A Downburst Study of the 29-30 June 2013 North American Derecho

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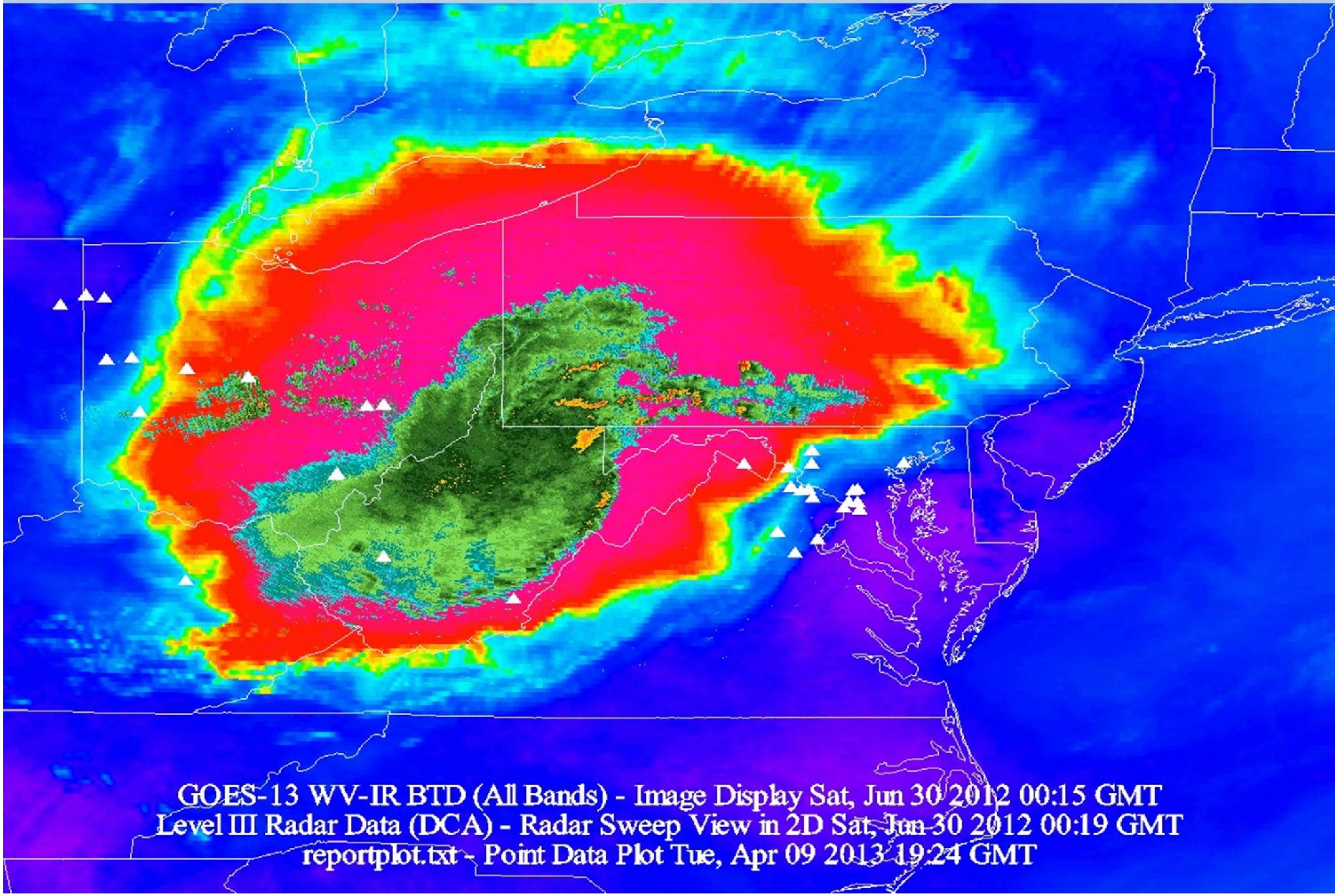
Derecho Overview



Purpose of this Study

- To identify and document severe downburst events from the time of derecho initiation over northern Indiana to the time that the derecho-producing convective system (DCS) moved off the Atlantic coast.
- Apply GOES-13 Rapid Scan Operations (RSO) water vapor (WV) - thermal infrared (IR) channel brightness temperature differencing (BTD) imagery, level-II NEXRAD imagery, and Rapid Refresh (RAP) model-derived microburst prediction algorithm output, including the Microburst Windspeed Potential Index (MWPI), to demonstrate the development and evolution of severe DCS-generated winds.

Significance

- Expansive
- Affected millions of people
- Broke many records for highest winds
- Left five million without power
- Traveled 700 miles in 12 hours

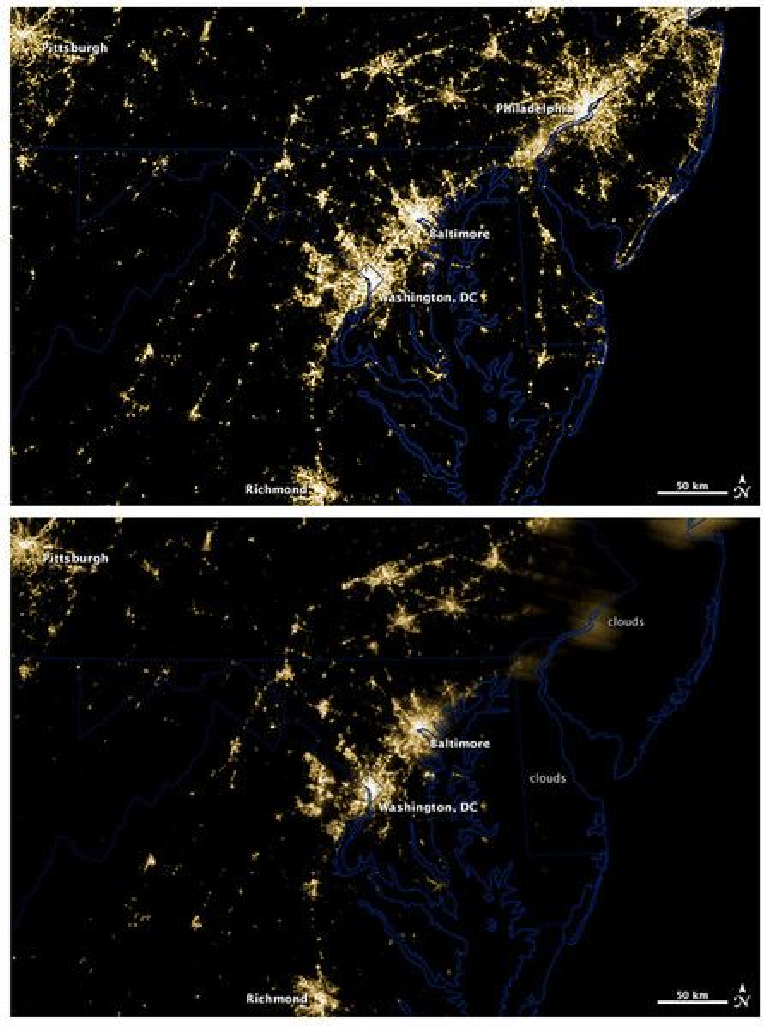


Photo: NASA

Definition of a Derecho

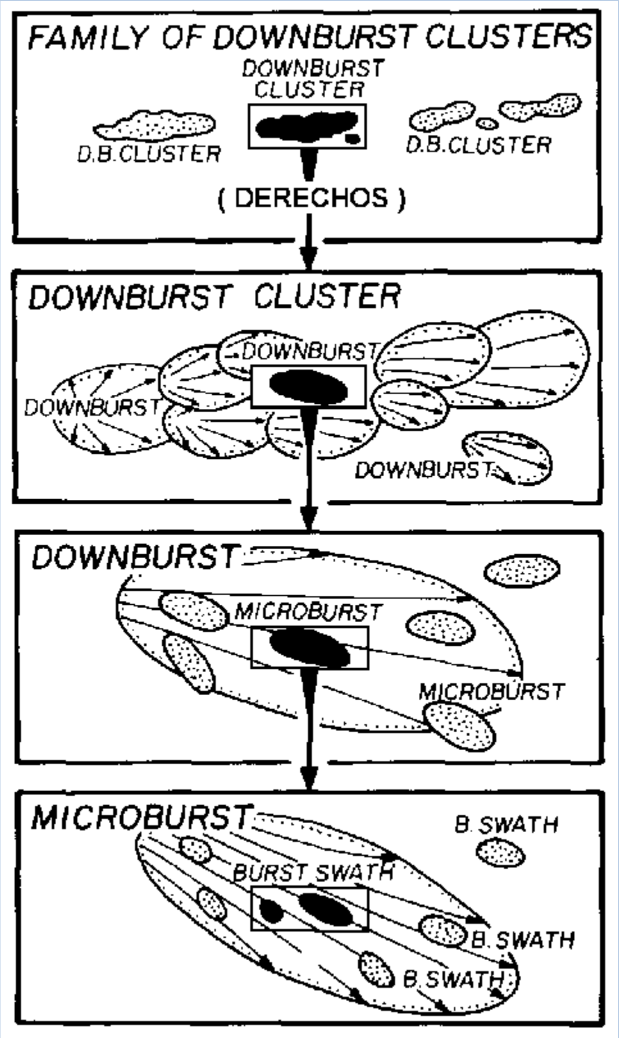
- Widespread, long-lived wind storm that is associated with a band of rapidly moving showers or thunderstorms (Storm Prediction Center, “About Derechos”)
- Criteria:
  – Travels continuously (or nearly continuously) for more than 240 miles
  – Winds gust exceeding 58 mph along most points on the path

Definition of a downburst

- Concentrated areas of strong winds produced by convective downdraft
- Process of formation:
  - Air is cooled by evaporation, melting, or sublimation of precipitation in clouds
  - Chilled air is denser that surroundings and accelerates downward
  - Hit surface and spreads out in all directions

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)

Downbursts and Derechos

- Any family of downburst clusters produced by an extratropical mesoscale convective weather system (Johns and Hirt 1987)
- Derechos occur when atmospheric conditions support the continuous generation of downbursts in the same area

Definition of a progressive derecho

- Squall line
- One to multiple bow echoes
- Typically result of stationary front in a stagnant synoptic weather pattern
- Derecho motion dependent on thunderstorm propagation
  - Development of new storms from existing ones
- Often associated with heat waves

