Challenges in Forecasting Disruptive Weather

Jon Nese (j2n@psu.edu)
Penn State Meteorology and Atmospheric Science

Pennsylvania PUC Annual Safety Seminar
State College, PA
September 3, 2025

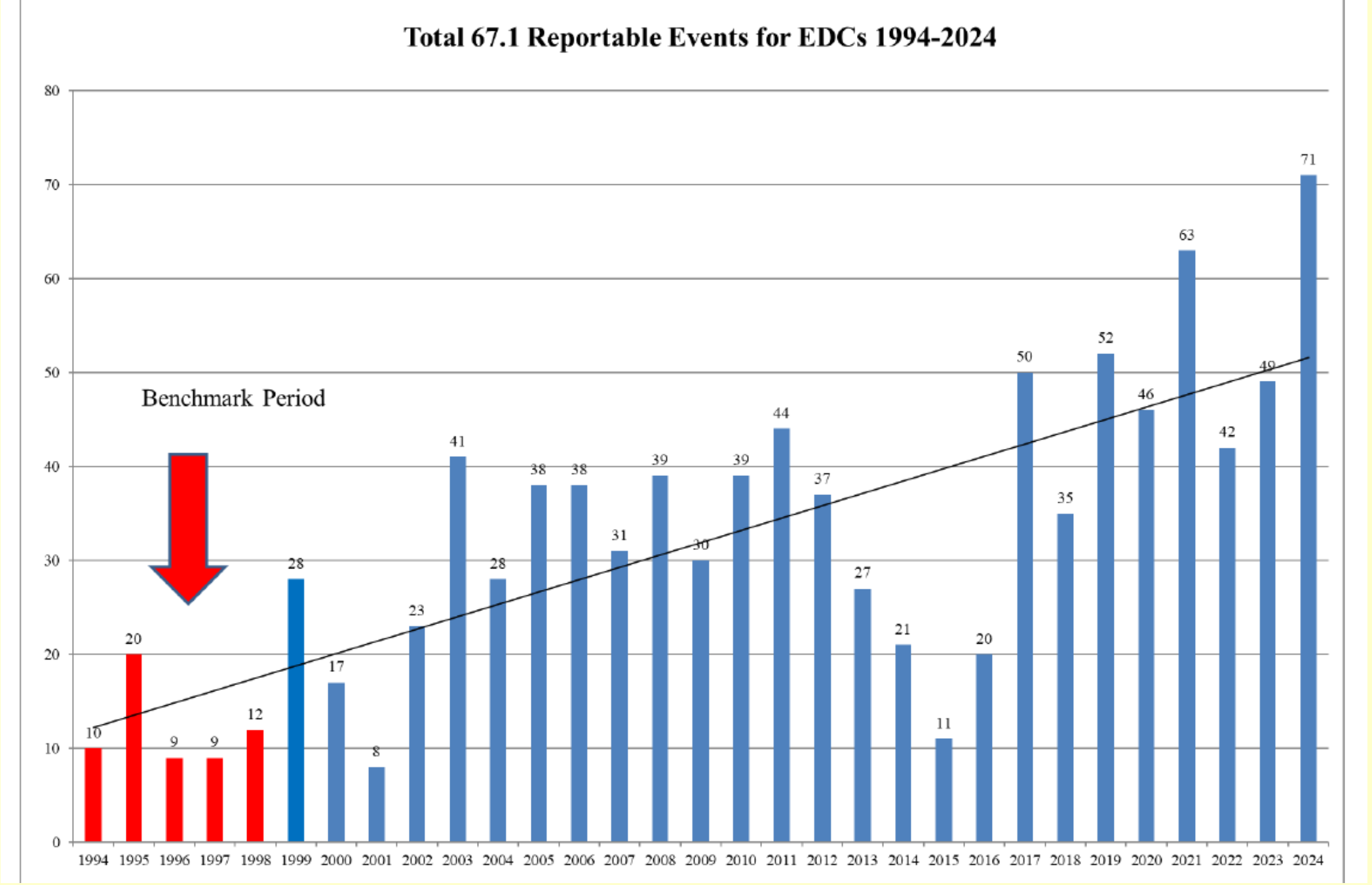
Challenges in Forecasting Disruptive Weather

"… Given the increased frequency of severe weather and the impacts it can and does have on the Commonwealth's electric distribution network …"

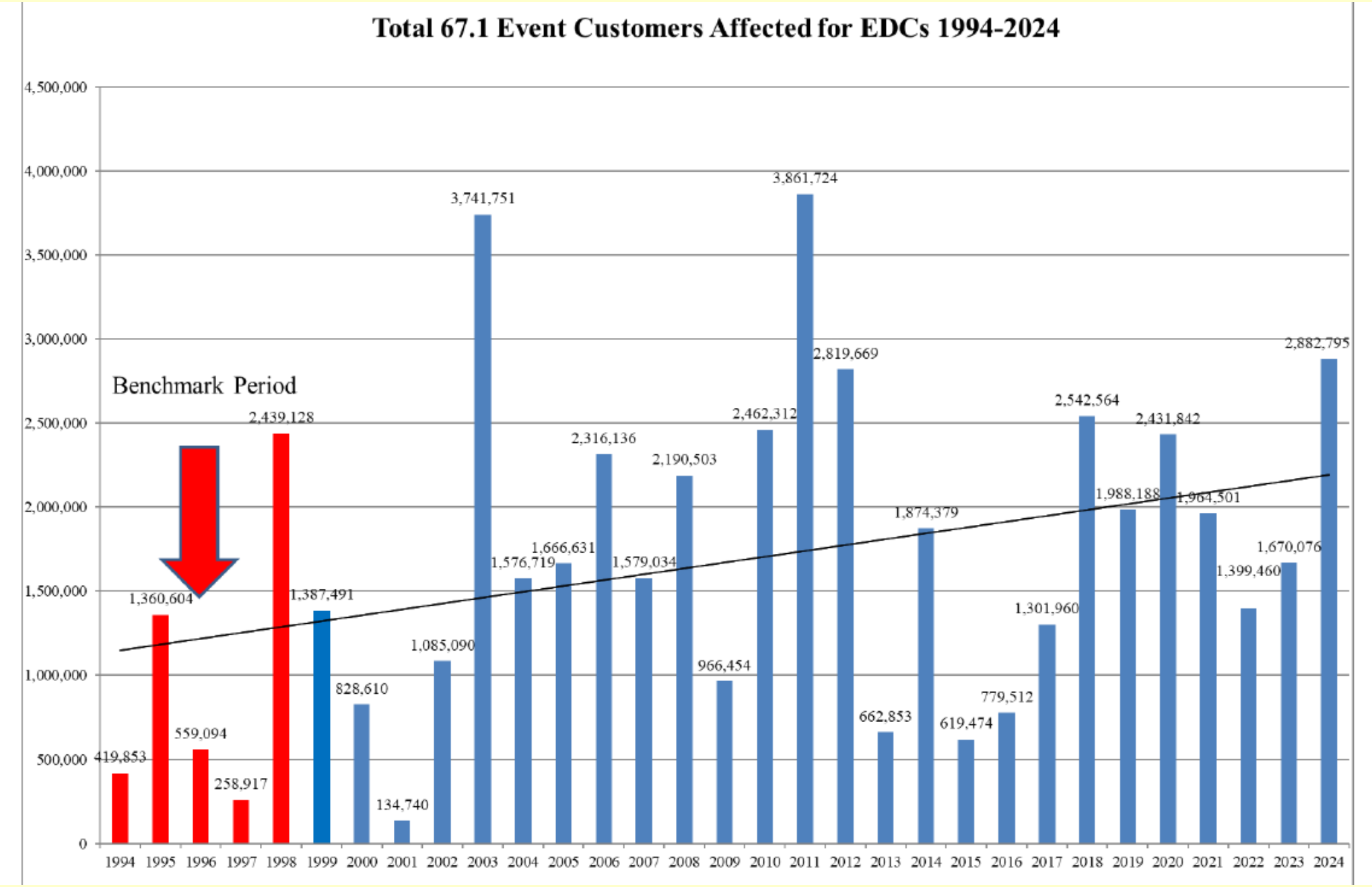
- Severe Thunderstorms (wind)
- Heavy snow / ice
- Heat

Outline

- Severe Weather Event Trends
- Geographical Distribution of Severe Weather
- National Weather Service Severe Weather Products
- Trends in Forecast Accuracy
- The Kingpin of Electrical Distribution Disrupters
- Modern Forecasting Tools

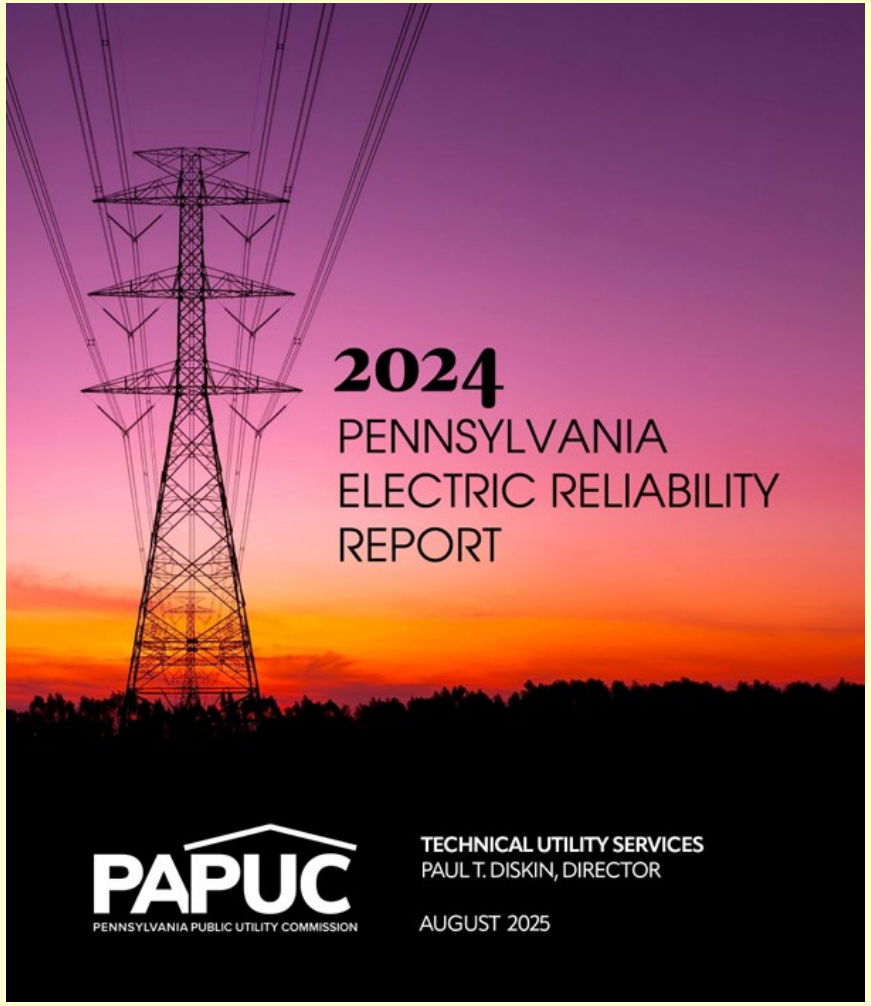


Source: 2024 Pennsylvania Electric Reliability Report (EDC = Electric Distribution Company)



Source: 2024 Pennsylvania Electric Reliability Report (EDC = Electric Distribution Company)

TUS recommends that EDCs, as they continue to improve upon their capital improvement plans, LTIIPs, and required emergency response and business continuity plans,[17] evaluate the impact of increasingly severe weather on their systems and look to increase resiliency in those plans. In



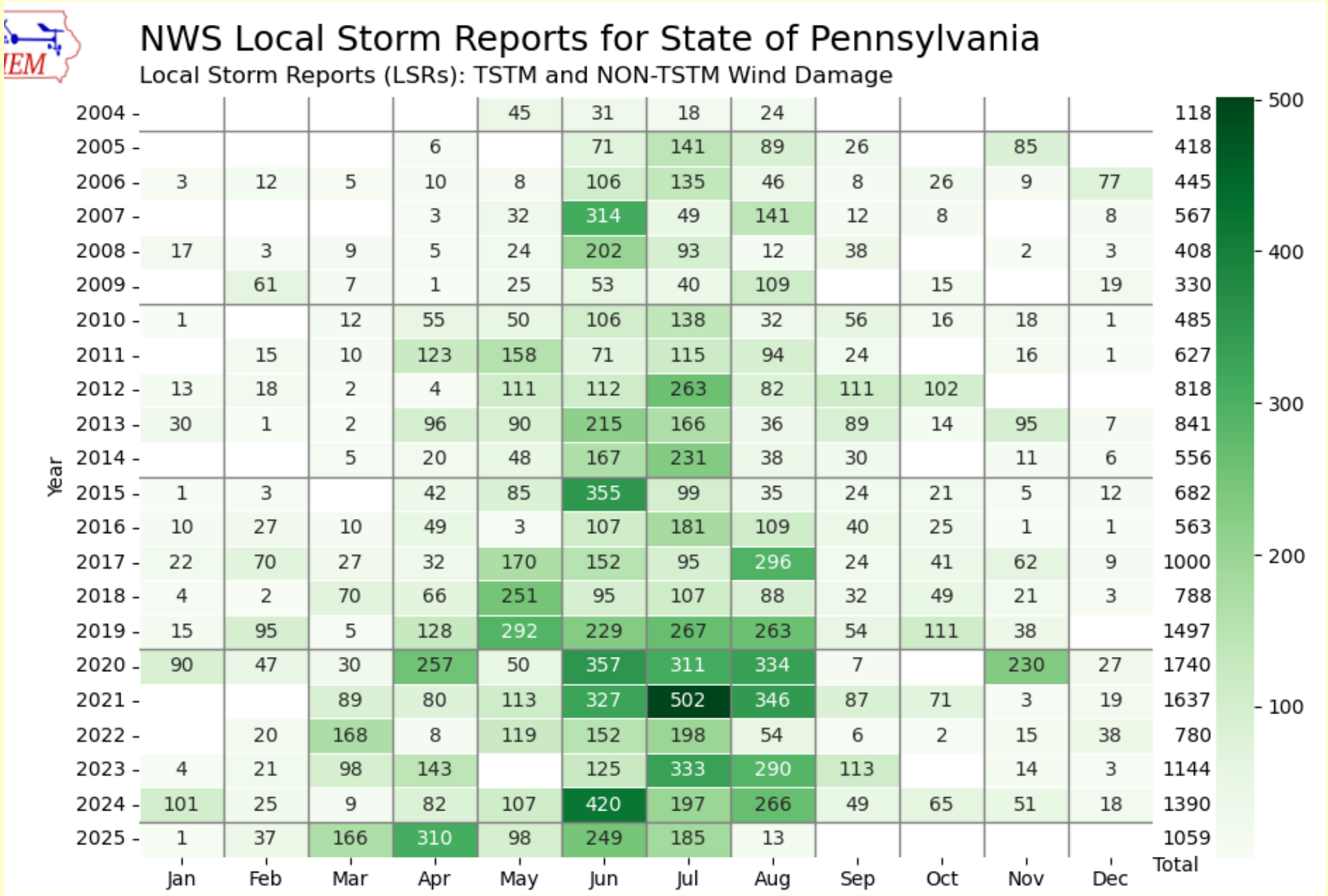
- What does “severe” mean in this context?
- Are such (weather) events actually becoming more frequent?

Meteorological Definitions

- To a meteorologist: “Severe” refers to thunderstorms that produce big (1”+) hail, strong winds (50 kt+), and/or tornado

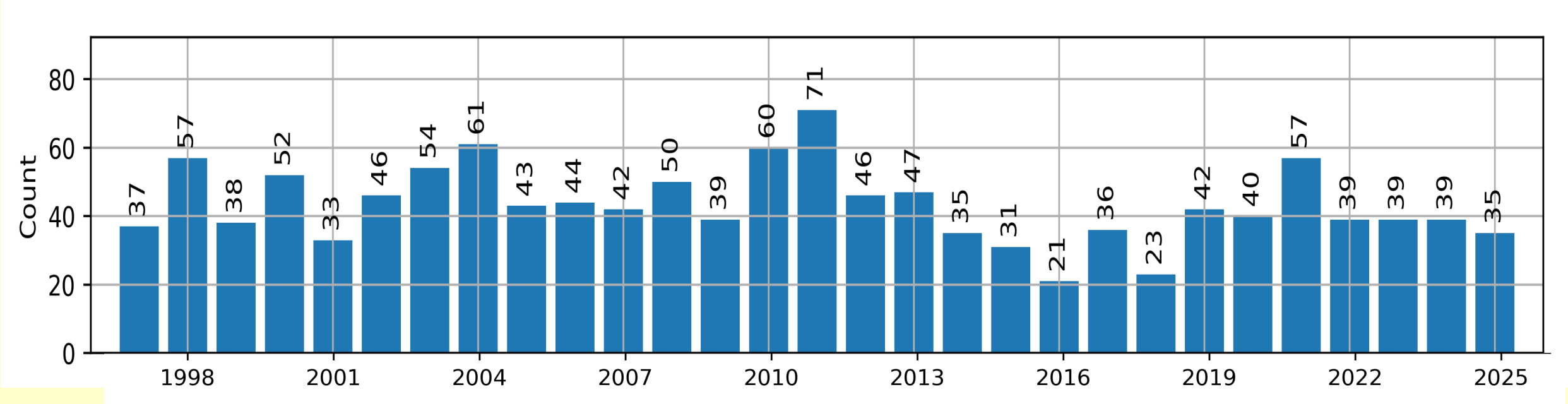
- Severe Thunderstorm **Watch** means conditions are favorable for severe thunderstorms to occur

- Severe Thunderstorm **Warning** means a severe thunderstorm is occurring or is imminent



https://mesonet.agron.iastate.edu/plotting/auto/

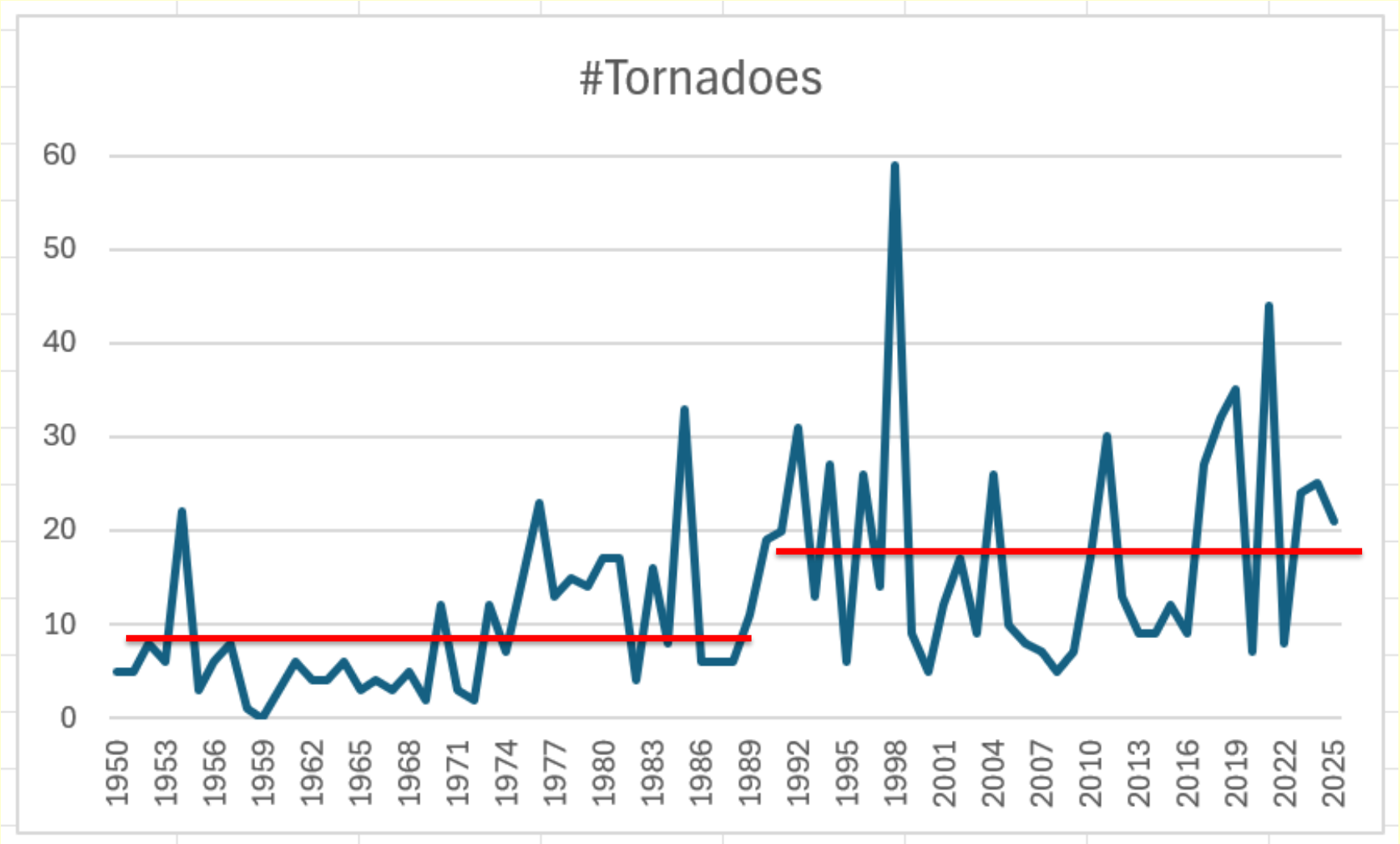
Severe Thunderstorm Watches Including at Least a Part of Pennsylvania



- These are issued by the Storm Prediction Center in Norman, OK, staffed by some of the best severe weather forecasters in the world

https://mesonet.agron.iastate.edu/plotting/auto/

Number of tornadoes in PA as proxy for severe weather frequency

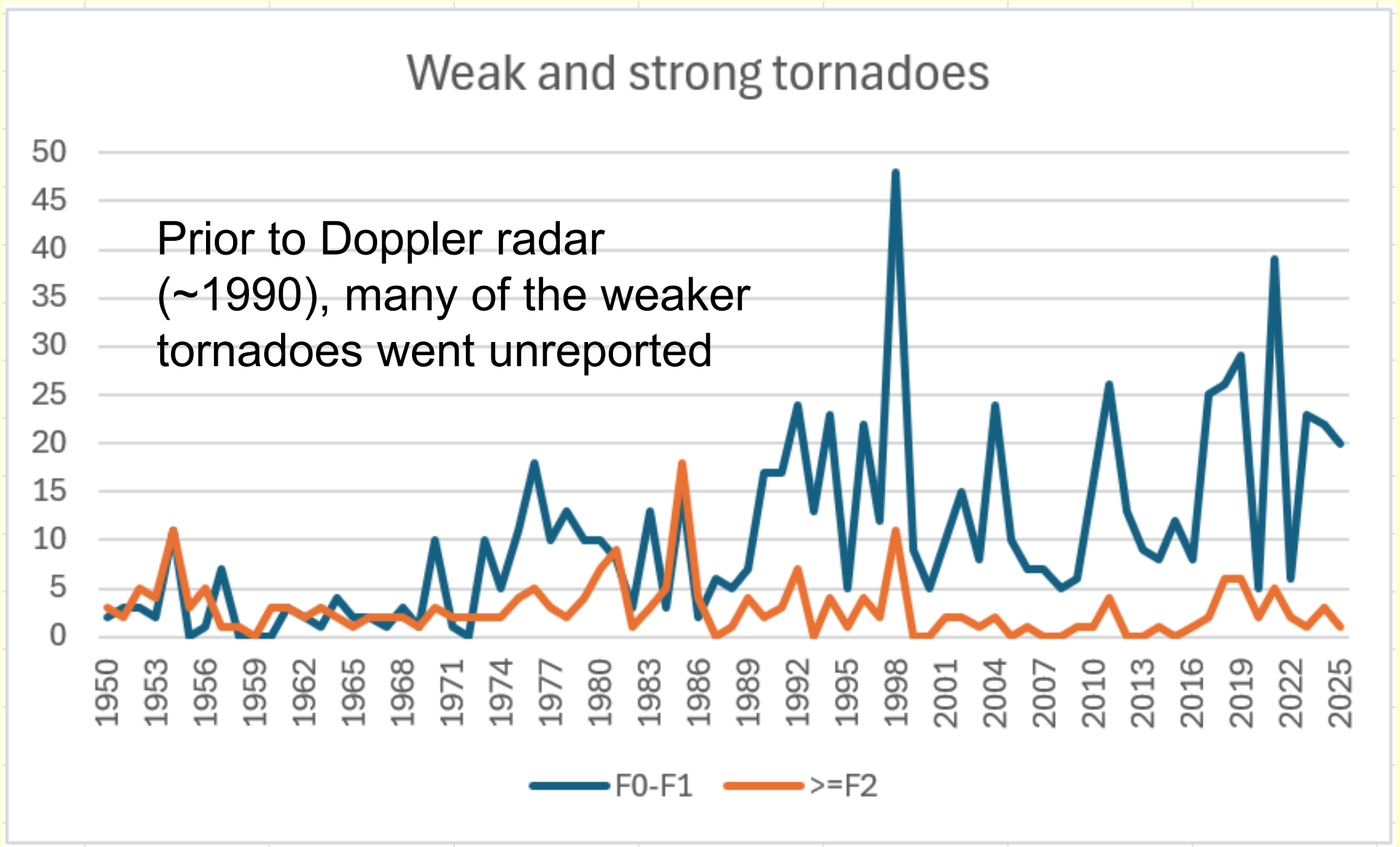


Not common event … lots of variability from year to year

Averages

1950s-80s:	9
1990s-2020s:	18

Number of tornadoes in PA as proxy for severe weather frequency



Stronger tornadoes have always been well documented, and there's really no trend in them

