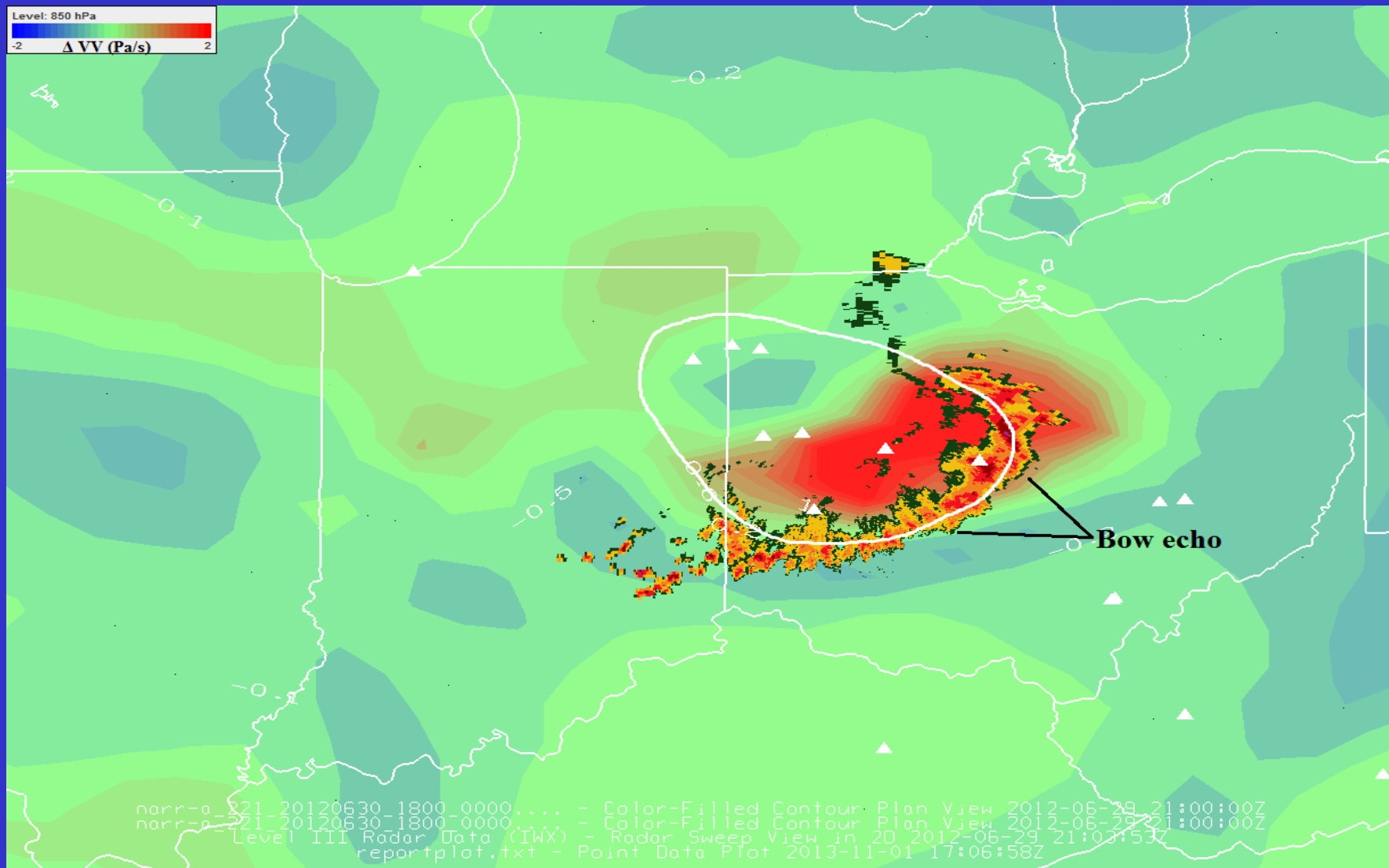
Mature Phase: VV Difference
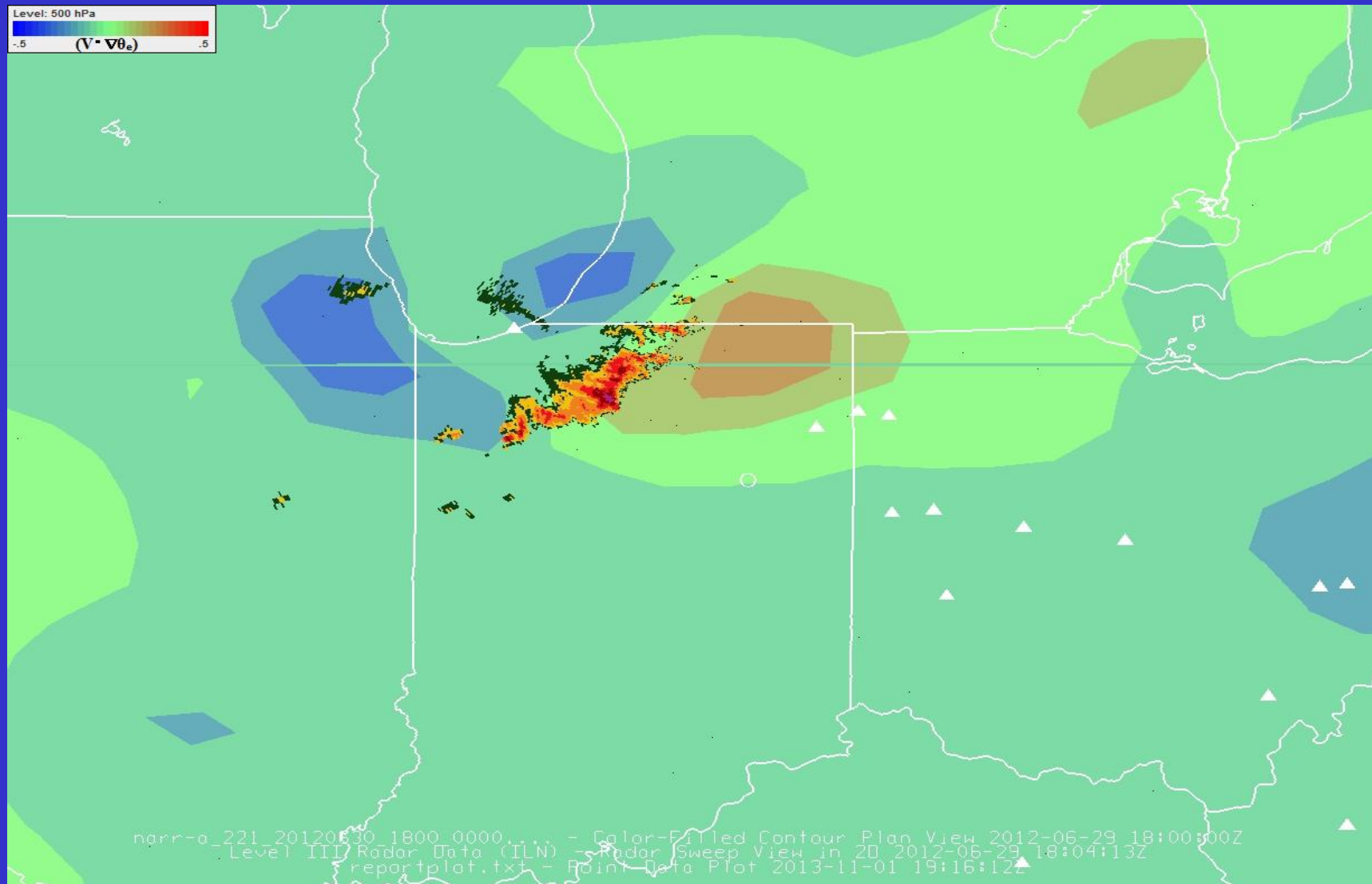
