



A. Ashton



M. Meredith



A. Ashton

## *Anatomy of a Canadian Derecho: The Historic Derecho of May 21 2022*

Great Lakes Operational  
Meteorology Workshop  
May 24 - 25 2023

**Arn Ashton**

Ontario Storm Prediction Centre



Environment and  
Climate Change Canada  
Environnement et  
Changement climatique Canada



A. Ashton



A. Ashton

## *Overview:*

- ❑ The Derecho, defined.
- ❑ May 21 2022 derecho summary / impacts.
- ❑ How does it stack up against other derechos?
- ❑ Forecasting derechos: A multi-prong approach.
  - ❑ Why are they difficult to forecast?
  - ❑ A deeper dive for a greater understanding of their formation, persistence, demise.
  - ❑ Some 'standout' observations of our derecho, and 'forecast testing' with other derechos.
- ❑ Summary of forecast techniques (and reviewed by Rich Thompson, SPC).

## What makes a Derecho special?

- ❑ We all know the definition: Widespread, long-lived, extreme wind storm associated with a band of rapidly-moving thunderstorms (often at exceptional speeds); **> 650 km damage length & > 100 km width;** **Winds > 93 km/h** along MOST of its length (with swaths of **stronger** gusts).
- ❑ A reminder of why stronger gusts are problematic:
  - ❑ **Wind Load =  $1/2 \rho V^2 A$**  ( $V$ = wind speed;  $\rho$ = air density;  $A$ = object area)
  - ❑ Example on 10 m<sup>2</sup>: 90 km/h wind  $\longrightarrow$  3600 N versus 130 km/h wind  $\longrightarrow$  7565 N.
- ❑ The derecho dilemma:
  - ❑ Standard-issue QLCs are a dime a dozen, but derechos are a rare subset, requiring a fuzzy set of ingredients (broad wind shear spectrum) to ensure their formation, and maintain their longevity.
  - ❑ Parameter space offers few 'eureka moments'.
  - ❑ Rich Thompson (SPC): 'Extreme convective wind' events rank among their most challenging (more so than tornado outbreaks).



# How to **FORECAST** a Derecho? *Out of curiosity: latest payable version ChatGPT4:*

❑ Q: Based on published scientific literature, how does a meteorologist forecast derechos?

❑ A: A derecho is a widespread, long-lived, straight-line windstorm associated with a fast-moving group of severe thunderstorms. Meteorologists forecast derechos using a combination of observational data, numerical weather prediction models, and knowledge of the atmospheric conditions necessary for derecho formation. Here are the key steps in forecasting derechos:

1. Analyze current atmospheric conditions: Meteorologists monitor parameters like instability (Convective Available Potential Energy or CAPE), wind shear (speed and directional changes in the wind with height), and moisture content in the atmosphere. These factors are crucial for the development of severe thunderstorms and can help identify regions with favorable conditions for derecho formation.

2. Monitor synoptic-scale features: Large-scale weather systems, such as low-pressure systems, frontal boundaries, and upper-level disturbances like shortwave troughs, can trigger or enhance thunderstorm development. Meteorologists track these features to anticipate areas where severe weather may occur.

3. Utilize numerical weather prediction models: Meteorologists rely on computer models to simulate the evolution of the atmosphere and provide guidance on the timing, location, and intensity of severe weather. Models like the North American Mesoscale (NAM), Global Forecast System (GFS), and High-Resolution Rapid Refresh (HRRR) can provide insights into the potential for derecho development.

4. Examine radar and satellite data: Meteorologists monitor radar data to identify storm systems that show signs of organizing into linear convective systems, or "squall lines," which can evolve into derechos. Satellite imagery can help track the progress of these systems and provide information on cloud-top temperatures, which may indicate storm intensity and organization.

5. Monitor storm reports and real-time observations: Meteorologists keep an eye on storm reports, such as wind damage or severe wind gusts, as well as real-time weather observations, like surface wind speeds and directions. This information helps them assess whether a derecho is ongoing or imminent, and allows them to update their forecasts accordingly.

6. Issue watches and warnings: If conditions become favorable for derecho development or if a derecho is detected, meteorologists issue severe thunderstorm watches, warnings, or special weather statements to inform the public about the potential hazards. The Storm Prediction Center (SPC) in the United States, for example, provides outlooks and risk assessments for severe weather events, including derechos.

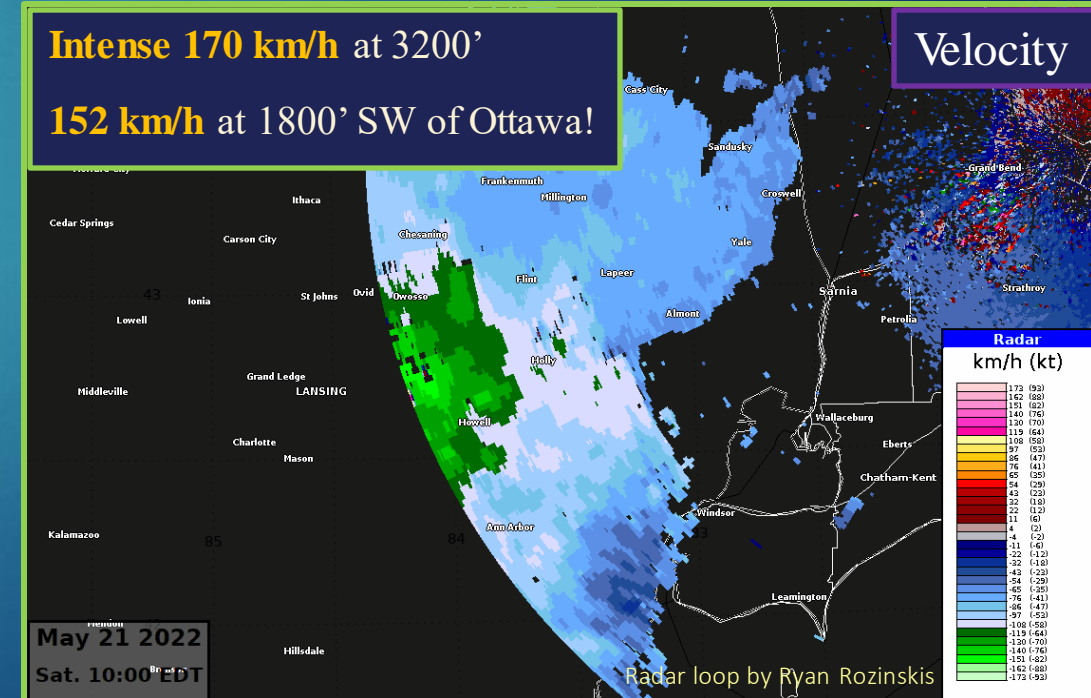
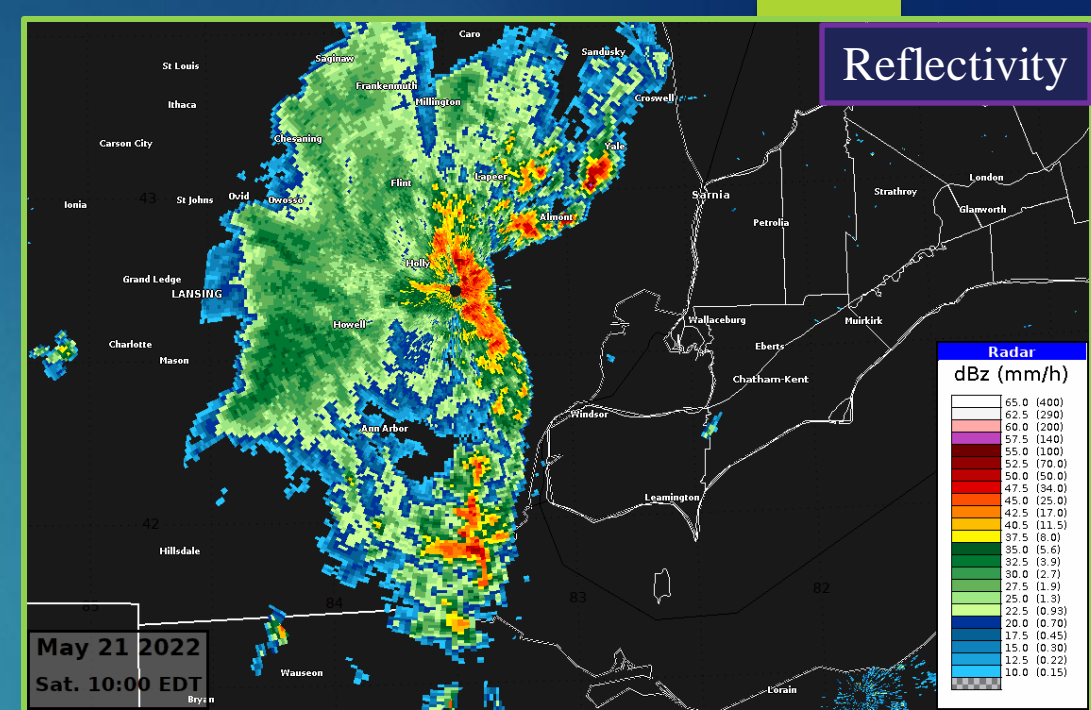
7. Communicate forecast updates: Meteorologists continuously update their forecasts and communicate the information to the public and emergency management agencies. Social media, television, radio, and other communication channels are used to disseminate this information.

In summary, meteorologists forecast derechos by monitoring atmospheric conditions, analyzing numerical weather prediction models, and interpreting radar and satellite data. They then issue watches and warnings and communicate the forecast updates to the public to ensure preparedness and safety during these potentially destructive windstorms.

**Not  
helpful!**

# Summary of the Great Derecho of May 21 2022:

- ❑ The last derecho to hit Canada was in July 2006.
- ❑ One of the top extreme Canadian weather events of 2022.
- ❑ Affected 41 % of Canada's population (wide swath from Windsor through Quebec City).
- ❑ Extensive damage over 1000 km in length. Four embedded tornadoes including two EF2s (Uxbridge, Lake Scugog).
- ❑ **12 fatalities** mostly from falling trees.
- ❑ Deadliest convective storm to hit Ontario since May 31 1985.
- ❑ 1.1M customers without power; nearly **\$1B damage** (CatIQ), ranked as the 6<sup>th</sup> costliest natural disaster (insurance claims).



*Summary: In the belly of the beast (S Ottawa):*



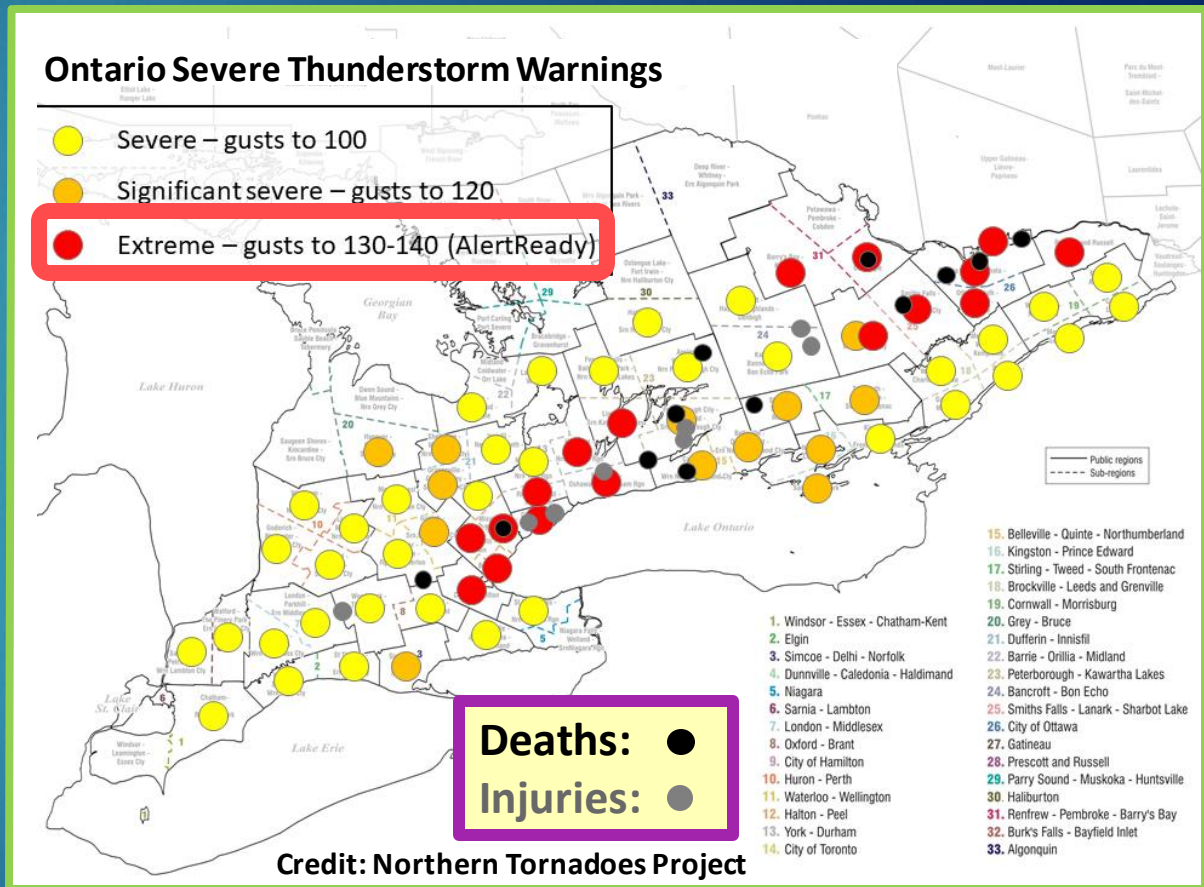
Video by Mitch Meredith (but I was sitting right beside him slack-jawed).



# Impacts and Warnings

Damage Path: Unprecedented number of reports

ECCC Warnings

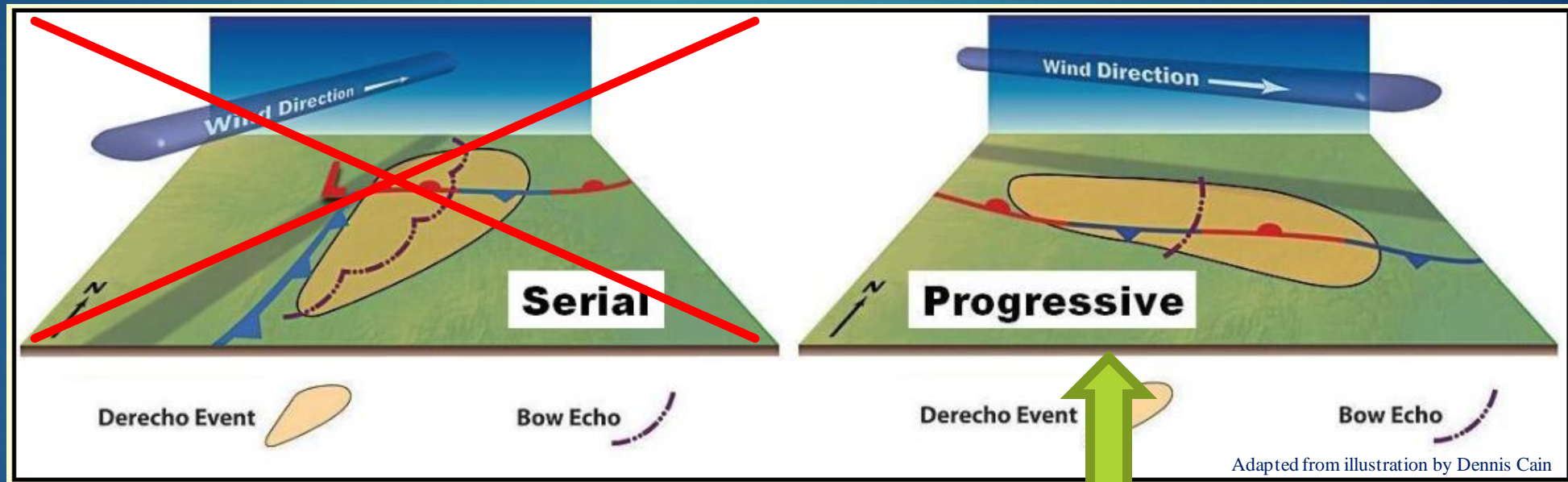


## Differentiating Derechos:

### Serial versus Progressive:

Serial: Dynamically-driven linked to a strong, migratory low with strong low-mid tropospheric flow (easier to model / forecast).

Progressive: Narrower, and associated with more subtle weather features...i.e. weak low pressure and not necessarily strong/extreme low-mid tropospheric winds (but line-normal). Intense surface winds are due to storm-induced downdrafts.



Our May 21 2022 Derecho



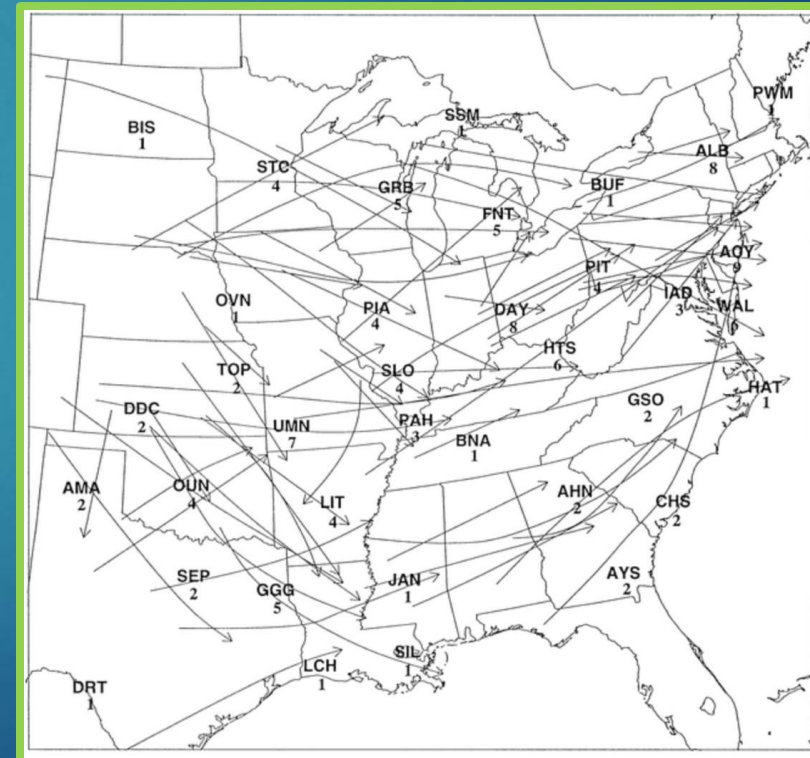
## Understanding *PROGRESSIVE* Derechos:

- ❑ Those pesky PROGRESSIVE derechos:
  - ❑ Often weakly-forced, with unremarkable synoptic wind fields.
  - ❑ Formation and persistence **dependent on small-scale processes**: condensation, melting, evaporation, strong latent heat release (aiding in precipitation-lifting leading to strong downdrafts / cold pool).
  - ❑ Therefore, models tend to mis-forecast.
  - ❑ ‘Optimum balance’ between strong up-sheared updrafts and strong cold pool.
  - ❑ Strong link between heat waves and progressive derechos (**Elevated Mixed Layer**).

## Understanding *PROGRESSIVE* Derechos:

- Analysis: 'Evans and Doswell, 2001, Examination of Derecho Environments using Proximity Soundings, Weather and Forecasting':
  - 67 derechos: 27 WEAK forcing, ~~30 STRONG forcing, 10 HYBRID~~
  - Weak forcing ~ primarily summertime progressive derechos.
  - 113 proximity soundings.
  - Span of a decade.

(Centroid and Number of proximity soundings per derecho).





## All derechos in study:

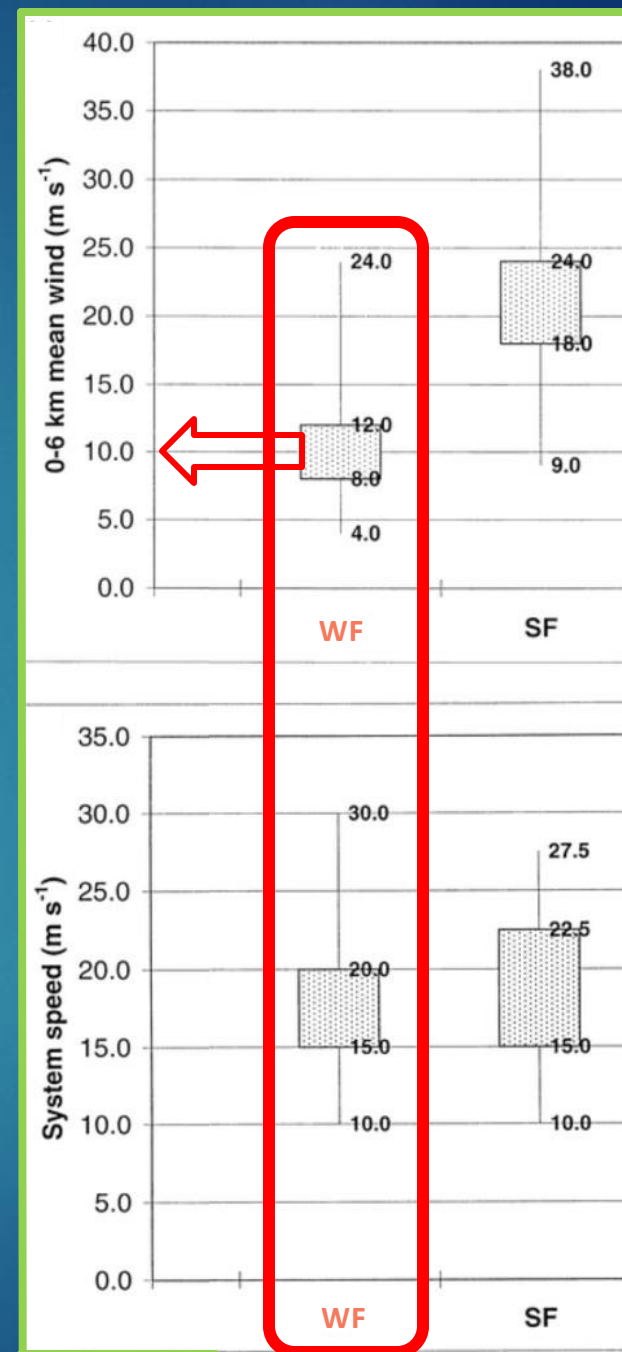
Mean, 0-6 km steering flow winds:

(WF = Weak Forcing i.e. warm season progressive)

(SF = Strong Forcing)

Mean 0-6 km mean winds average less  
in progressive derechos.

(Propagation largely due to storm-scale  
processes and rapid new cell formation).



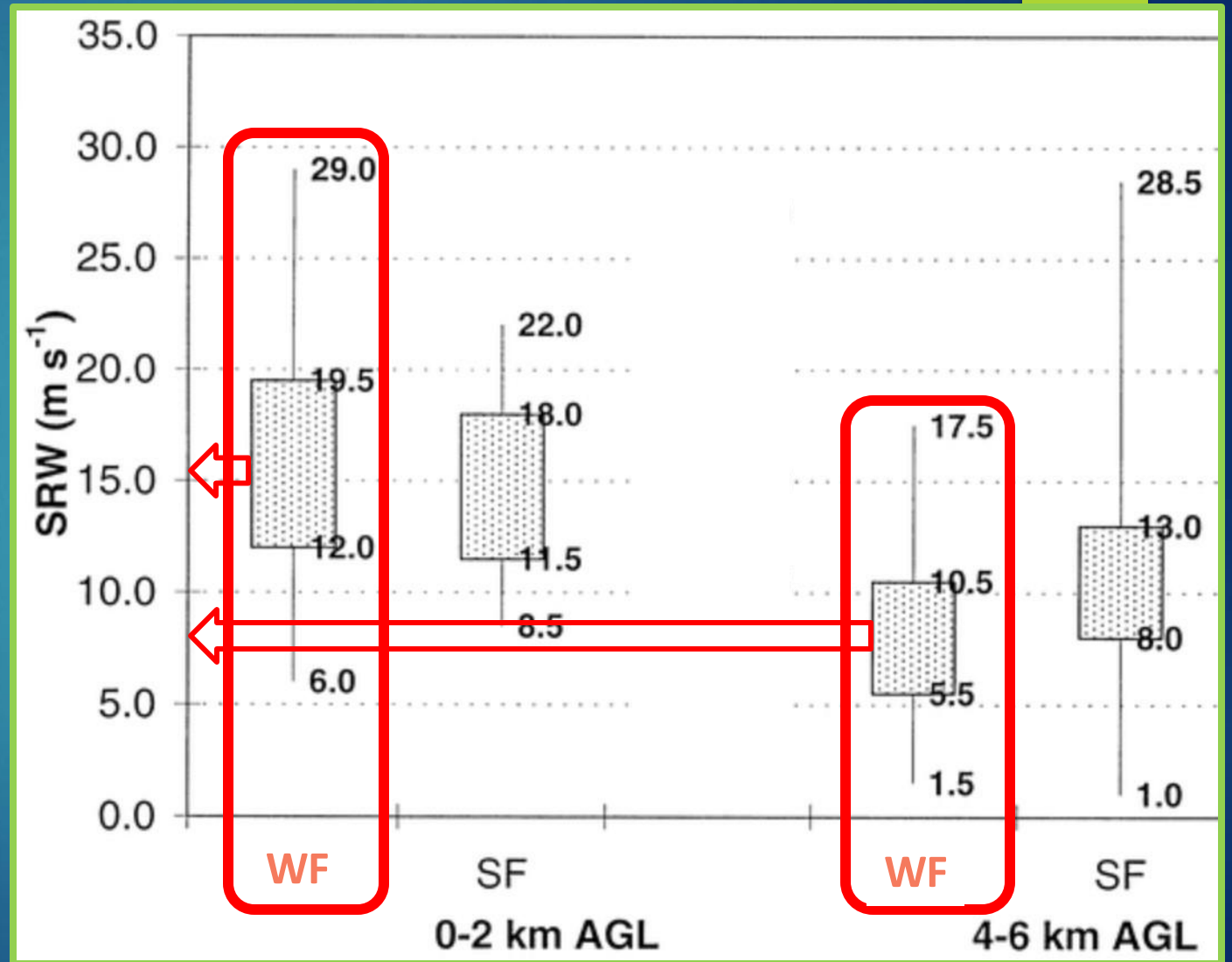
## All derechos in study:

### Storm-Relative Winds (SRW):

(WF = Weak Forcing i.e. warm season progressive)

(SF = Strong Forcing)

Why?: Weaker SRW aloft support tilted storms and fast-moving outflow increases low-level SRW.





