An Analysis of High-Impact, Low-Predictive Skill Severe Weather Events in the Northeast U.S.

Matthew Vaughan, Brian Tang, and Lance Bosart

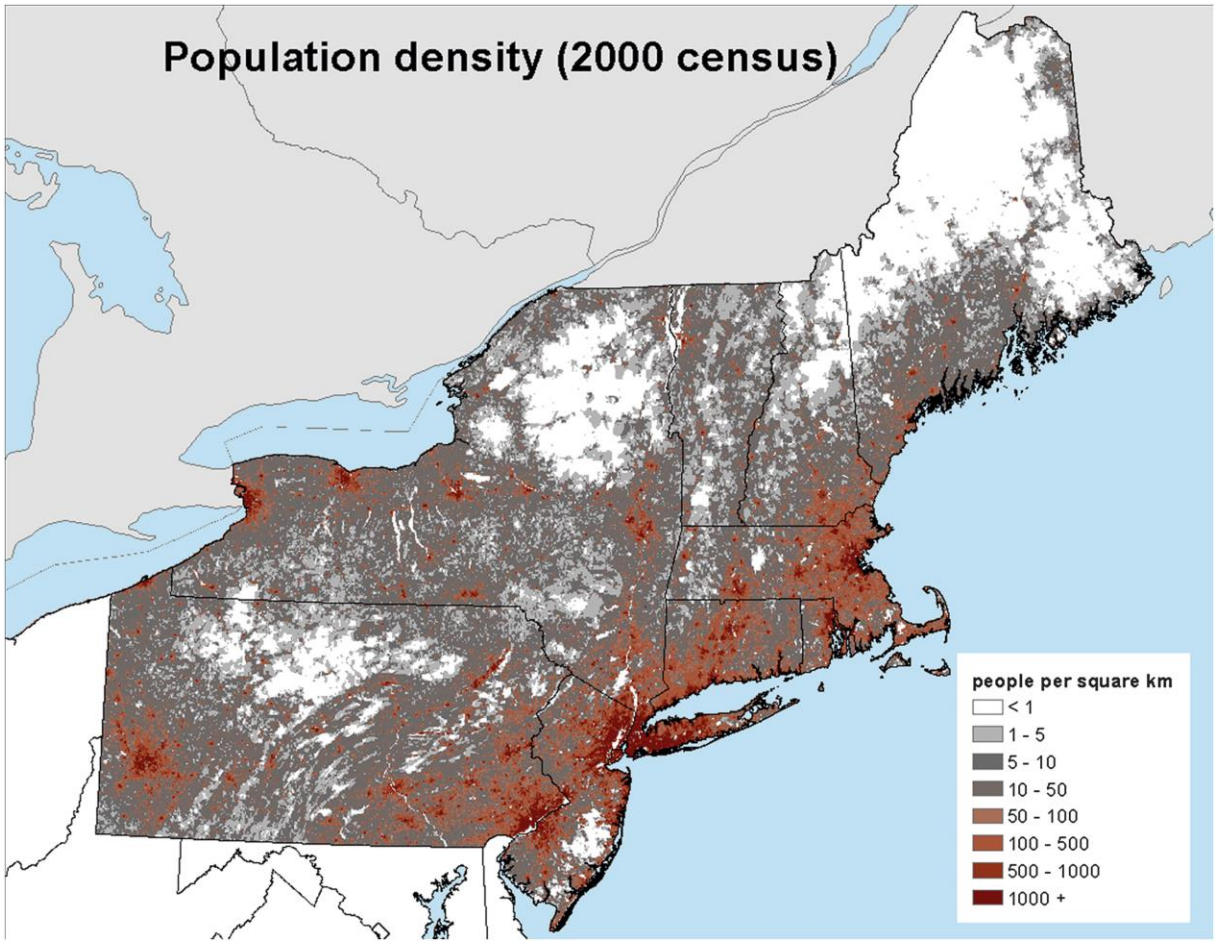
Department of Atmospheric and Environmental Sciences
University at Albany/SUNY
Albany, NY 12222

Master's Thesis Seminar
Albany, NY
2 December 2015

Supported by the NOAA Collaborative Science, Technology and Applied Research Program (NA13NWS4680004)

Motivation

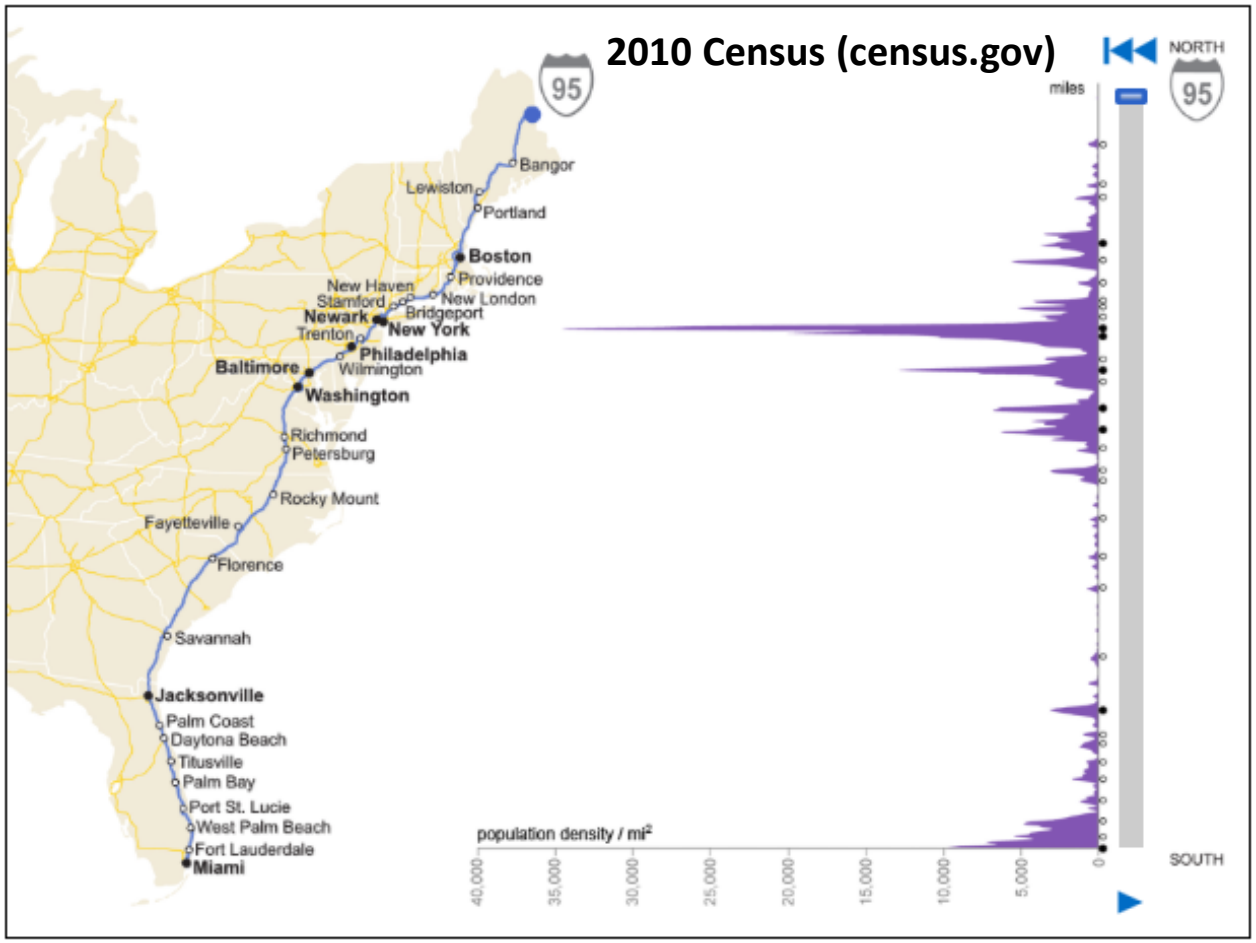
- Severe weather impacts on the Northeast
  - Densely populated, major metropolitan areas



Hurlbut and Cohen (2014)

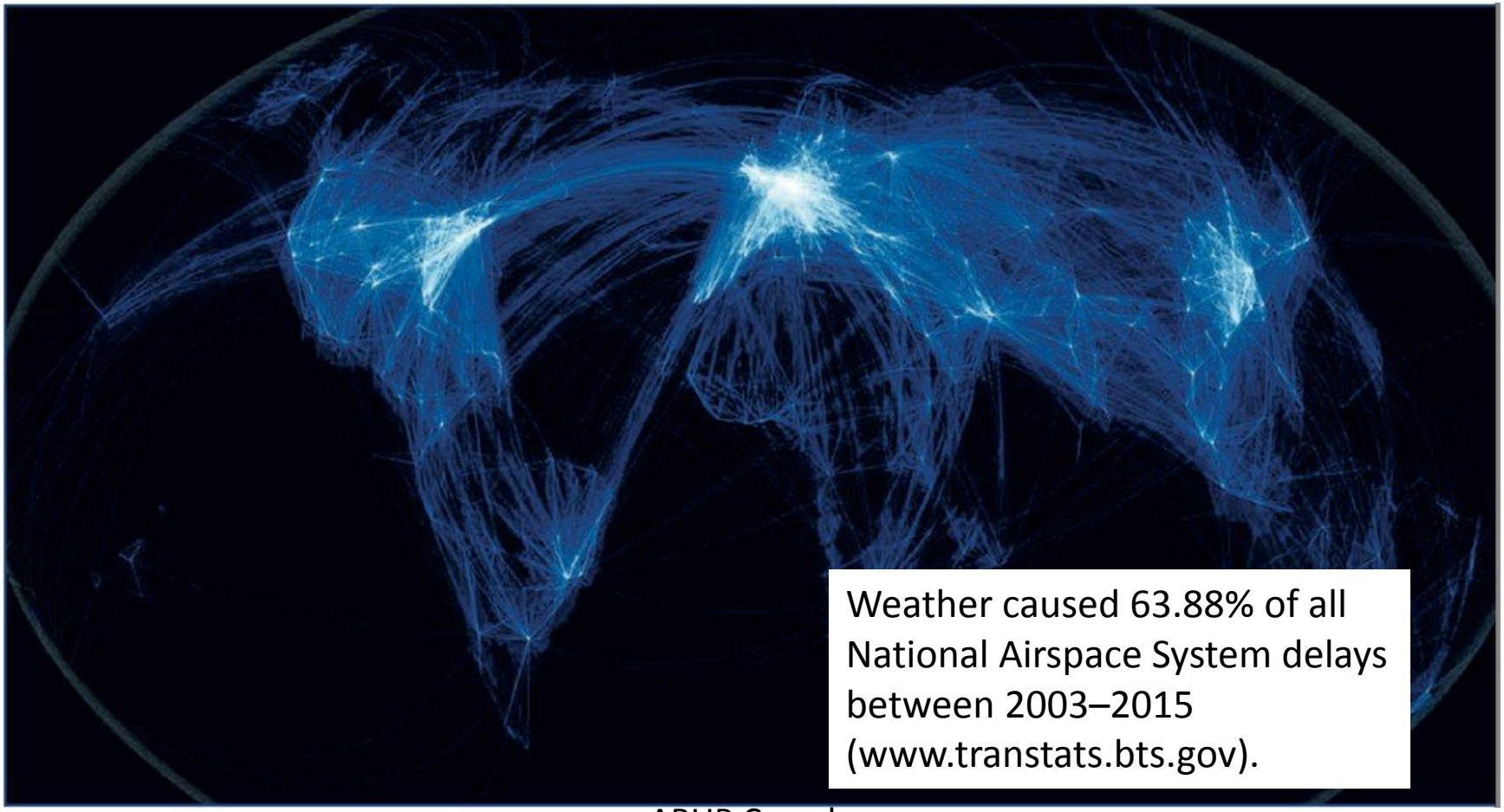
Motivation

- Interstate 95 corridor from Boston through Washington D.C. = most densely populated region in U.S.



Motivation

- Severe weather impacts on the aviation
  - 8 of 25 busiest airports in the U.S. are found north of D.C. and east of Pittsburg, PA



Motivation

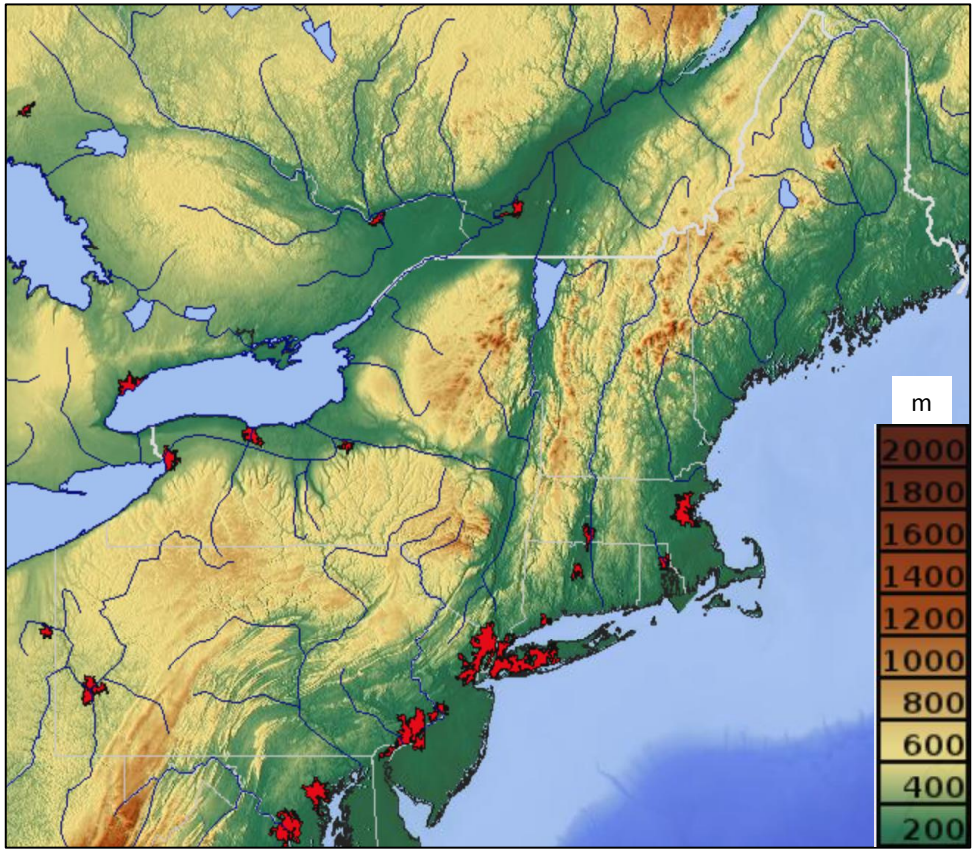
- Severe weather impacts on the aviation
  - 8 of 25 busiest airports in the U.S. are found north of D.C. and east of Pittsburg, PA

Motivation

- Severe weather impacts on the aviation
  - 8 of 25 busiest airports in the U.S. are found north of D.C. and east of Pittsburg, PA

Motivation

- The Northeast provides a challenging forecast environment
  - Complex terrain, lake-water boundaries

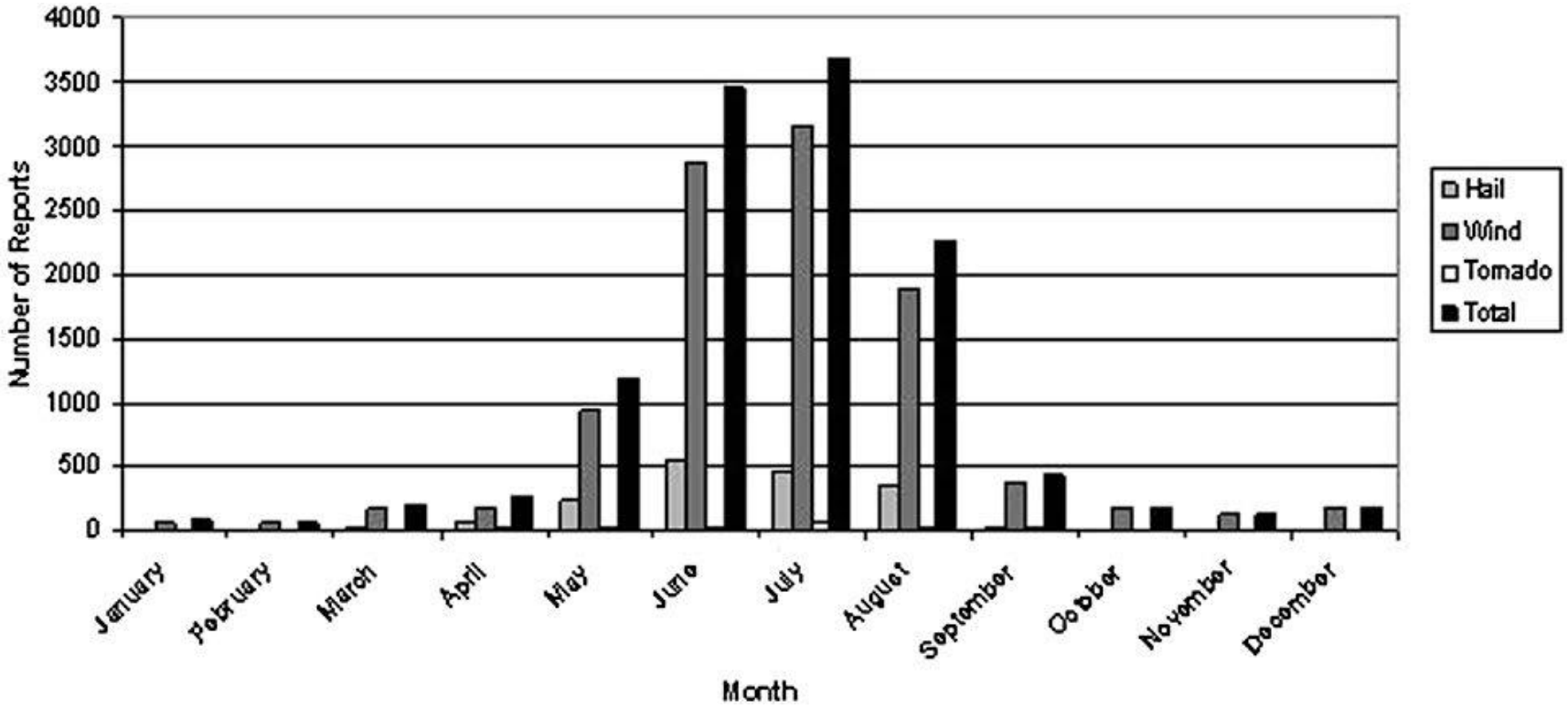


maps-for-free.com

BACKGROUND LITERATURE

Background

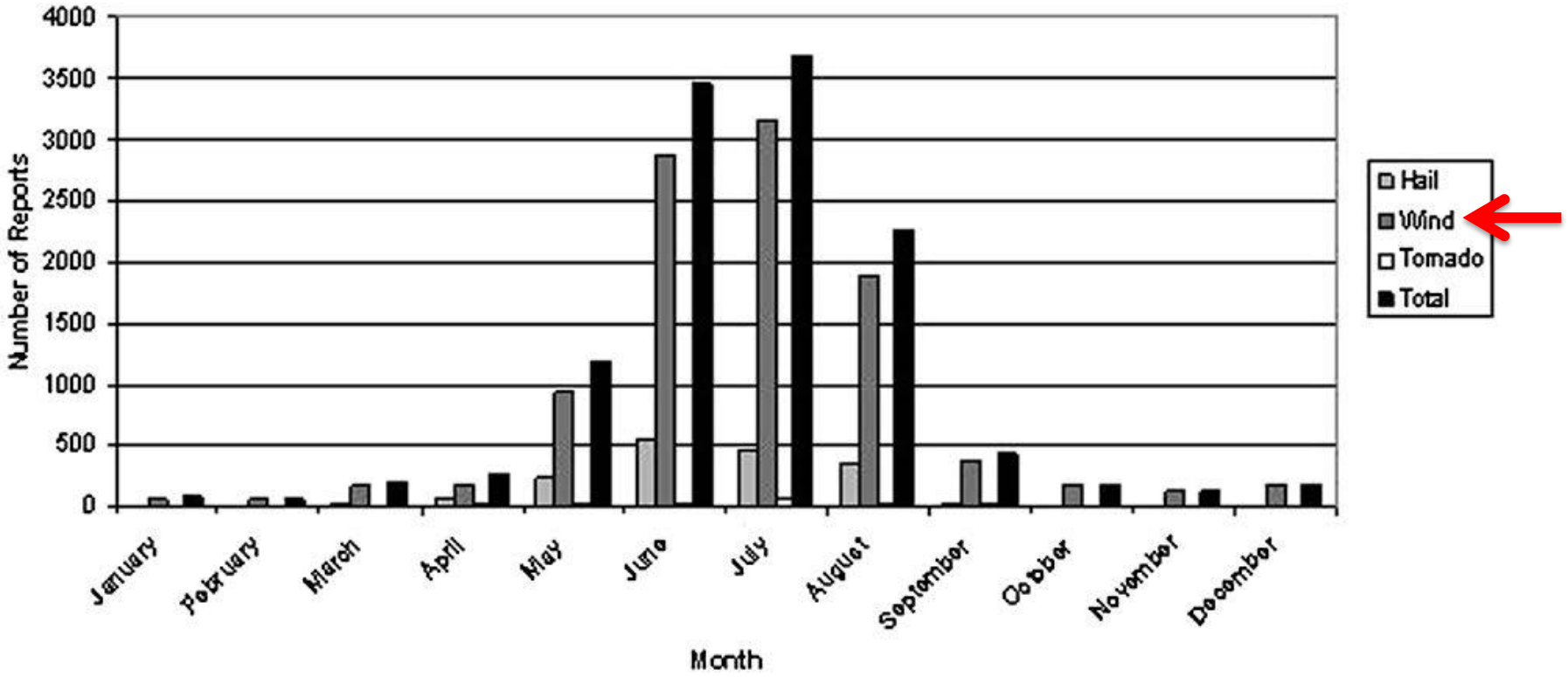
- Monthly climatology of severe reports in the Northeast (1999–2009)



Hurlbut and Cohen (2014)

Background

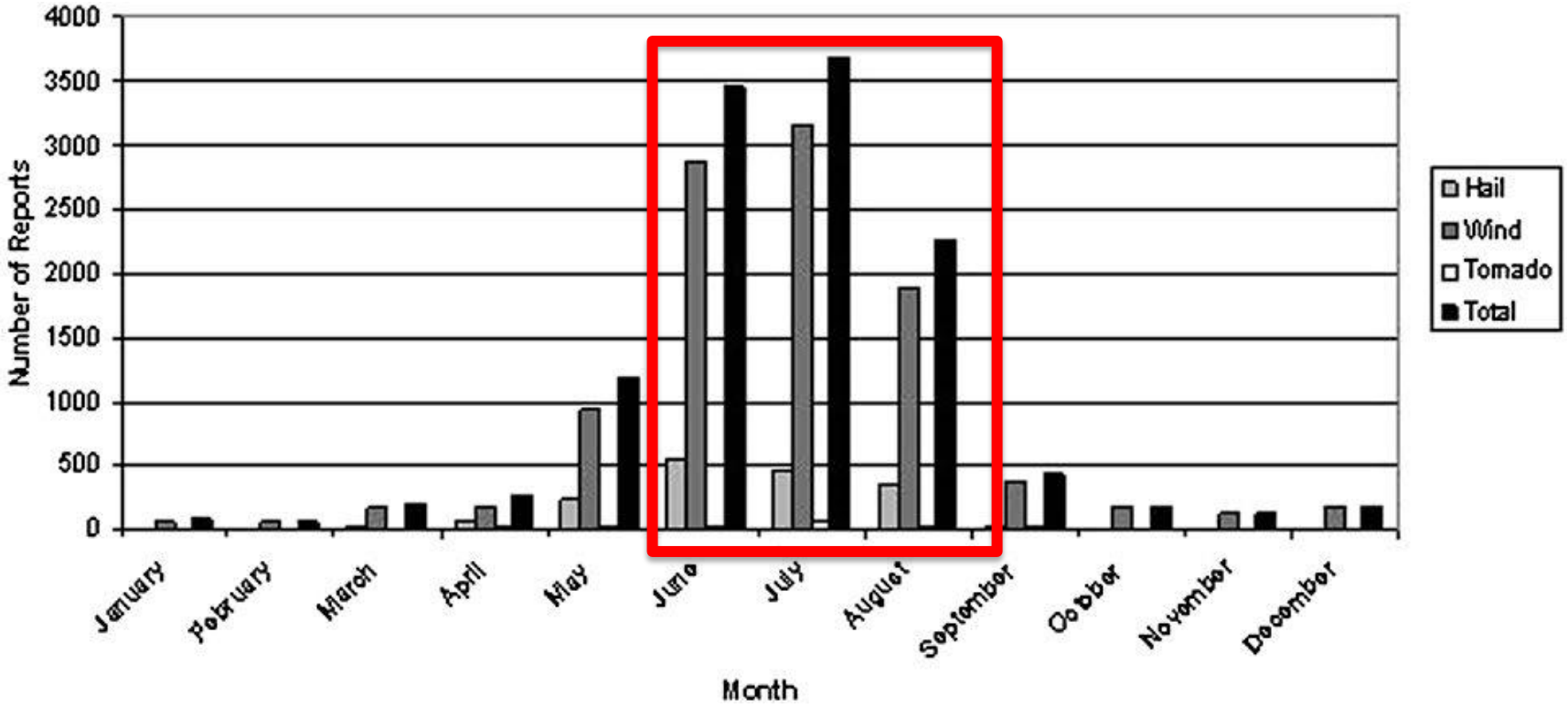
- Monthly climatology of severe reports in the Northeast (1999–2009)



Hurlbut and Cohen (2014)

Background

- Monthly climatology of severe reports in the Northeast (1999–2009)

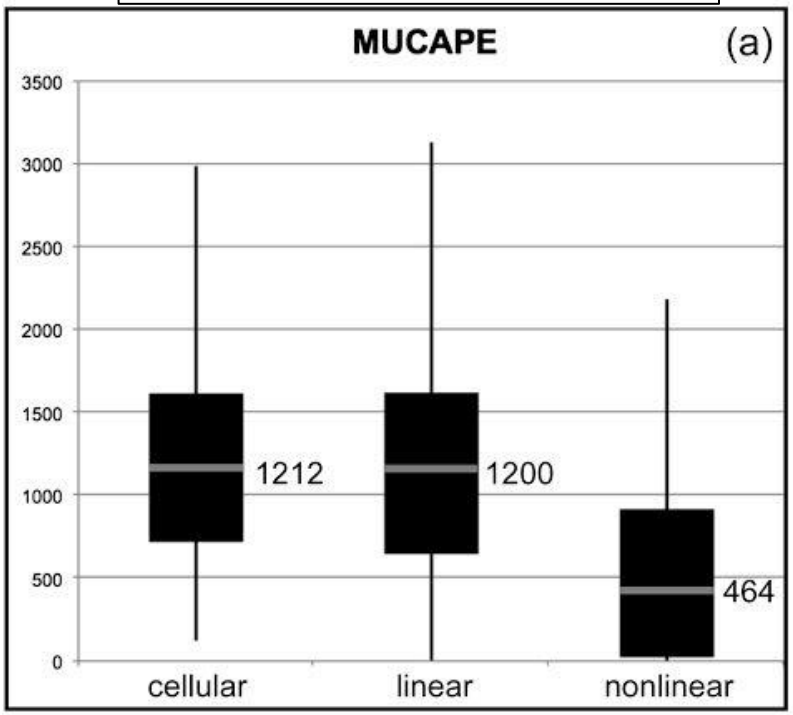


Hurlbut and Cohen (2014)

Background

- Recent research suggests MUCAPE is weaker for coastal Northeast severe linear events than non-severe MCSs in the Great Plains

Coastal Northeast

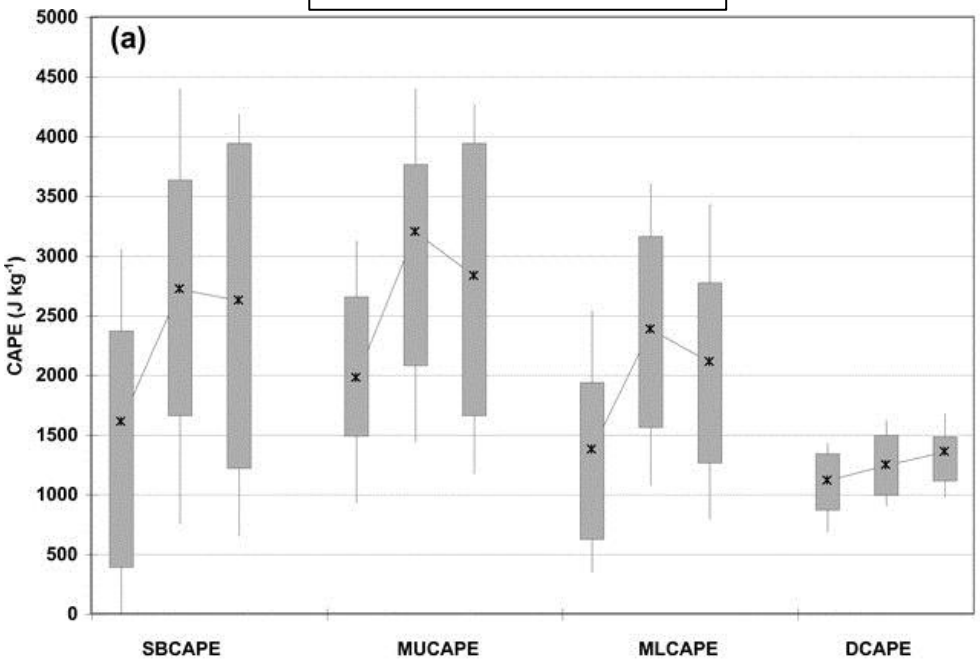


Lombardo and Colle (2011) [NARR reanalysis]

Background

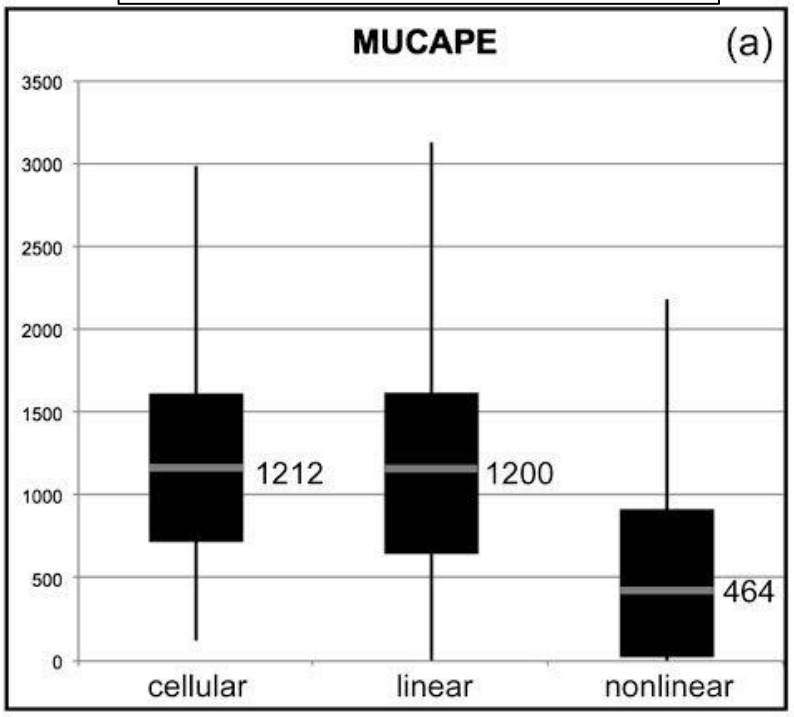
- Recent research suggests MUCAPE is weaker for coastal Northeast severe linear events than non-severe MCSs in the Great Plains

Great Plains



Cohen et. al. (2007) [3-h proxy soundings]

Coastal Northeast

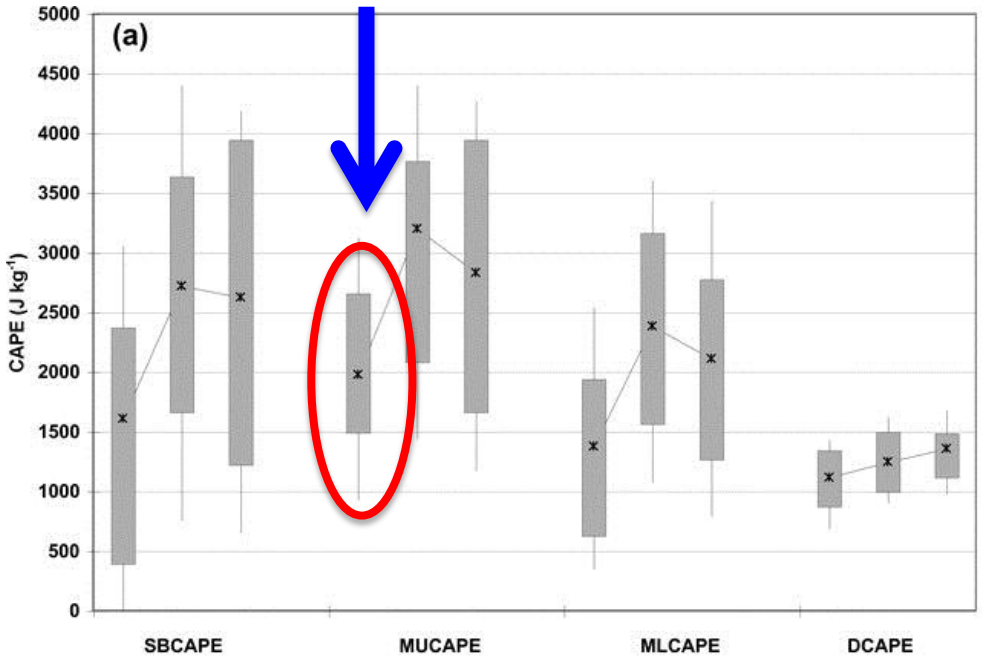


Lombardo and Colle (2011) [NARR reanalysis]

Background

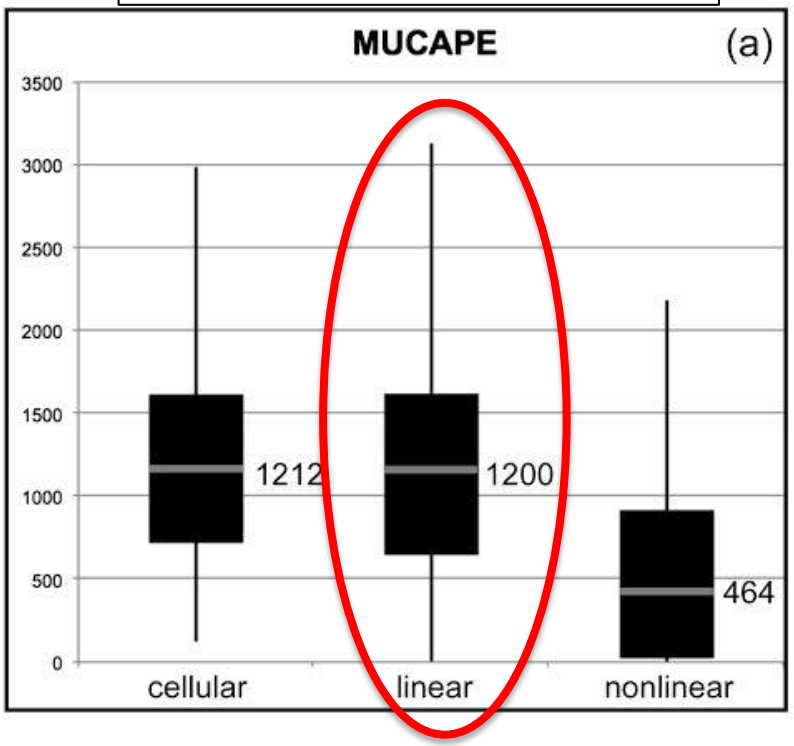
- Recent research suggests MUCAPE is weaker for coastal Northeast severe linear events than non-severe MCSs in the Great Plains

Non-Severe MCS



Cohen et. al. (2007) [3-h proxy soundings]

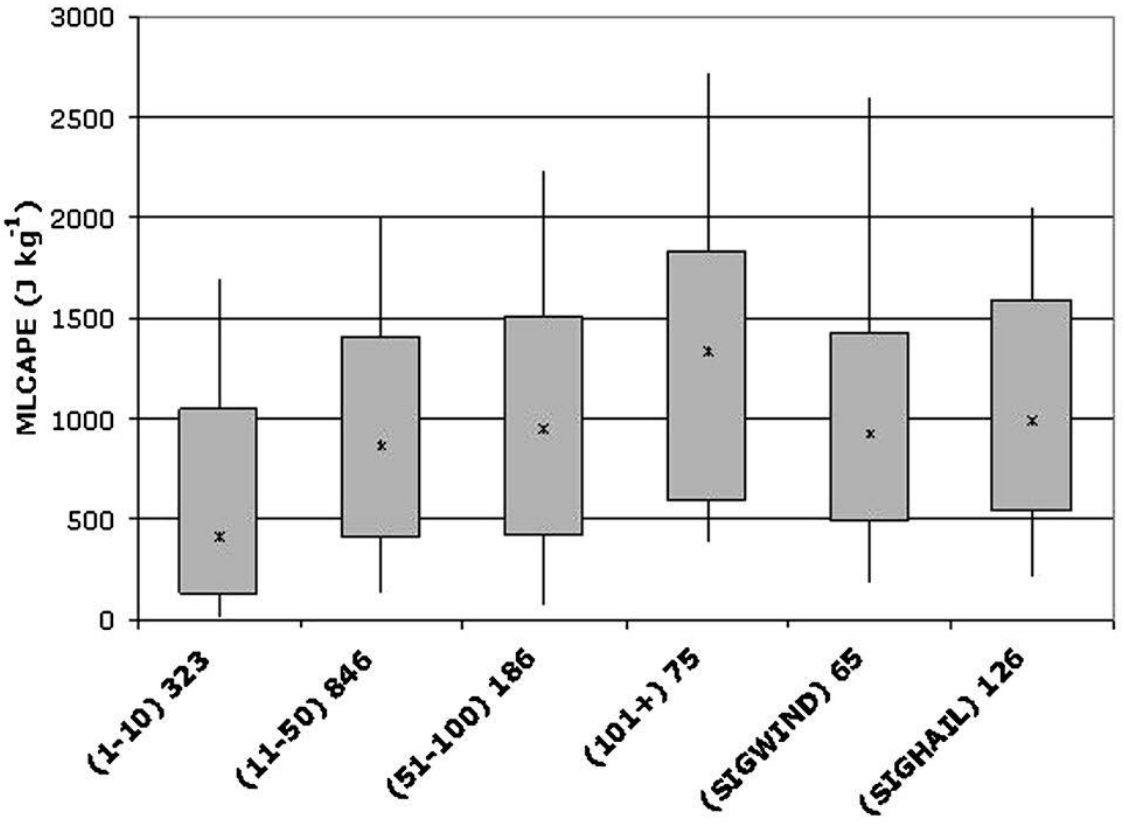
Coastal Northeast



Lombardo and Colle (2011) [NARR reanalysis]

Background

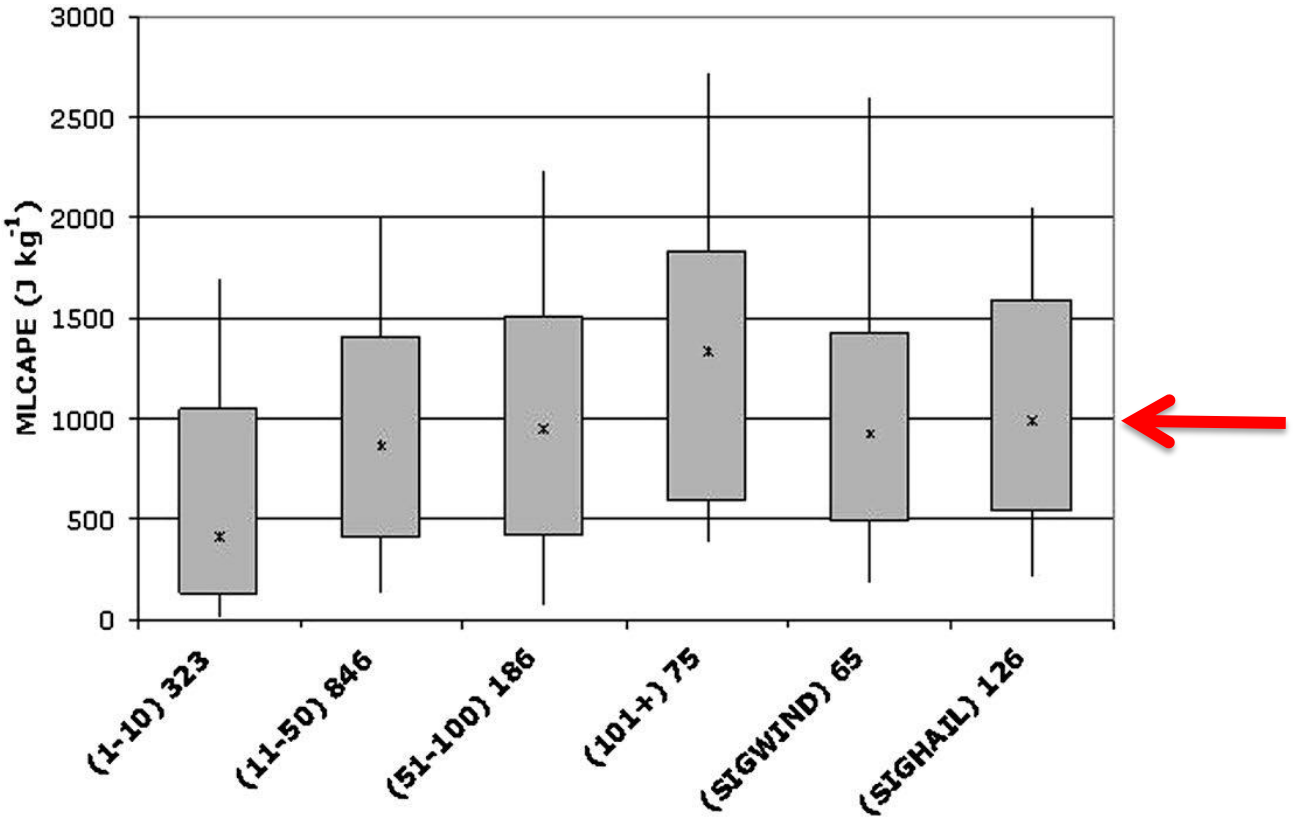
- Northeast CAPE
  - Hurlbut and Cohen (2014) used 6-h proximity soundings to evaluate Northeast severe weather environments