Increase is due to better reporting

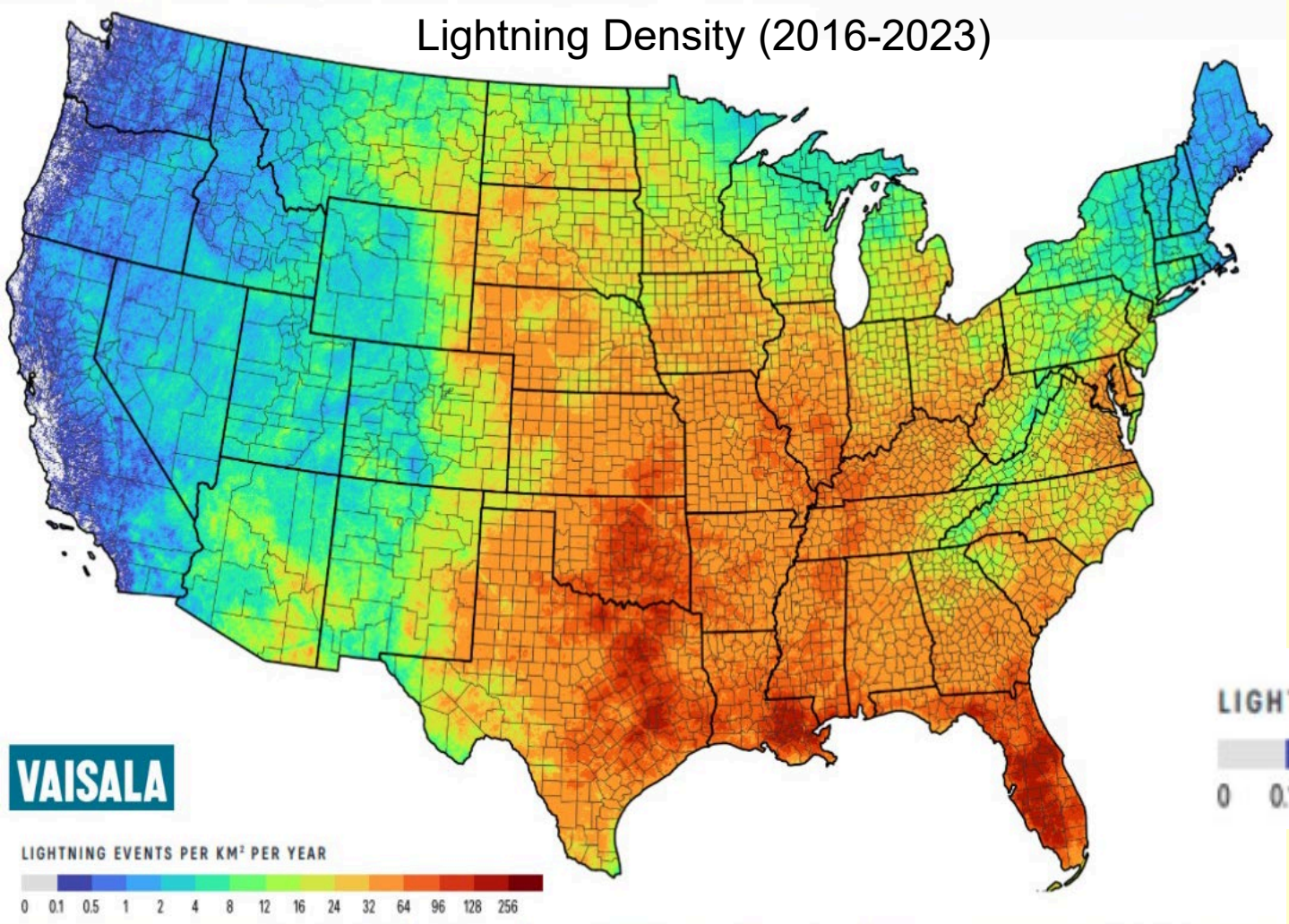
Severe Weather Event Trends

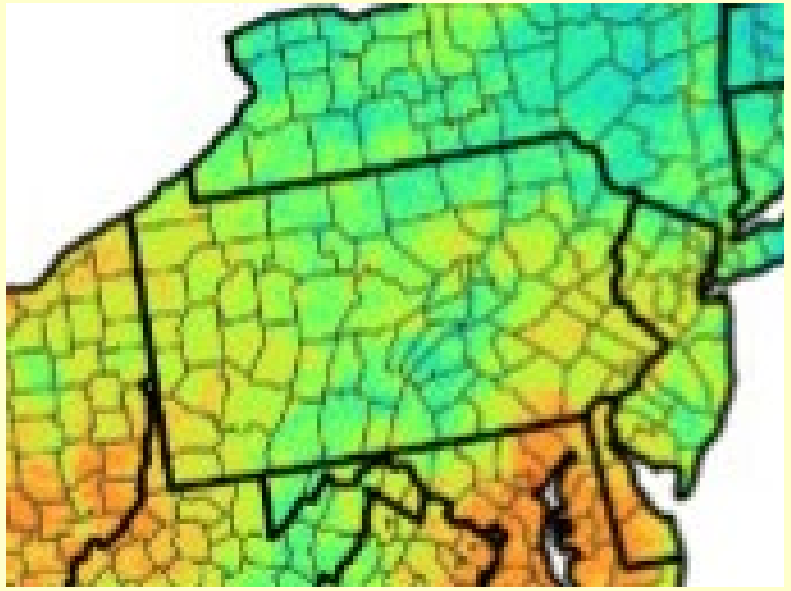
- No compelling meteorological evidence of a consistent upward trend in the number of severe-thunderstorm-related weather events, at least not in last 30 years or so

- Observing networks (both technology and people) are getting better, so the number of **reports** of severe weather is increasing

Geographical Distribution of Severe Weather

Distribution of thunderstorms is not uniform across Pennsylvania



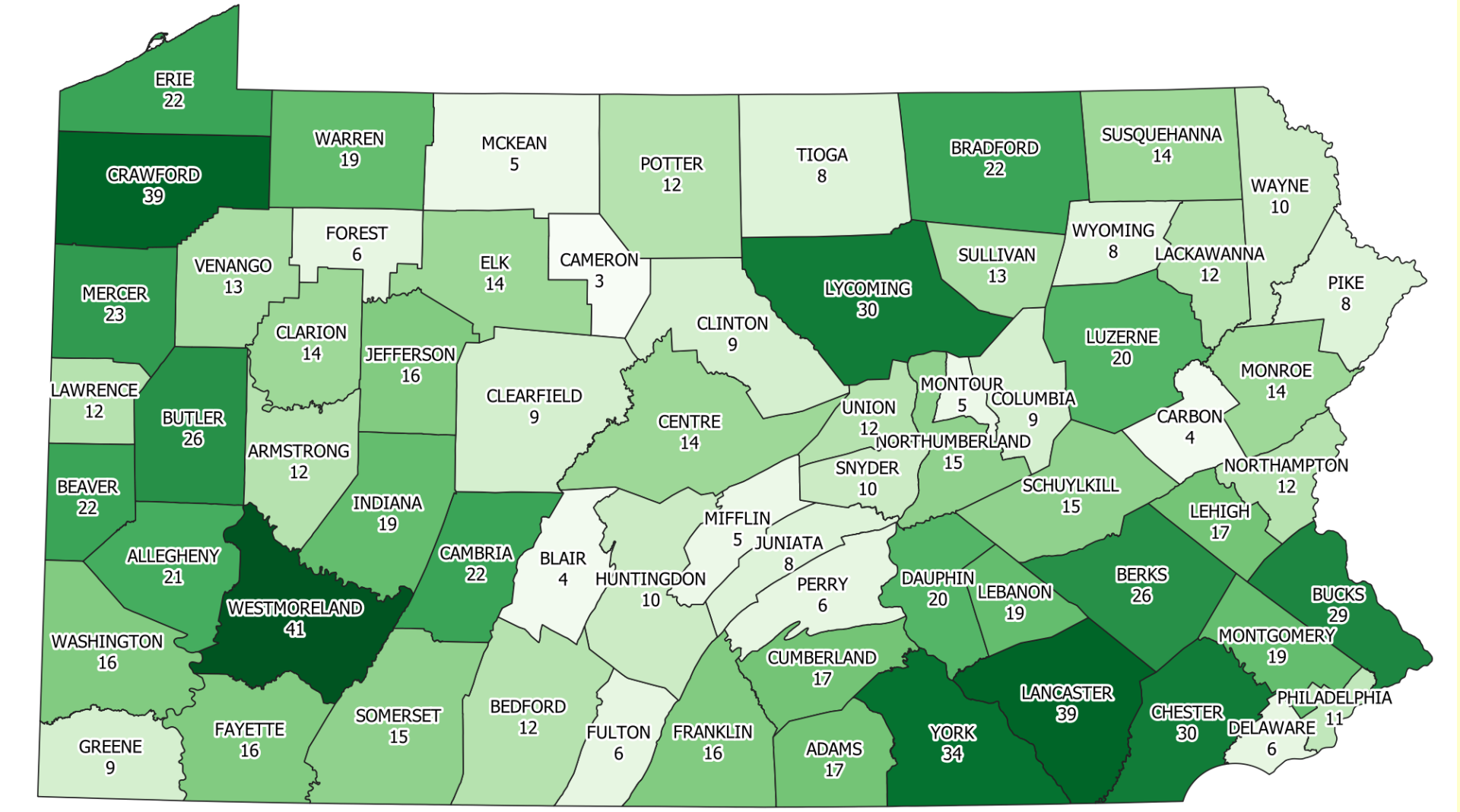


https://www.xweather.com/annual-lightning-report

STORMSELL
stormsellweather.com

Number of Tornadoes 1950-2023

Last Updated 02/29/2024



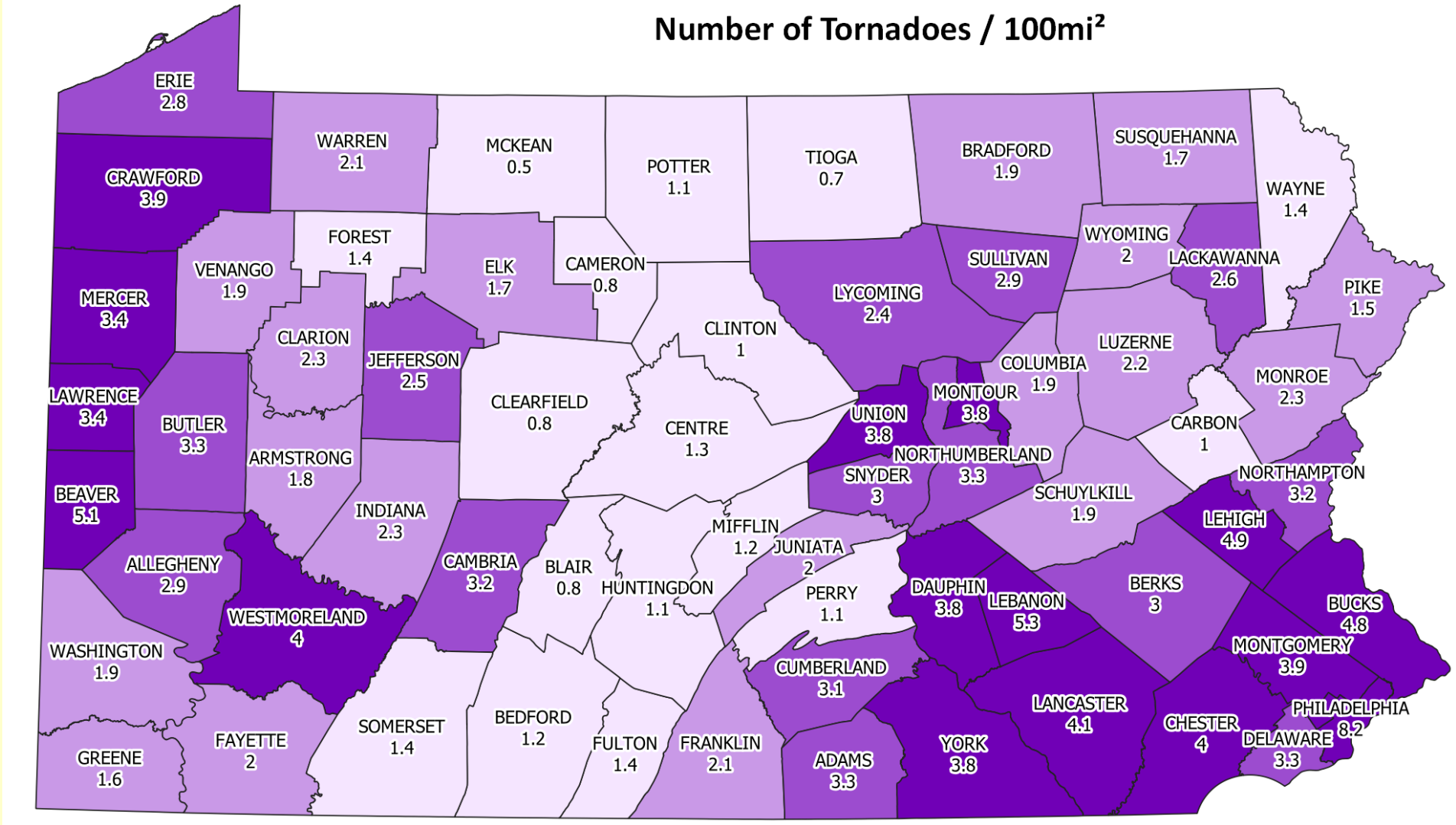
https://stormsellweather.com/patornadoes/statistics.html

STORMSELL
stormsellweather.com

Pennsylvania Tornado Density

1950-2023

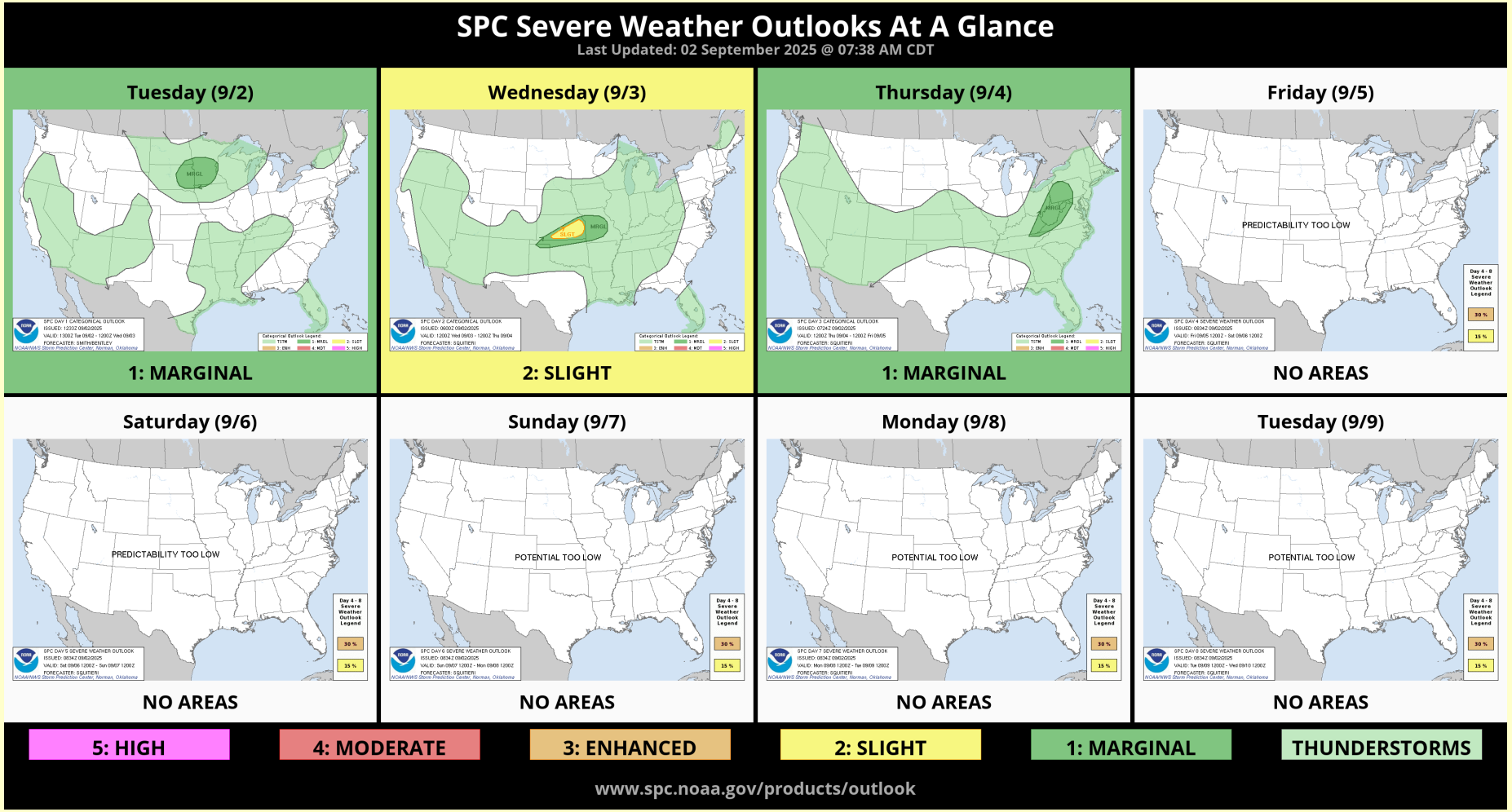
Last Updated 02/29/2024



https://stormsellweather.com/patornadoes/statistics.html

National Weather Service Severe Weather Forecast Outlooks

National Weather Service Provides Seven-Day Probabilistic Severe Thunderstorm Outlooks



https://www.spc.noaa.gov/public/swodyoverview.html

National Weather Service has Many Advanced Warning Products for Hazardous Weather

U.S. Day 3-7 Hazards Outlook

Created September 01, 2025

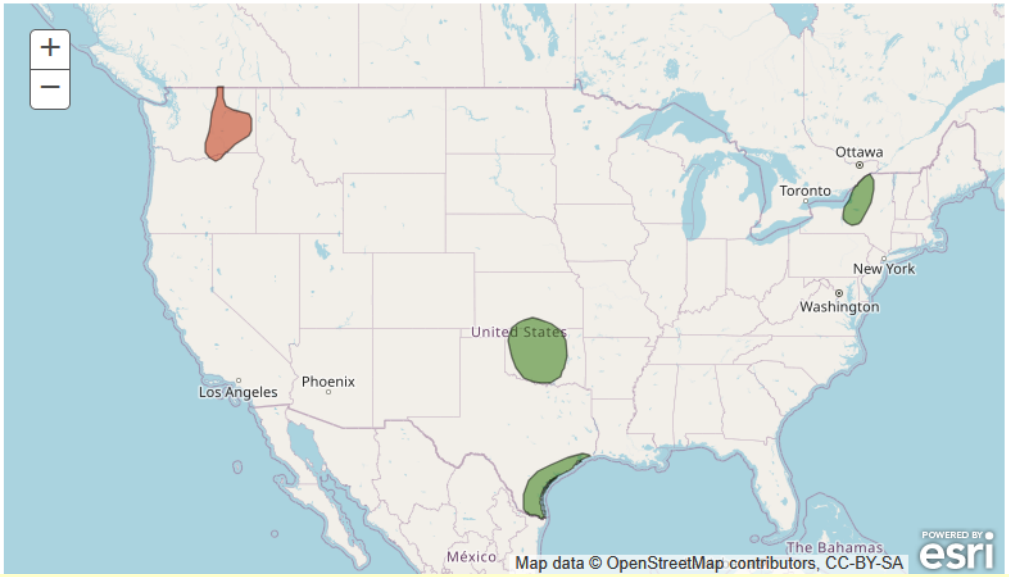
NOTE: These products are only created Monday through Friday.
Please exercise caution using this outlook during the weekend.

Precipitation	☑
Temperature	☑
Wildfires	☑
Soils	☐
Flooding	☐

Legend

- Flooding Likely
- Flooding Occurring or Imminent
- Flooding Possible
- Freezing Rain
- Heavy Precipitation
- Heavy Rain
- Heavy Snow
- Hazardous Heat
- Hazardous Cold
- Frost/Freeze
- High Winds
- Significant Waves
- Critical Wildfire Risk
- Severe Weather

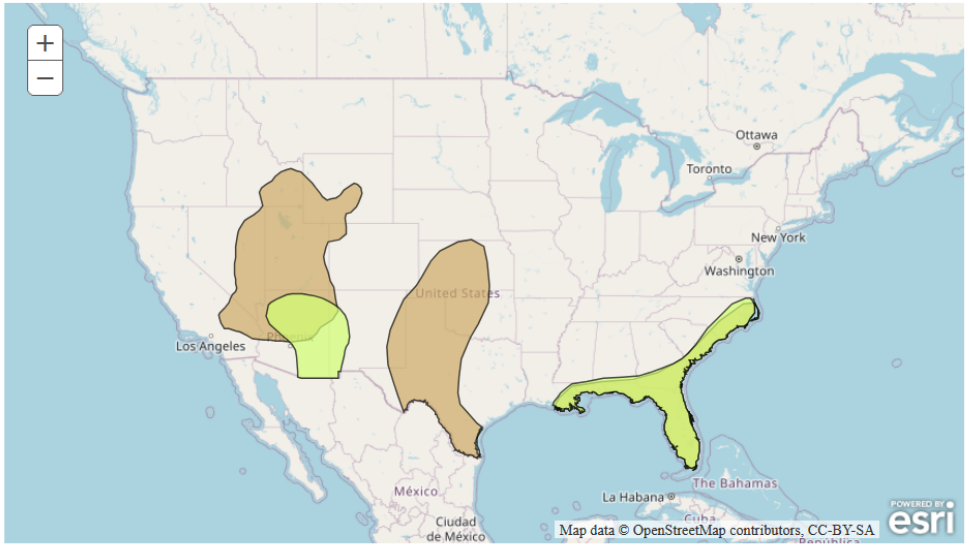
Valid September 04, 2025 - September 08, 2025



https://www.wpc.ncep.noaa.gov/threats/threats.php

U.S. Week-2 Hazards Outlook

Type and Period	Temperature	Precipitation	Snow	Wind	Rapid Onset Drought
Composite Days 8-14 Map	No Hazards	No Hazards	No Hazards	No Hazards	No Hazards
Probabilistic Days 8-14 Map	No Hazards	☑	No Hazards	☑	