All derechos in study:

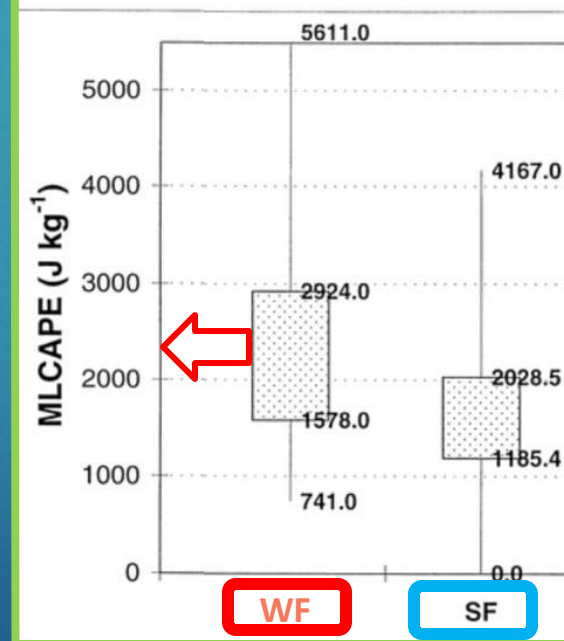
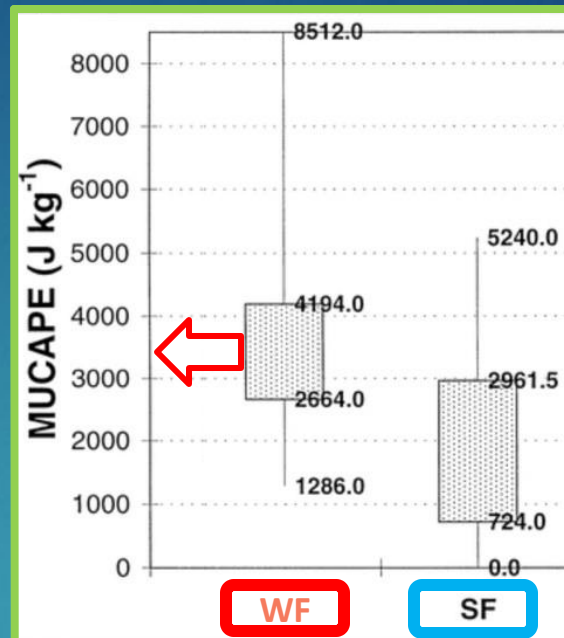
MUCAPE, MLCAPE

(WF = Weak Forcing i.e. warm season progressive)

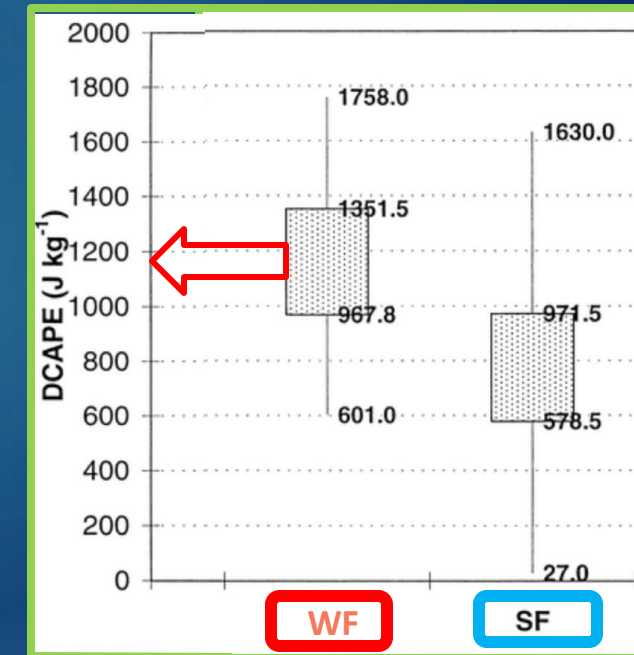
(SF = Strong Forcing)

No surprises here: Big CAPE for the summer derechos.

Ditto for DCAPE.



& DCAPE



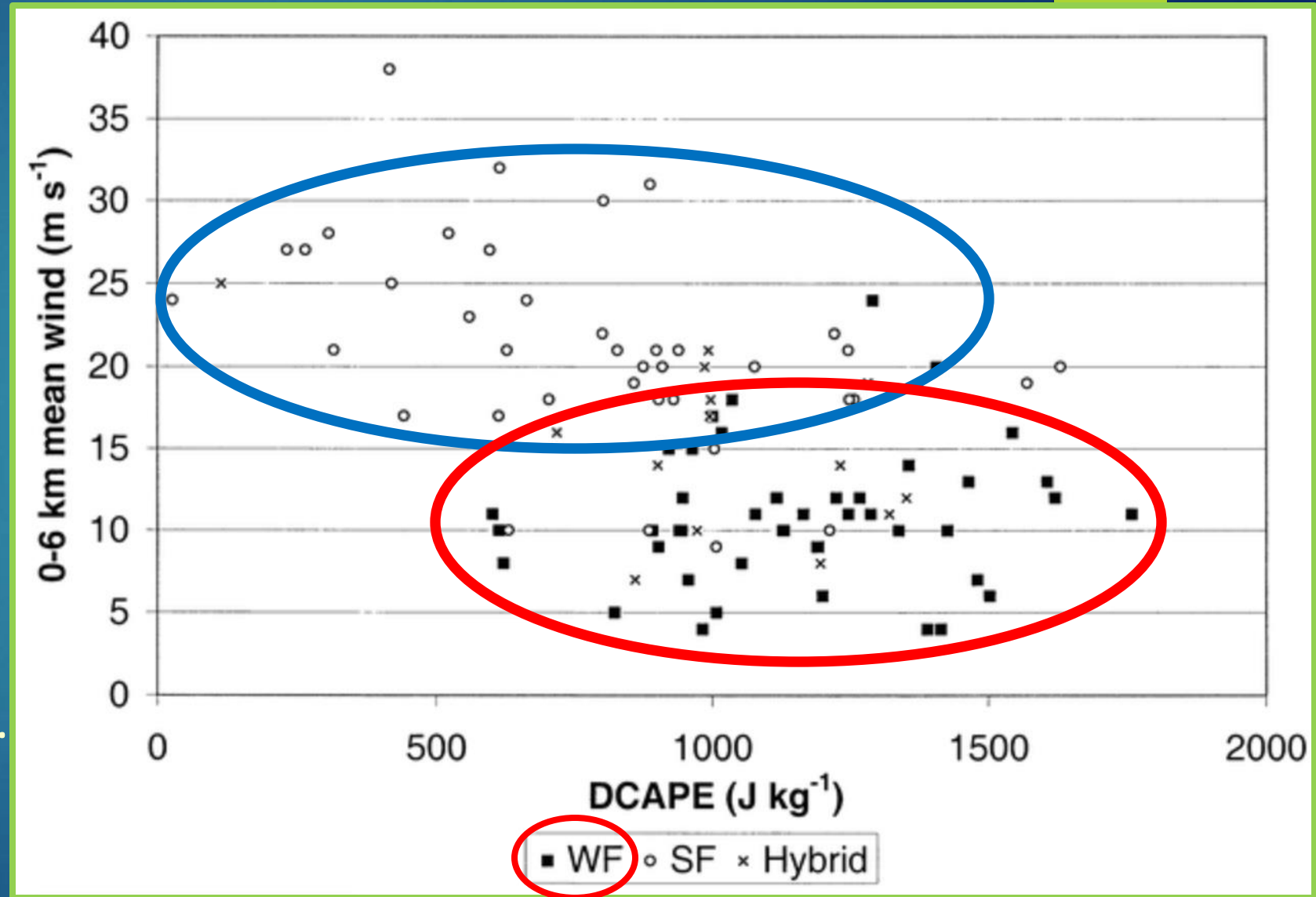
## All derechos in study:

DCAPE vs.  
0-6 km Mean Wind

(WF = Weak Forcing i.e. warm season  
progressive)

(SF = Strong Forcing)

Decent separation revealing  
greater importance of large  
DCAPE in progressive derechos.

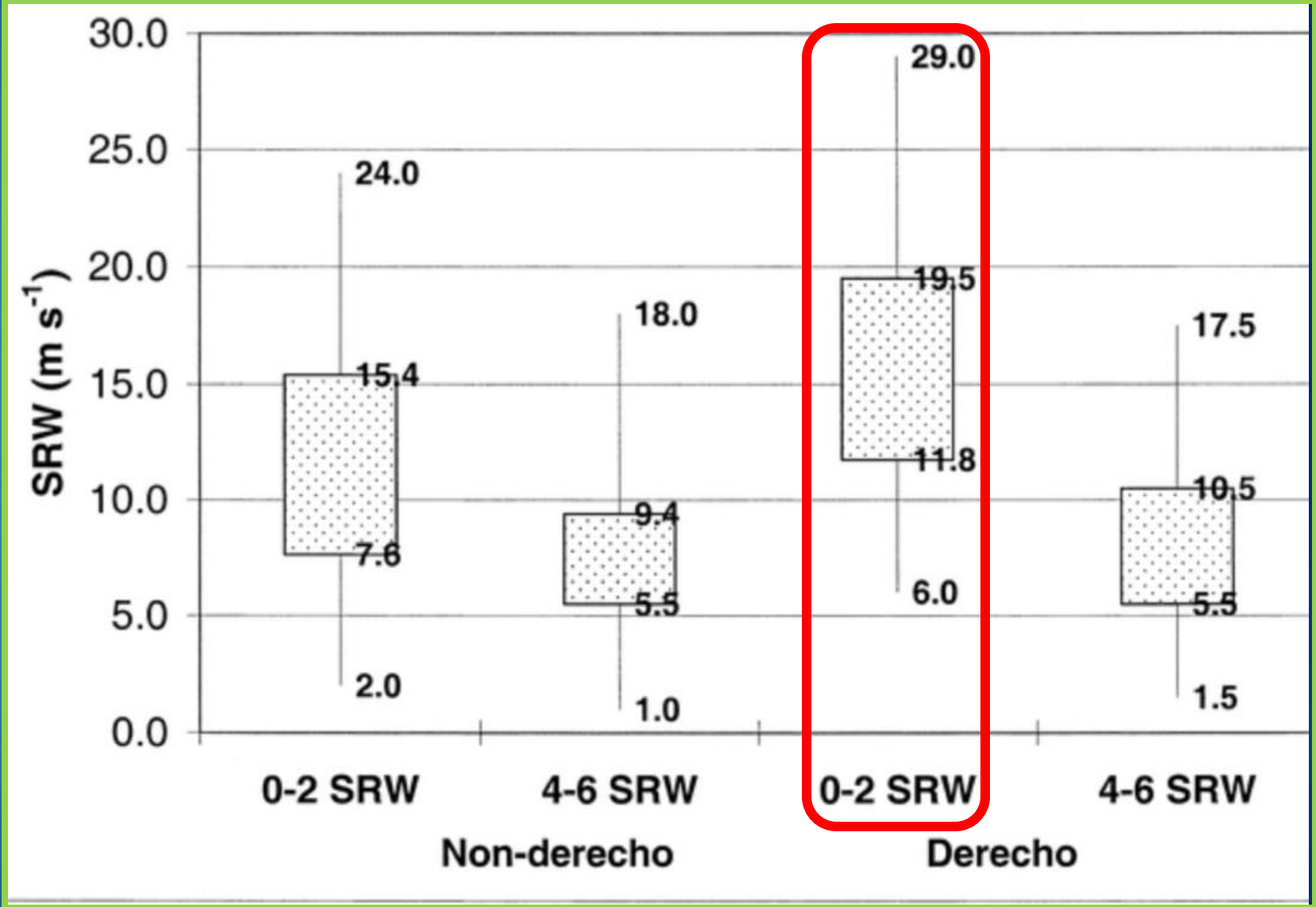




*DERECHOS vs. NON-DERECHOS:  
(Storm-relative winds)*

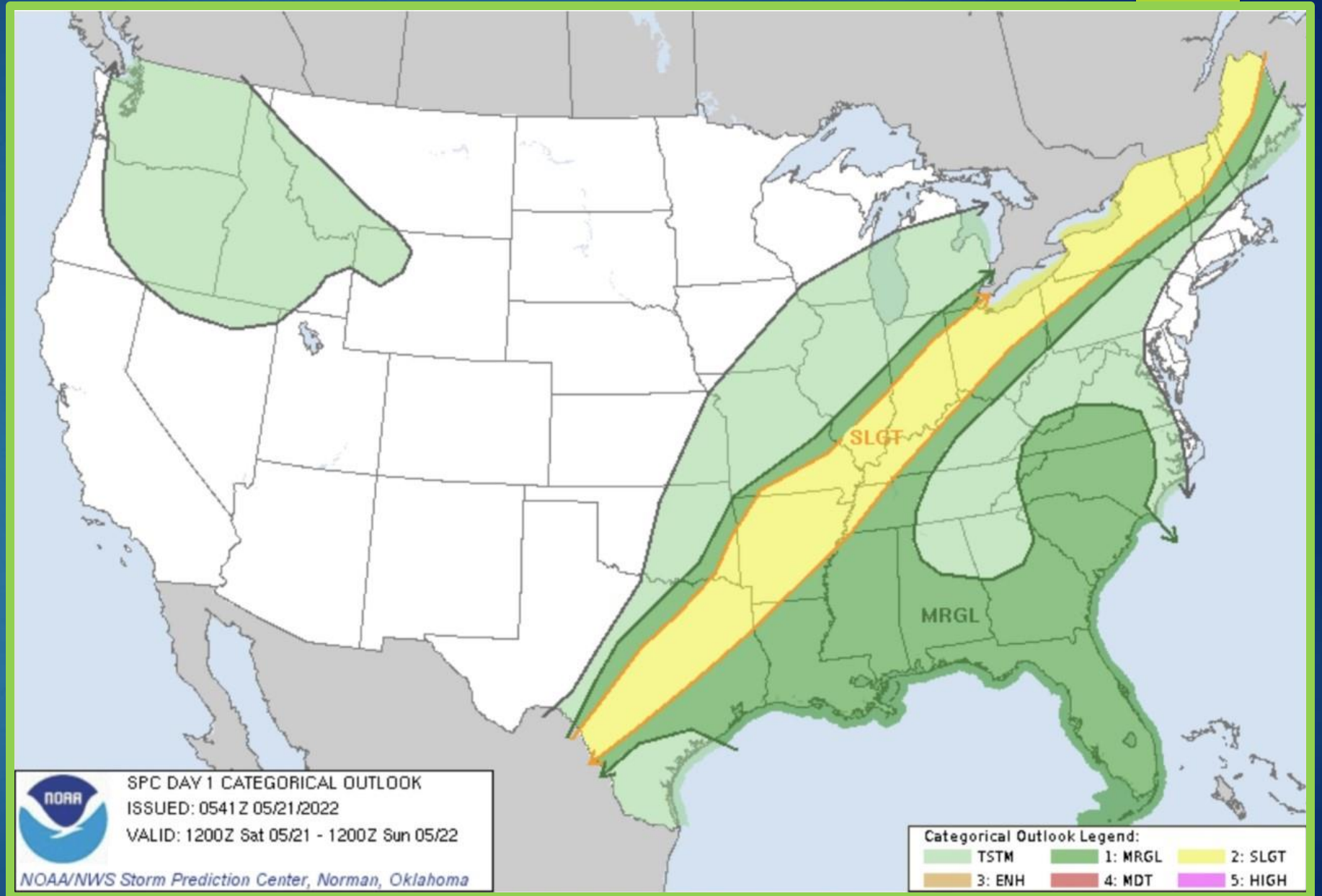
*13 warm season (WF)  
NON-derechos  
Versus 67 derechos:*

0-2 km SRW HIGH in derechos:  
tilted storms and faster-moving  
outflow increases low-level SRW.



*Forecasts:  
May 21 2022*

SPC Day **ONE**  
Outlook 06Z

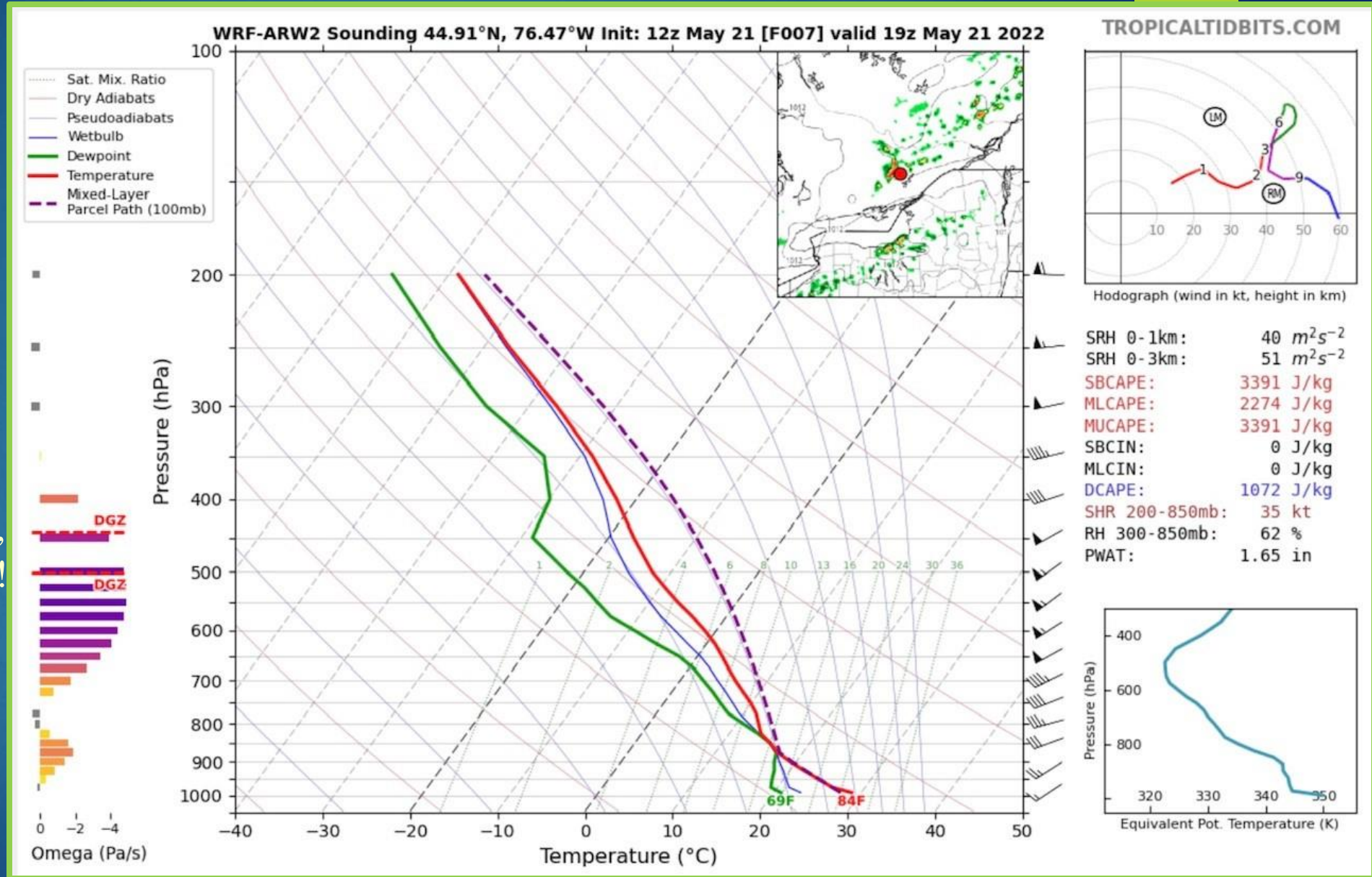


*Model World*  
*May 21 2022*

WRF-ARW2

Spot Sounding 19Z  
(12Z run)

Big CAPE, steep lapse rates,  
uni-directional shear. Oh oh!





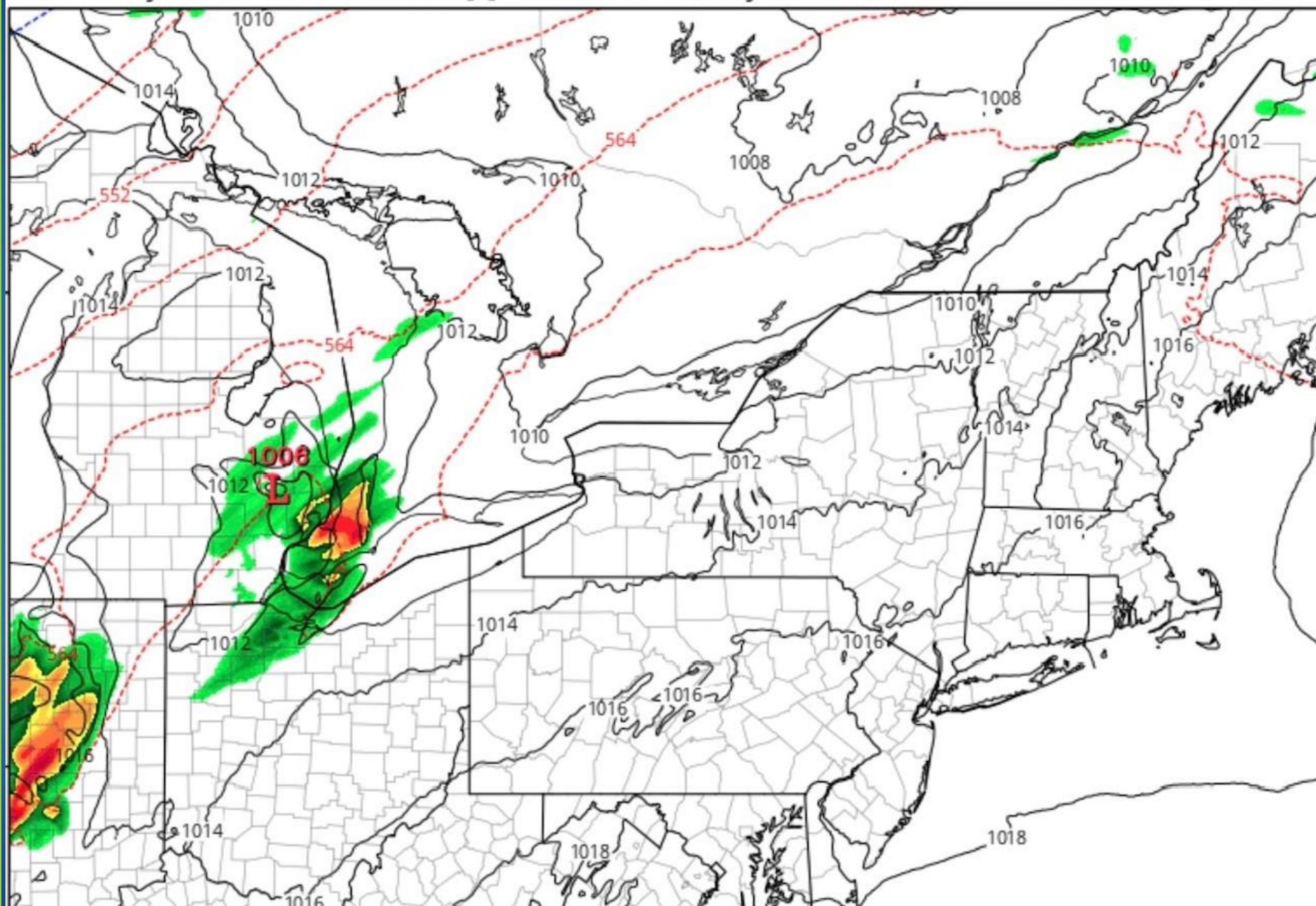
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [3] valid at 15z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