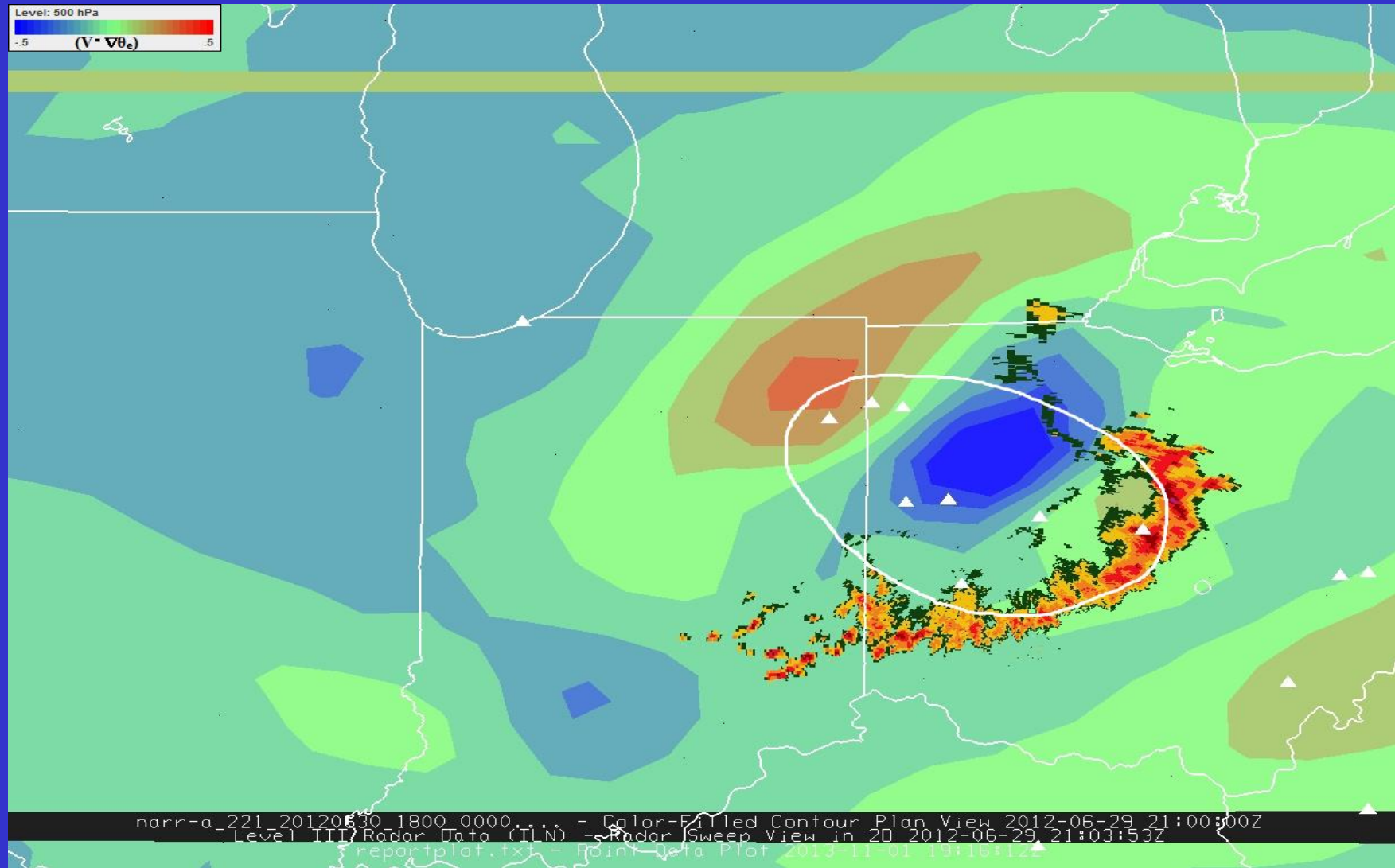# Mature Phase: VV Difference