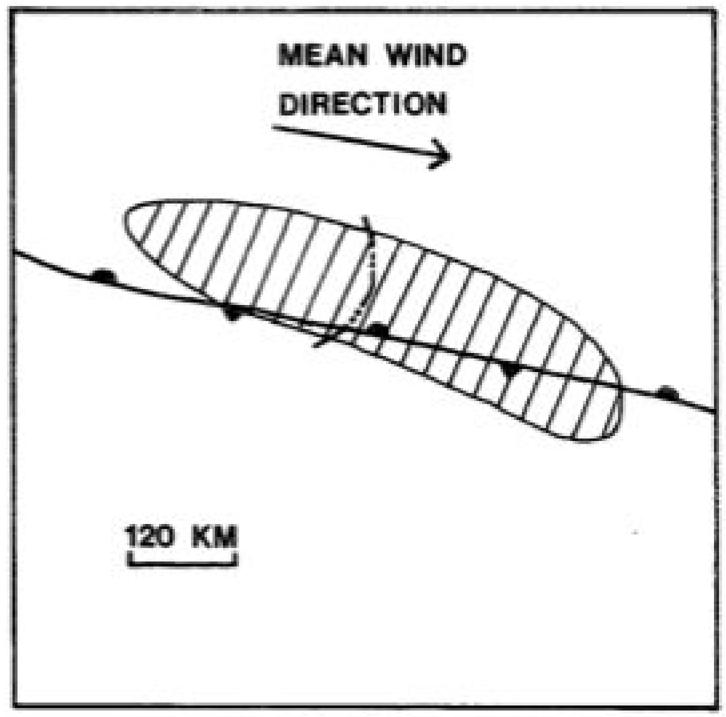


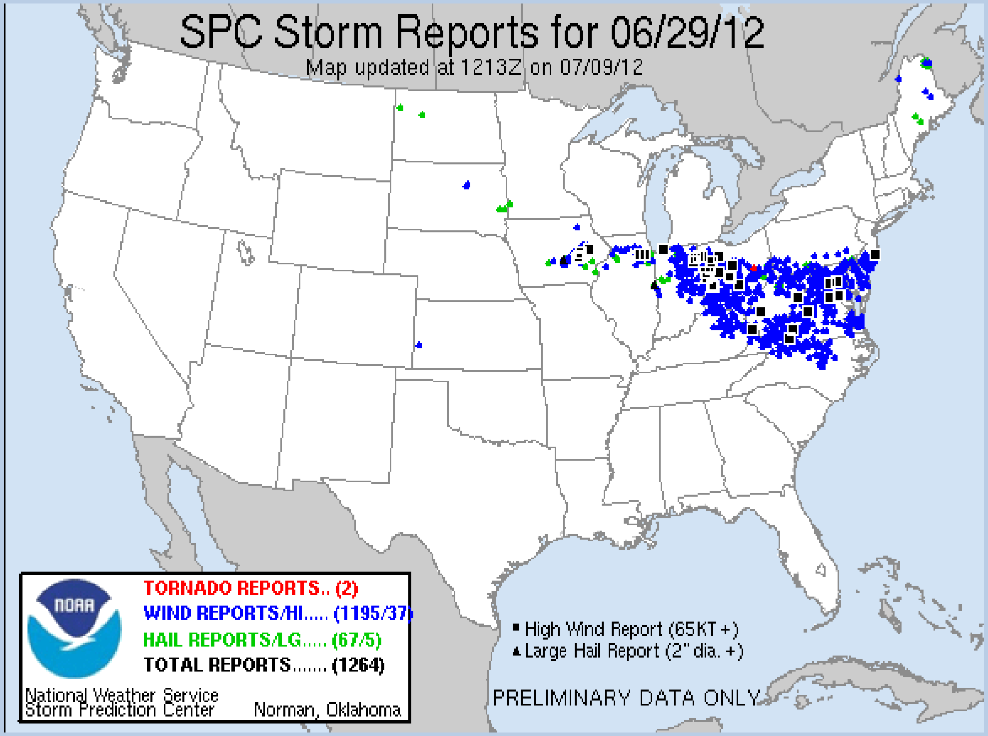
FIG. 3. Schematic representation of features associated with a progressive derecho near midpoint of lifetime. Total area affected by derecho during lifetime indicated by hatching. Frontal and squall line symbols are conventional.

From Johns and Hirt (1987)

METHODOLOGY

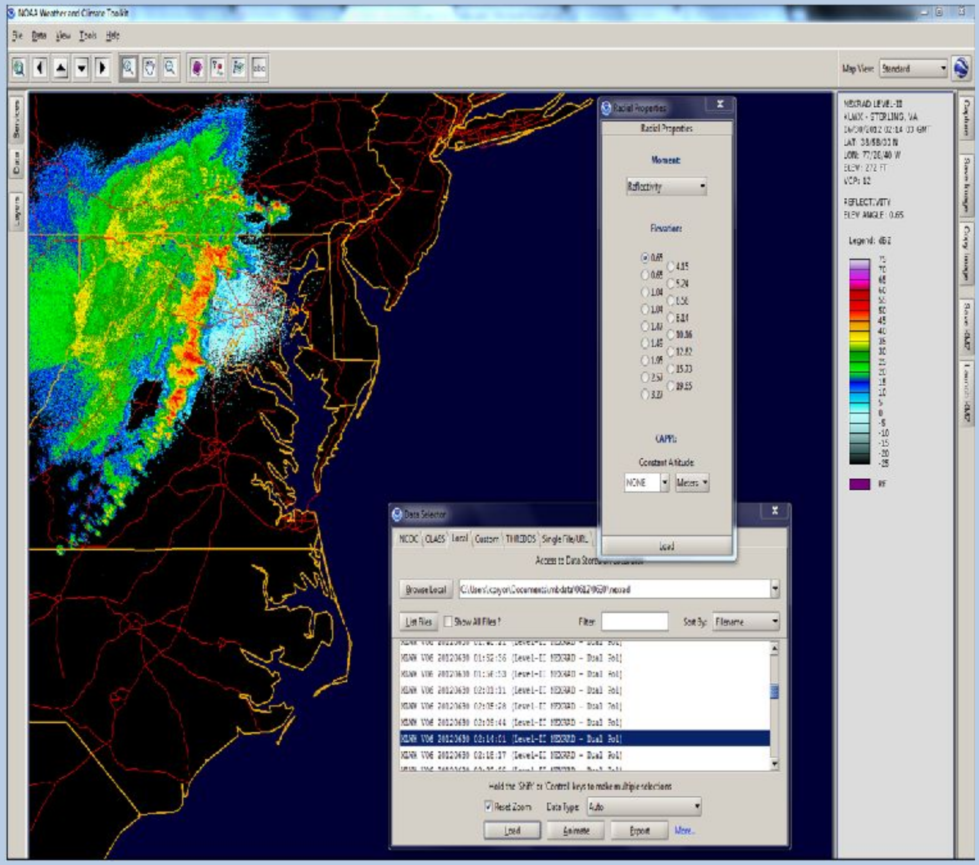
Wind Reports

- Wind reports taken from the National Weather Service
- 107 – Recorded wind speeds
- 33 – Determined to be downbursts



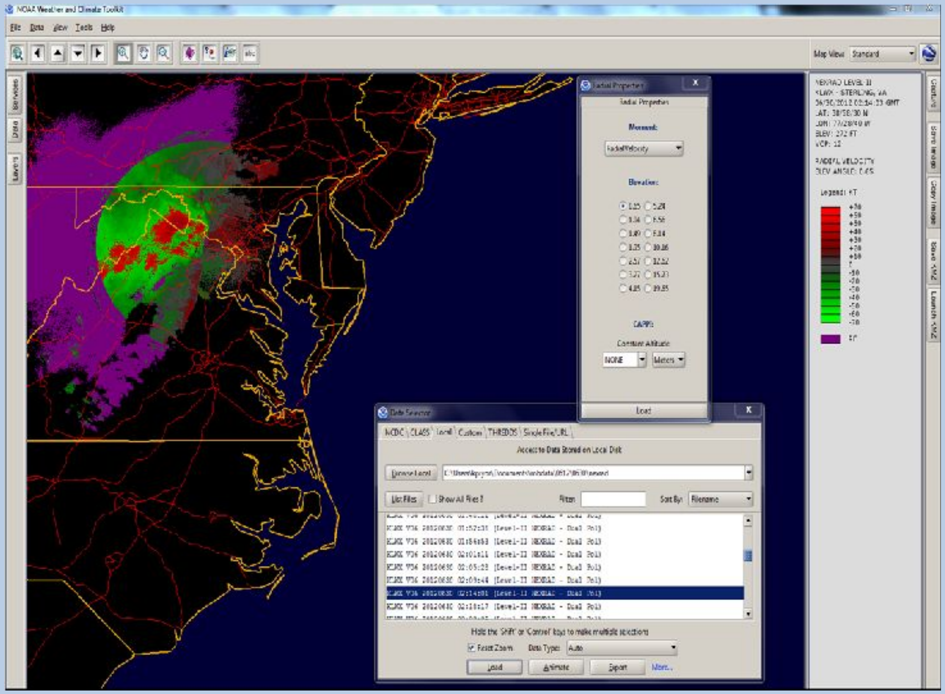
Creating Images

- Used NOAA Weather and Climate Toolkit
- Plotted latitude and longitude
- Decided gust front or downburst
- On leading edge of storm ➔ gust front
- In areas of high reflectivity ➔ downburst



Radial Velocity

- Measurement of phase (frequency) shifts due to moving particles to compute air velocity
- Folds over after certain value:
  - Maximum unambiguous velocity and range



Density of Wind Reports

- Increase in density in the Baltimore-Washington metro area
- Partially due to increase in population
- Also, because the conditions in the area were very favorable for downburst generation
  - As seen from MWPI, $\Delta\theta_e$
  - Dry air, EML
  - Instability

Microburst Potential Parameters

- Microburst Windspeed Potential Index (Pryor 2011):
- MWPI ≡ $\{(CAPE/100)\}+\{\Gamma + (T-Td)_{850}-(T-Td)_{670}\}$