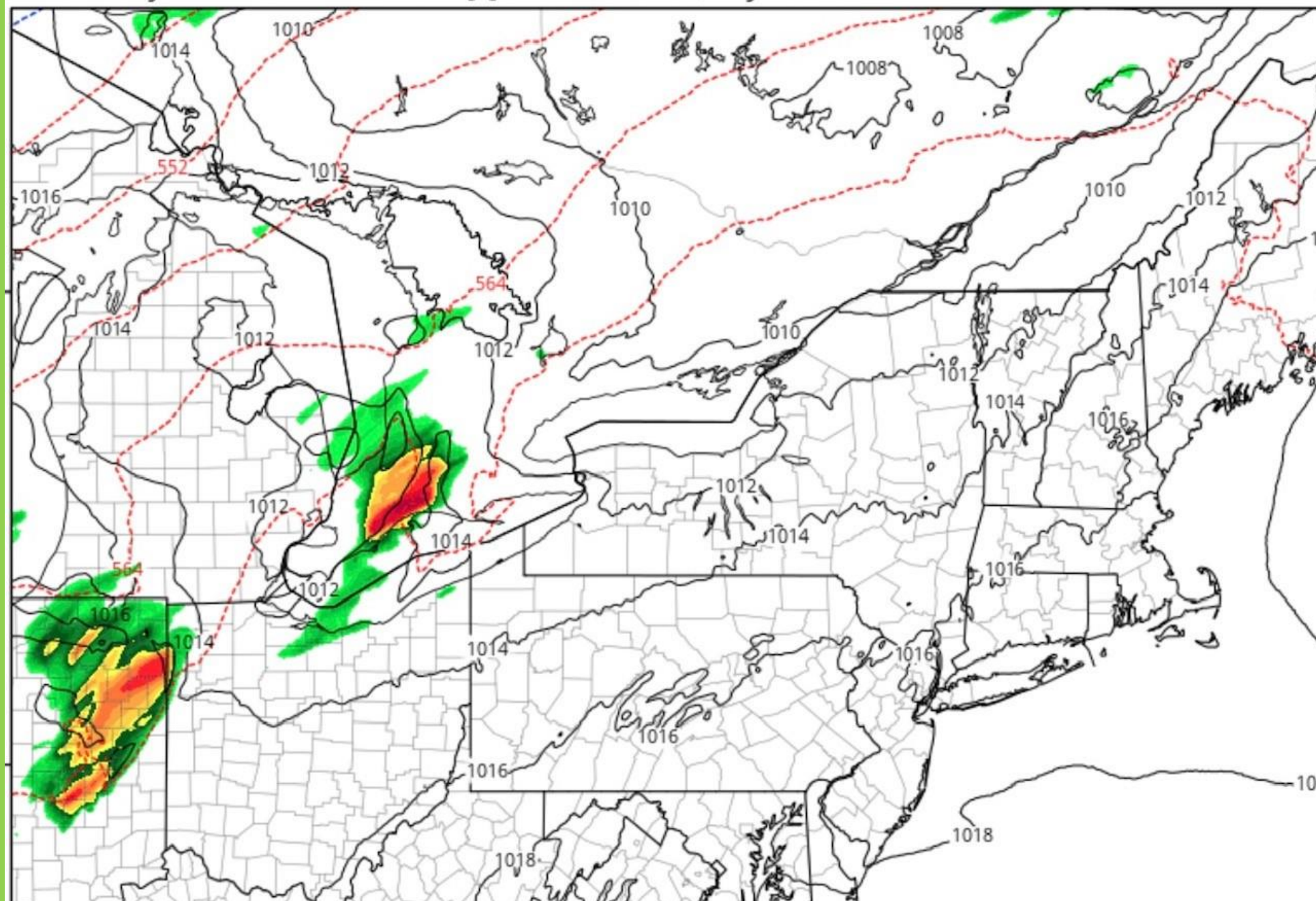
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [4] valid at 16z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

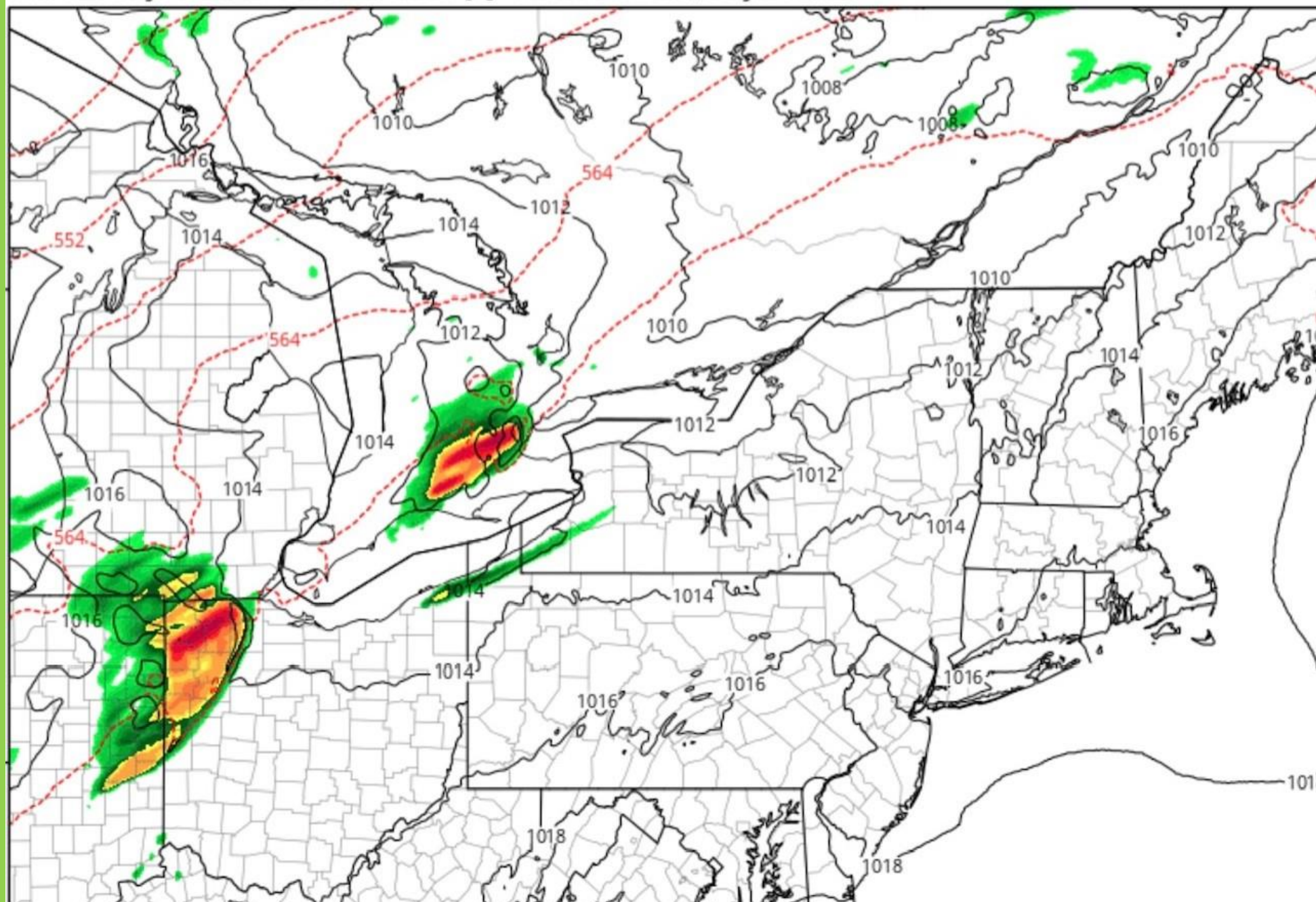
Init: 12z May 21 2022 Forecast Hour: [5] valid at 17z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run

Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





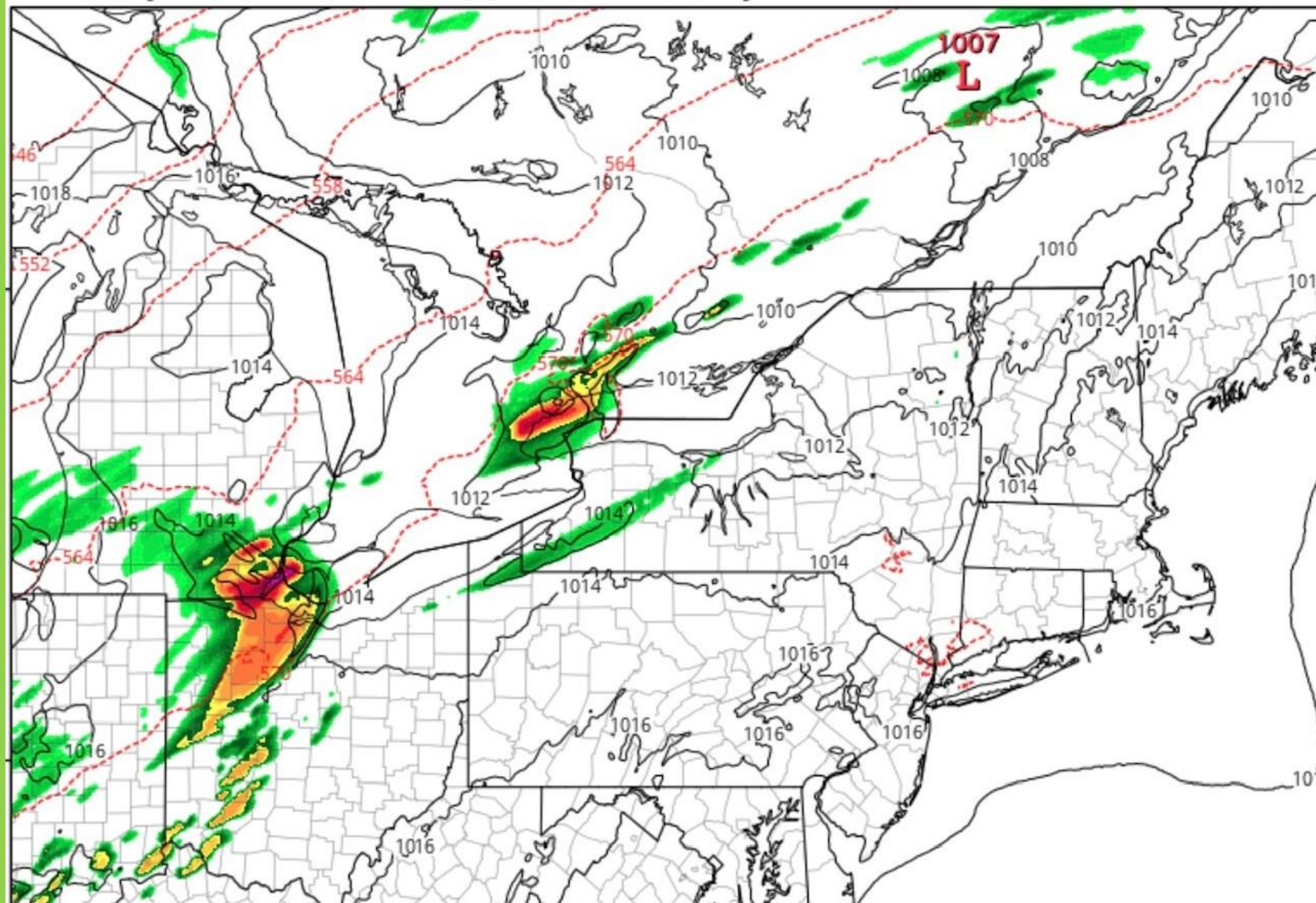
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [6] valid at 18z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





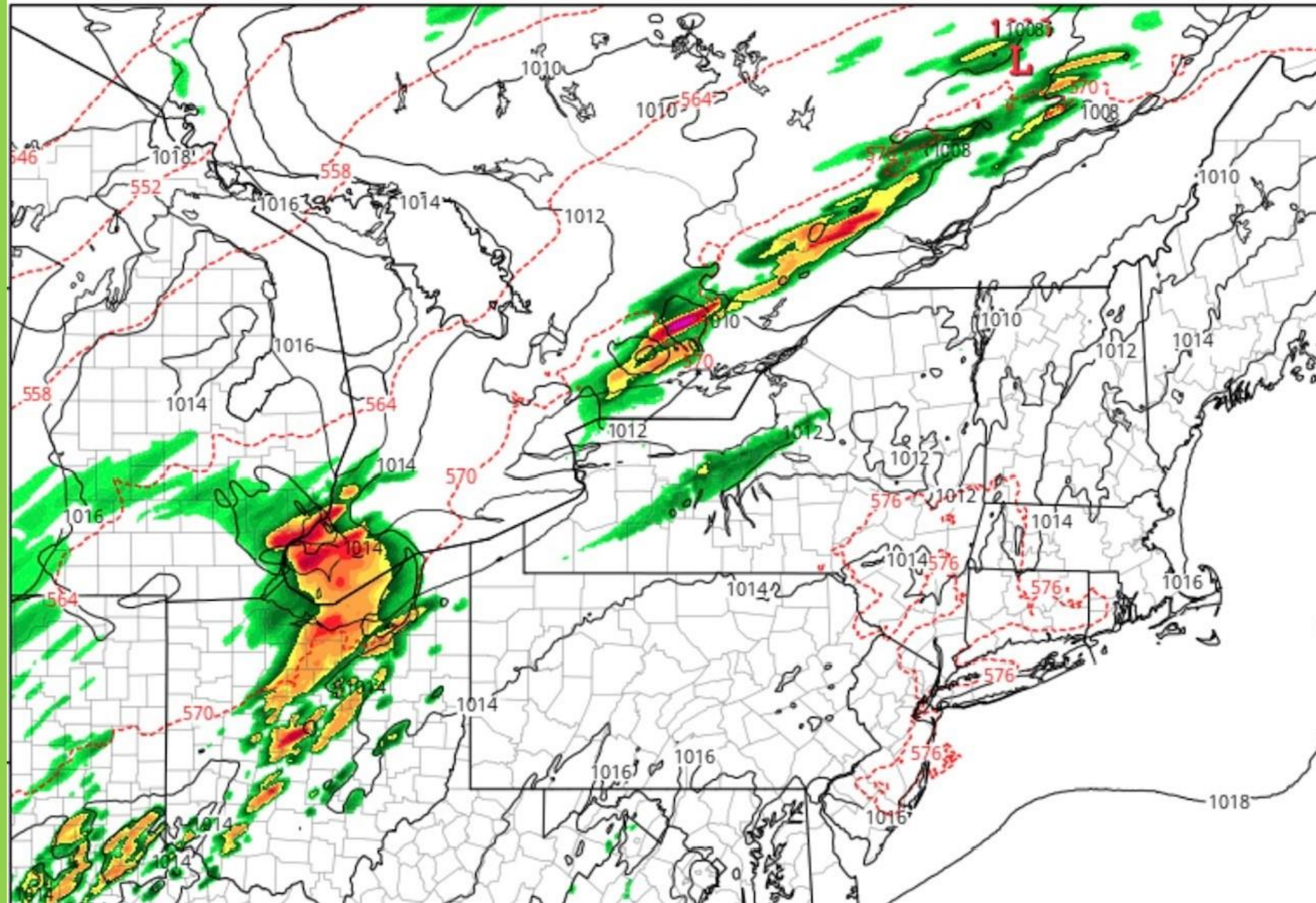
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [7] valid at 19z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





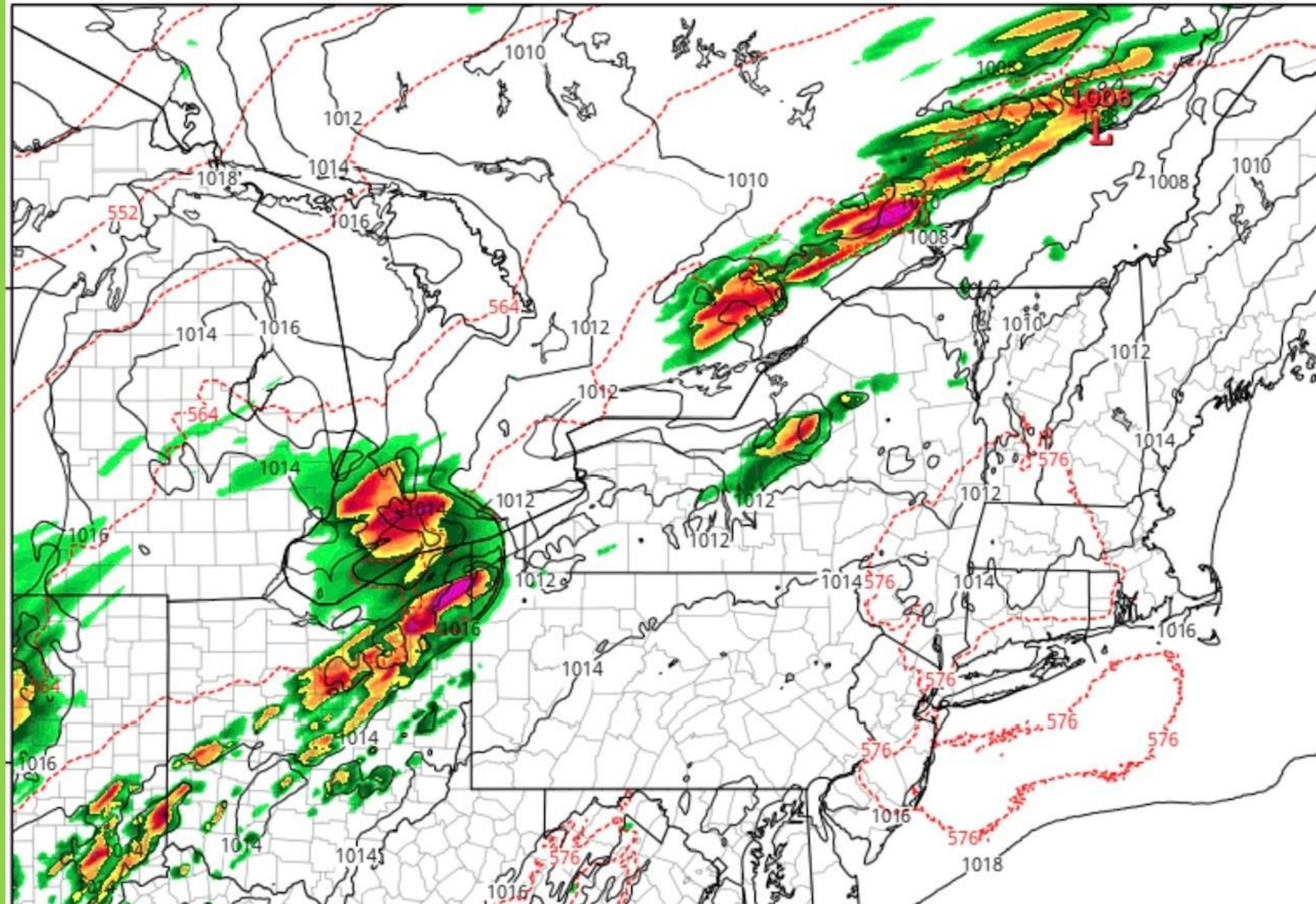
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [8] valid at 20z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





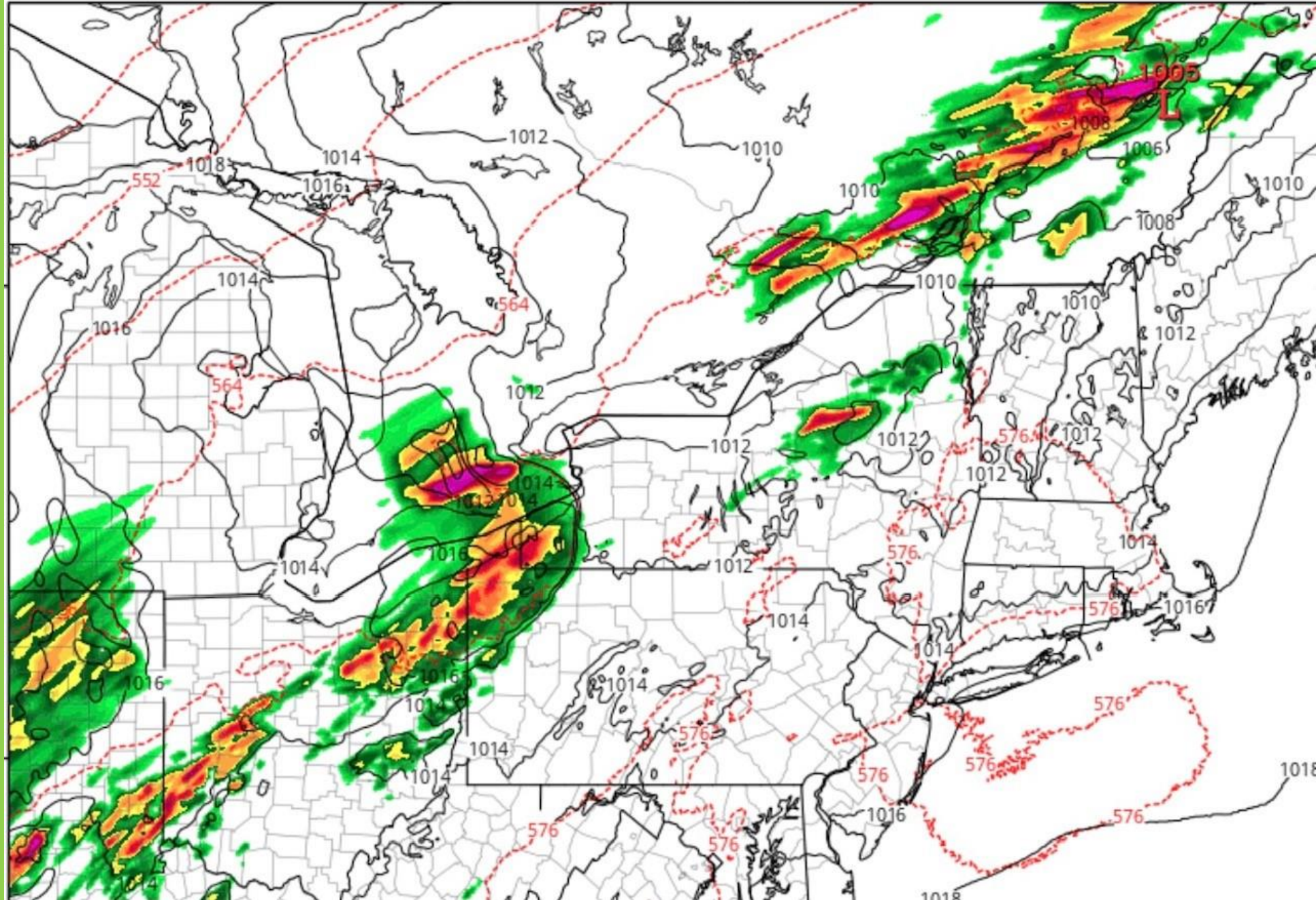
HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [9] valid at 21z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





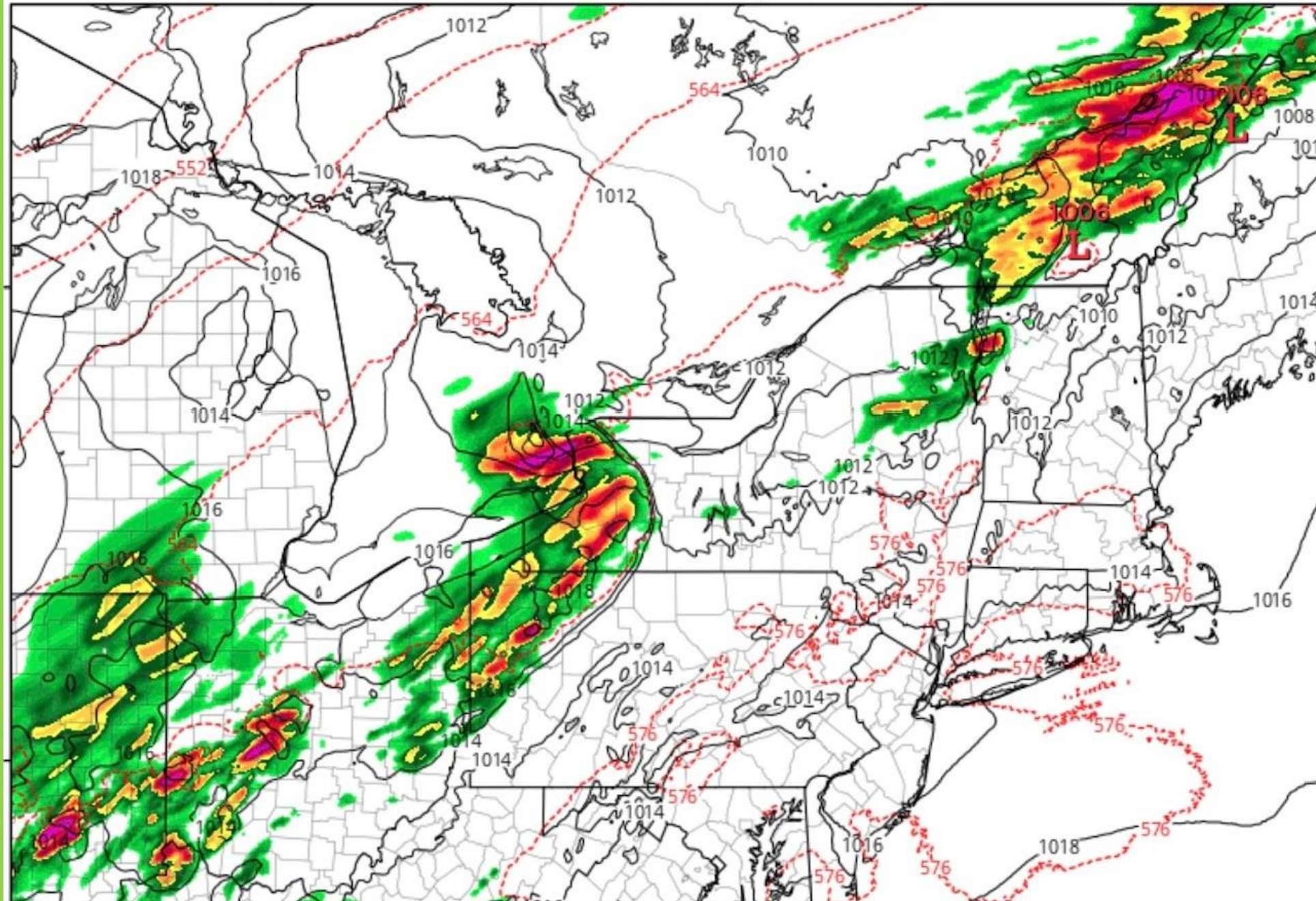
# HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [10] valid at 22z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