Hurlbut and Cohen (2014) [6-h proximity soundings]

Background

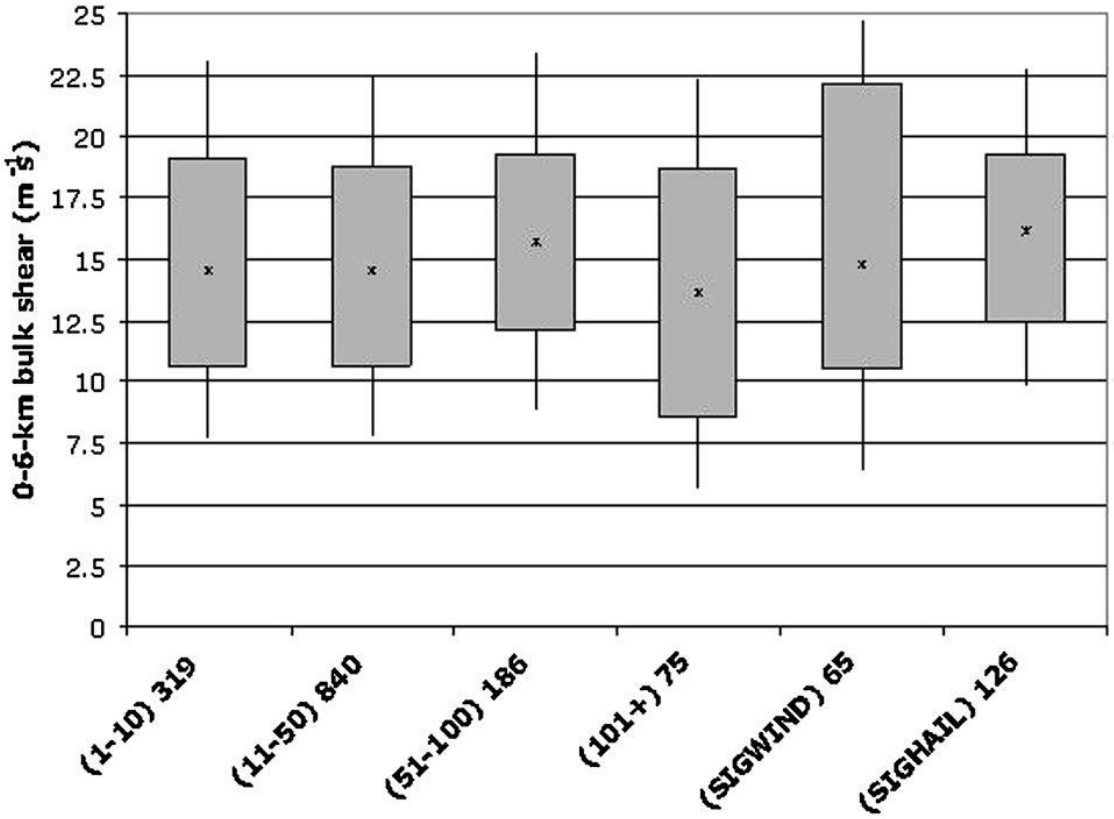
- Northeast CAPE
  - Majority of events have MLCAPE < 1000 J kg^{-1}



Hurlbut and Cohen (2014) [6-h proximity soundings]

Background

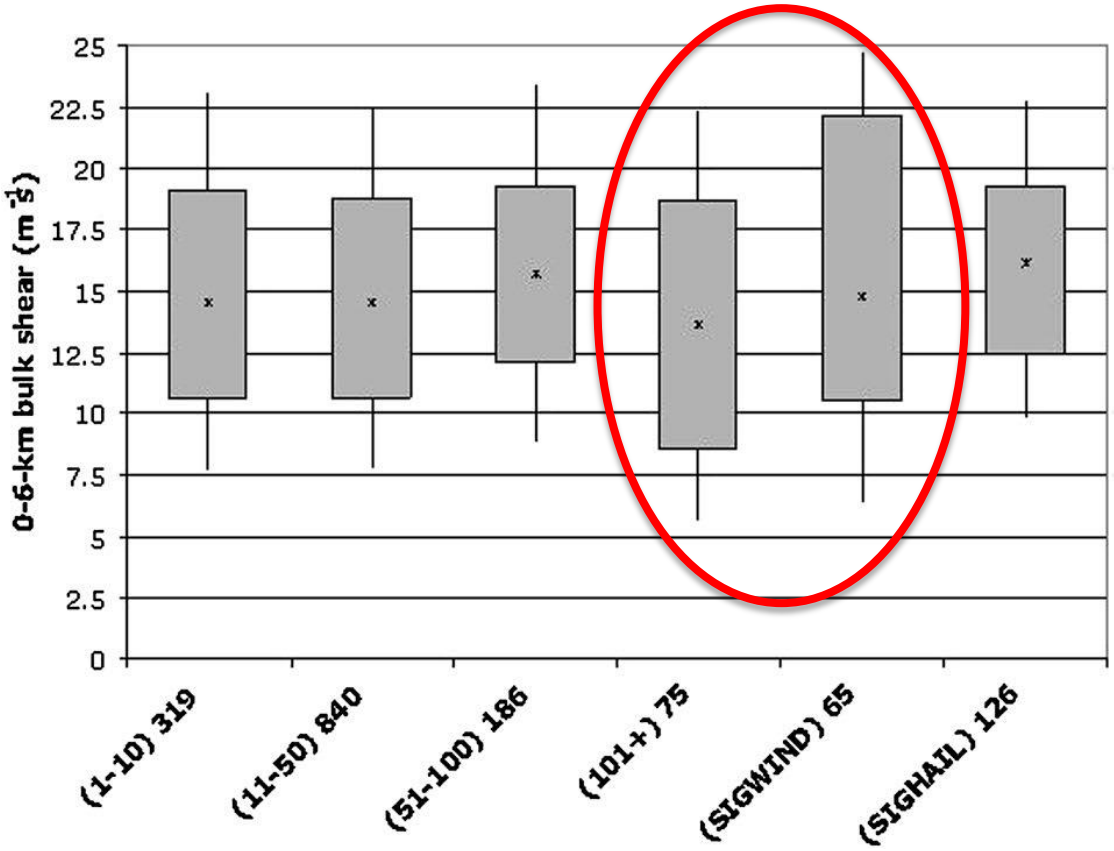
- Northeast deep-layer shear
  - Bulk wind shear (0–6 km) medians for all events hovers between ~13–16 m s^{-1} (~25–31 kt)



Hurlbut and Cohen (2014) [6-h proximity soundings]

Background

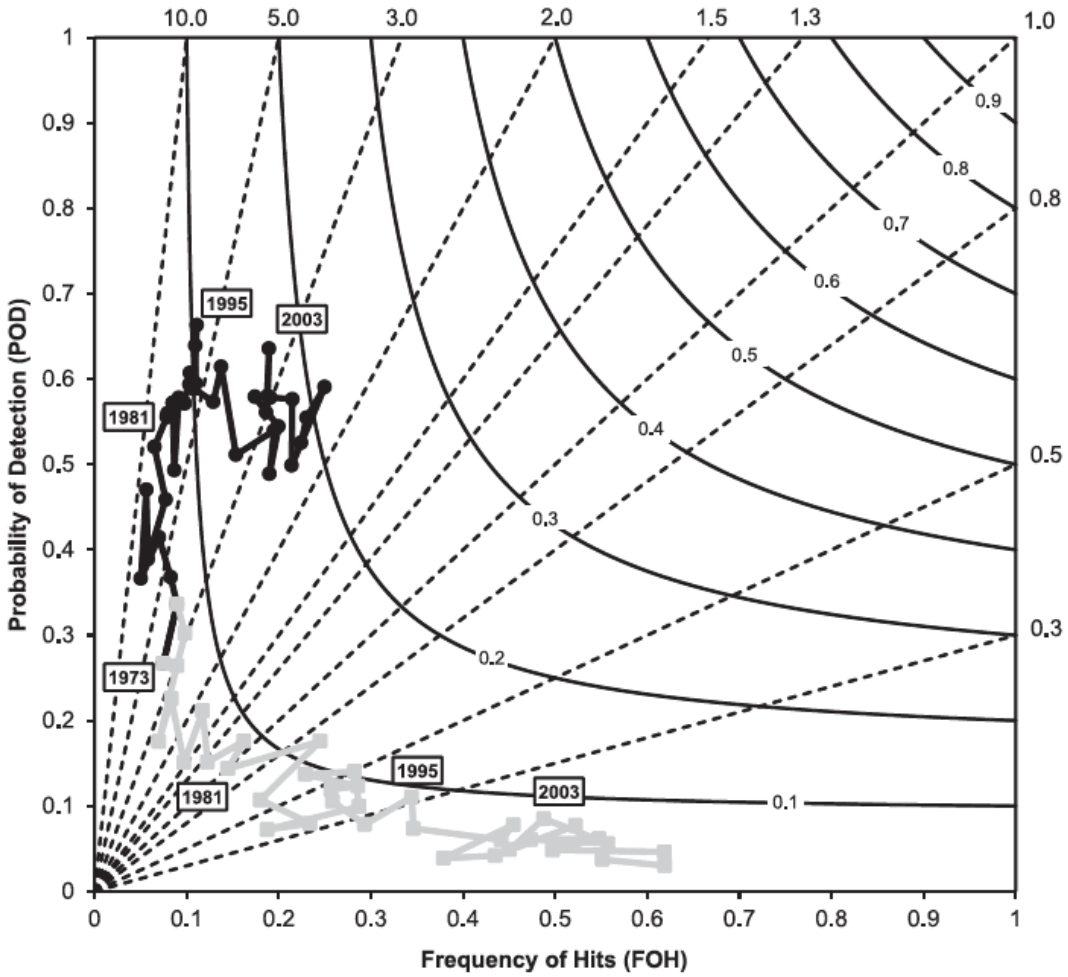
- Northeast deep-layer shear
  - Bulk wind shear (0–6 km) medians for all events hovers between ~13–16 m s^{-1} (~25–31 kt)



Hurlbut and Cohen (2014) [6-h proximity soundings]

Background

- Hitchens and Brooks (2012) verified SPC day-1 slight-risk convective outlooks over CONUS
  - Found increased forecast performance with time

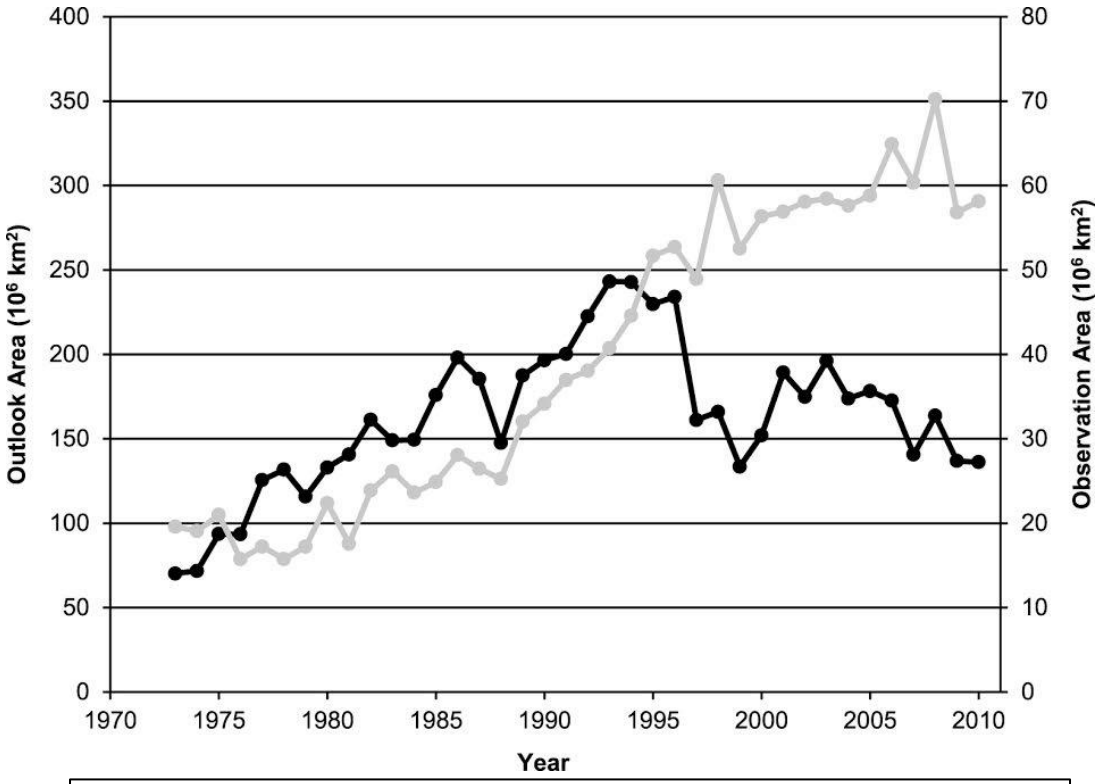


- Black line represents slight-risk performance
- Gray line represents moderate-risk performance

Source: Hitchens and Brooks(2012)

Background

- Found increasing severe report areal coverage with time
- Slight-risk outlook area peaks in 1994
  - Trend suggests better FOH scores are due to well-placed, smaller risk areas



- Black line represents annual slight-risk outlook area
- Gray line represents severe report area

Source: Hitchens and Brooks(2012)

Research Goals

- Evaluate slight-risk forecast performance over the Northeast
- Build database of events with poor forecast skill
- Analyze environments conducive to poor forecast skill

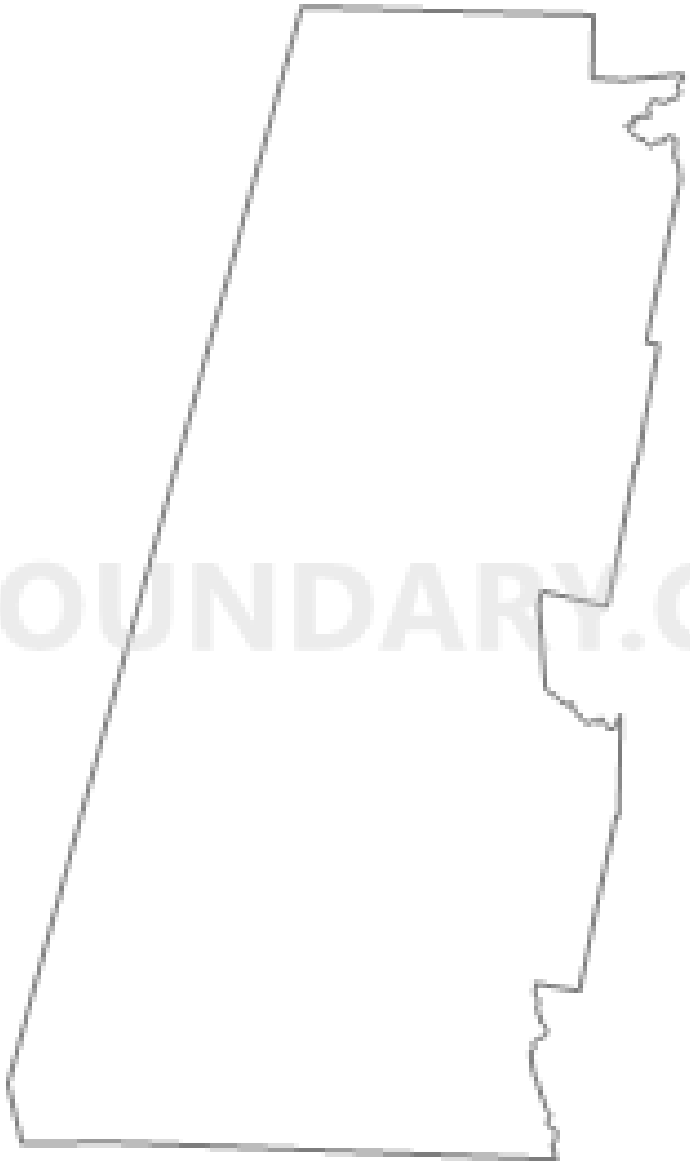
Research Goals

- **Evaluate slight-risk outlook performance over the Northeast**
- Build database of events with poor forecast skill
- Evaluate environments conducive to poor forecast skill

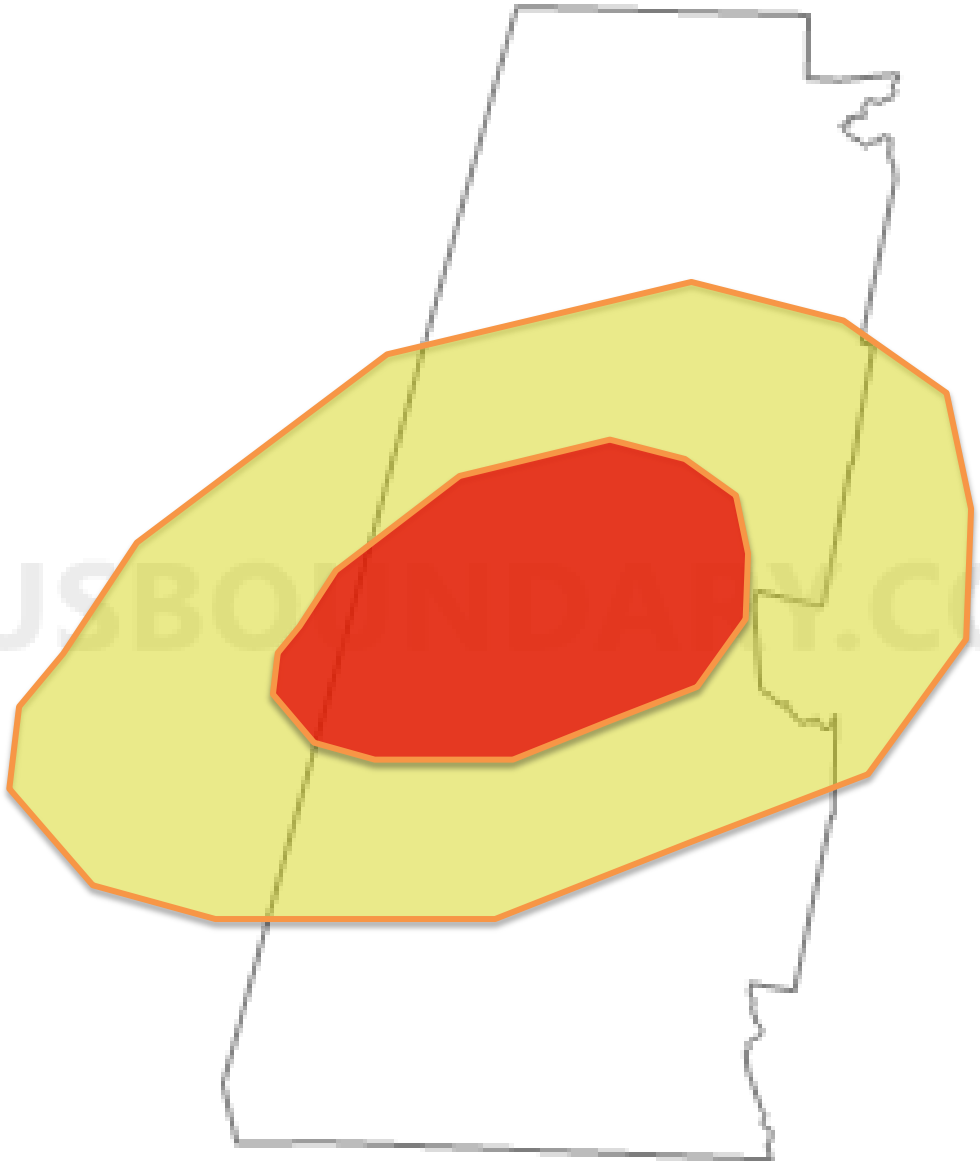
Methodology: Game Plan

- Establish Northeast domain to evaluate forecast skill
- Plot slight-risk convective outlook contours over the domain
- Evaluate outlooks with valid storm reports and compare to CONUS verification
  - Similar verification methodology to Hitchens and Brooks (2012)
- Mod and high contours within slight contours were included (i.e. everywhere inside the slight was treated the same)