Extreme Heat
- High Risk
- Moderate Risk
- Slight Risk

Much Above Normal Temperatures
- High Risk
- Moderate Risk
- Slight Risk

Heavy Precipitation
- High Risk
- Moderate Risk
- Slight Risk

Composite
- Flooding Possible
- Rapid Onset Drought

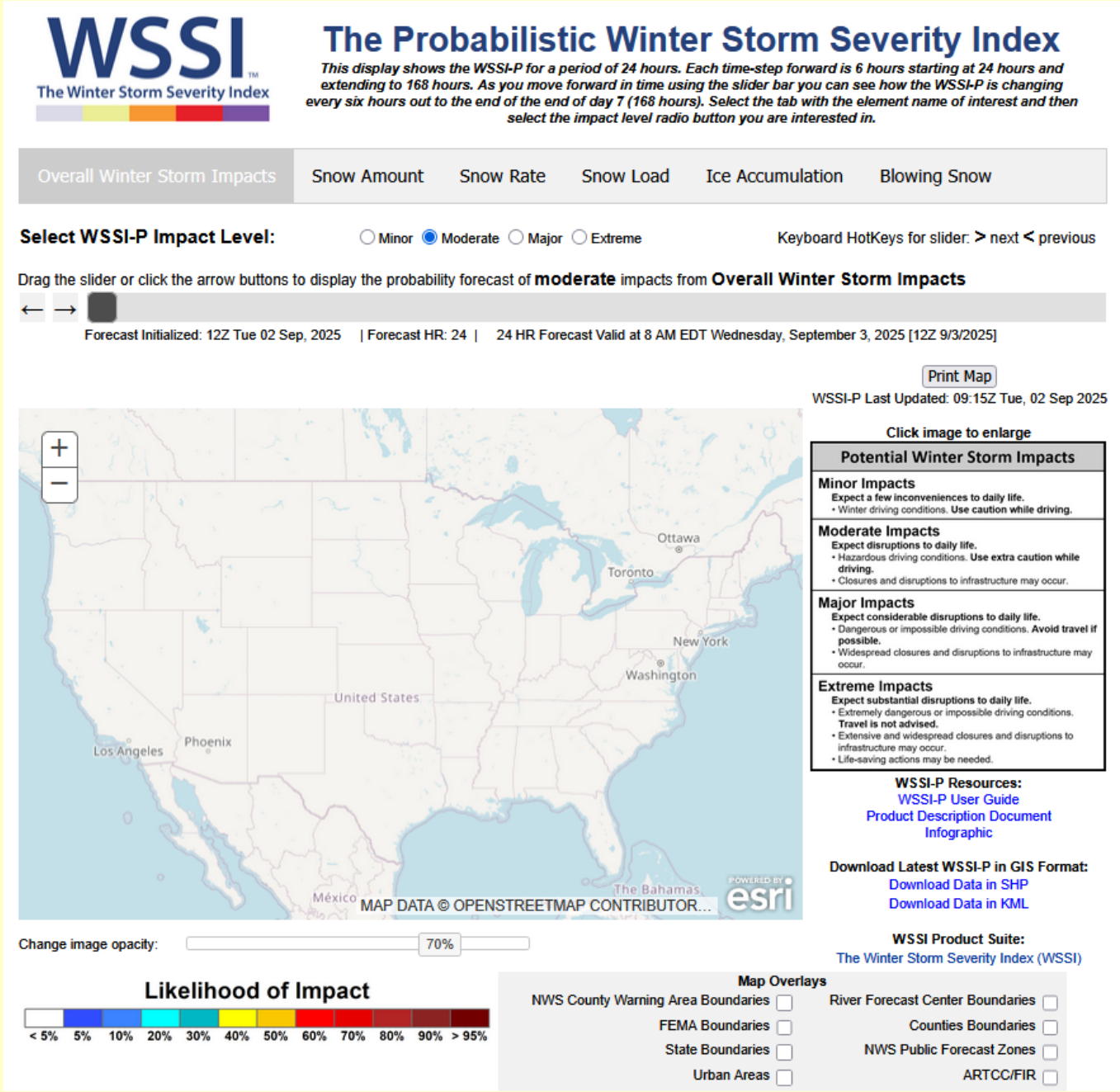
Much Below Normal Temperatures
- High Risk
- Moderate Risk
- Slight Risk

High Winds
- Moderate Risk
- Slight Risk

Heavy Snow
- High Risk
- Moderate Risk
- Slight Risk

https://www.cpc.ncep.noaa.gov/products/predictions/threats/threats.php

National Weather Service Provides Seven-Day Probabilistic Winter Storm Severity Outlooks



https://www.wpc.ncep.noaa.gov/wwd/wssi/prob_wssi.php

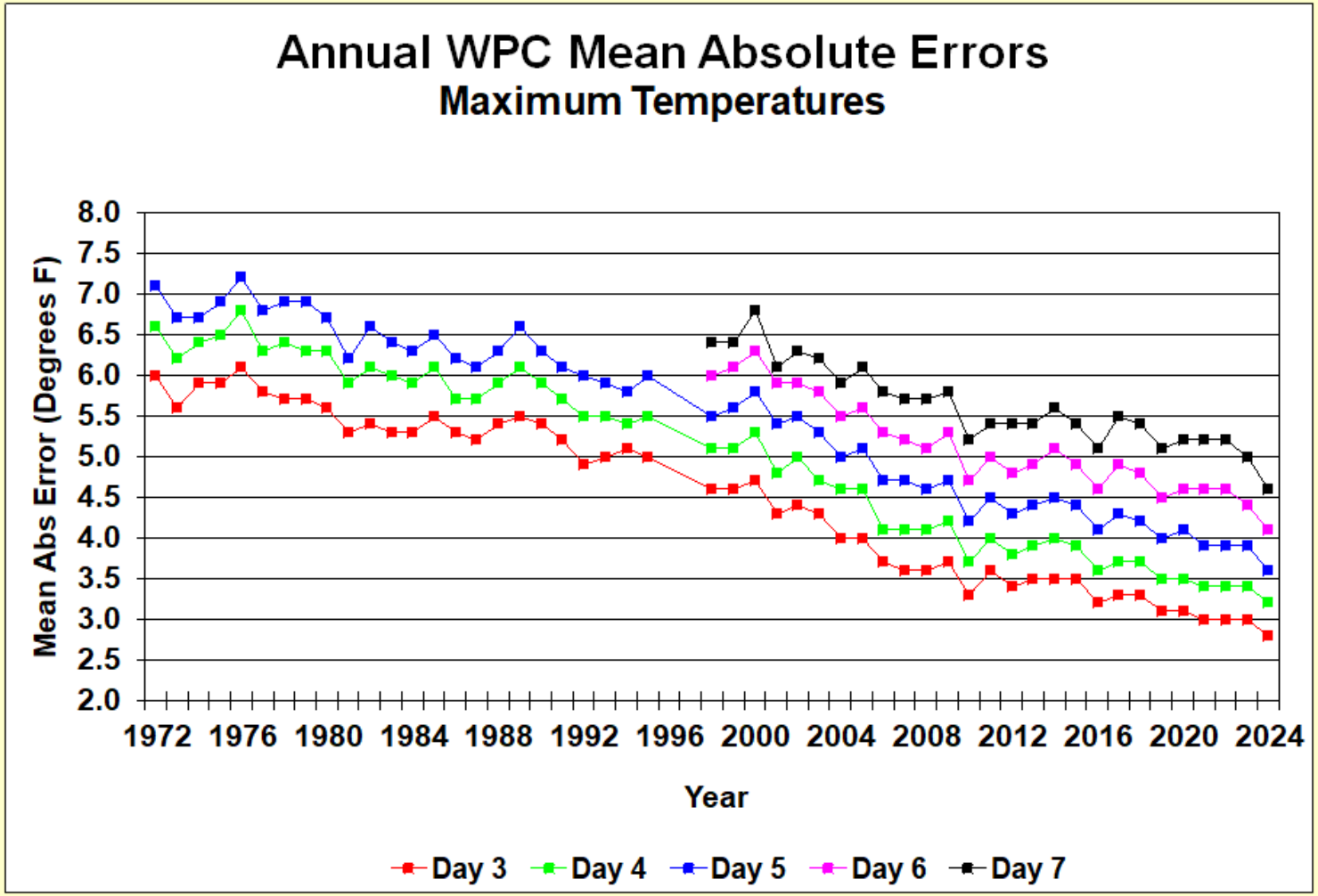
Trends in Forecast Accuracy

Weather forecast accuracy has improved steadily, albeit slowly

- Better observations (better data → better forecasts)
- Improved understanding of atmosphere
- Improvements in computer models
- Faster computers

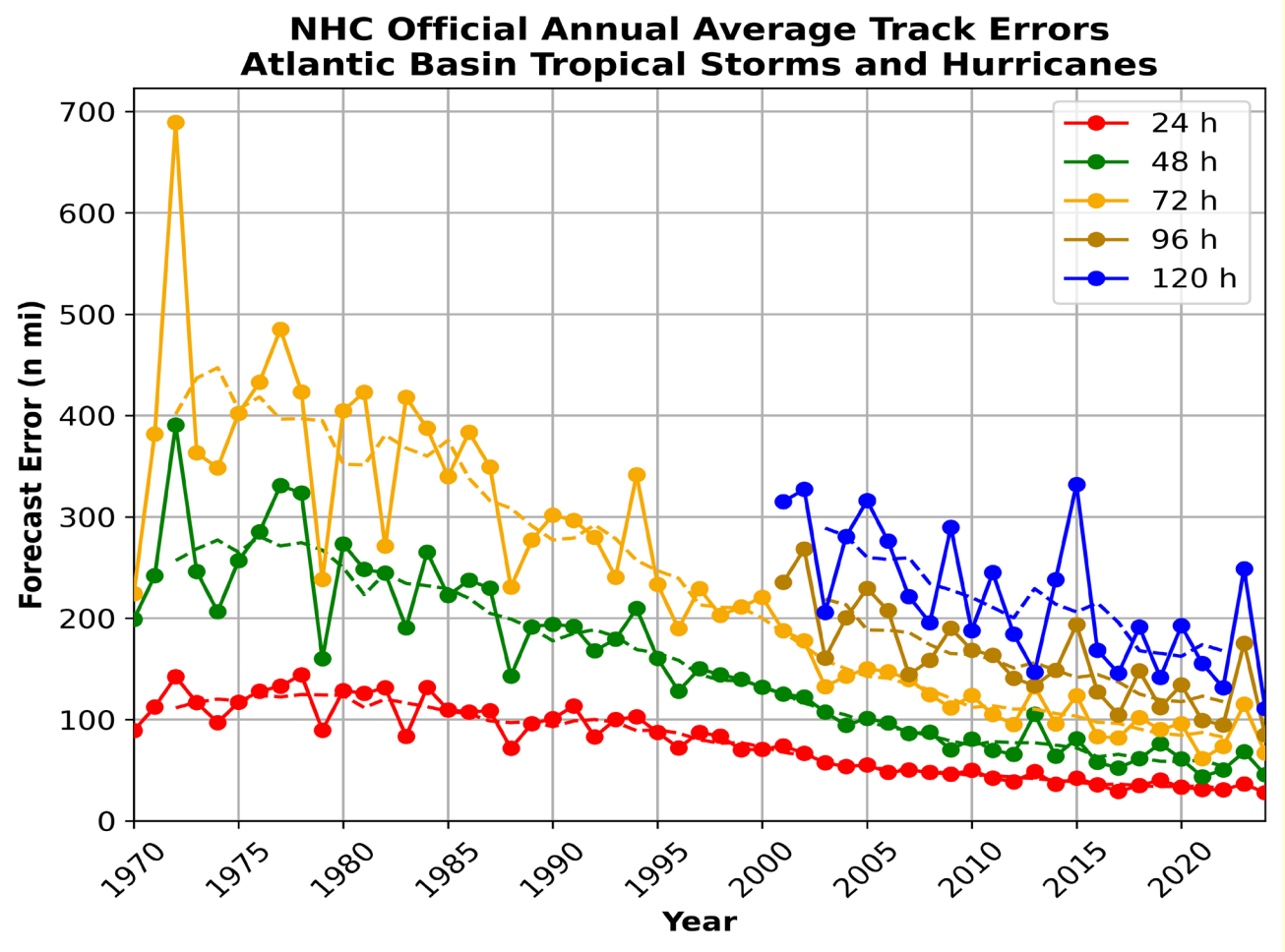
Forecasts are correct a lot more than perceived …
the most difficult forecasts tend to be the ones involving active weather (which people notice)

Weather forecast accuracy has improved steadily, albeit slowly



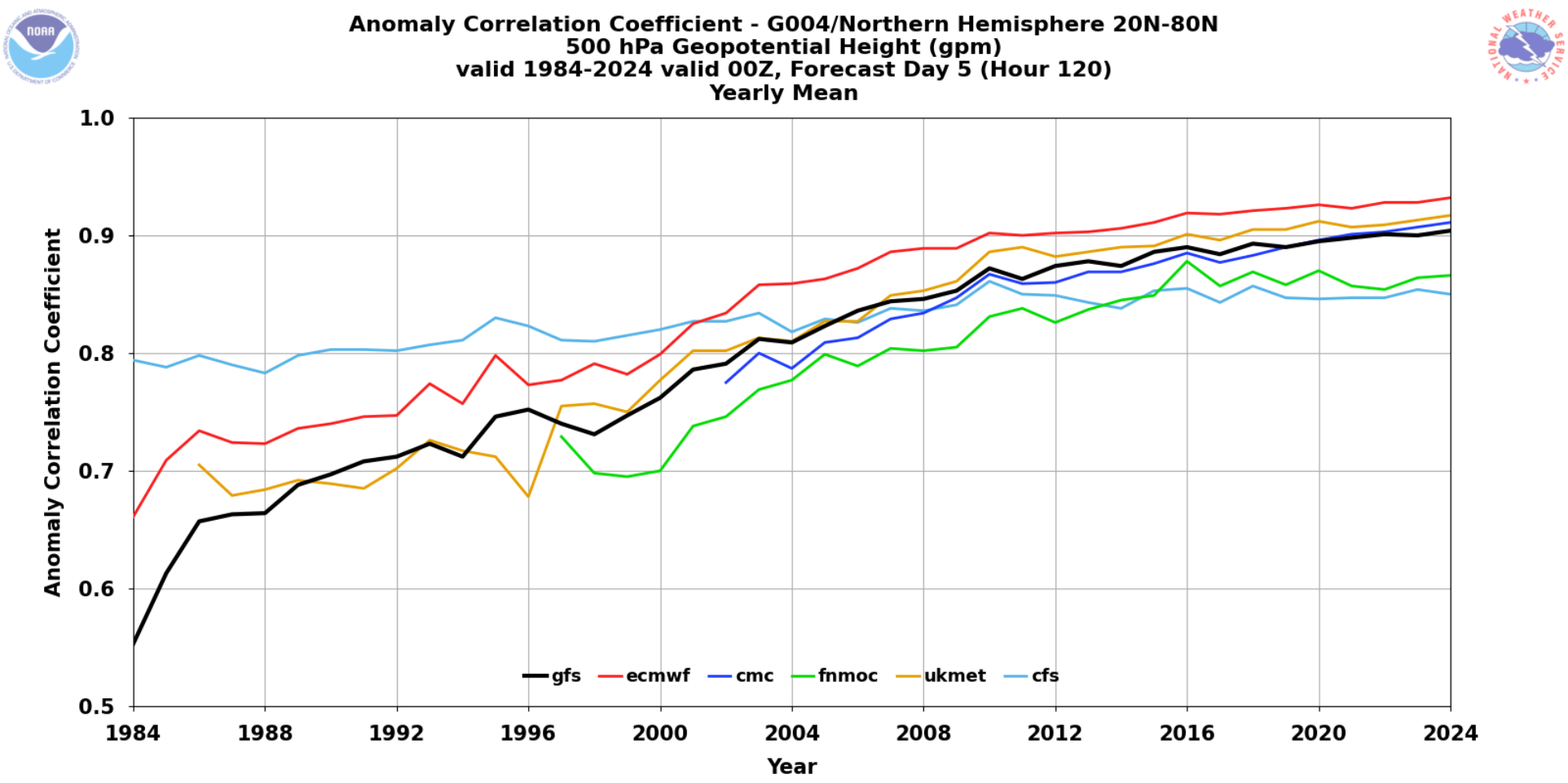
https://www.wpc.ncep.noaa.gov/html/hpcvrftxt.html

Weather forecast accuracy has improved steadily, albeit slowly



https://www.nhc.noaa.gov/verification/

Weather forecast accuracy has improved steadily, albeit slowly



https://www.emc.ncep.noaa.gov/users/verification/para.php

Challenges remain with forecasts of highly disruptive weather

Tornadoes

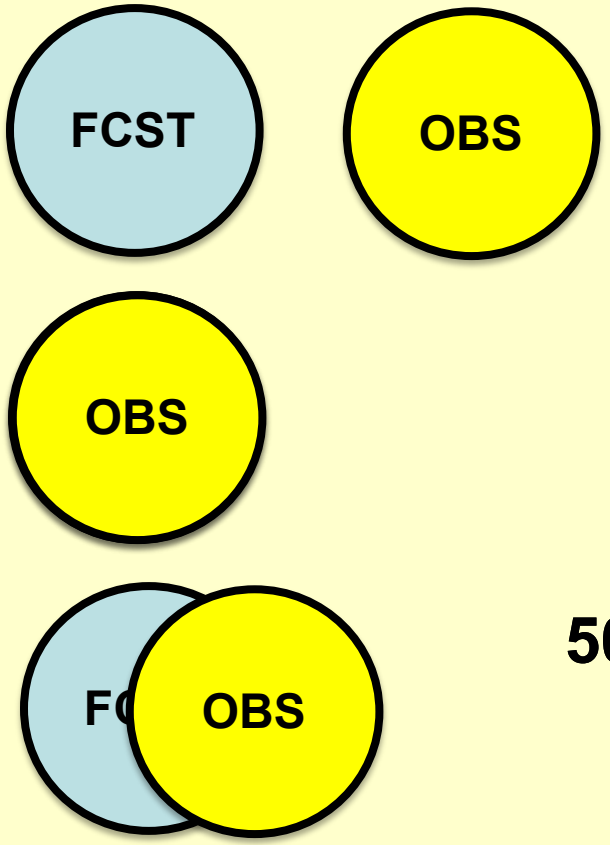
- Tornado warning false alarm rate: ~70%
- Tornadoes without warning **: ~35%
- Average warning lead time: ~13 minutes

** Nearly all unwarned tornadoes are weak and short-lived

May 6, 2025, Bangor (Northampton CT)
credit: Caroline Kline

Challenges remain with forecasts of highly disruptive weather

2” of rain in a day

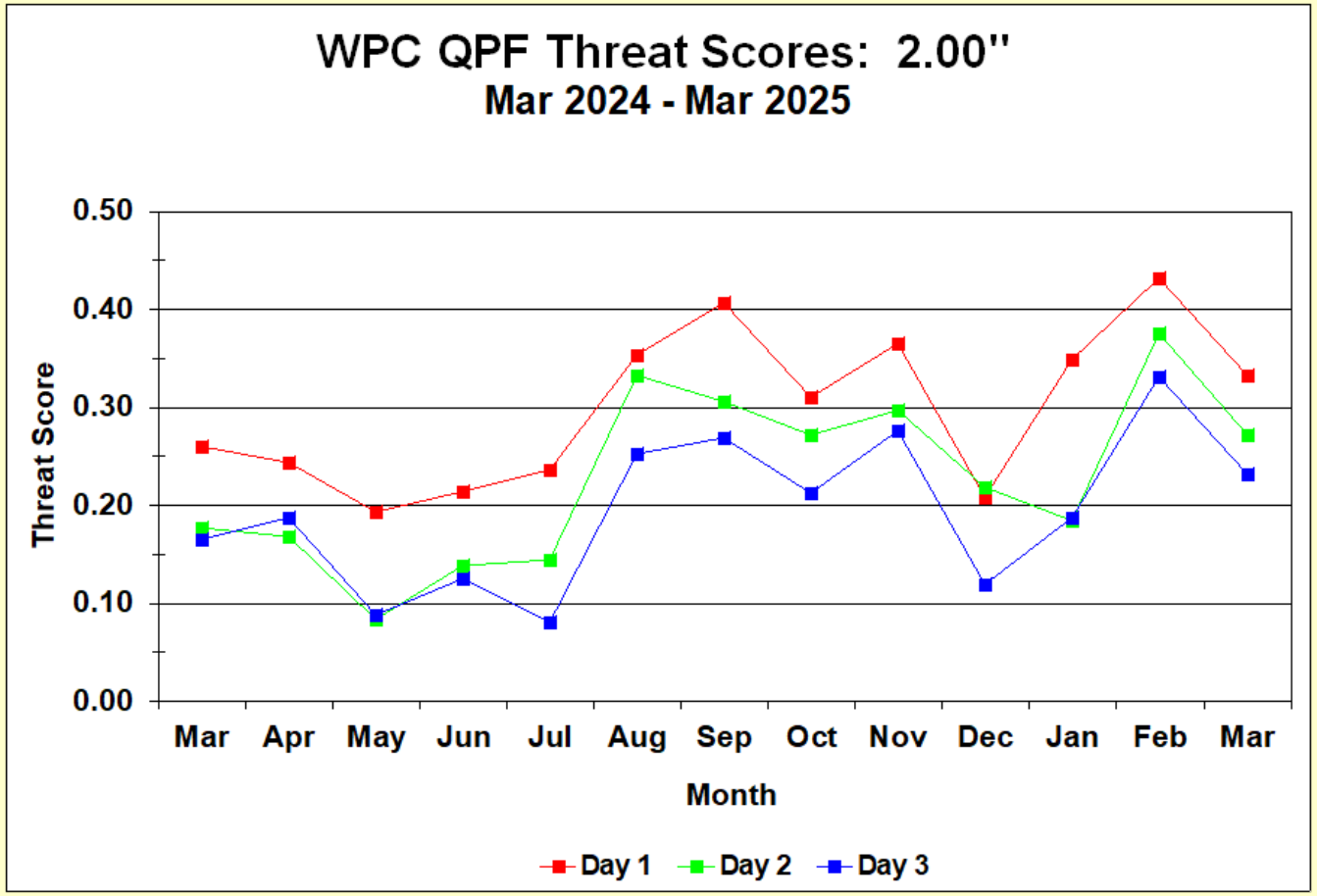


0

1

50% overlap

0.33

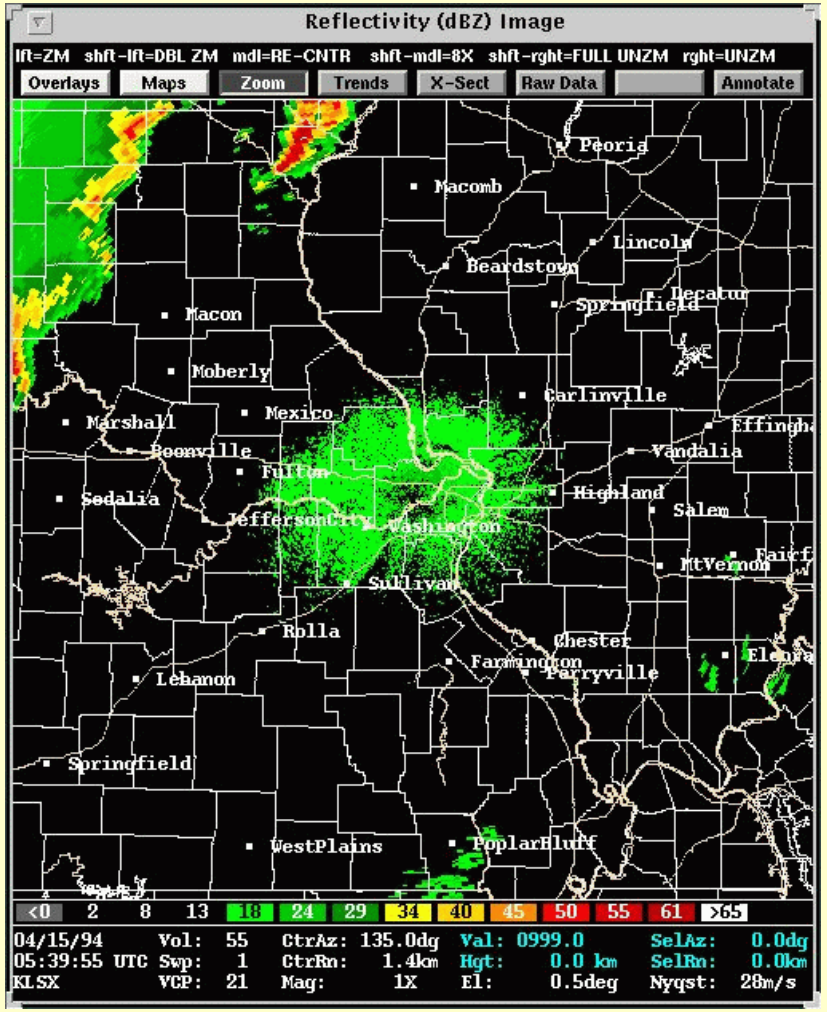


https://www.nhc.noaa.gov/verification/

The Kingpin of Electrical Distribution Disruptors

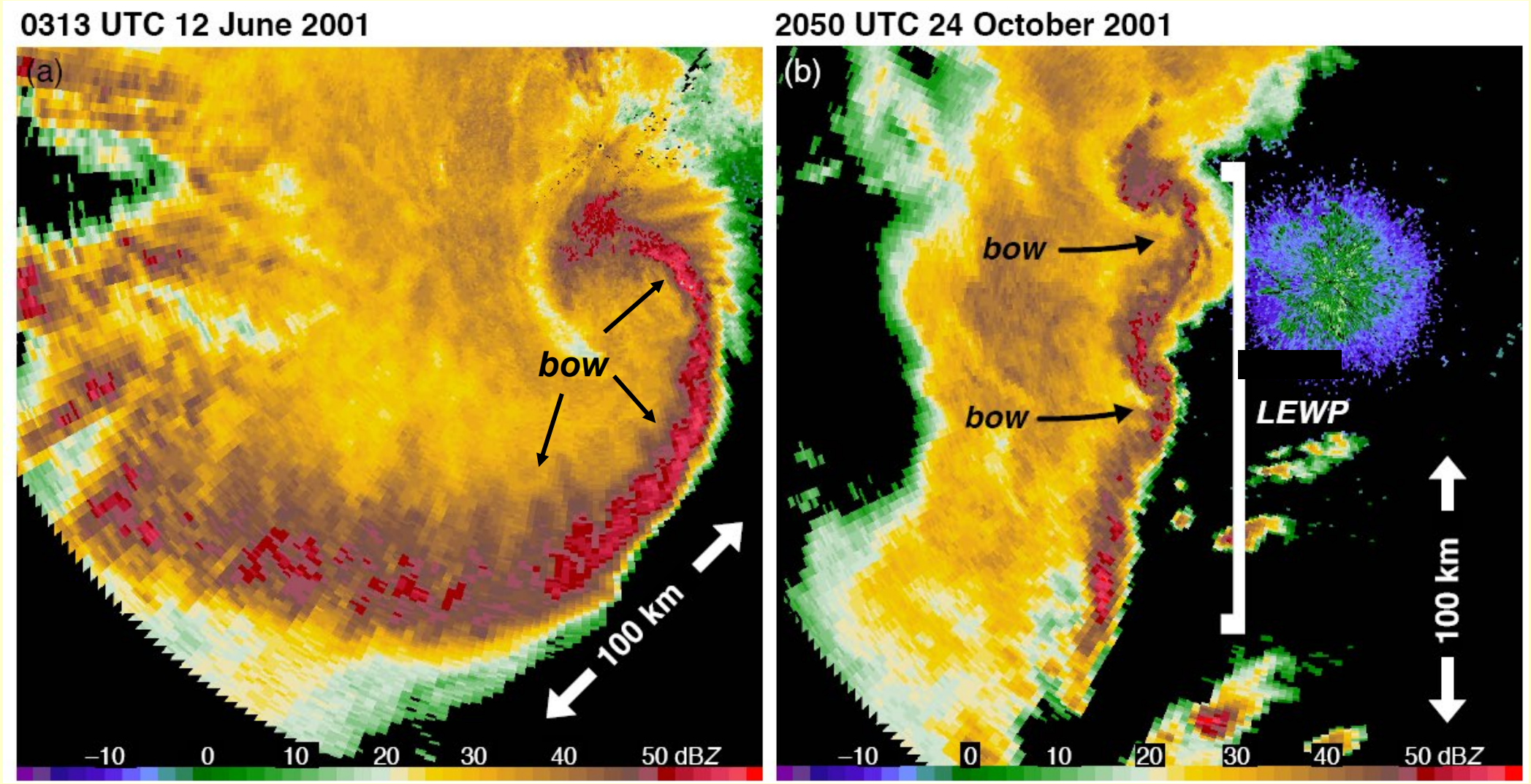
The most significant thunderstorm-related disrupters are large clusters called mesoscale convective systems (MCS) that last several hours.