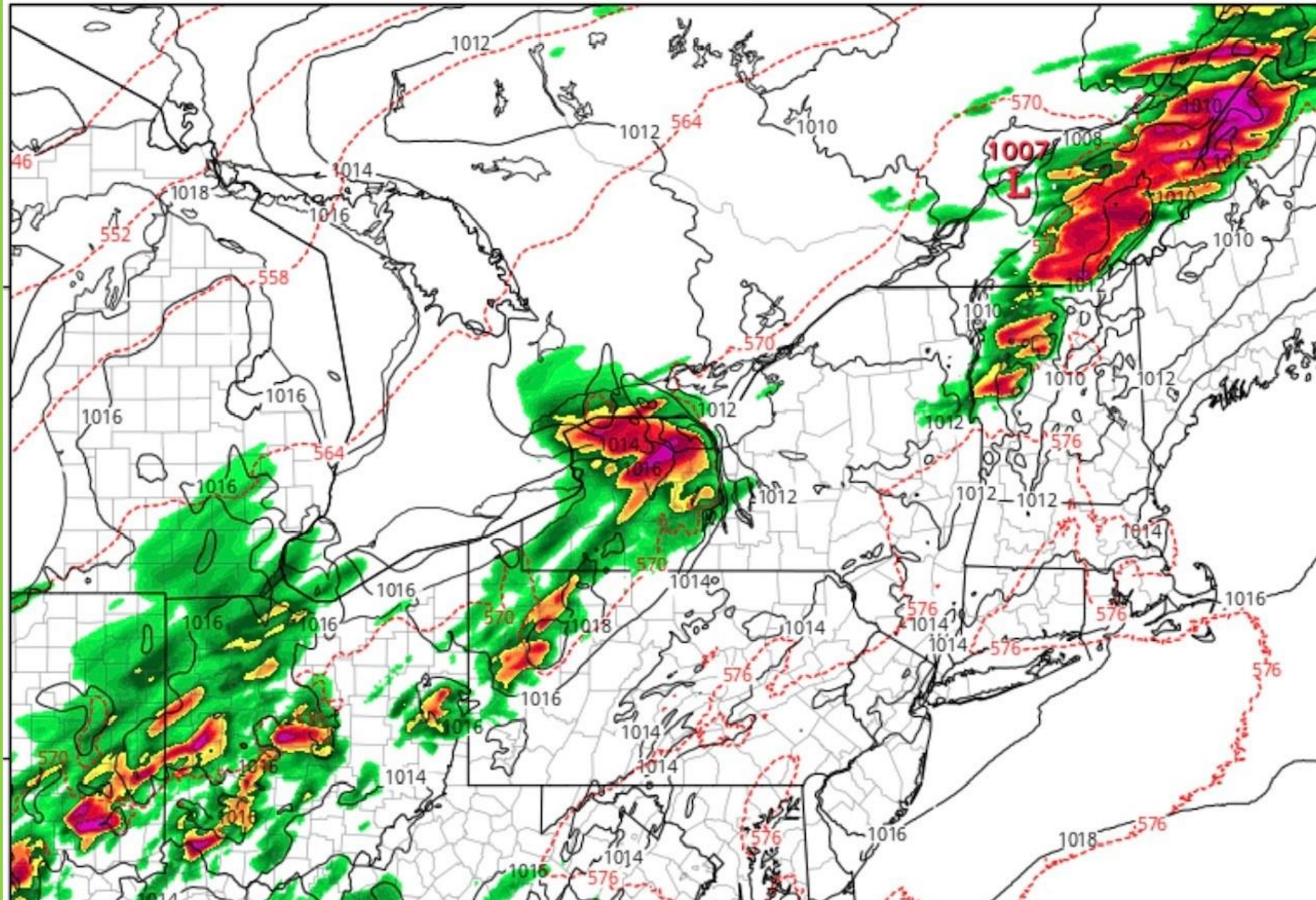
HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [11] valid at 23z Sat, May 21 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?





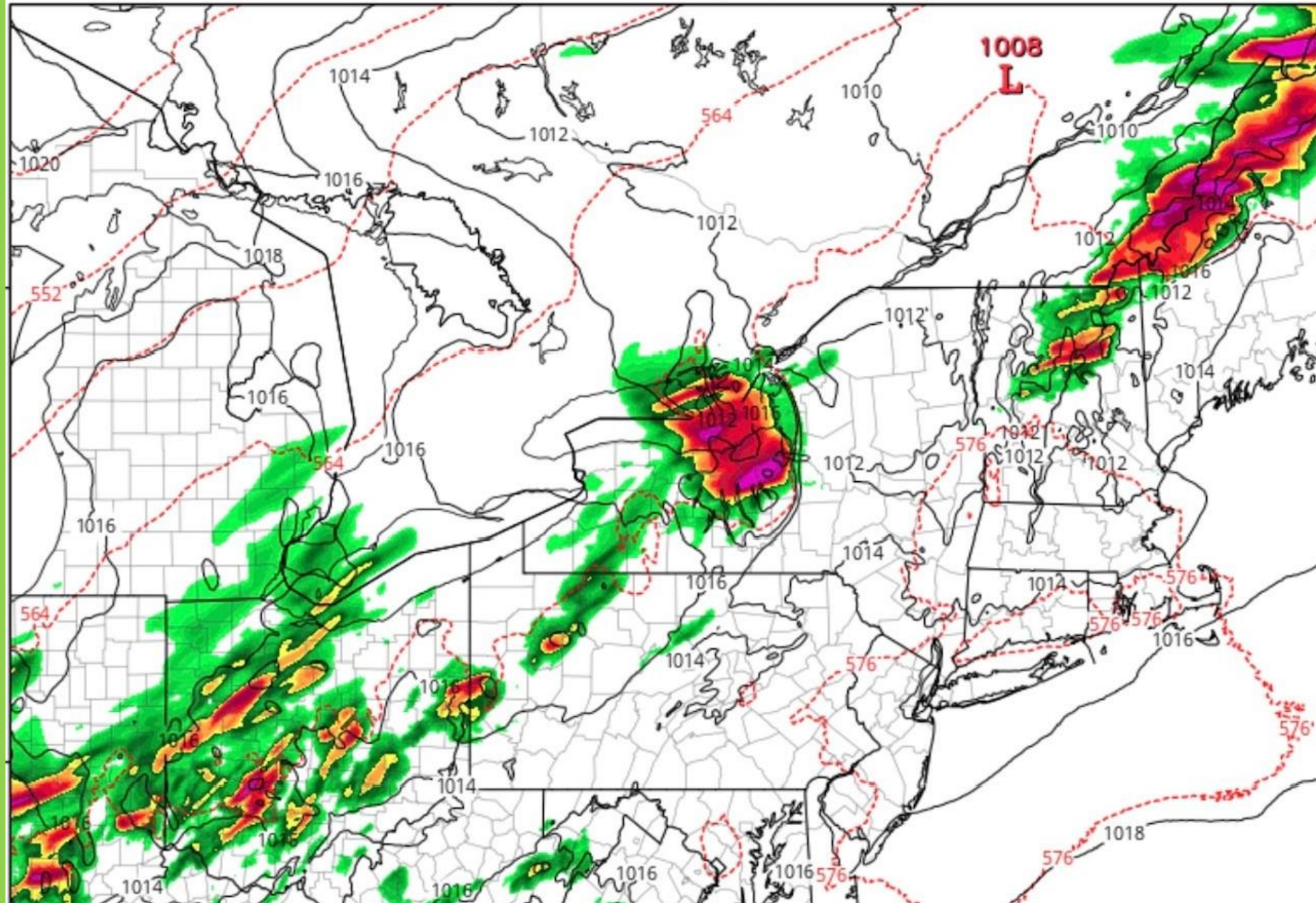
HRDPS 1-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z May 21 2022 Forecast Hour: [12] valid at 00z Sun, May 22 2022

*Model World*  
May 21 2022

HRDPS 12Z run  
Precip Rate  
(hourly 15-24Z)

Typical cellular convective  
day? More robust QLCS  
late in day?



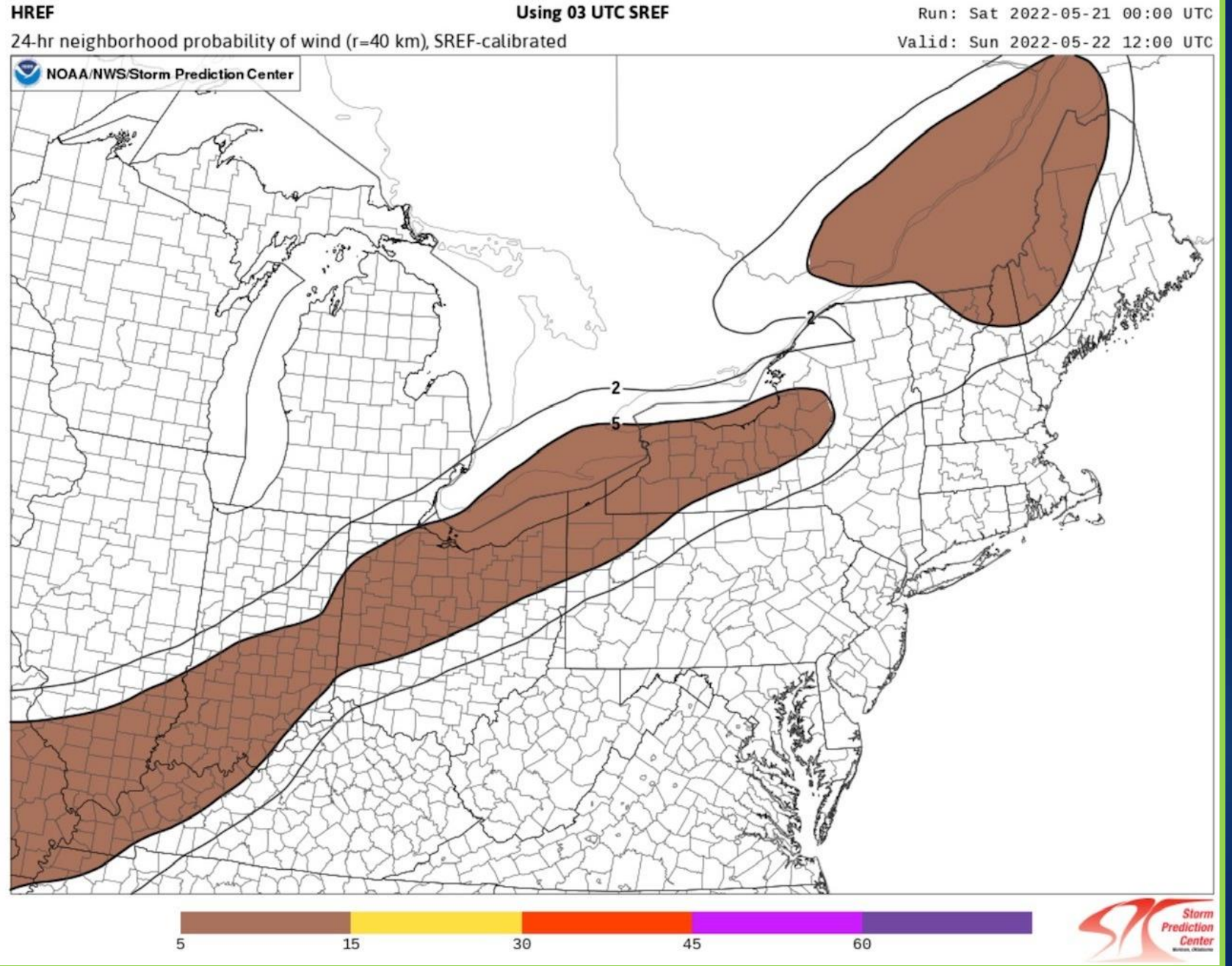


*Model World*  
May 21 2022

HREF 00Z run

24 hour PROB WIND

Not a strong 'signal'  
(and a little too far south).

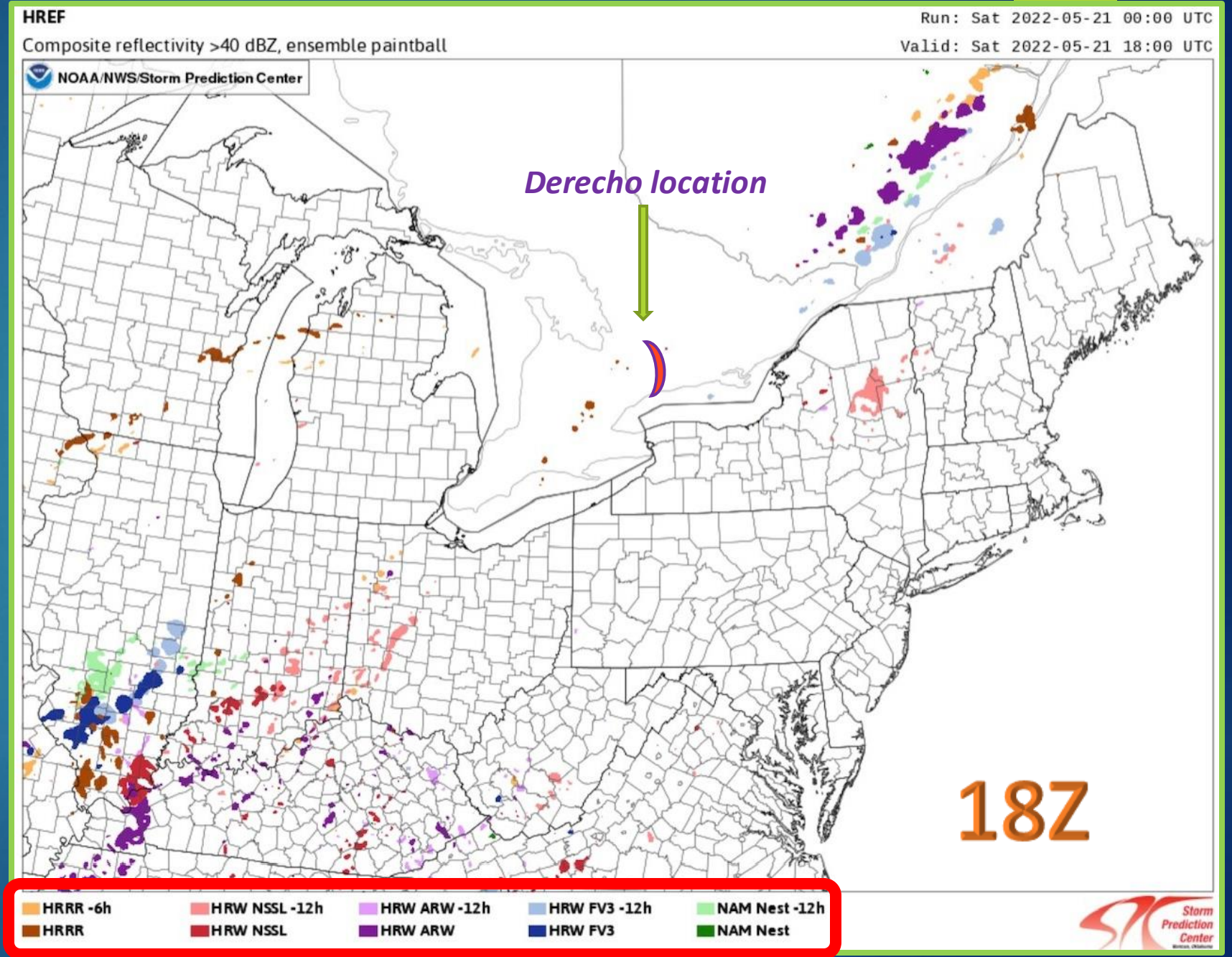




*Model World*  
*May 21 2022*

HREF  
(00Z run)

Composite Reflectivity  
> 40 dBZ (paintball ensemble)

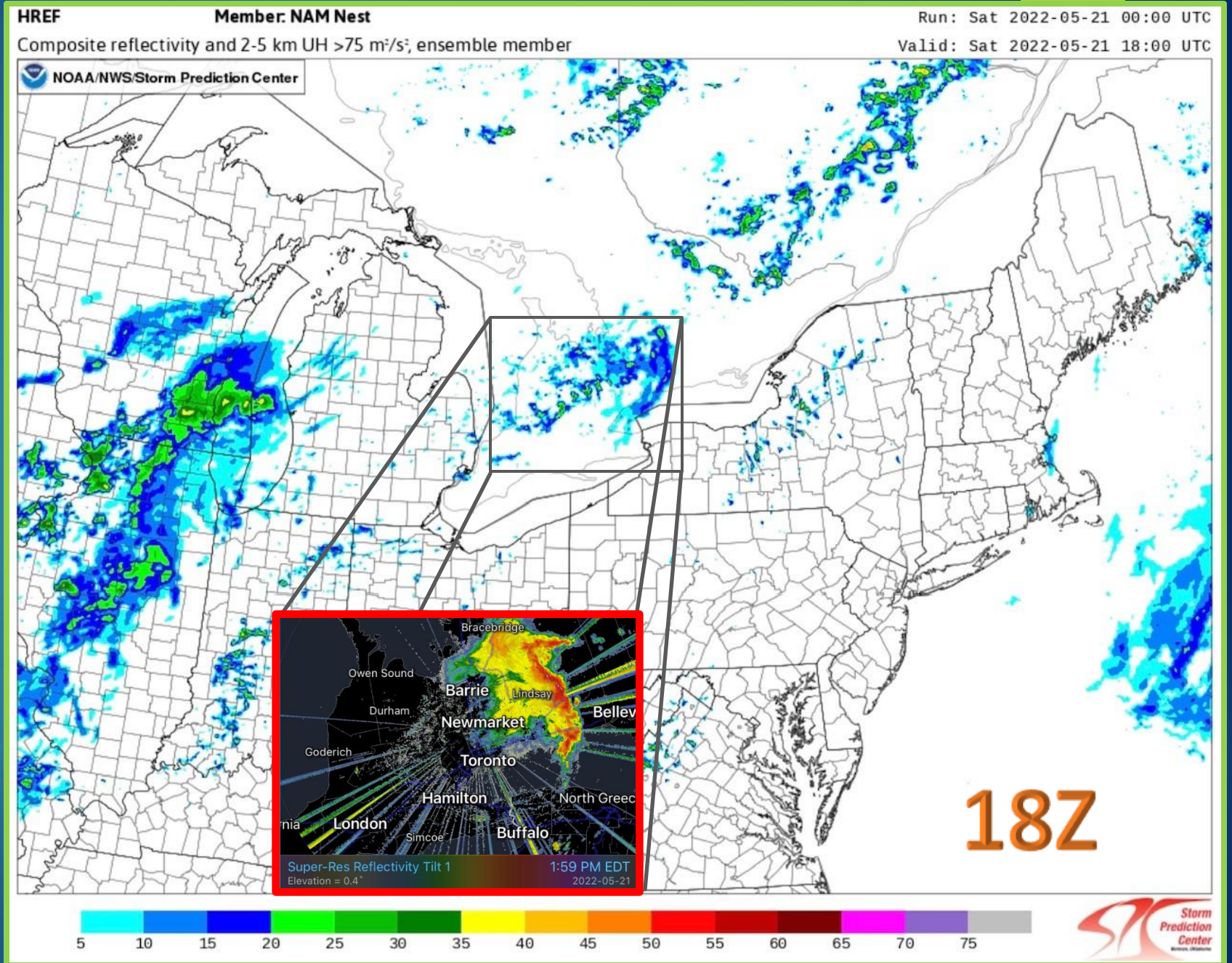




*Model World*  
*May 21 2022*

NAM Nest  
(00Z run)  
Composite Reflectivity

‘Semblance’ of a  
convective band.



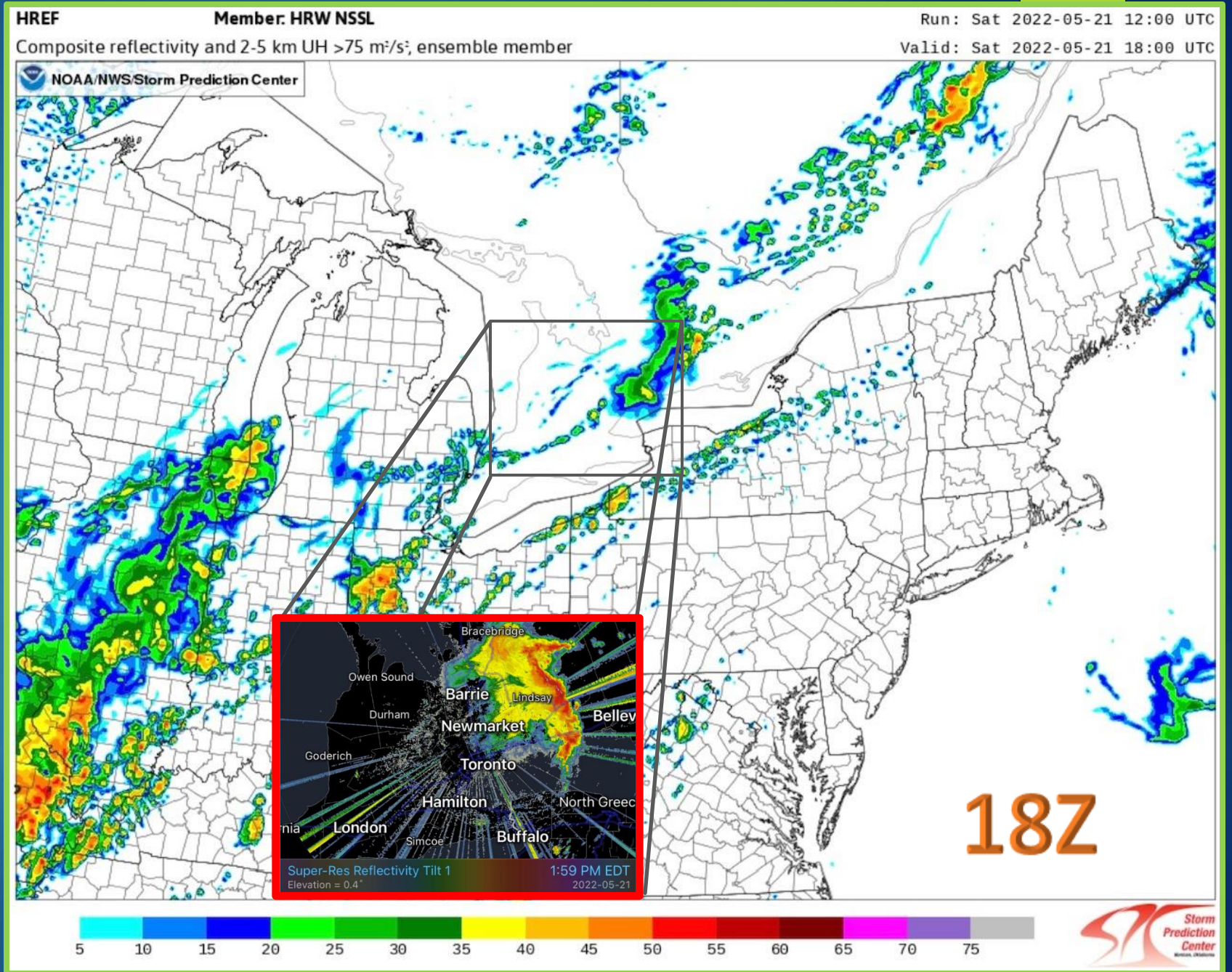


*Model World*  
*May 21 2022*

The 'much loved' NSSL  
(12Z run)

Composite Reflectivity

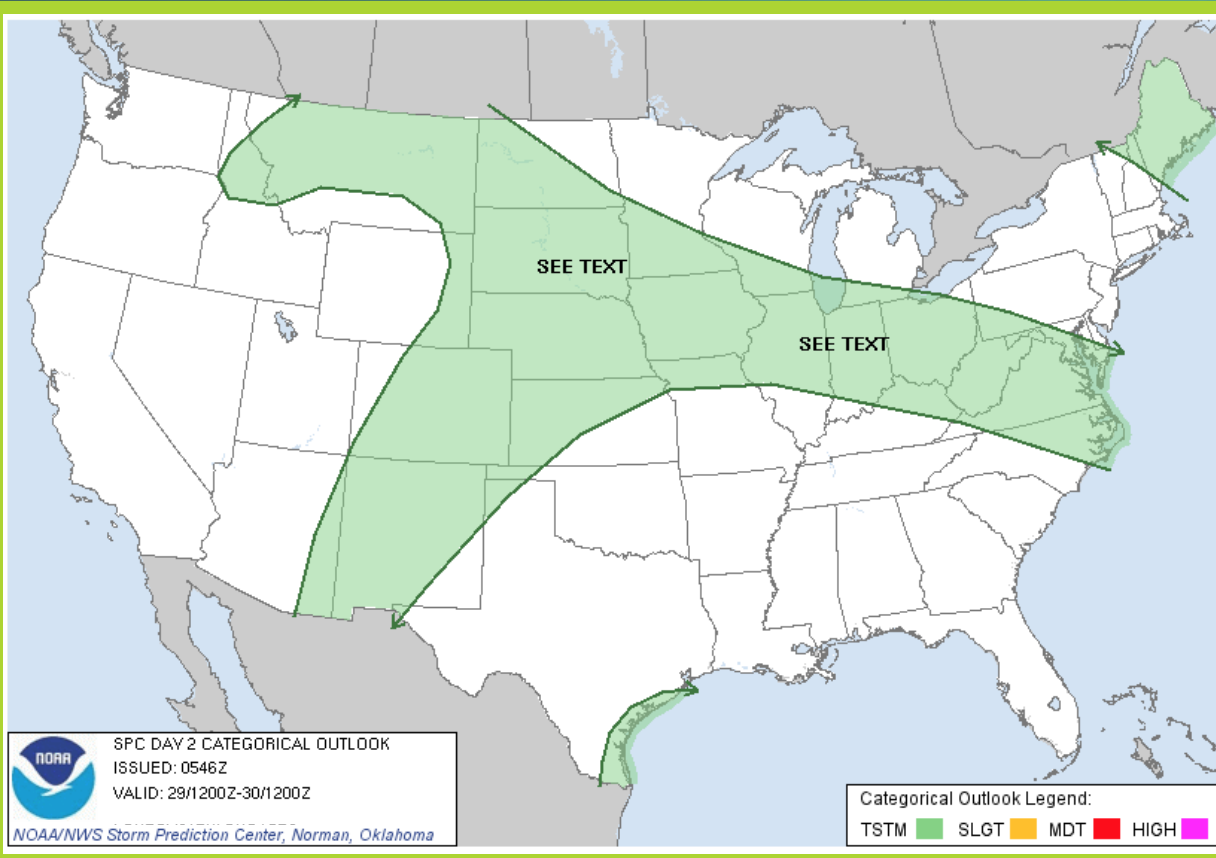
'Semblance' of a  
convective band.