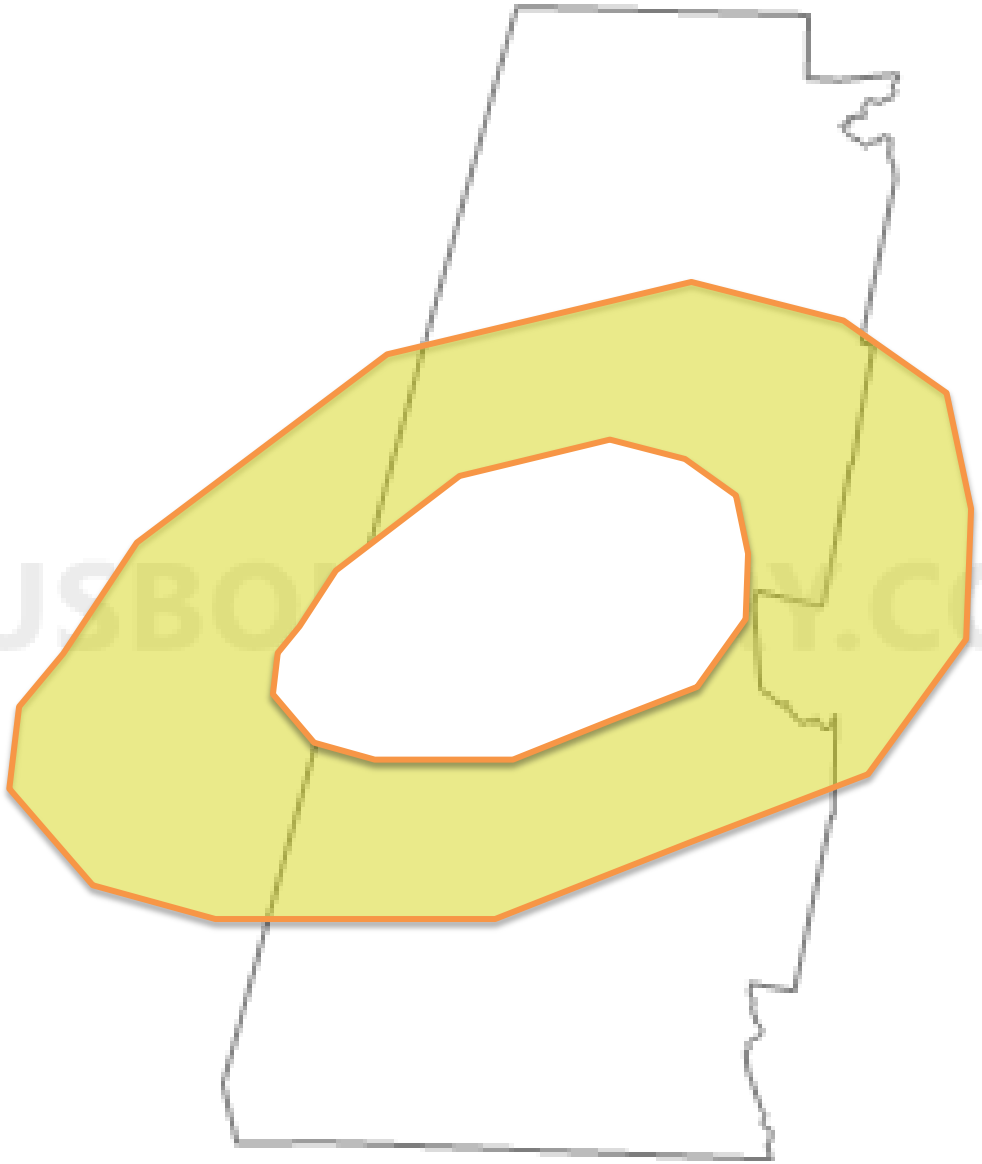
Mod and High Outlooks Included



Mod and High Outlooks Included

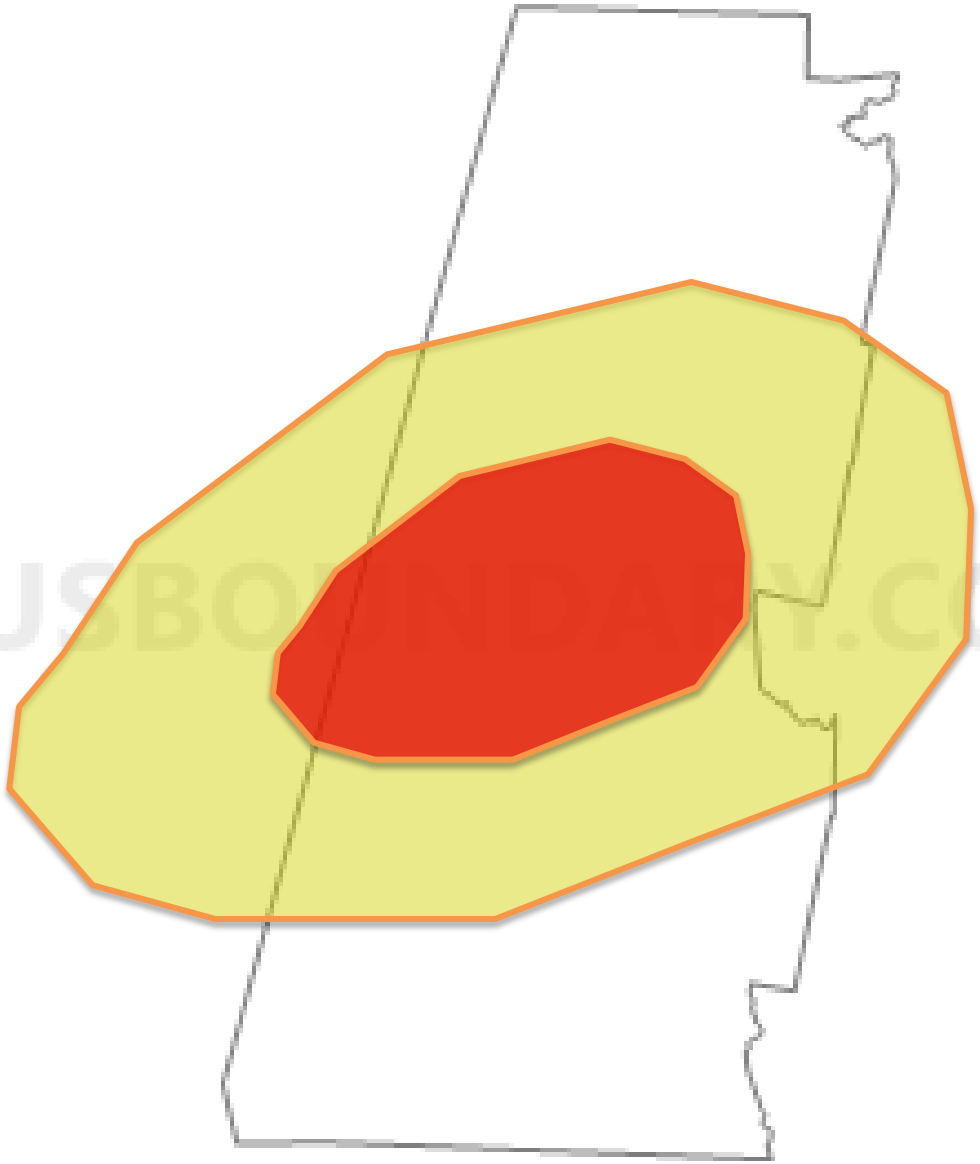


Mod and High Outlooks Included

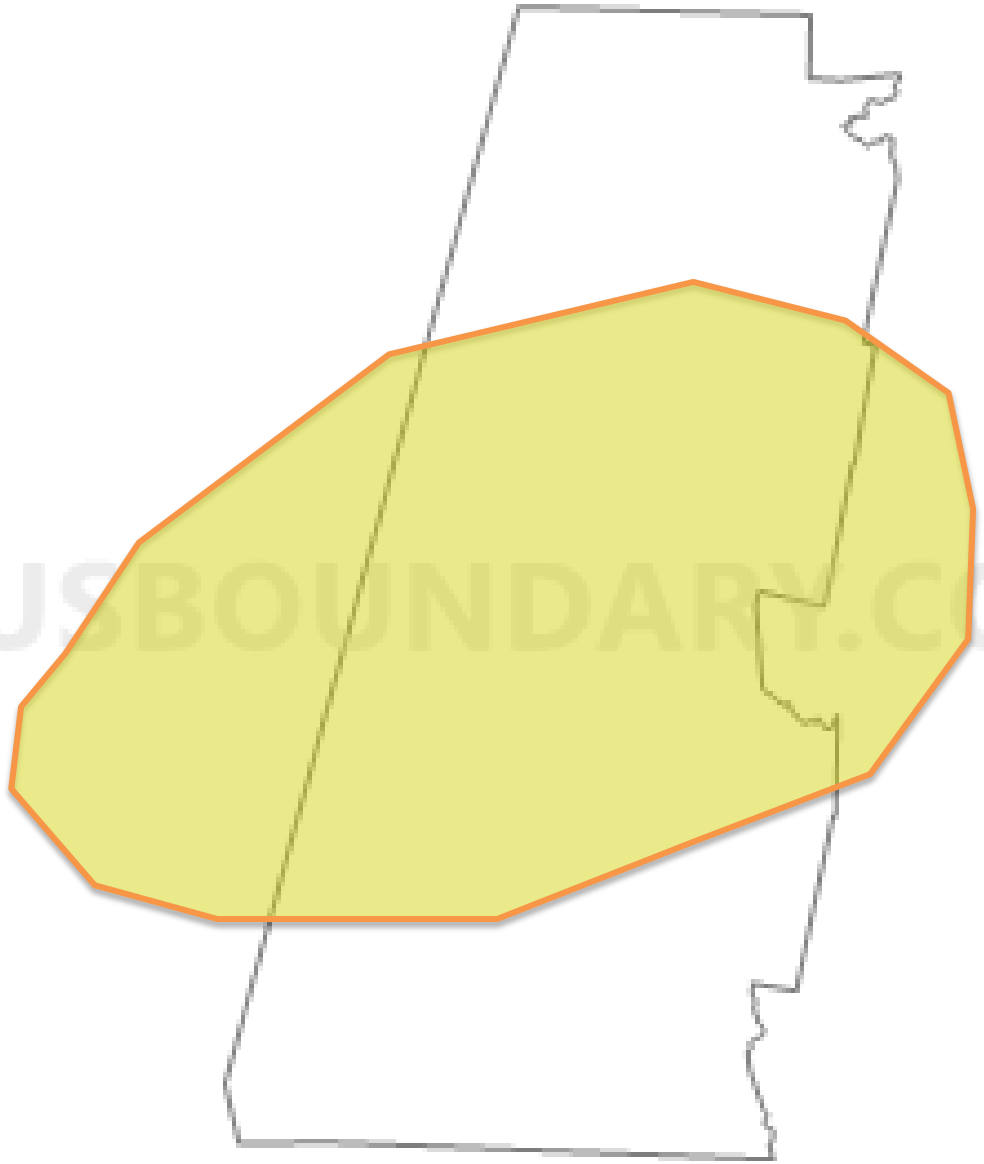


Mod and High Outlooks Included

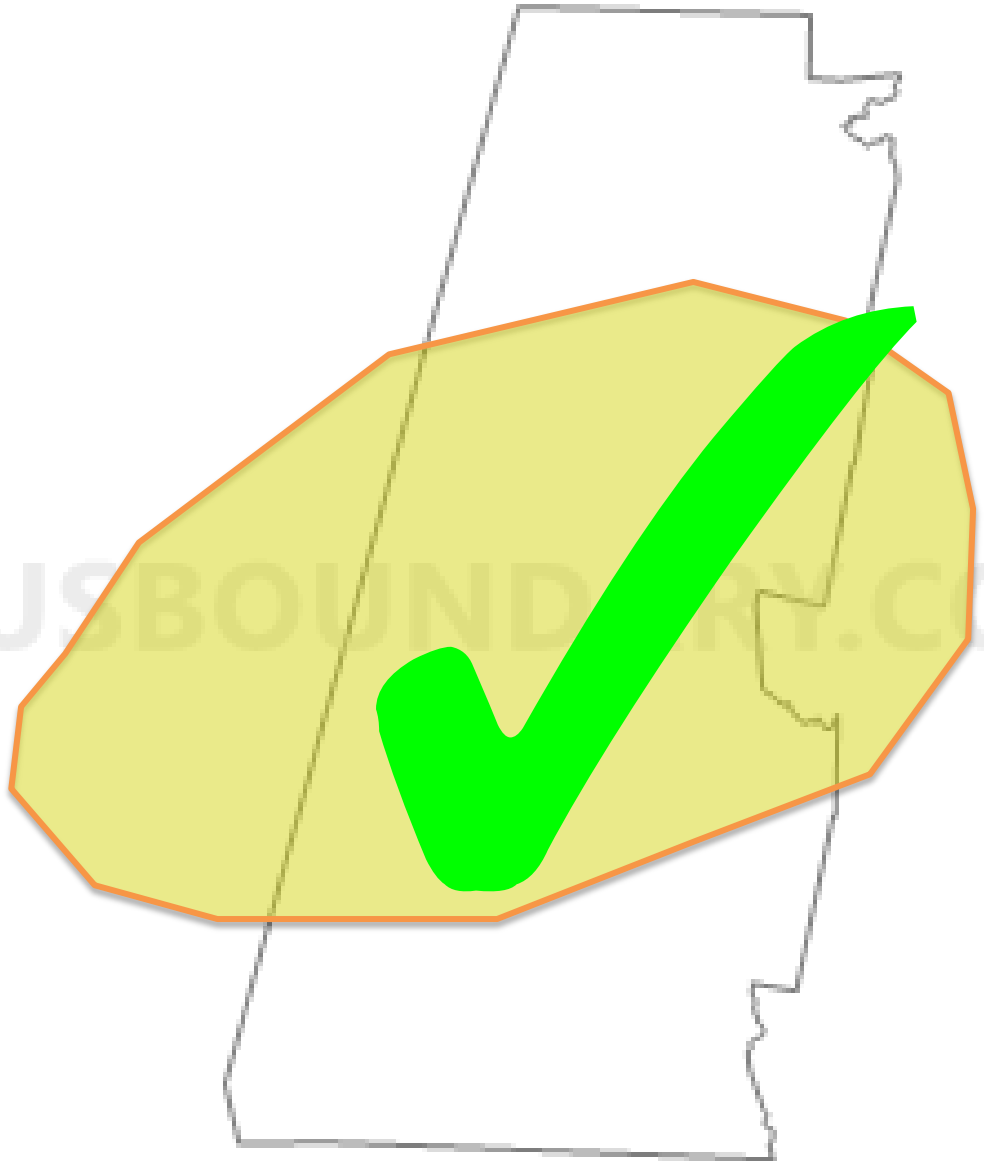
Mod and High Outlooks Included



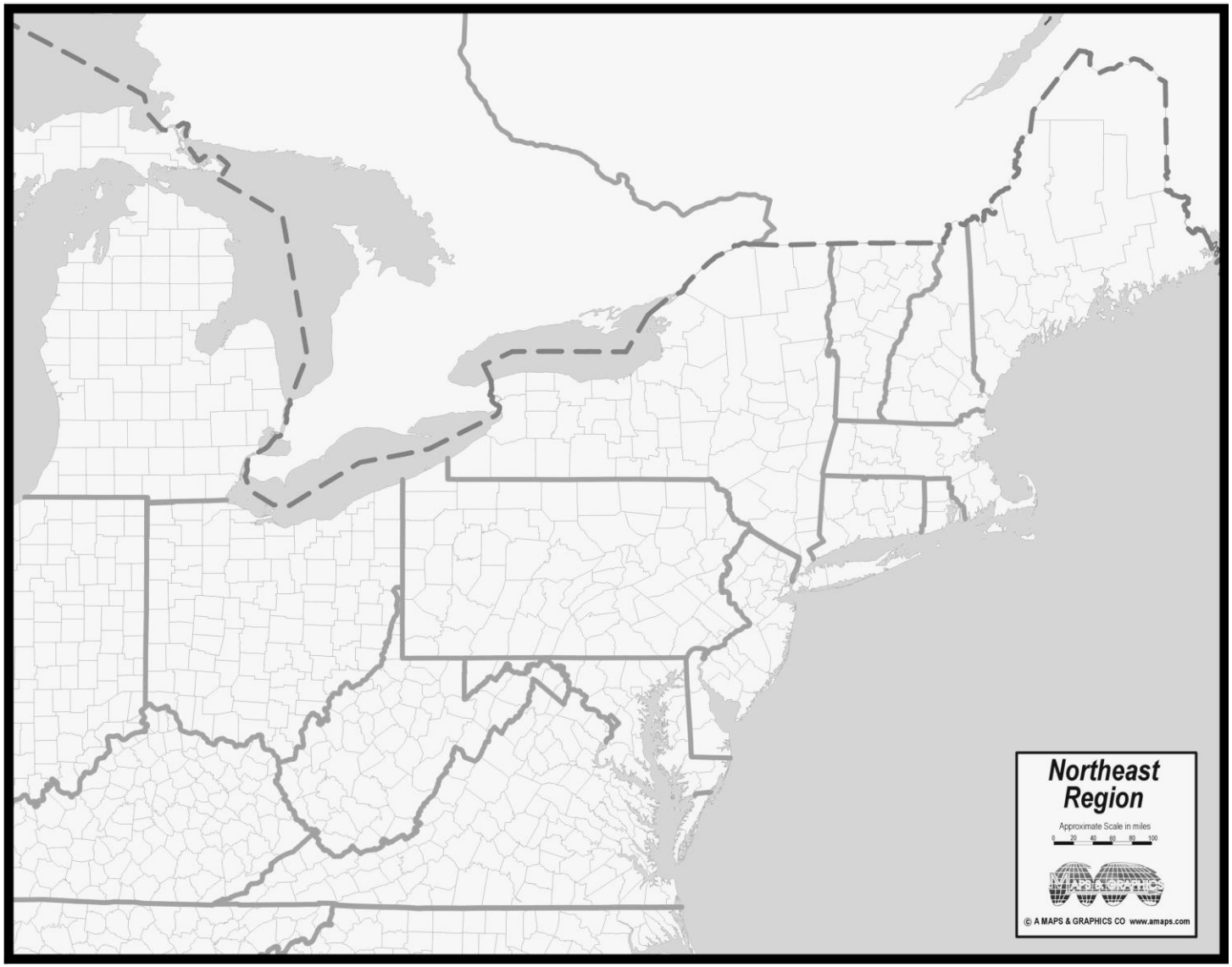
Mod and High Outlooks Included



Mod and High Outlooks Included

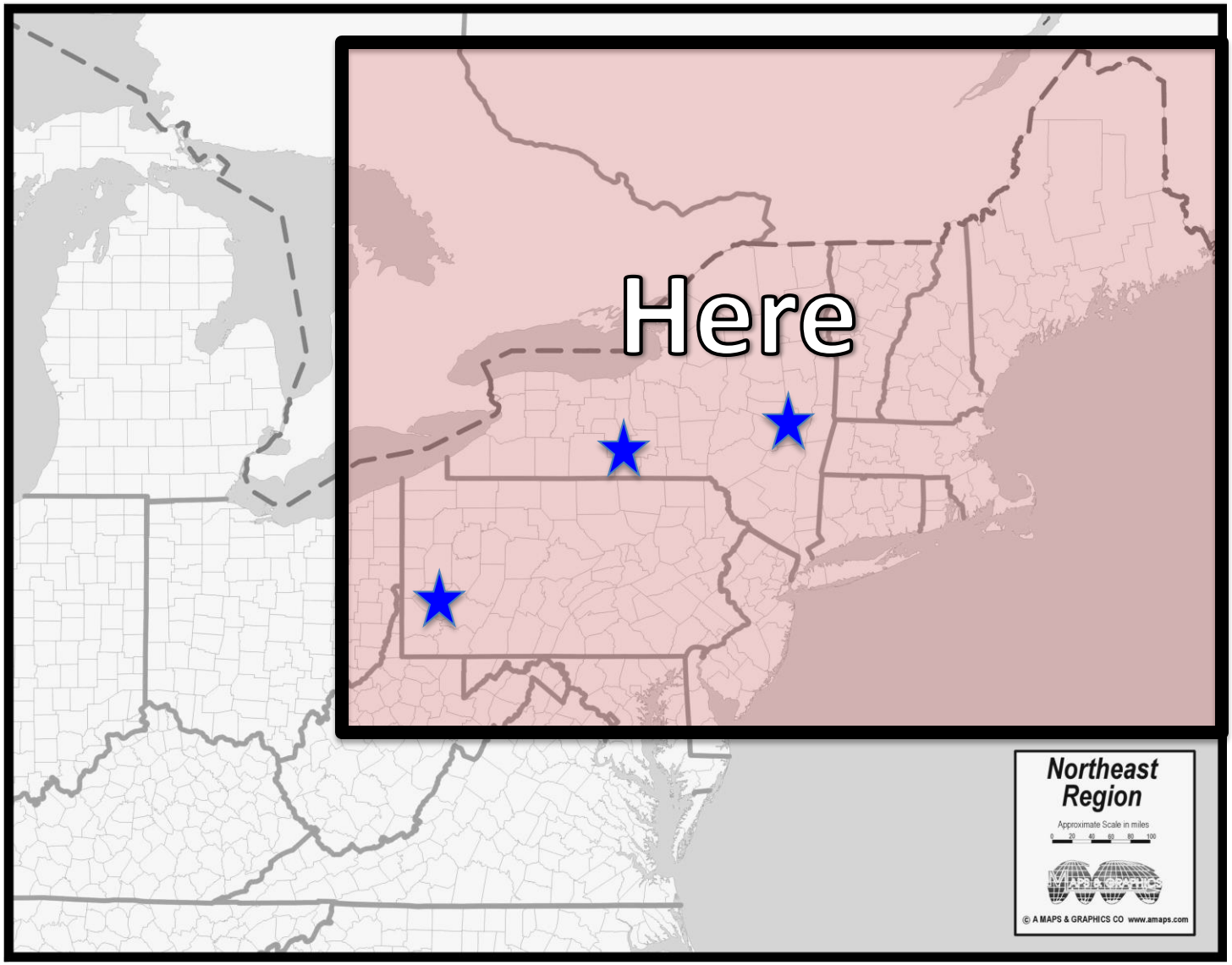


Northeast Domain



Courtesy of amaps.com

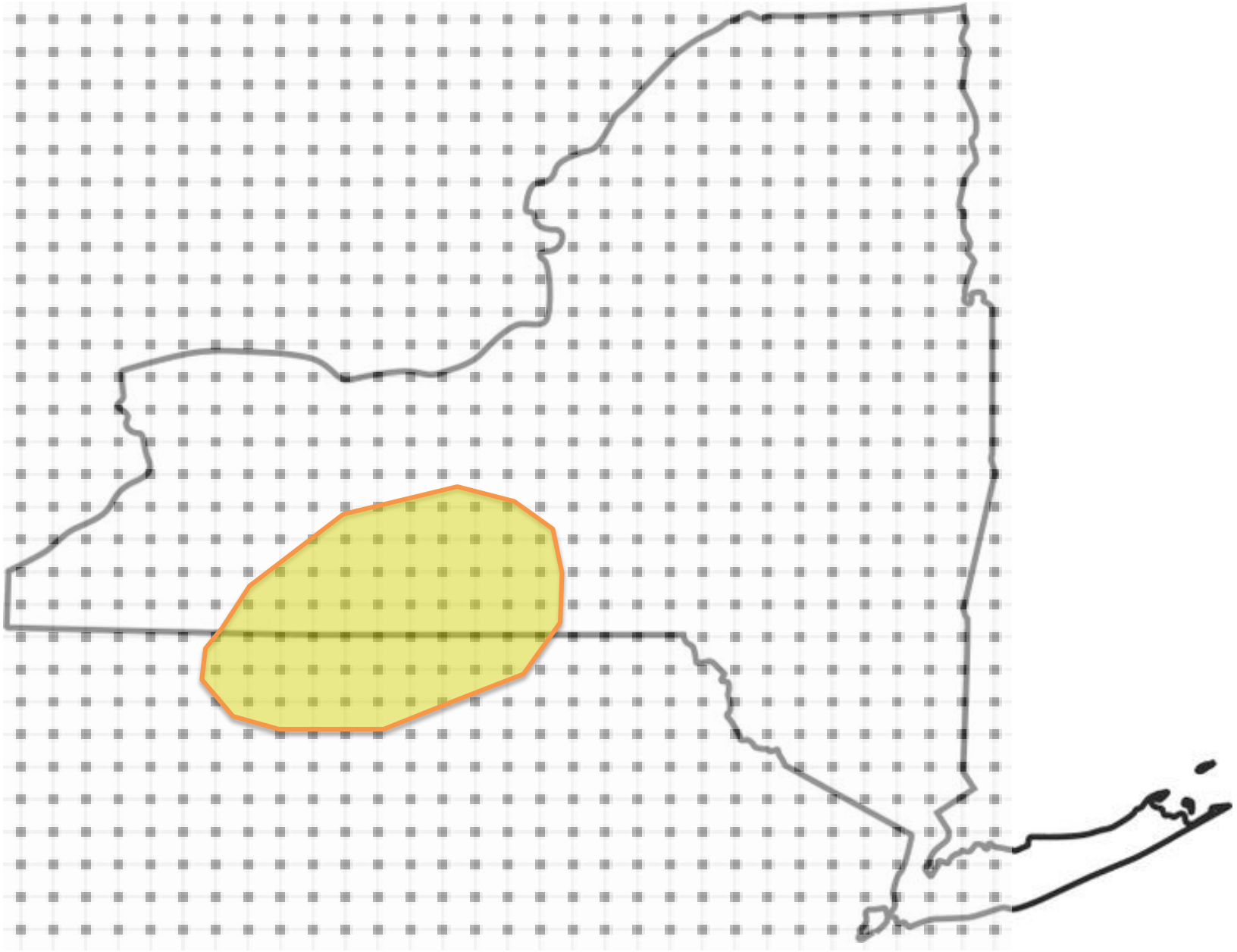
Northeast Domain



Courtesy of amaps.com

Algorithm Example

Algorithm Example

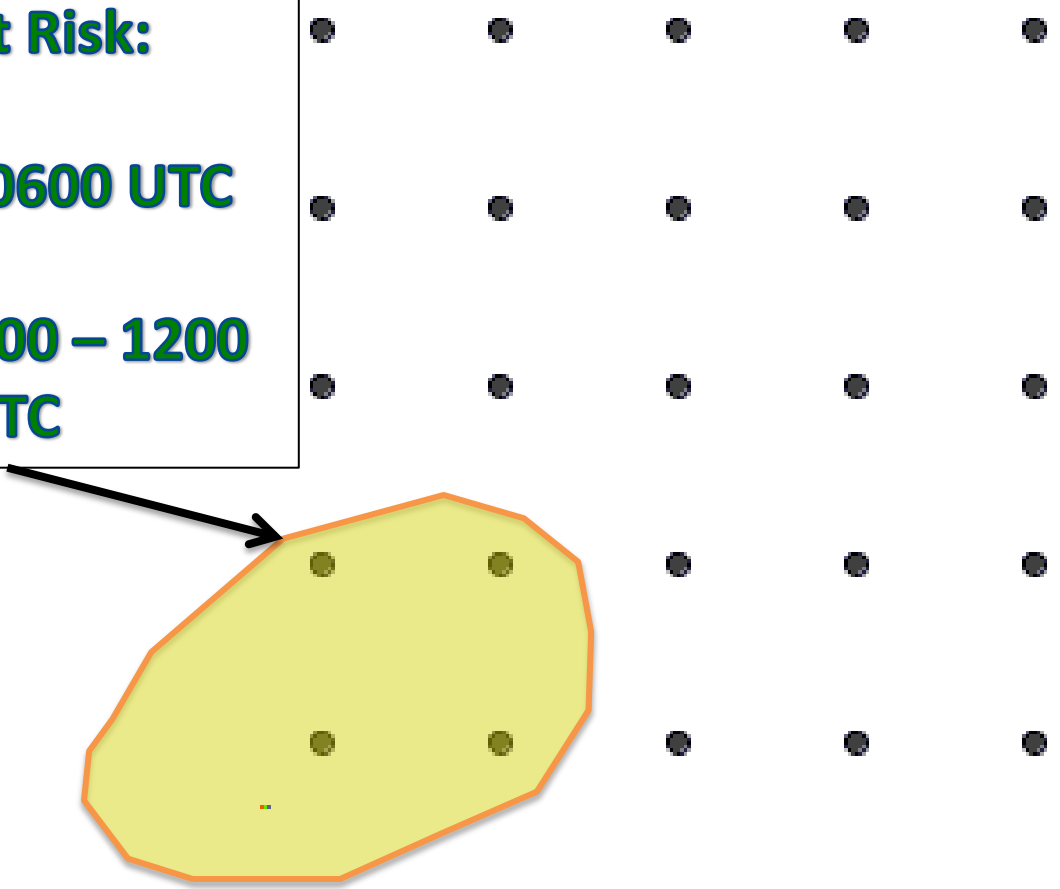


Algorithm Example

Slight Risk:

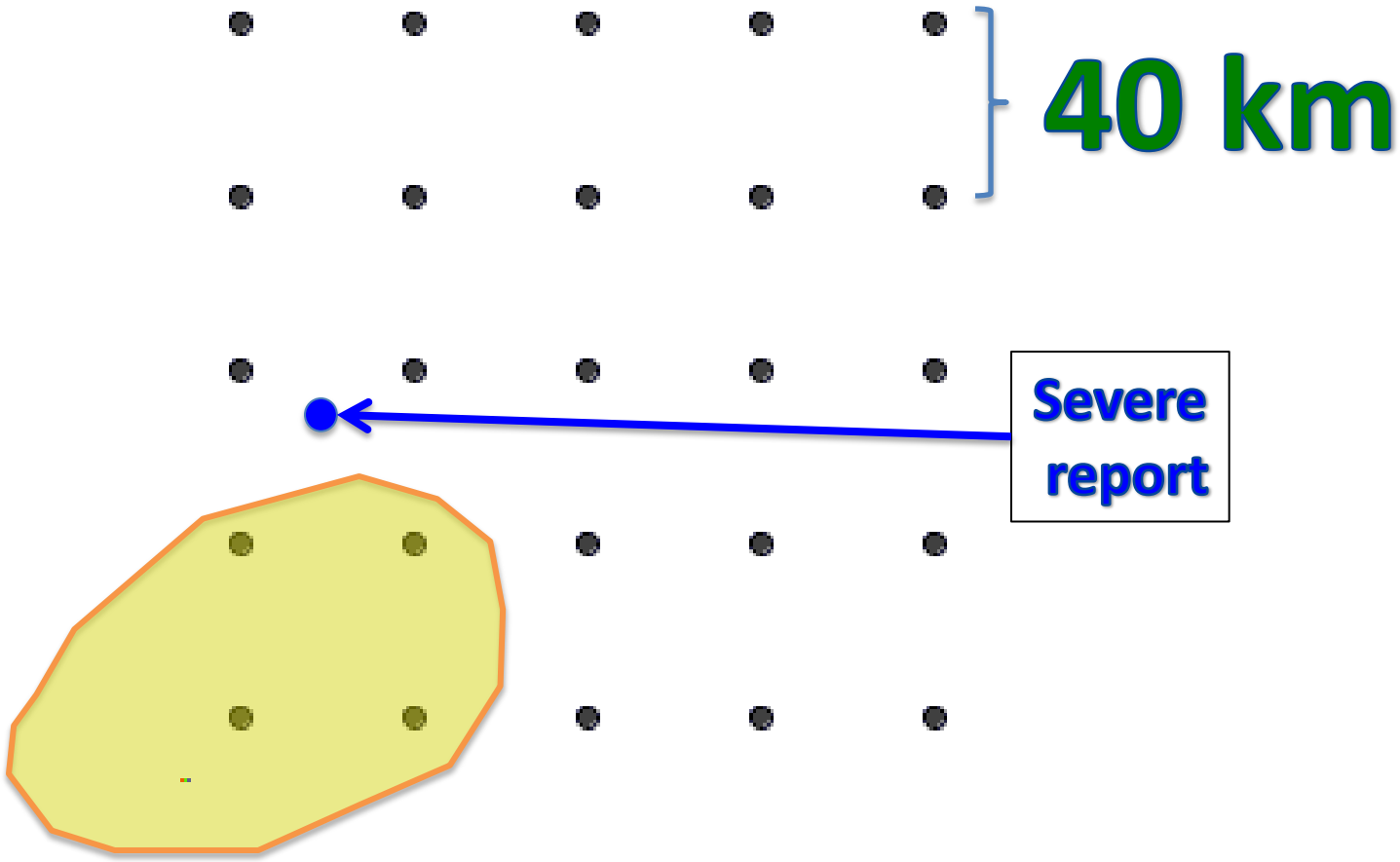
Issued: 0600 UTC

Valid: 1200 – 1200 UTC

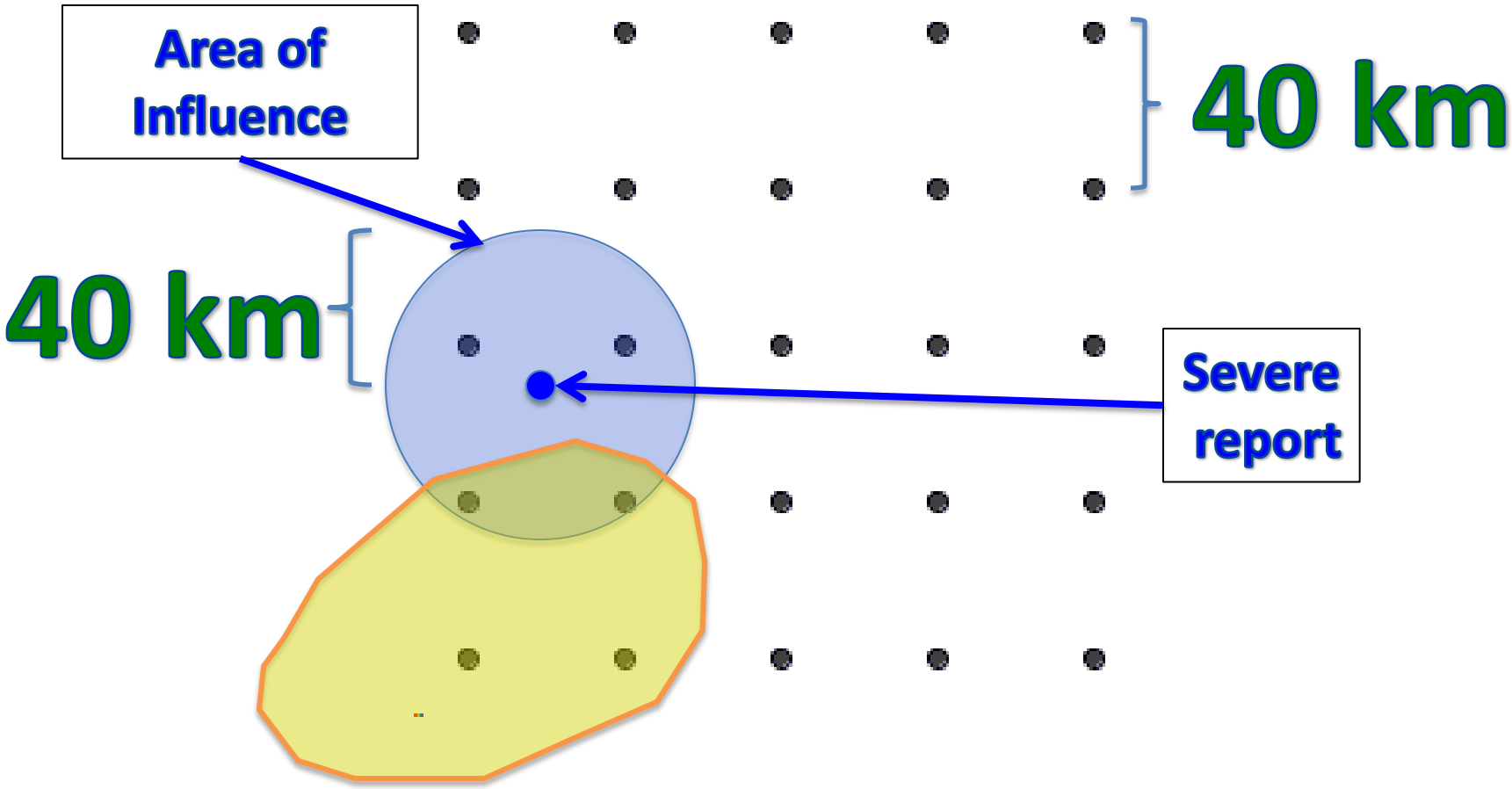


40 km

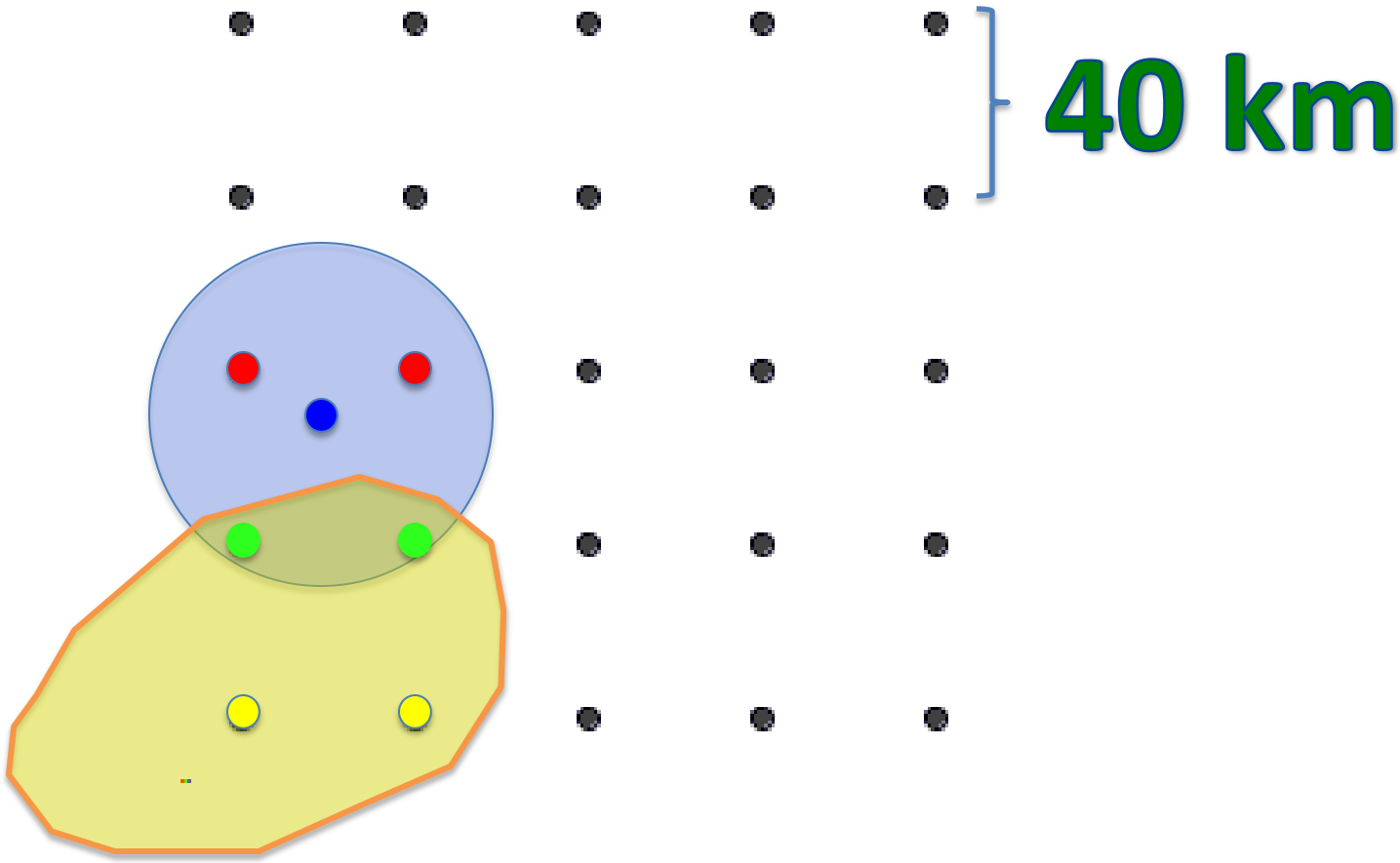
Algorithm Example



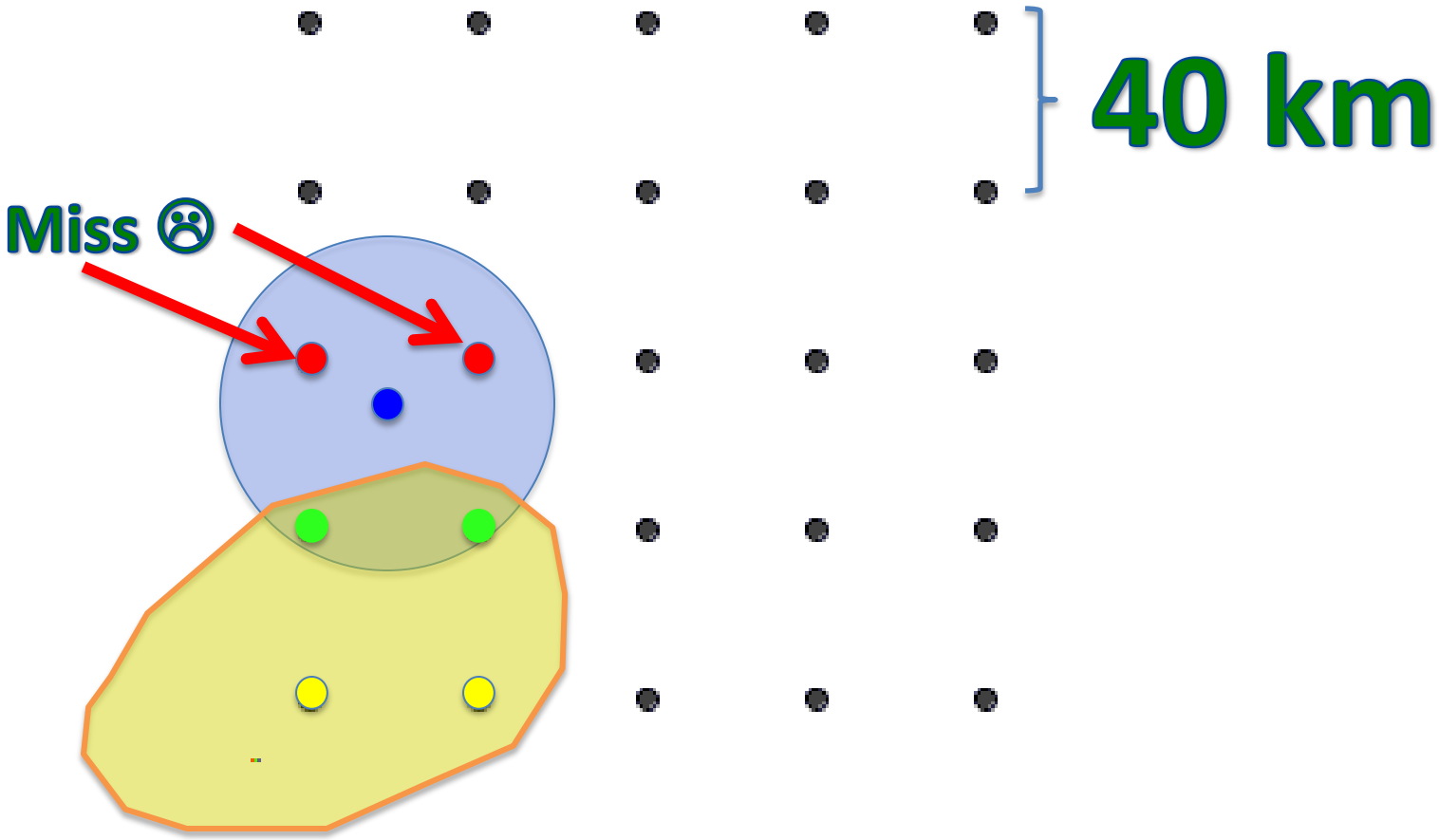
Algorithm Example



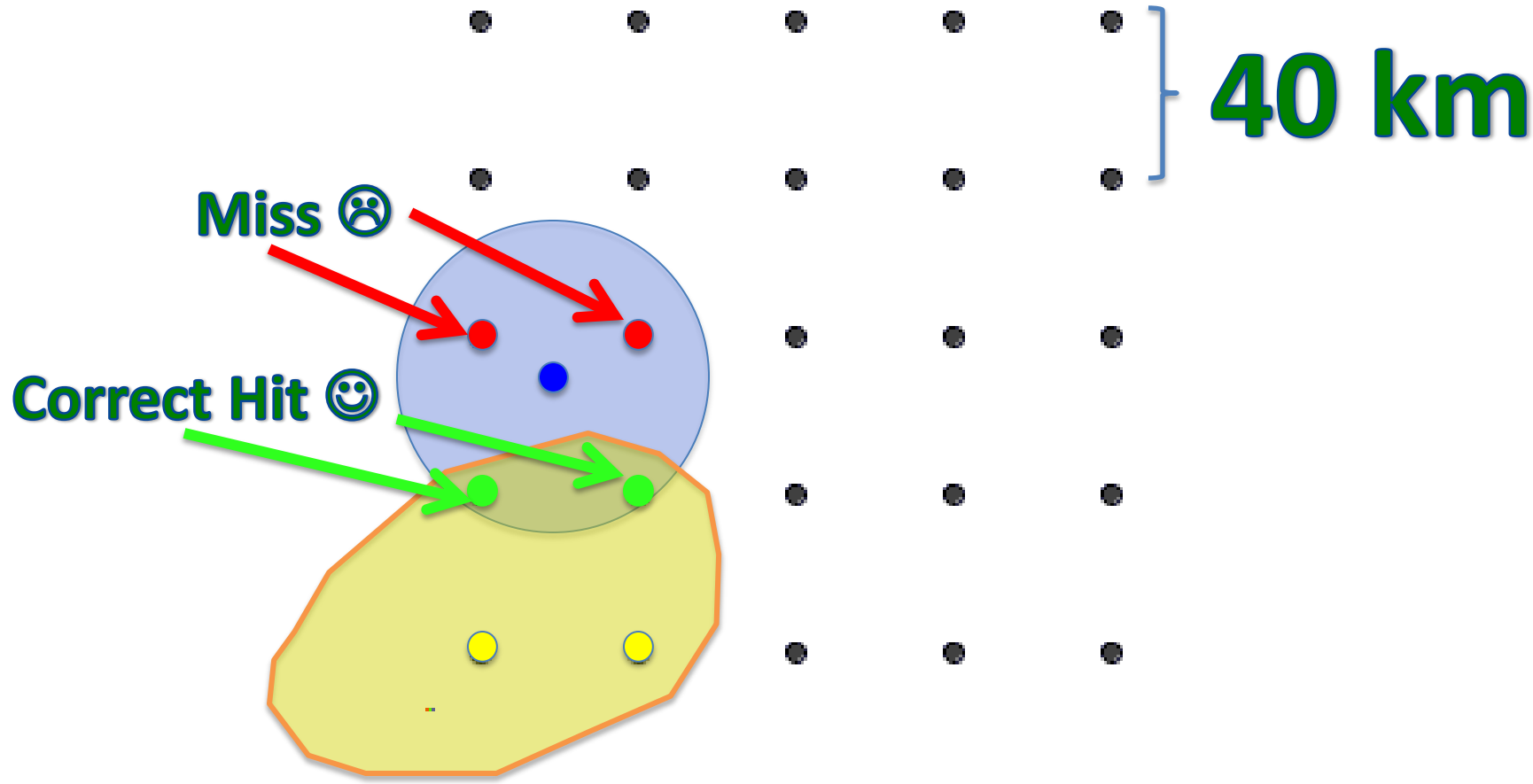
Algorithm Example



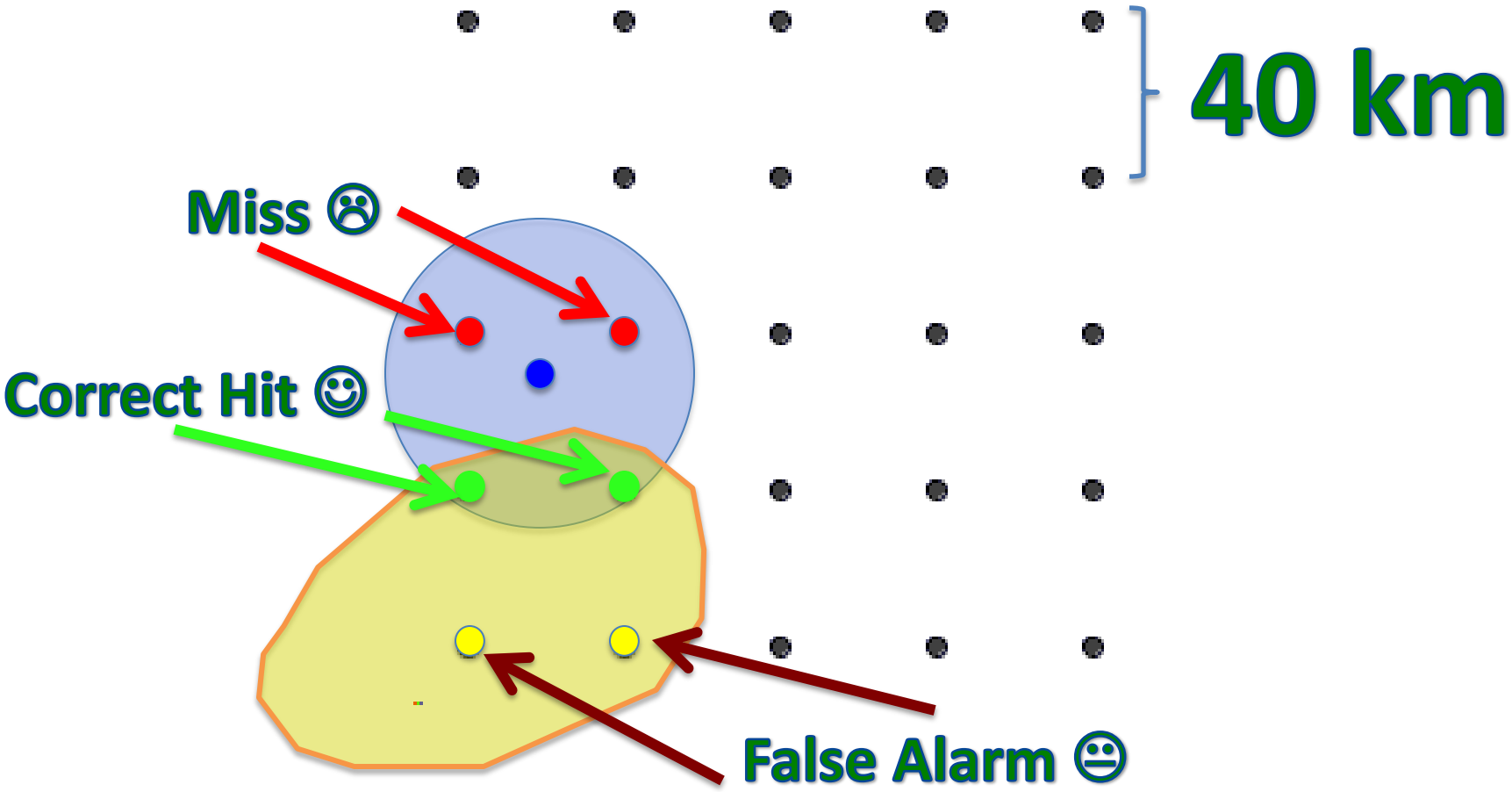
Algorithm Example



Algorithm Example



Algorithm Example



Methodology: Evaluation

$$POD = \frac{a}{a+c}$$

$0 \leq POD \leq 1$, best score: POD = 1, best score ≠ perfect forecast

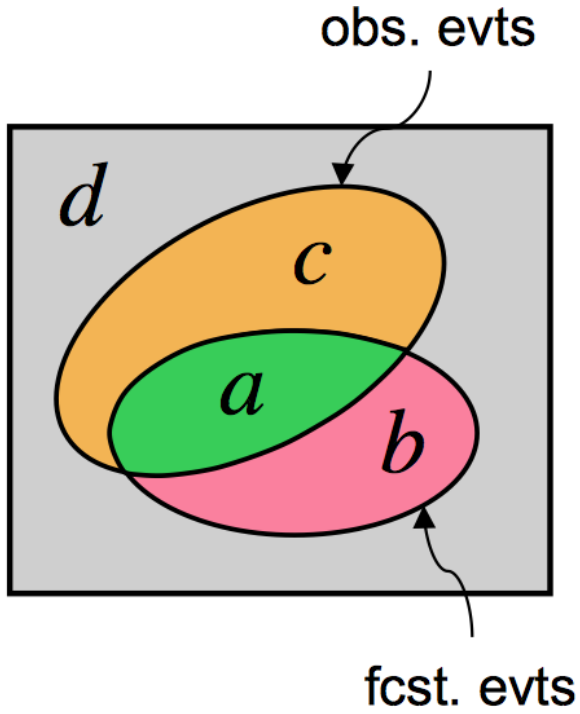
$$FAR = \frac{b}{a+b}$$

$0 \leq FAR \leq 1$, best score: FAR = 0, best score ≠ perfect forecast

$$TS = CSI = \frac{a}{a+b+c}$$

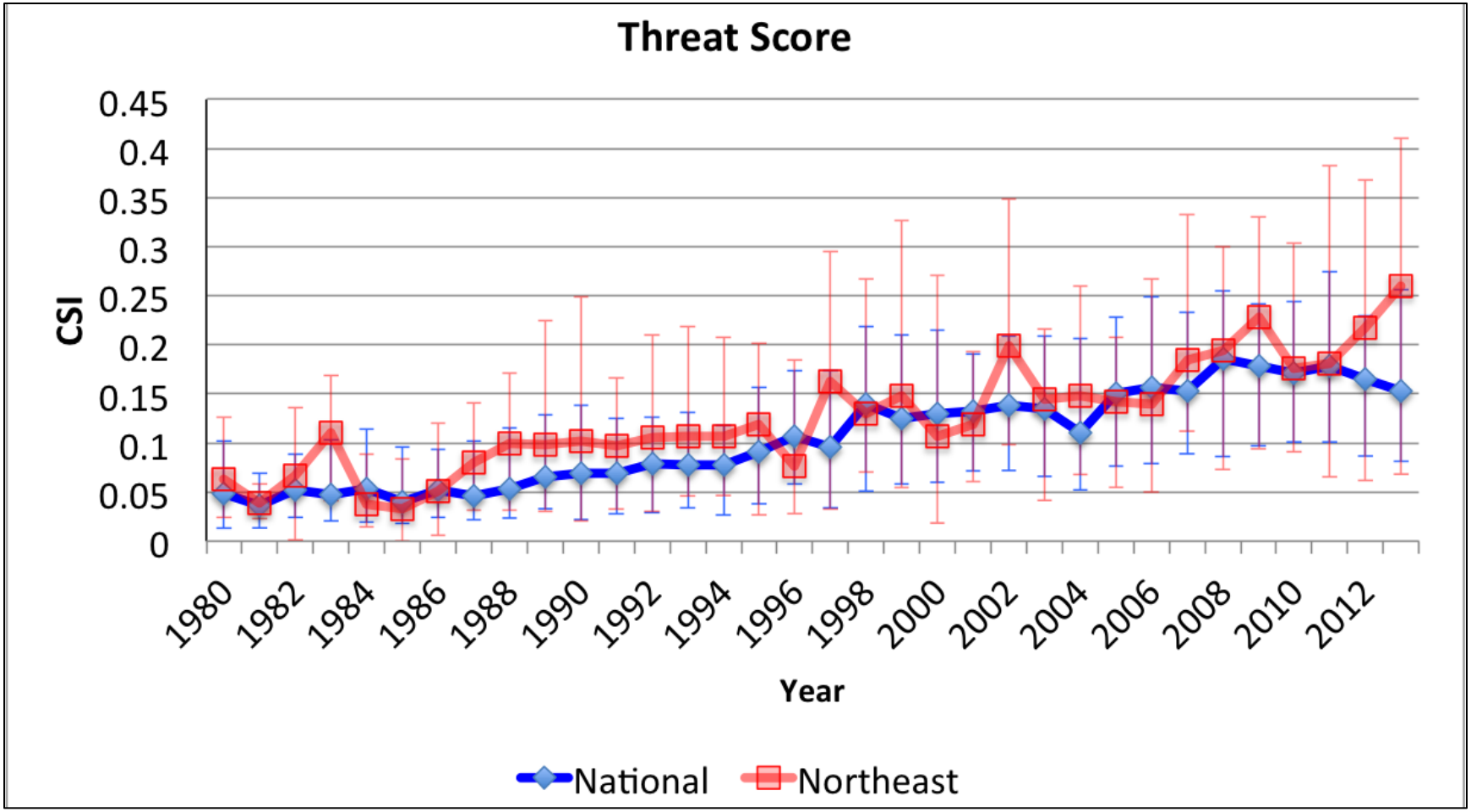
$0 \leq TS \leq 1$, best score: TS = 1, **best score = perfect forecast**

Contingency Table	Observed Y	Observed N
Forecast (Y)	Correct Hit (A)	False Alarm (B)
Forecast (N)	Miss (C)	Correct null (D)



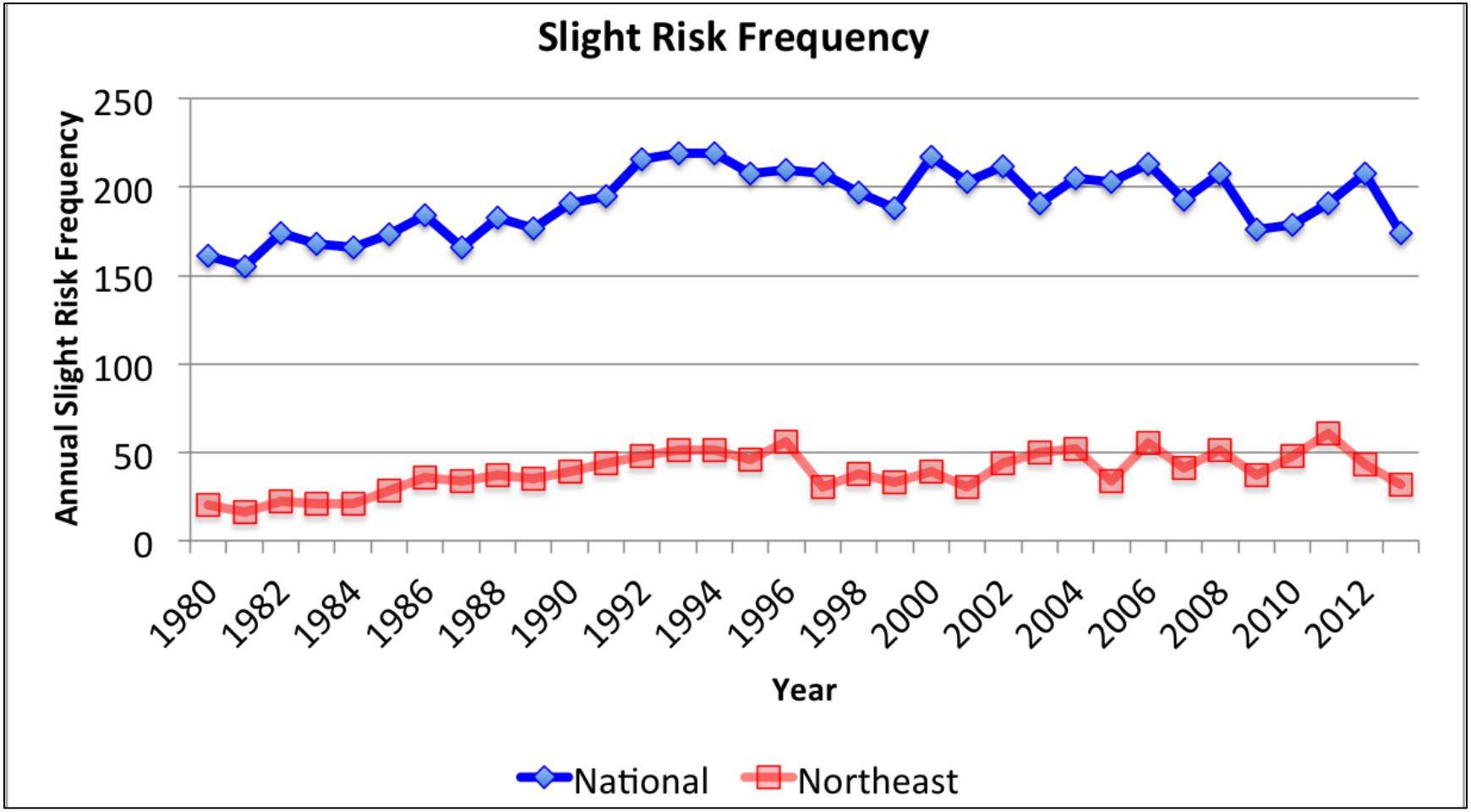
SLIGHT-RISK SKILL SCORES

Northeast and CONUS:
TS



Median is plotted with the 25th and 75th percentiles in the whiskers.