  Updraft Downdraft

Reflects both updraft and downdraft instability

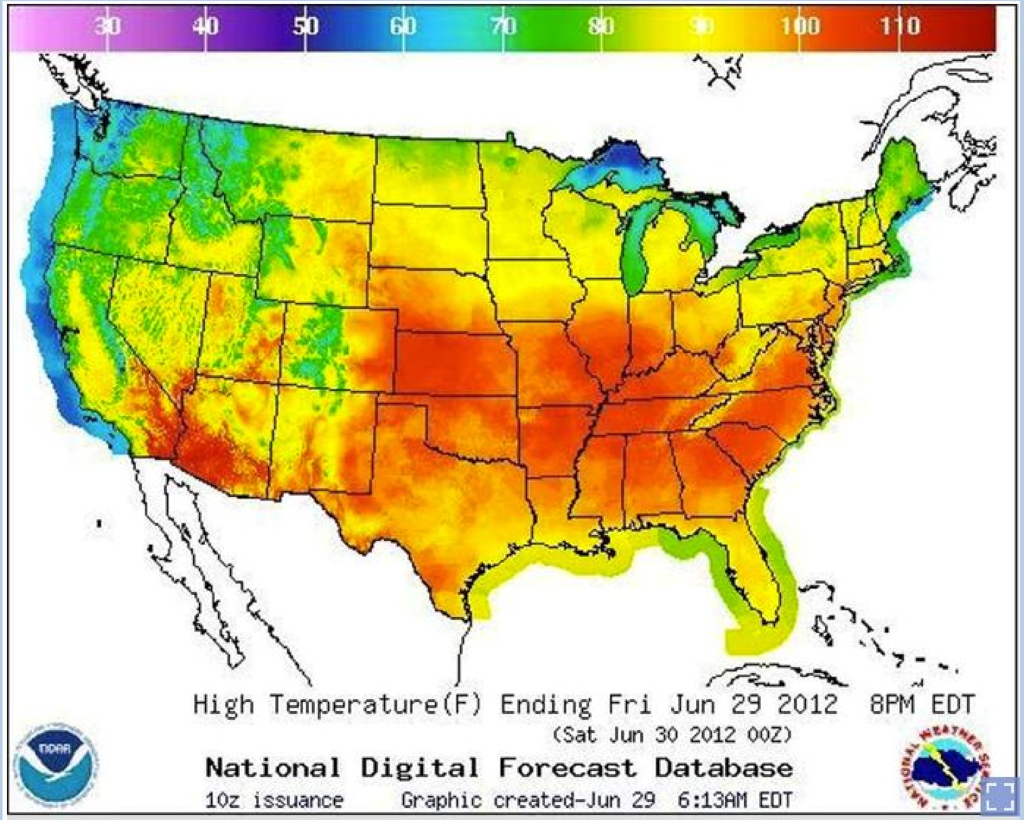
•Vertical equivalent potential temperature difference ($\Delta\theta_e$) (Atkins and Wakimoto 1991):

- $\Delta\theta_e = \theta_{e\ max}$ (near surface) - $\theta_{e\ min}$ (mid-troposphere)
- Infers presence of mid-tropospheric dry air layer

PREEXISTING ATMOSPHERIC CONDITIONS

Heat wave over the south

- Stationary high-pressure area over the southern states
- Prolonged heat wave over southern Plains, Ohio Valley, and Southeast states for days prior to June 29th
- Several locations, including Charlotte, Nashville, Raleigh, and Washington, D.C. set or tied all-time June records.

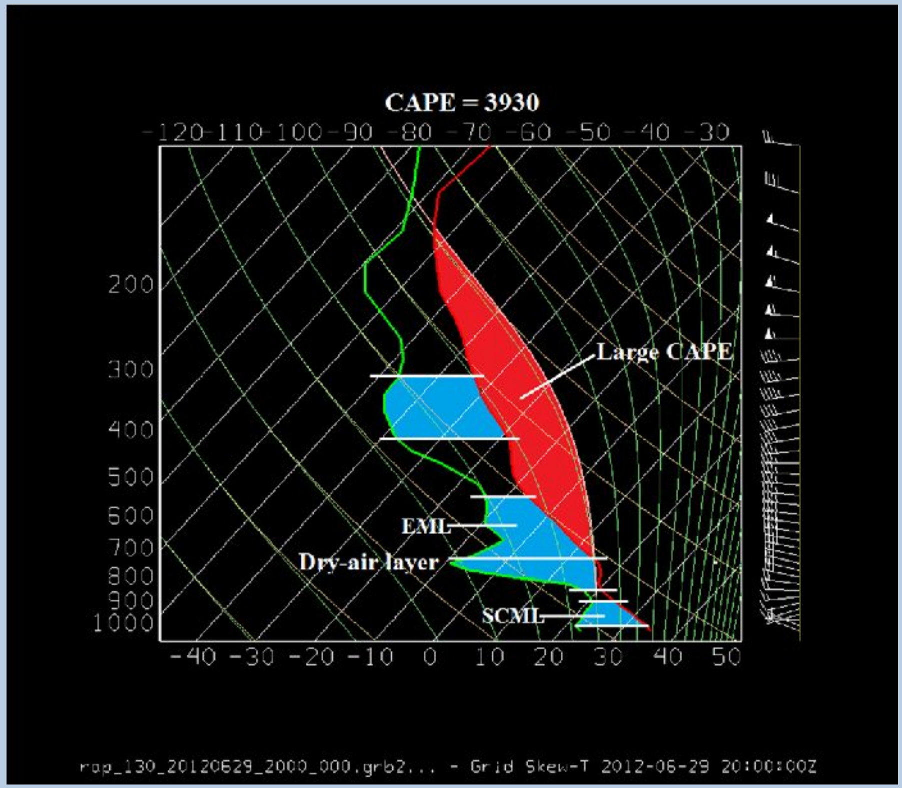


Definition of the Elevated Mixed Layer (EML)

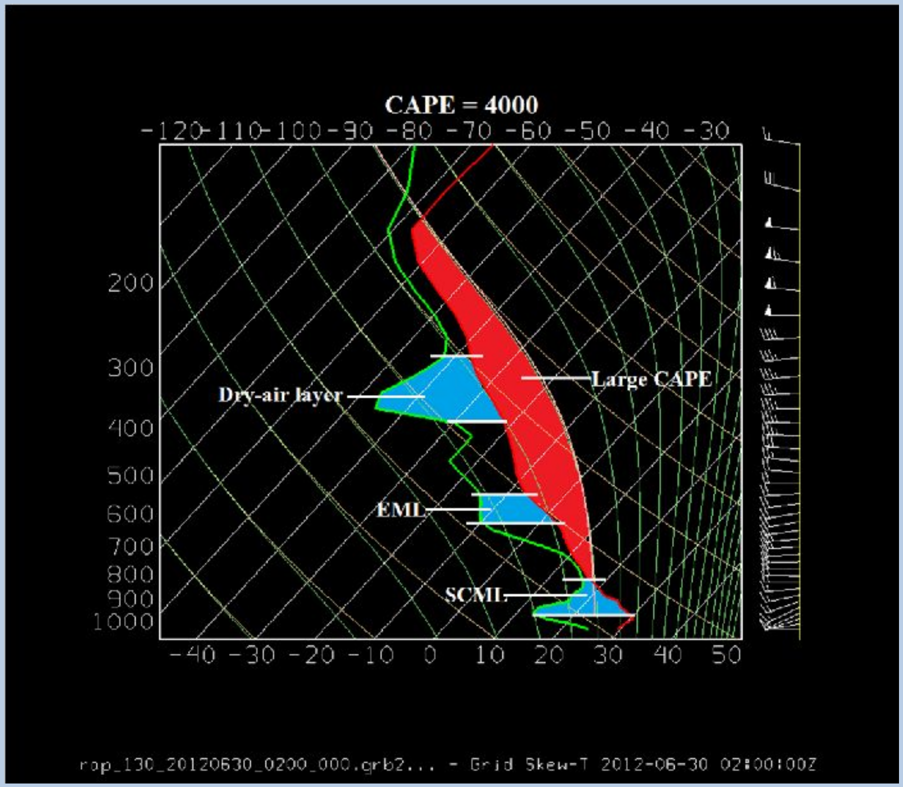
- Layer of air in the mid-troposphere that originates over arid, elevated terrain
- Very steep lapse rates
- Encourage the formation of strong updrafts
- Responsible for the intensity of storms over the Great Plains
- Acts as a cap on thunderstorm development

RAP Model Sounding Profiles

Dayton, Ohio
2000 UTC 29 June



Reston, Virginia
0200 UTC 30 June



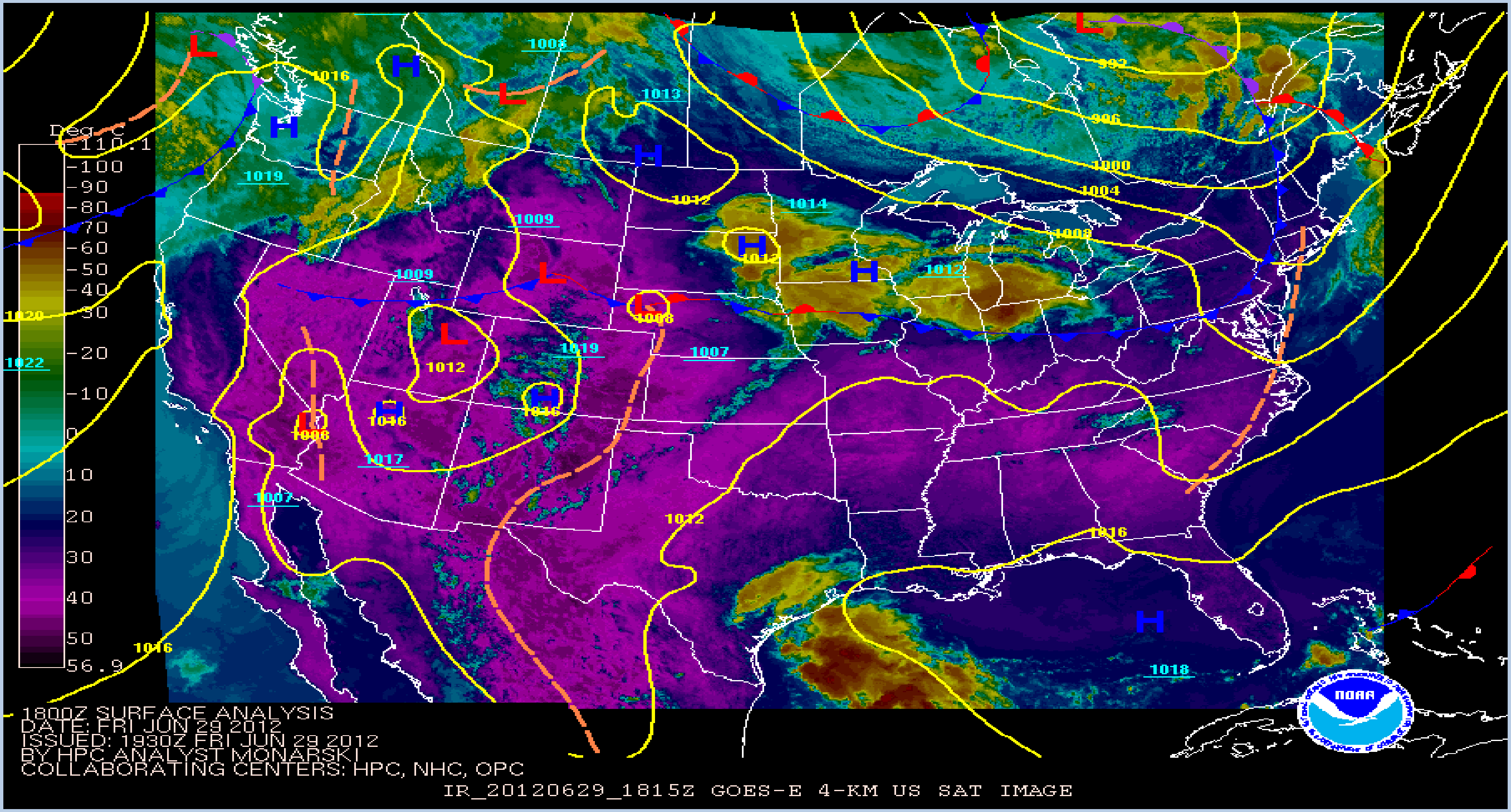
RAP model sounding profiles echo the favorable environment for severe downbursts with very large convective available potential energy (CAPE) and a prominent EML between the 500 and 700-mb levels.