Mature Phase: VV Difference

Mature Phase: VV Difference

Mature Phase: Theta-e Advection

Mature Phase: Theta-e Advection

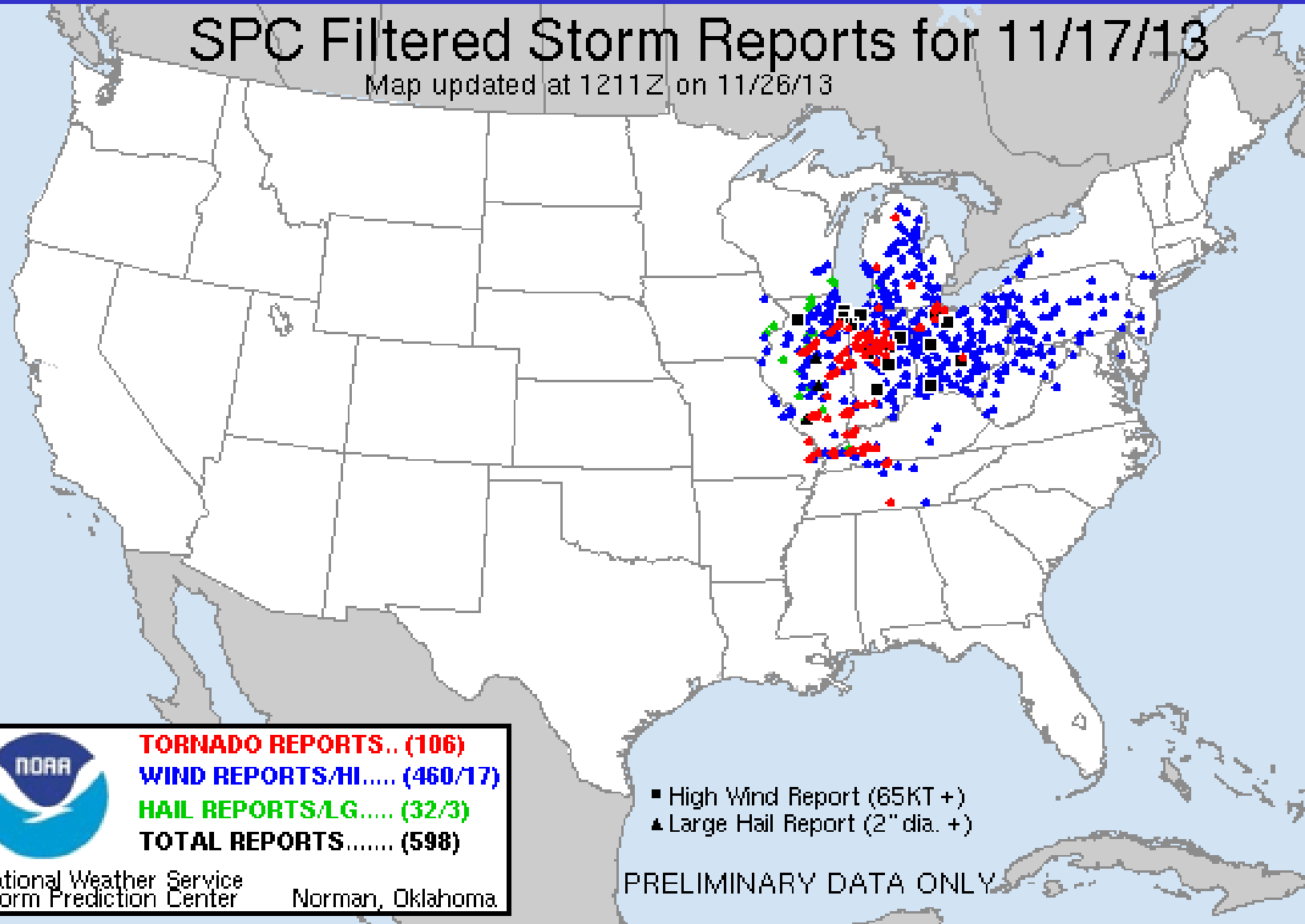# Case 2: 17-18 November 2013 Midwest-Ohio Valley Squall Line

- During the morning of 17 November 2013, an area of thunderstorms organized into a squall line over Illinois ahead of an intense upper-level disturbance and strong cold front.

- The squall line tracked rapidly eastward at an average speed of 40 knots through the lower Great Lakes and Ohio Valley during the afternoon and evening.

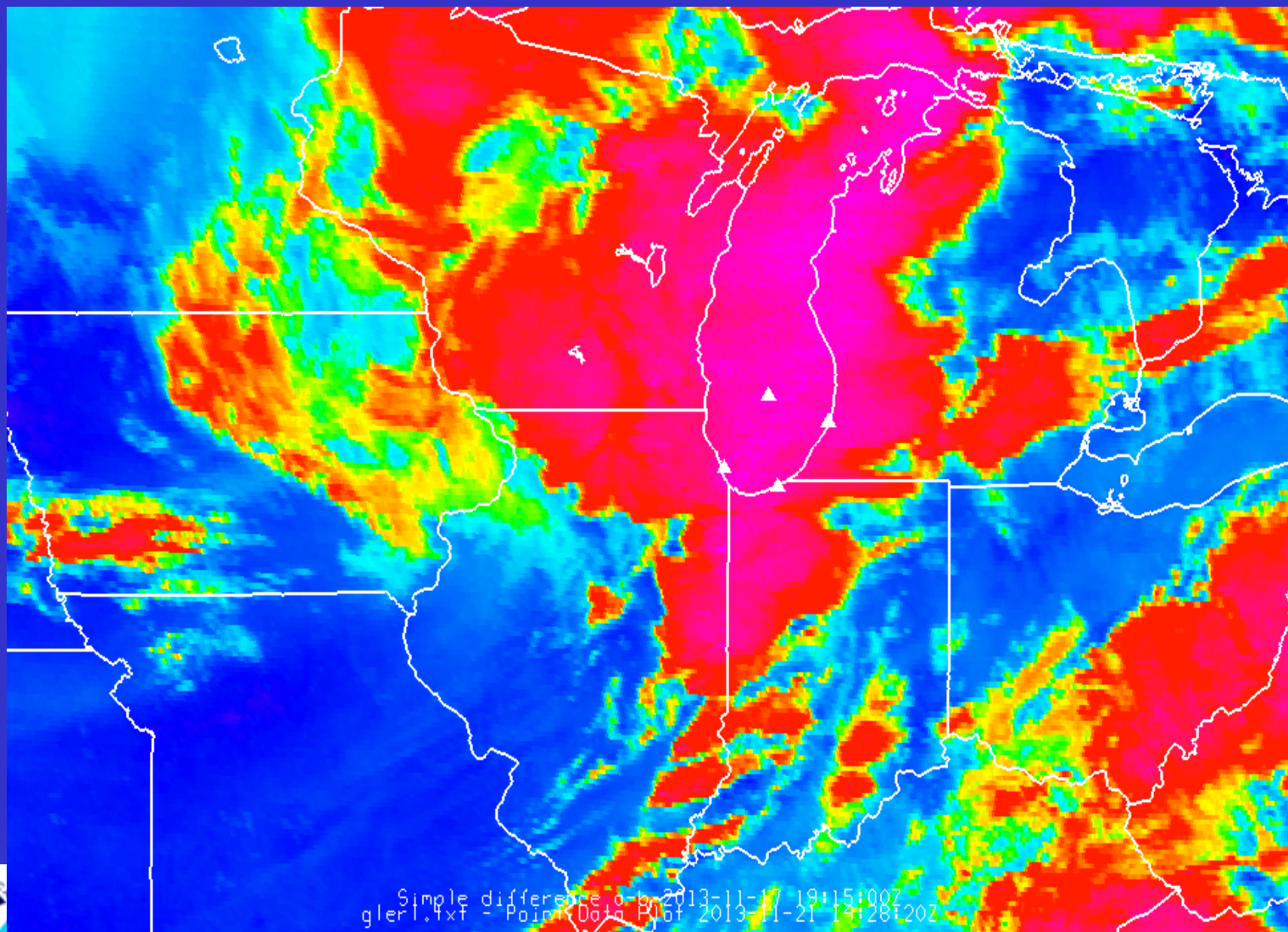- More typical of a cool-season severe MCS.