Northeast and CONUS: Slight Risk Frequency



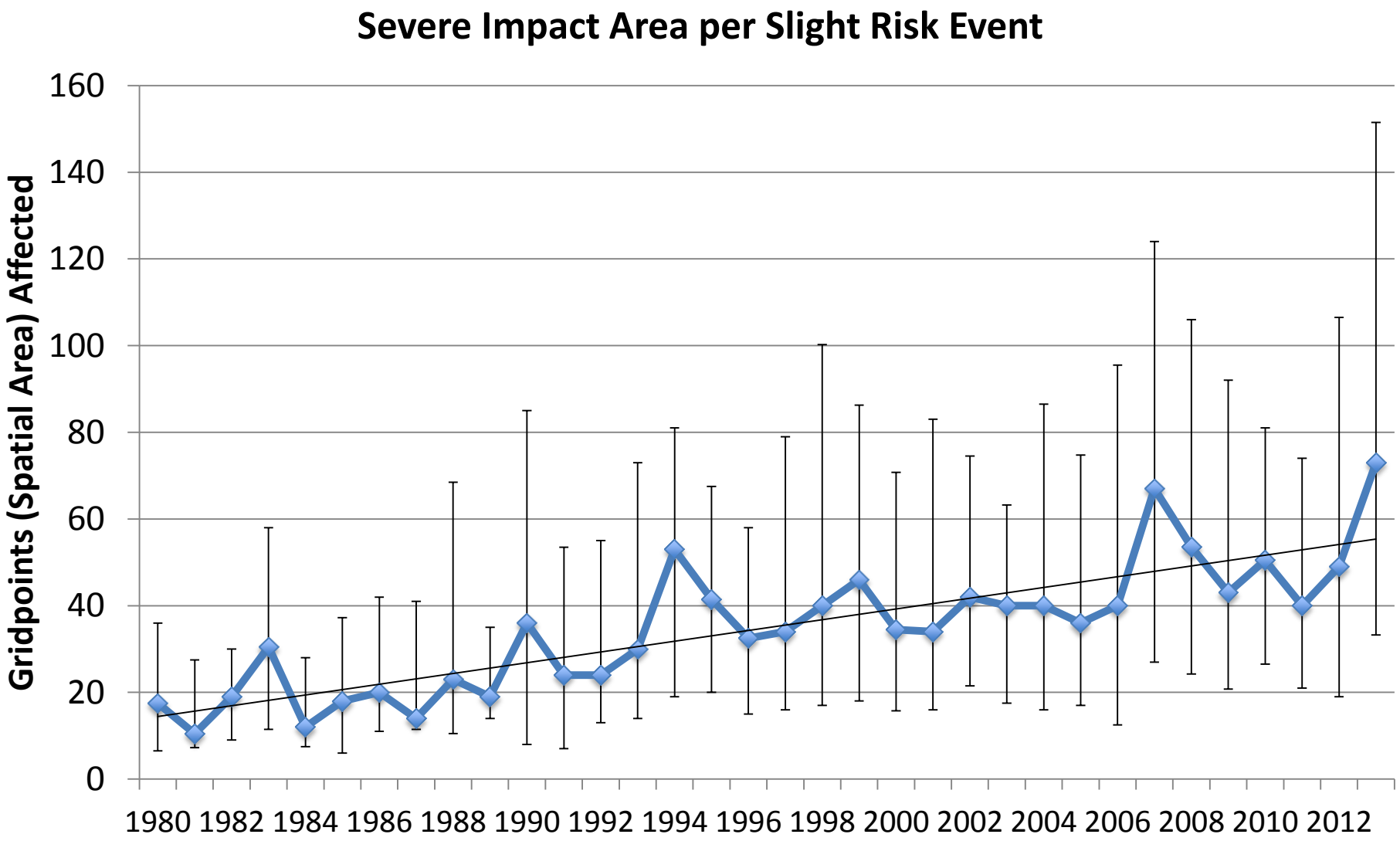
Research Goals

- Evaluate slight-risk forecast performance over the Northeast
- **Build database of events with poor forecast skill**
- Evaluate environments conducive to poor forecast skill

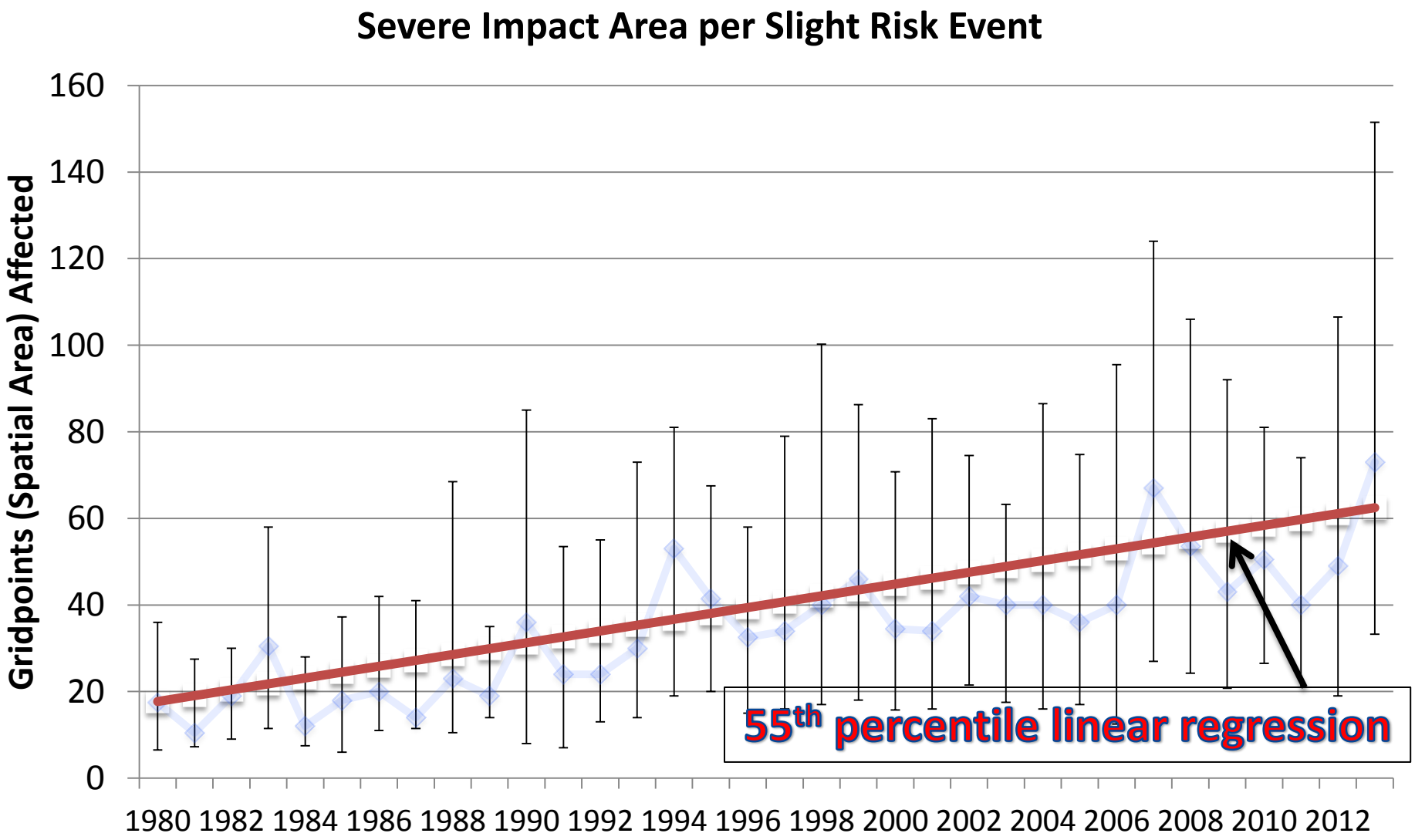
Database Criteria

- For inclusion in the 1980–2013 database, an event must meet at least 1 of 2 criteria:
  - Have a slight risk contour within the NE domain
  - Have a sufficiently high impact to warrant inclusion
    - How do we define “high impact”?

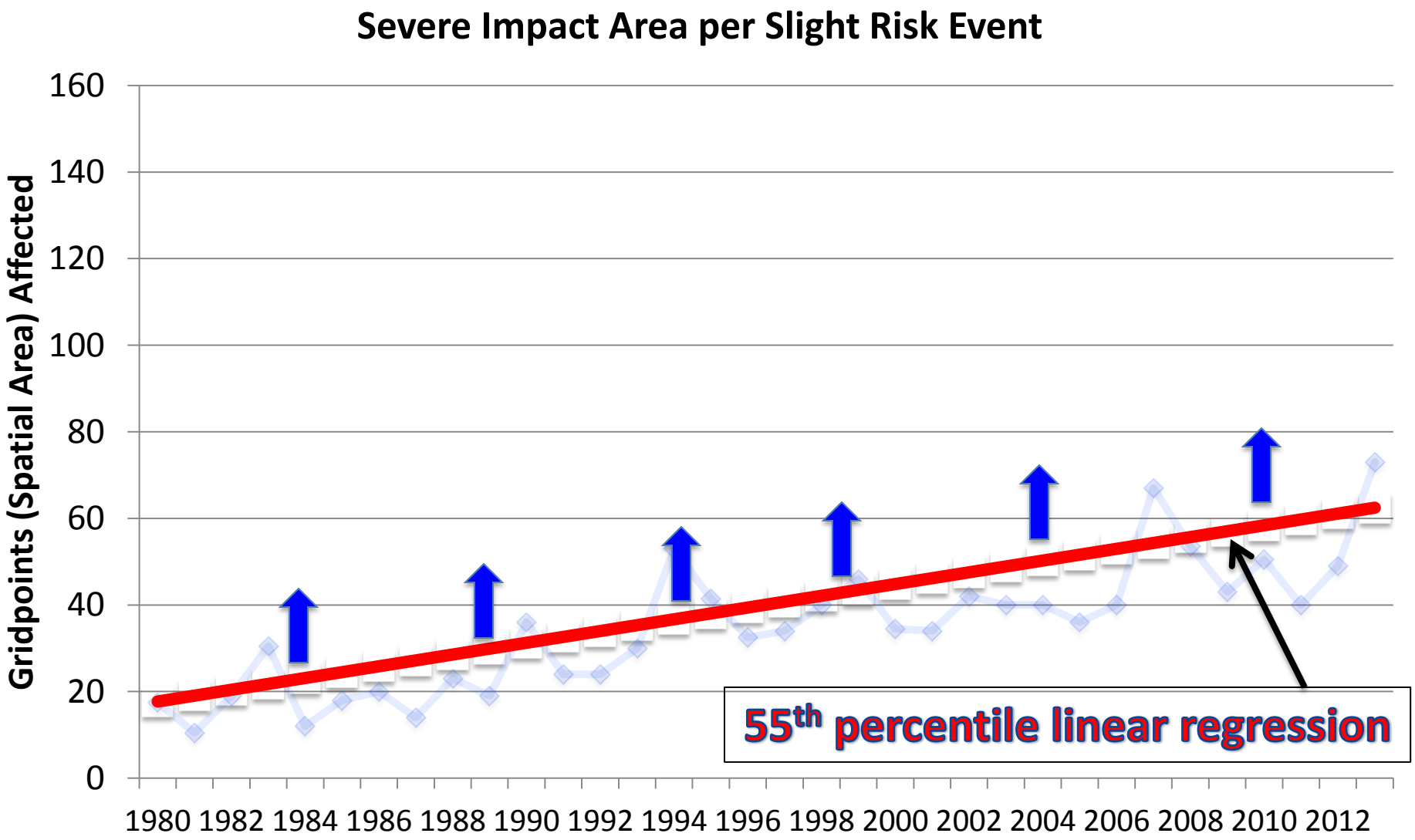
Northeast Severe Report Trend



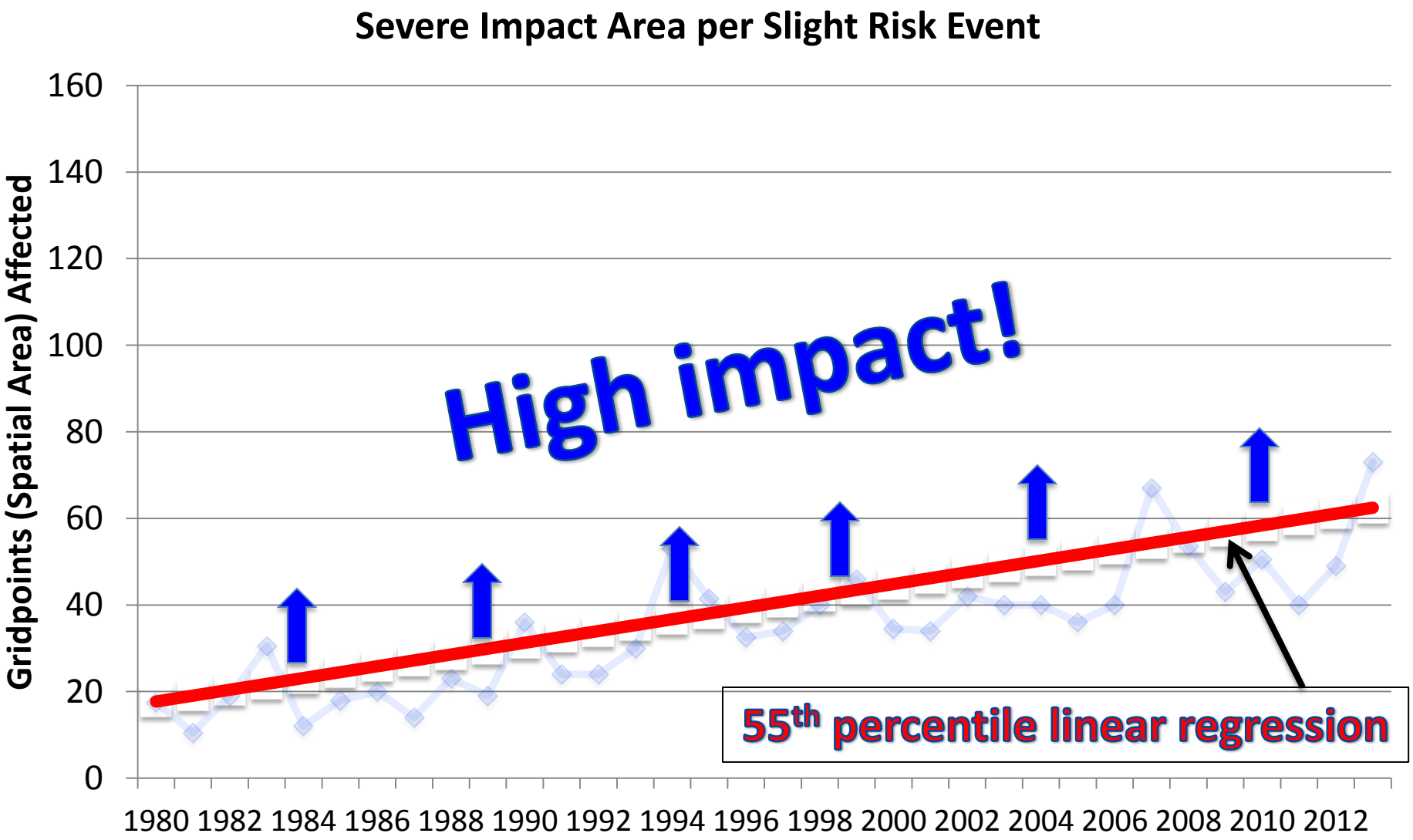
Northeast Severe Report Trend



Northeast Severe Report Trend



Northeast Severe Report Trend



High-Impact Database: Quick Stats

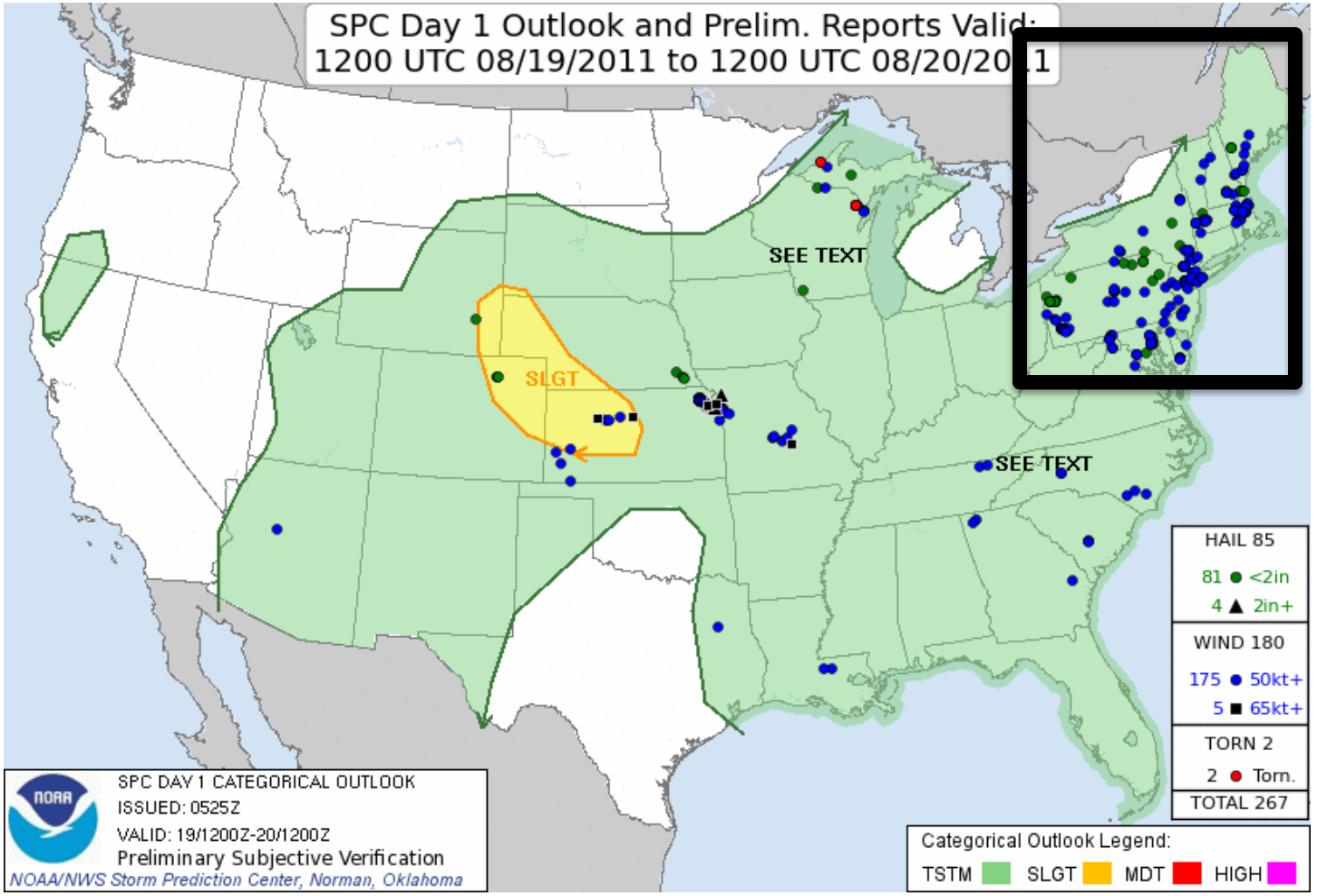
- Event days = **1503**
- Slight-risk days = **1300**
- High-impact events without slight-risk = **203**

TYPES OF LOW-PREDICTABILITY EVENTS

Type 1 (Low POD) Example

Reports captured = 0 Reports missed = 200

POD = 0 FAR = N/A TS = 0



Types of Low Predictability Events

Type 1

- Low POD

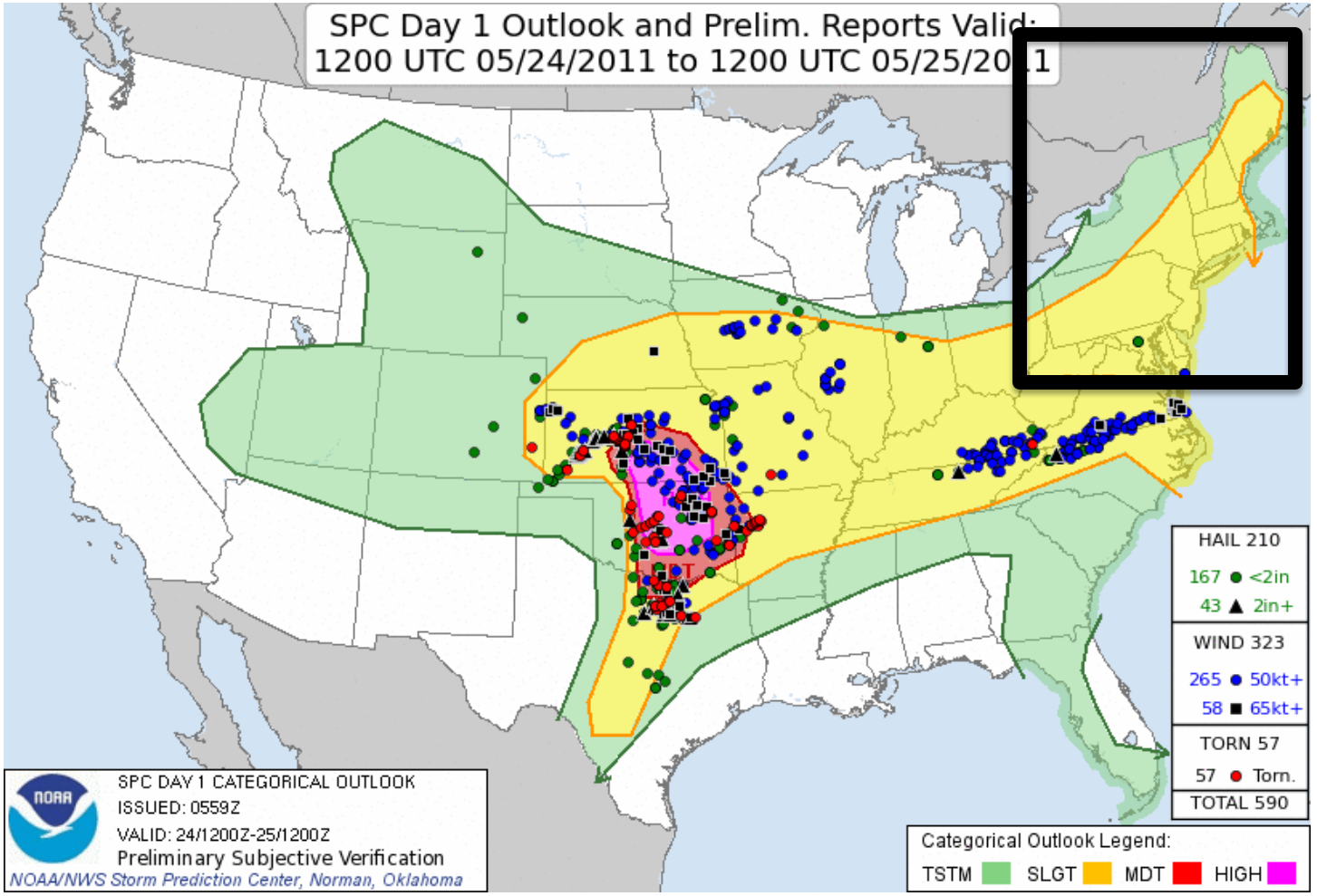
- Type 1
  - High impact
  - Lowest 25th percentile POD score

- Expected little severe wx
- Ends up over-performing

Type 2 (High FAR) Example

Reports captured = 2 Reports missed = 0

POD = 1 FAR = .986 TS = .014



Types of Low Predictability Events

- Expected to perform well
- Ends up under-performing

Type 2

- High FAR

Type 2

- Highest 25th percentile FA area
- Lowest 25th percentile severe report area

Types of Low Predictability Events

Type 1

- Low POD

- Type 1
  - High impact
  - Lowest 25th percentile POD score

Type 2

- High FAR

- Type 2
  - Highest 25th percentile FA area
  - Lowest 25th percentile severe report area

- No events meet both requirements

COLLECT EVENTS WITH GOOD FORECAST SKILL FOR COMPARISON

Type of High Predictability Events

Good Event

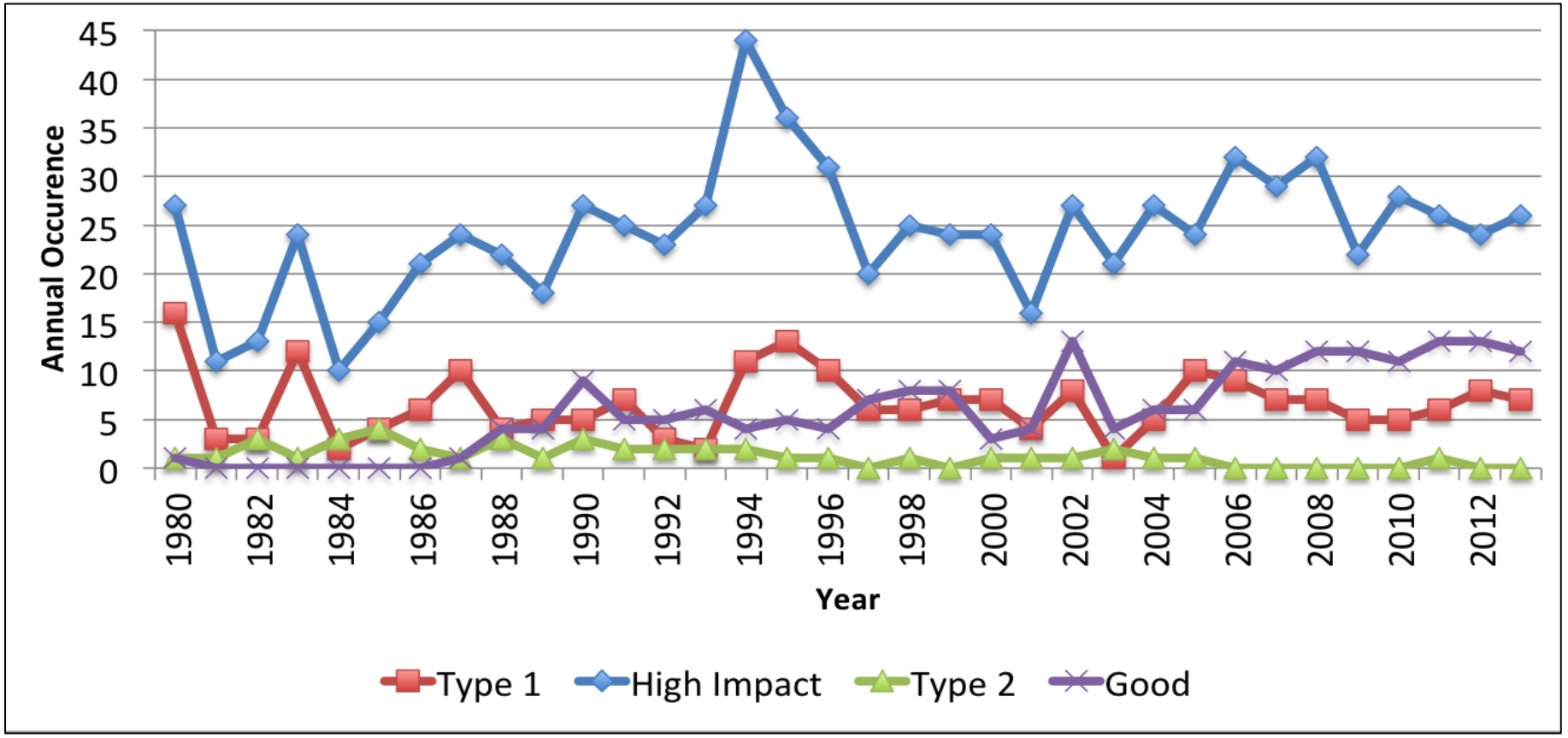
- High TS

- Good Event
  - High impact
  - Highest 25th percentile threat score

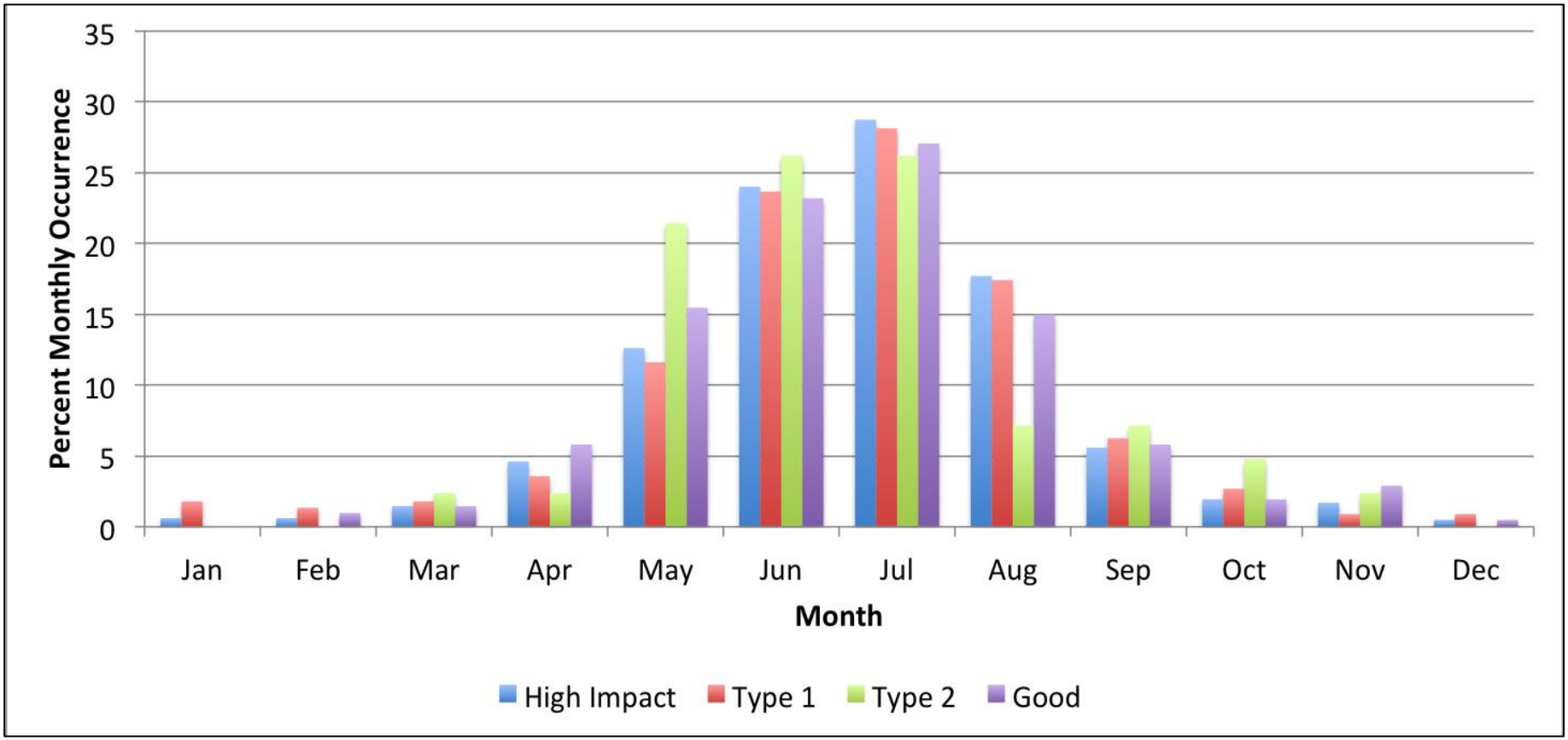
- Expected to perform well
- Performs well (perhaps too well)

HIGH-IMPACT, LOW-PREDICTIVE SKILL CLIMATOLOGY

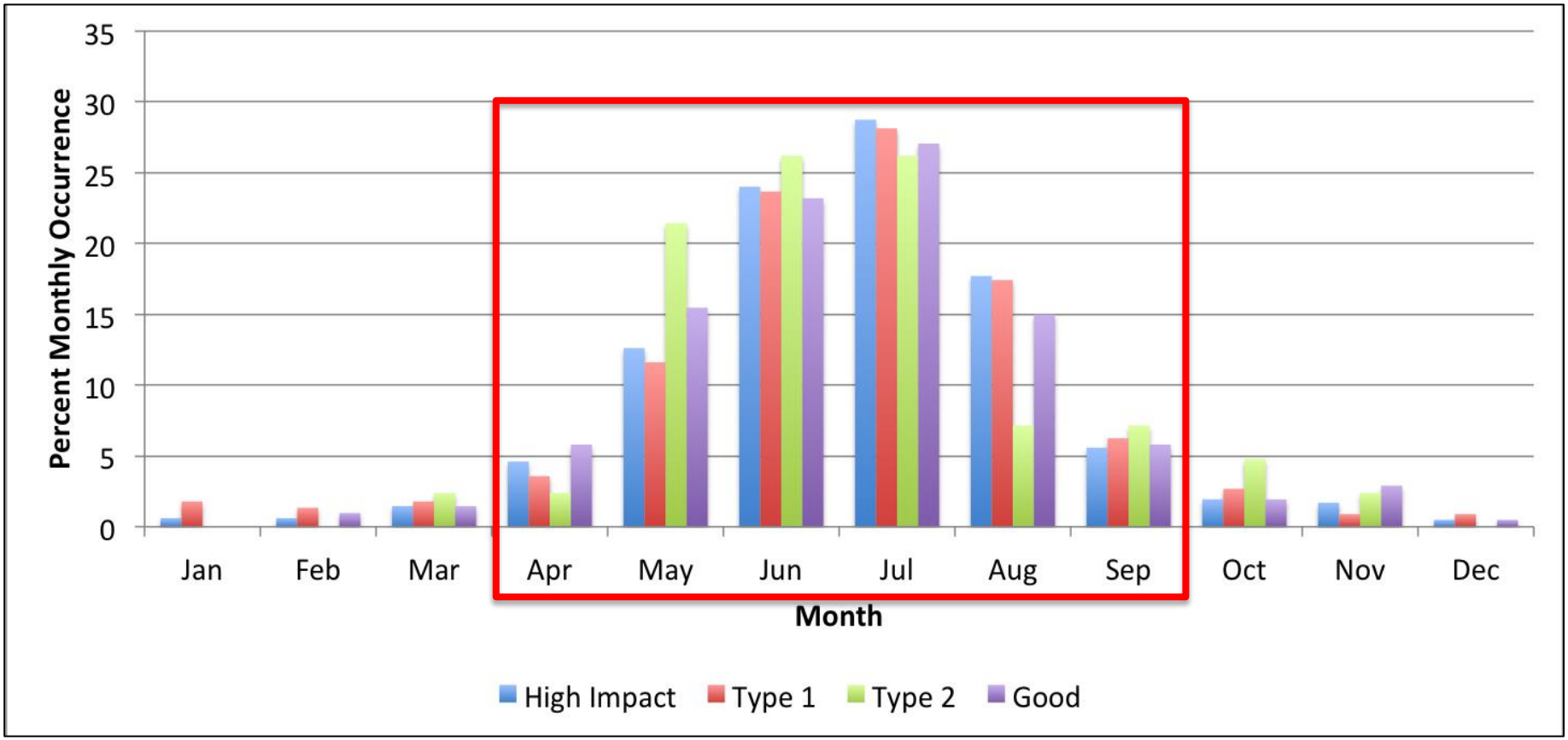
Annual Frequency



Monthly Frequency



Monthly Frequency



Research Goals

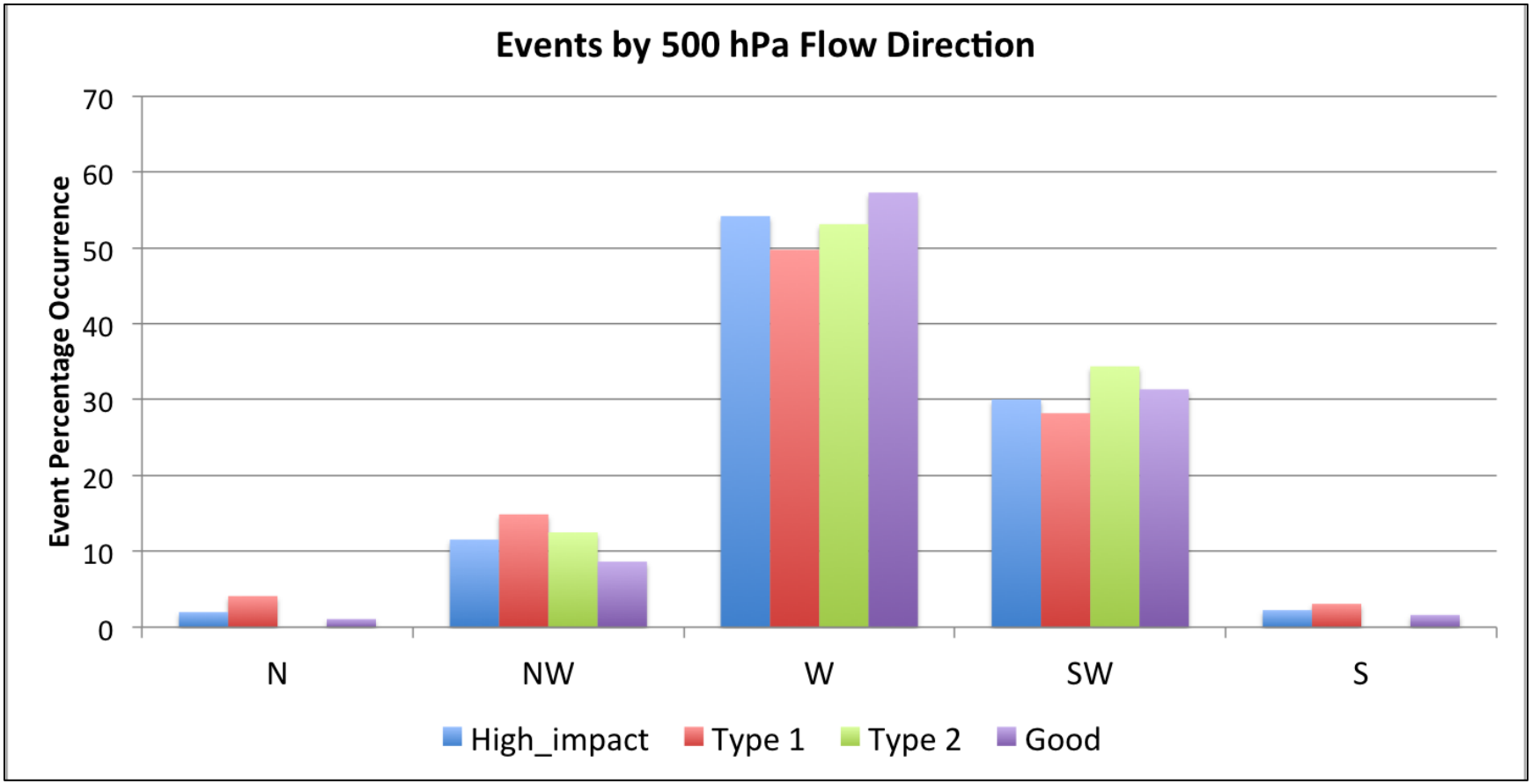
- Evaluate slight-risk forecast performance over the Northeast
- Build database of events with poor forecast skill
- **Evaluate environments conducive to poor forecast skill**