June 29th EML

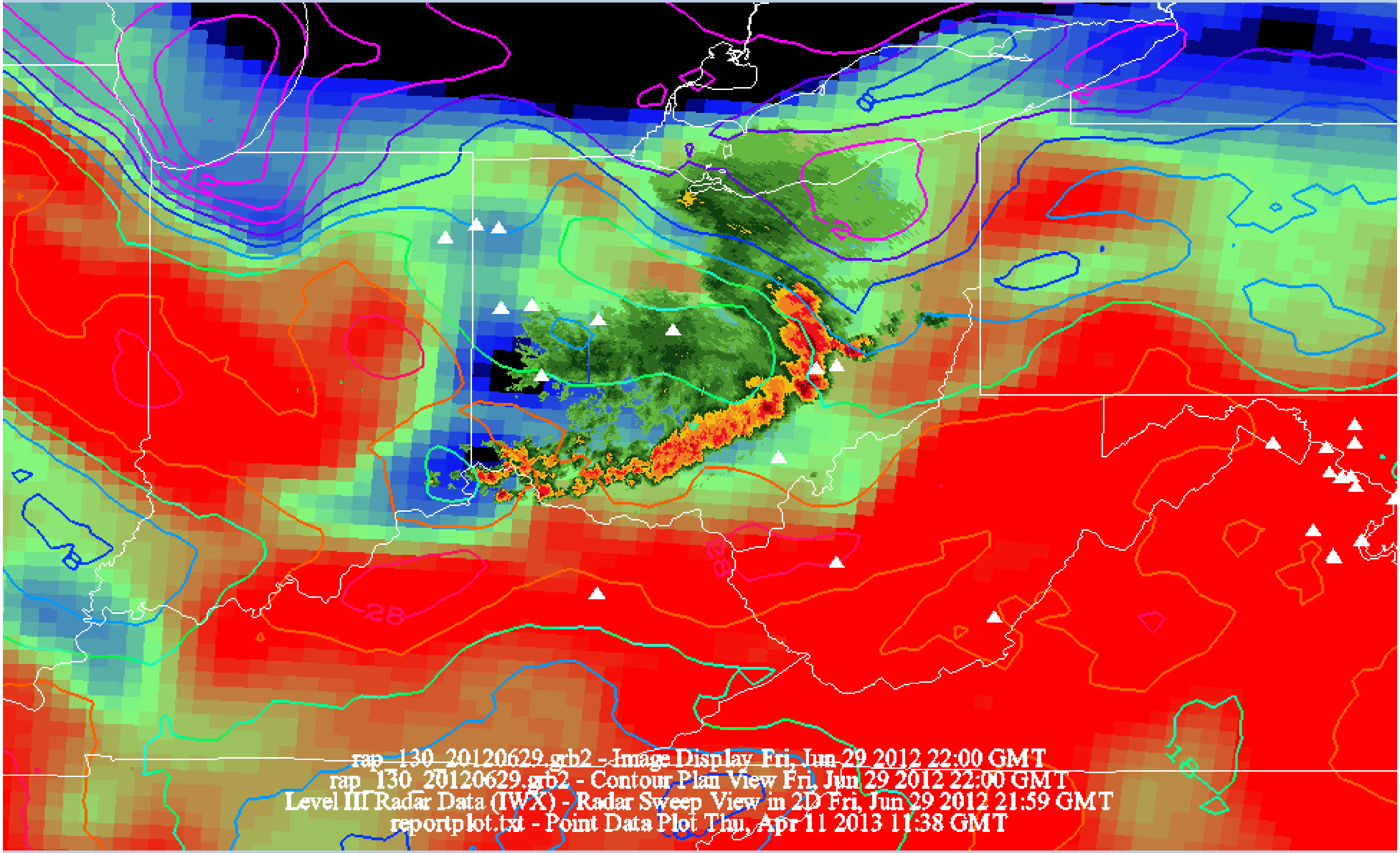
- Unusually expansive
- Extended from Rockies and northern Plains to mid Atlantic coast
- Normally does not extend farther eastward than the Appalachians

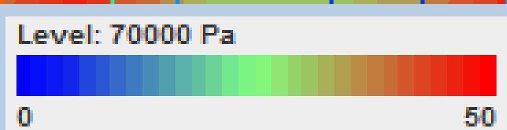
Reason for expansiveness

- Result of a persistent deep westerly flow on the north side of a stationary high-pressure area located over the southern states.



RAP Model MWPI-$\Delta\theta_e$-NEXRAD Composite



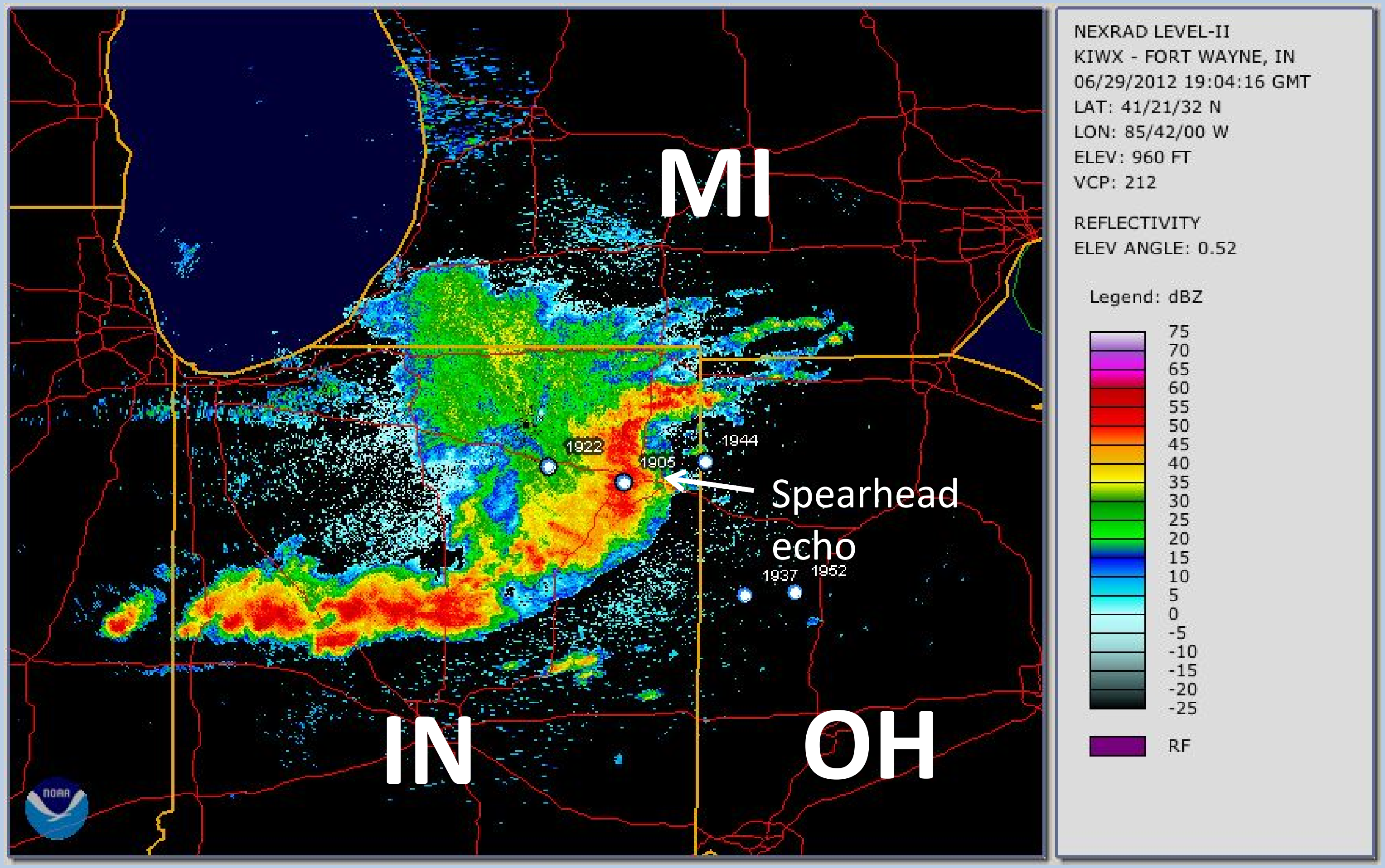


$$MWPI \equiv \{(CAPE/100)\}+\{\Gamma + (T-Td)_{700}-(T-Td)_{550}\}$$

Morning and Early Afternoon
Iowa, Illinois, and Indiana

- Storms begin over Iowa and Illinois
  - Scattered instances of severe hail and winds
- Move into northern Indiana
  - Convective system strengthens
  - Thunderstorms begin to bow downstream towards Fort Wayne