Squall lines (shown below) are the most common type of MCS.



Some squall lines develop “bows”: Bow echoes

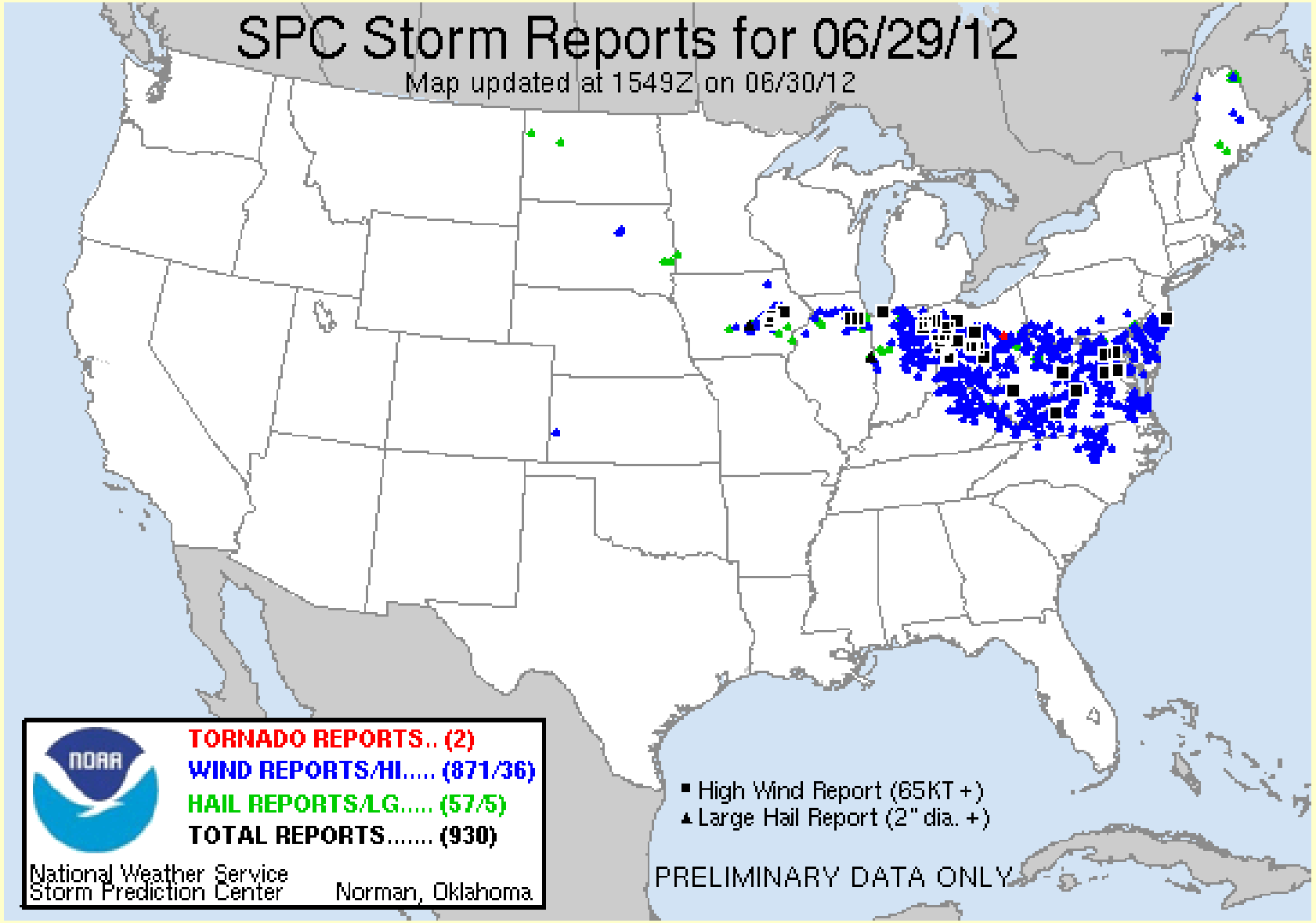
The bowing segments indicate strong outflowing winds



Derecho

Generic term for a thunderstorm-generated windstorm that produces widespread damage

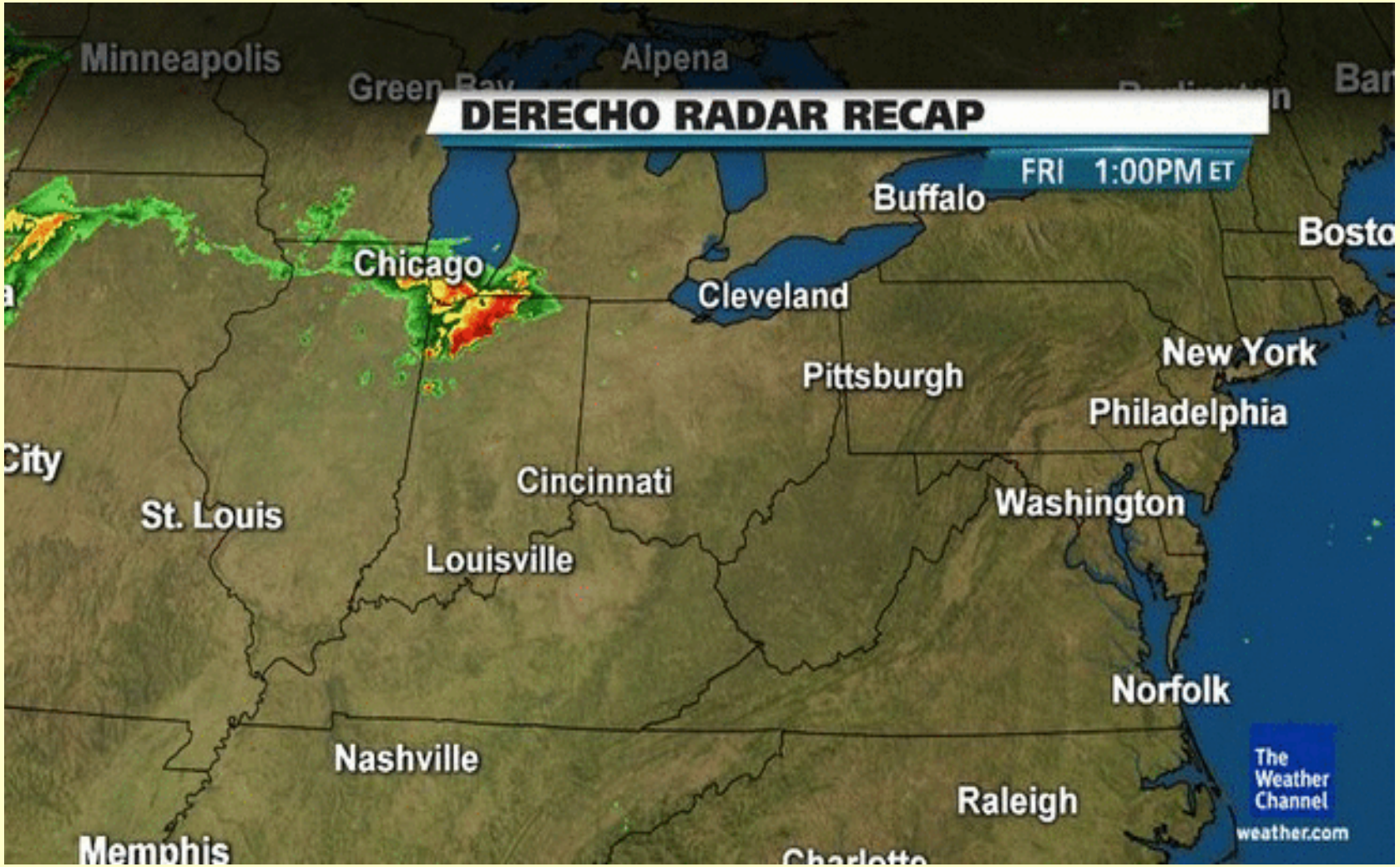
Most of these are due to bow echoes



https://www.spc.noaa.gov/climo/online/

weak wind shear

June 29, 2012 Derecho

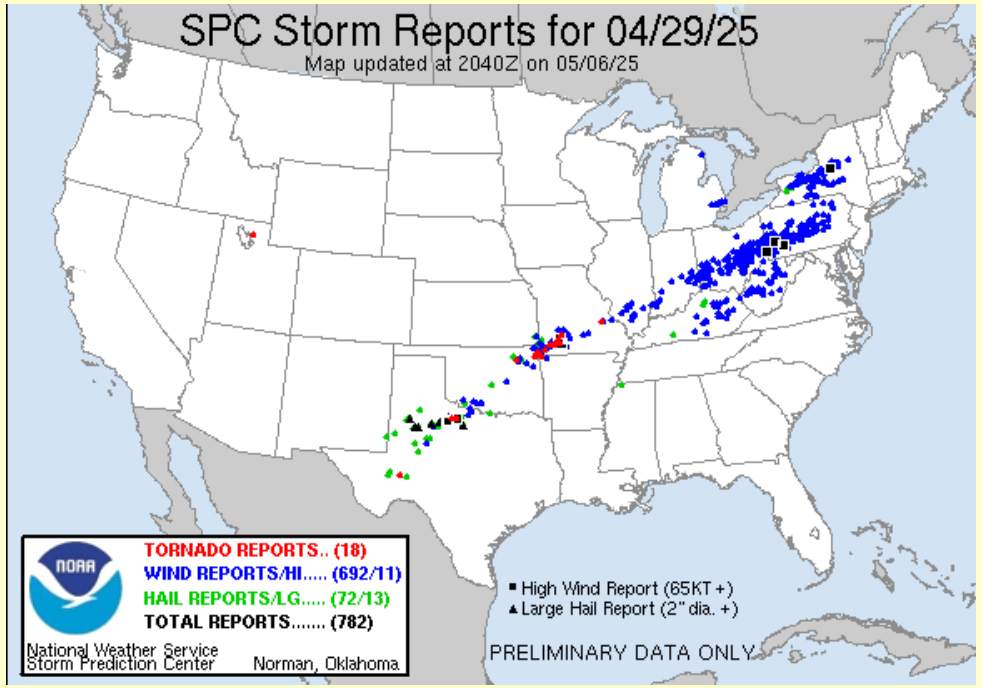


The Weather Channel

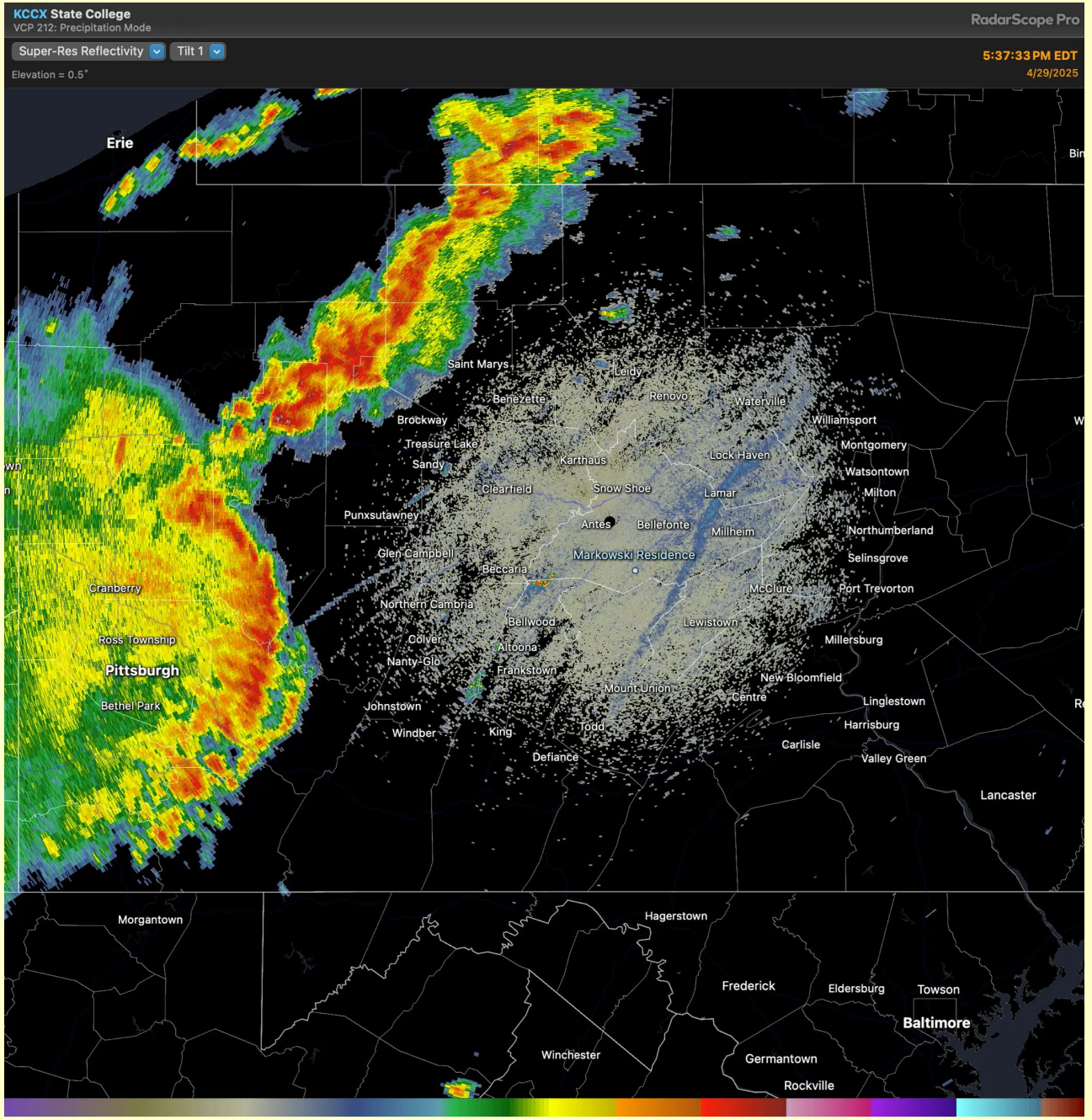
- ~600 mile long track in span of ~12 hr
- 4.2M customers lost power, 1M in OH, 1M in VA, 1.6M in MD

Wikipedia

April 29, 2025 … almost a derecho



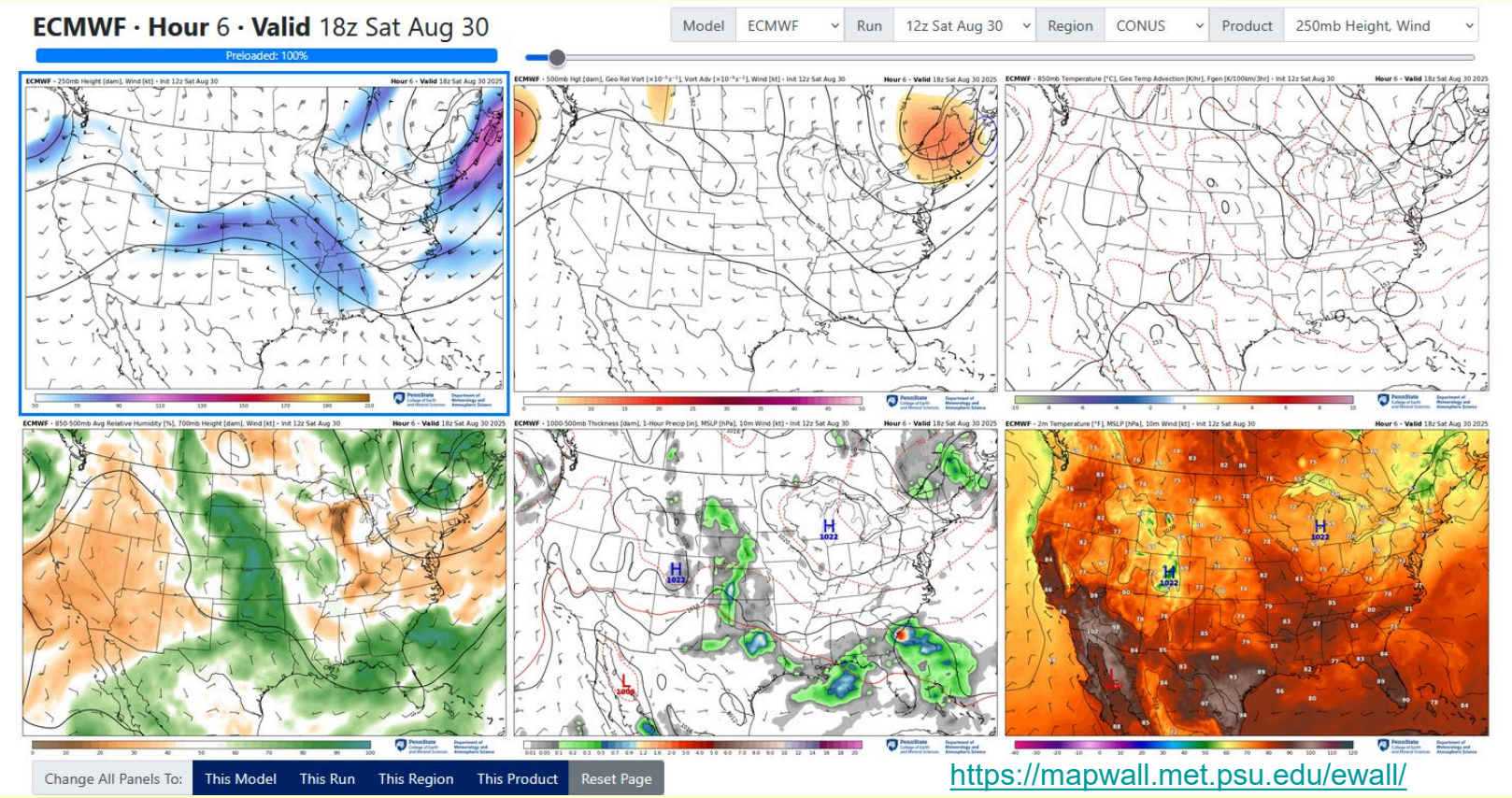
https://www.spc.noaa.gov/climo/online/



At peak, >557K customers w/out power

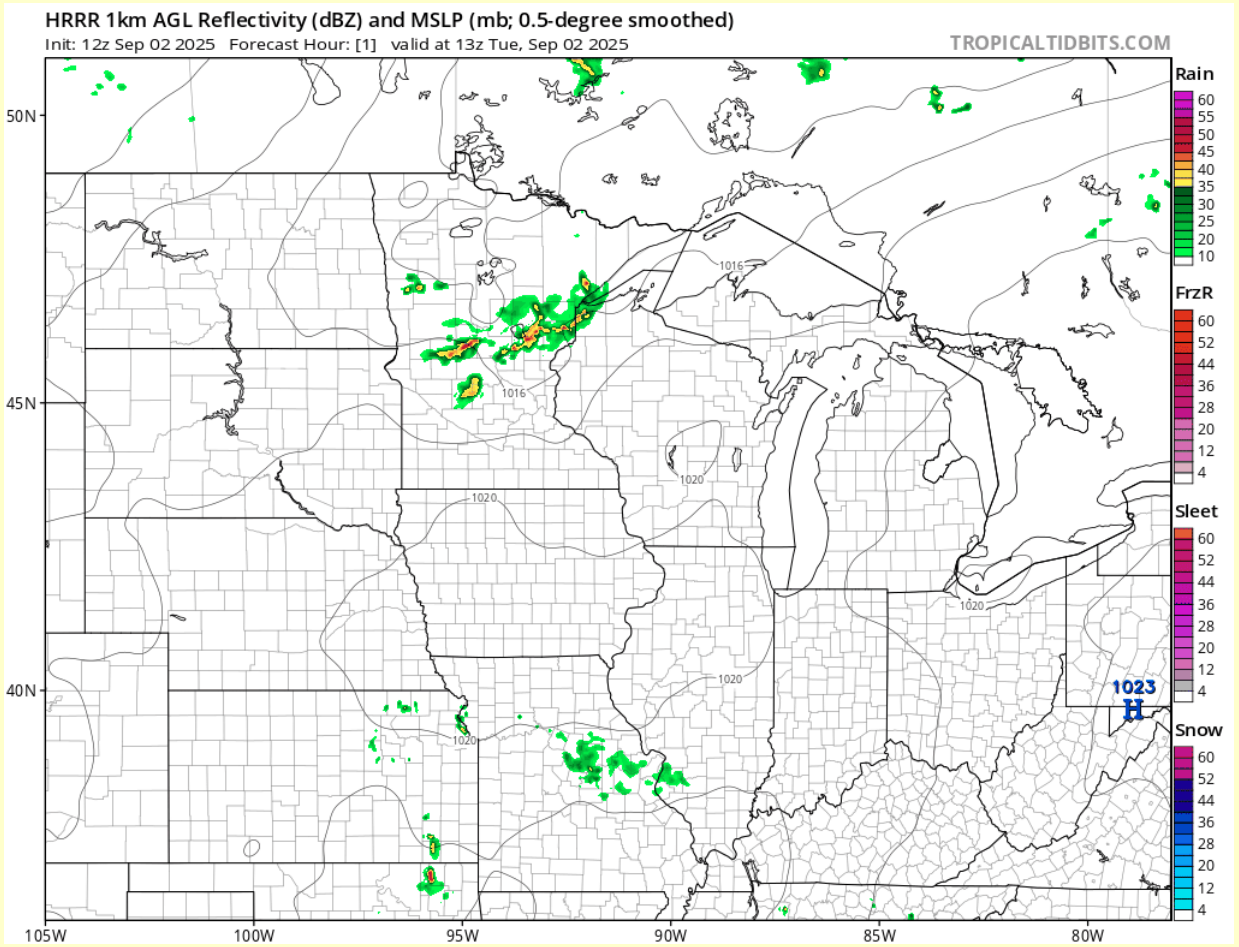
Modern Forecasting Tools

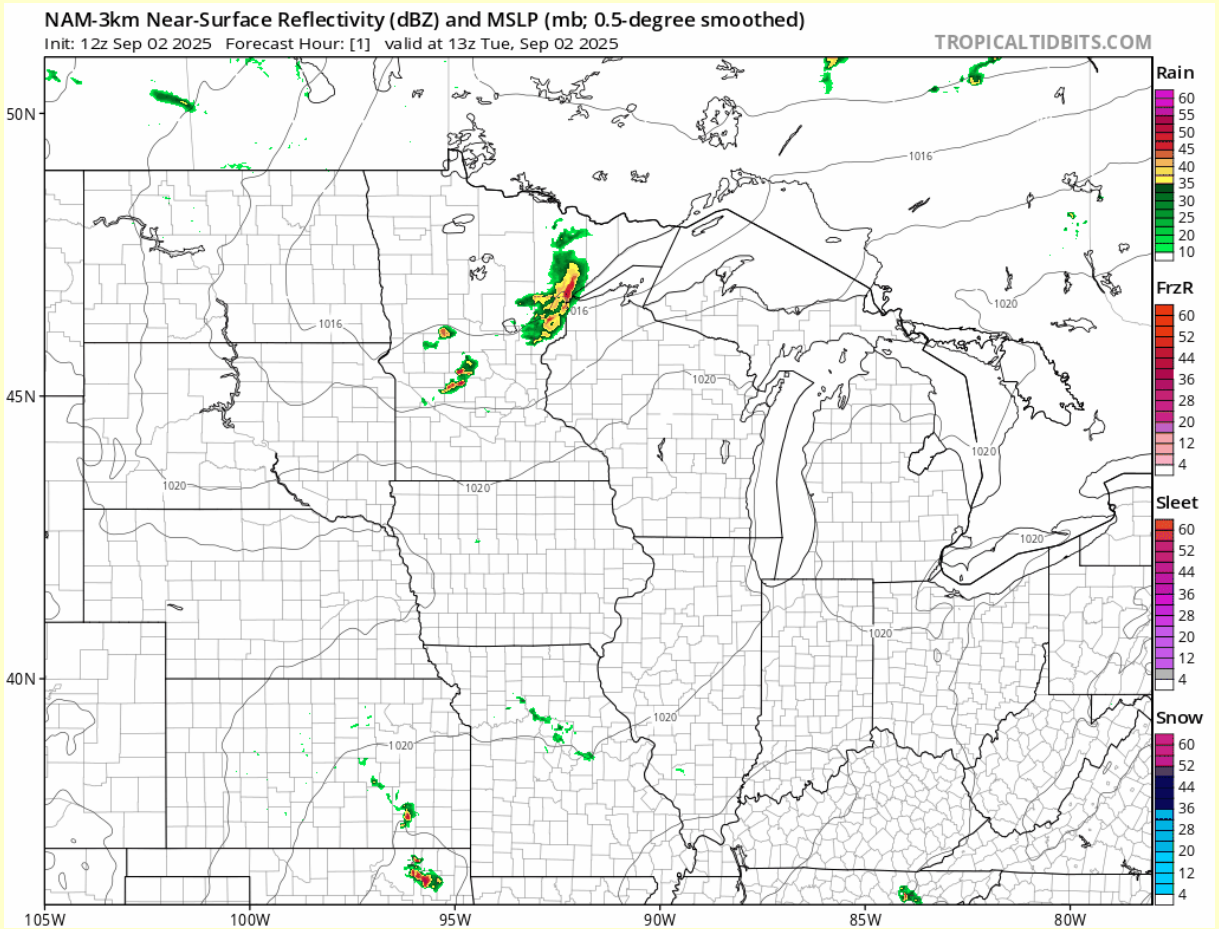
Computer models solve (on supercomputers) the equations that govern how important weather variables (such as pressure, wind, humidity) evolve.