EVENT-CENTERED COMPOSITES

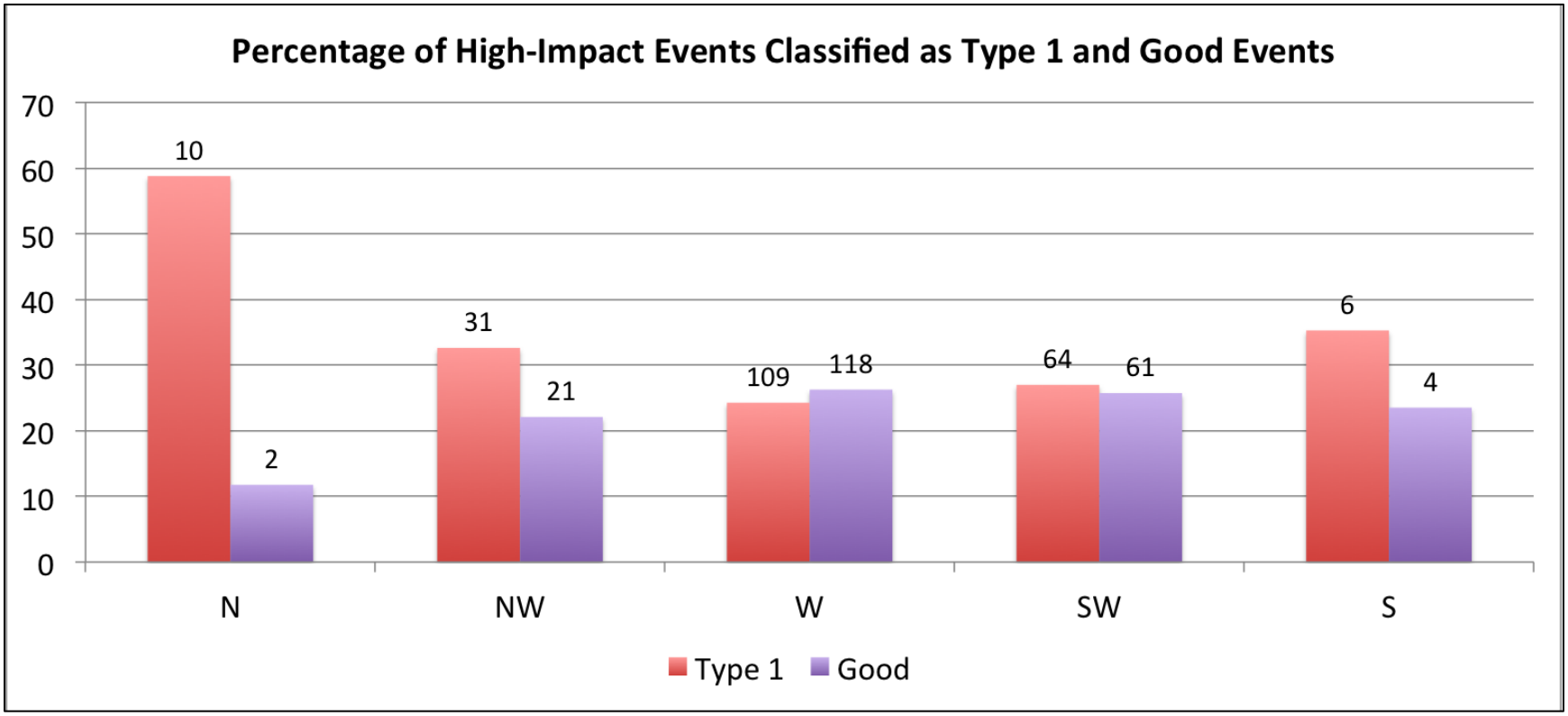
Event Centering Technique

- 0.5° NCEP Climate Forecast System Reanalysis (CFSR)
  - Chose morning (1200 UTC) for synoptic analysis, afternoon (1800 UTC) for severe weather parameter analysis
- Type 1 and Good forecast events centered on the point of maximum report density
  - Composited April–September to capture majority (93%) of high-impact events
- Type 2 events centered at centroid of the slight-risk region

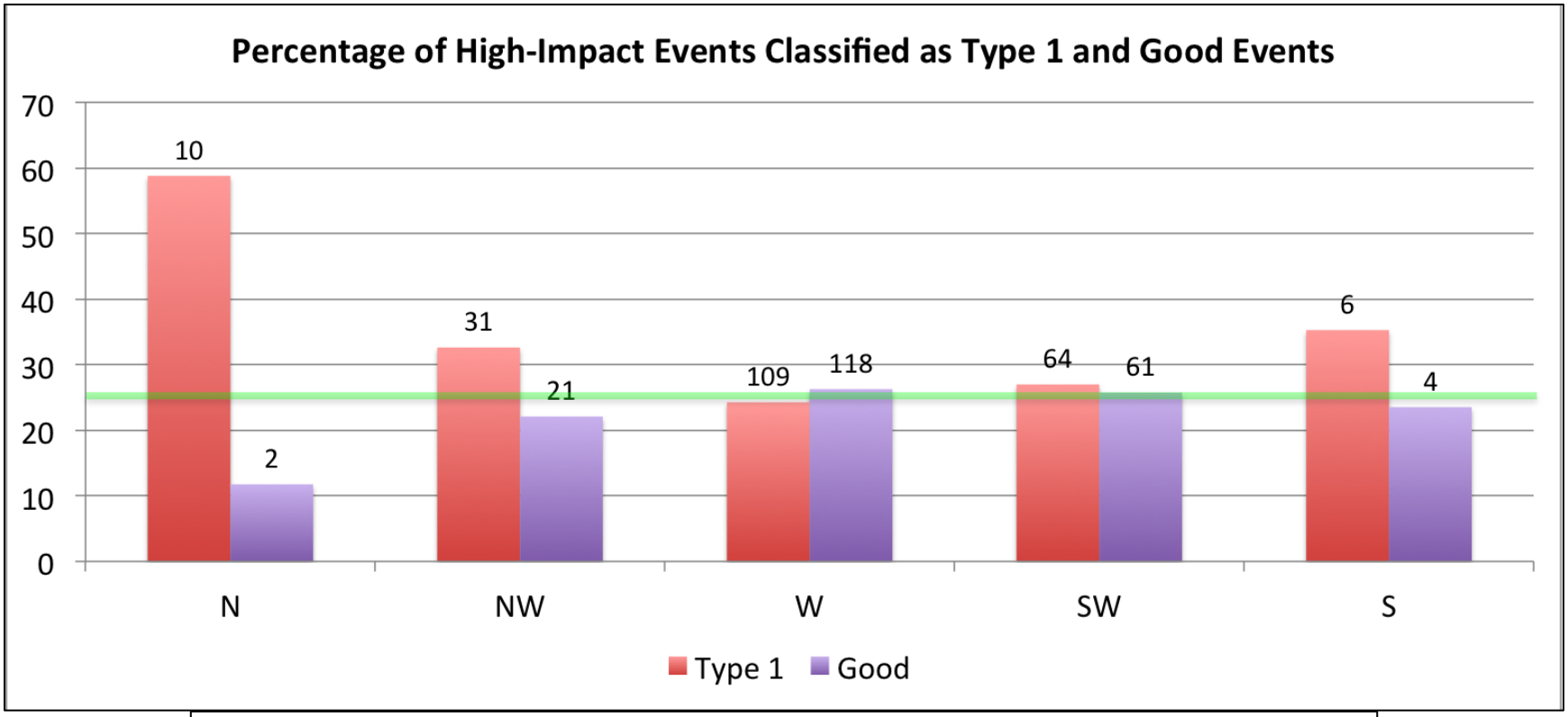
Event Climatology



Event Climatology

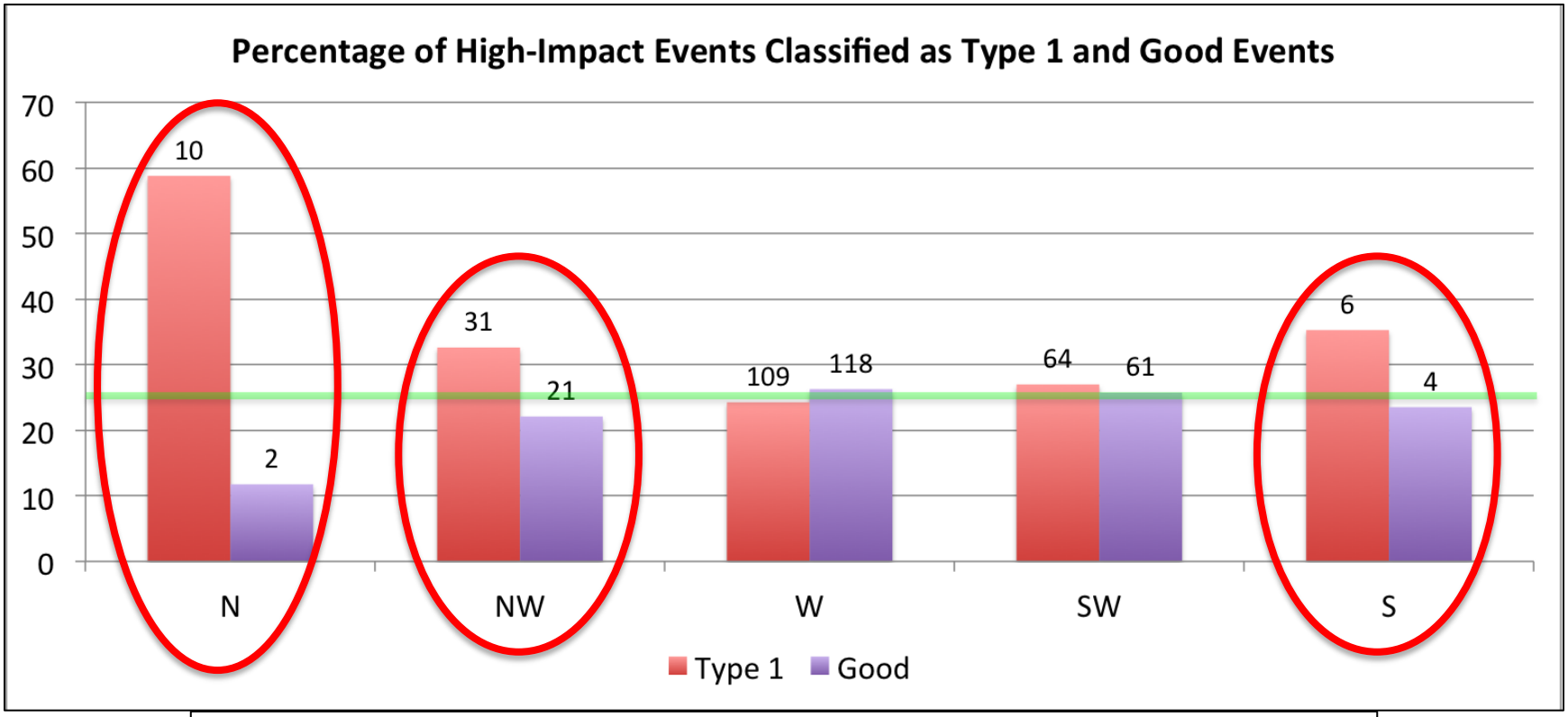


Event Climatology



Numbers indicate raw number of events. Green line indicates expected value based on methodology.

Event Climatology

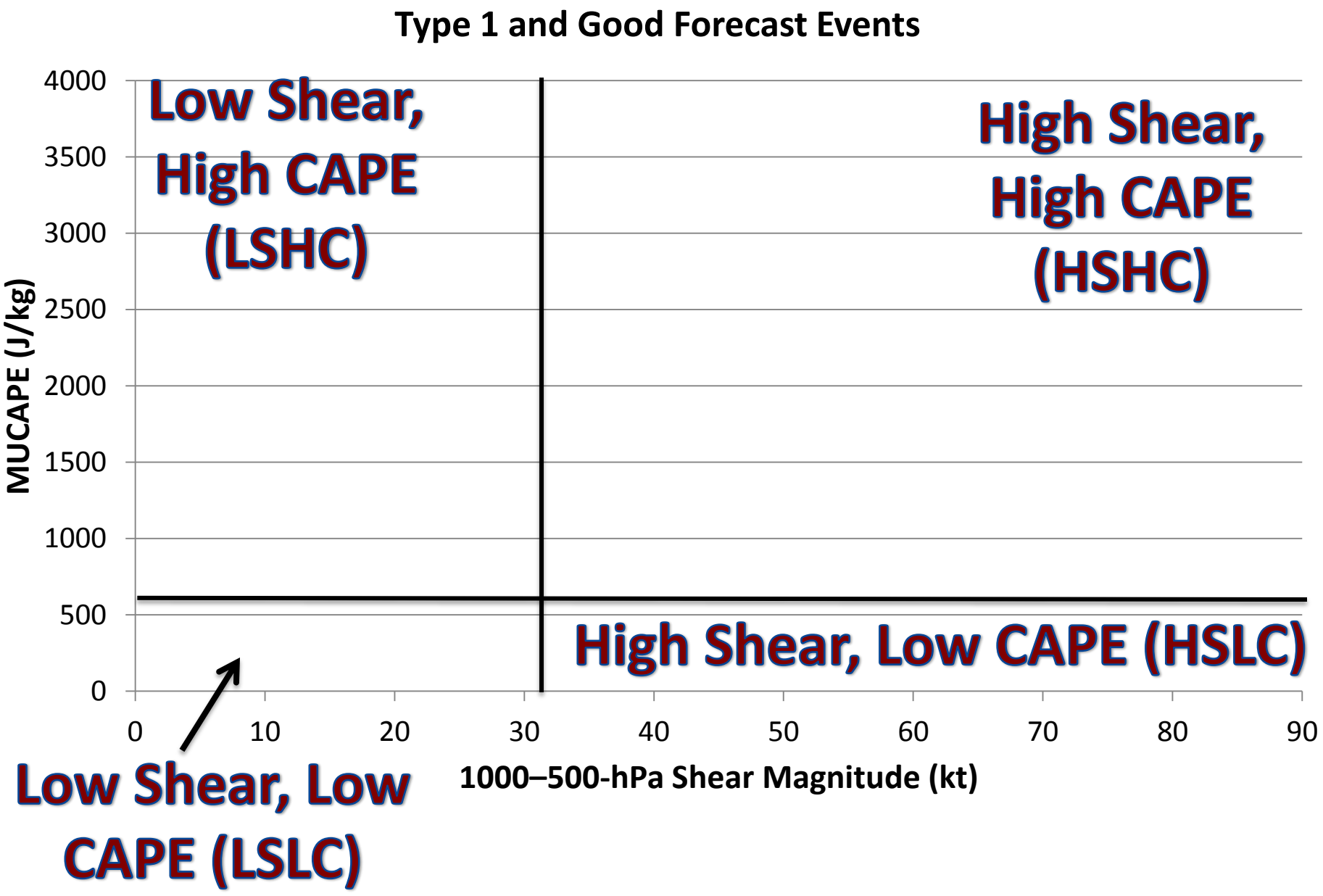


Numbers indicate raw number of events. Green line indicates expected value based on methodology.

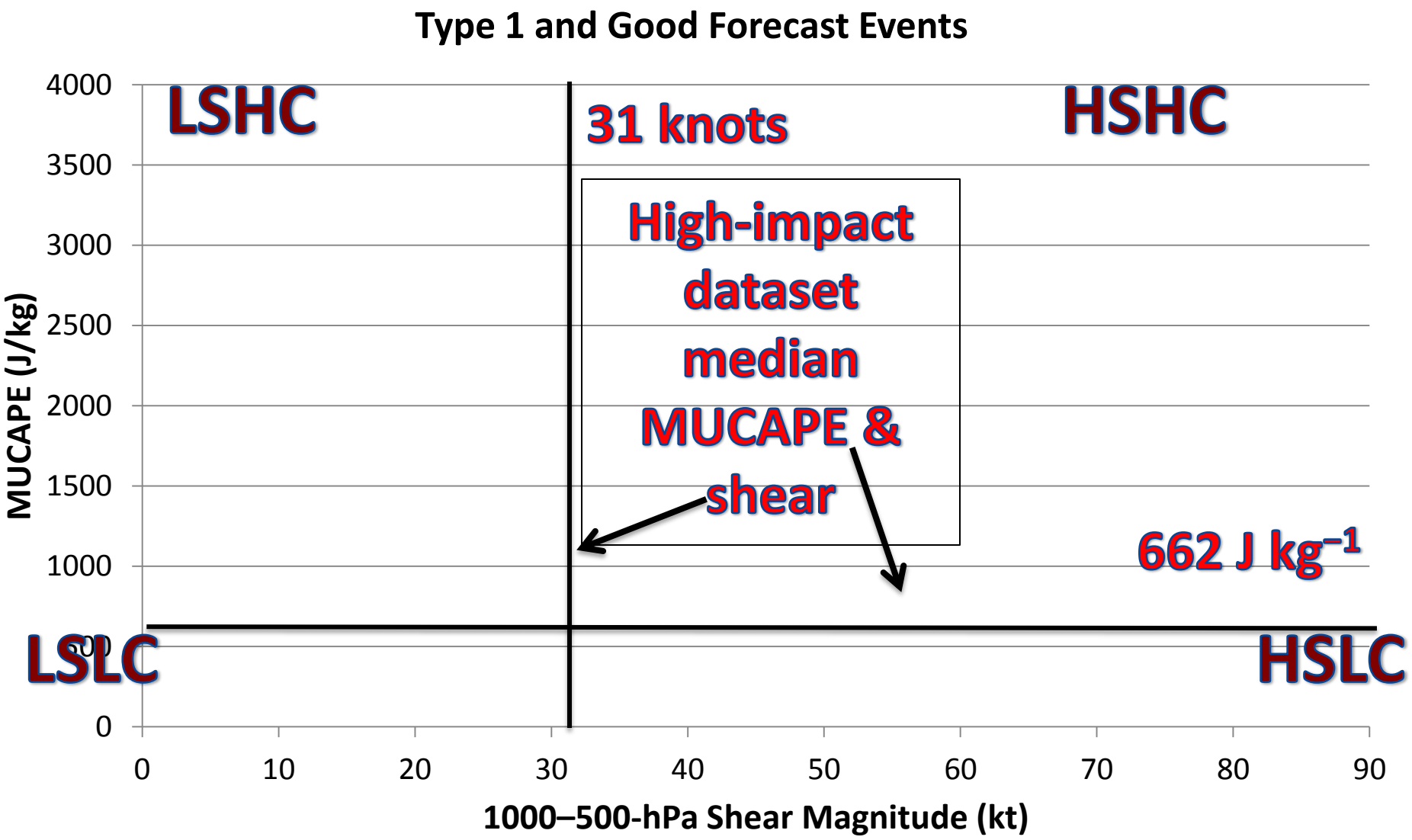
SEVERE WEATHER PARAMETER ANALYSIS

(MUCAPE & DEEP-LAYER SHEAR)

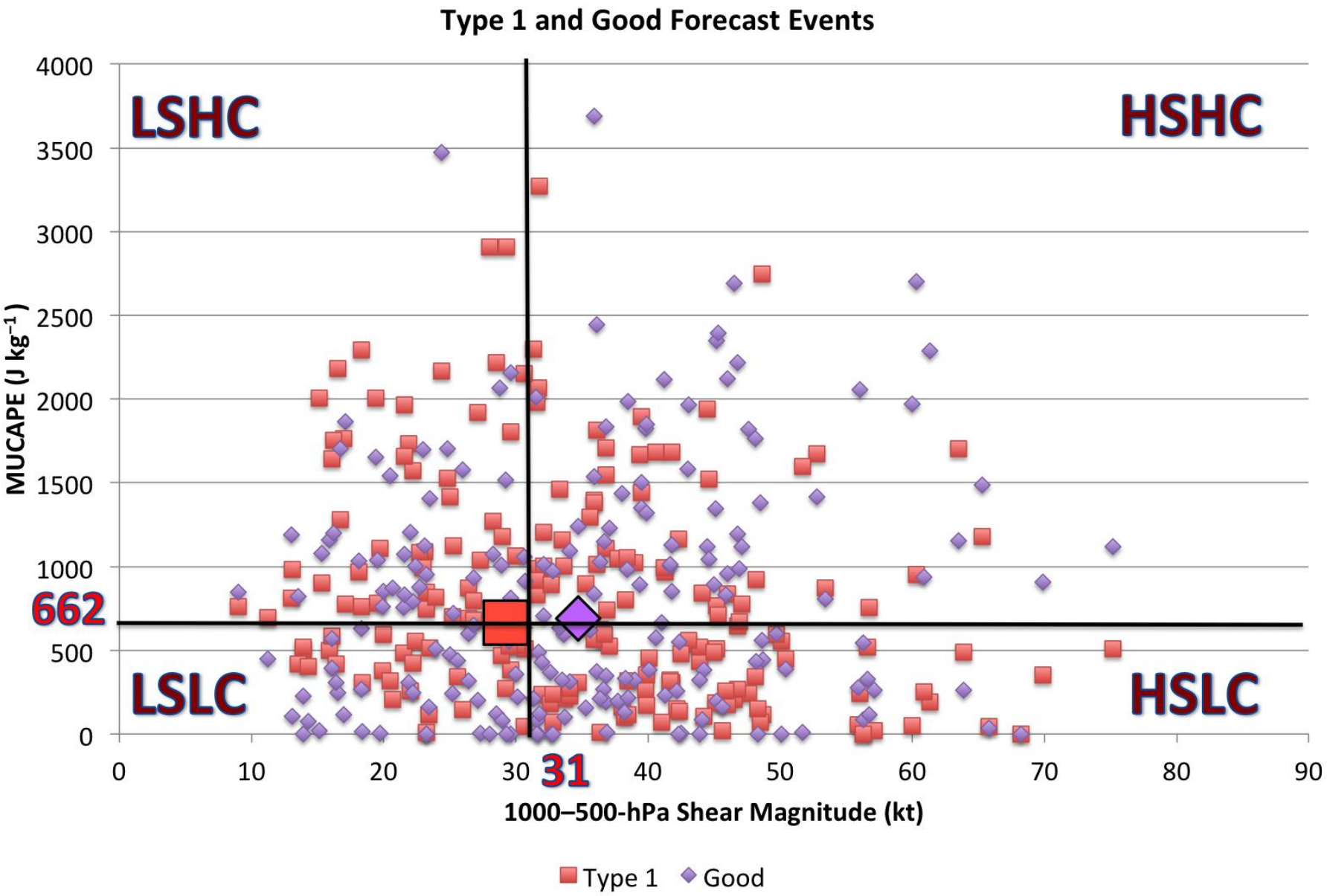
MUCAPE-Shear Phase Space



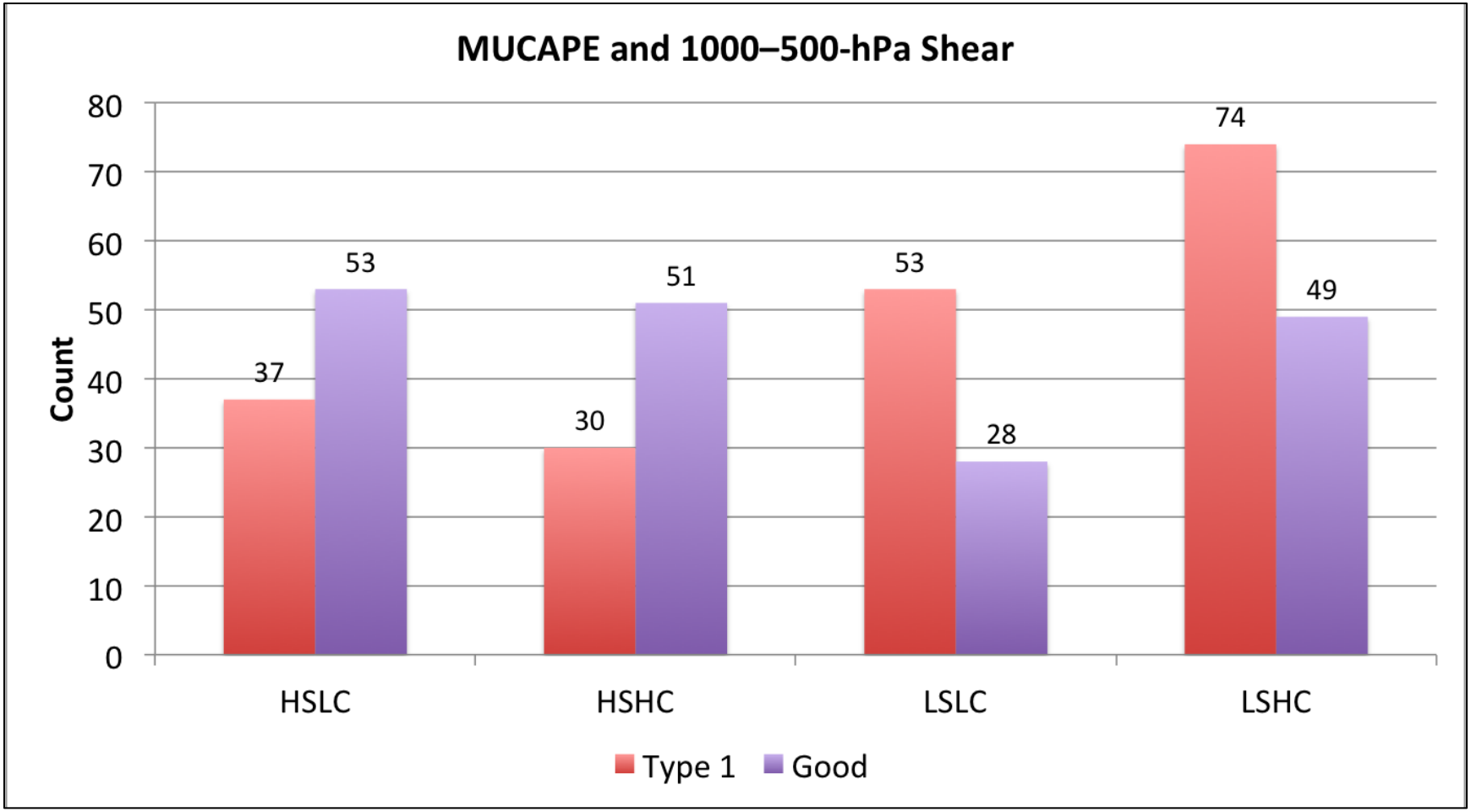
MUCAPE-Shear Phase Space



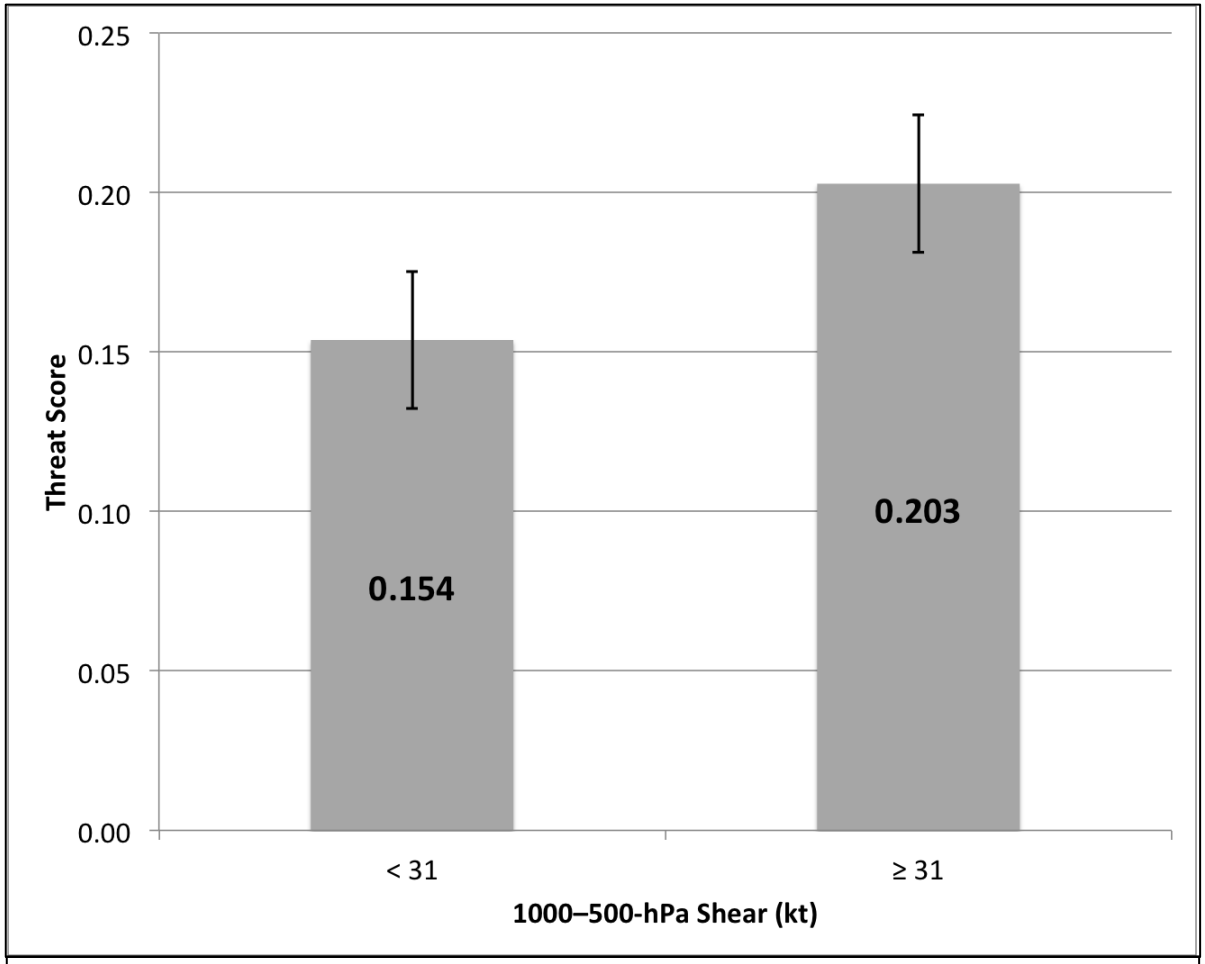
MUCAPE-Shear Phase Space



MUCAPE-Shear Phase Space



Threat Scores of High-Impact Events

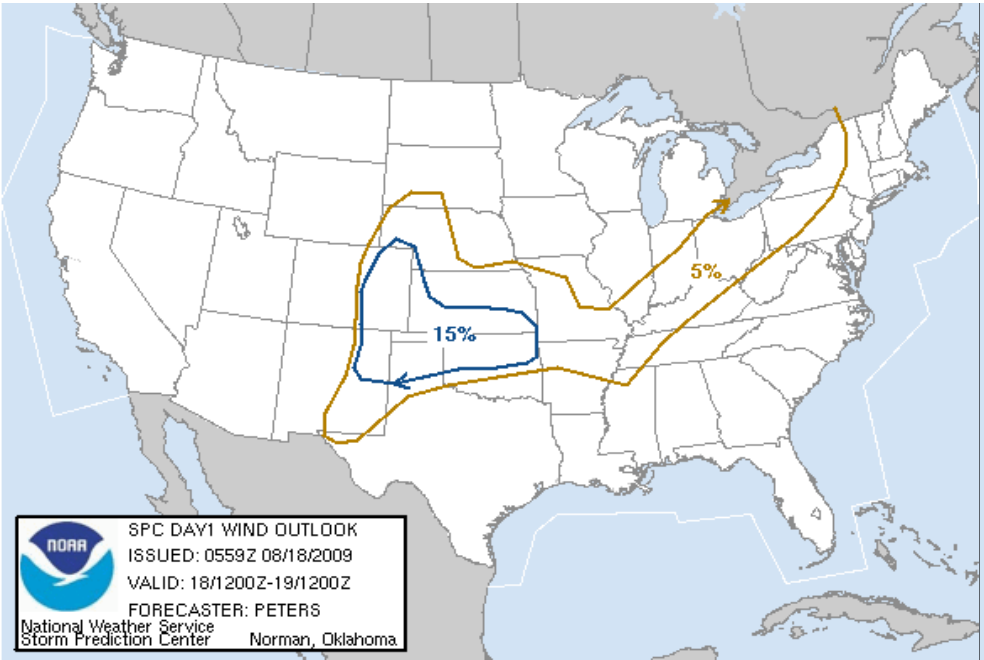


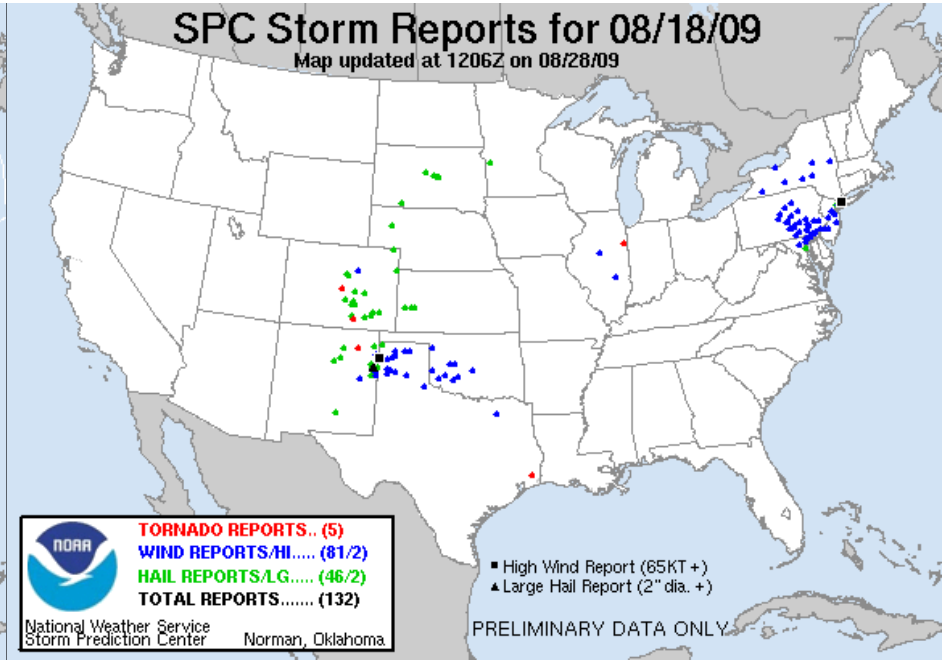
Average threat scores of high-impact events occurring under low (< 31 kt) and high (≥ 31 kt) 1000–500-hPa shear. Whiskers are confidence intervals at the 99% level.

EXAMPLE CASE

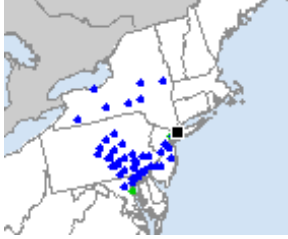
18 August 2009 Severe Wind Event **(LSHC)**

- Type 1 under-predicted storm
- SPC issued 5% wind outlook for Northeast

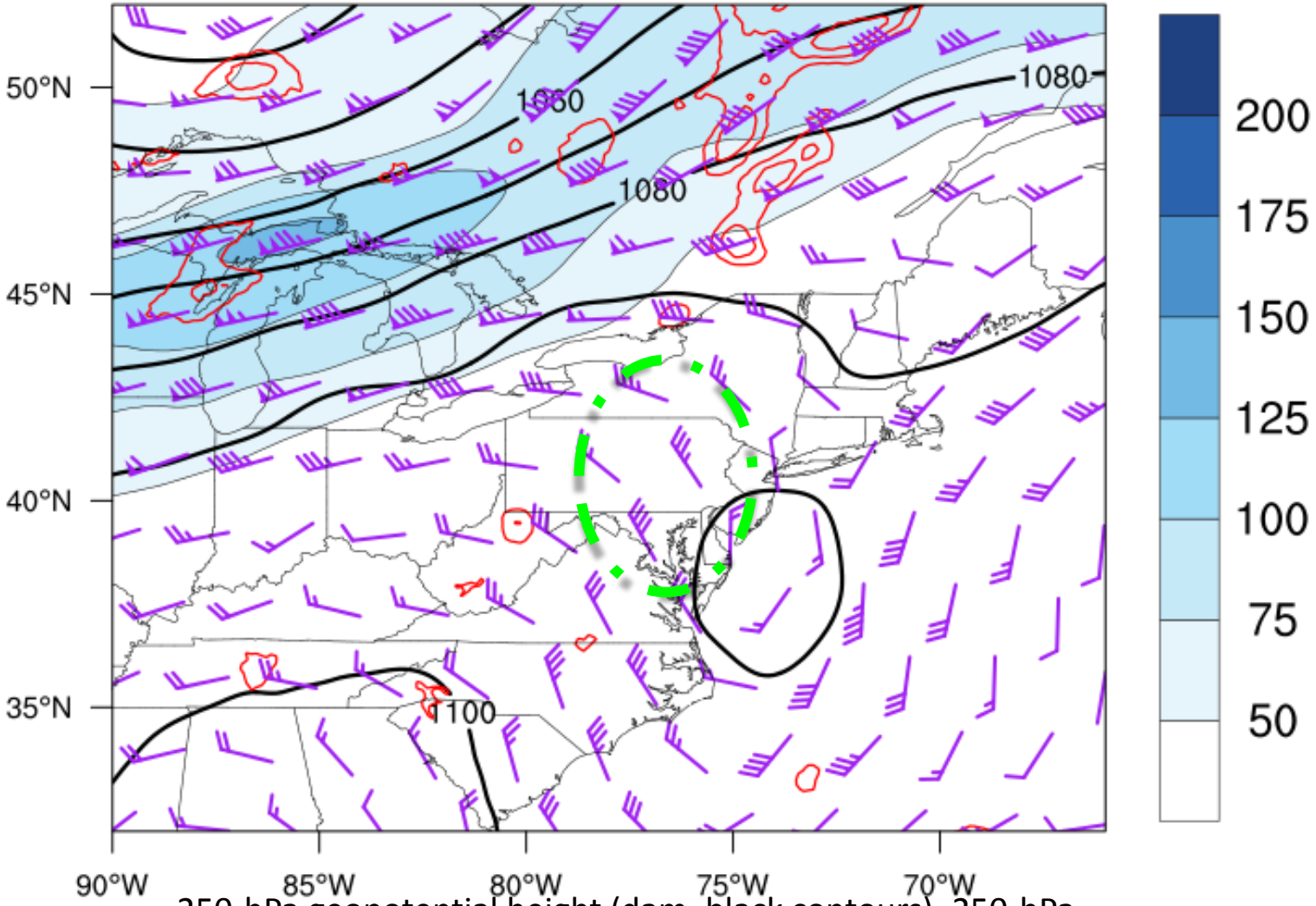




Synoptic Overview

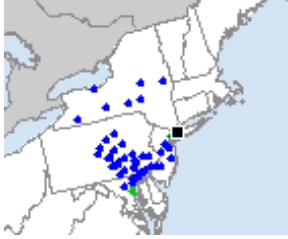


250 hPa 1600 UTC 18 August 2009

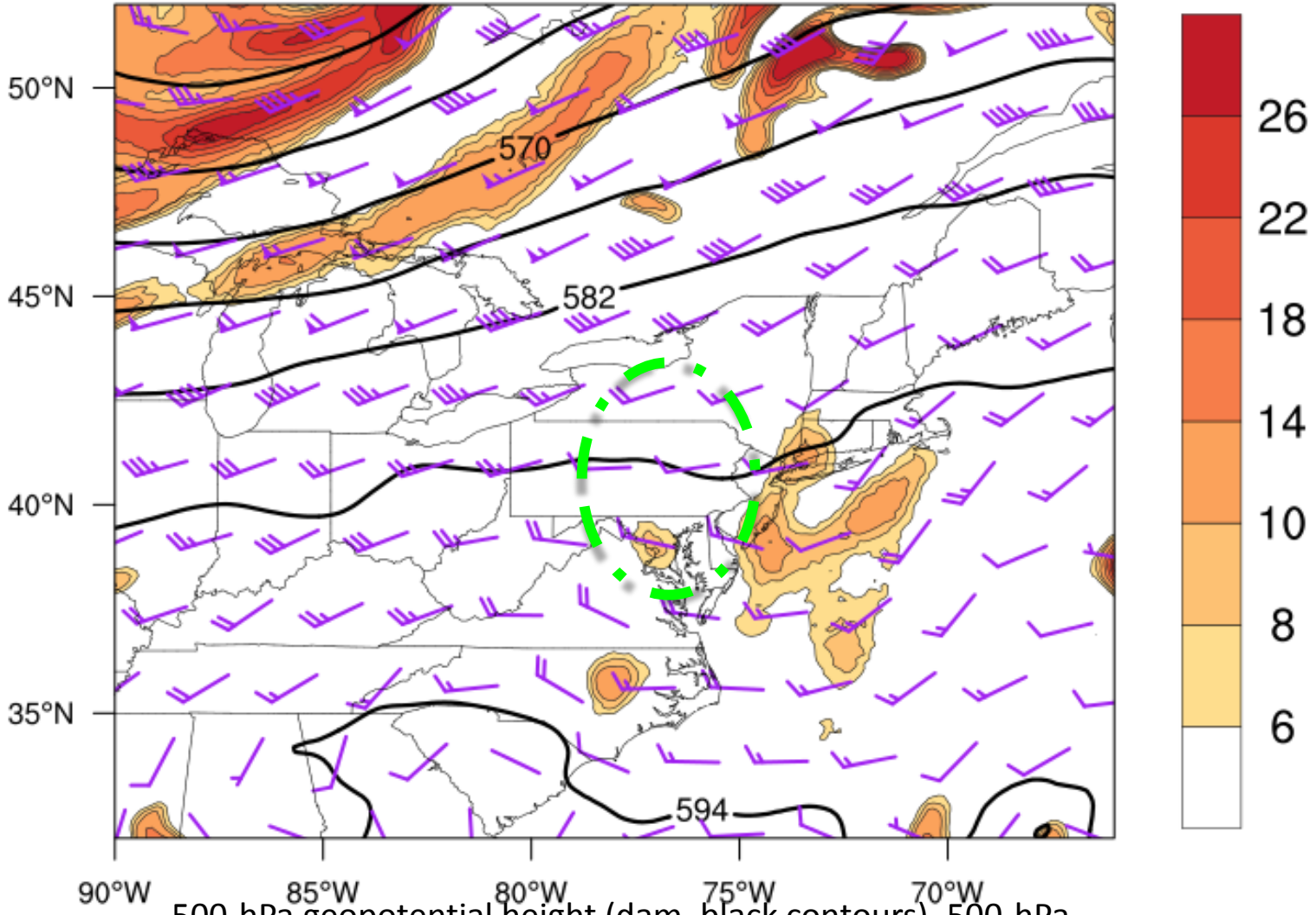


250-hPa geopotential height (dam, black contours), 250-hPa winds (knots, shaded and barbed), divergence ($\times 10^{-5}$ s^{-1}, red contours)