19:04 GMT Over Northern Indiana



Morning and Early Afternoon (*cont.*)
Iowa, Illinois, and Indiana

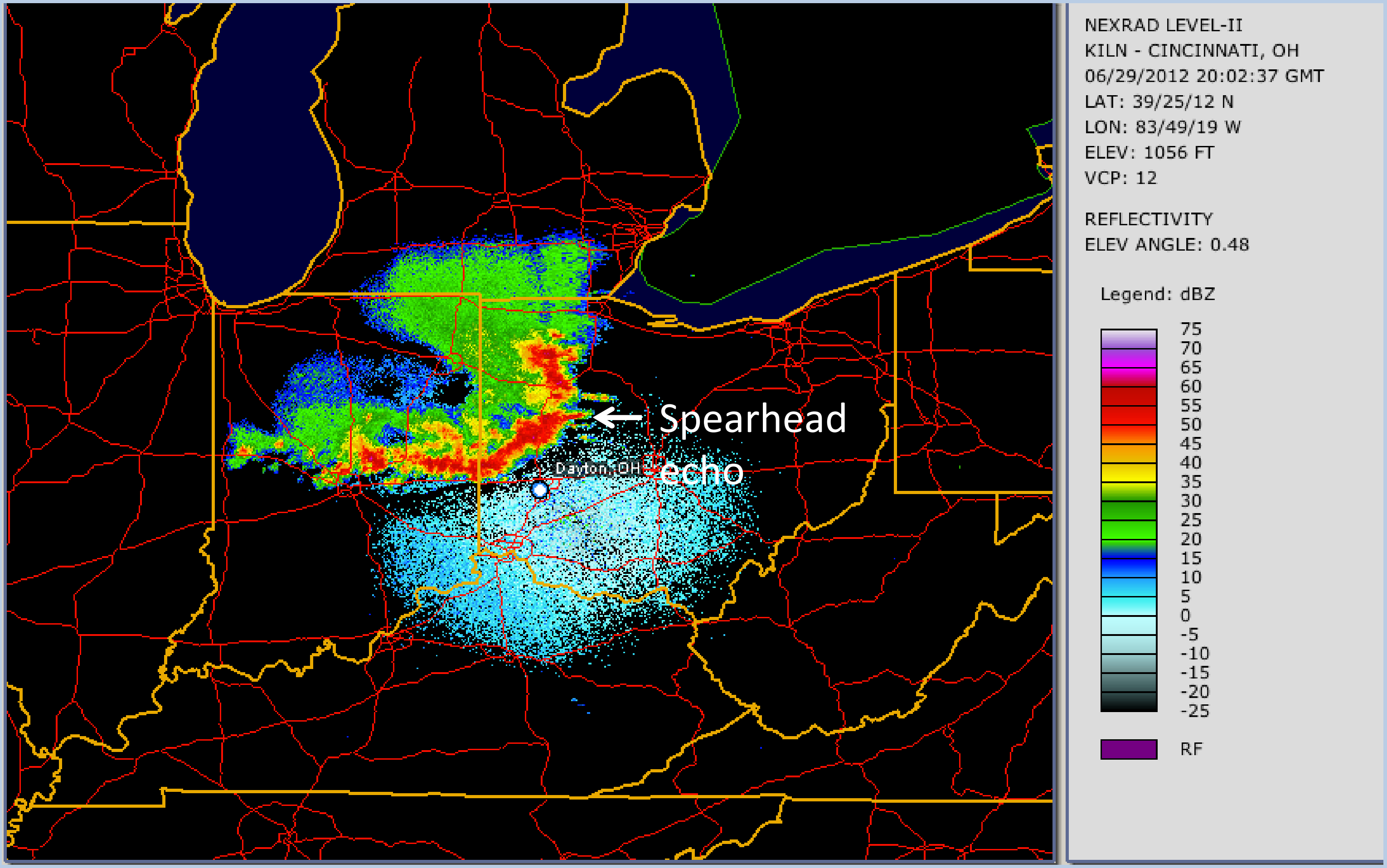
- Meanwhile, new storms develop south across central Indiana
- Surface heating allows EML cap to be breached
- Vigorous storm updrafts
  - Result of hot, humid surface air with steep lapse rates

Late Afternoon and Early Evening

Ohio, Kentucky, West Virginia

- Squall line accelerates east-southeast across central and southern Ohio
- Becomes strongest and most organized
- Reaches northern Kentucky and western West Virginia by 19:00 EDT

20:02 GMT
Above Dayton, OH



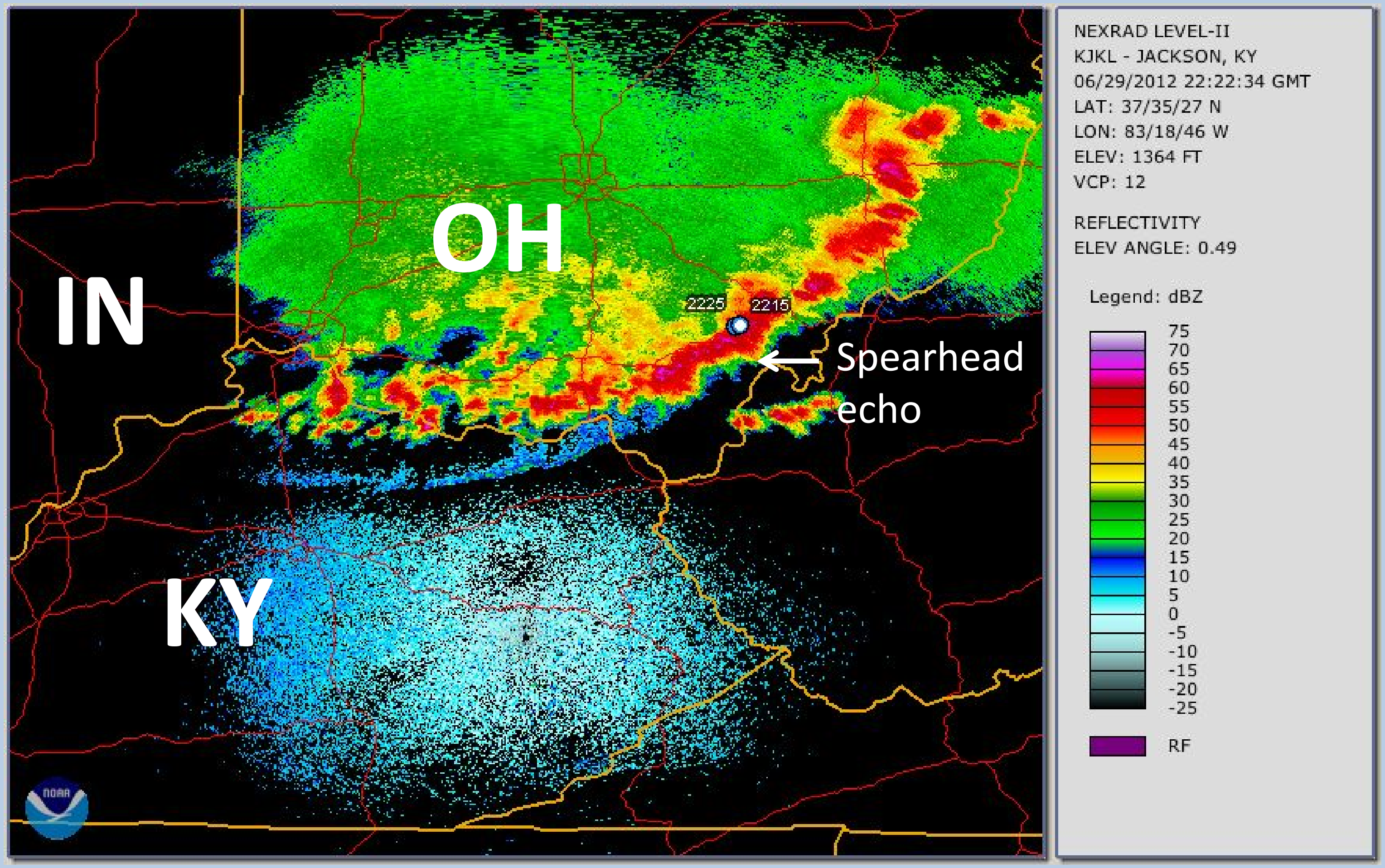
Location of some of the highest wind gusts

Late Afternoon and Early Evening (*cont.*)

Ohio, Kentucky, West Virginia

- Bow moving at an average speed of 65 mph
- Bow's shape shows how it absorbed thunderstorms that formed ahead of it
- Fast eastward propagation favored to the north of the front
- Slower south or southeastward motion favored to the south

22:22 GMT Over Southern Ohio (18:22 EDT)