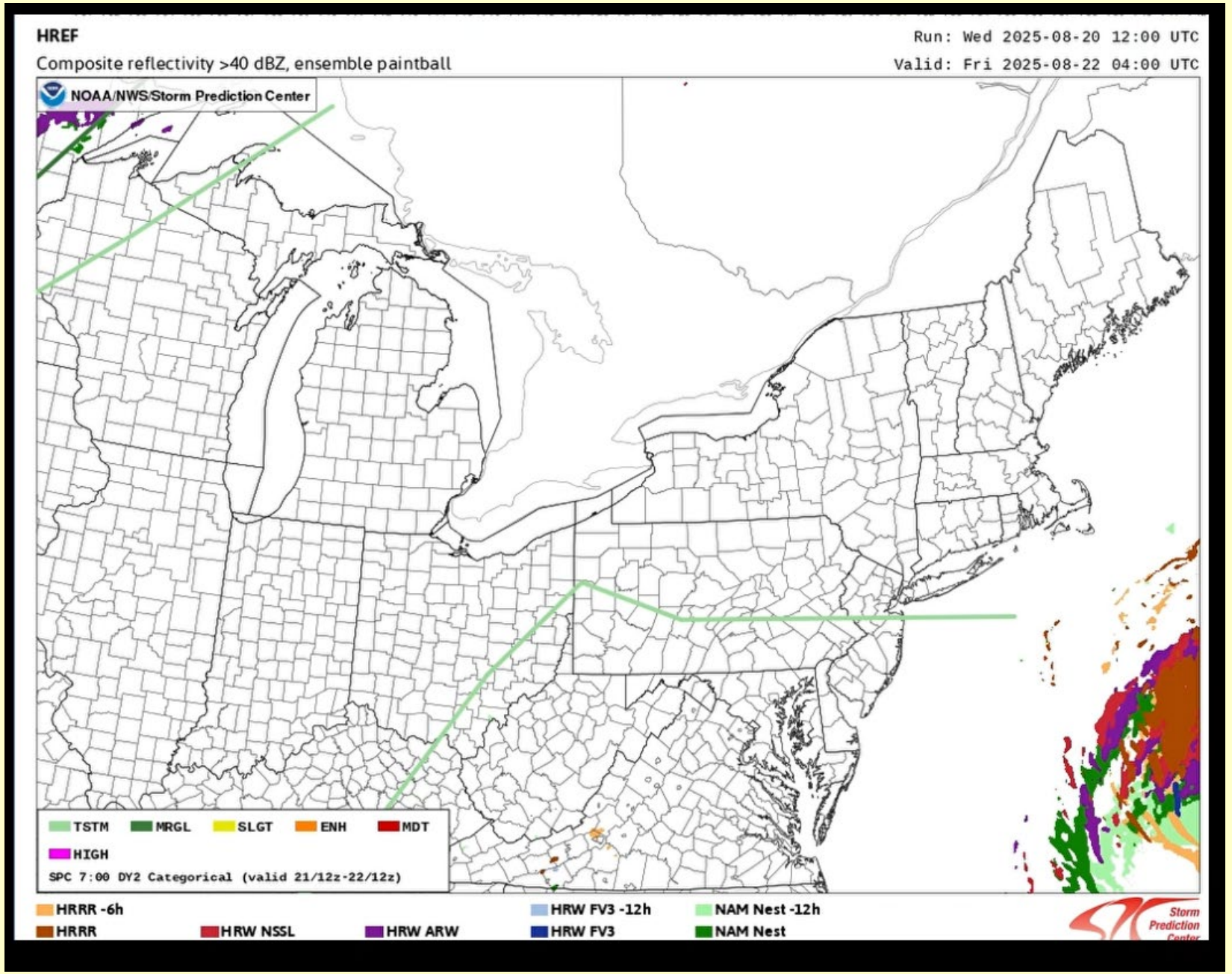
They provide guidance, not gospel, but they are essential in modern forecasting.

- Some modern weather computer models are “convection-allowing”, meaning they are capable of simulating (approximately) squall lines and even, in some cases, individual thunderstorms



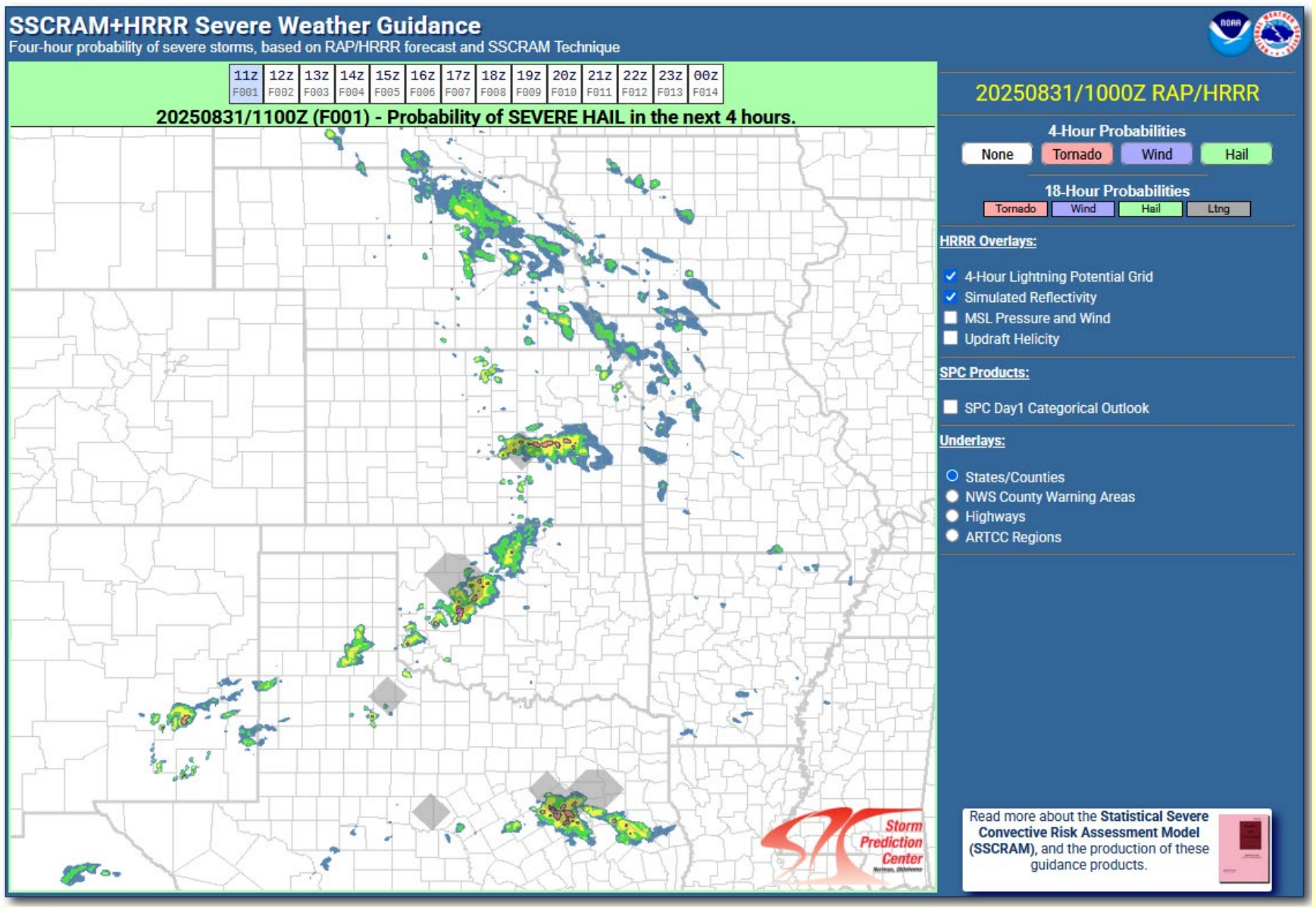


https://www.tropicaltidbits.com/



- Such models are even run multiple times with slightly different starting values
- This creates an **ensemble** of solutions
- Gives a sense for the variety of possible forecasts and their associated probability.

https://cams.nssl.noaa.gov/?model=mpasht_nssl&product=cref_uh075&sector=spc_conus&postage_stamp=false



NWS working on experimental hybrid techniques involving statistics and modeling to provide very short-term (next few hours) forecasts of severe hail and winds.

https://www.spc.noaa.gov/exper/hrrr/sscram/

AI and Weather Forecasting

- AI (Artificial Intelligence) models are “trained” on datasets derived from past events – because they are statistical in nature, they don’t need supercomputers.
- If a dataset does not contain examples of an event, then an AI model cannot predict that event.
- Weather AI models have been able to, in many cases, match (or even slightly exceed) the accuracy of “regular” models.
- Real test comes when the weather is extreme or disruptive (rare events), and I have yet to see any evidence that an AI model routinely outperforms a “regular” model in such situations.
- AI models will not replace “regular” model, they will become another tool.

Final Thoughts

- No evidence of a consistent trend in severe weather frequency (that would disrupt electrical distribution) in recent years/decades in Pennsylvania … lots of year-to-year variability

- Forecast accuracy improvements have been steady but generally slow … plethora of forecast products available on time scales of hours to 7+ days.

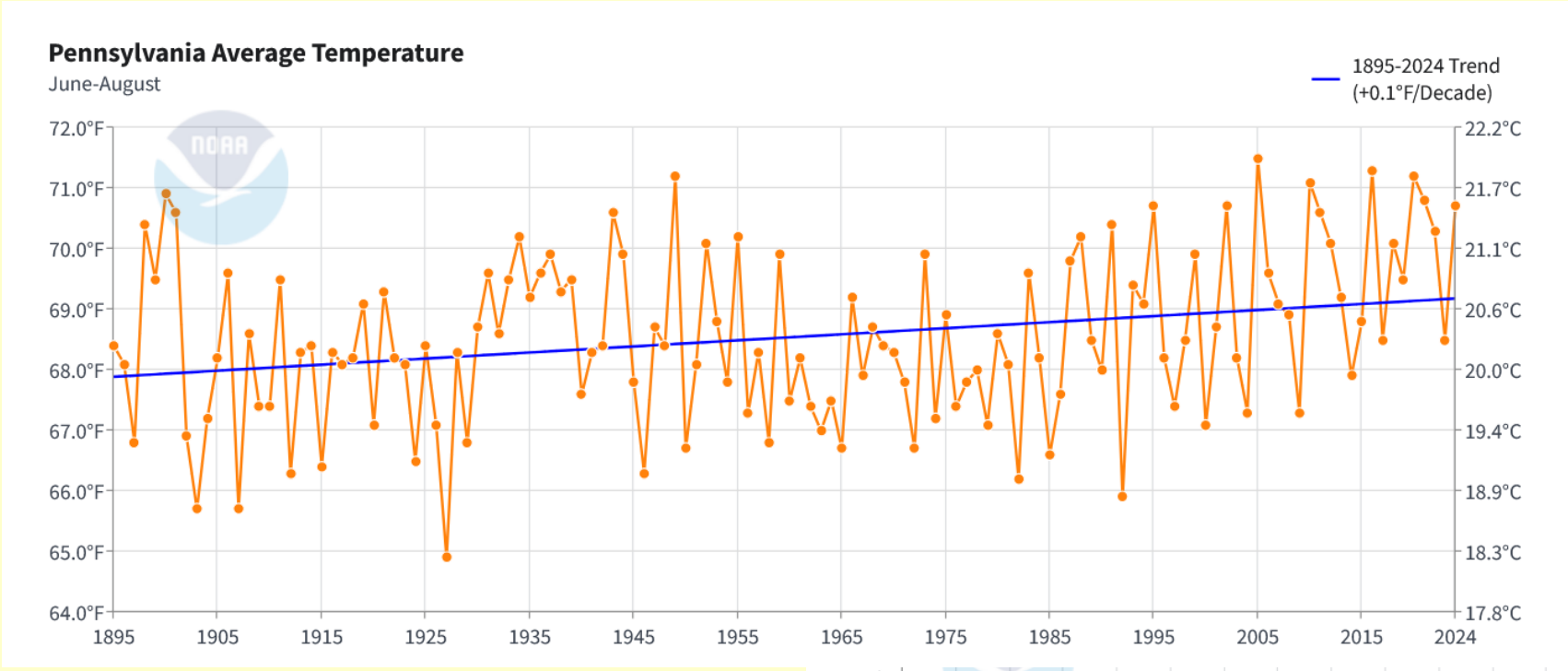
- Modern computer models are capable of simulating thunderstorm-scale phenomena, and will only get better with time.

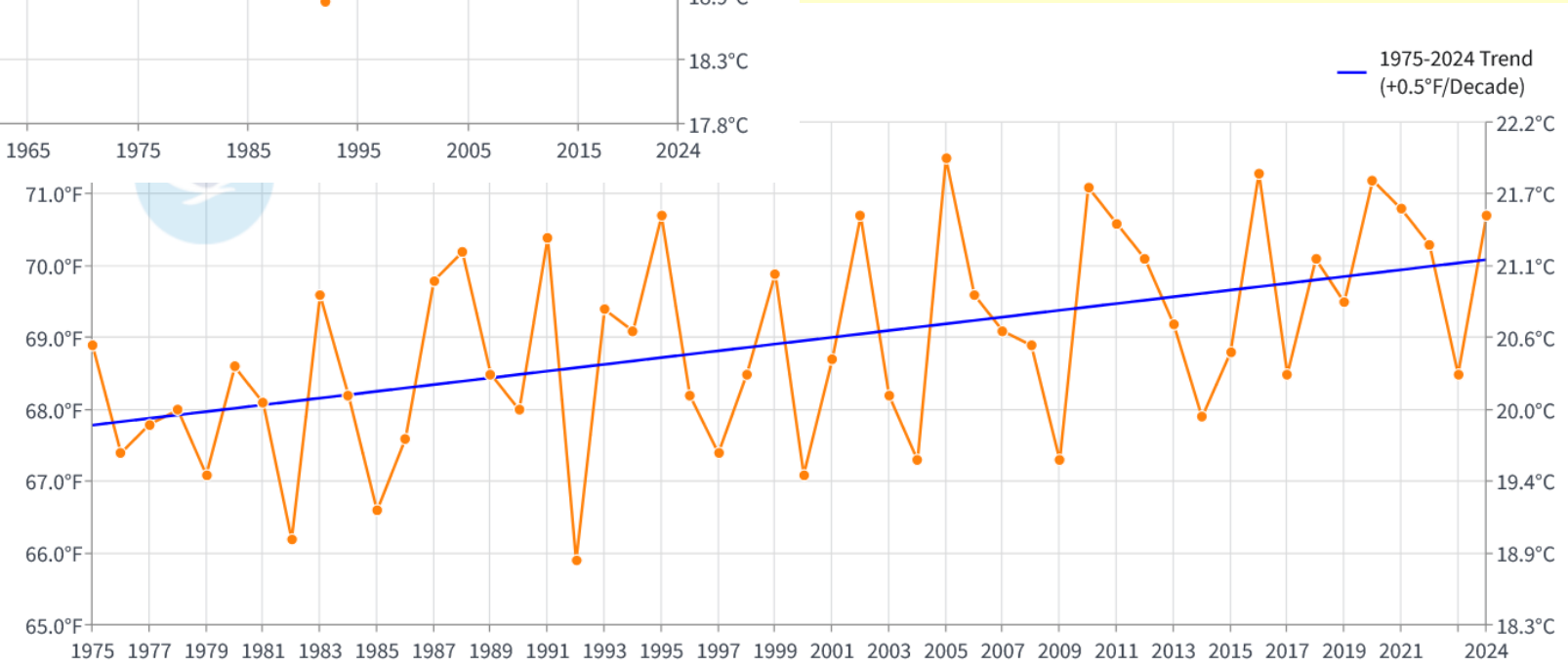
Challenges in Forecasting Disruptive Weather

Jon Nese
Penn State Meteorology and Atmospheric Science

Pennsylvania PUC Annual Safety Seminar
State College, PA
September 3, 2025

Summer Temperature Trends



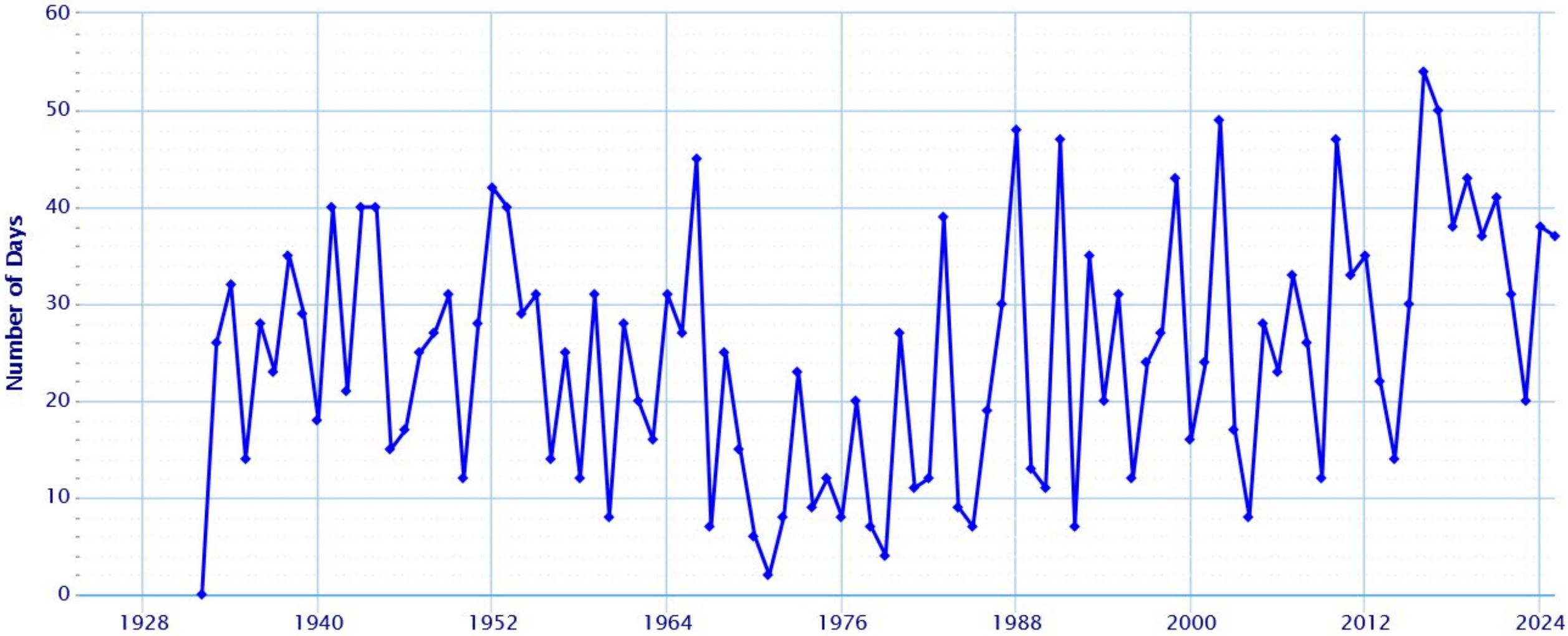


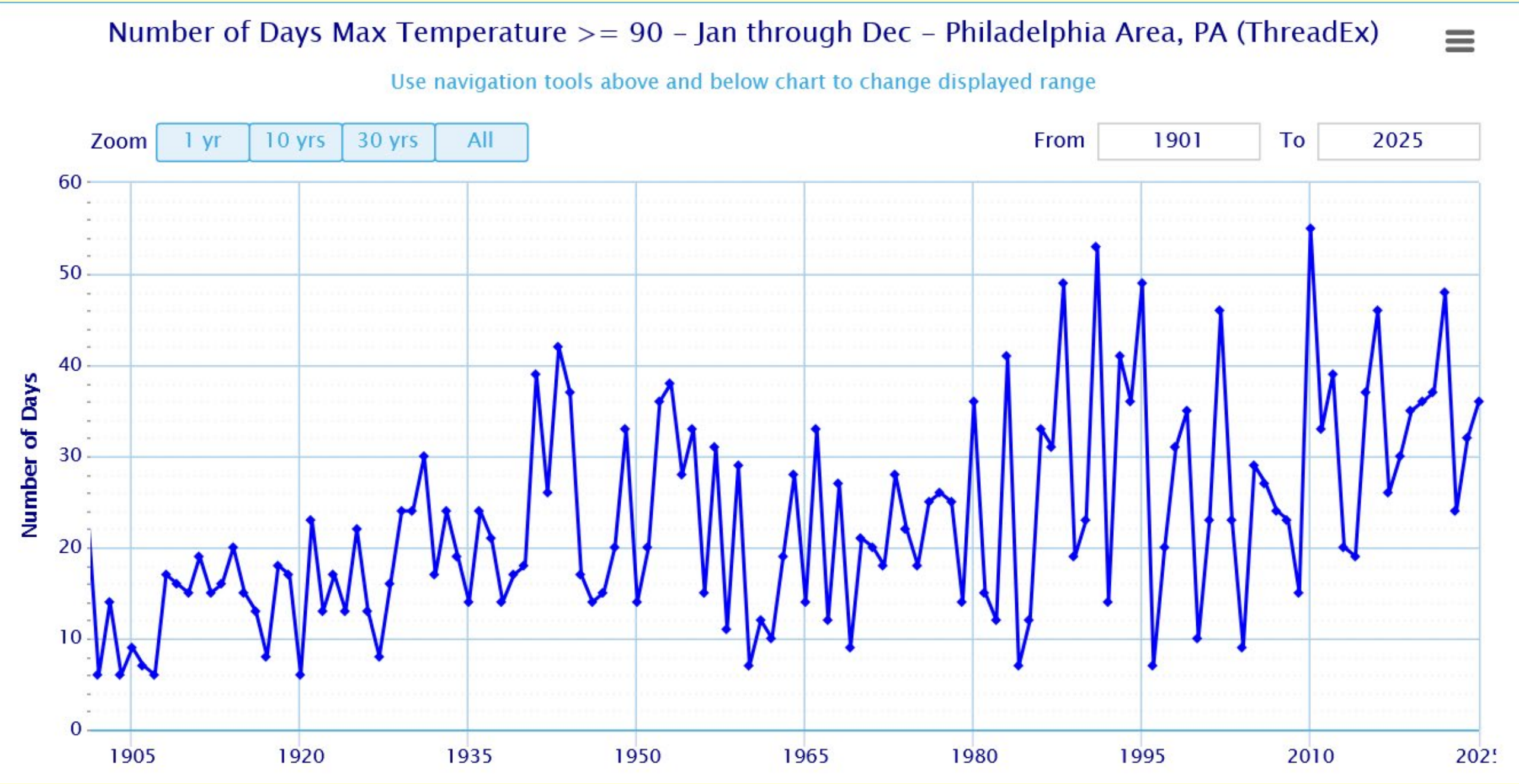
Number of Days Max Temperature >= 90 – Jan through Dec – SHIPPENSBURG, PA