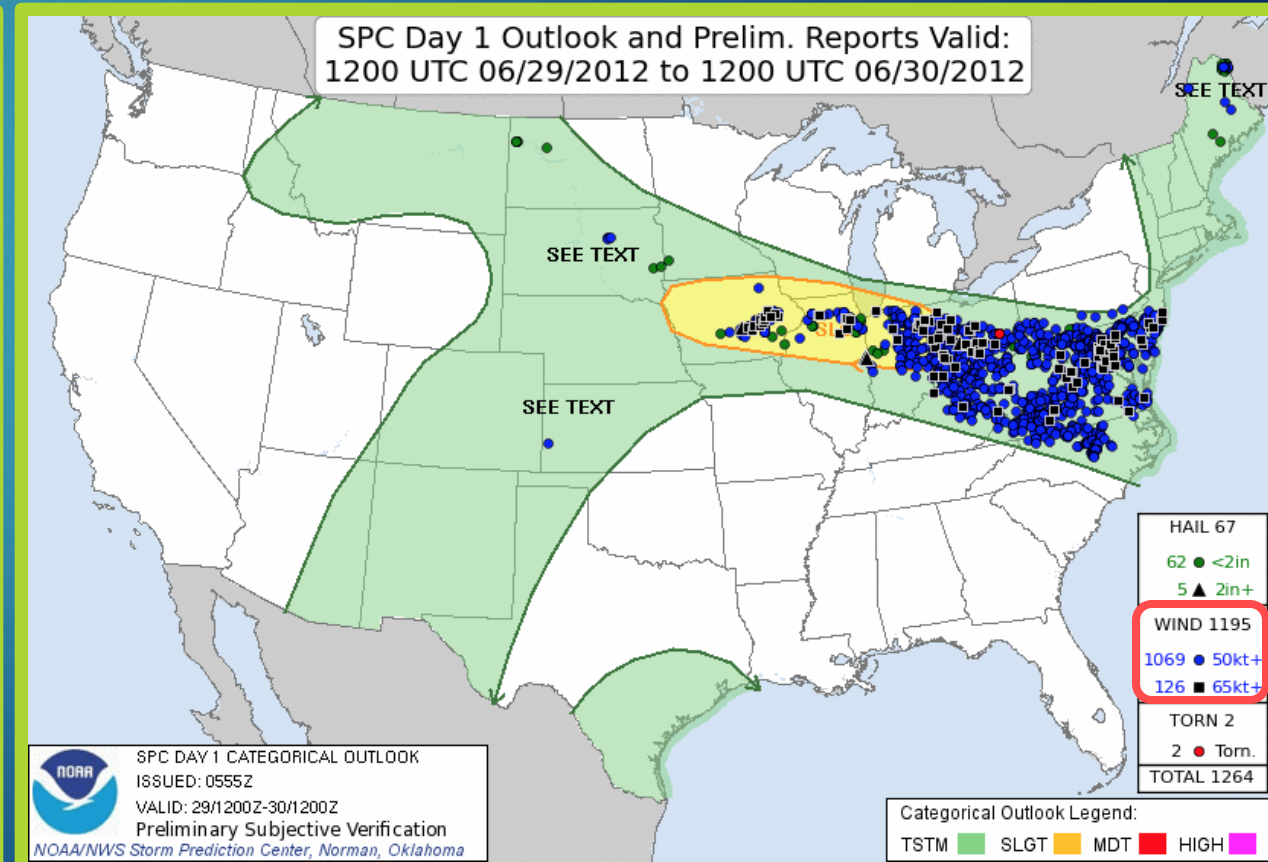
# The 'Problematic' Progressive Derecho of June 29 2012 (*'Ring of Fire Derecho'*)

❑ **Not well forecast** in advance: NAM and GFS provided little assistance. Some CAMs clued in the morning of.

## SPC's Day TWO Forecast



## SPC's Day ONE Forecast & Verif





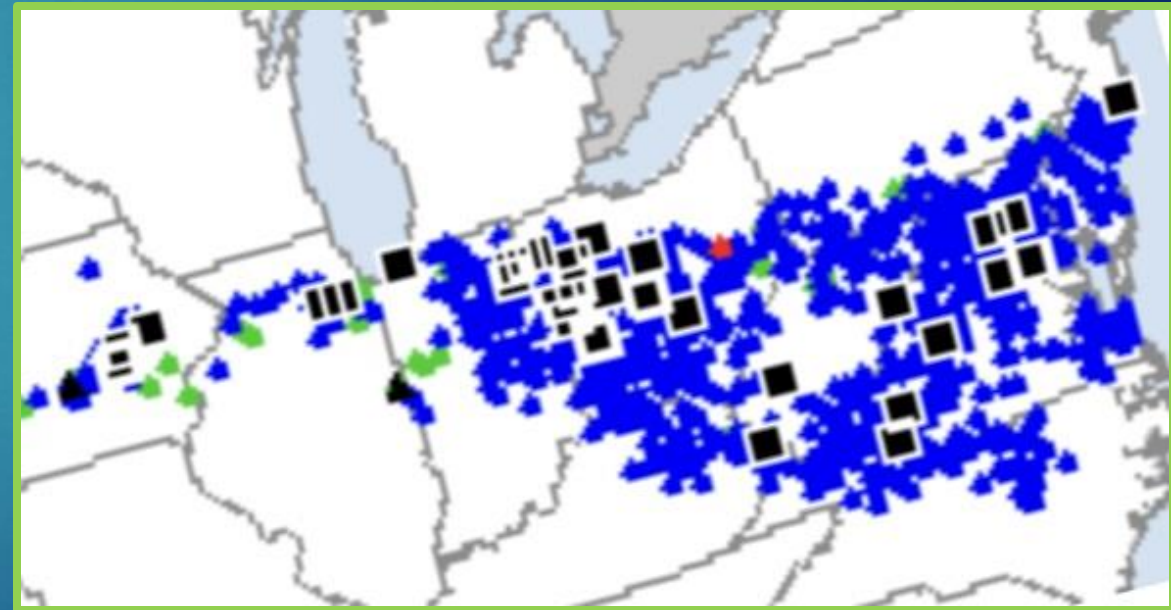
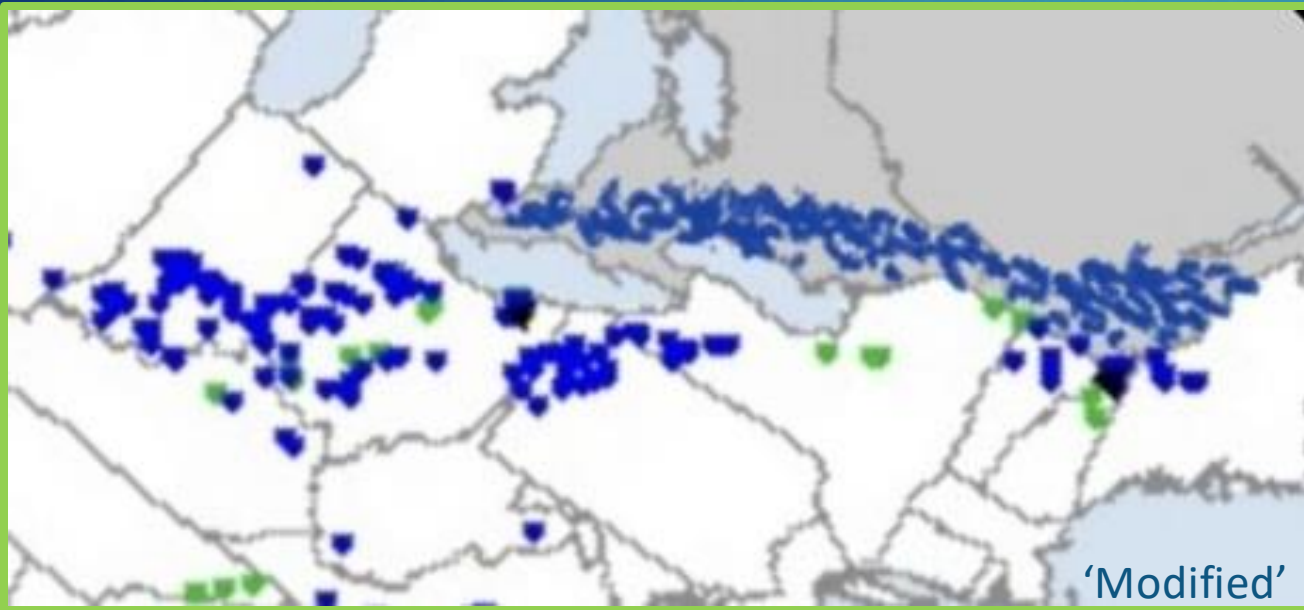
*Progressive Derecho  
Case Comparison*

May 21 2022

**Storm Reports**

June 29 2012

**Direction of Motion / Orientation 'normalized' for ease of comparison**



(SPC Storm Reports)

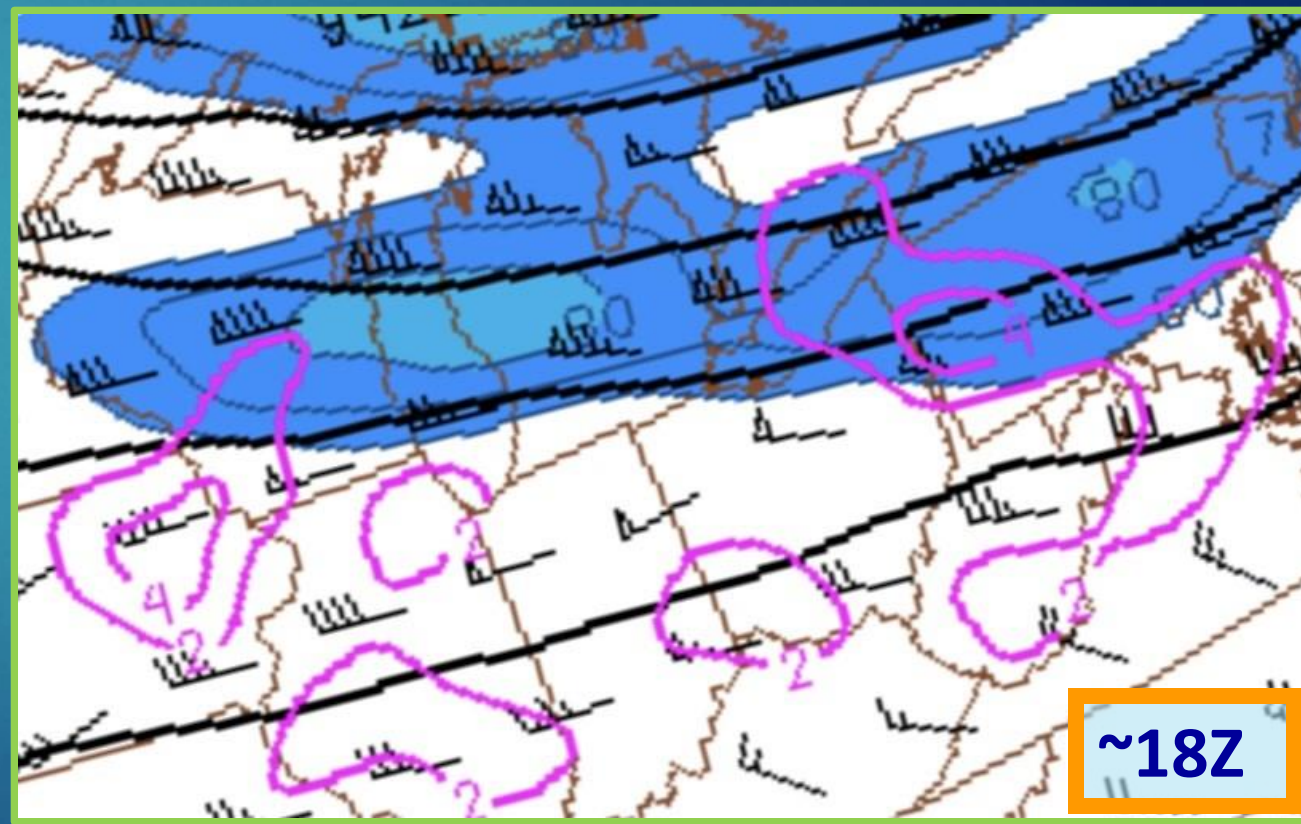
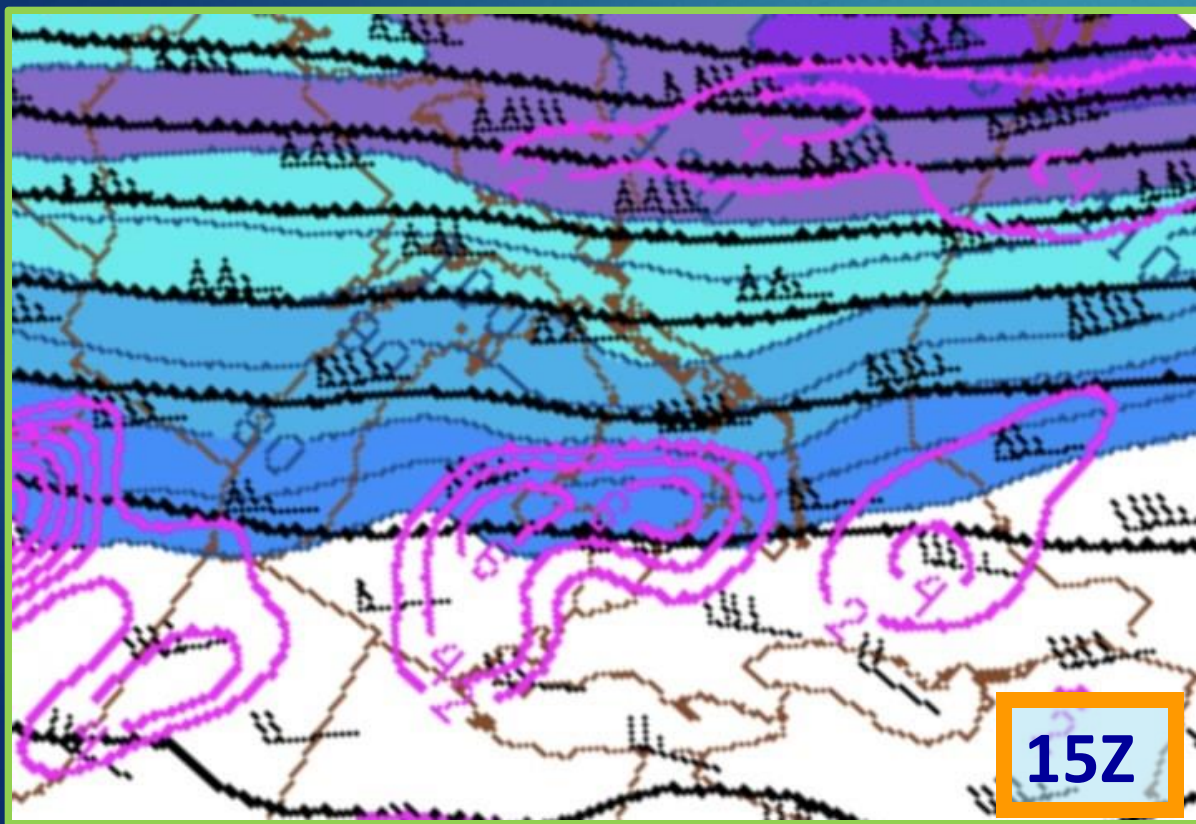
# Case Comparison

May 21 2022

300 mb JET

June 29 2012

'Snap Shots' about an hour or two from event start time



(SPC Mesoanalysis)

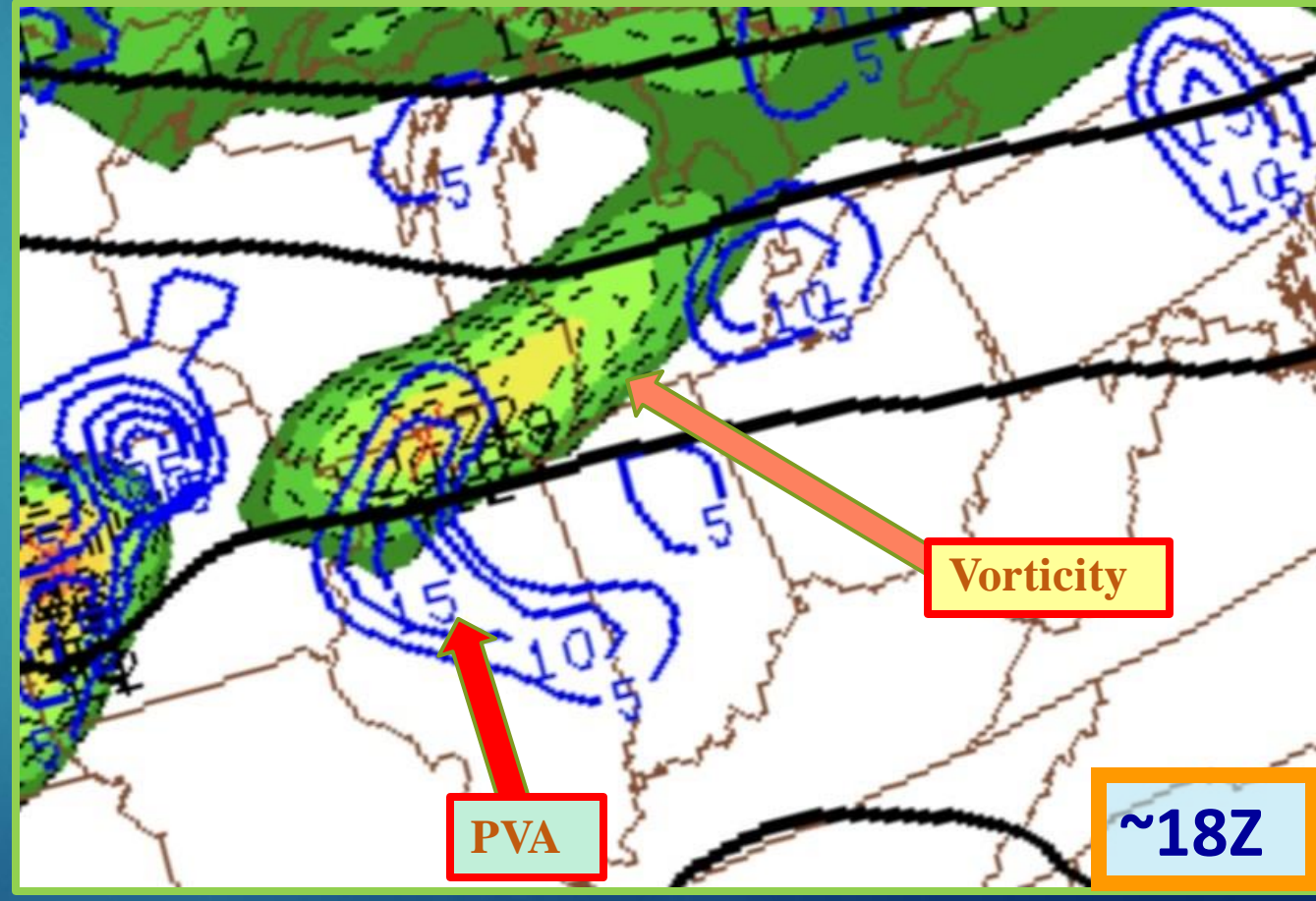
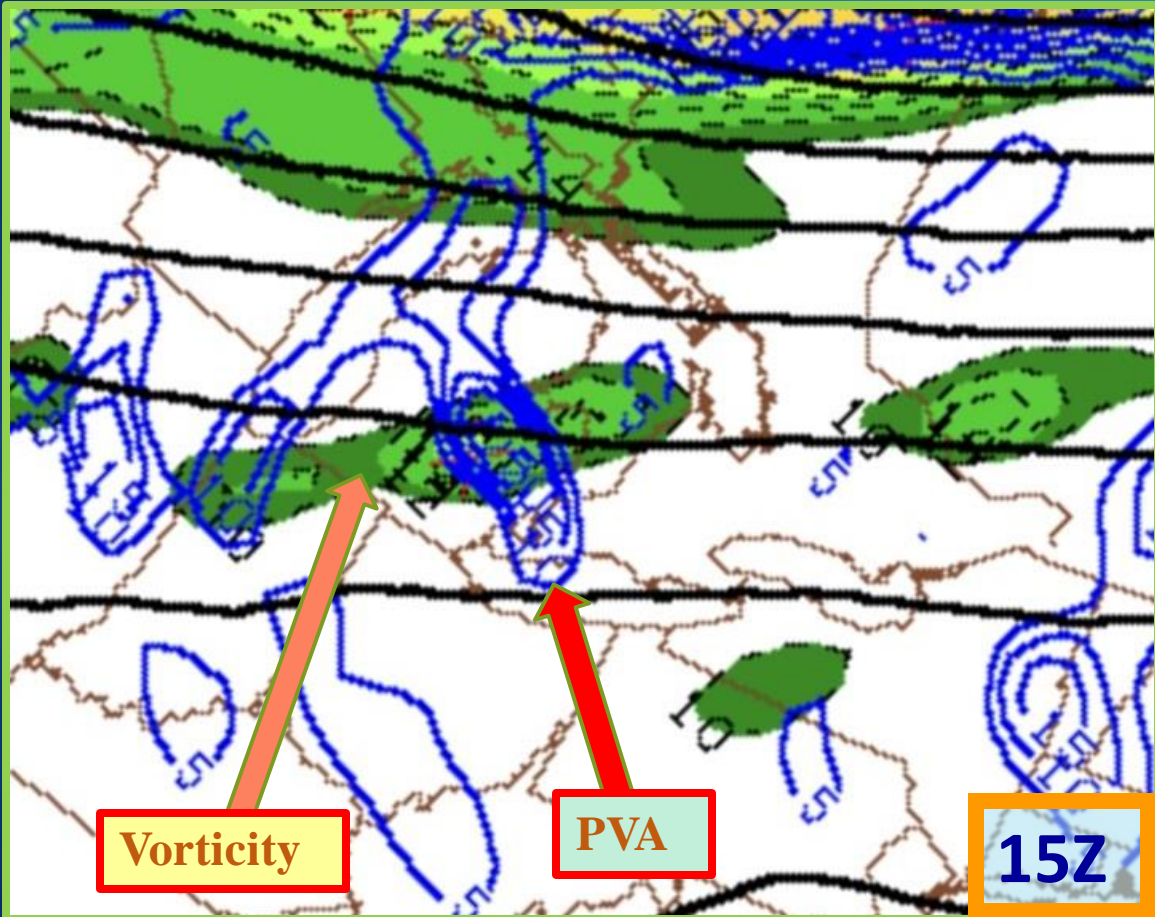


# Case Comparison

May 21 2022

500 mb VORT

June 29 2012



(SPC Mesoanalysis)