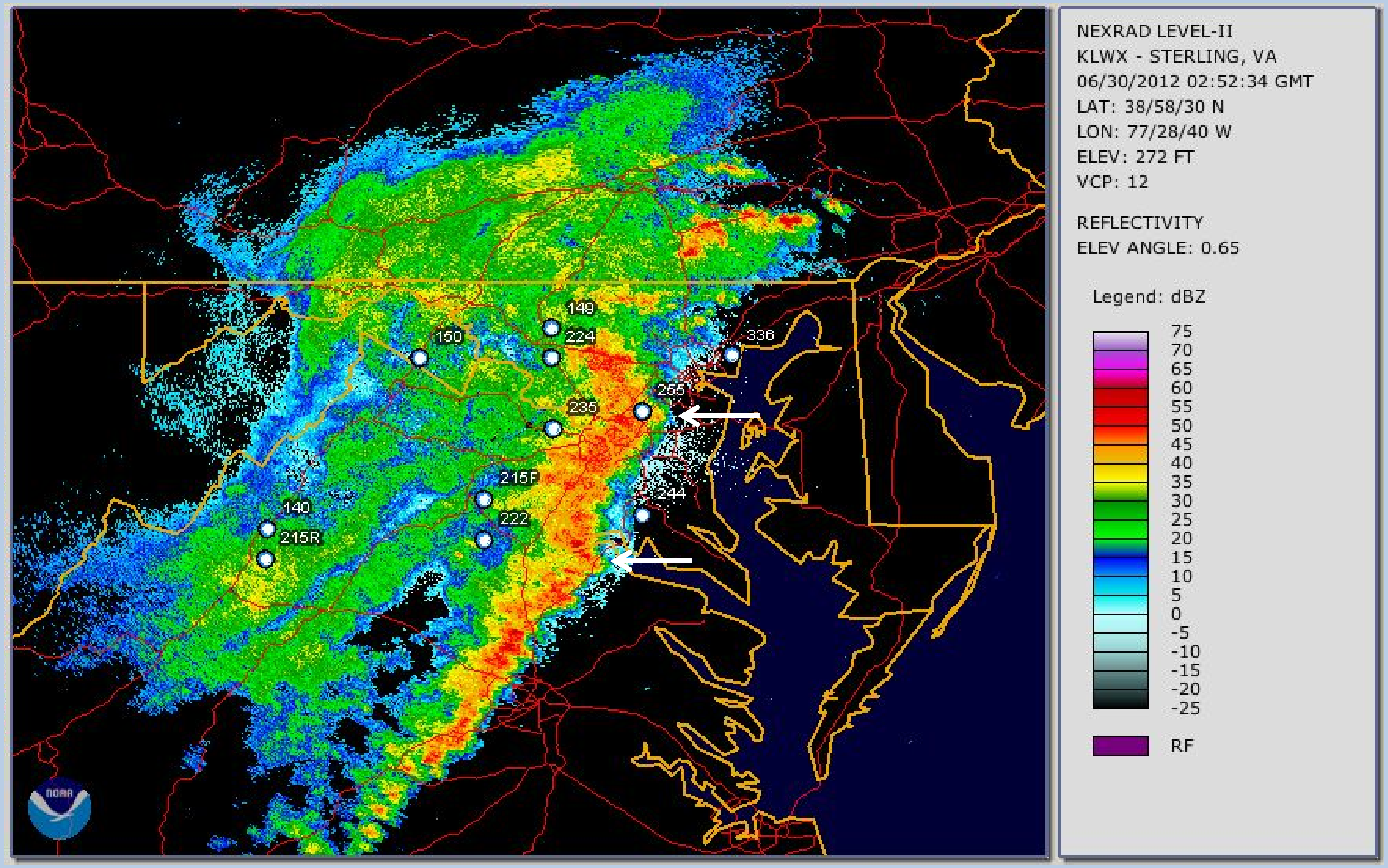


Late Evening

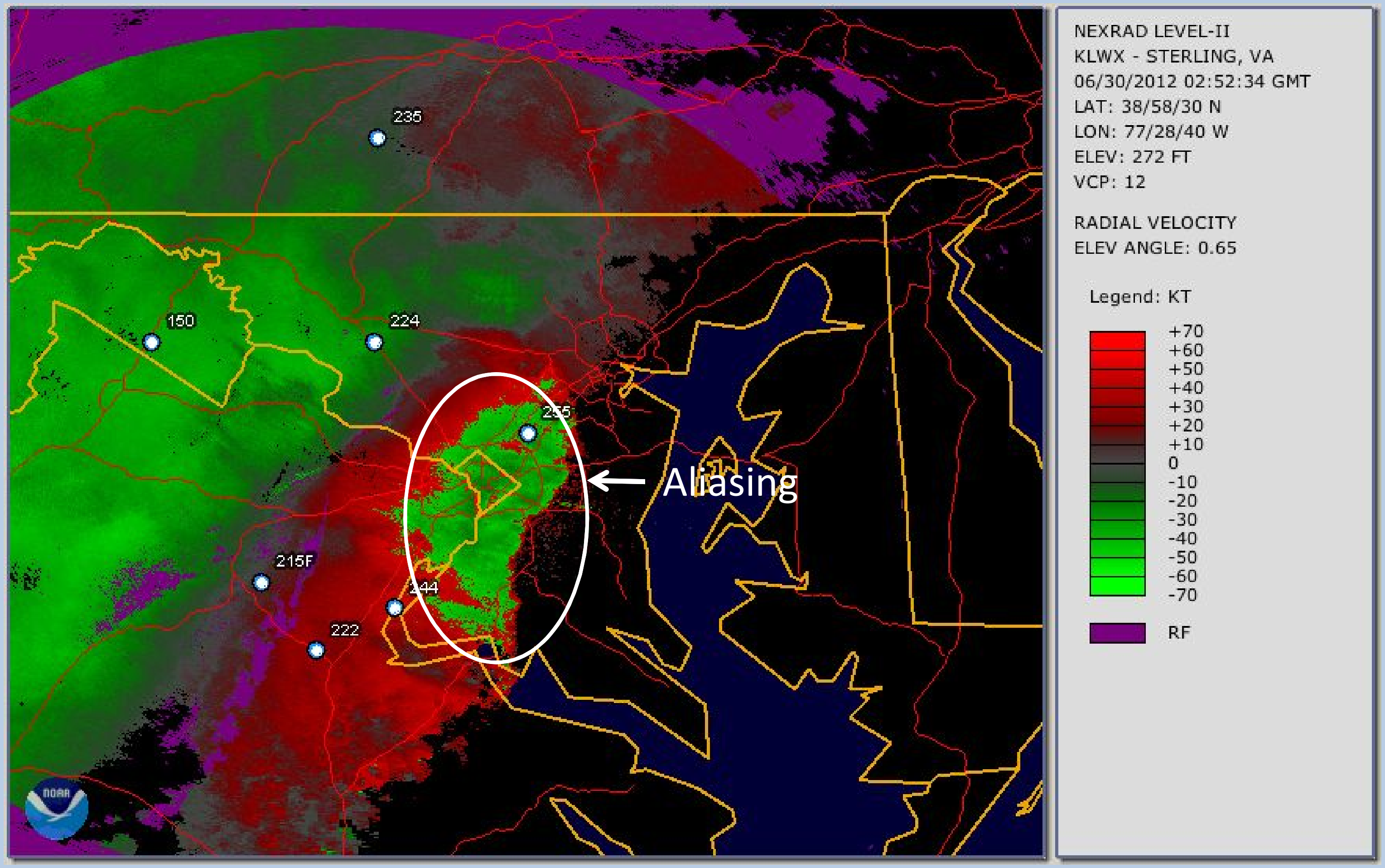
West Virginia, North Carolina, Pennsylvania, Maryland, District of Columbia

- Storms slightly weaken over Appalachians
- Regain strength as they continue east and southeast of the mountains
- Swath of damage 300 miles wide
- Midnight – squall line from northeast Baltimore to Virginia-North Carolina border northeast of Raleigh