Use navigation tools above and below chart to change displayed range

Zoom | 1 yr | 10 yrs | 30 yrs | All

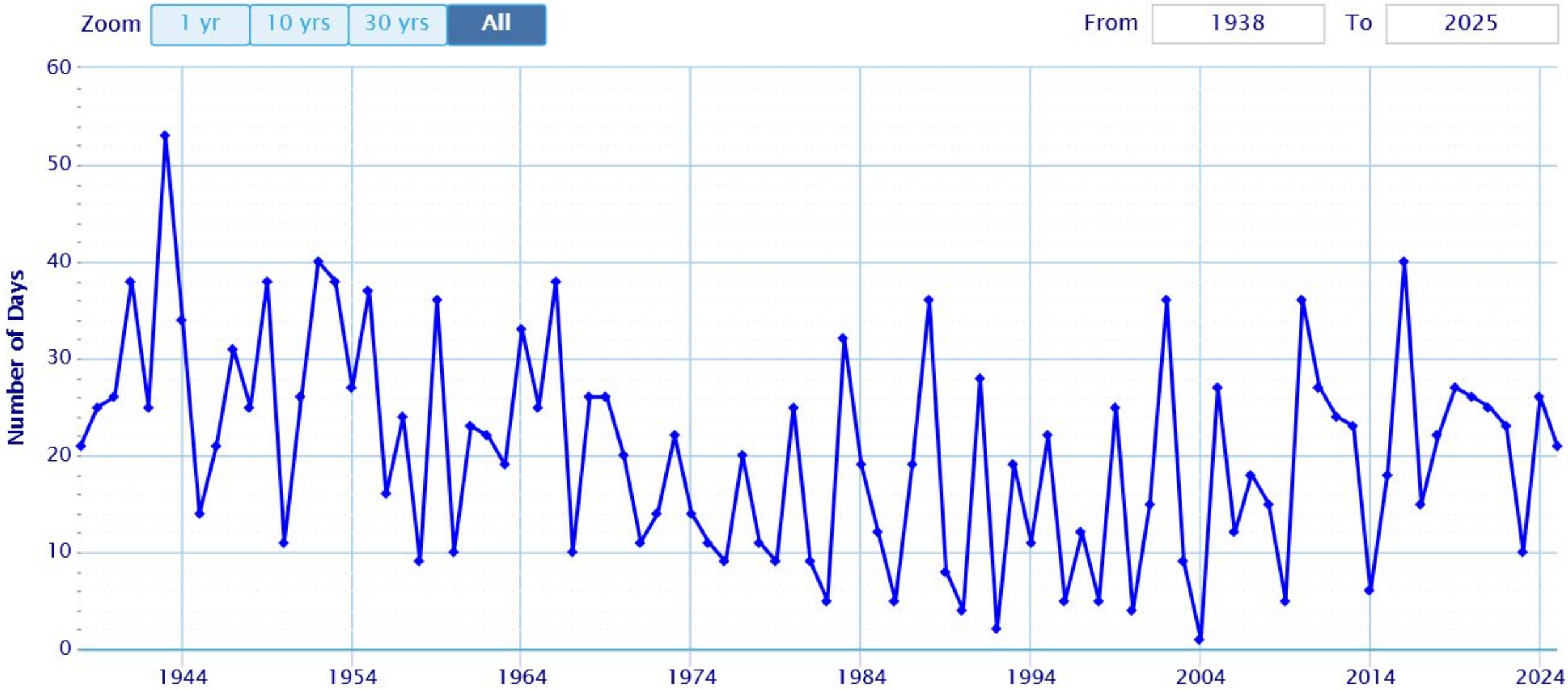
From 1923 To 2025

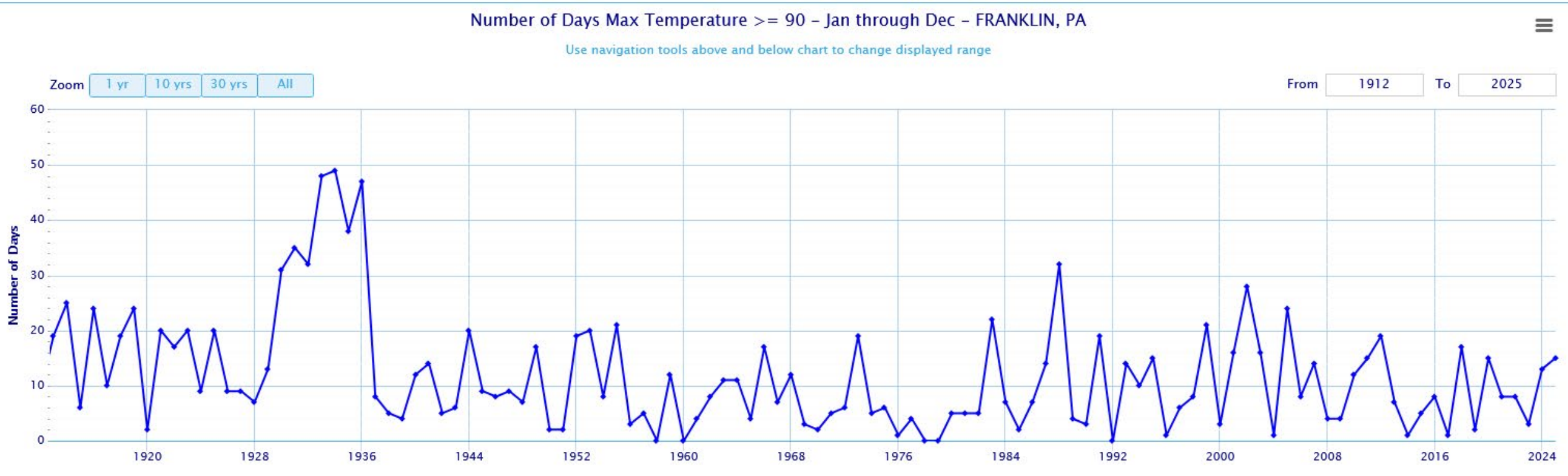


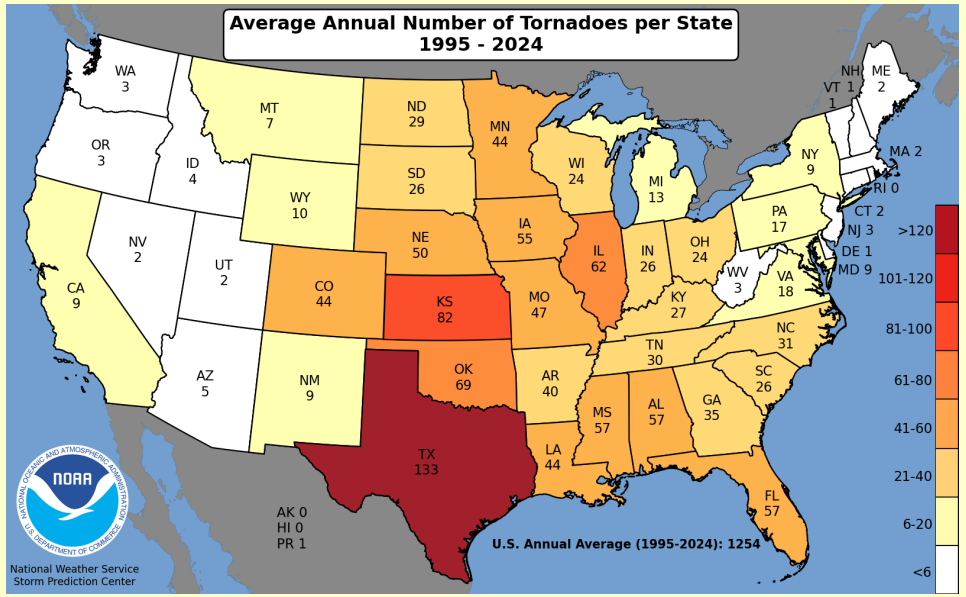

Number of Days Max Temperature >= 90 – Jan through Dec – Philadelphia Area, PA (ThreadEx)
Use navigation tools above and below chart to change displayed range
Zoom
1 yr
10 yrs
30 yrs
All
From
1901
To
2025
Number of Days
60
50
40
30
20
10
0
1905
1920
1935
1950
1965
1980
1995
2010
202

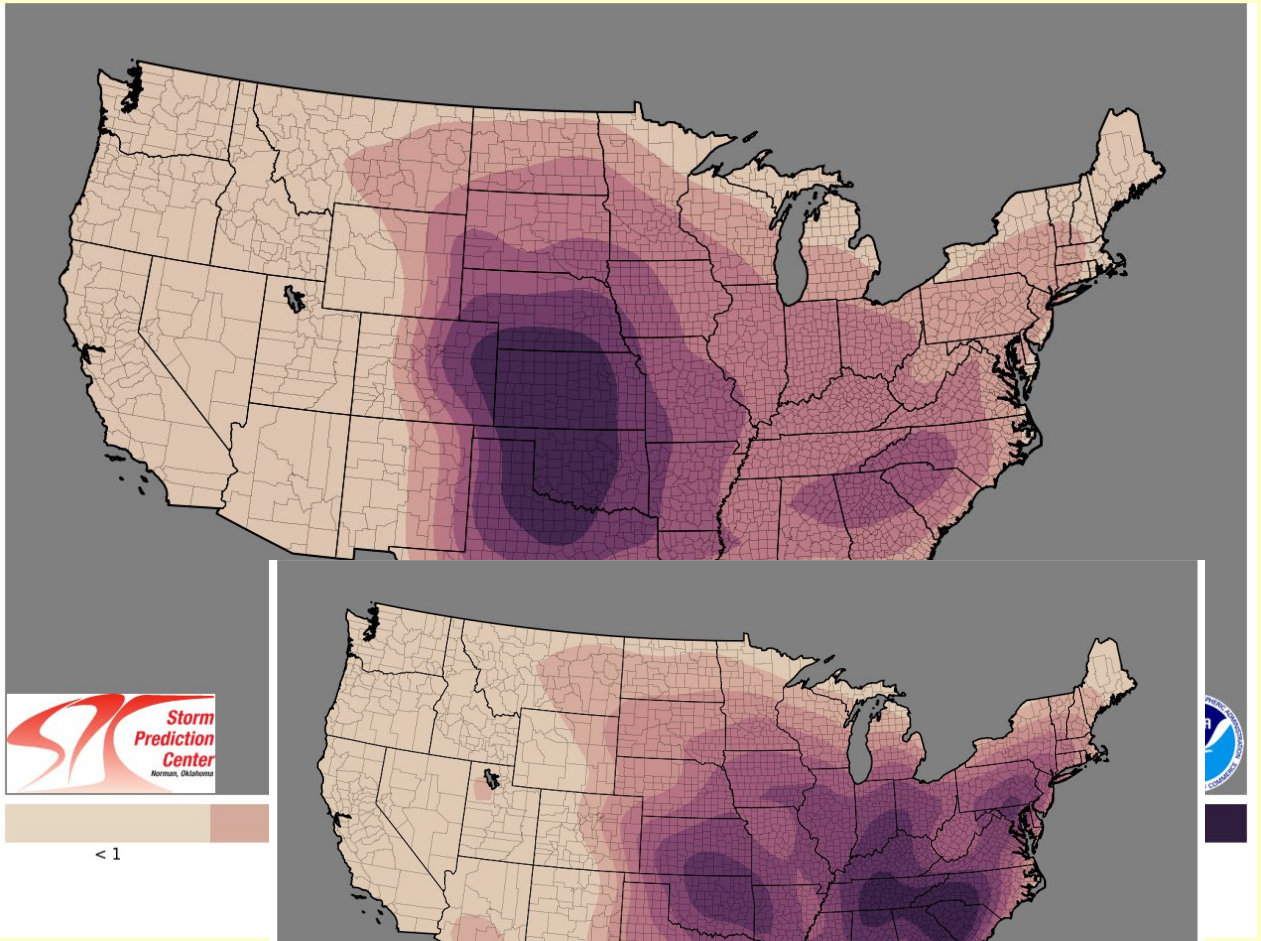
Number of Days Max Temperature >= 90 – Jan through Dec – LEWISTOWN, PA

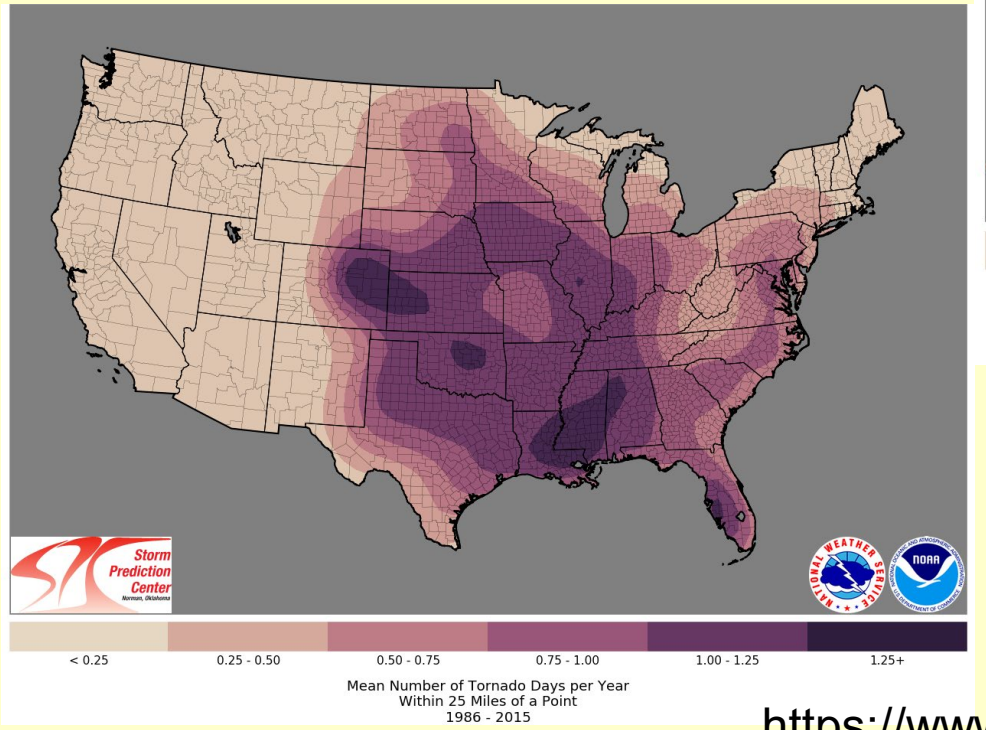
Use navigation tools above and below chart to change displayed range



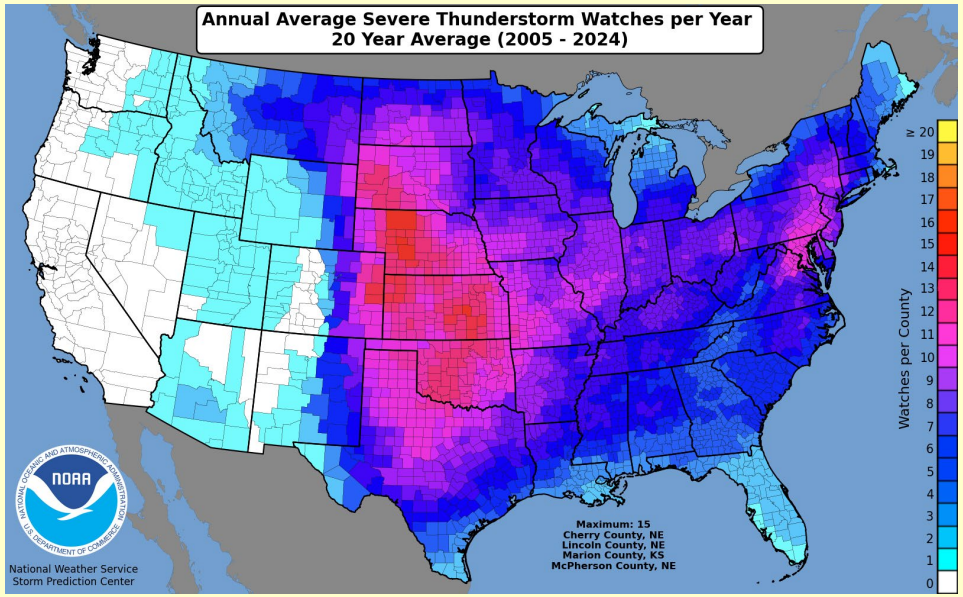

Number of Days Max Temperature >= 90 – Jan through Dec – FRANKLIN, PA
Use navigation tools above and below chart to change displayed range
Zoom
1 yr
10 yrs
30 yrs
All
From
1912
To
2025
Number of Days
60
50
40
30
20
10
0
1920
1928
1936
1944
1952
1960
1968
1976
1984
1992
2000
2008
2016
2024

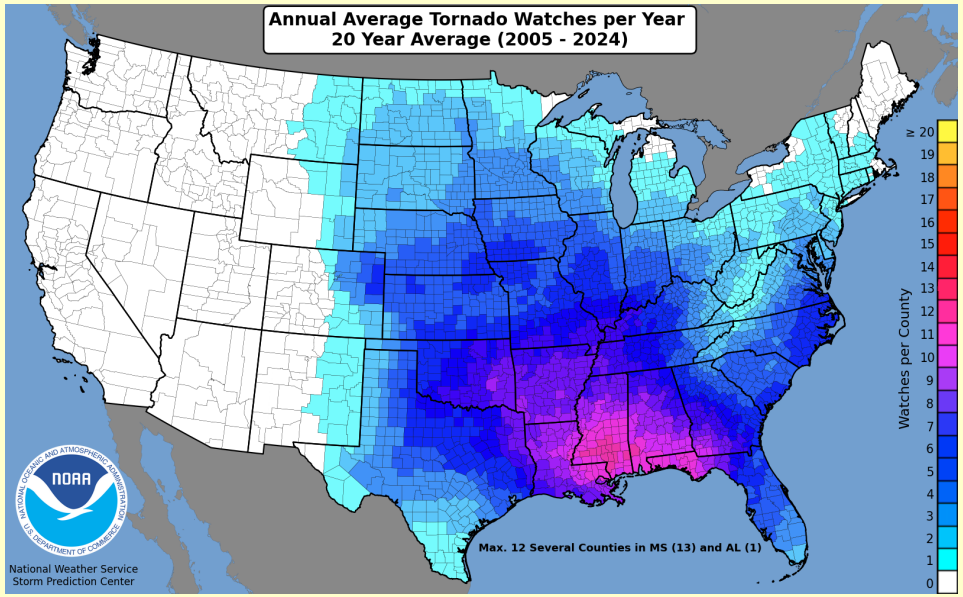






https://www.spc.noaa.gov/wcm/

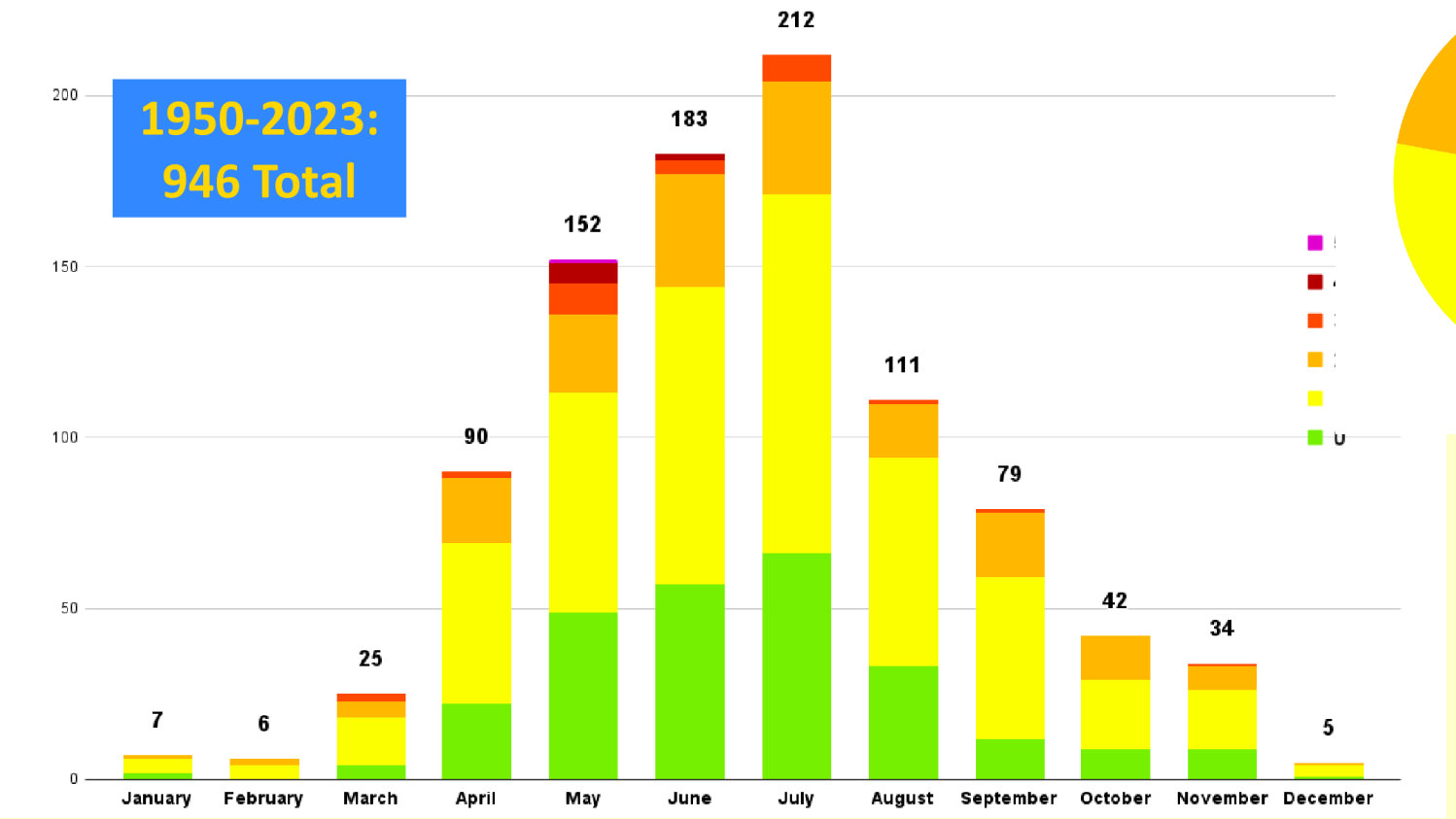




https://www.spc.noaa.gov/wcm/

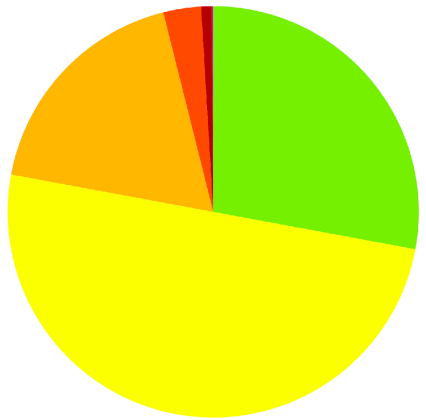
Pennsylvania Tornadoes by Month

Chart updated 02/



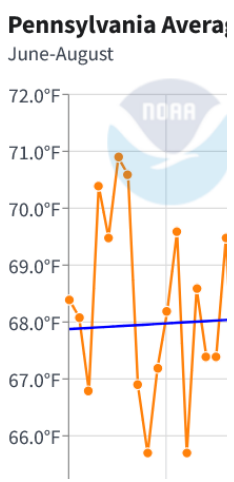
Pennsylvania Tornadoes by Rating

Last updated 02/29/2024



- 0: 264 (27.9%)
- 1: 473 (50.0%)
- 2: 172 (18.2%)
- 3: 28 (3.0%)
- 4: 8 (0.8%)
- 5: 1 (0.1%)