Synoptic Overview

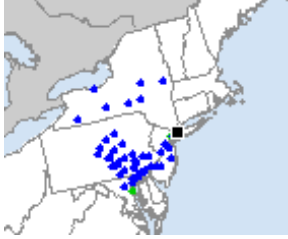


500 hPa 1600 UTC 18 August 2009

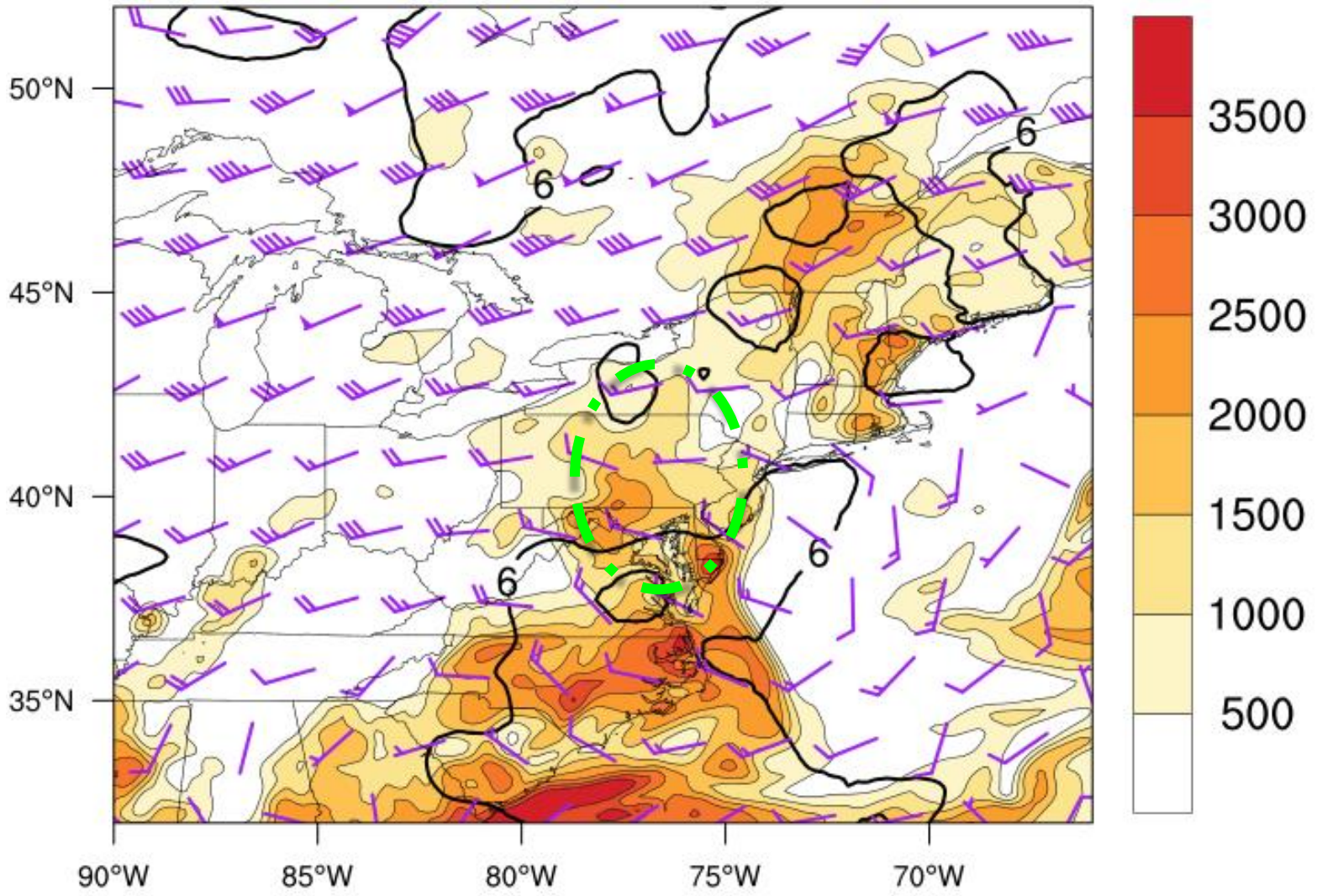


500-hPa geopotential height (dam, black contours), 500-hPa winds (knots, barbed), 500-hPa relative vorticity ($\times 10^{-5}$ s^{-1}, shaded)

Synoptic Overview

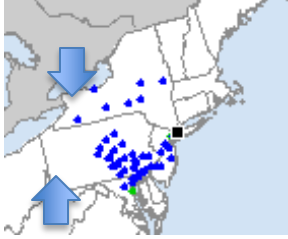


SBCAPE & shear 1600 UTC 18 August 2009

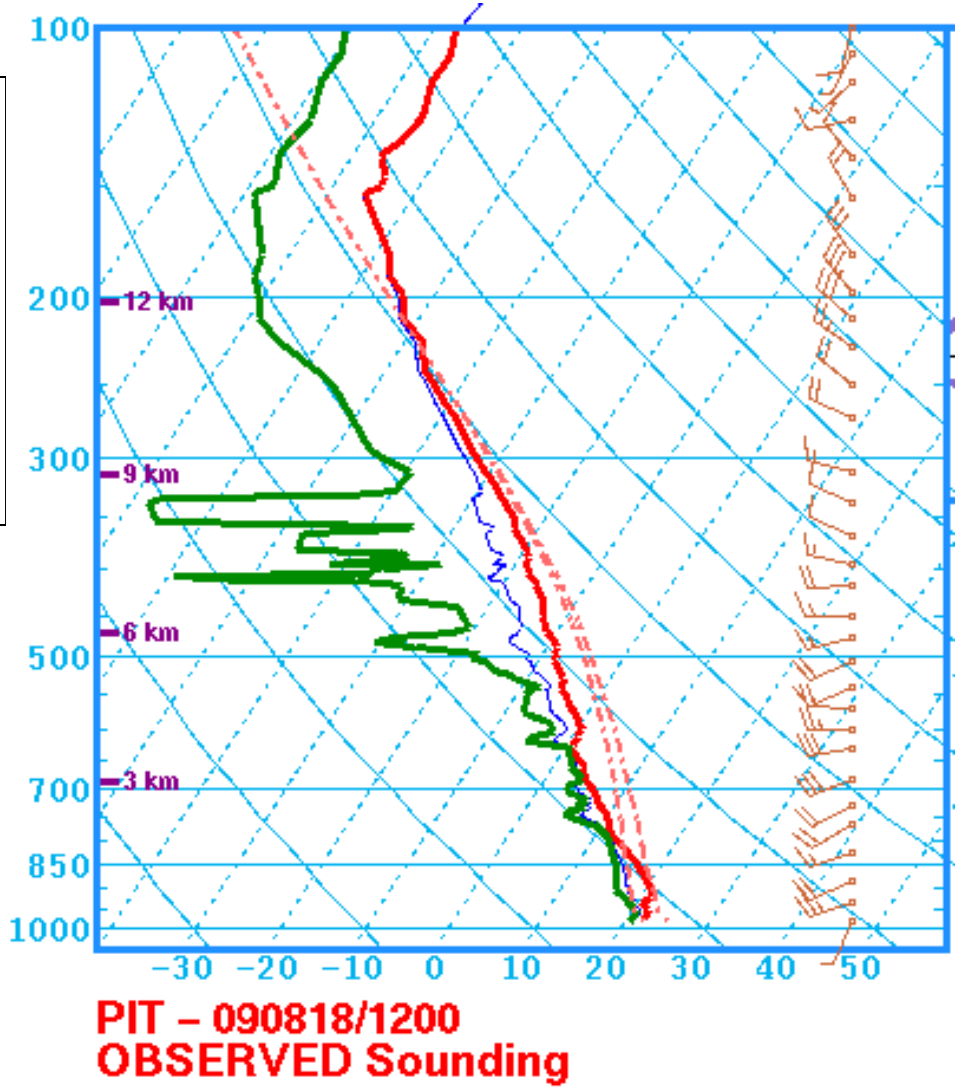


700–500-hPa lapse rate (K/km, black contours), 1000–500-hPa shear (knots, barbed), surface-based CAPE(J/kg, shaded)

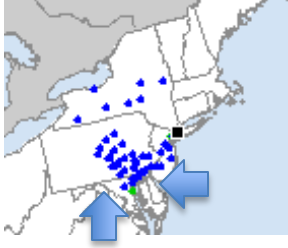
Morning Sounding: Convective Initiation



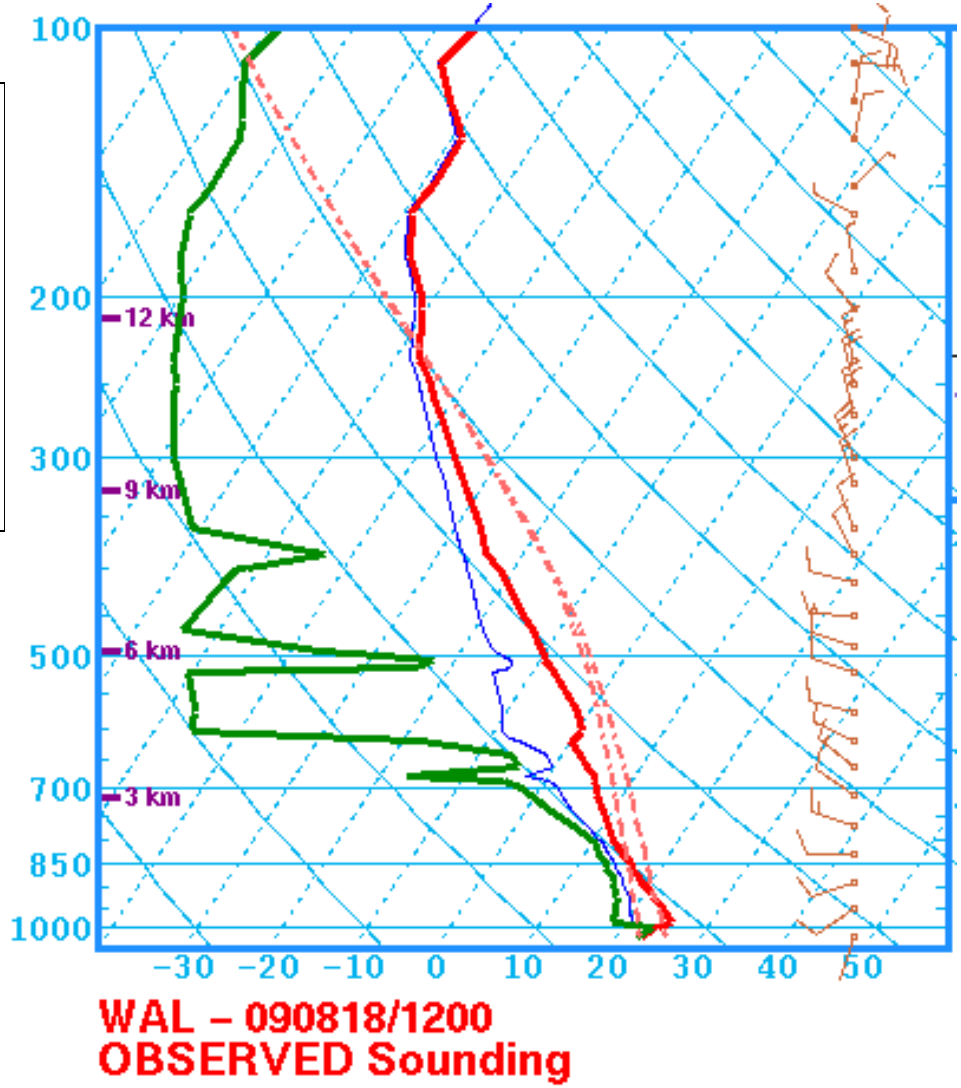
- MLCAPE: 1948 J kg^{-1}
- MLCIN: -167 J kg^{-1}
- 6-km shear: 12 kt
- 3-km shear: ~28 kt
- DCAPE: 510 J kg^{-1}



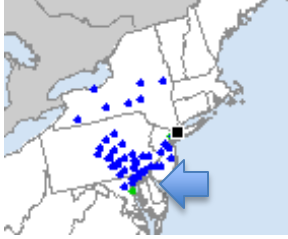
Morning Sounding: Severe Report Location

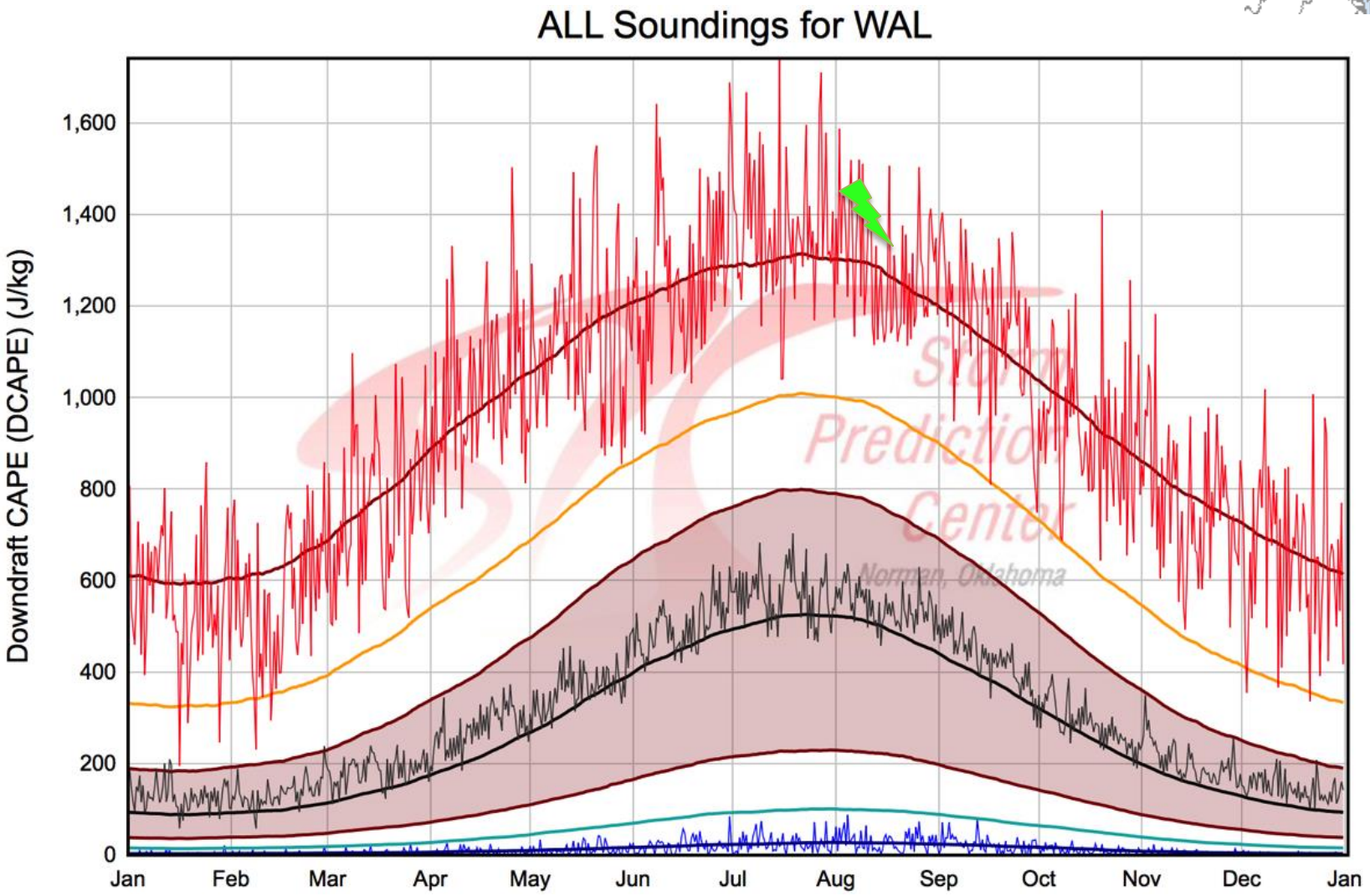


- MLCAPE: 2192 J kg^{-1}
- MLCIN: -233 J kg^{-1}
- 6-km shear: 12 kt
- DCAPE: 1294 J kg^{-1}