17-18 November 2013 Squall Line

SPC Filtered Storm Reports for 11/17/13
Map updated at 1211Z on 11/26/13

TORNADO REPORTS.. (106)
WIND REPORTS/HI..... (460/17)
HAIL REPORTS/LG..... (32/3)
TOTAL REPORTS....... (598)

National Weather Service
Storm Prediction Center   Norman, Oklahoma

■ High Wind Report (65KT +)
▲ Large Hail Report (2"dia. +)

PRELIMINARY DATA ONLY

GOES-13 17 November

Simple difference a-b 2013-11-17 19:15:00Z
glerl.1xt - Point Data Plot 2013-11-21 14:28:12Z

BTD (K)

-50

0

L

Squall
line

Simple difference a-b 2013-11-17 19:02:00Z
glerl.txt - Point Data Plot 2013-11-21 14:28:20Z

Imagery
☑ GOES-13 (All Bands) - Image Display

BTD (K)
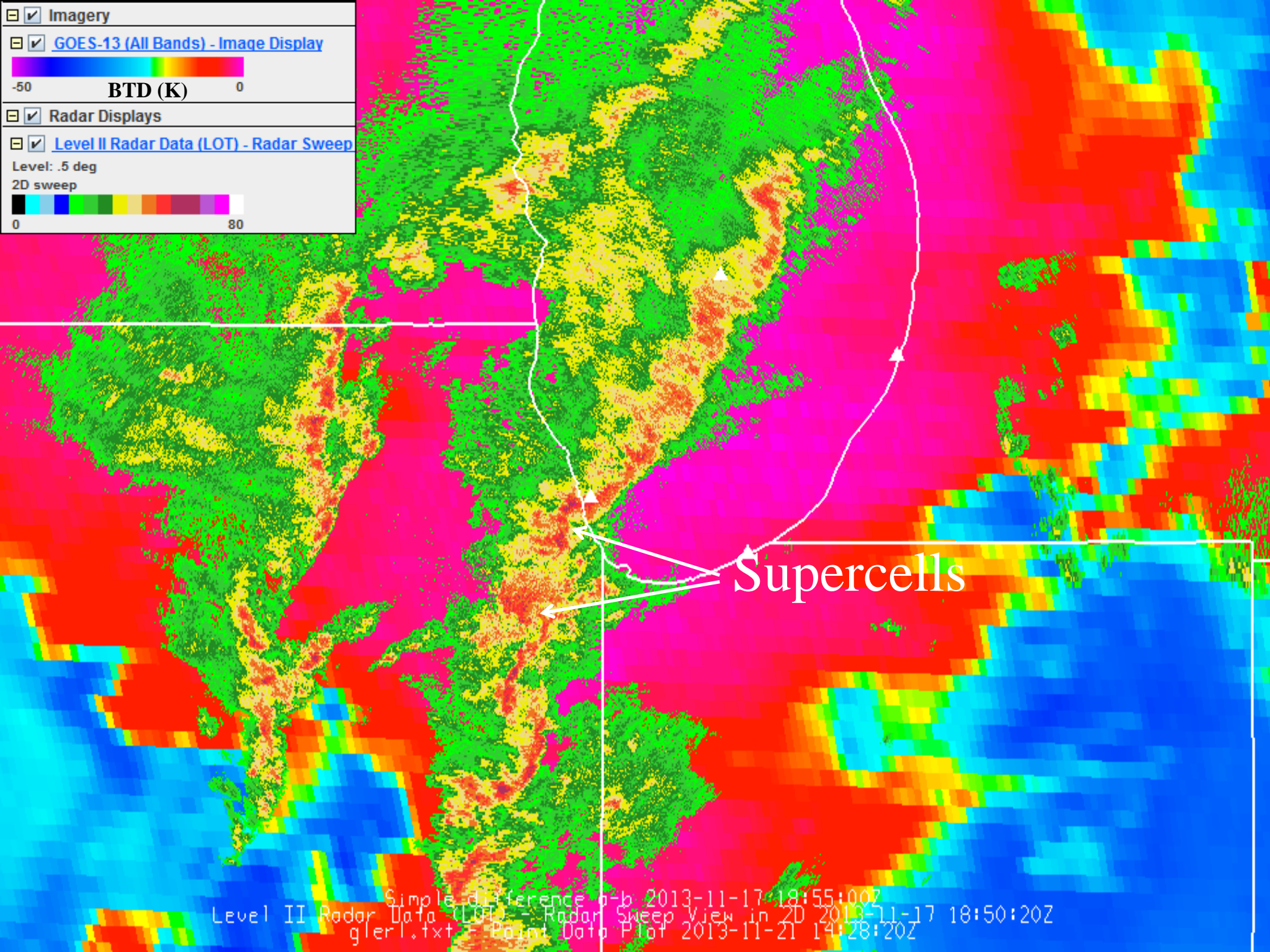-50   0

☑ Radar Displays
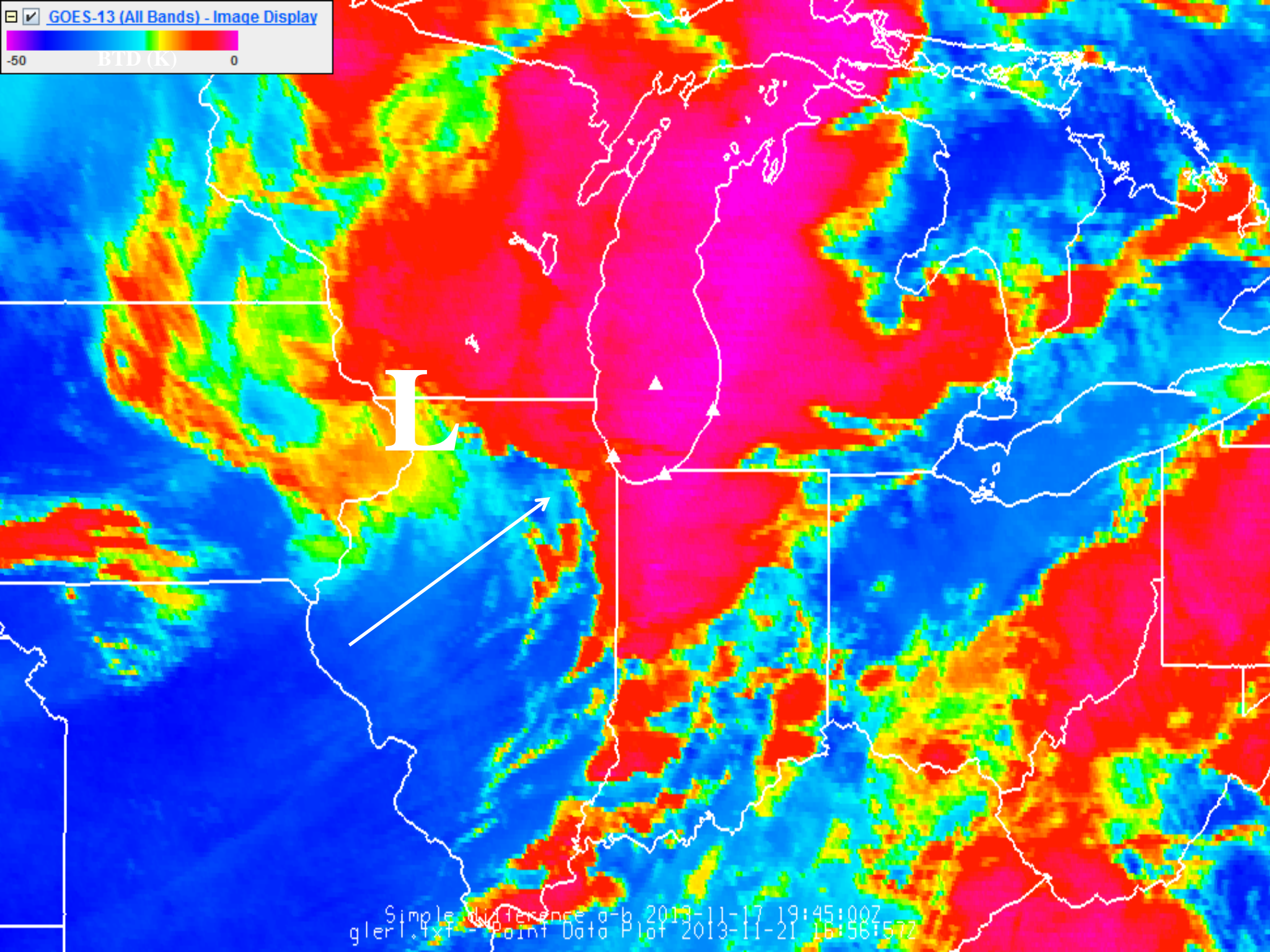☑ Level II Radar Data (LOT) - Radar Sweep
Level: .5 deg
2D sweep

0   80

Supercells

Simple difference a-b 2013-11-17 18:55:00Z
Level II Radar Data (LOT) - Radar Sweep View in 2D 2013-11-17 18:50:20Z
glerl.txt - Point Data Plot 2013-11-21 14:28:20Z

BTD (K)

-50   0

L

Simple difference a-b 2013-11-17 19:45:00Z
glerl.txt - Point Data Plot 2013-11-21 16:56:157Z
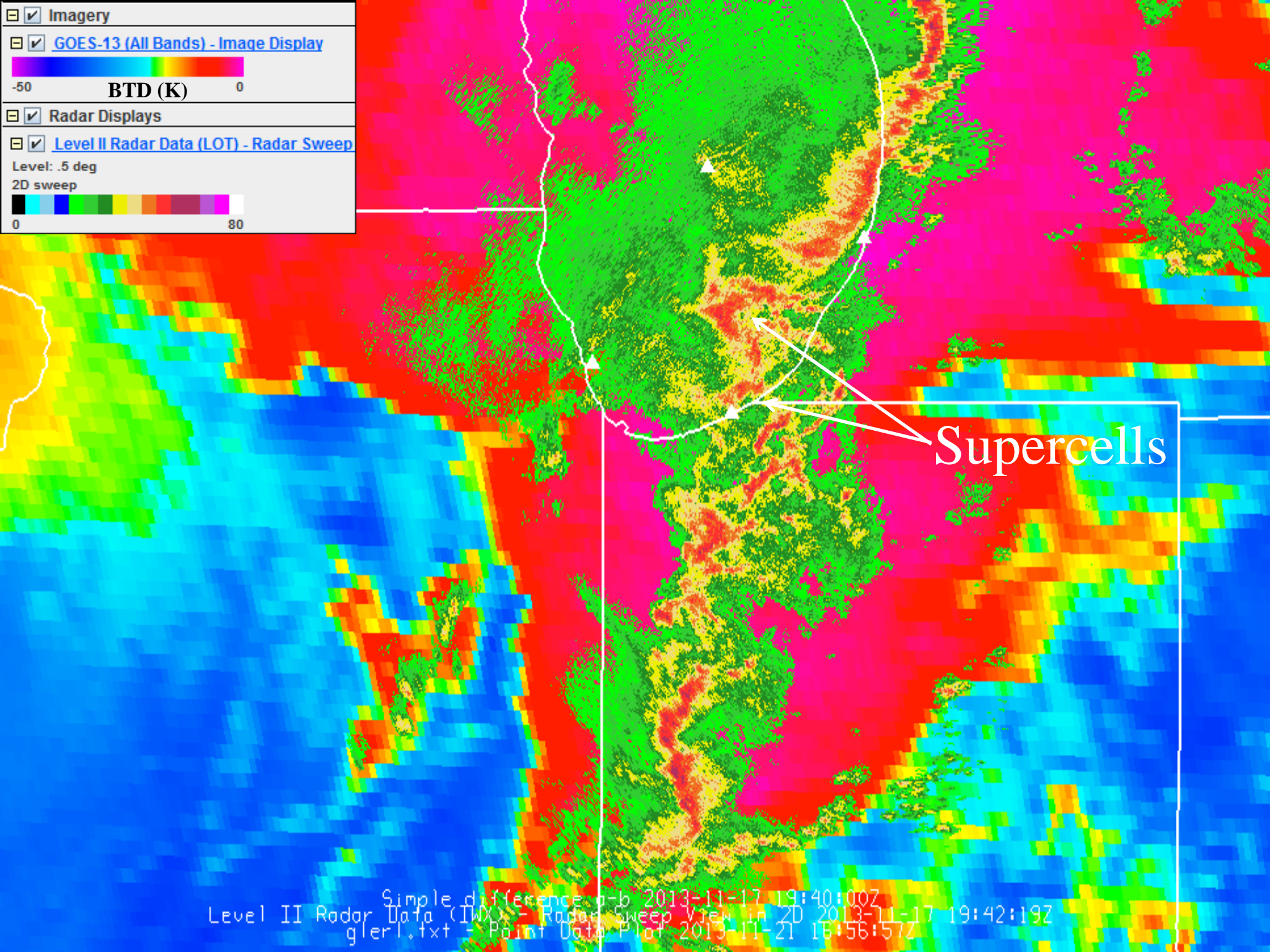
Supercells