1950-2023:
946 Total


Pennsylvania Avera
June-August
72.0°F
71.0°F
70.0°F
69.0°F
68.0°F
67.0°F
66.0°F

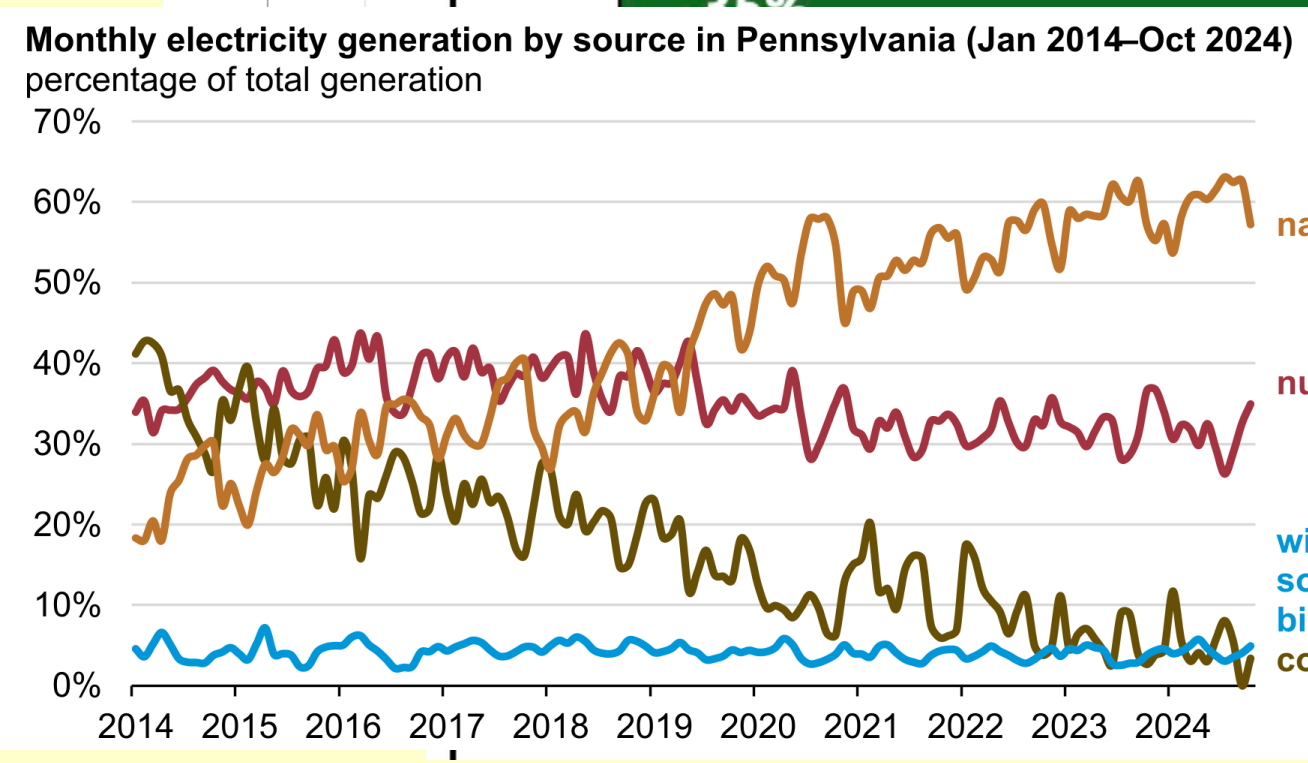
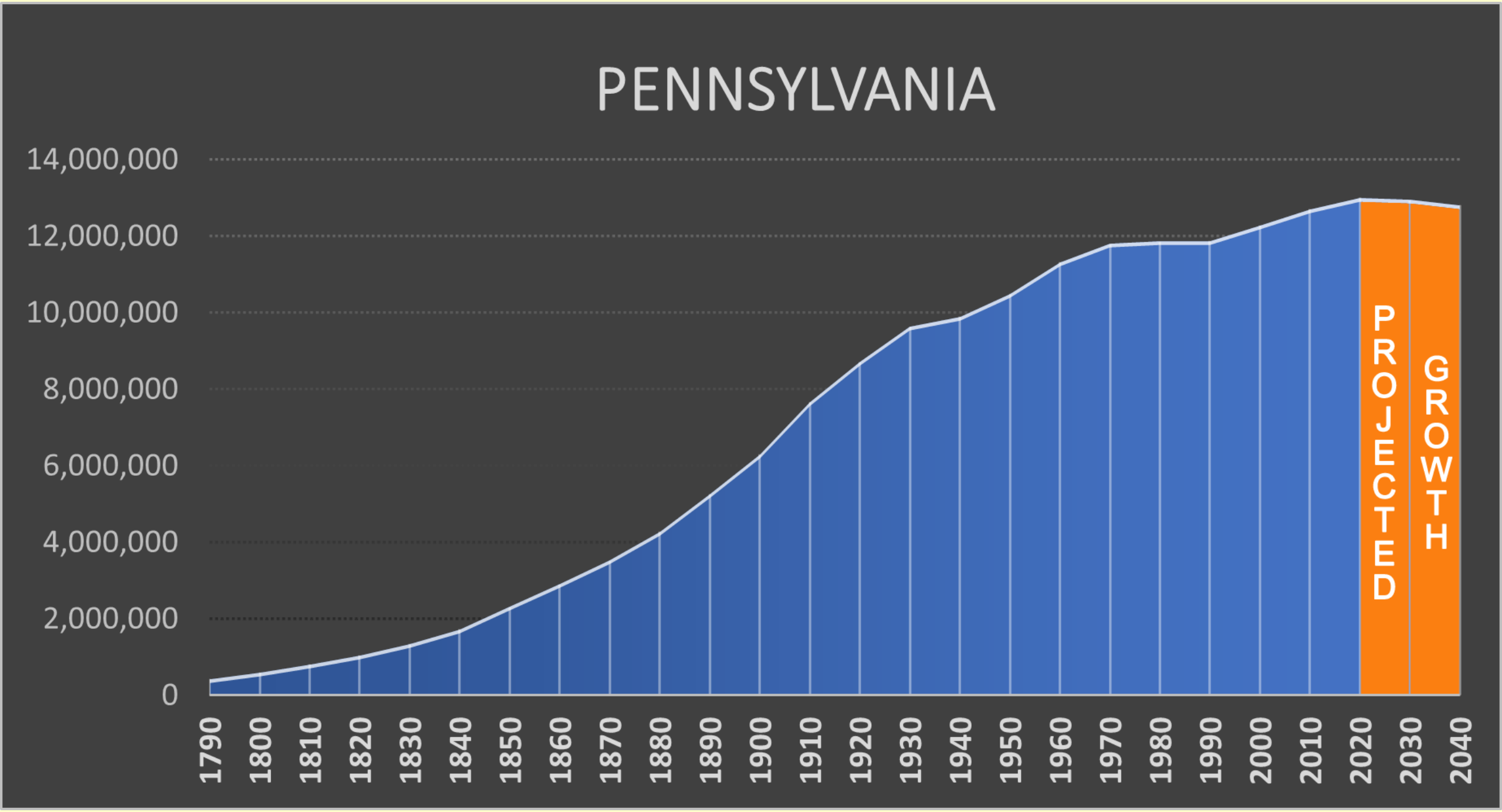

Monthly electricity generation by source in Pennsylvania (Jan 2014–Oct 2024)
percentage of total generation
70%
60%
50%
40%
30%
20%
10%
0%
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
natural gas
nuclear
wind, hydro, solar, and biomass
coal

Figure 1: PA Generation Mix (million megawatt hours)
250
200
32%
59%
5%
eia
2019
2021
2023
Other Renewable


PENNSYLVANIA
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
PROJECTED GROWTH

My name is Brent Killian I am a supervisor within the PA PUC's in the electrical safety division. We oversee and regulate the electric distribution companies in the Commonwealth. We are responsible for investigating accidents, fatalities, property damage, customer safety complaints as well as routine daily inspections of electric distribution facilities

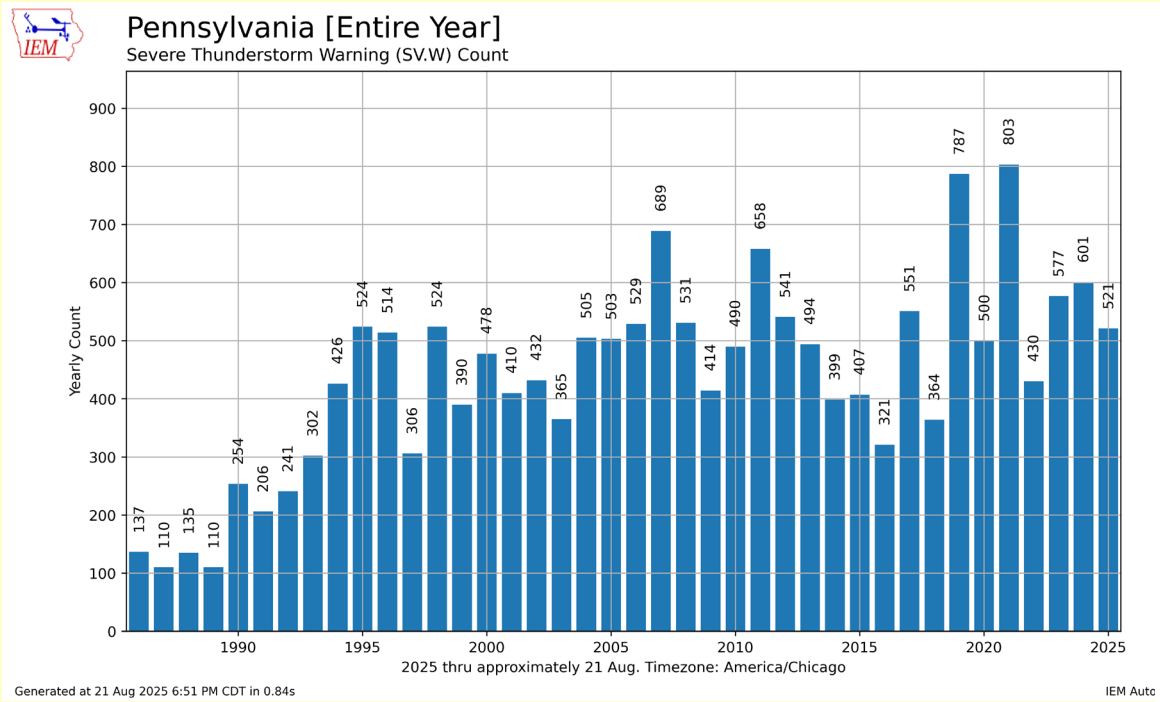
Given the increased frequency of severe weather and the impacts it can and does have on the Commonwealths electric distribution network could you direct me to one or more of your colleagues that may speak on forecasting and prediction. Have there been any new models or ways of thought to help better predict our weather here in PA as apposed to the traditional methods? I may not be articulating this well enough I would be happy to have a short phone call to clear up any confusion. I am able to adjust

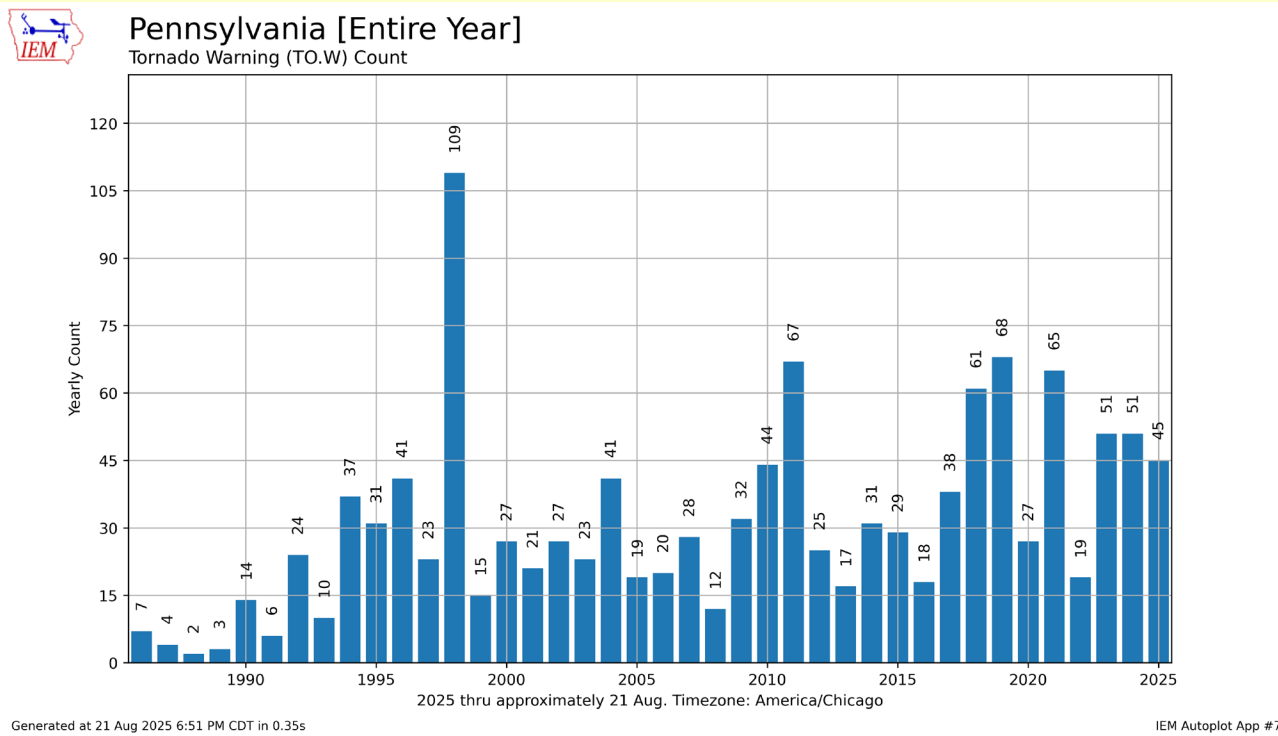
The audience would be PA PUC staff, Electric Distribution Companies (PECO, First Energy, PPL Duquesne Light, UGI Electric) and other interested parties.

Climatology of severe storms in PA
Climo of derechos - they are the big ones - Paul's stuff
Climatology of lightning

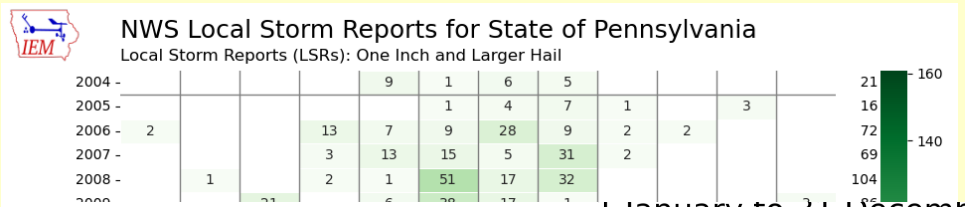
Bring lots of graphics, climo maps

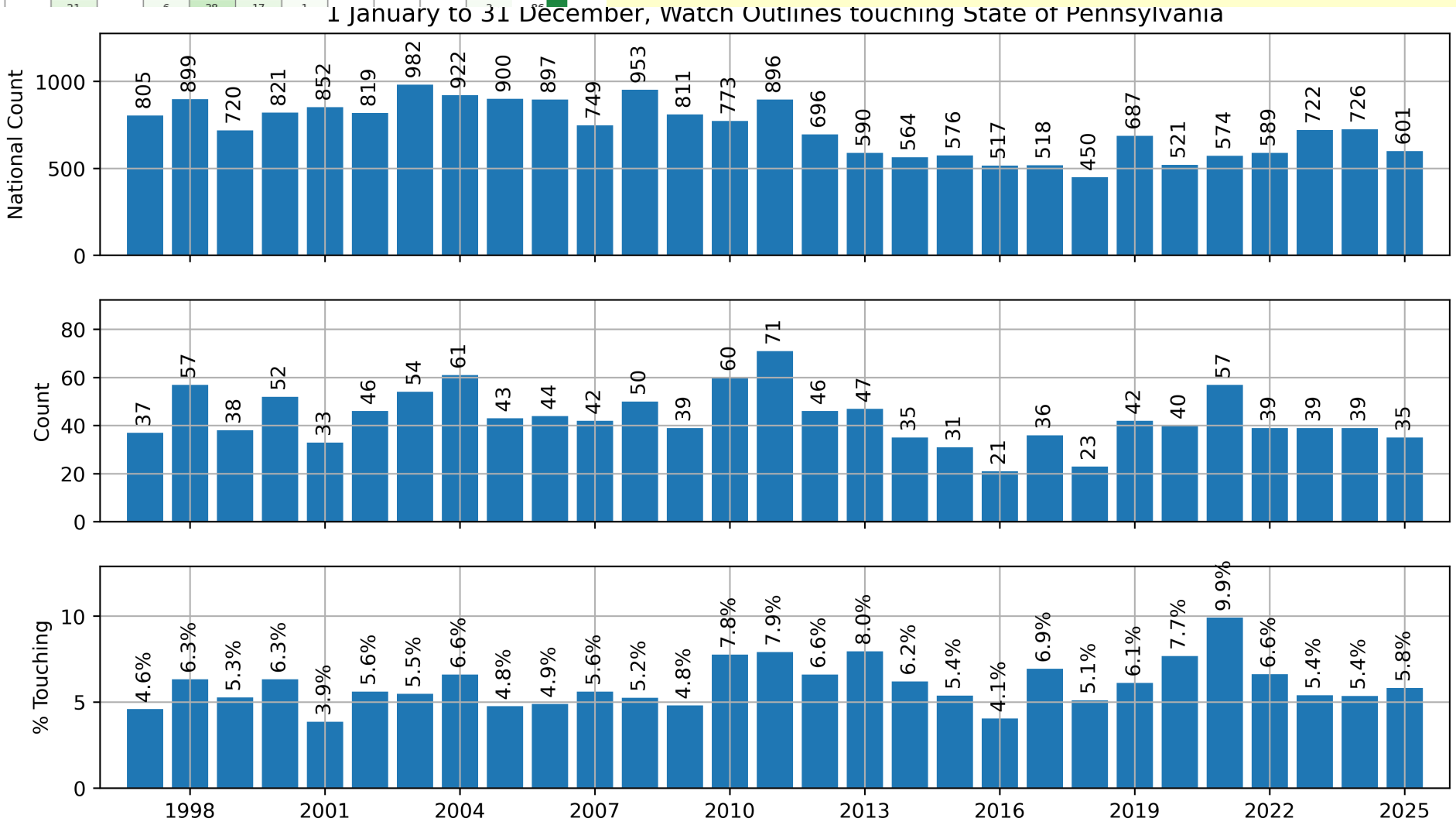
Speak to modeling - 3 km vs 1 km experimental.
Successes & failures


Pennsylvania [Entire Year]
Severe Thunderstorm Warning (SV.W) Count
Yearly Count
2025 thru approximately 21 Aug. Timezone: America/Chicago
Generated at 21 Aug 2025 6:51 PM CDT in 0.84s
IEM Auto


Pennsylvania [Entire Year]
Tornado Warning (TO.W) Count
Yearly Count
2025 thru approximately 21 Aug. Timezone: America/Chicago
Generated at 21 Aug 2025 6:51 PM CDT in 0.35s
IEM Autoplot App #7

Severe Thunderstorm Watches Touching at Least a Part of Pennsylvania

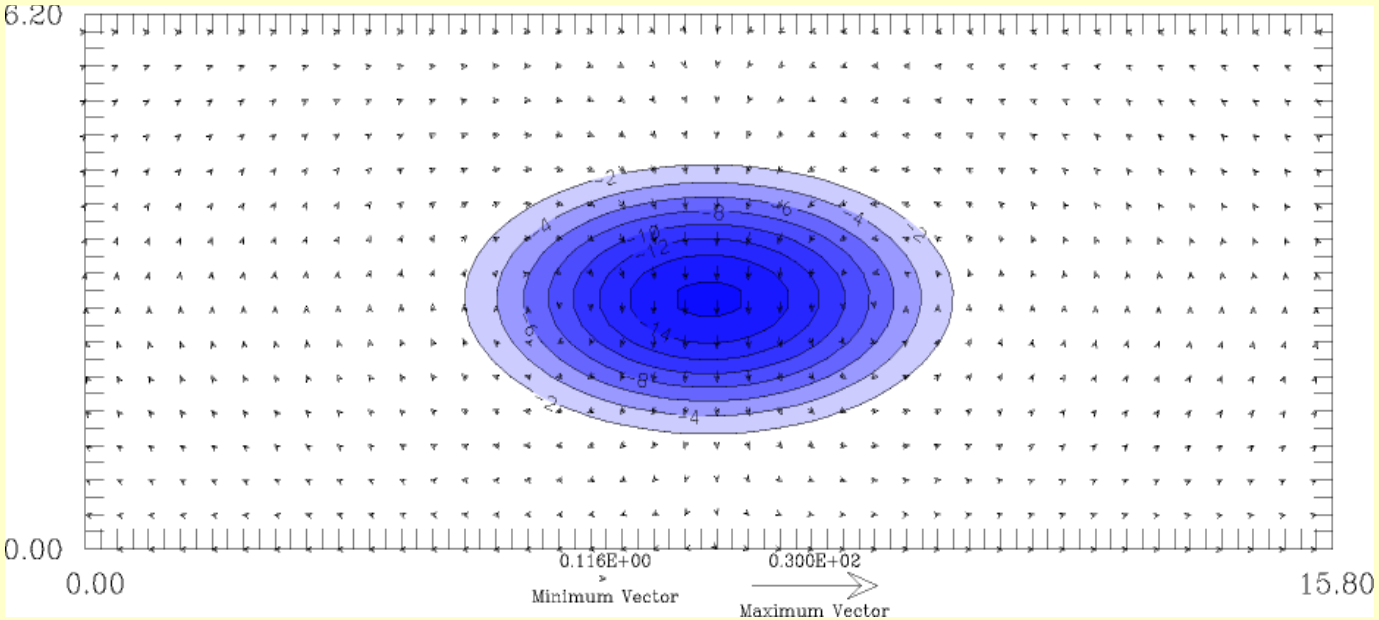




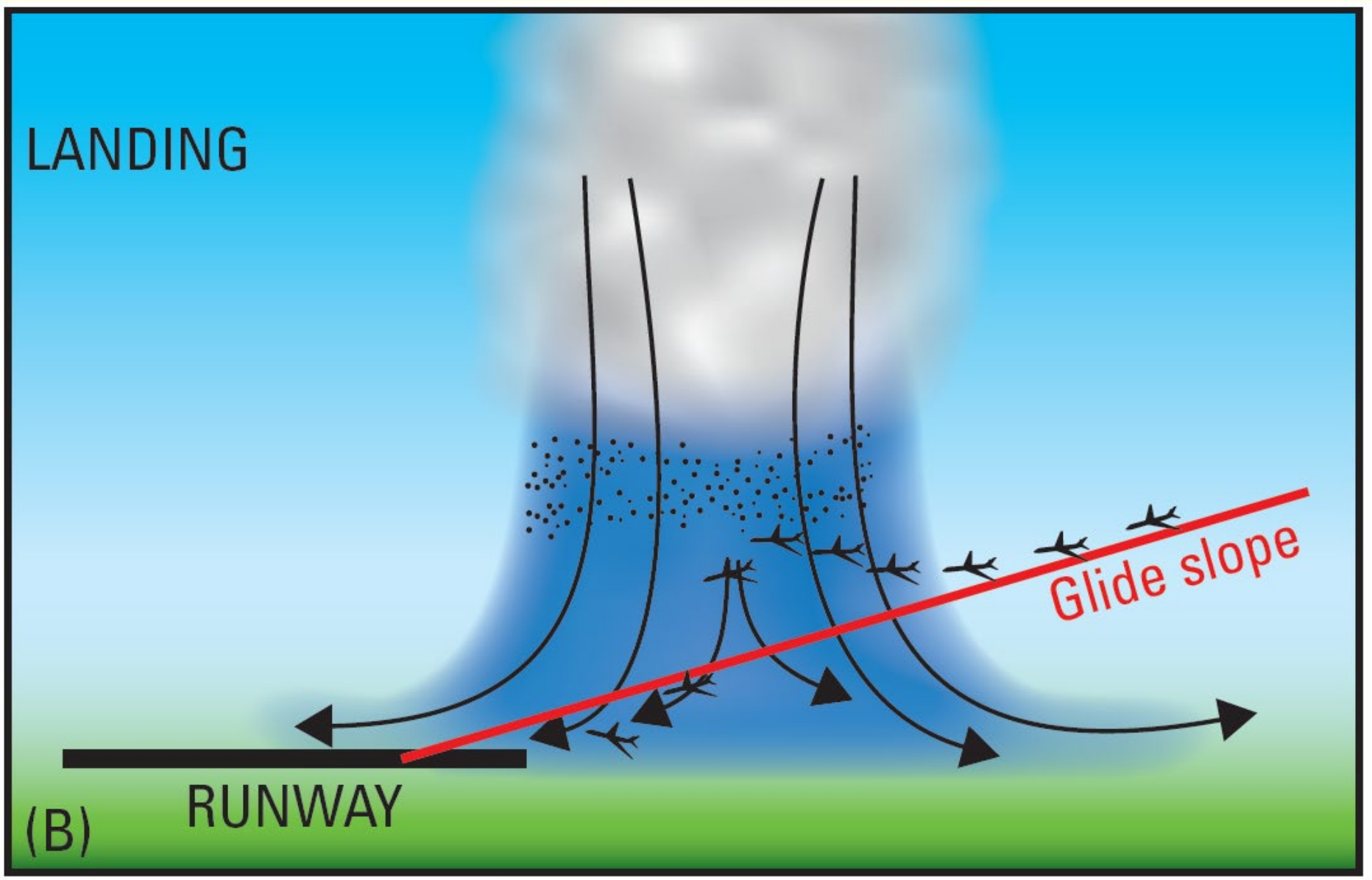
Microbursts / Downbursts

- Localized (few mile wide) region of rapidly sinking air associated with a thunderstorm
- Not as well simulated as larger features … can identify general area where likely, but not pinpoint specific locations.