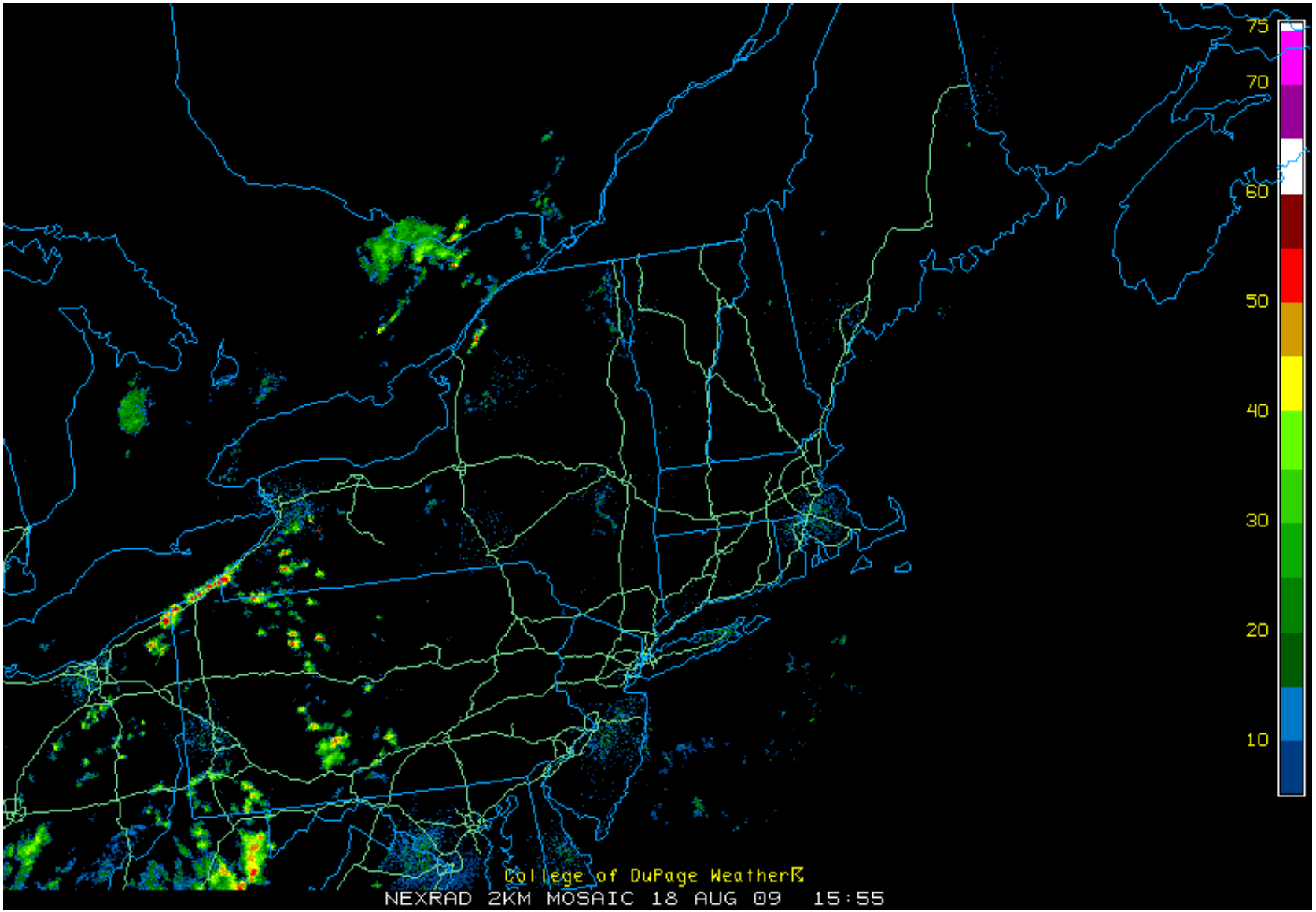
WAL Sounding Climatology



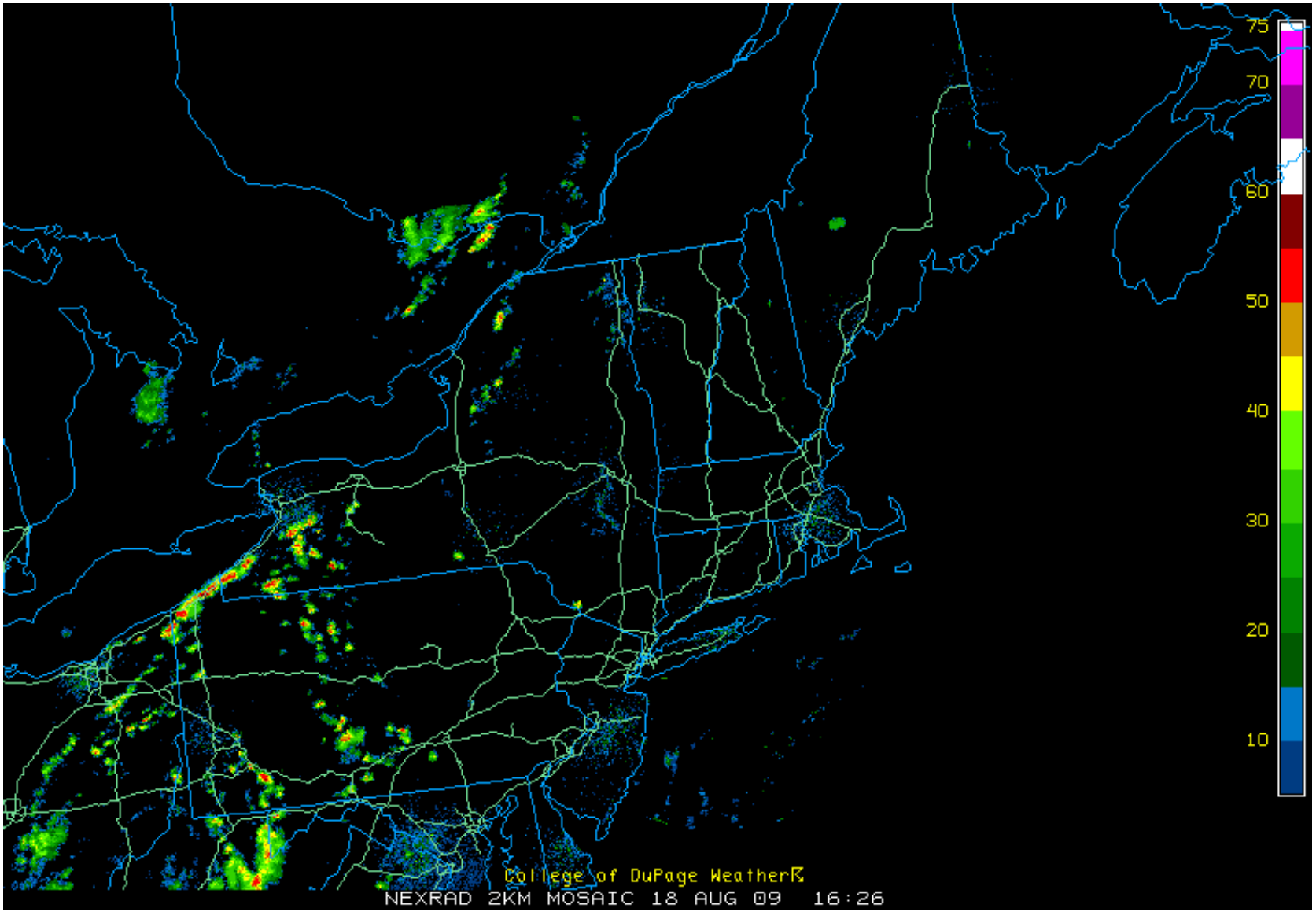


DCAPE: 1294 J/kg

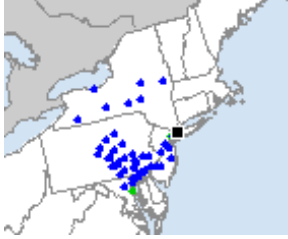
Radar 1600 UTC 18 Aug

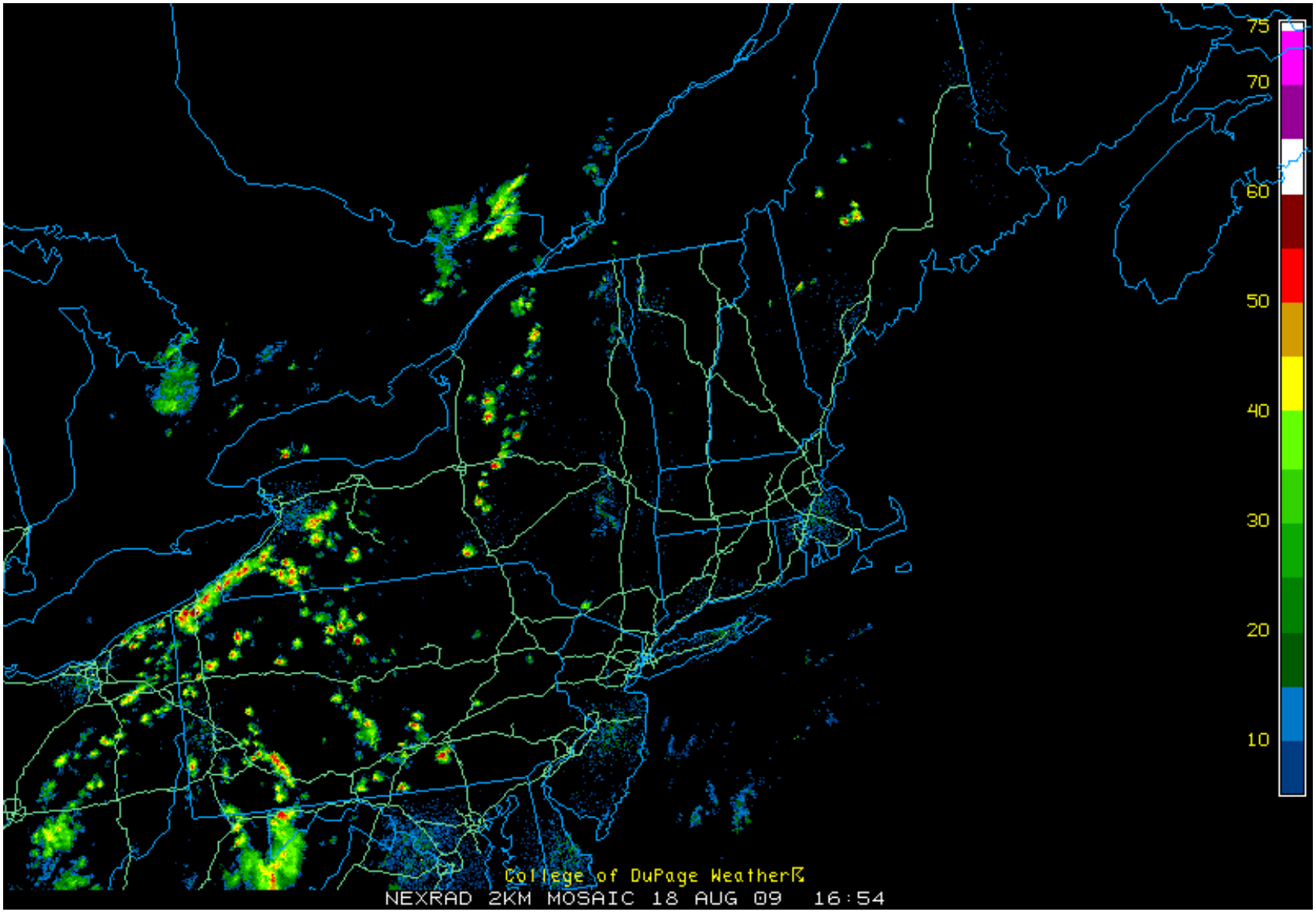


Radar 1630 UTC 18 Aug

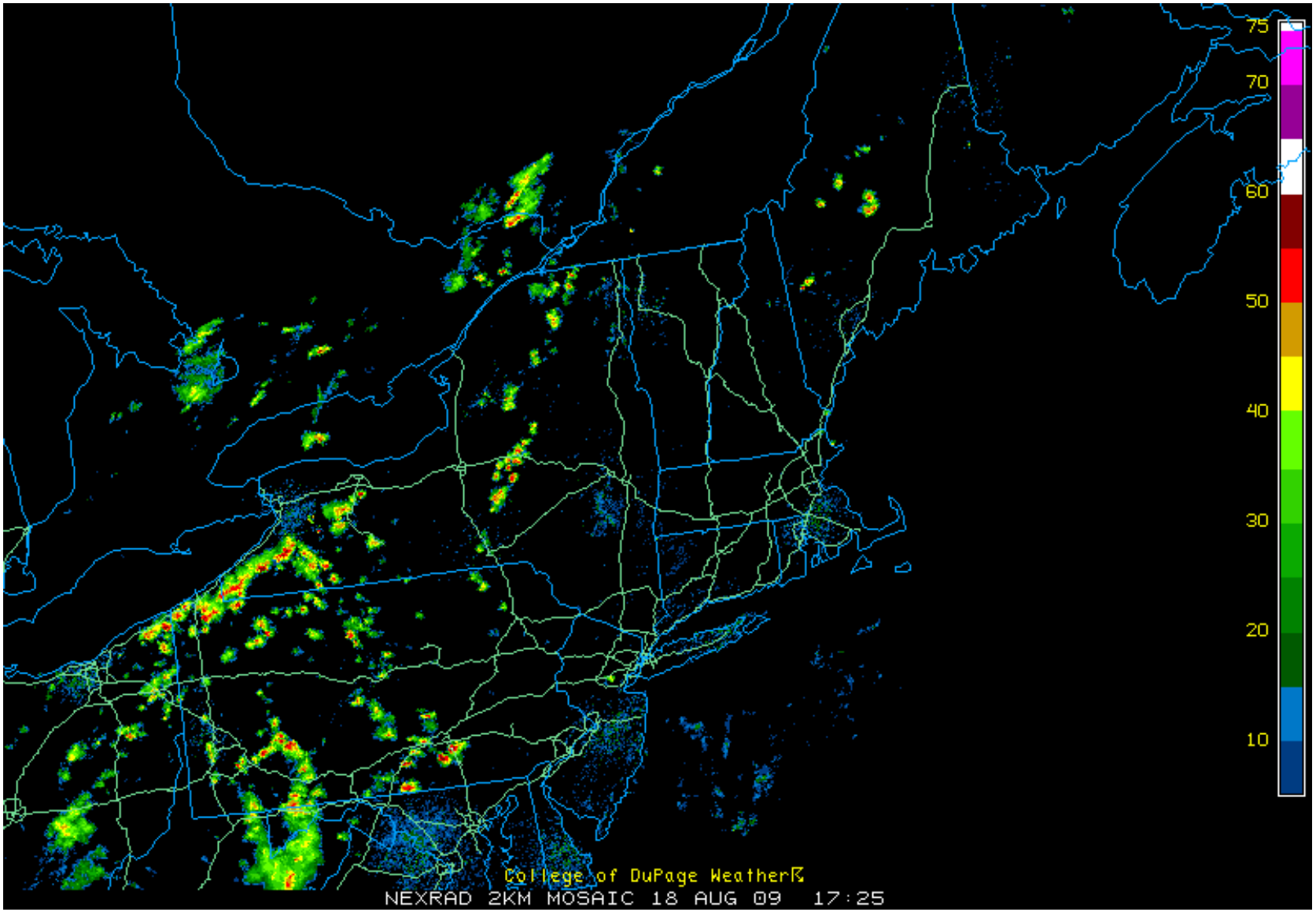


Radar 1700 UTC 18 Aug

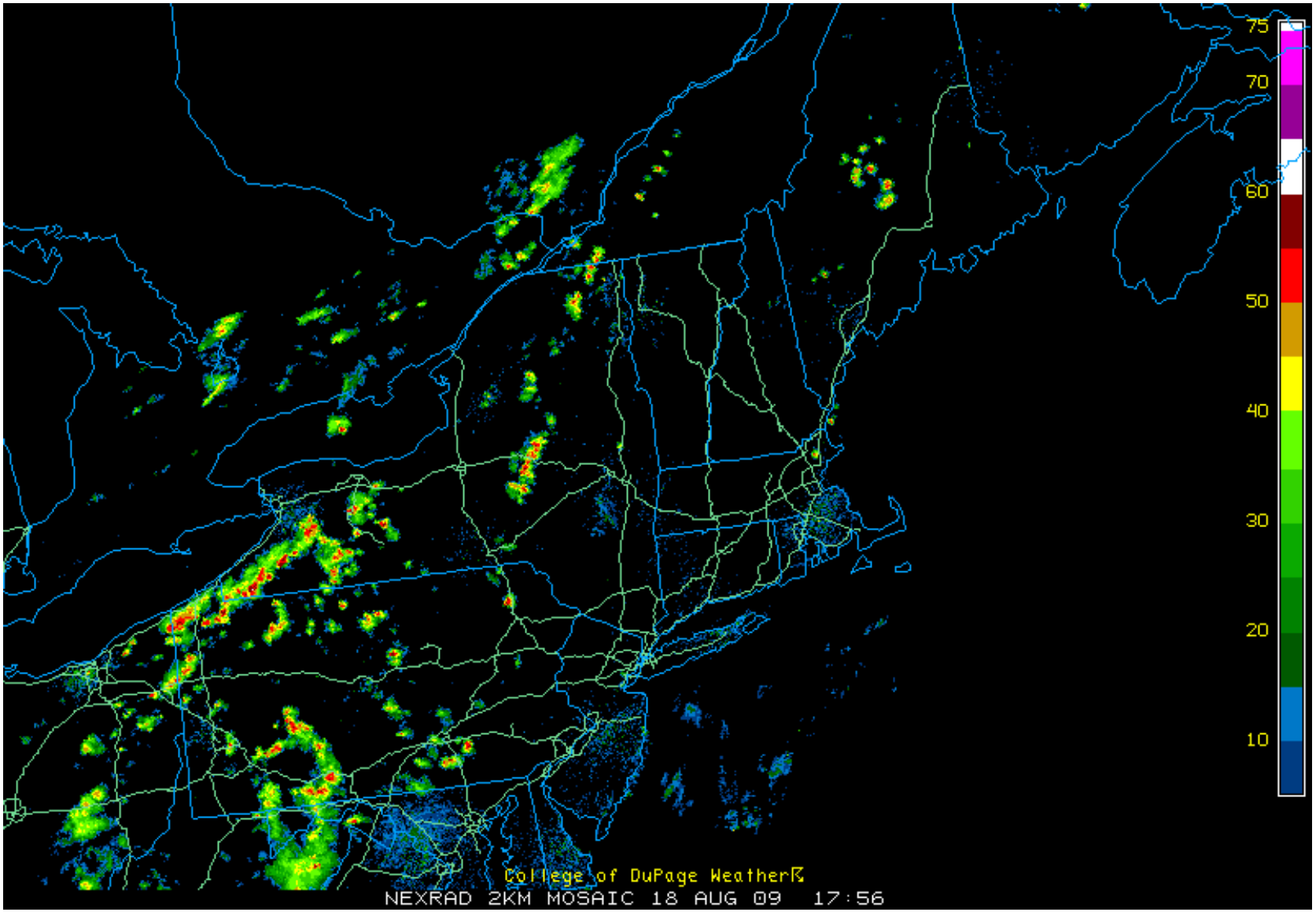




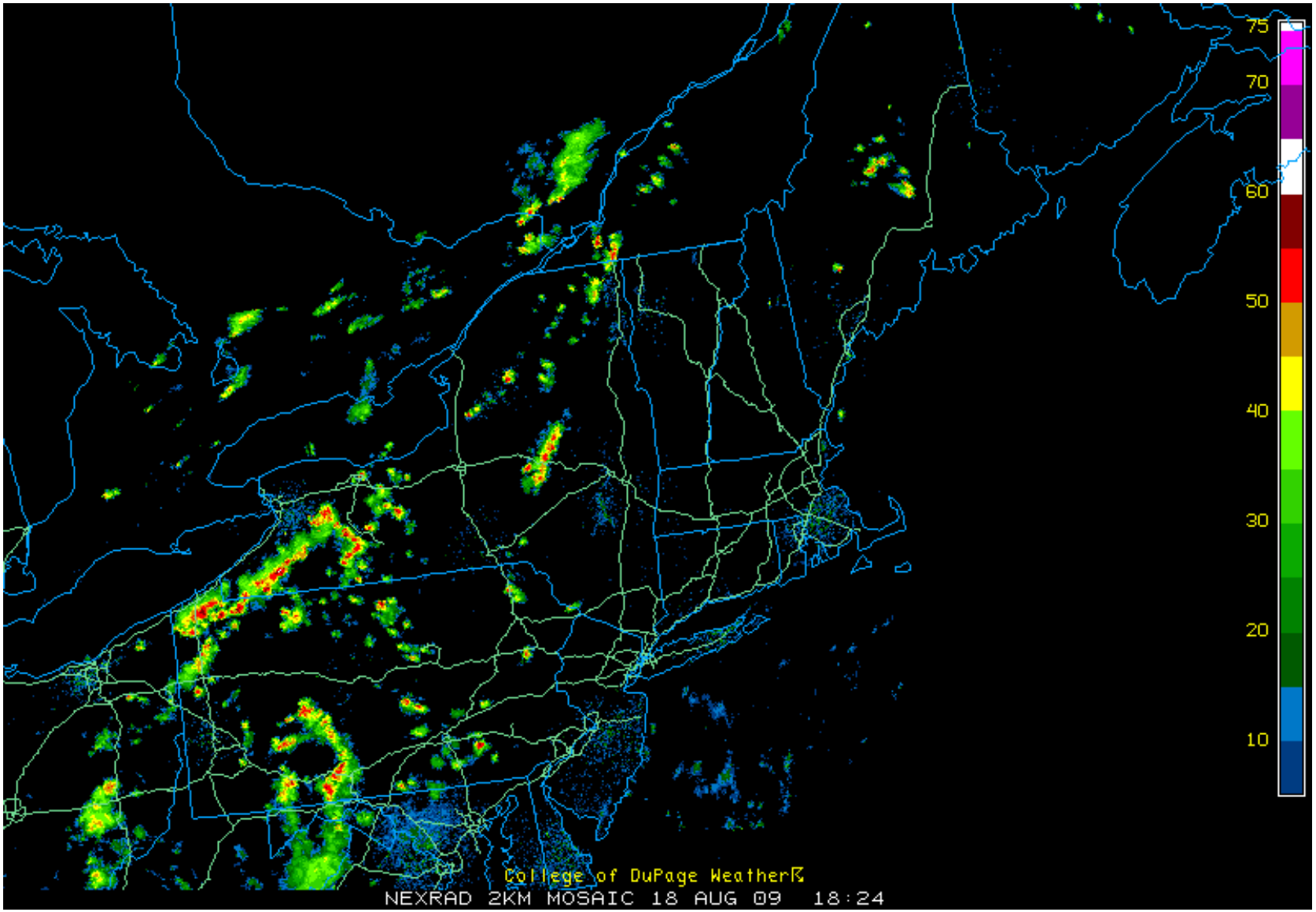
Radar 1730 UTC 18 Aug



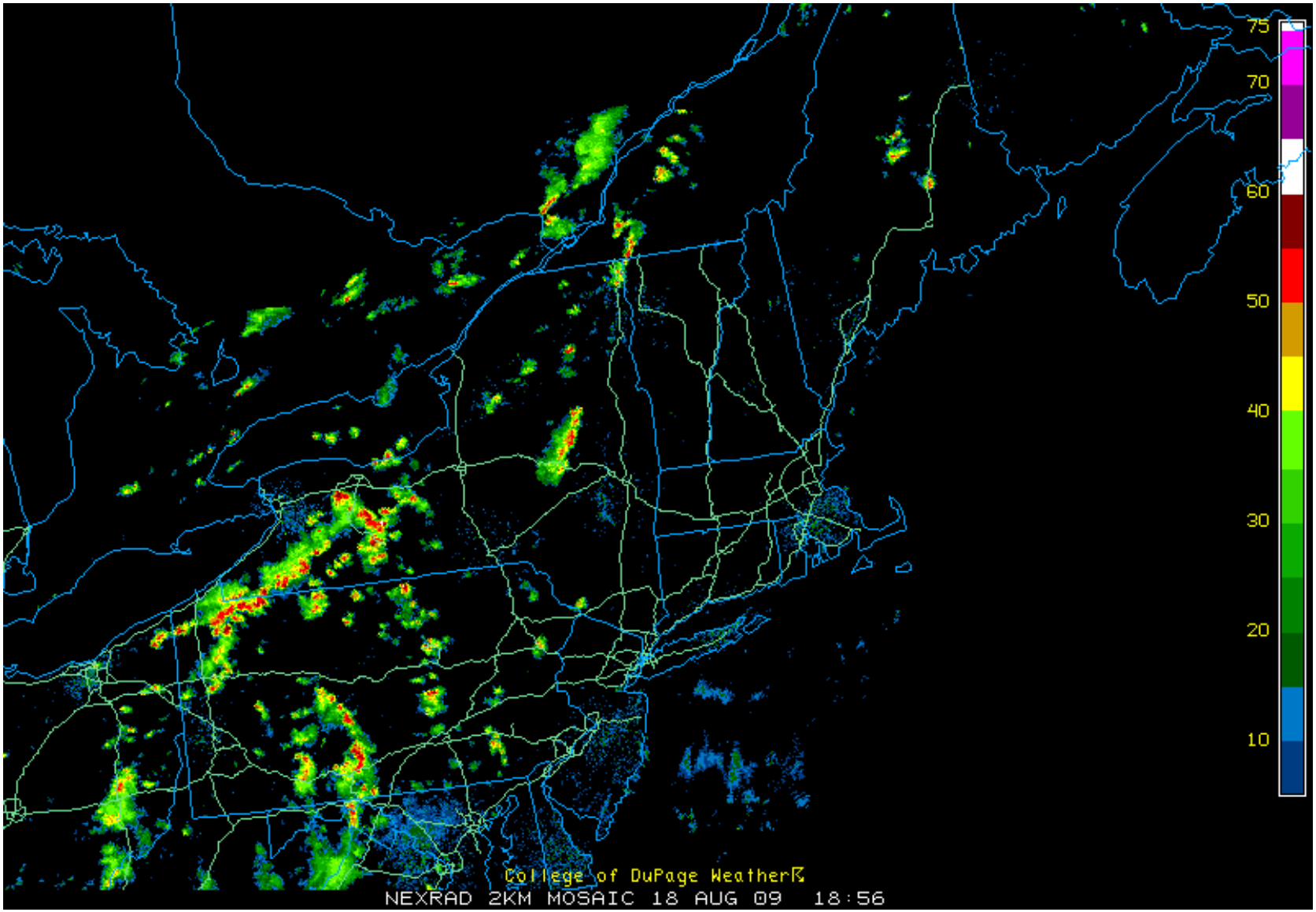
Radar 1800 UTC 18 Aug



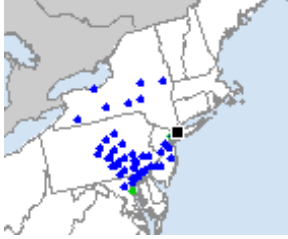
Radar 1830 UTC 18 Aug

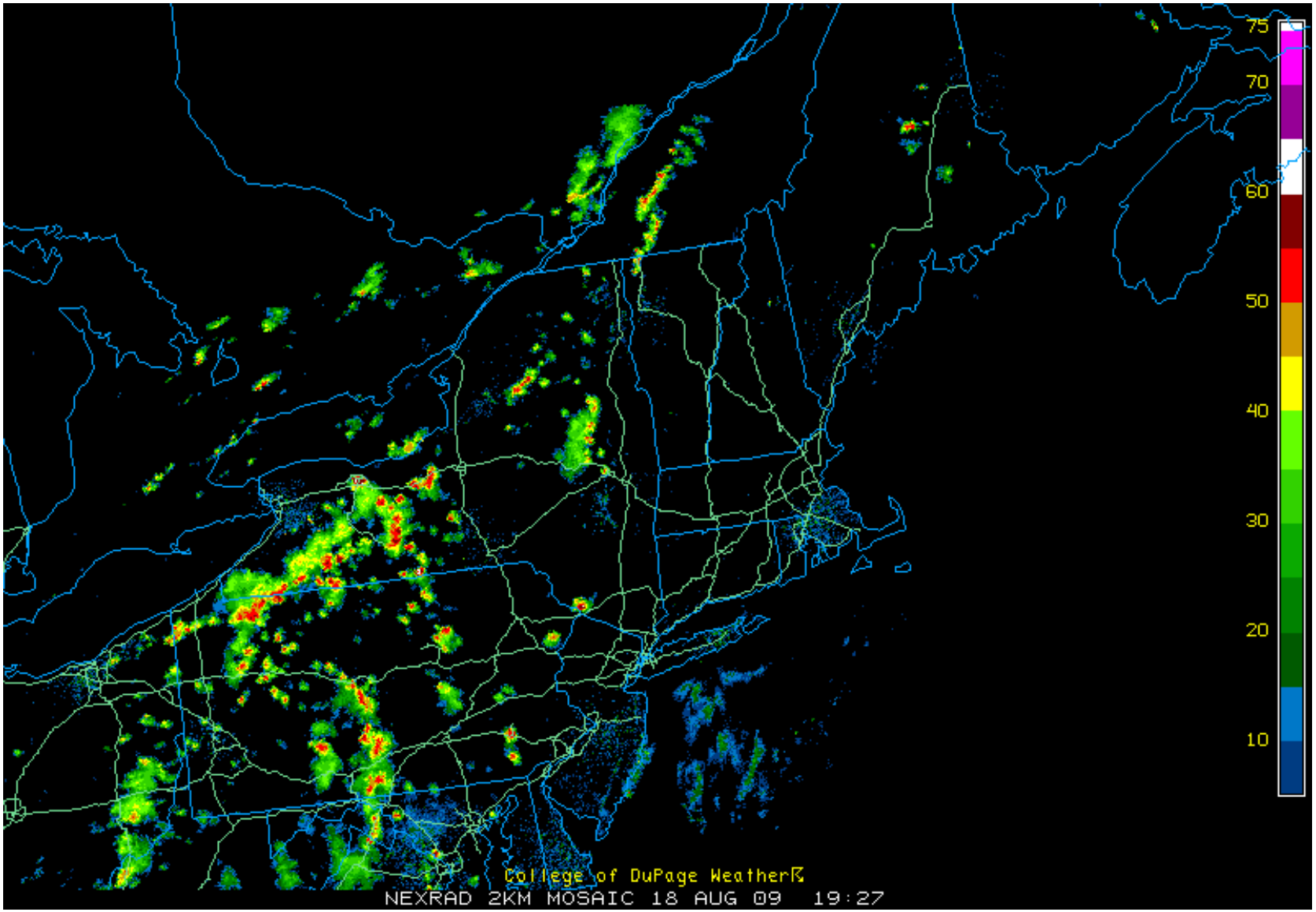


Radar 1900 UTC 18 Aug

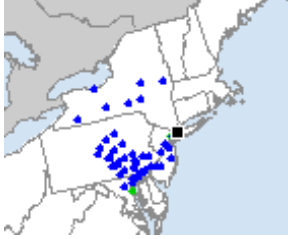


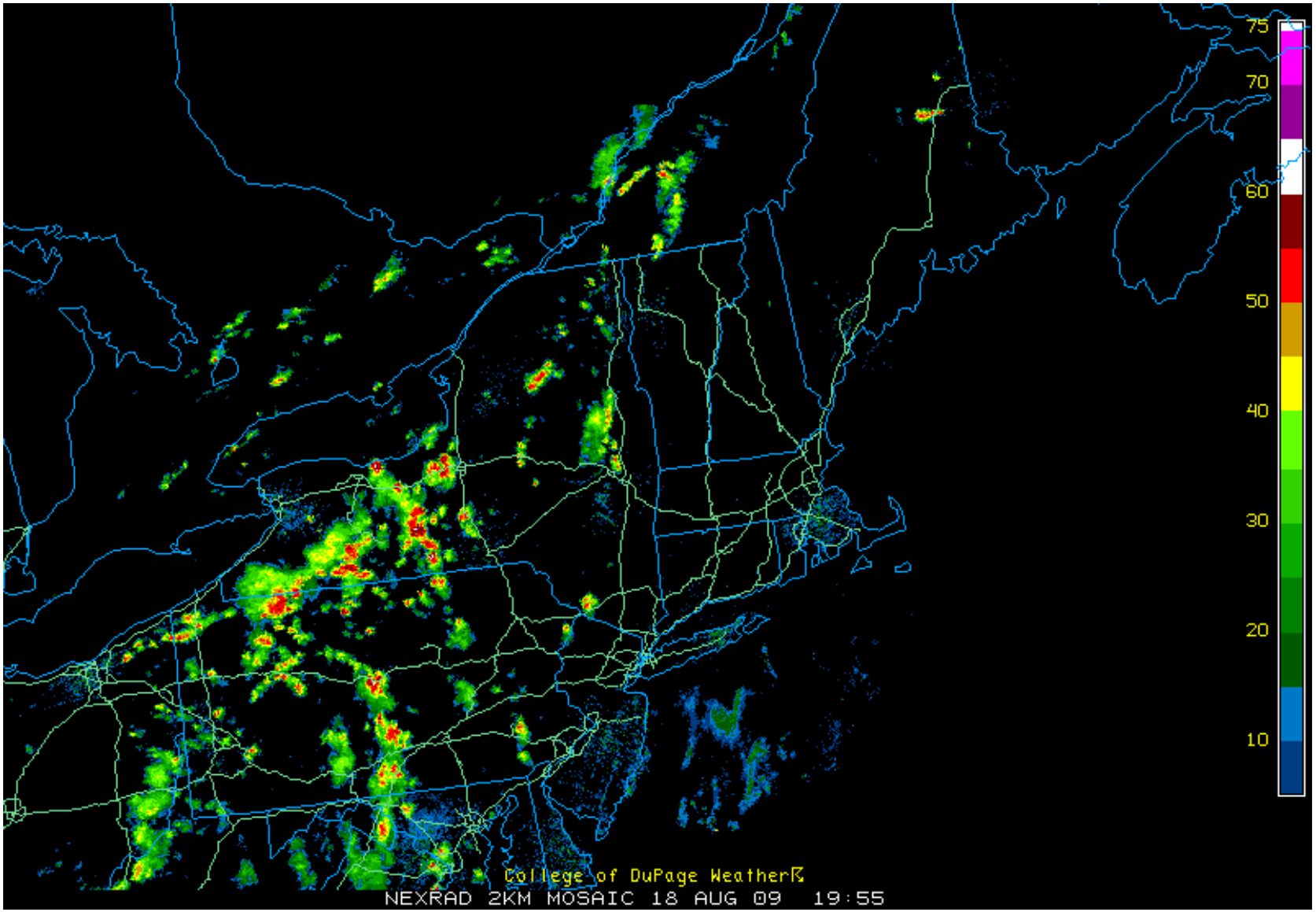
Radar 1930 UTC 18 Aug



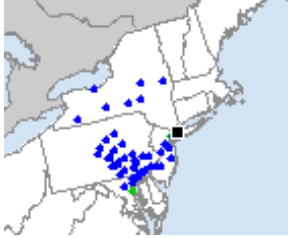


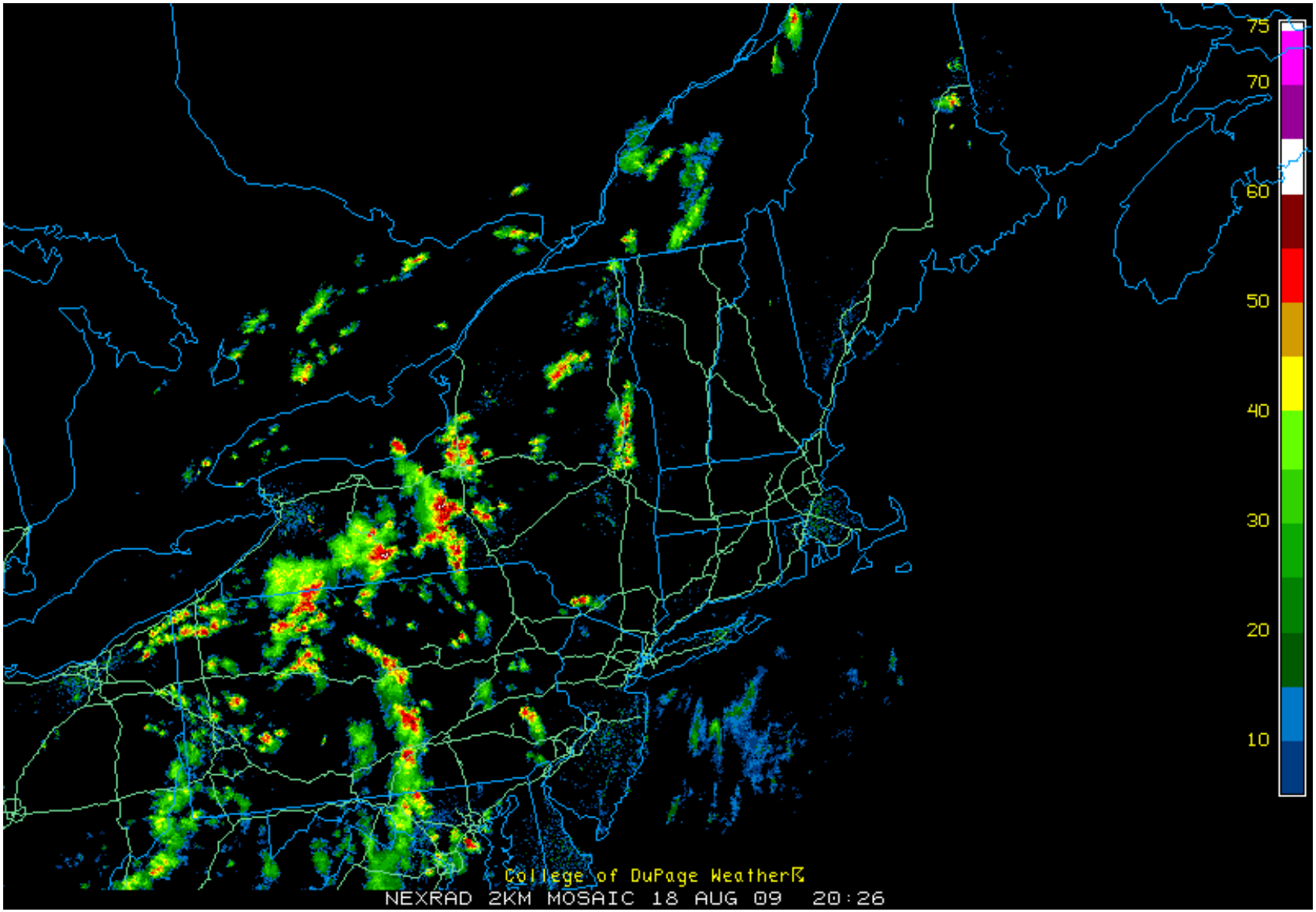
Radar 2000 UTC 18 Aug



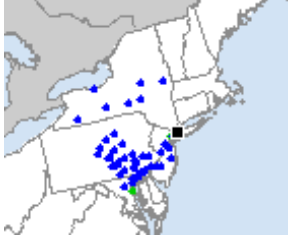


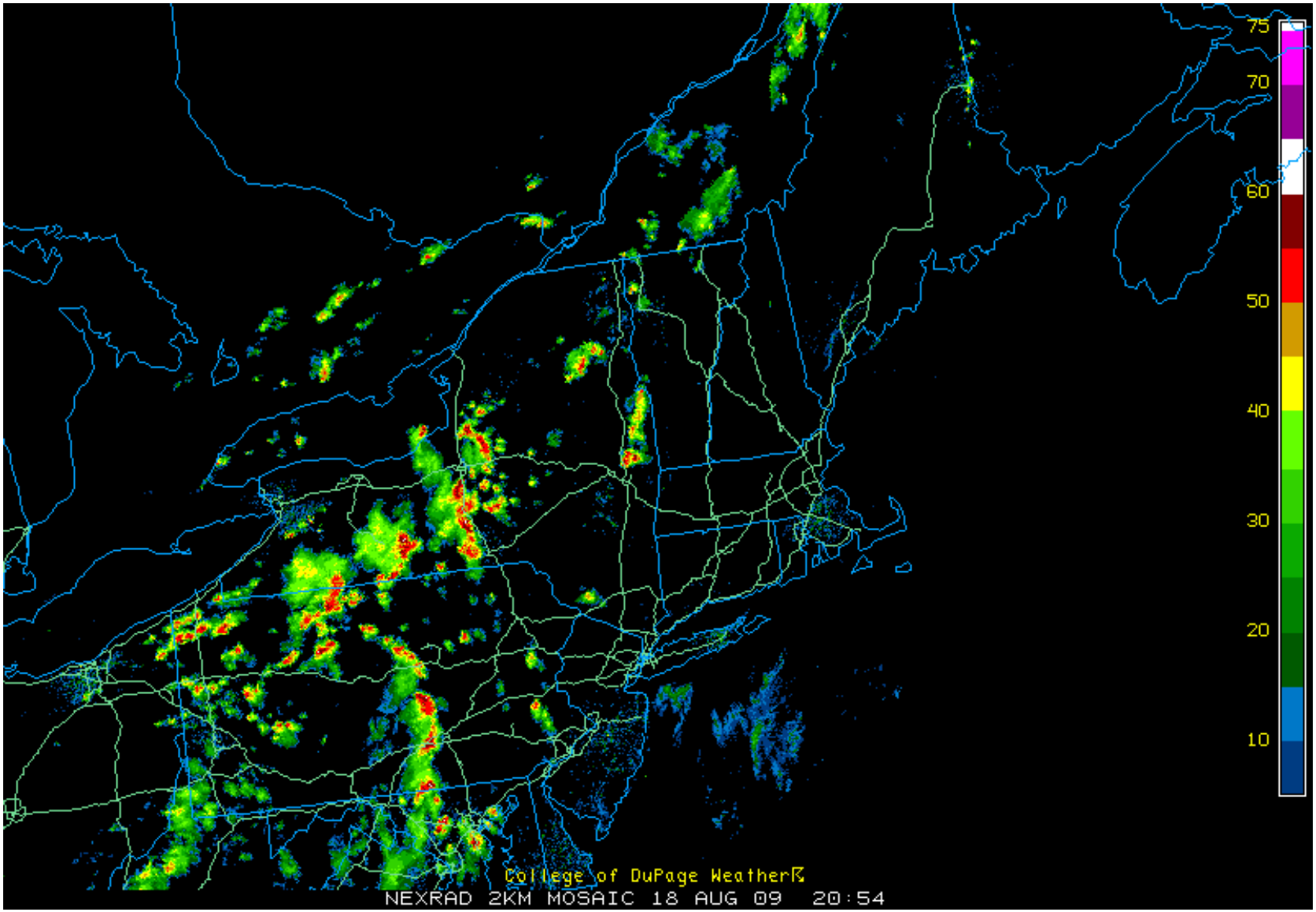
Radar 2030 UTC 18 Aug



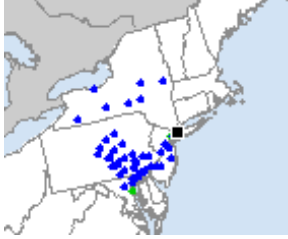


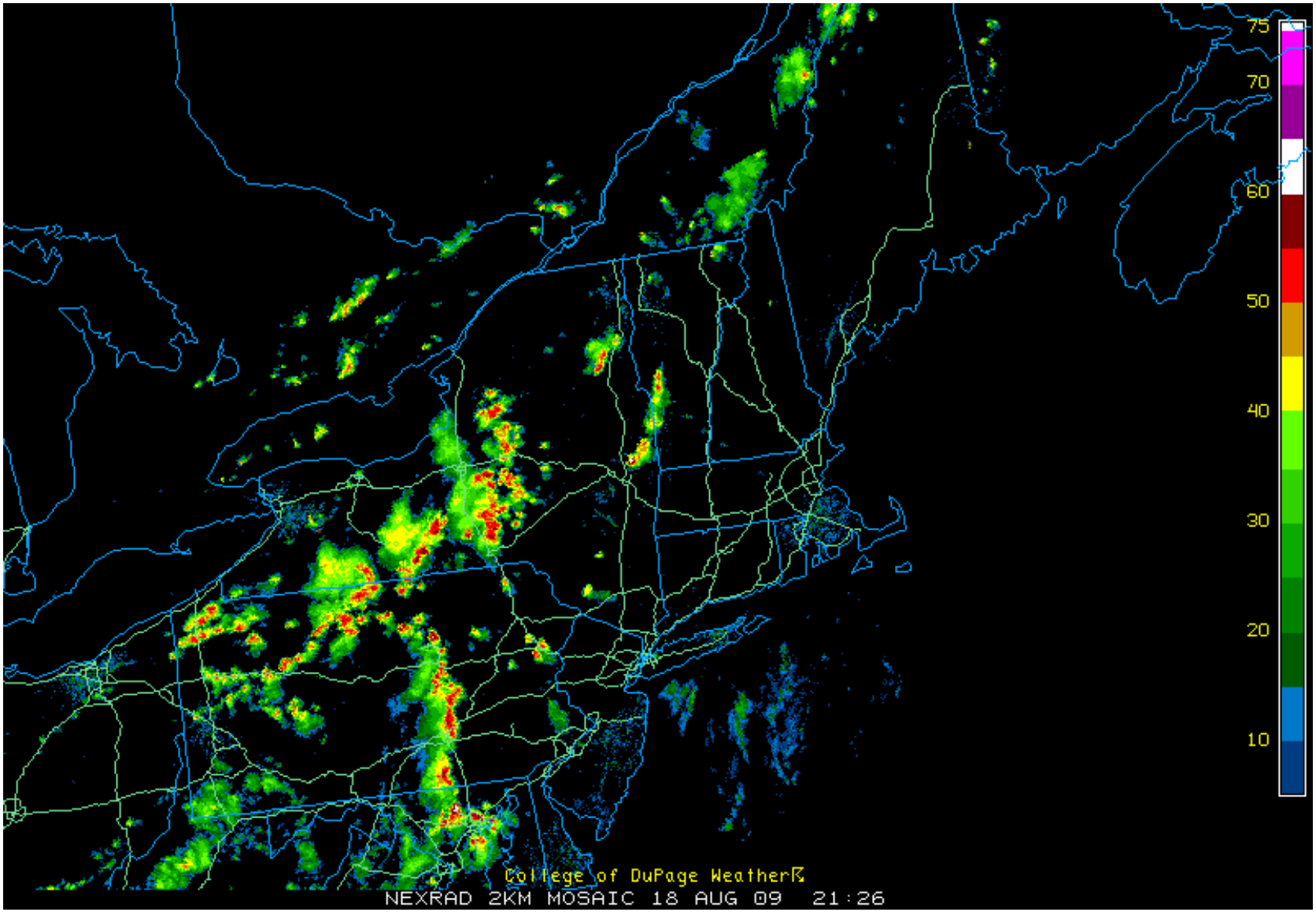
Radar 2100 UTC 18 Aug



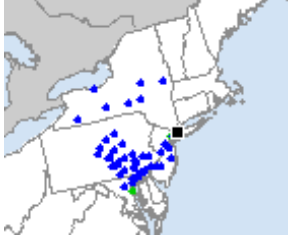


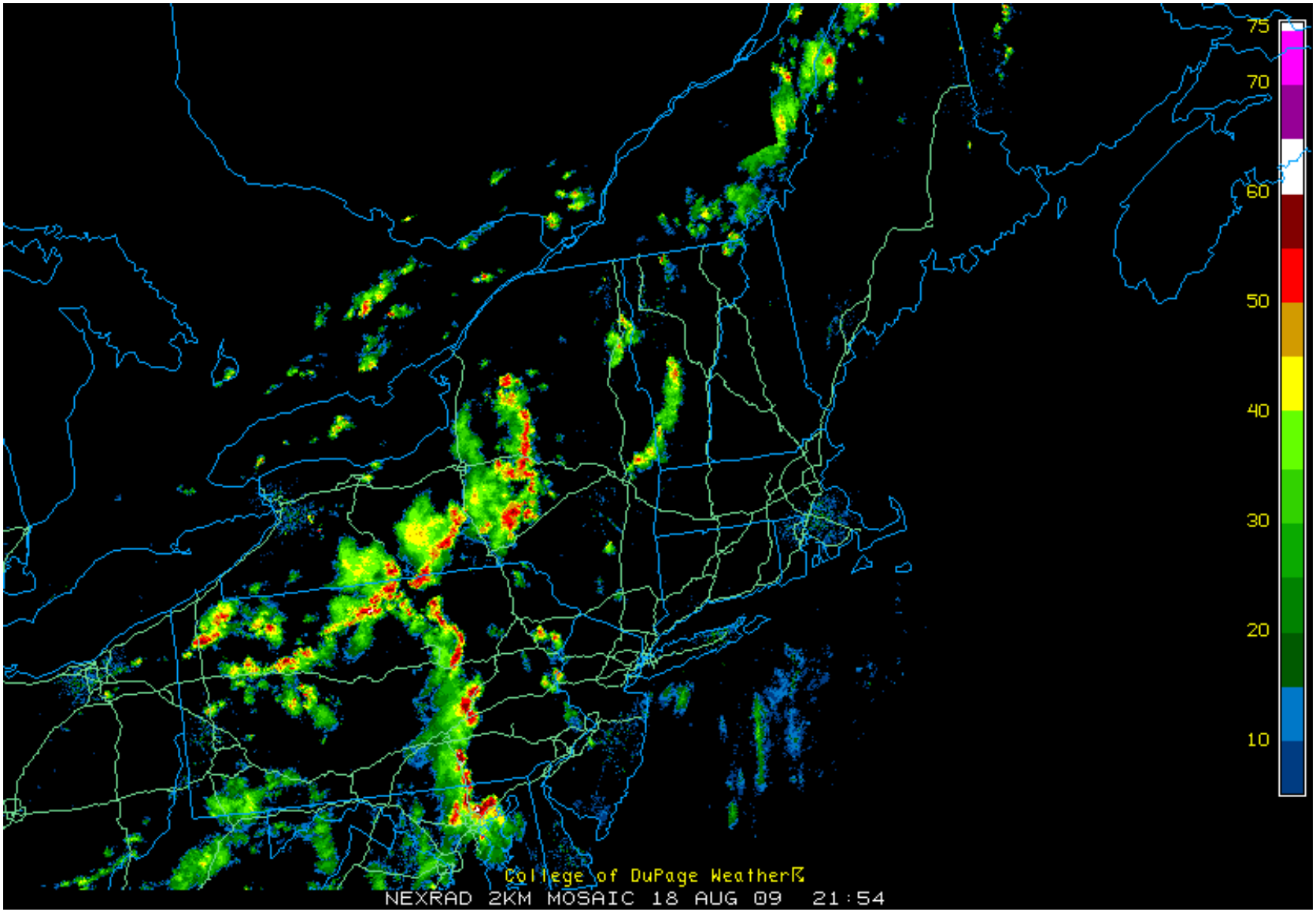
Radar 2130 UTC 18 Aug



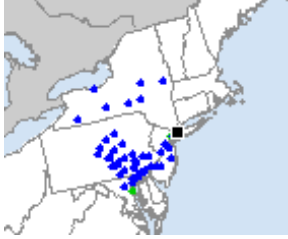


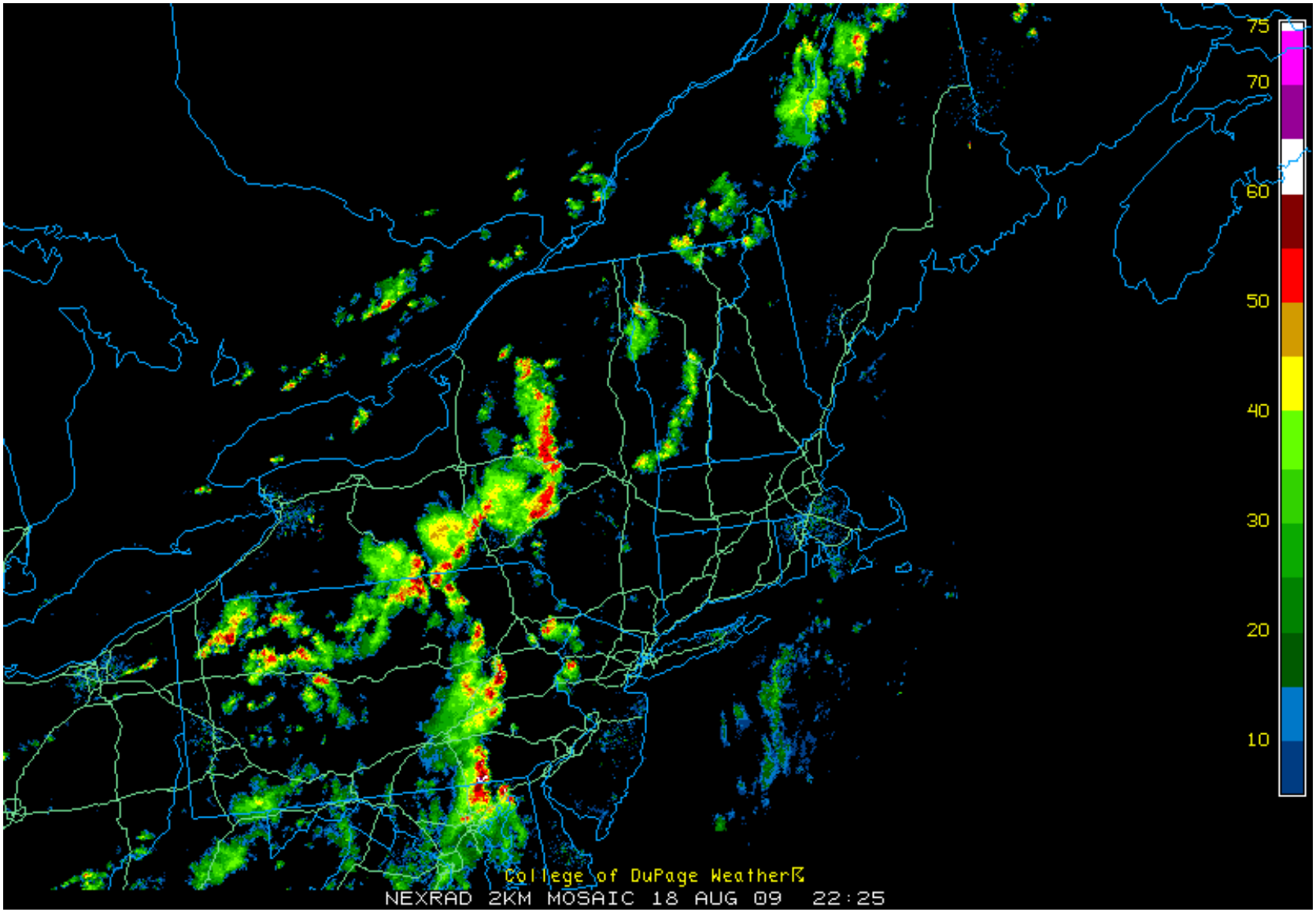
Radar 2200 UTC 18 Aug



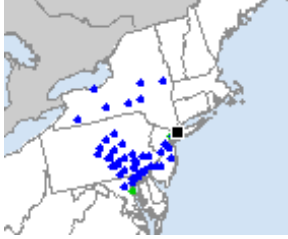


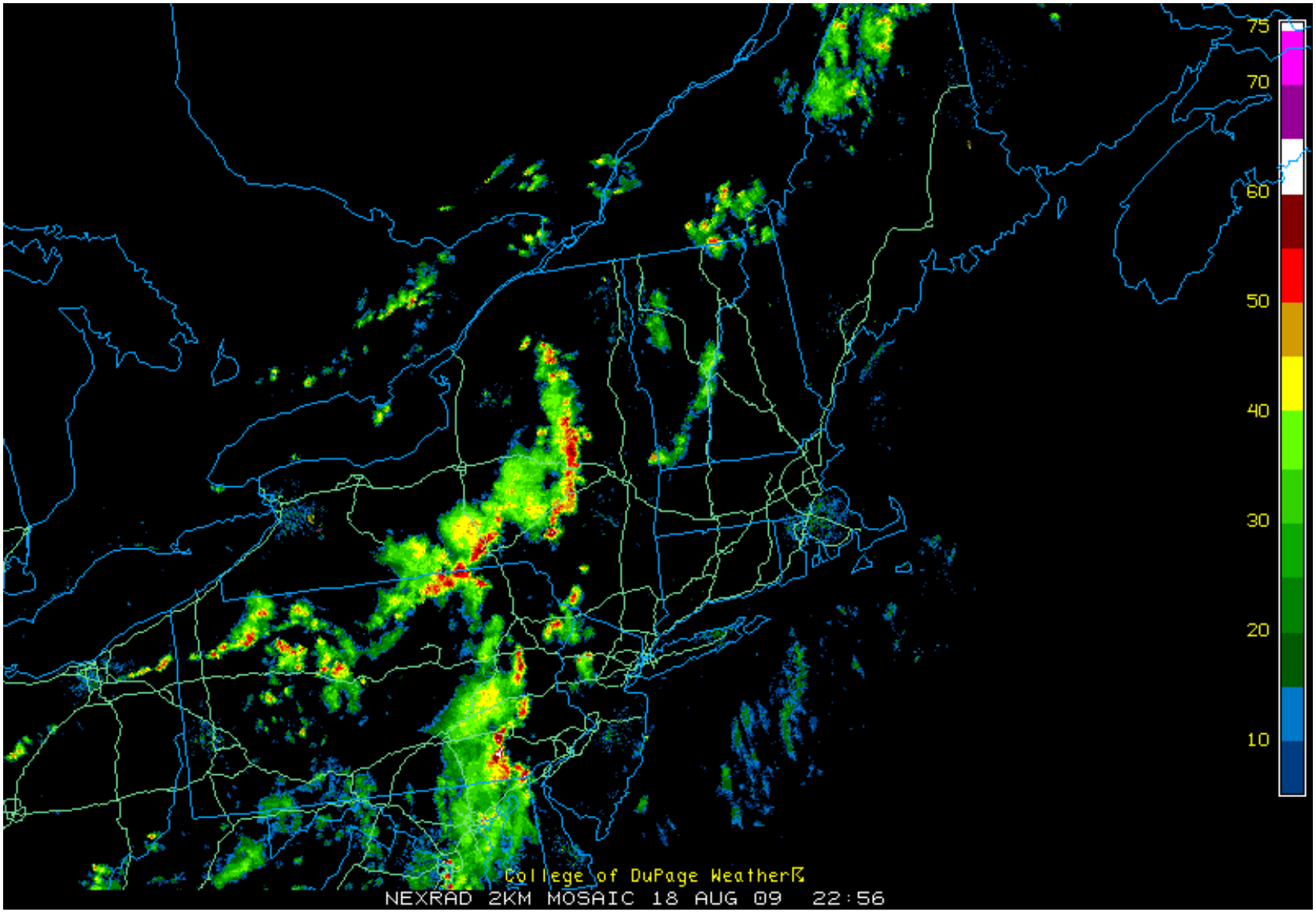
Radar 2230 UTC 18 Aug



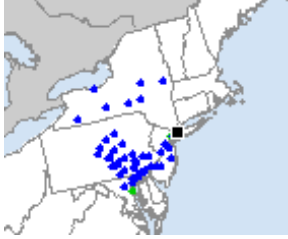


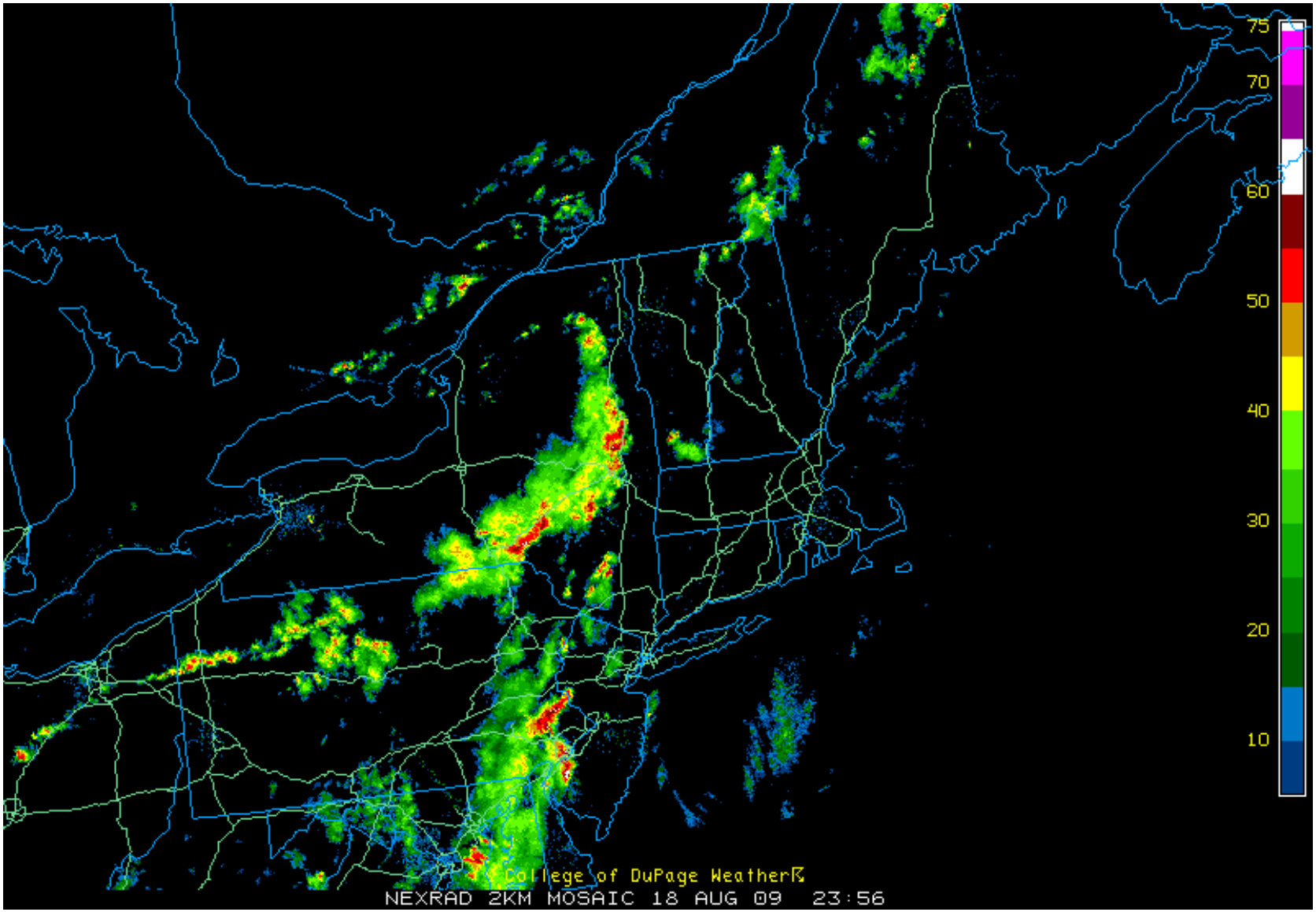
Radar 2300 UTC 18 Aug



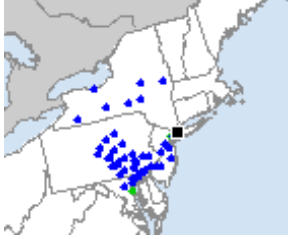


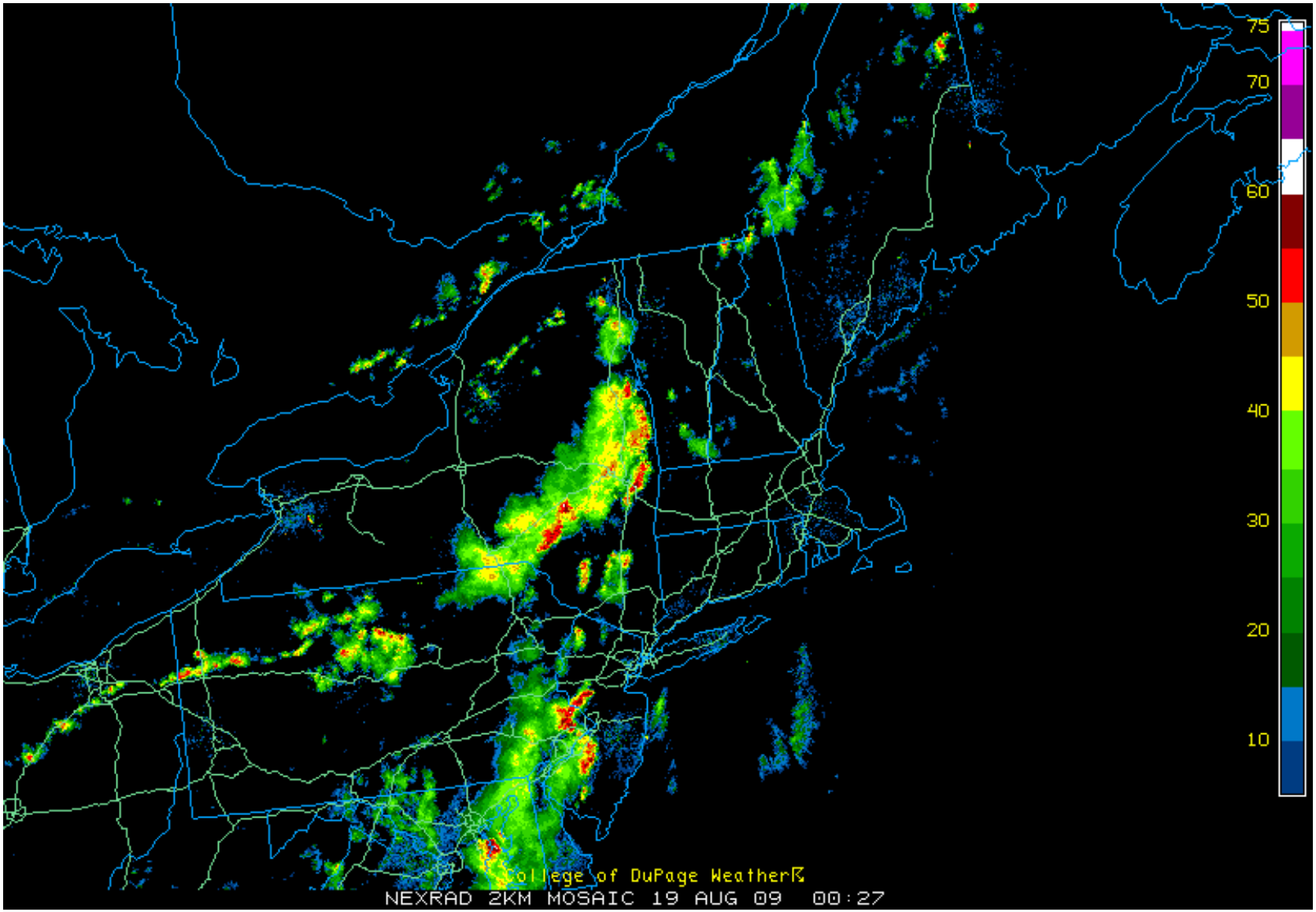
Radar 0000 UTC 19 Aug



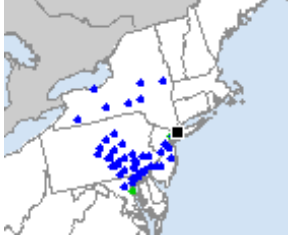


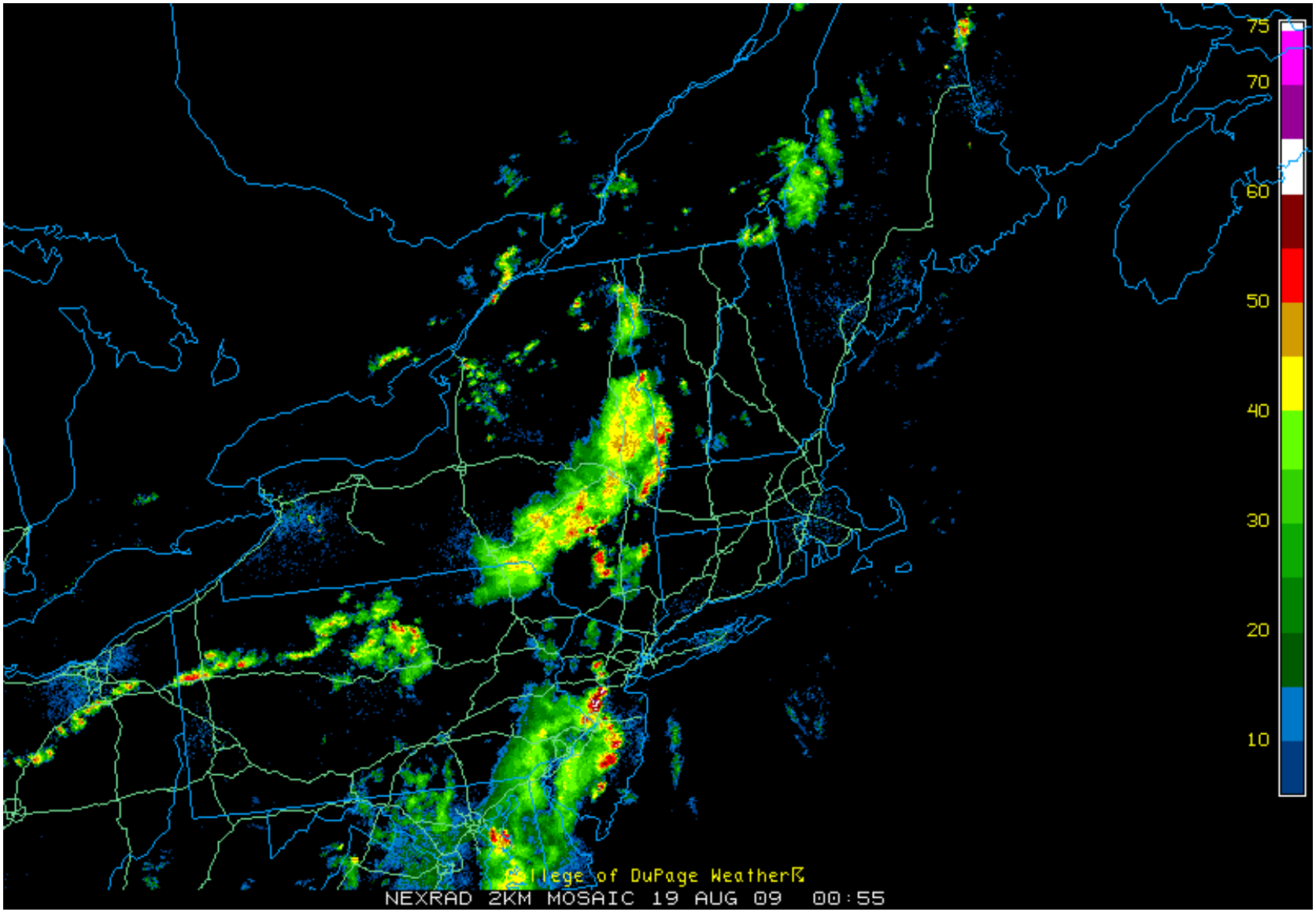
Radar 0030 UTC 19 Aug



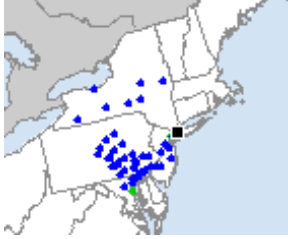


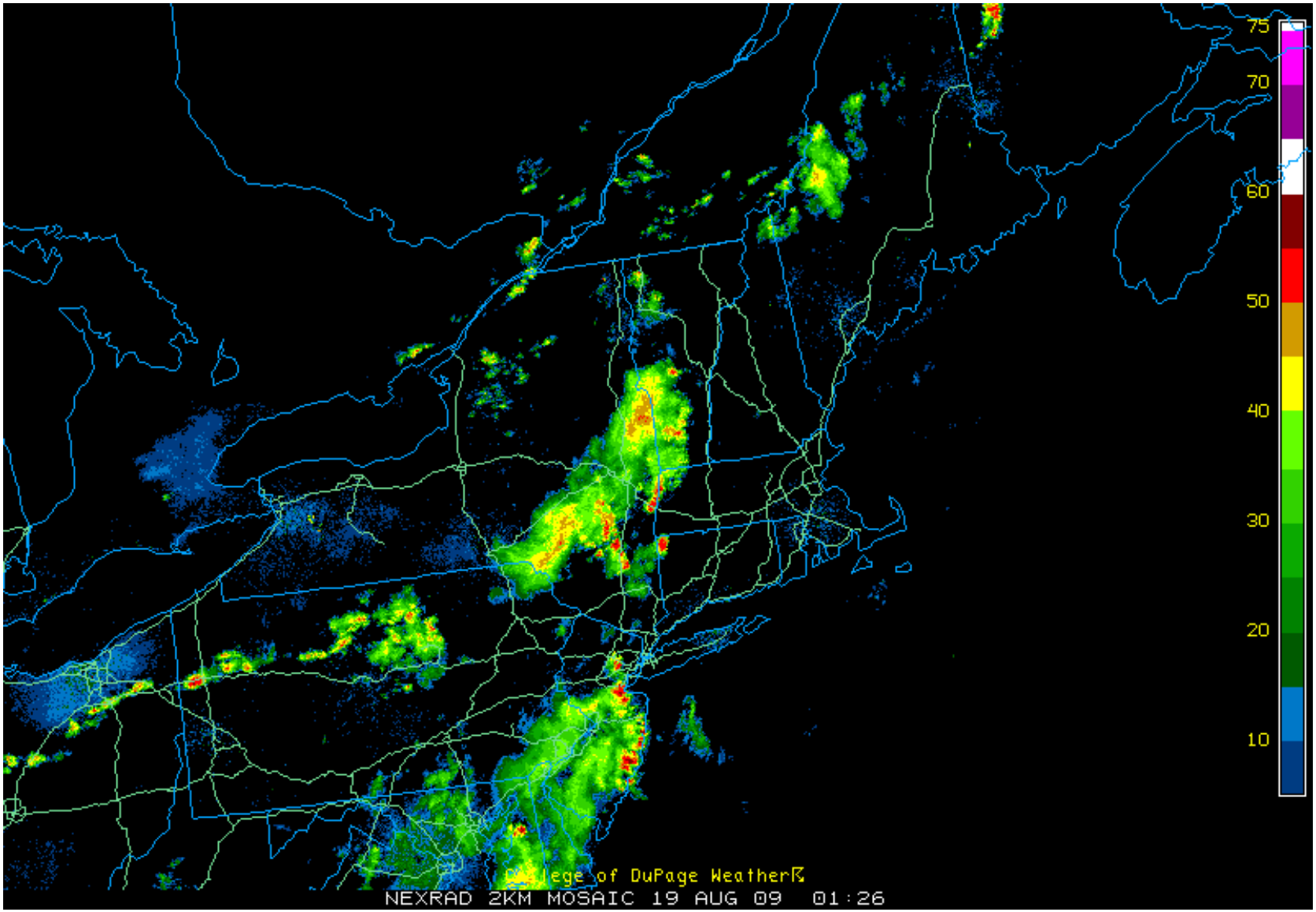
Radar 0100 UTC 19 Aug



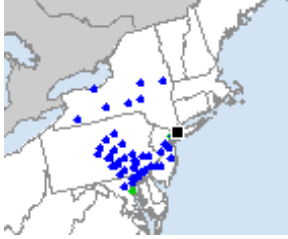


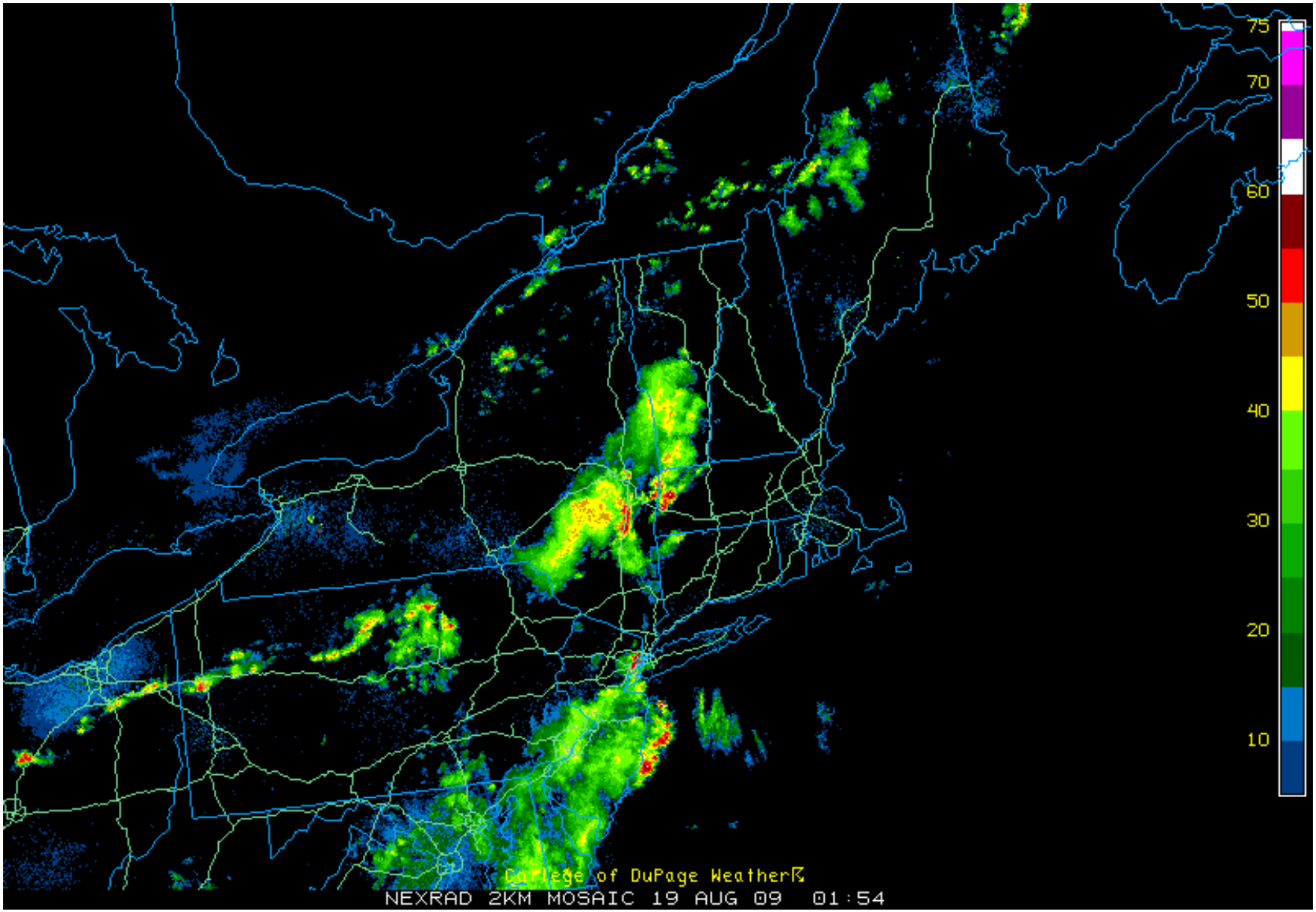
Radar 0130 UTC 19 Aug



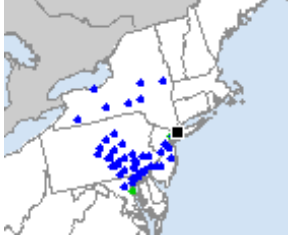


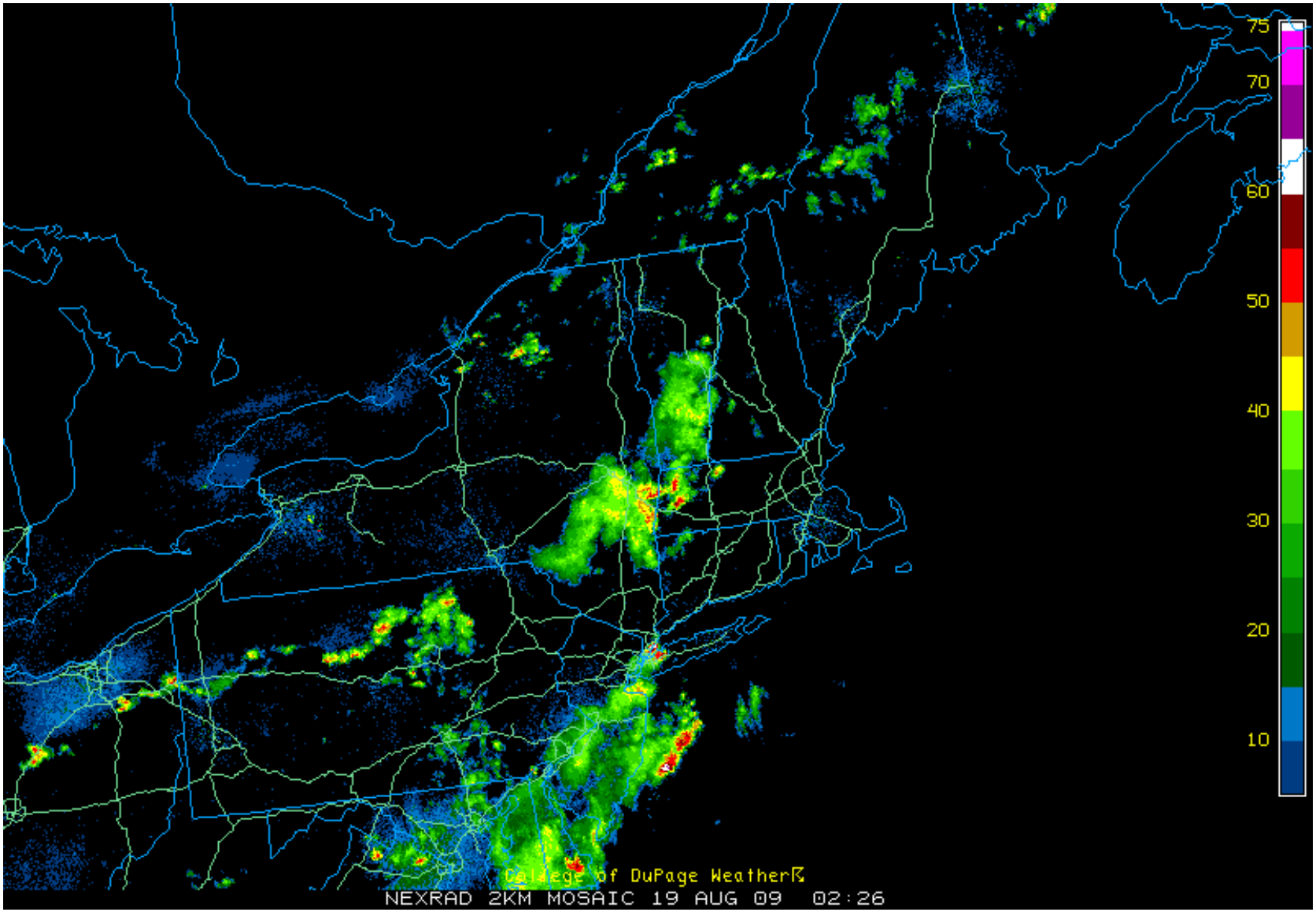
Radar 0200 UTC 19 Aug



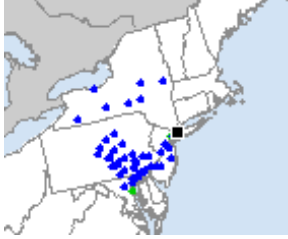


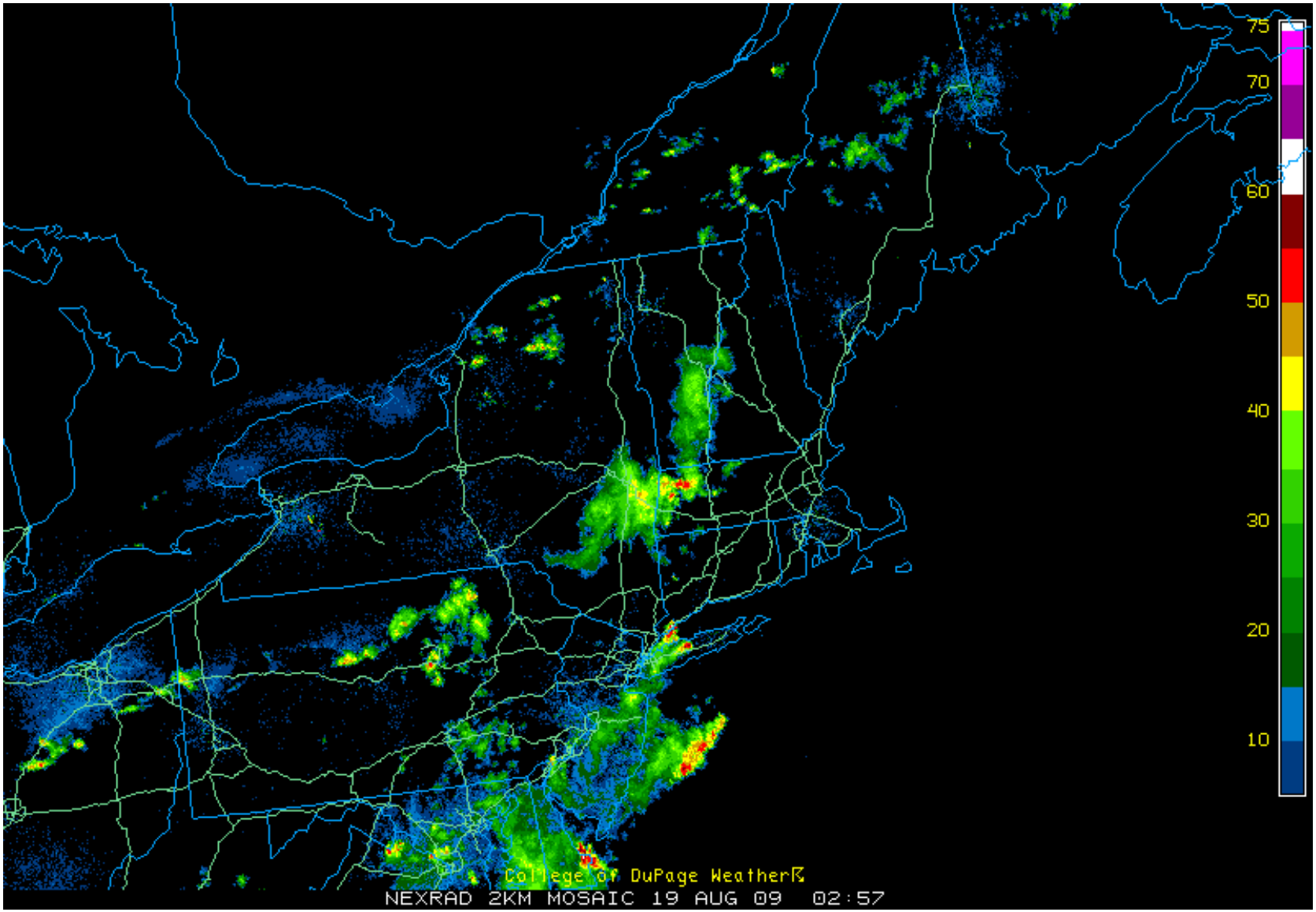
Radar 0230 UTC 19 Aug



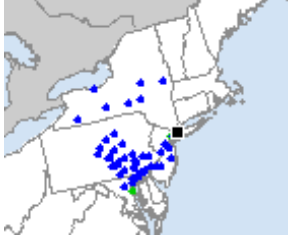


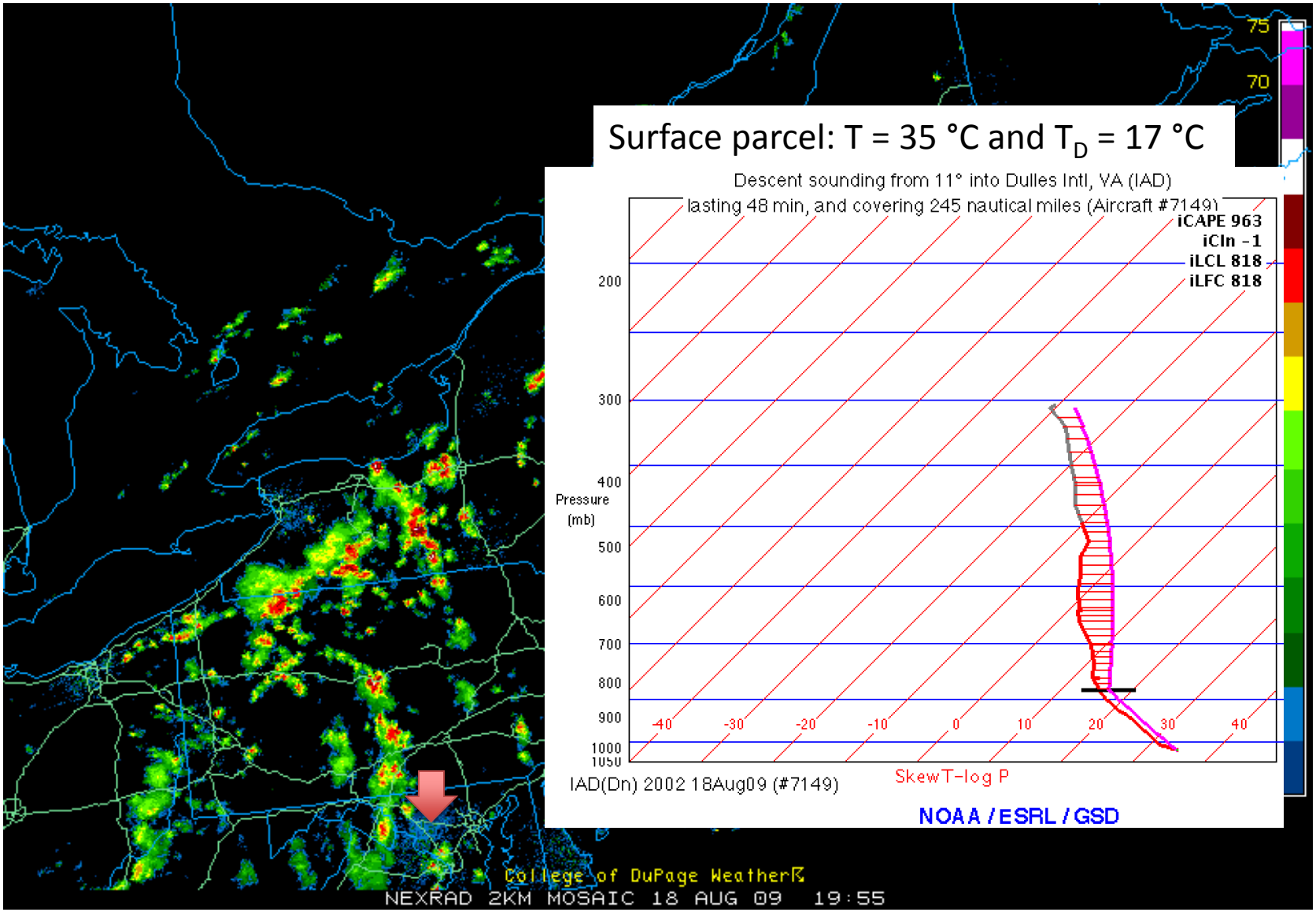
Radar 0300 UTC 19 Aug



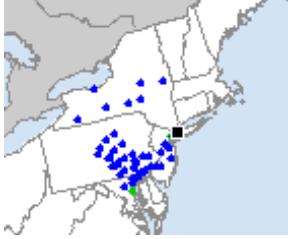


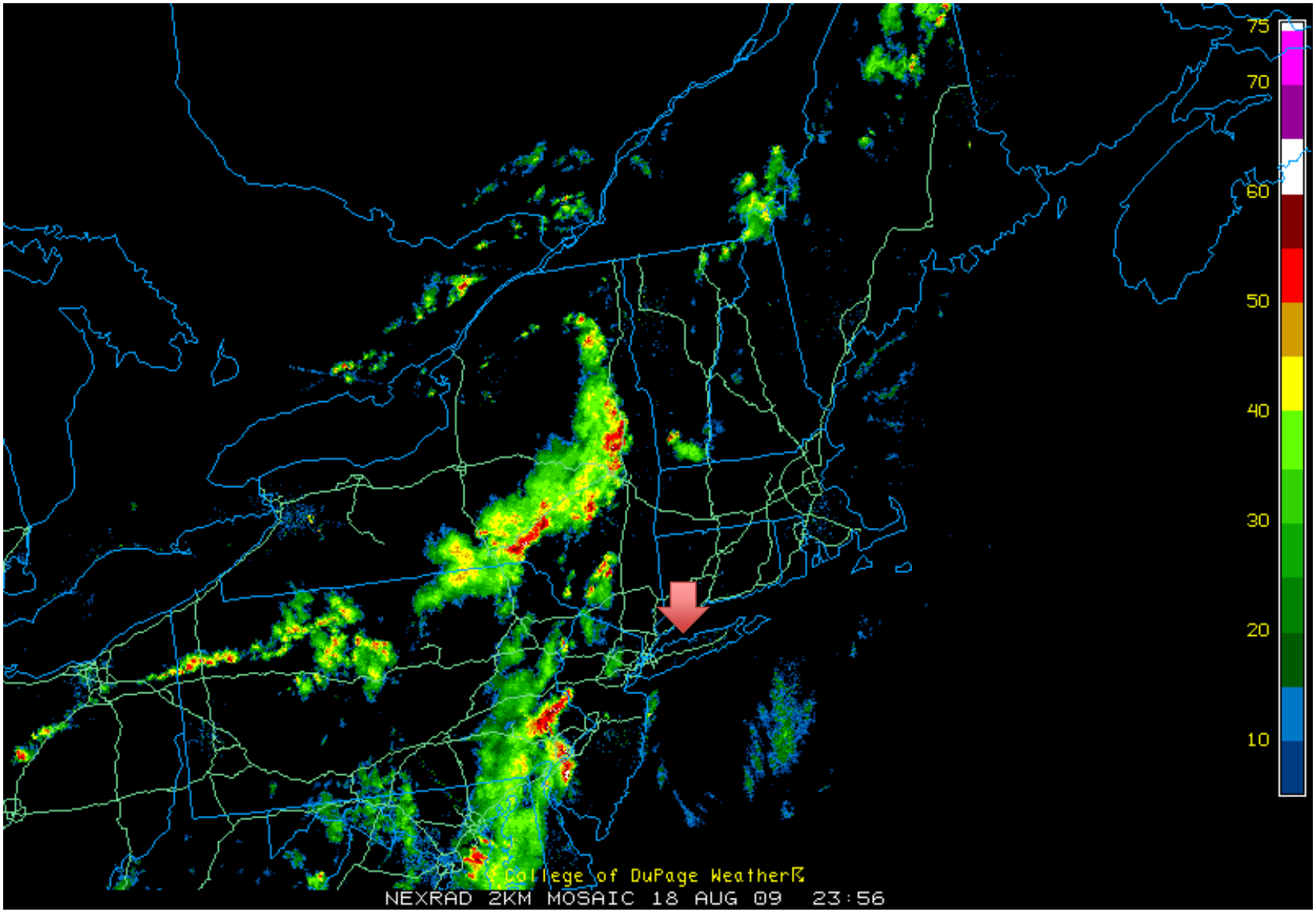
Radar 2000 UTC 18 Aug



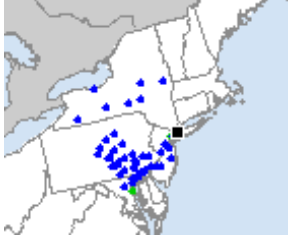