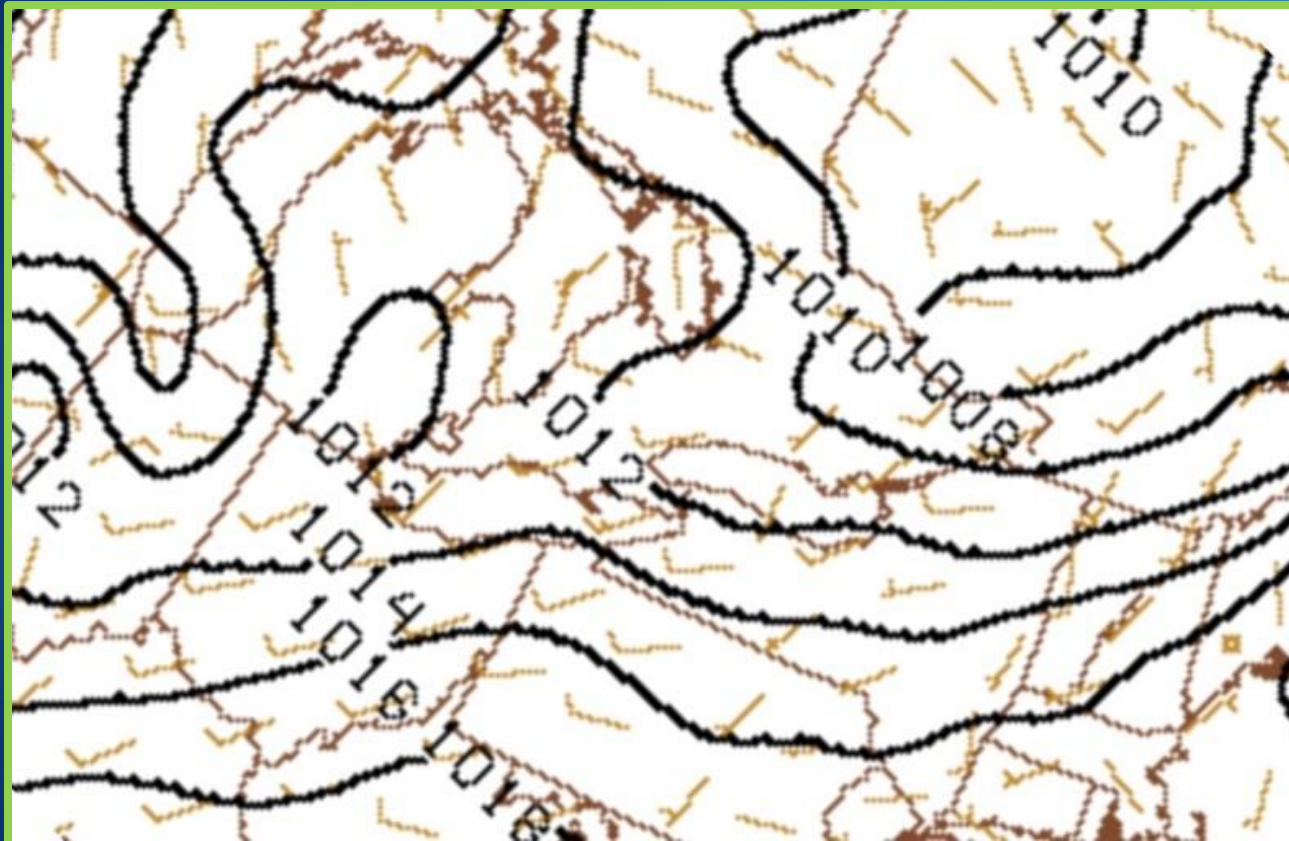


# Case Comparison

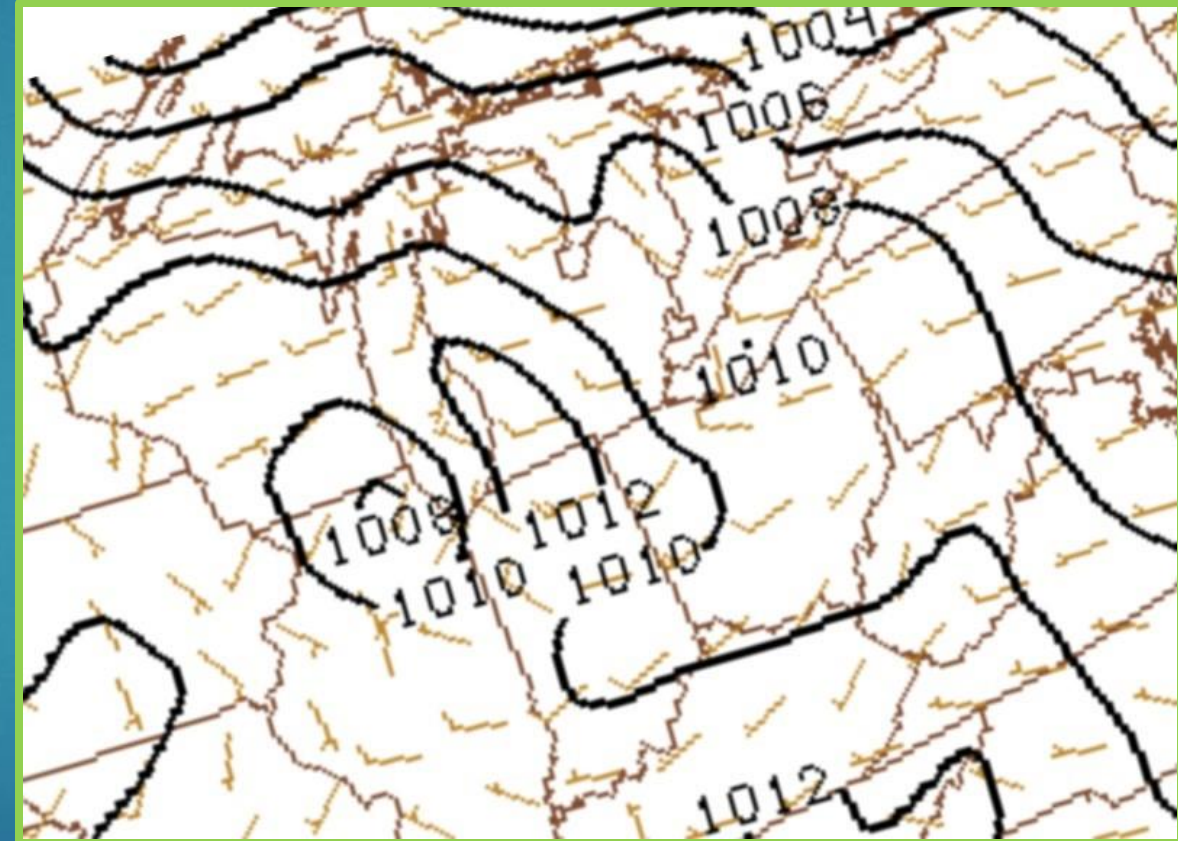
May 21 2022

MSLP

June 29 2012



15Z



~18Z

(SPC Mesoanalysis)

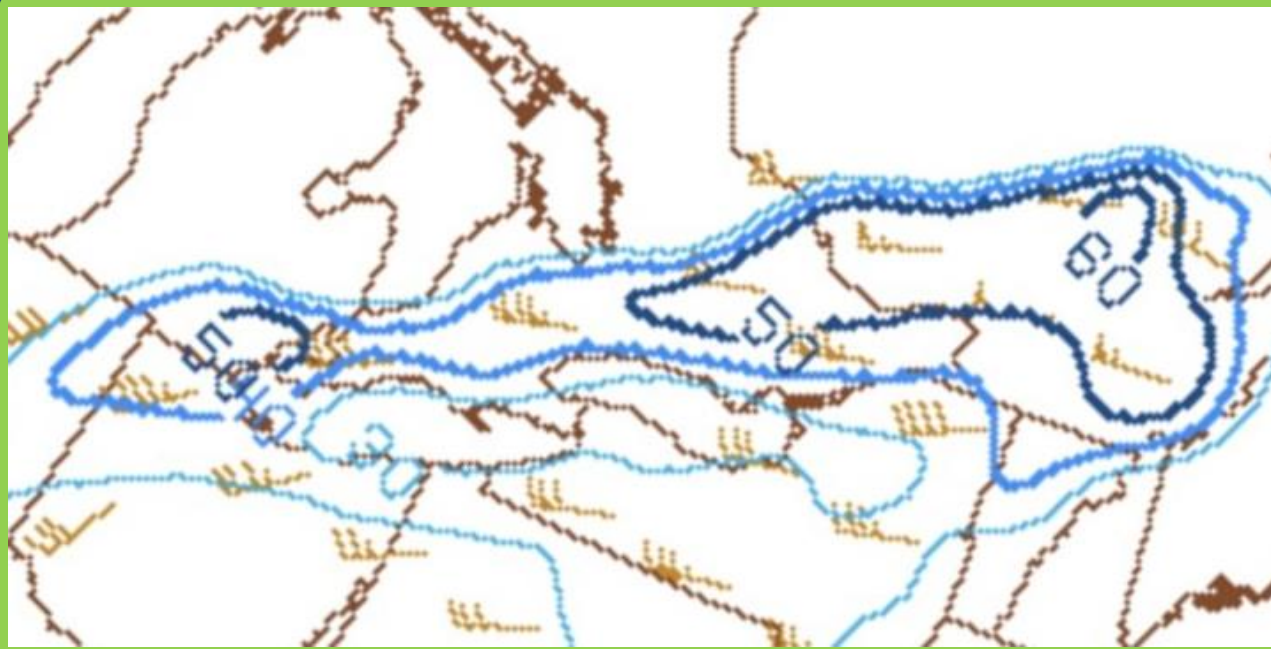


# Case Comparison

May 21 2022

## Effective Shear

June 29 2012



15Z



~18Z

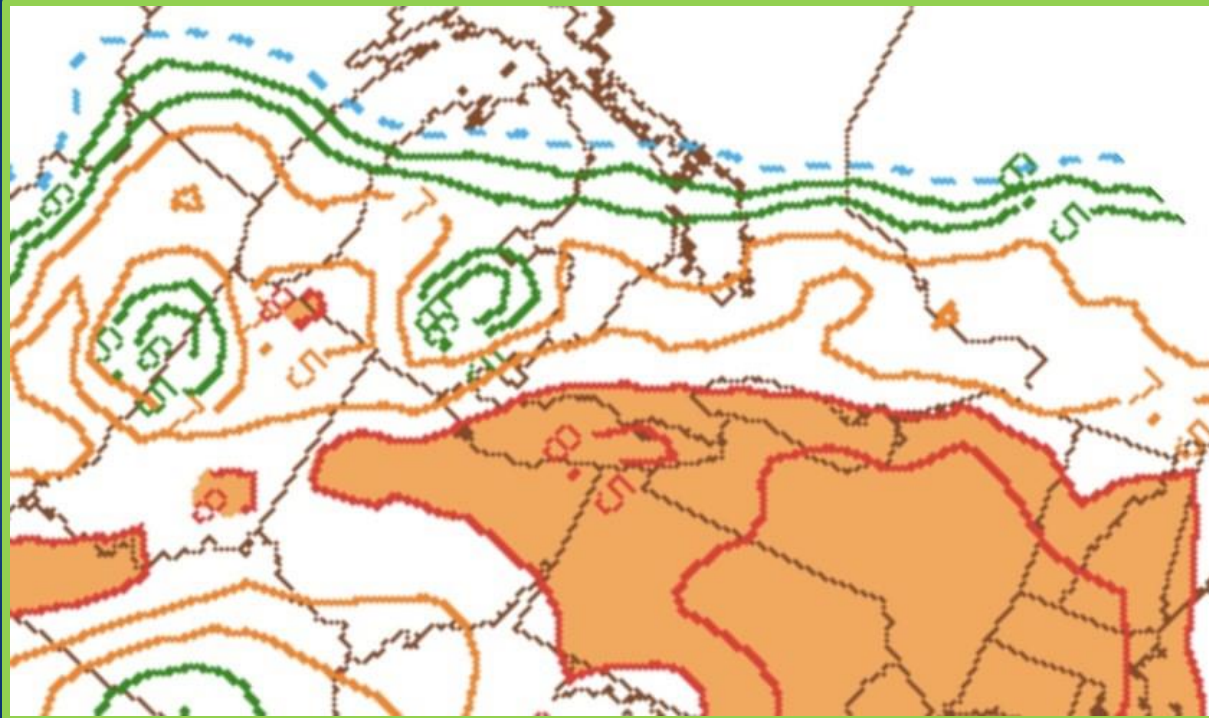
(SPC Mesoanalysis)

# Case Comparison

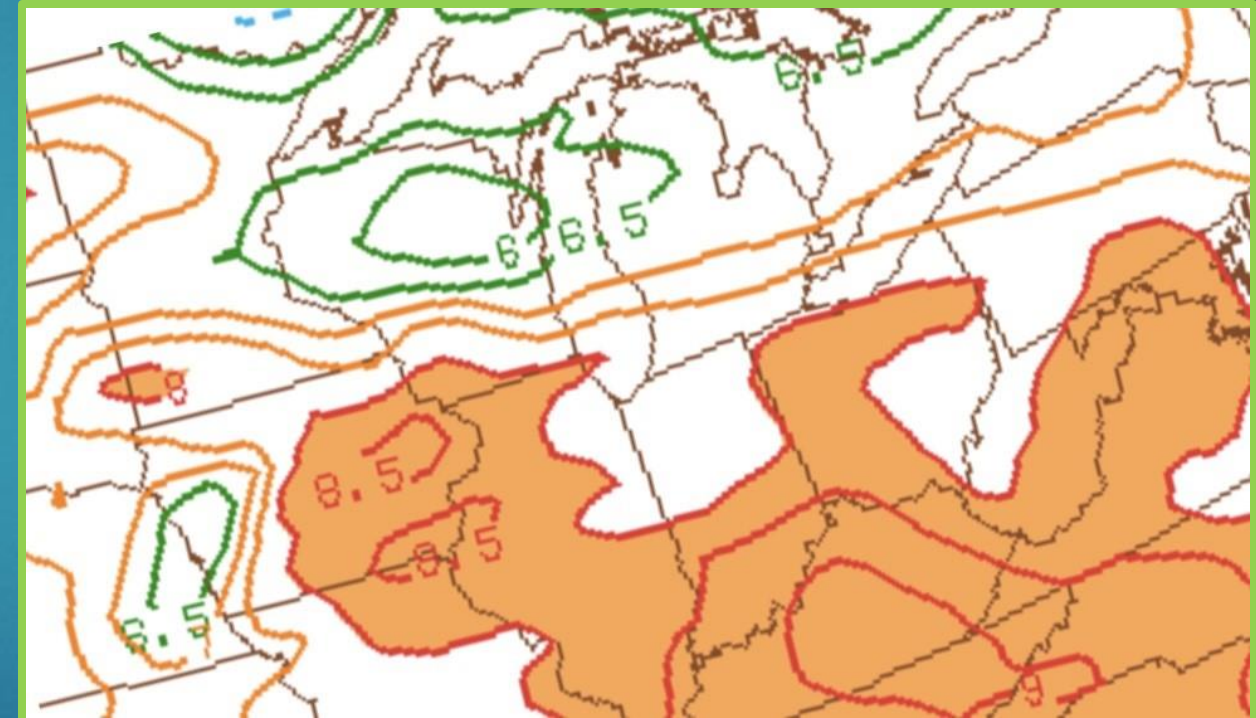
May 21 2022

## Mid-level Lapse Rates

June 29 2012



15Z



~18Z

(SPC Mesoanalysis)

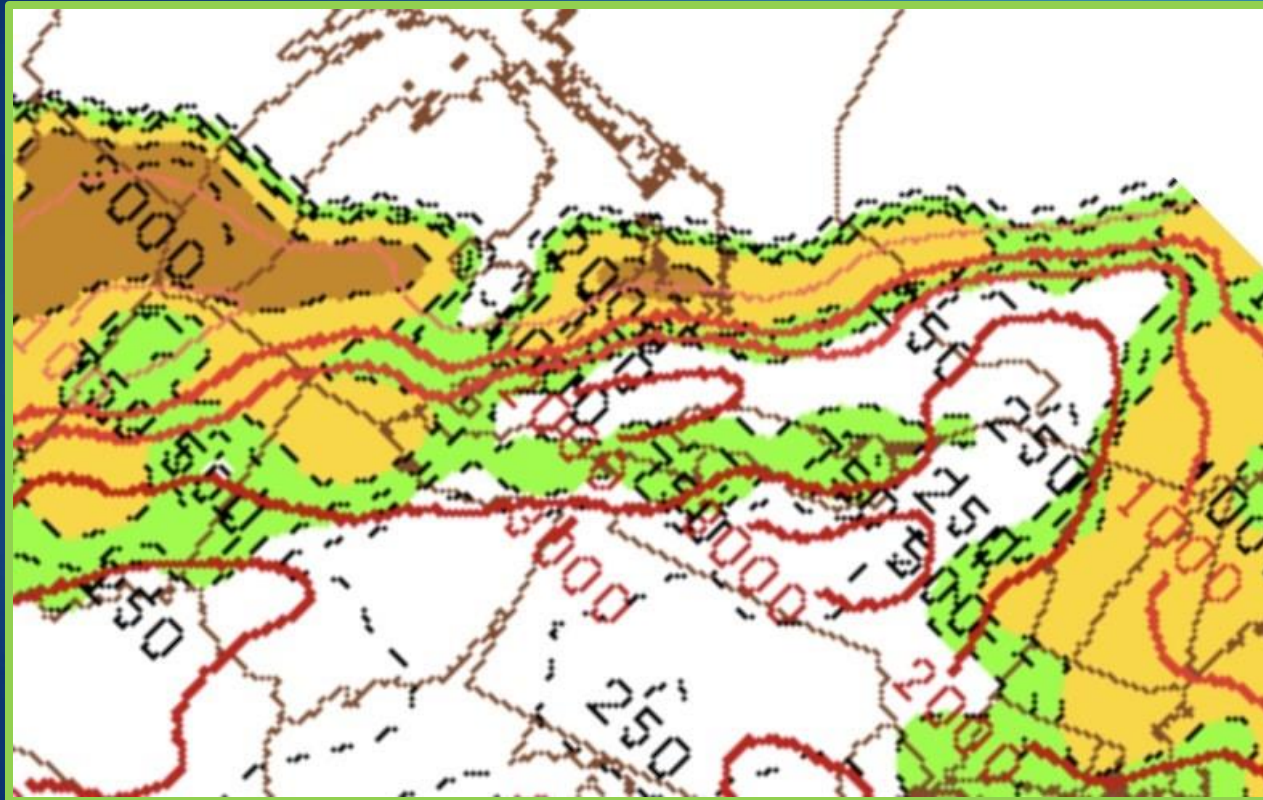


# Case Comparison

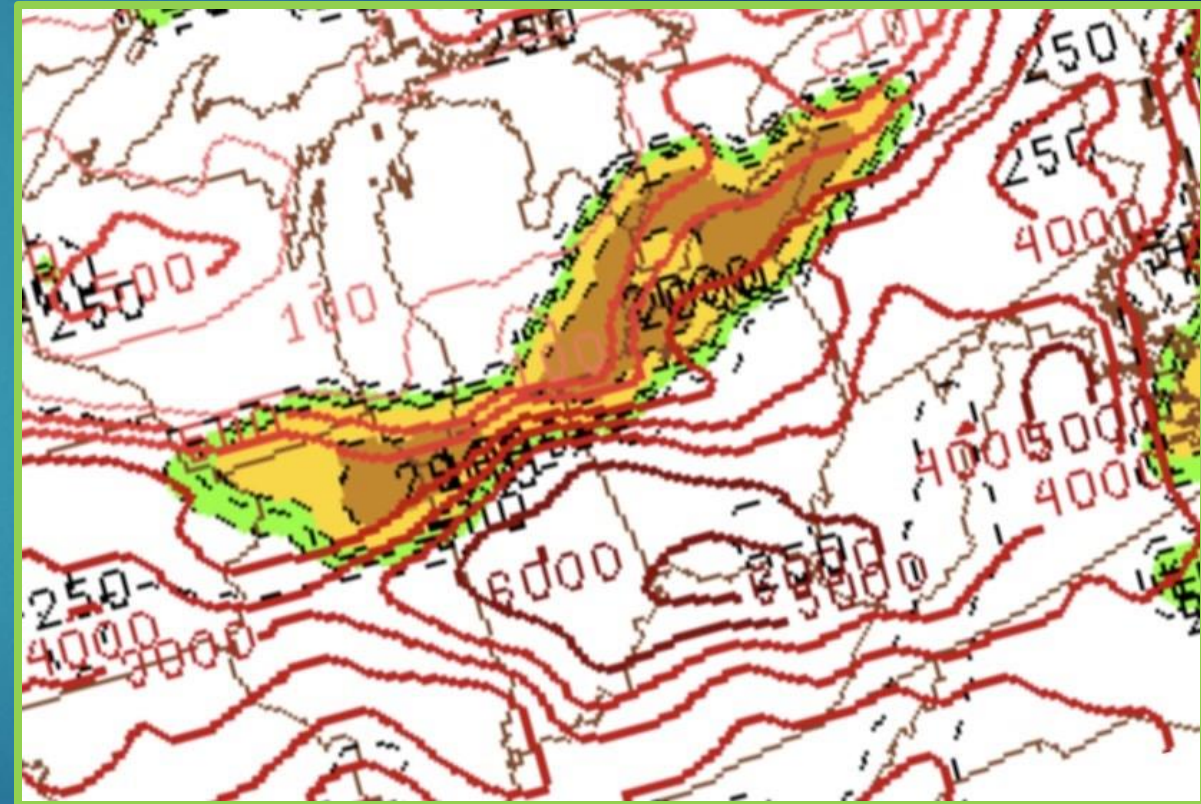
May 21 2022

MUCAPE

June 29 2012



15Z



~18Z

(SPC Mesoanalysis)

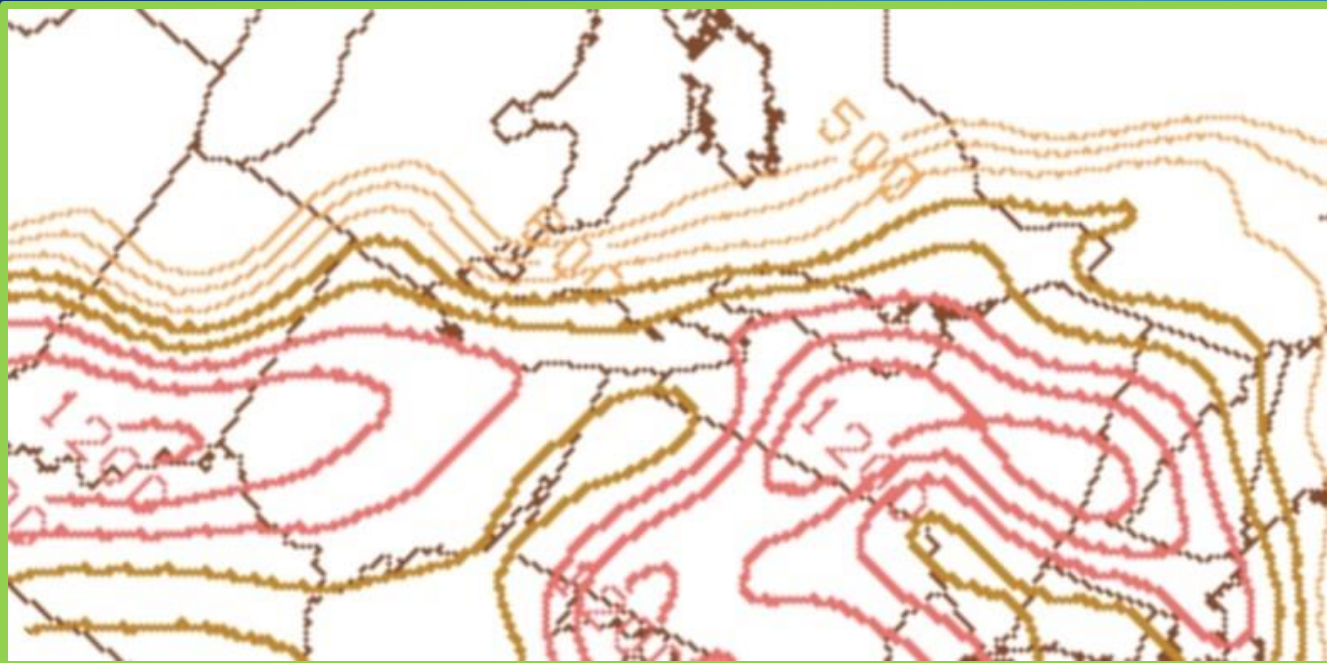


# Case Comparison: Overall MANY similarities

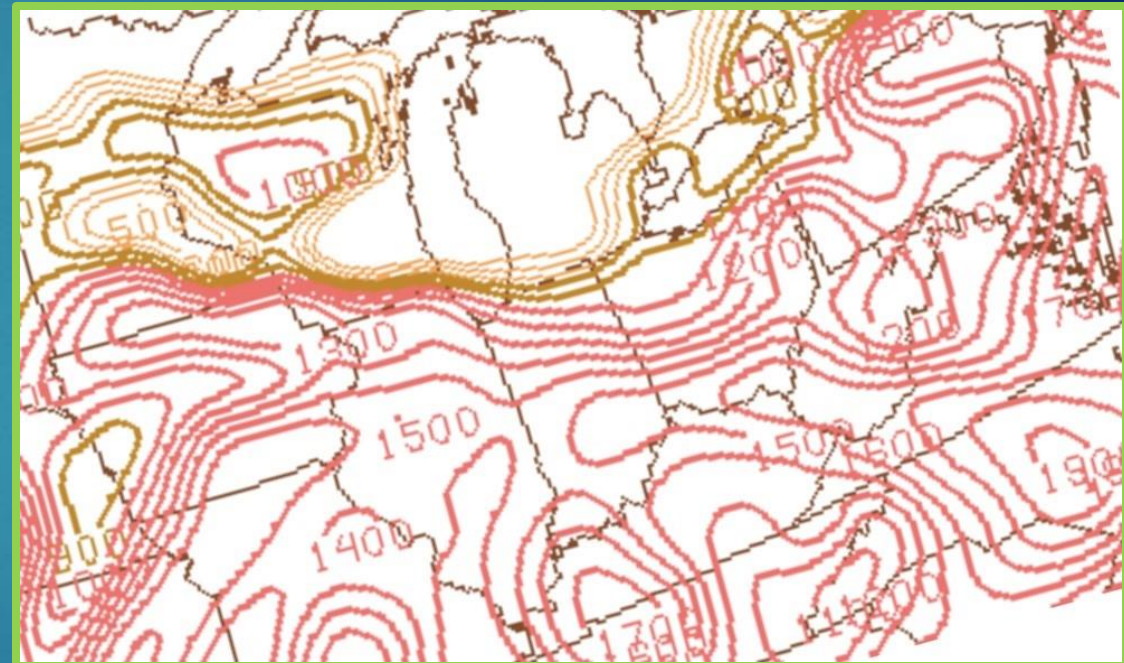
May 21 2022

DCAPE

June 29 2012



15Z




~18Z

(SPC Mesoanalysis)