Courtesy of Jim Ladue



Downbursts/microbursts are particularly dangerous for airplanes on final approach



Airports with Terminal Doppler Weather Radars (TDWRs)

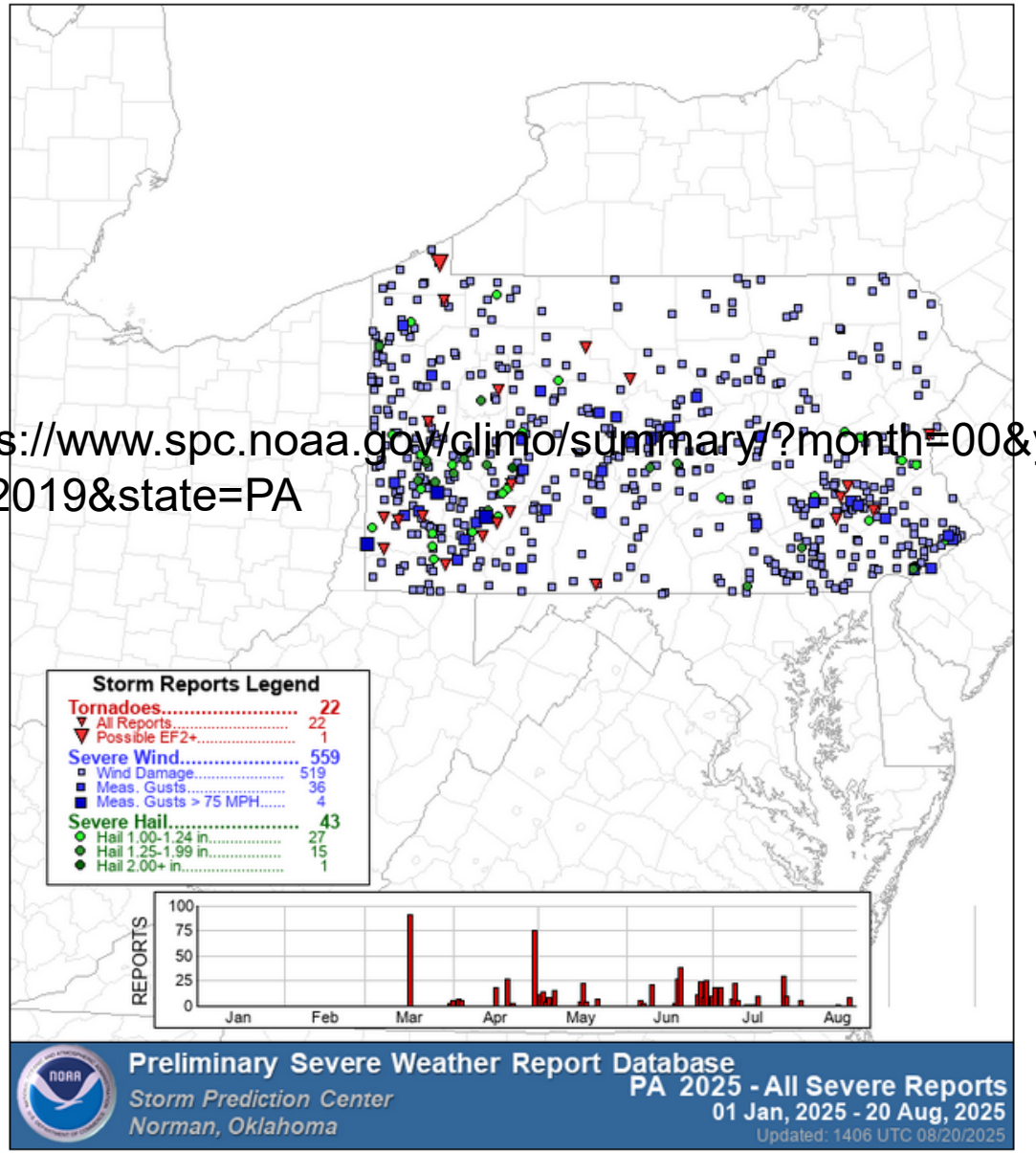
2025 | National | State | All | Tornado | Hail | Wind | Preliminary | Final | Map | Tables | Charts | STAMTS

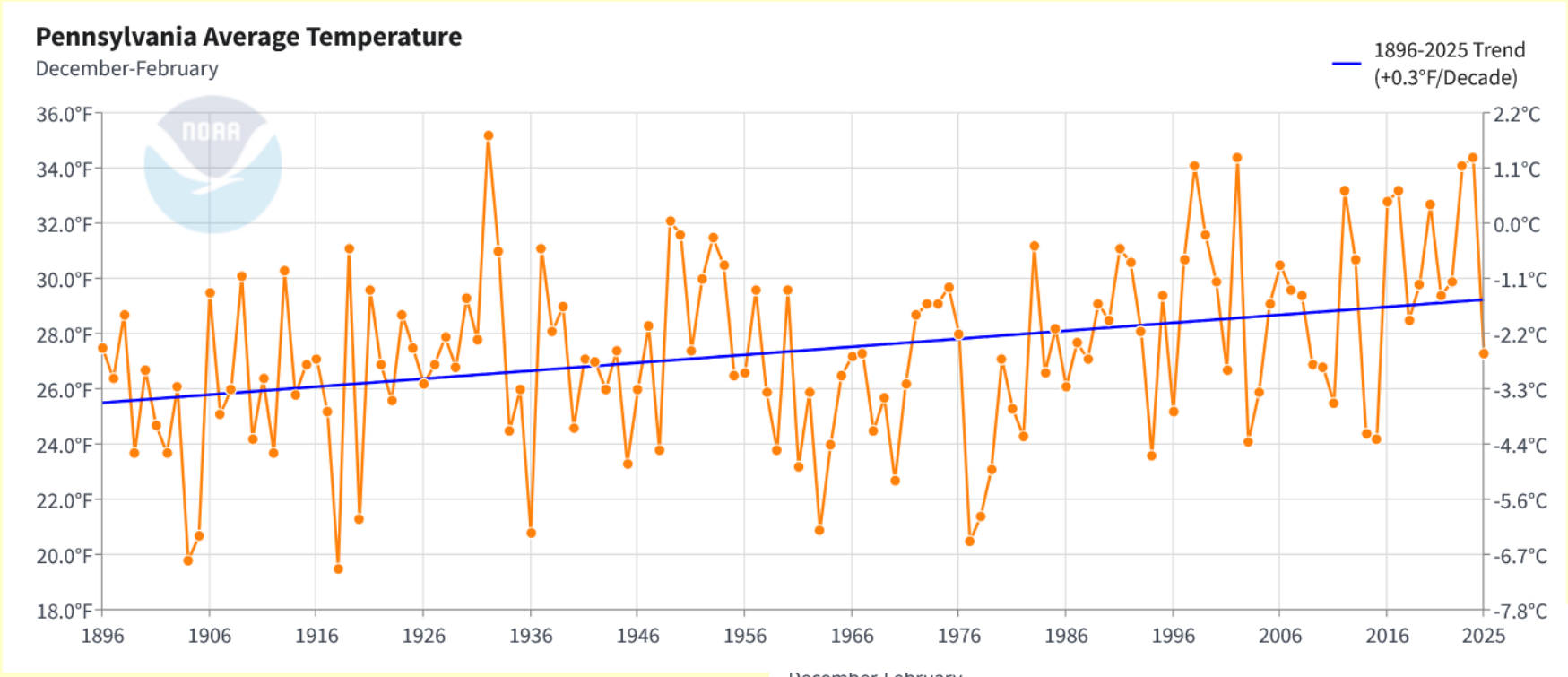
Pennsylvania (PA)

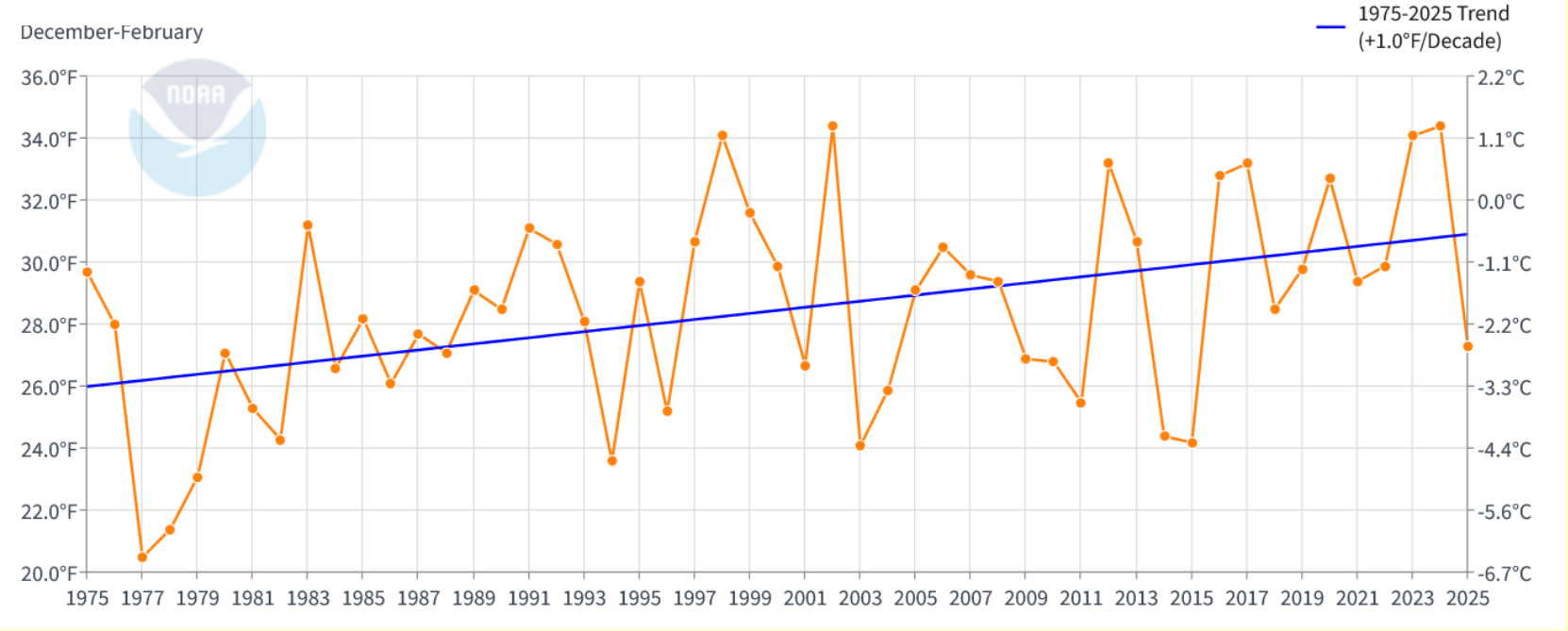
Annual | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

2025 Annual Preliminary Report Summary

https://www.spc.noaa.gov/climo/summary/?month=00&year=2019&state=PA




Pennsylvania Average Temperature
December-February
1896-2025 Trend
(+0.3°F/Decade)
36.0°F
34.0°F
32.0°F
30.0°F
28.0°F
26.0°F
24.0°F
22.0°F
20.0°F
18.0°F
2.2°C
1.1°C
0.0°C
-1.1°C
-2.2°C
-3.3°C
-4.4°C
-5.6°C
-6.7°C
-7.8°C
1896
1906
1916
1926
1936
1946
1956
1966
1976
1986
1996
2006
2016
2025


December-February
1975-2025 Trend
(+1.0°F/Decade)
36.0°F
34.0°F
32.0°F
30.0°F
28.0°F
26.0°F
24.0°F
22.0°F
20.0°F
2.2°C
1.1°C
0.0°C
-1.1°C
-2.2°C
-3.3°C
-4.4°C
-5.6°C
-6.7°C
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025

NOAA Advance Warning

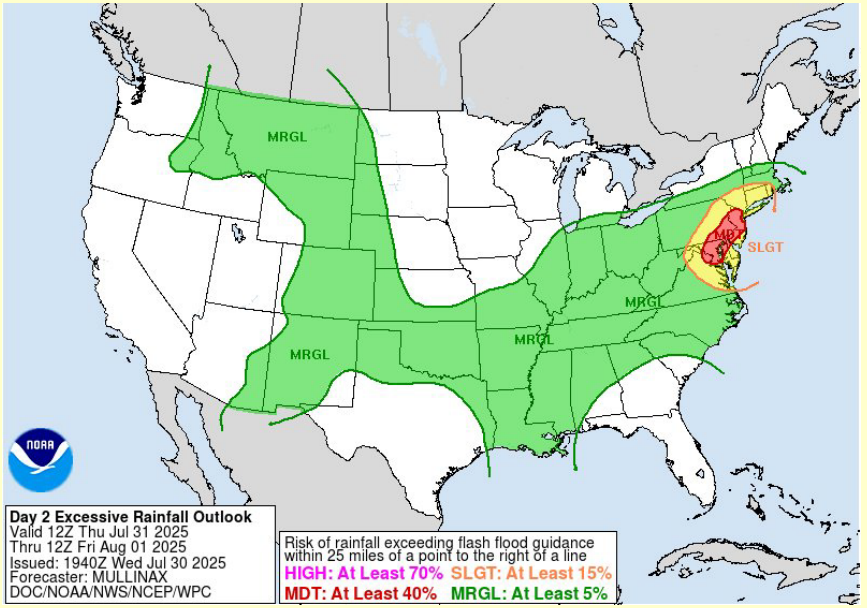
- https://www.cpc.ncep.noaa.gov/products/predictions/threats/extremesTool.php
- https://www.cpc.ncep.noaa.gov/products/predictions/threats/threats.php
- https://www.wpc.ncep.noaa.gov/threats/threats.php

- https://satable.ncep.noaa.gov/naefs/
- https://www.wpc.ncep.noaa.gov/qpf/excessive_rainfall_outlook_ero.php

https://www.weather.gov/

Winter
https://www.wpc.ncep.noaa.gov/wwd/wssi/prob_wssi.php

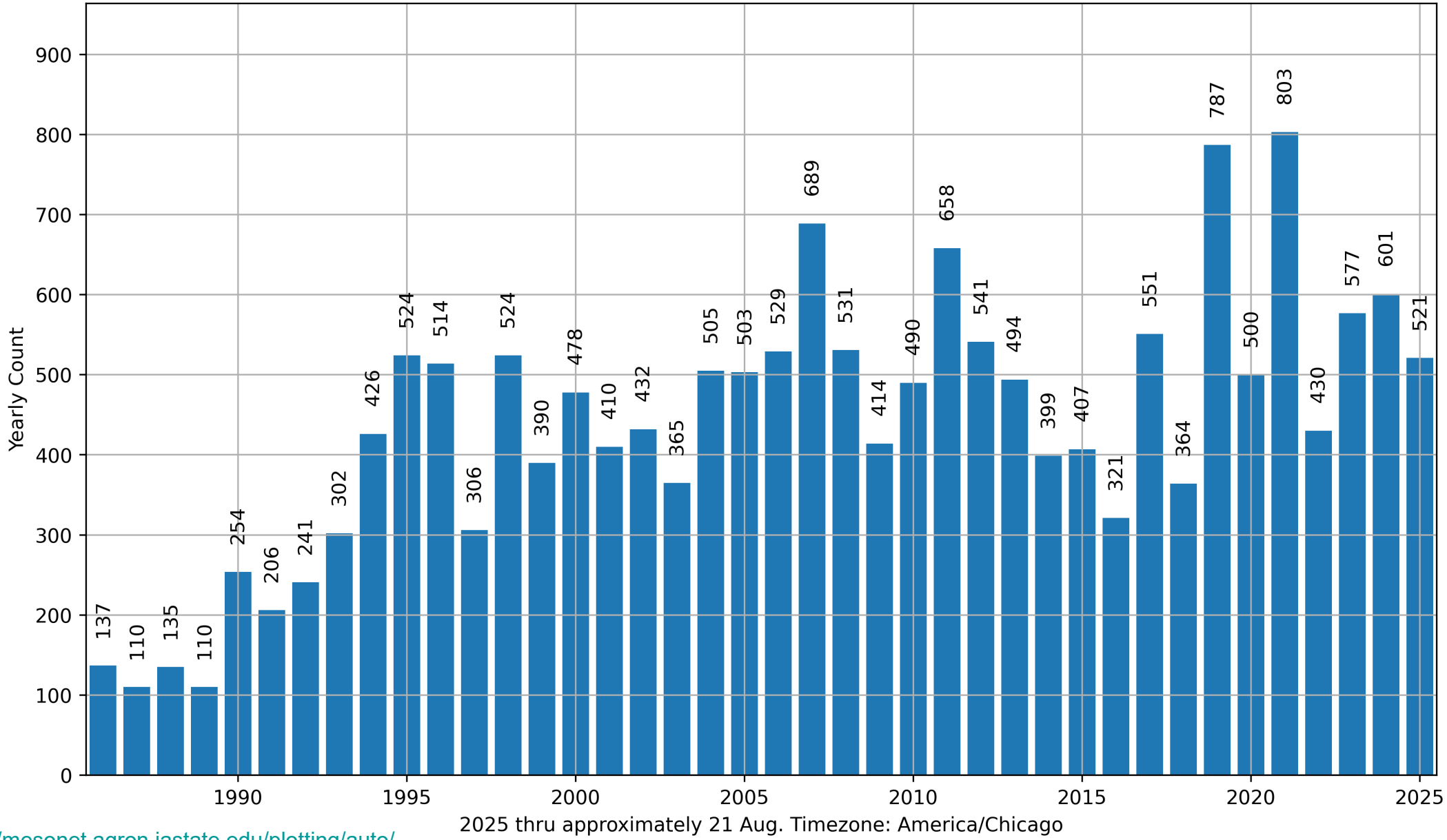
Severe
https://www.spc.noaa.gov/public/swodyoverview.html



- SHORT RANGE
- https://www2.mmm.ucar.edu/projects/ncar_ensemble/camviewer/
- https://cams.nssl.noaa.gov/?model=mpasht_nssl&product=cref_uh075&sector=spc_conus&postage_stamp=false
- Experimental SSCRAM: https://www.spc.noaa.gov/exper/hrrr/sscram/ (good use it!)

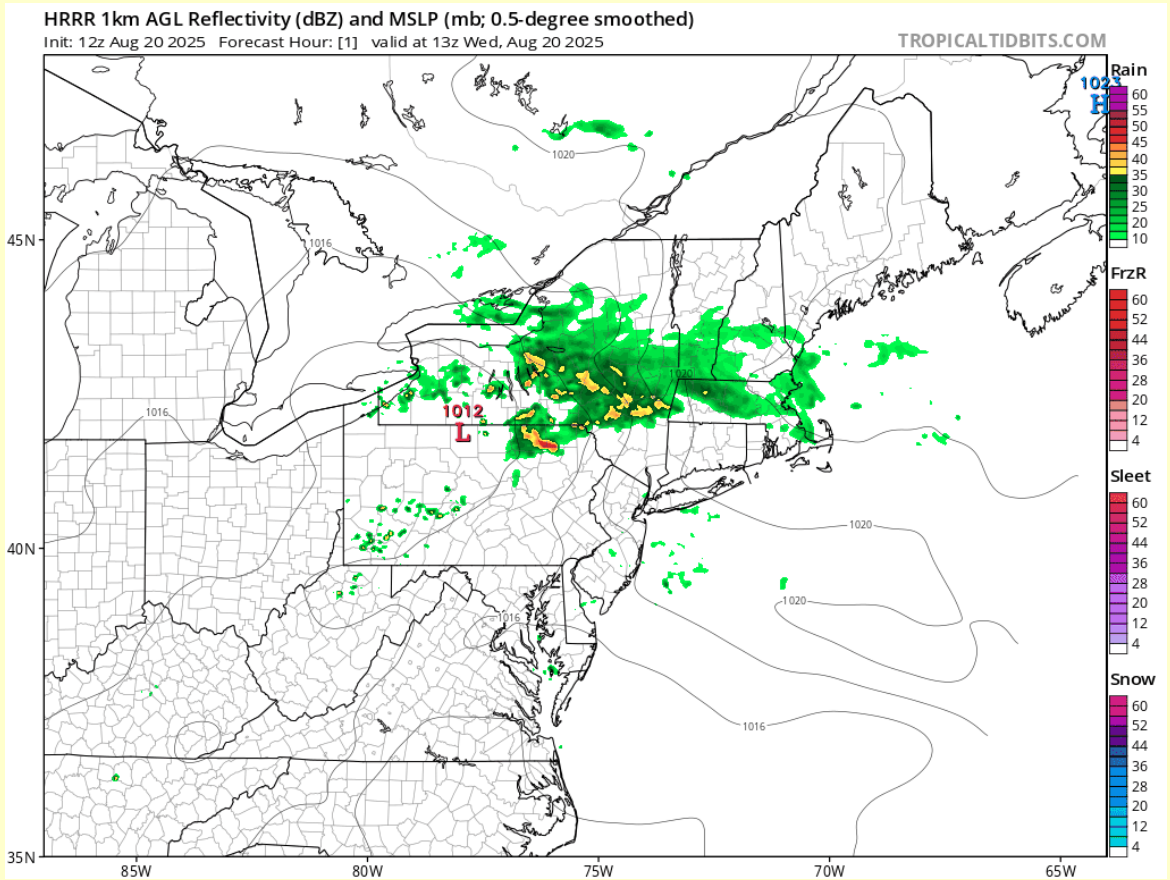
Pennsylvania [Entire Year]

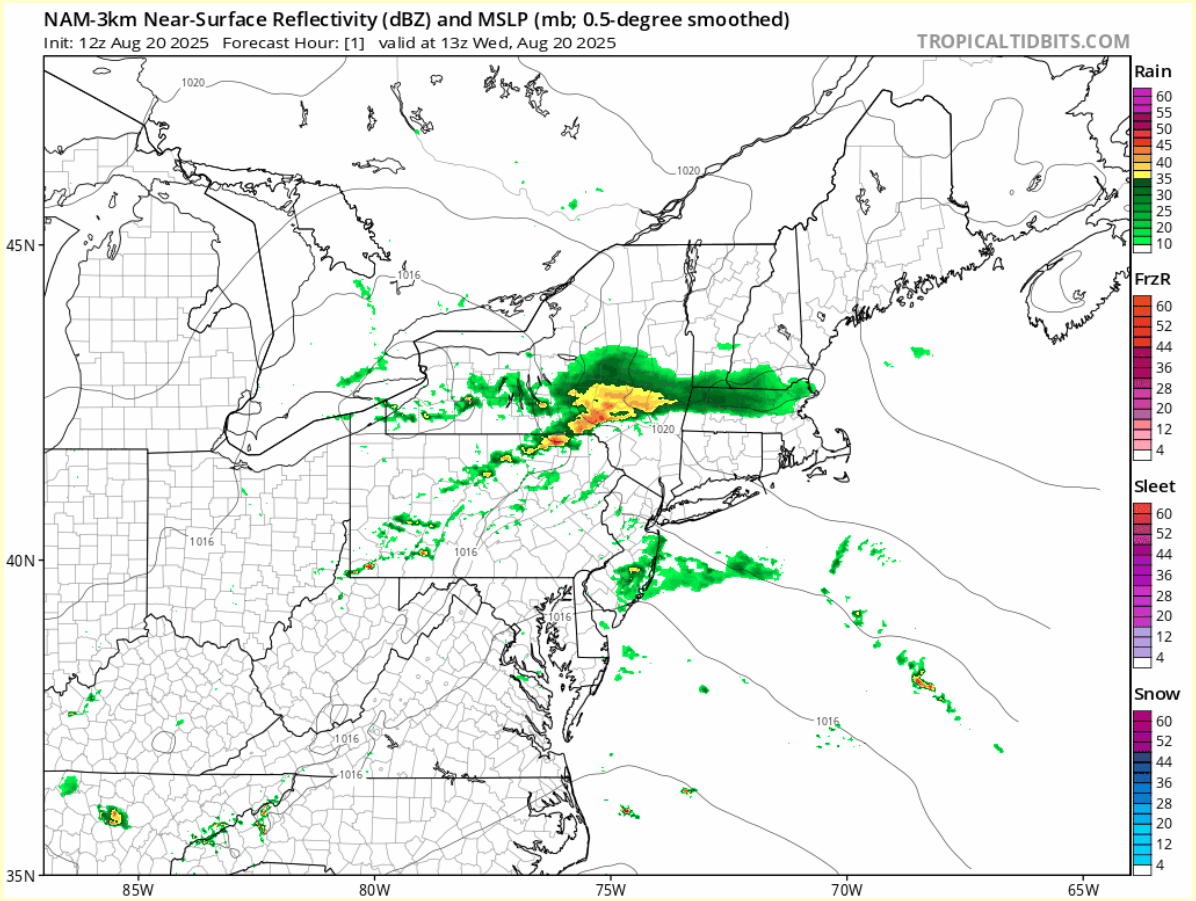
Severe Thunderstorm Warning (SV.W) Count



https://mesonet.agron.iastate.edu/plotting/auto/

- Some modern weather computer models are “convection-allowing”, meaning they are capable of simulating (approximately) squall lines and even, in some cases, individual thunderstorms





https://www.tropicaltidbits.com/

Researchers at National Center for Atmospheric Research are Experiment with AI in Severe Thunderstorm Forecasting

https://www2.mmm.ucar.edu/projects/ncar_ensemble/camviewer/