Radar 0000 UTC 19 Aug



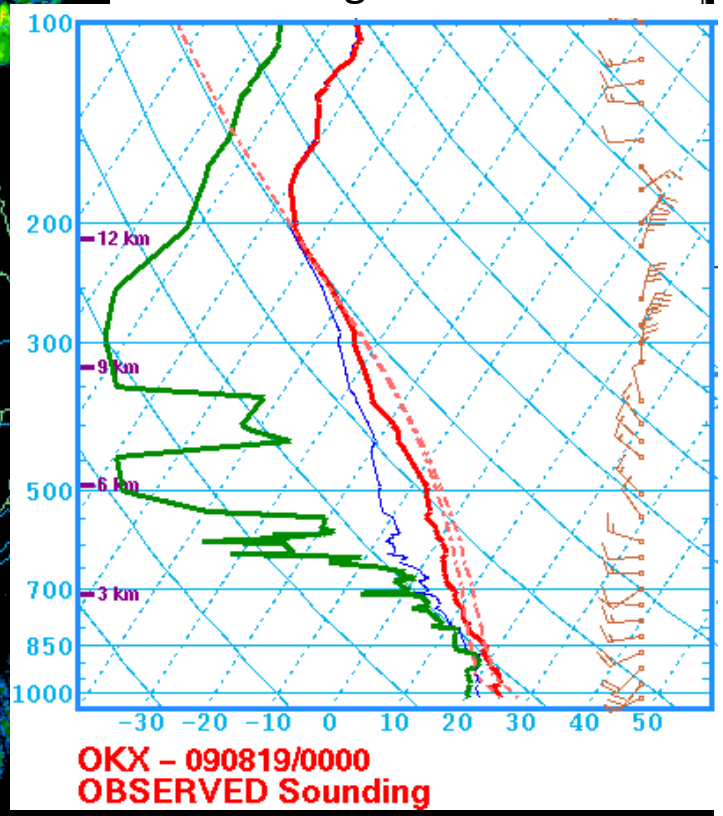


Radar 0000 UTC 19 Aug

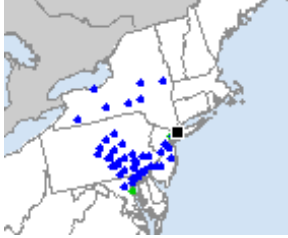


- MLCAPE: 1945 J kg^{-1}
- MLCIN: -178 J kg^{-1}
- 6-km shear: 16 kt
- DCAPE: 1199 J kg^{-1}

77 kt wind gust at 0233 UTC

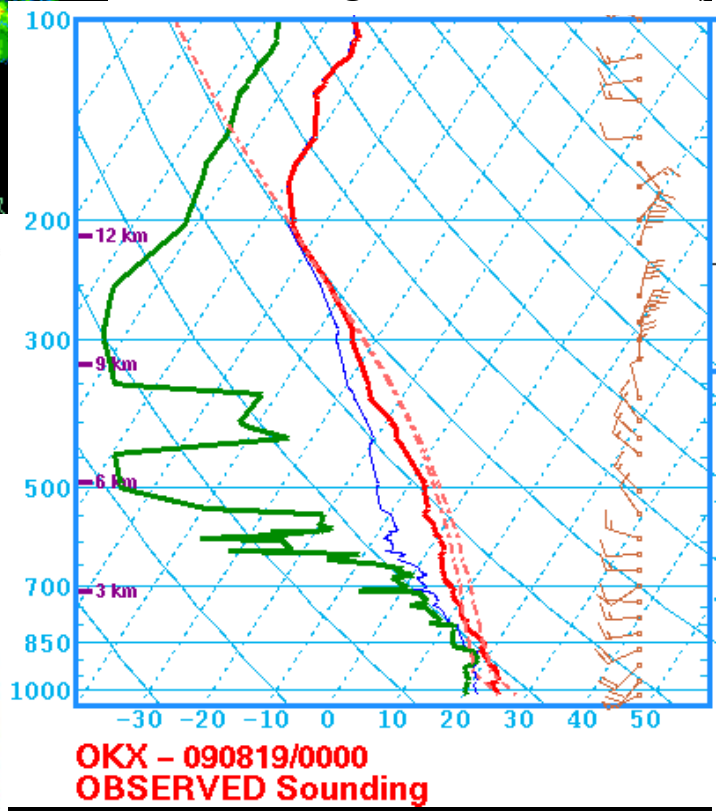


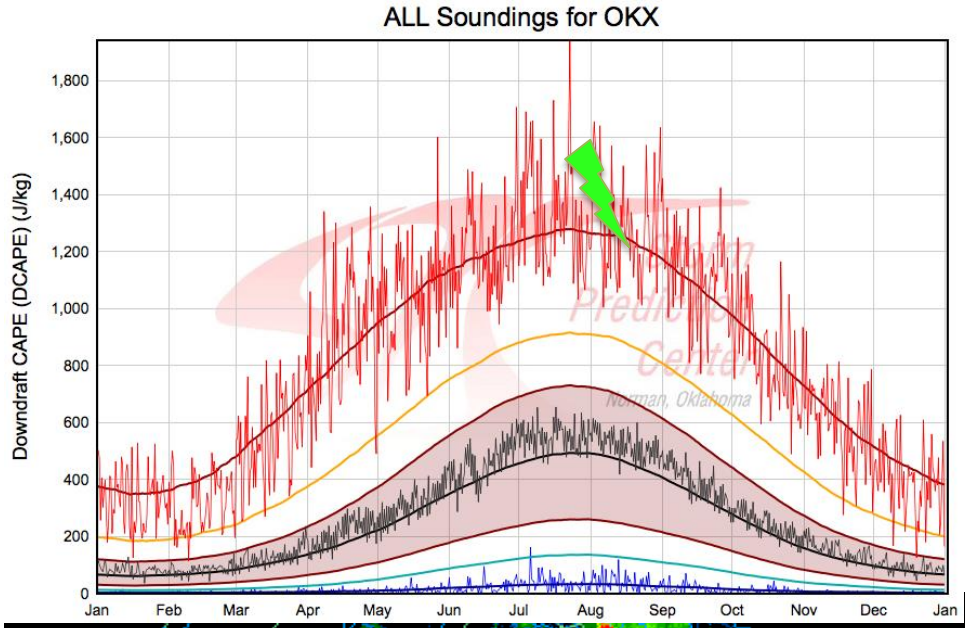
Radar 0000 UTC 19 Aug

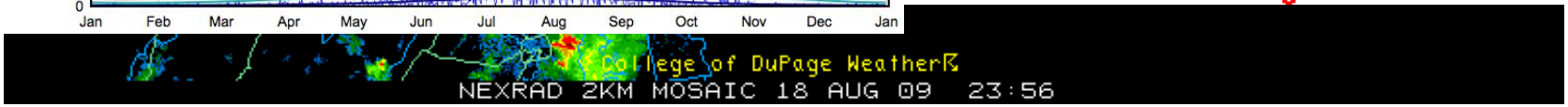


- MLCAPE: 1945 J kg^{-1}
- MLCIN: -178 J kg^{-1}
- 6-km shear: 16 kt
- DCAPE: 1199 J kg^{-1}

77 kt wind gust at 0233 UTC







Case Summary

- Low Shear High CAPE (LSHC) event.
  - Weak synoptically forced environment
  - Orography and lake boundaries critical in convective initiation
  - Convective initiation environment differed from environment to the east where most severe reports occurred.

- Type 1 LSHC cases often feature storms propagating into environments with higher PBL heights and greater DCAPE

- In the absence of strong low-to-mid level flow and large vertical wind shear, large DCAPE and high PBL heights likely contribute to the severe wind threat

General Summary

- Low-predictive skill climatology results:
  - Northeast has better threat scores than CONUS
  - Peak in JJA for low-POD events, little yearly variation
    - Most common under westerly, southwesterly, and northwesterly 500-hPa flow regimes
  - High-FAR events not as common in recent years

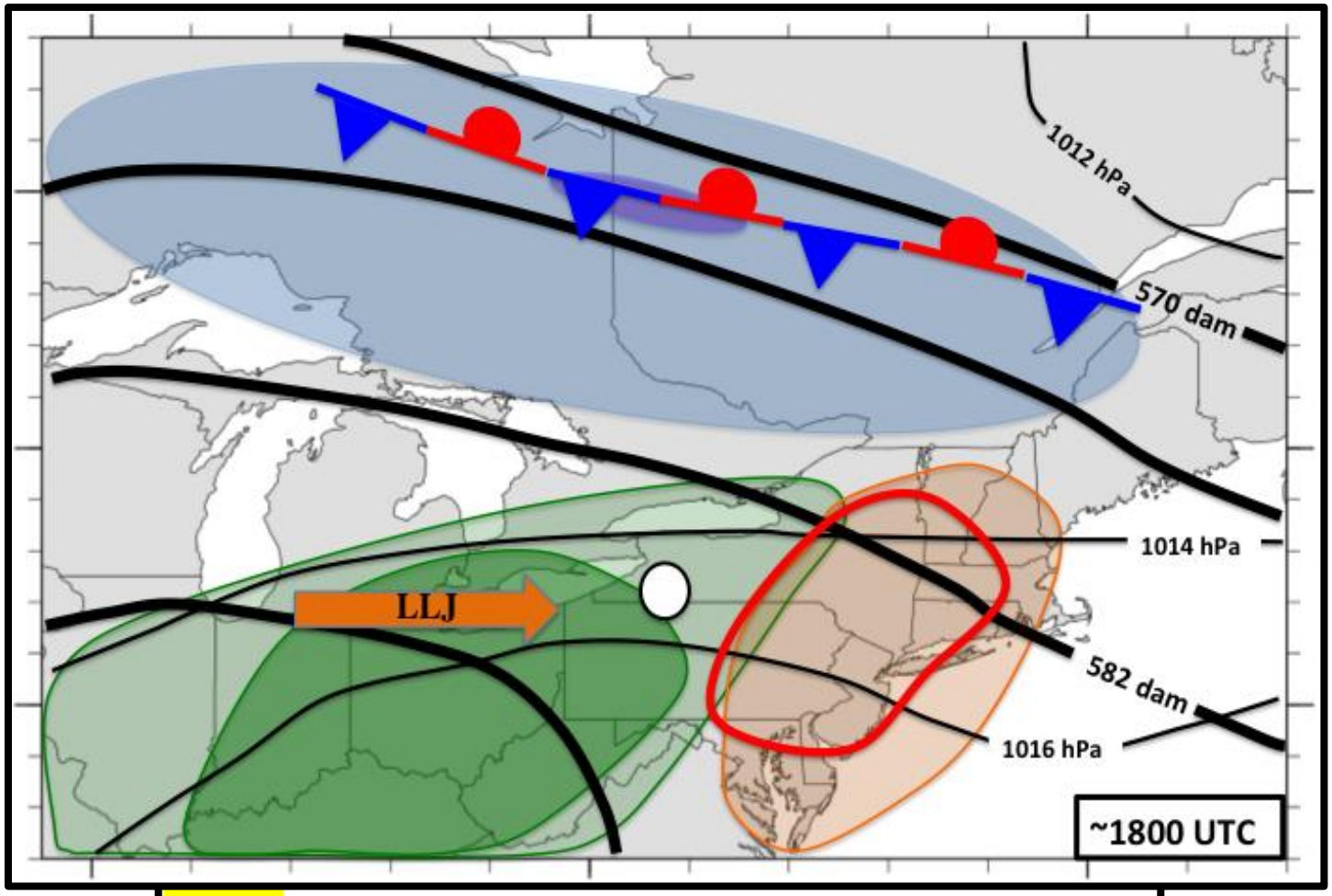
- Composite results:
  - Deep-layer shear a significant predictive skill discriminator
  - Northerly, northwesterly, and southerly flow regimes have lowest skill
  - Synoptic setup similar between good and low-POD cases but key features (trough, baroclinicity, etc.) stronger in good cases
- Case study results:
  - Low-POD, low-shear events often propagate into higher-PBL, higher-DCAPE environments
  - High shear, low CAPE low-POD events often exhibit insolation-driven, high-PBL instability

Acknowledgements

- Family (parents, siblings Meghan and Chris)
- Drs. Lance Bosart & Brian Tang
- UAlbany faculty and staff
- Teachers at ERAU and in Berkshire County
- Fellow graduate students

FIN

Northwesterly Flow Low-POD Event Conceptual Model



Key

- Low LCL heights
- 250-hPa jet
- 500-hPa geopotential heights
- High precipitable water
- High DCAPE and higher LCL heights
- Initiation point
- Enhanced severe wind threat
- Mean sea level pressure
- Surface boundary
- LLJ — Low-level jet