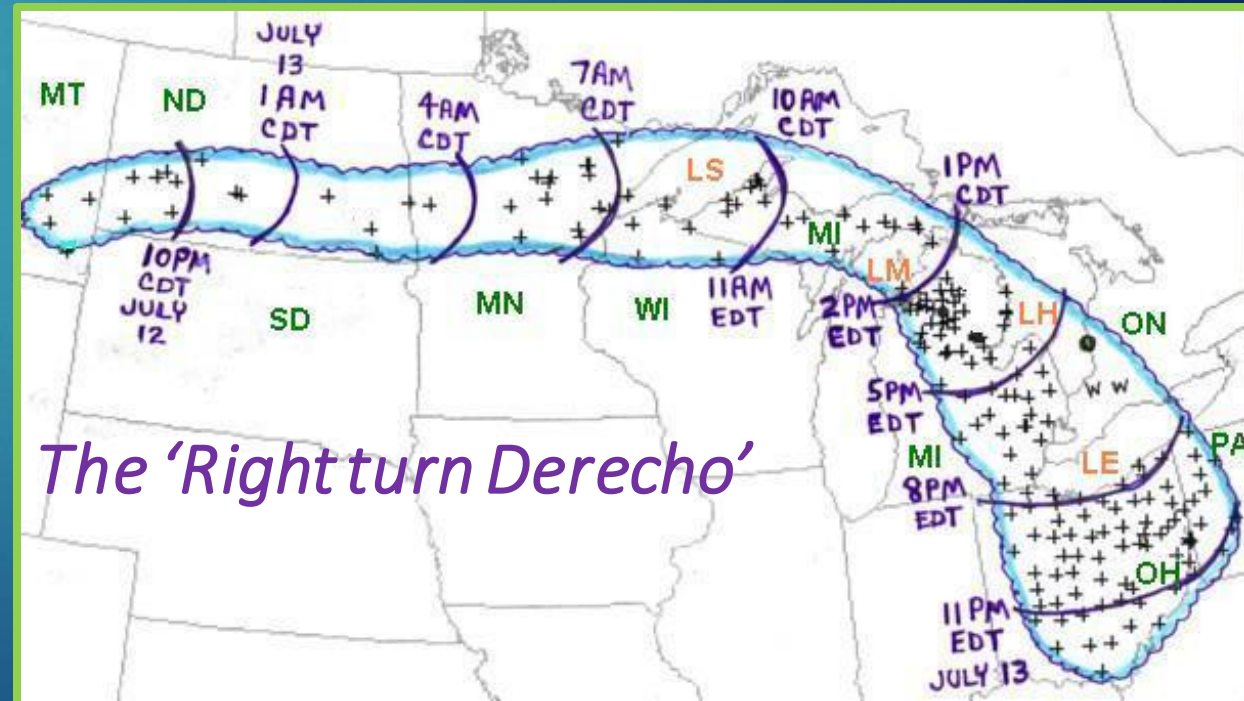
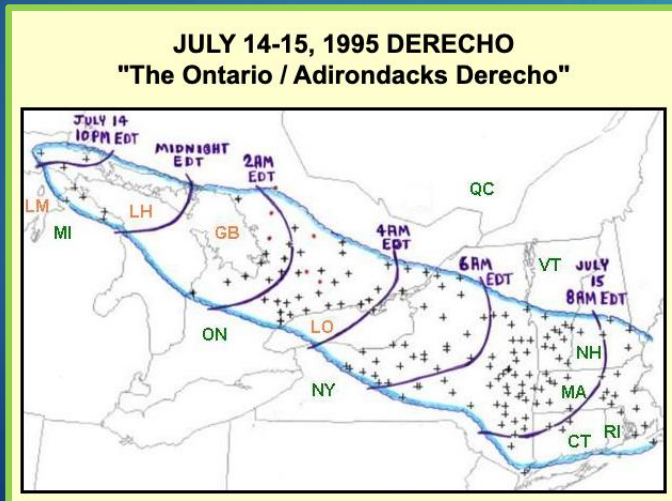
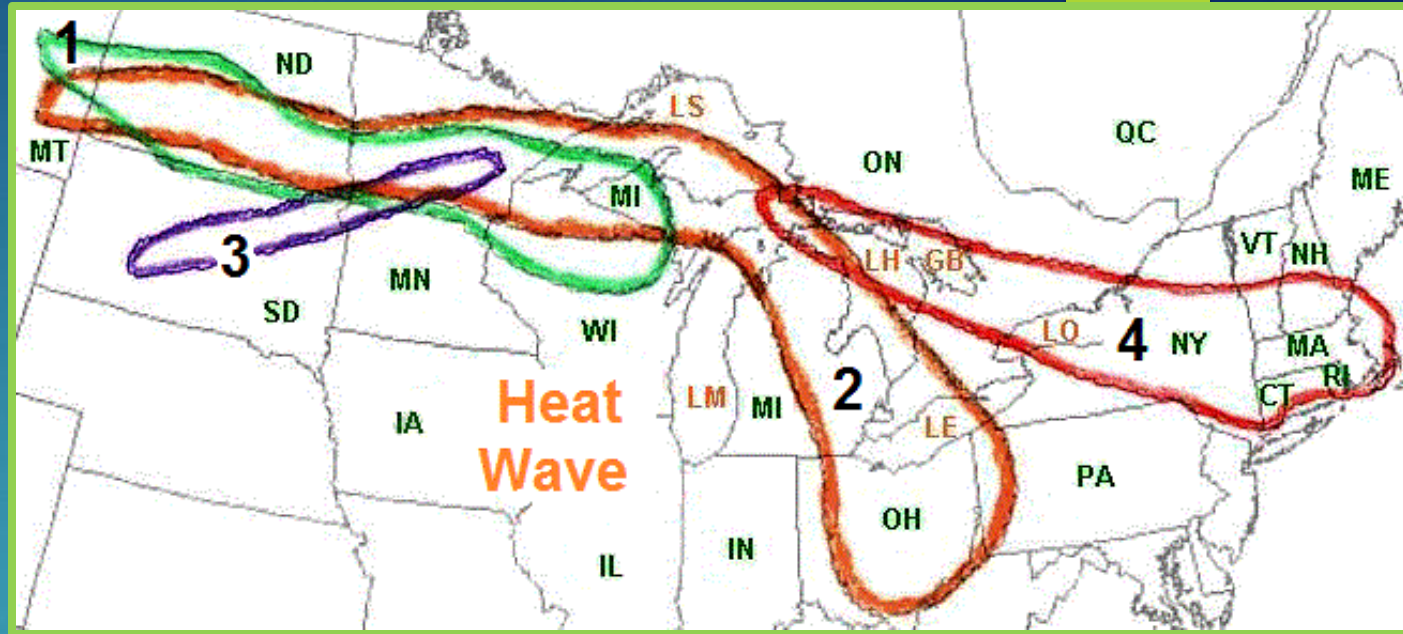


## *Standout observations of the May 21 2022 Derecho:*

- ❑ Extraordinary system **speed** of 120 km/h: **the NUMBER ONE DERECHO INDICATOR** (emphasized by Rich).
- ❑ Strength of **cold pool** (most dramatic temperature drop in our derecho versus non-derechos).
  - ❑ Our May 21 2022 derecho: **COLD 17-18C outflow temperature** (lapse rate **8.3**)
  - ❑ Our June 10 2020 (non-derecho) QLCS: **20-21C** (lapse rate 6.3)
  - ❑ Our July 19 2020 (non-derecho) QLCS: **20-21C** (lapse rate 6.4)
- ❑ **Duration** of strongest winds inside the belly of the cold pool (order of minutes compared to a shorter mean duration of other MCSs). (Linkages to strength and depth of cold pool?)
- ❑ Extraordinary **wind gusts** reported at several of our observation sites.
- ❑ Extraordinarily steep (700-500 mb mid-level) **lapse rates** (for Southern Ontario). 

# Nature's Derecho Lab: The Derecho Family of July 11-15 1995

- ❑ (1) Montana – Upper Michigan: July 11-12<sup>th</sup>.
- ❑ (2) The 'Right Turn Derecho': July 12-13<sup>th</sup>. Travelled 1400 miles in 27 hours. Avg speed 85 km/h. 7 fatalities.
- ❑ (3) South Dakota – Minnesota: July 13-14<sup>th</sup>.
- ❑ (4) The 'Ontario / Adirondacks Derecho': July 14-15<sup>th</sup>. Travelled 800 miles in 12 hours. Avg speed 110 km/h. 7 fatalities.





# Nature's Derecho Lab: The Derecho Family of July 11-15 1995

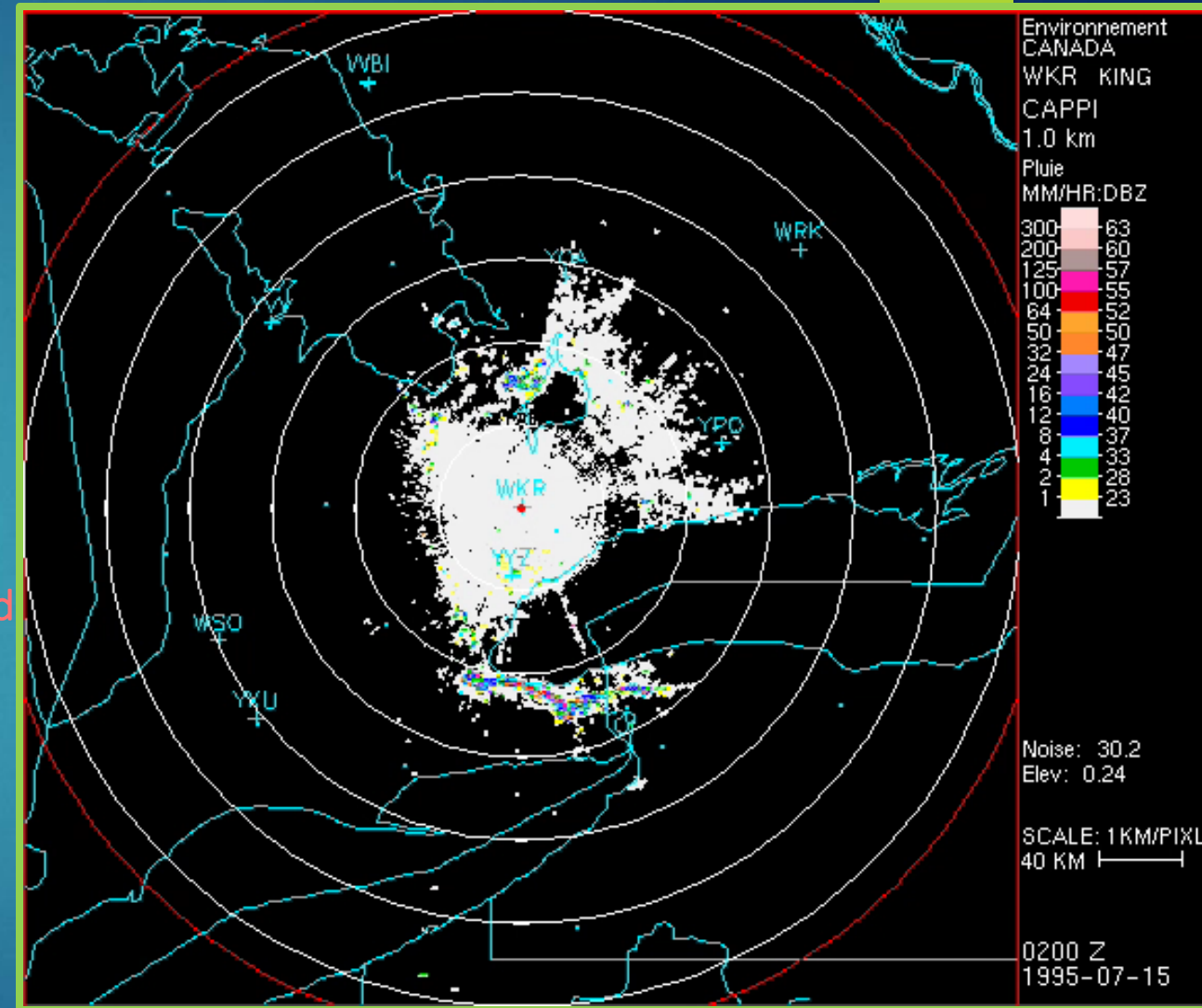
- ❑ (1) Montana – Upper Michigan: July 11-12<sup>th</sup>.
- ❑ (2) The 'Right Turn Derecho': July 12-13<sup>th</sup>. Travelled 1400 miles in 27 hours. Avg speed 85 km/h. 7 fatalities.
- ❑ (3) South Dakota – Minnesota: July 13-14<sup>th</sup>.
- ❑ (4) The 'Ontario / Adirondacks Derecho': July 14-15<sup>th</sup>. Travelled 800 miles in 12 hours. Avg speed 110 km/h. 7 fatalities.



Q: What did they all have in common?

A: All progressive derechos on northern fringe of an extreme heat dome.

(Over 1000 heat-related deaths in Midwest)

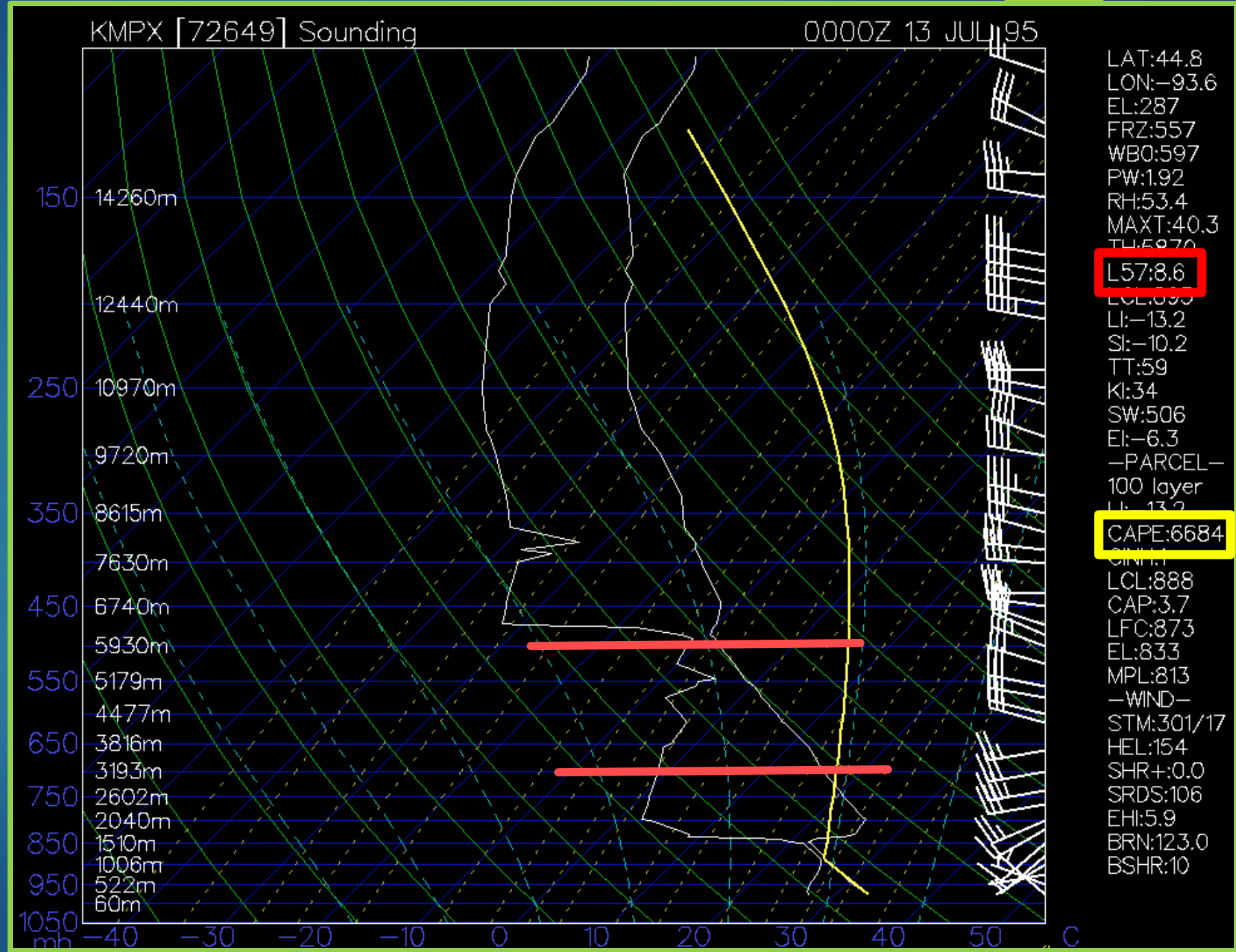


*EMLs, L57 and heatwaves:*

*Minneapolis Sounding  
(00Z July 13<sup>th</sup> 1995)*

700-500 mb Lapse Rate: 8.6

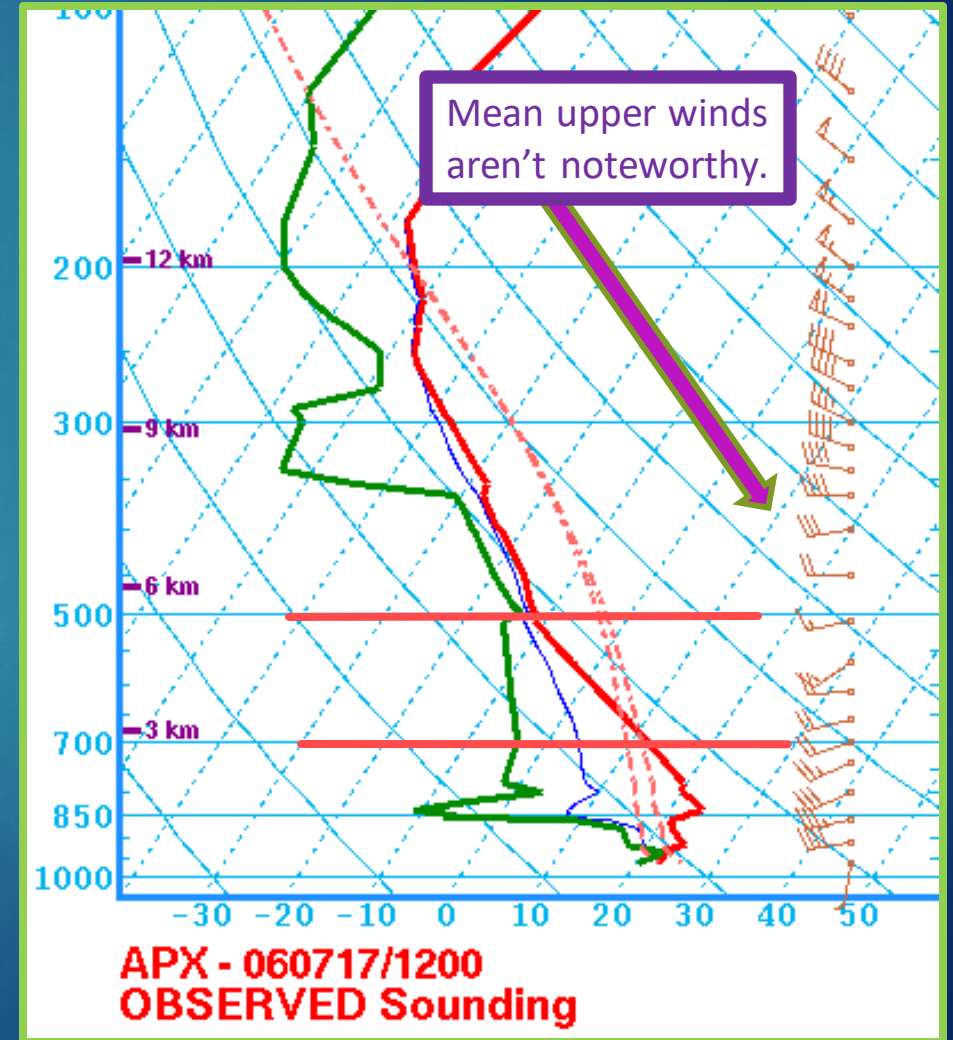
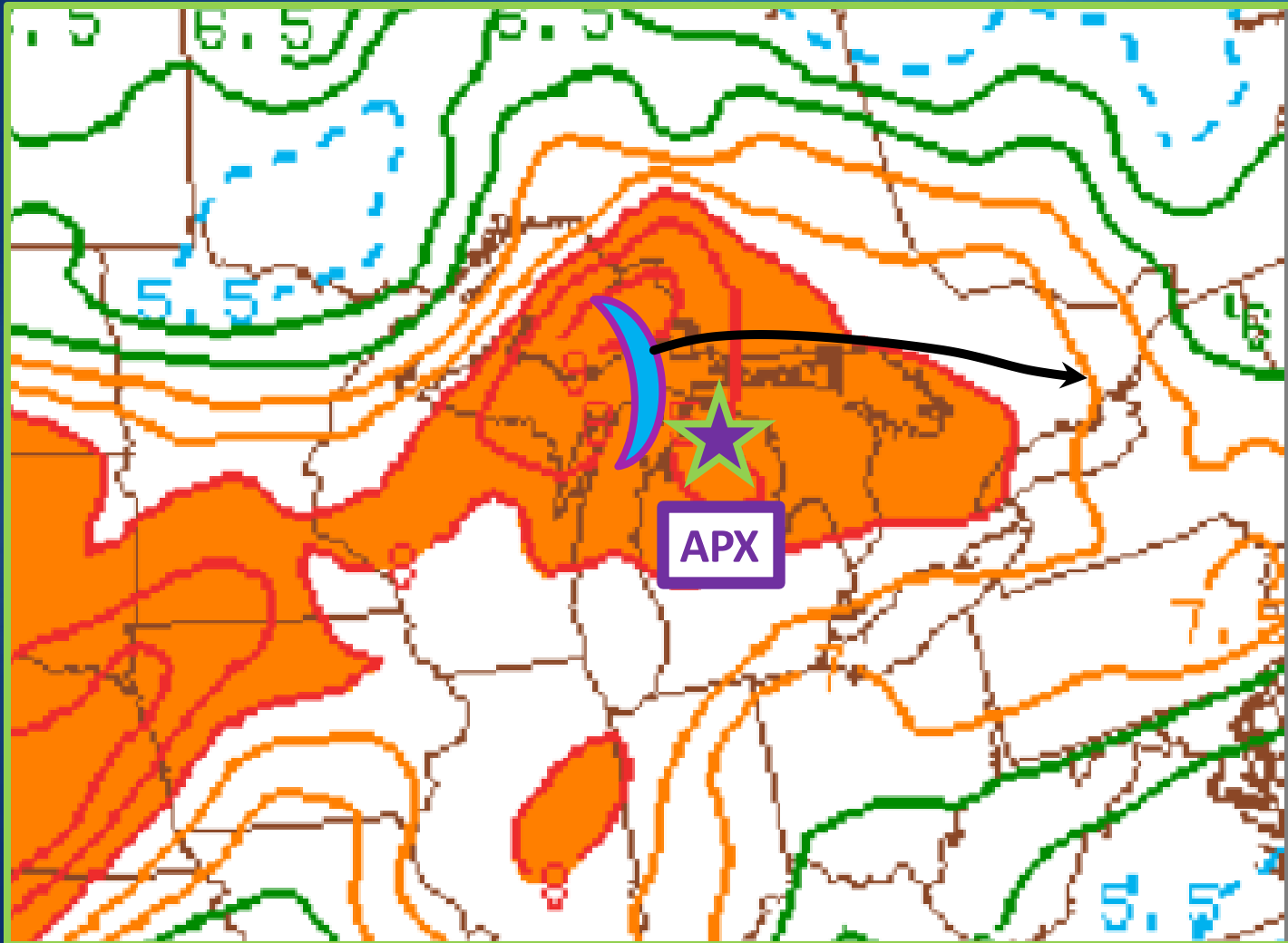
800 mb T = 25°C