Simple difference a-b 2013-11-17 19:40:00Z
Level II Radar Data (IWX) - Radar Sweep View in 2D 2013-11-17 19:42:19Z
glerl.txt - Point Data Plot 2013-11-21 16:56:57Z

Mature Phase: VV Difference

Mature Phase: VV Difference

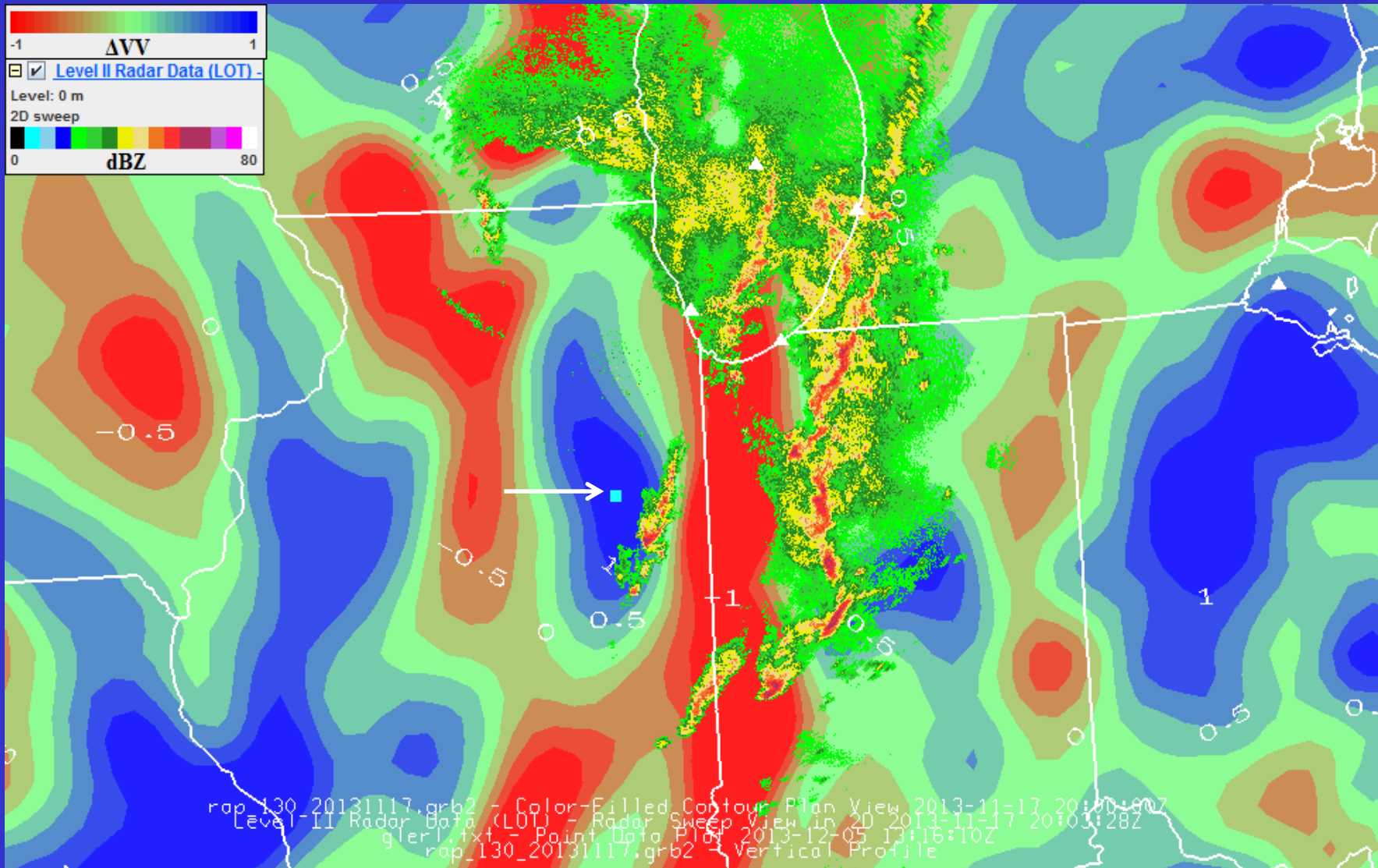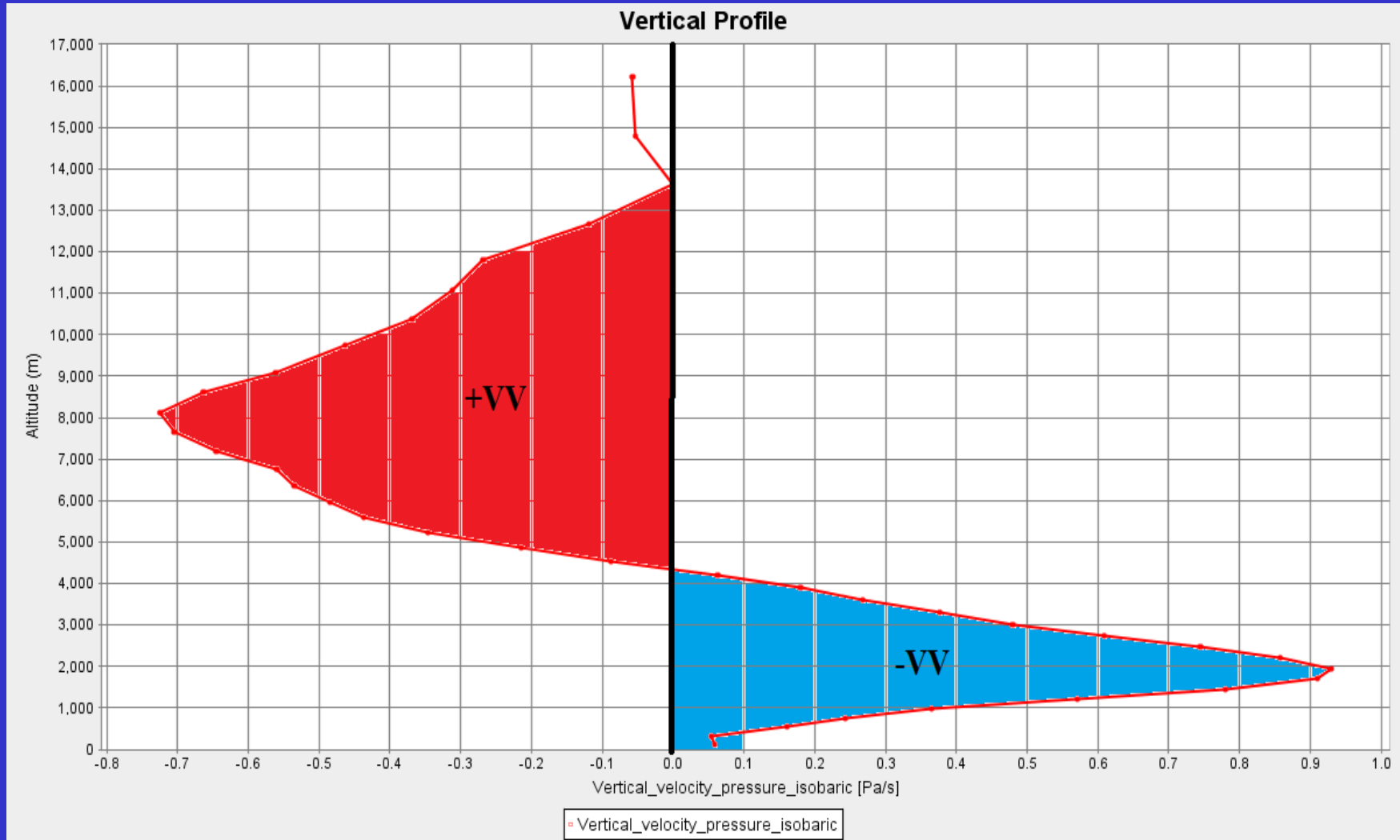# Mature Phase: Theta-e Advection
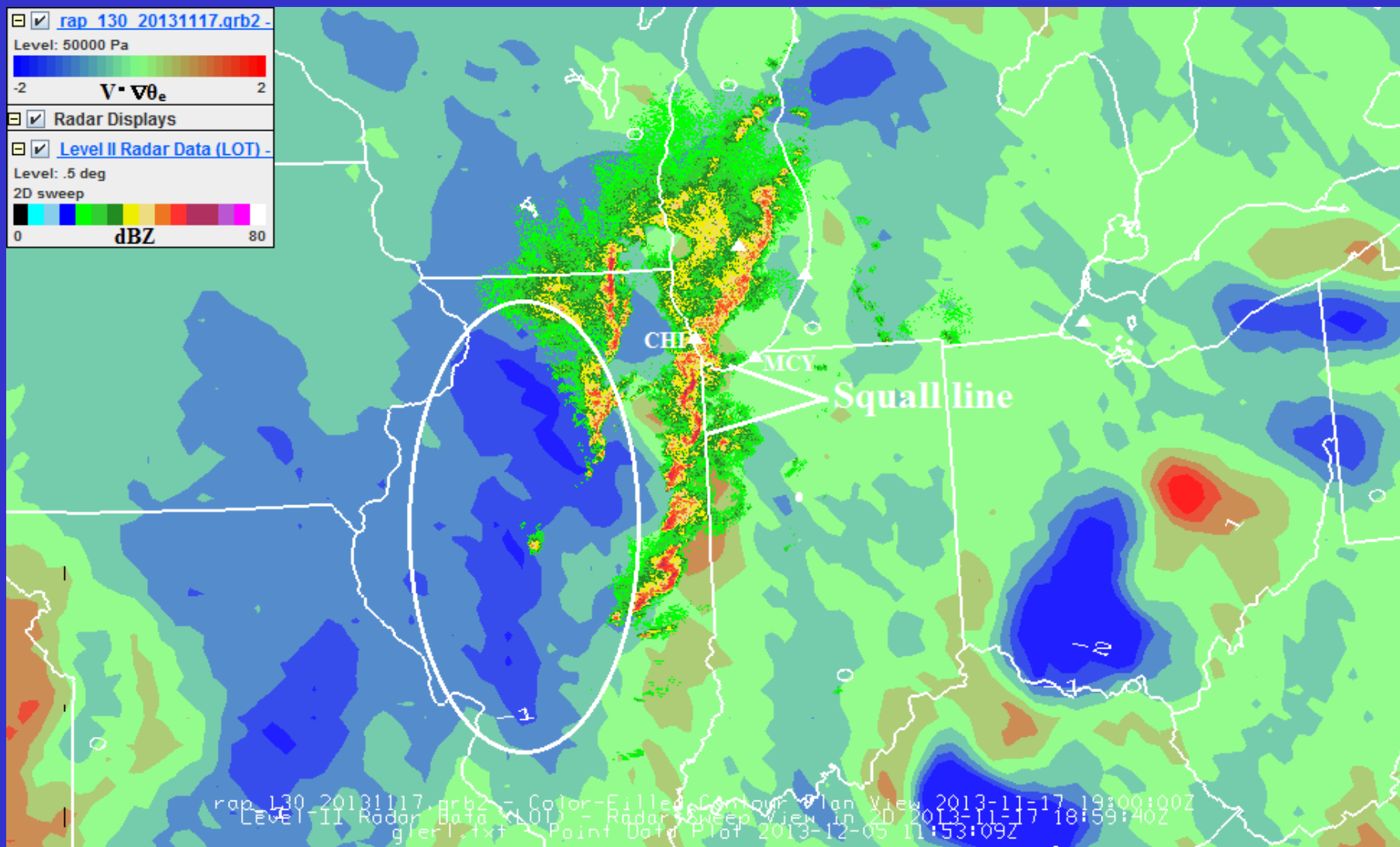
Mature Phase: Theta-e Advection
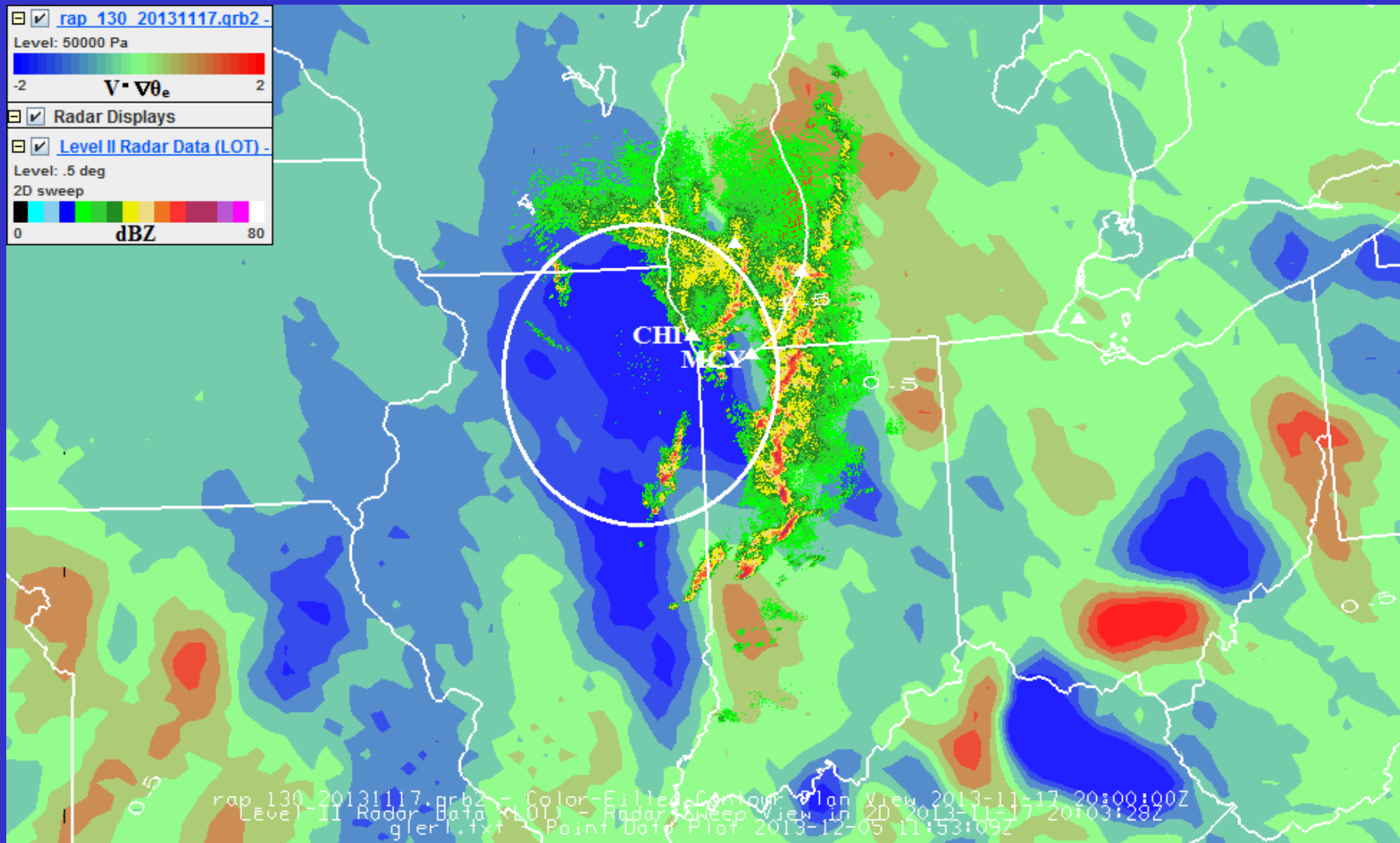
Discussion