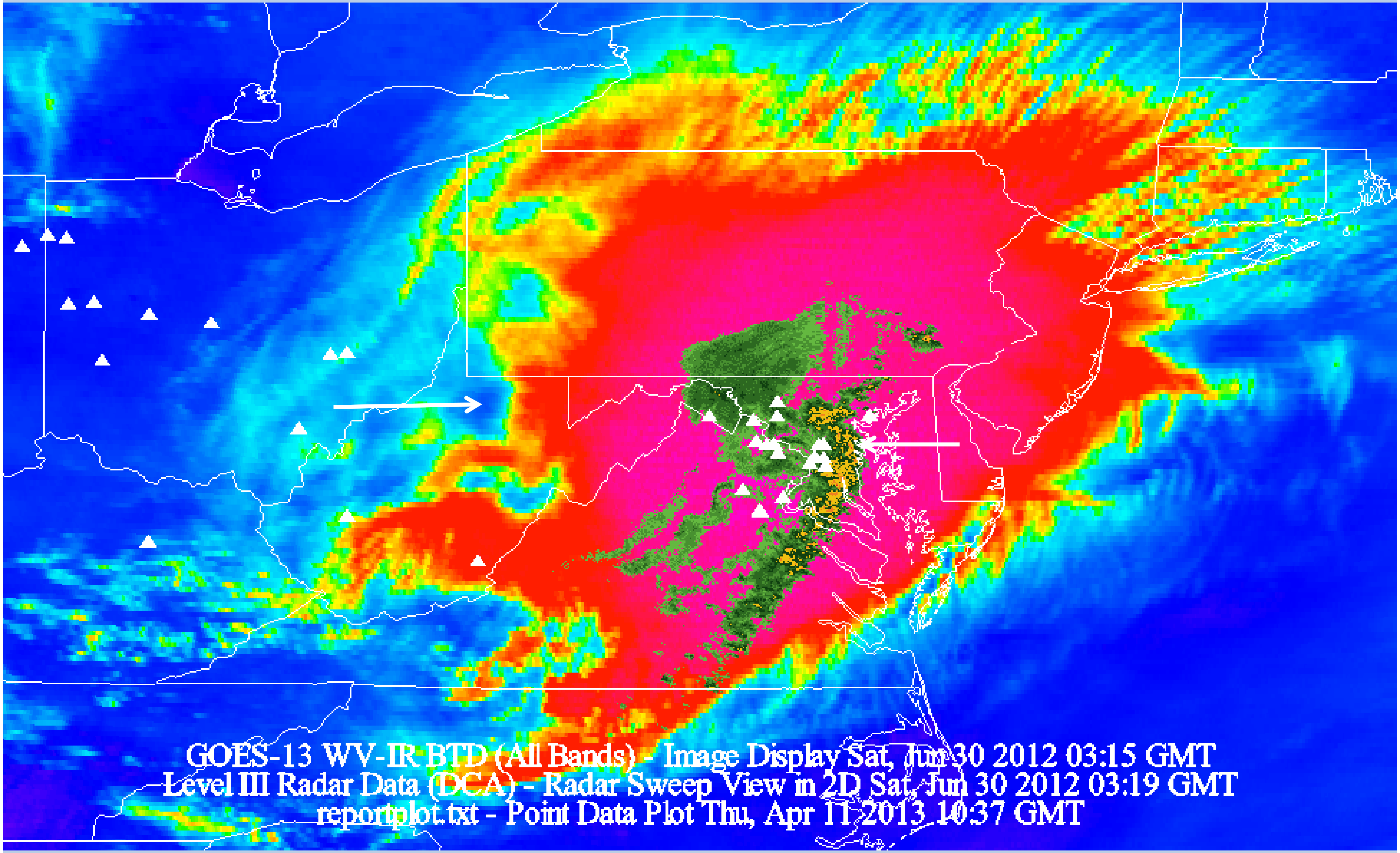
Sterling, VA NEXRAD



Sterling, VA NEXRAD

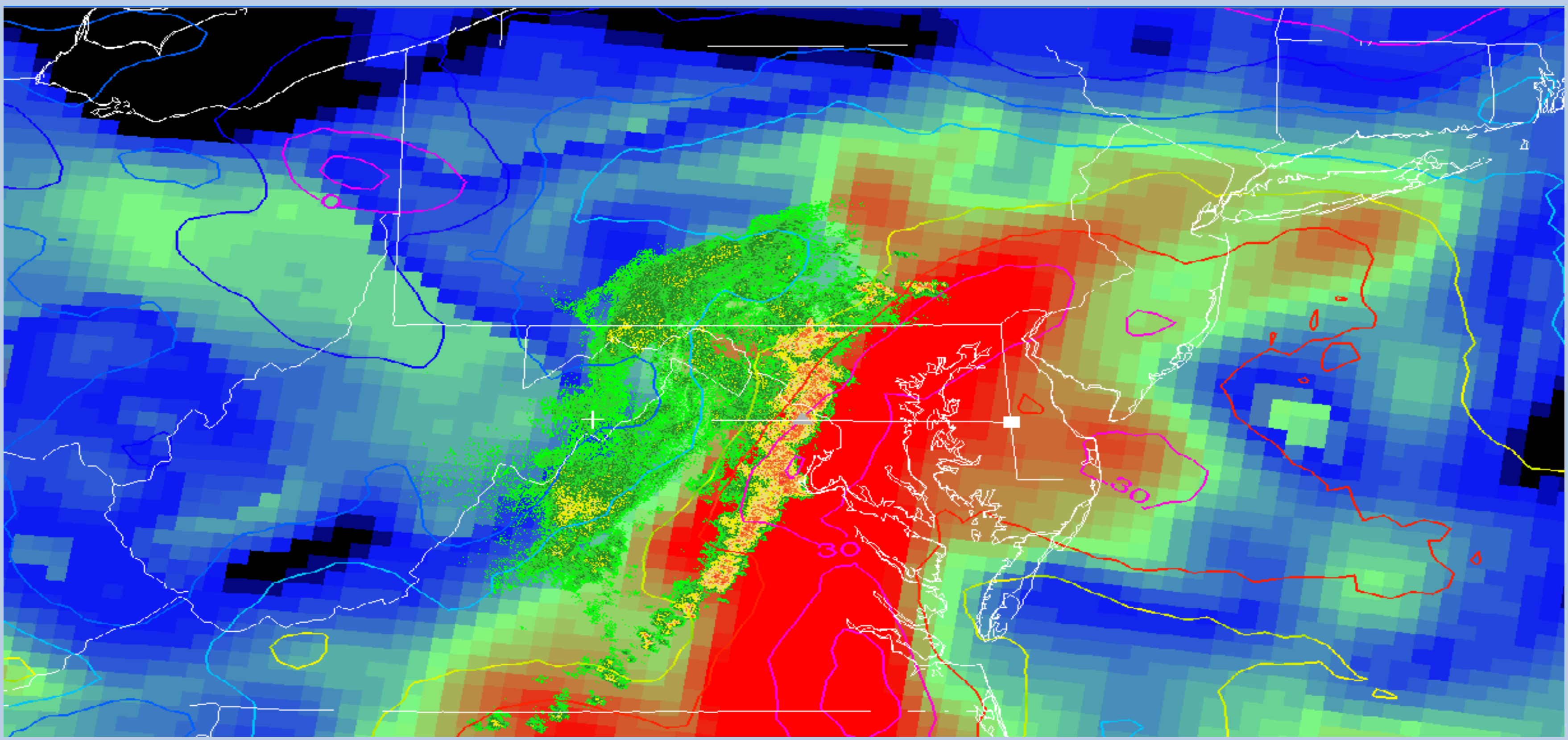


GOES-13 RSO WV-IR BTD/Radar

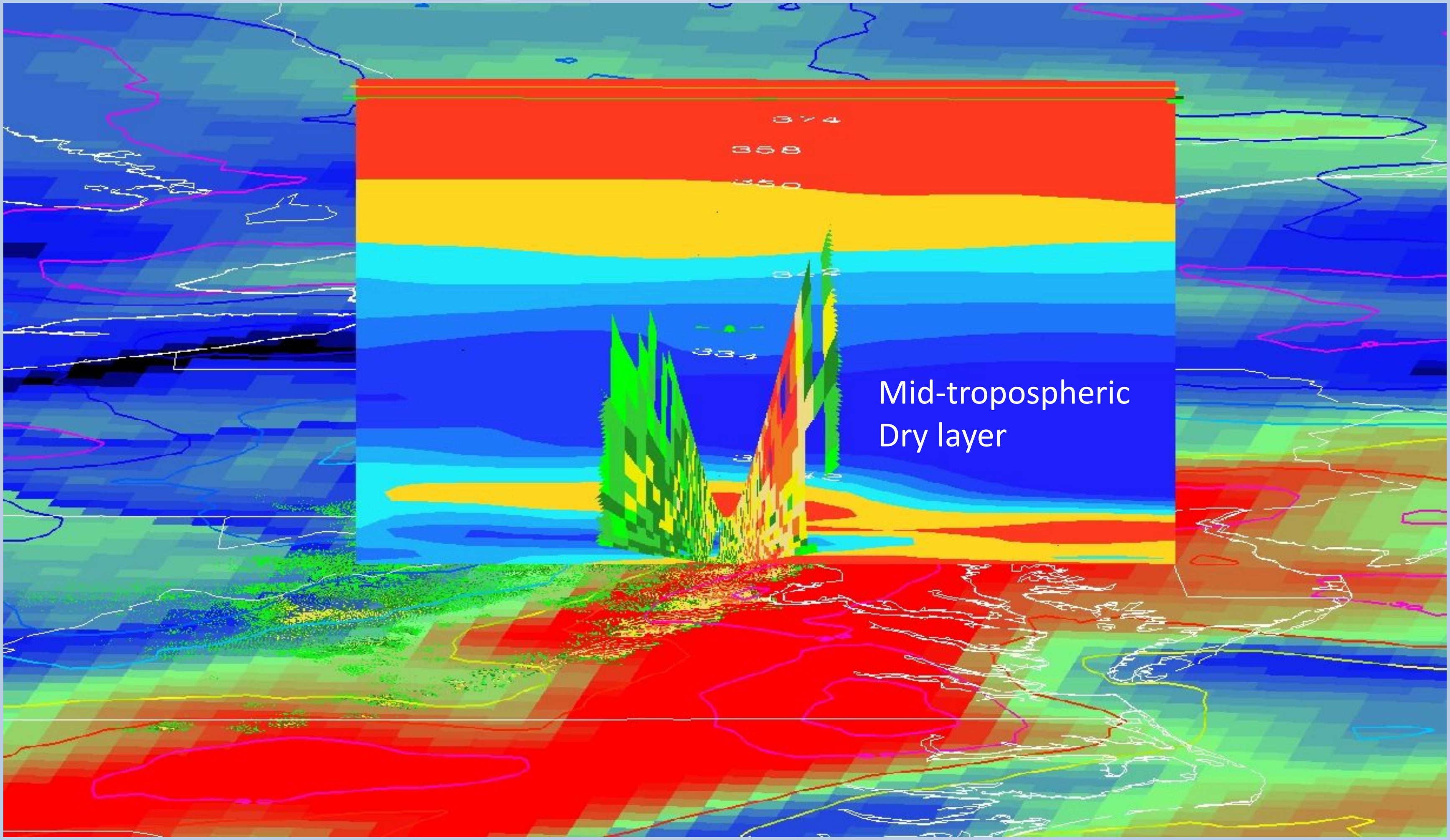


Why the system did not weaken across the Appalachians

- Most convective systems like this collapse across the mountains because they reach the end of the EML – not true for this storm.