# Extreme Lapse Rates and Progressive Derechos: 3 Examples

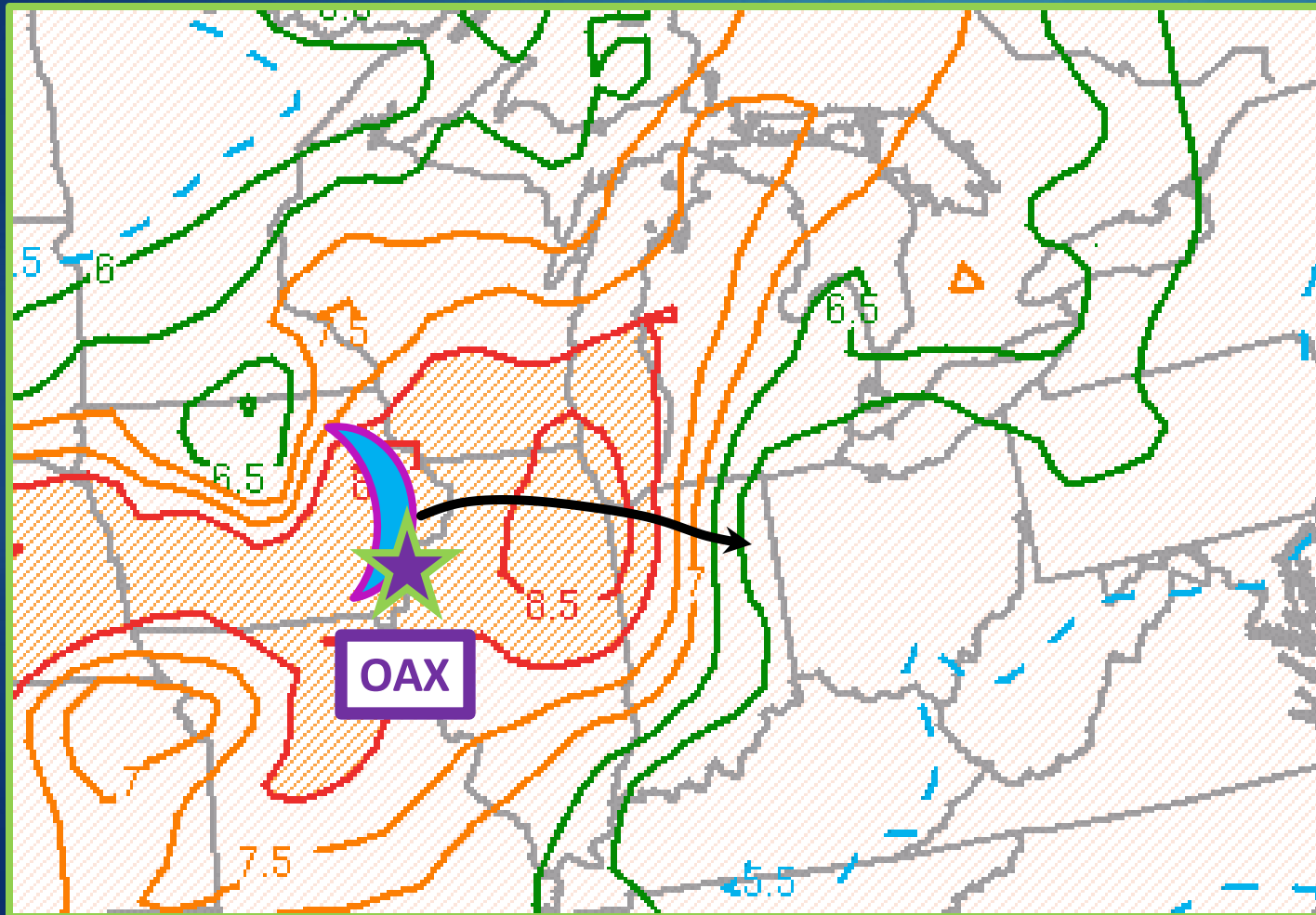
## July 17<sup>th</sup> 2006 – Deadly NE Ontario Derecho



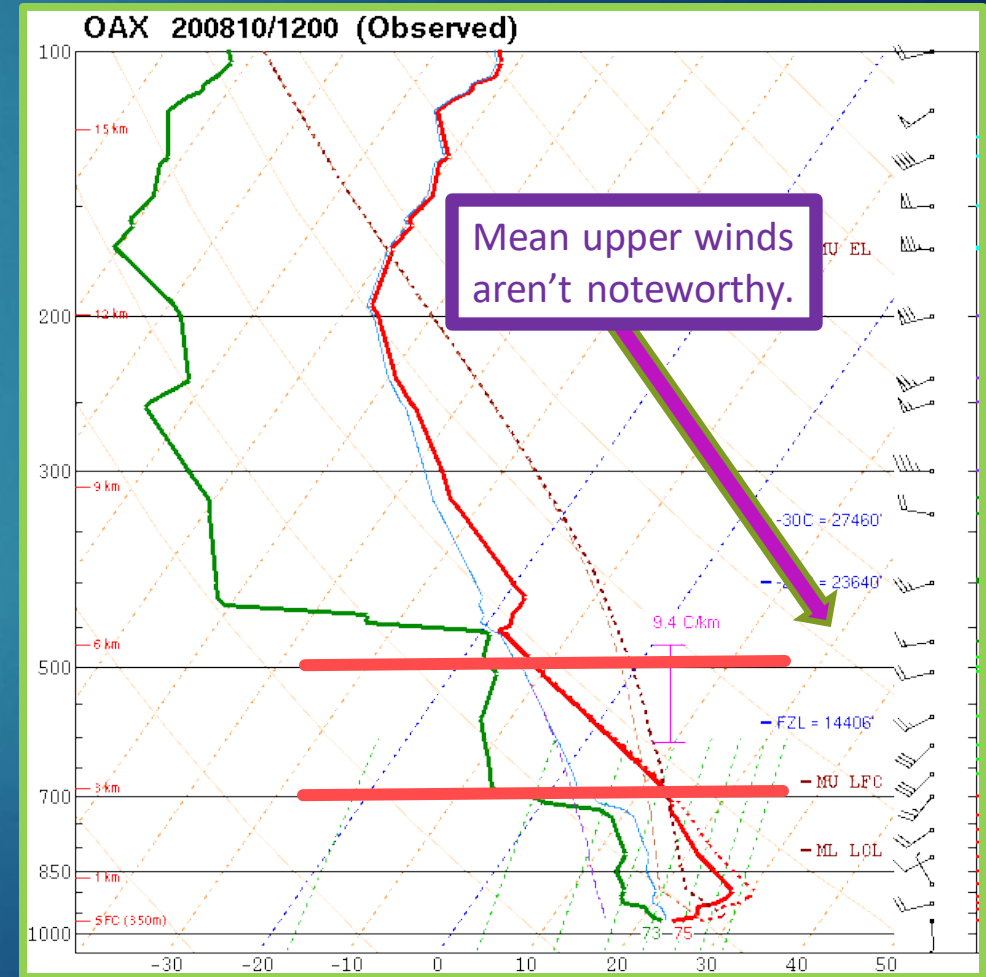
(SPC Mesoanalysis)

# Extreme Lapse Rates and Progressive Derechos: 3 Examples

## Aug 10<sup>th</sup> 2020: 'The Corn Belt Derecho'



(SPC Mesoanalysis)





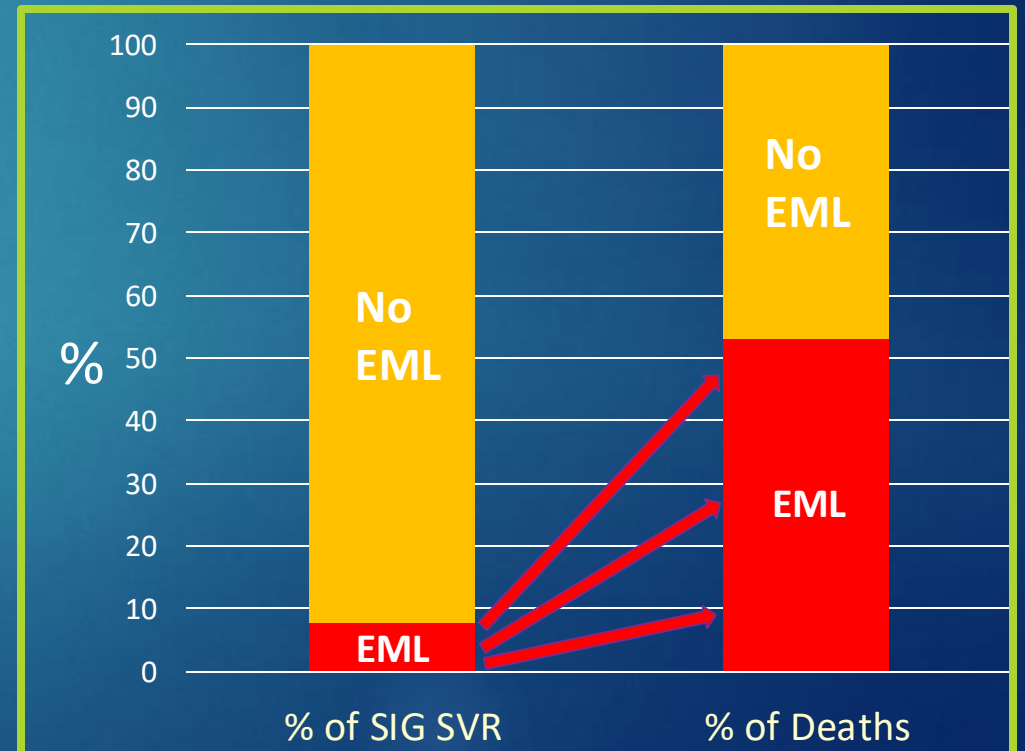
# Extreme Lapse Rates and Progressive Derechos: 3 Examples

'Boundary Waters' Derecho – July 4-5 1999: 4 fatalities, 70 injured.



## Some probing questions regarding Mid-Level Lapse Rates:

- ❑ Banacos P and Ekster M, Aug 2010, “The Association of the Elevated Mixed Layer with Significant Severe Weather Events in the Northeastern United States”, Weather and Forecasting.
- ❑ 36 years of SIG SVR events (1970-2006), distinguished between EML vs. non-EML (based on soundings).
- ❑ 447 event days ( $\geq 65$  knots;  $\geq$  EF2;  $\geq 2$  “ hail)  $\Rightarrow$  only 36 associated with an EML (7.6%).
- ❑ SIG SVR events linked to EML disproportionately accounted for 52.9% of fatalities and 45% of injuries (many were derechos).





## *Some probing questions regarding Mid-Level Lapse Rates:*

- ❑ **Do all OUR derechos exhibit steep lapse rates? (L57 in brackets)** (Archived observed soundings (Plymouth State Weather Centre)). Only Canadian / Great Lakes progressive derechos. (NA ~ insufficient sounding data).

- ❑ June 7 1991 (NA)

- ❑ June 4 1993 (8+ °C/km)

- ❑ July 13 1995 (8-9)

- ❑ July 15 1995 (8.6)

- ❑ May 31 1998 (8.3)

- ❑ June 29 1998 (~7.5)

- ❑ Sept 7 1998 (8)

- ❑ July 4 1999 (8-8.5)

- ❑ June 11 2001 (~7.75)

- ❑ July 17 2006 (9)

- ❑ Aug 4 2008 (7.5-8)

- ❑ June 18 2010 (7.5-8)

- ❑ July 11 2011 (NA)

- ❑ June 29 2012 (8.5-9)

- ❑ June 12 2013 (8.5)

- ❑ July 20 2016 (8-8.5)

- ❑ June 11 2017 (NA)

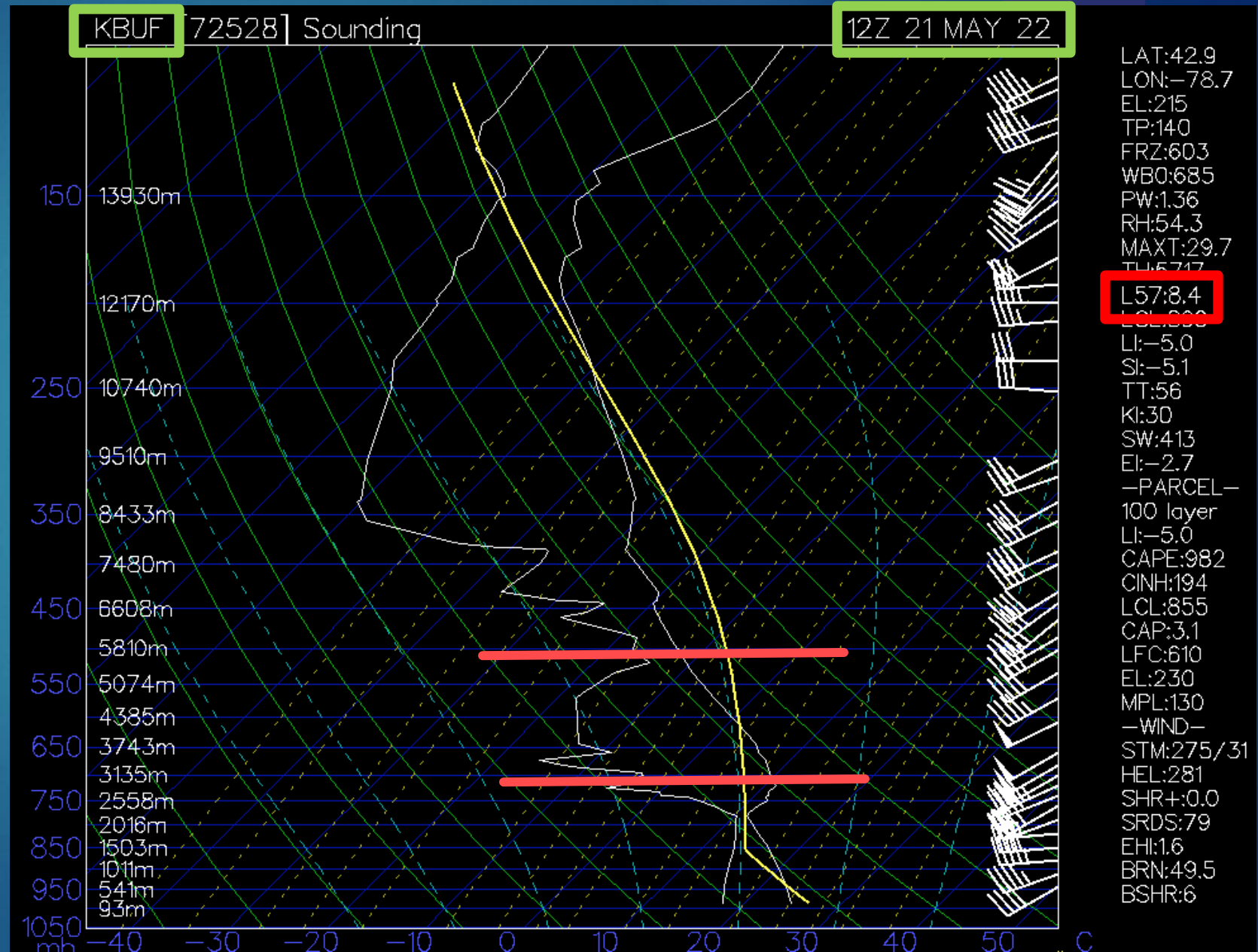
- ❑ Aug 10 2020 (8.7)

- ❑ **May 21 2022 (8.4)**

# Some probing questions regarding Mid-Level Lapse Rates:

May 21 2022 Buffalo Sounding 12Z

Conclusion: Steep lapse rate signal apparent with derechos (EML & very dry mid levels) supportive of fat CAPE (most robust updrafts maximize entrainment, reinforcing cold pool strength).





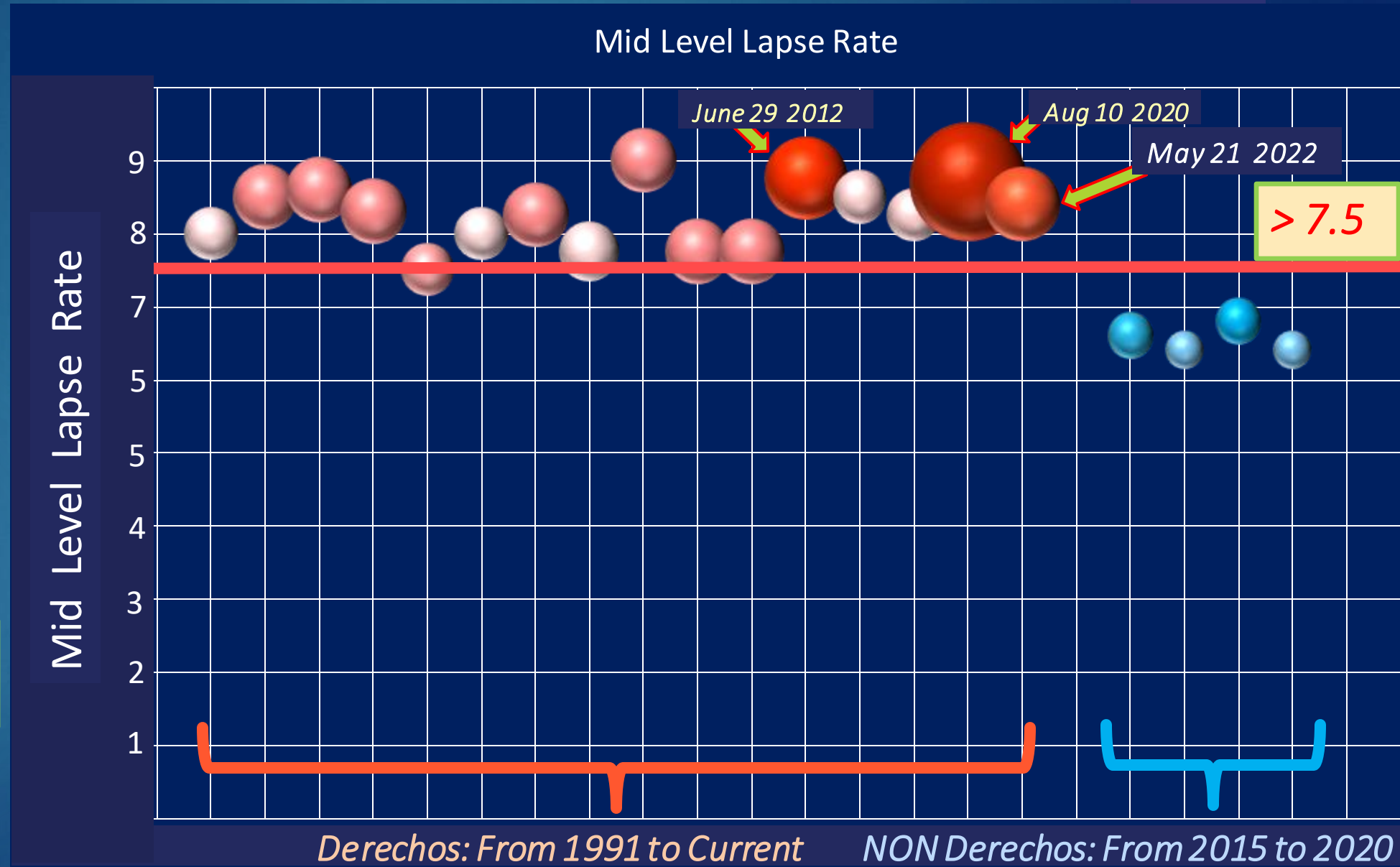
# Mid Level Lapse Rates: Great Lakes (Progressive) Derechos versus Non Derechos:

## Assumptions:

- Mid West & Great Lakes.
- NON derechos: Major QLCS events in Ontario.
- Observed proximity soundings.
- Event severity: Increases with size and colour depth.
- Severity: Pop, damage, extent.

Are derechos becoming more impactful?

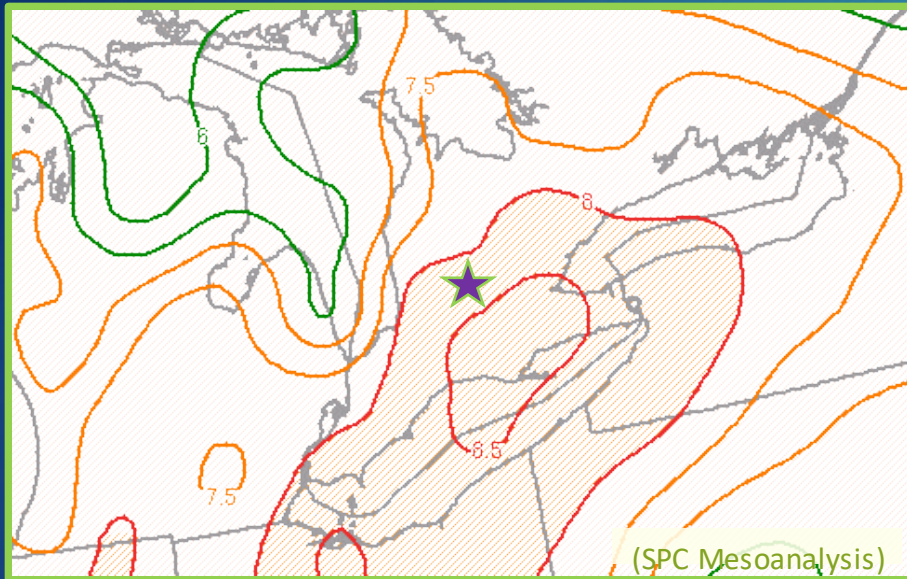
Good separation in parameter space?!



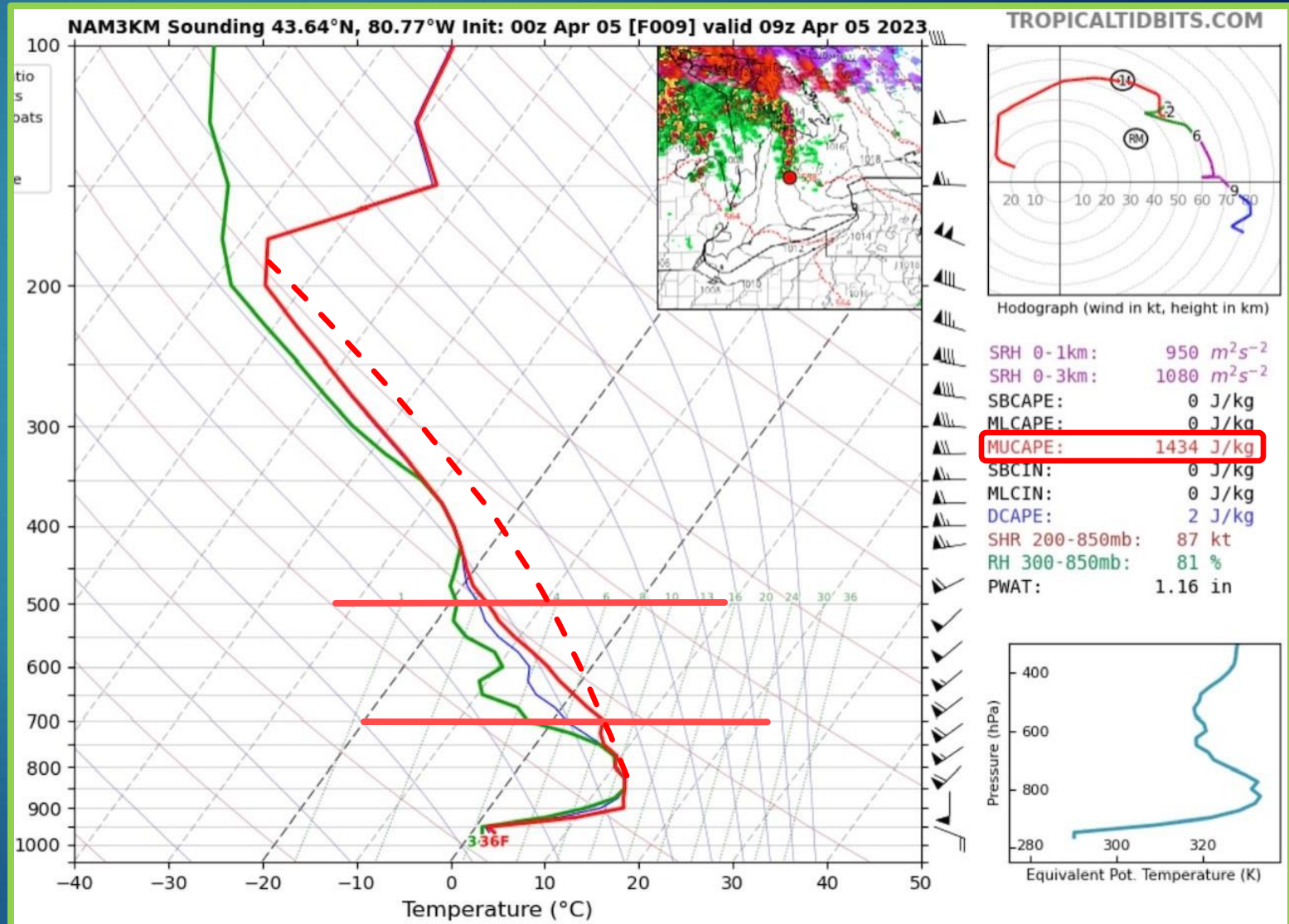
# Some probing questions regarding Mid-Level Lapse Rates:

- ❑ NULL cases: Do all of OUR extreme lapse rates lead to derechos? (Well, NO!)

April 5<sup>th</sup> 2023 (08Z):



Our April record-breaking 'heatwave' followed shortly thereafter.





## Putting it all together: Progressive Derecho Forecasting Techniques

- ❑ (1) Pattern recognition (synoptic 'macro-scale') is your forecast starting point (models decent)
  - ❑ Progressive derechos **REQUIRE abundant CAPE** (extreme?)...usually linked to northern fringe of significant heat waves.
  - ❑ Usually triggered by a vorticity maximum (often subtle) along weak frontal boundary. Unidirectional (**line-normal**) shear. **Strong deep layer wind fields NOT REQUIRED.**
  - ❑ **Steep 700-500 mb lapse rates** (enhanced evaporative cooling). Virtual necessity? ( $\geq 8$  °C/km).
- ❑ (2) Weightiest portion of derecho forecasting: **NOWCASTING / REAL-TIME DETECTION (Primarily radar):**
  - ❑ Most storm clusters will NOT evolve into a derecho. But, if radar 'echo mass' (reflectivity) increases along leading edge with optimum orthogonal unidirectional upper winds relative to a developing line cluster, be vigilant: 'Early signs'?
  - ❑ 'Background' fields: **Extreme LAPSE RATES**, large CAPE and DCAPE, decent orthogonal unidirectional deep winds.
  - ❑ Are these fields supportive of further **development downstream? (time of day?)**.
  - ❑ Signs of robust cold pool: trailing stratiform cross-section (radar) (upshear QLCS-tilting), increasingly dramatic temperature drop with cold pool passage.
  - ❑ System speed **the NUMBER ONE DERECHO INDICATOR (>100 km/h)**. (Strong indicator of cold pool strength).
  - ❑ (Of course!) keep on top of observed wind gusts!



# Thanks!



Environment and  
Climate Change Canada  
Environnement et  
Changement climatique Canada