- For both cases, SCW occurrence was associated with the development of a distinct upper tropospheric upward/lower tropospheric downward vertical velocity couplets to the rear of leading convective storm lines of the mature MCSs.

- Regions of significant mid-tropospheric negative theta-e advection on the rear flanks of MCSs signified the presence of a strong RIJ and channeling of mid-tropospheric dry (low theta-e) air into the stratiform precipitation region and leading convective storm line.

Discussion

- Ascending front-rear flow overlying strong, deep cold pools rearward of the leading convective storm lines:

    - induces the development of horizontal vorticity cells on the storm's rear flank that channel drier mid-tropopheric air forward toward leading edge of the MCS.

    - results in the development of an elevated RIJ that interacts with the leading line storms of the MCS to produce widespread downburst activity.

- Highest wind gusts were associated either with embedded supercell storms, or the apex of bow echoes where rear inflow was strongest.

Future Work

- Further observational data analysis in which temporal and spatial patterns, both horizontal and vertical, of NWP model-simulated VV and theta-e advection fields will be compared to patterns of satellite and radar observed severe wind-producing convective storm systems.

- Historical simulation of 30-km resolution Climate Weather Research and Forecasting (CWRF) model (Liang et al. 2012) data in comparison with 32-km North American Regional Reanalysis (NARR) and 13-km Rapid Refresh (RAP) model data will be conducted to infer any signals of SCW occurrence.

Future Work

- A relationship between VV and theta-e advection magnitudes and SCW occurrence can be applied to high-resolution geostationary satellite imager and sounder profile data, as well as to the CWRF model for the purpose of long range prediction. This step can be accomplished as a weather-scale run for each selected SCW case, where numerical instability occurrence in the CWRF model could serve as an additional signal.

Conclusions

- The lower-upper tropospheric vertical velocity difference and mid-tropospheric theta-e advection have been found to effectively indicate the favorability of an MCS to evolve into a SCW.

- The combined use of ΔVV and $\mathbf{V} \cdot \nabla\theta_e$ parameters, and GOES WV-IR BTD imagery shows potential as a short term SCW prediction technique, while incorporation into the CWRF model should improve long-range prediction of SCW development.

References

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References

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- Przybylinski, R.W., 1995: The bow echo. Observations, numerical simulations, and severe weather detection methods. *Wea. Forecasting*, **10**, 203-218.

- Smull, B. F., and R. A. Houze, Jr., 1987: Rear inflow in squall lines with trailing stratiform precipitation. Mon. Wea. Rev., 115, 2869-2889.

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