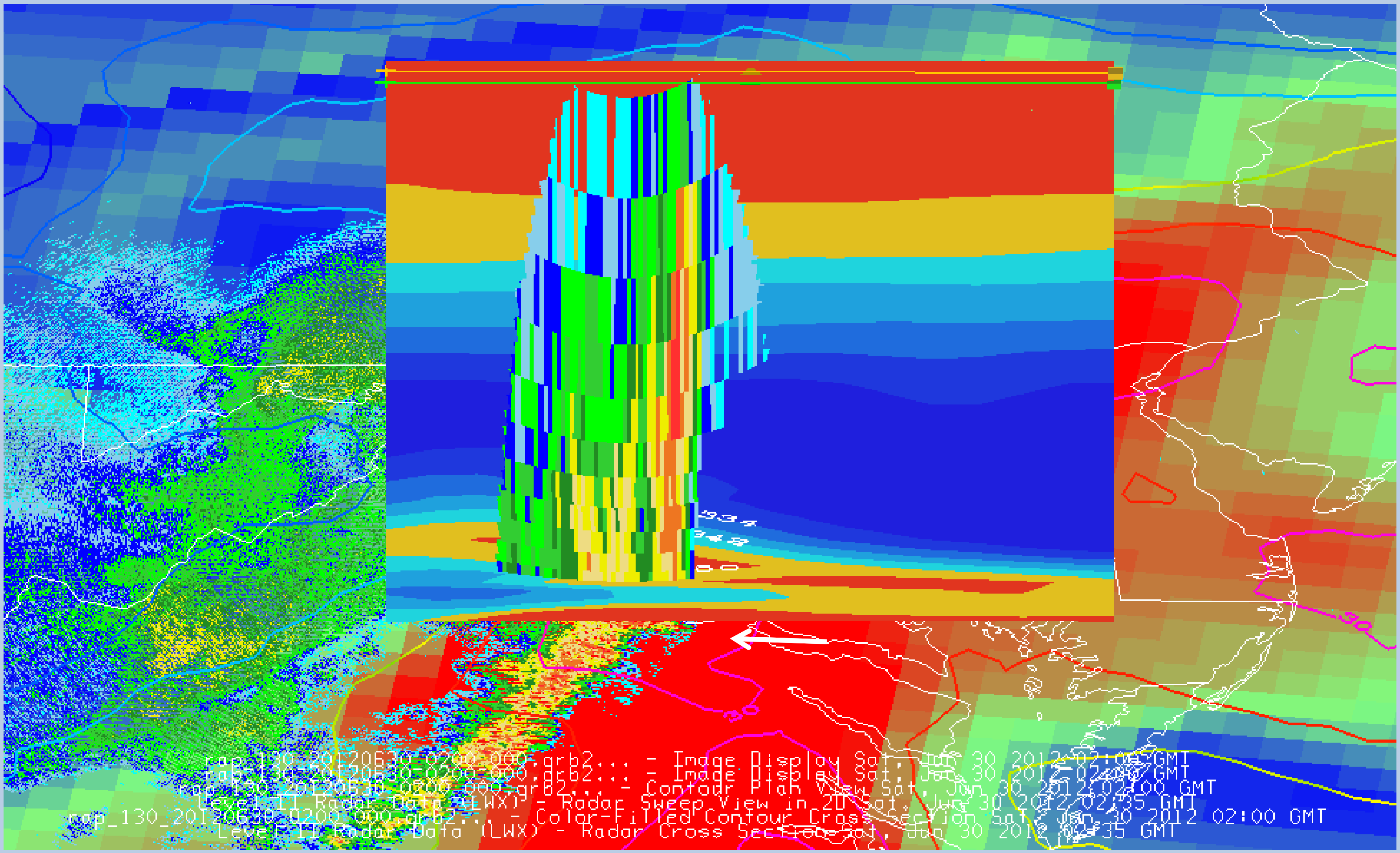


VA-DC-MD Downburst Clusters

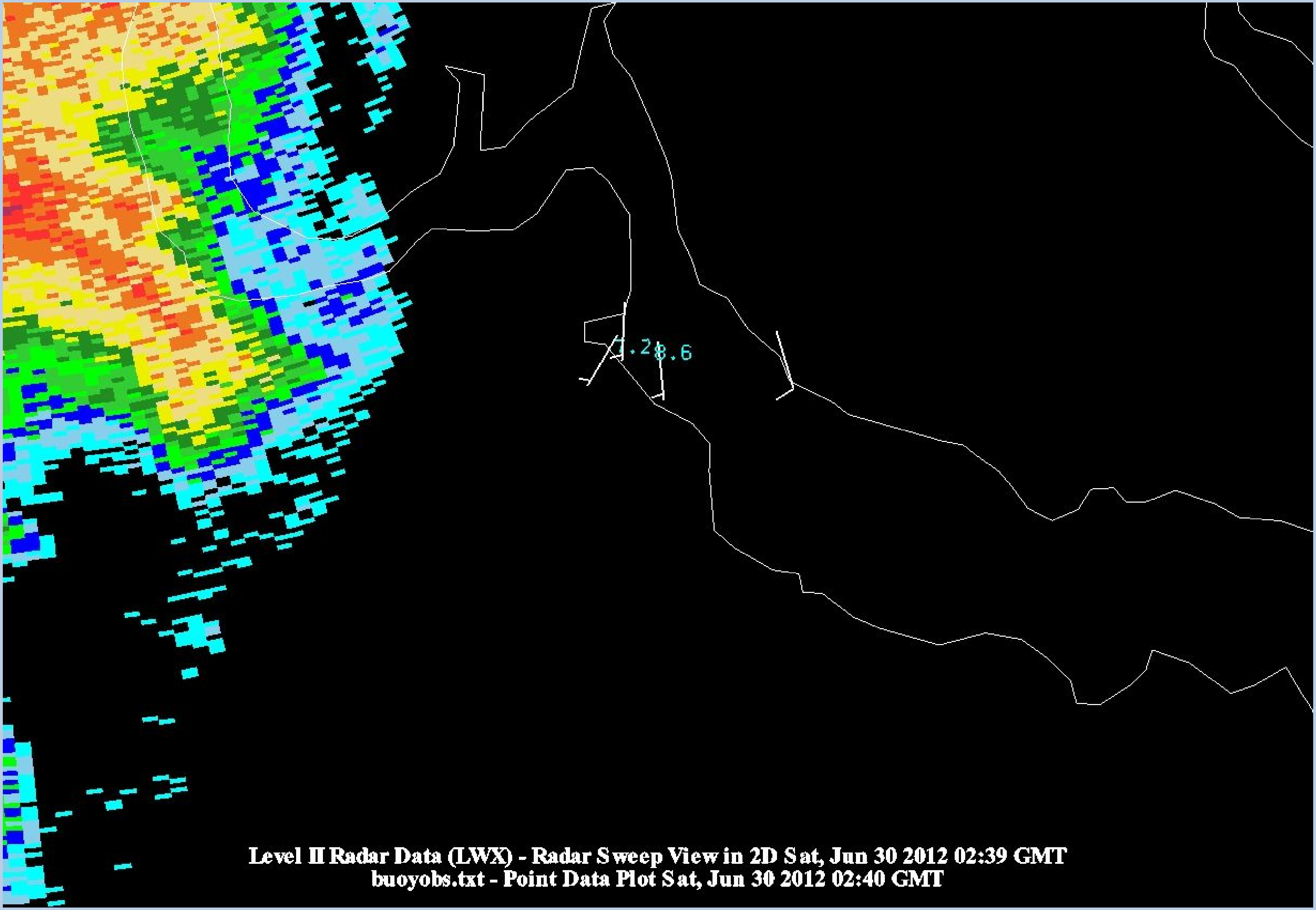


During the period of DCS re-intensification, and its track through the Washington, DC metropolitan area after 0200 UTC 30 June, the leading convective storm line was elevated through a prominent mid-tropospheric dry (low θ_e) layer.

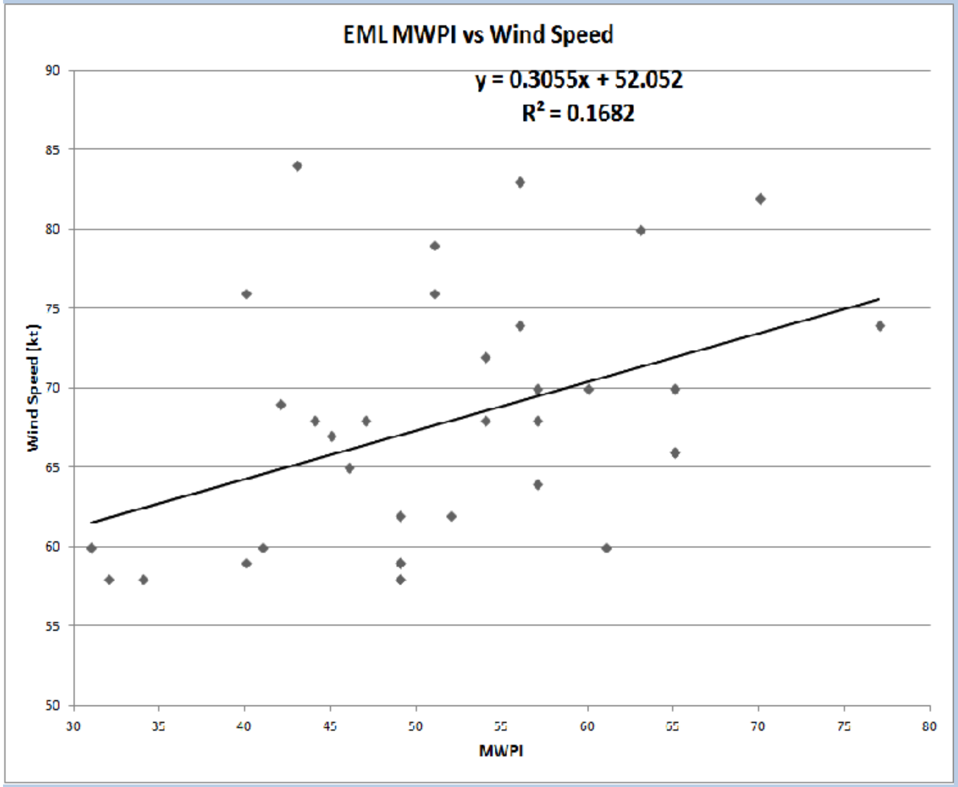
VA-DC-MD Downburst Clusters

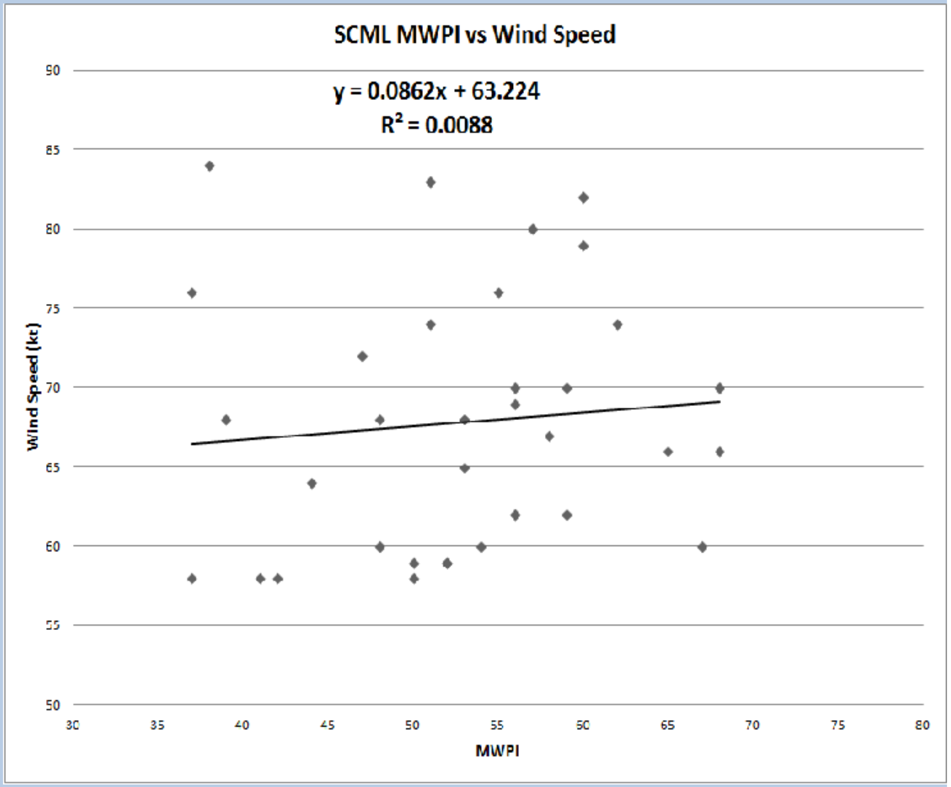


Dahlgren Downbursts



Statistical Analysis





There is a linear correlation between MWPI and wind speed. The greatest correlation and lowest standard error can be found with the EML MWPI, as compared to the lesser correlation found with the SCML MWPI and vertical $\Delta\theta_e$.

Conclusions

- Regions of concentrated enhanced severe winds were associated with downbursts and downburst clusters, especially in the Washington, DC metropolitan area.
- The presence of the EML, expressed as large MWPI and $\Delta\theta_e$ values, was a major forcing factor in downburst severity.
- The combined use of GOES, NEXRAD/TDWR, and NWP model data, as visualized in McIDAS-V, was effective in not only detecting downburst occurrence and diagnosing favorable environmental conditions, but also in building a conceptual model of severe downburst generation within the DCS.
- Serve as new derecho forecasting technique to be introduced to operational meteorology community via VISIT.

References

Atkins, N.T., and R.M. Wakimoto, 1991: Wet microburst activity over the southeastern United States: Implications for forecasting. *Wea. Forecasting*, **6**, 470-482.

Corfidi, S.F., J.S. Evans, and R.H. Johns, cited 2013: About Derechos. Available online at http://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm

Fujita, T.T., and H.R. Byers, 1977: Spearhead echo and downbursts in the crash of an airliner. *Mon. Wea. Rev*., **105**, 1292-146.

Fujita, T. T., and R. M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.*,**109**, 1438-1456.

Johns, R.H., and W. D. Hirt, 1987: Derechos: Widespread convectively induced windstorms. *Wea. Forecasting, 2, 32-49.*

Pryor, K.L., 2011: Microburst Nowcasting Applications of GOES. NOAA Technical Report NESDIS 140.

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