Numerical Weather Prediction Skill in Predicting Damaging Extreme Compound Weather Events

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(September 18, 1952 - May 24, 2025)

What is a compound (extreme) weather event?

Compound weather events….

Here's a definition: can take the form of weather-driven and/or climate-driven preconditions that aggravate local or regional conditions in time and space, or where hazards in multiple connected locations cause an aggregated impact (Zscheischler et al. 2018).

Two "non-extreme" weather phenomena that can combine to produce an extreme outage event—for example, heavy rain followed by high winds that each on its own would not cause many outages but combined together (in time and/or space) can more easily uproot trees and damage transmission and distribution infrastructure.

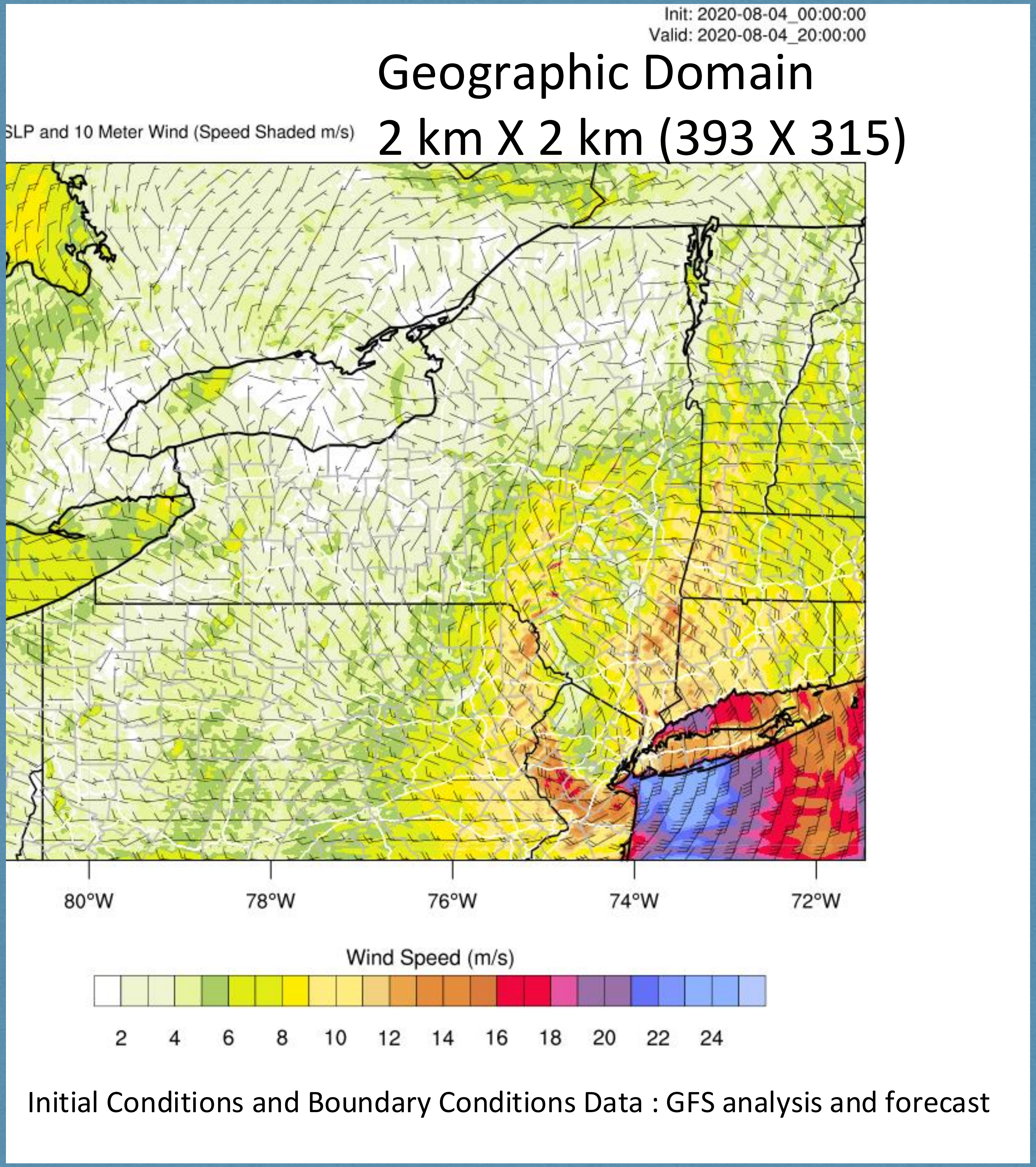
Outages by Event Type
Lake-Effect Snow, High Wind, Lakeshore Flood, Winter Storm, Blizzard, Flood, Cold/Wind Chill, Thunderstorm Wind 2022-12-23
Winter Storm, Heavy Snow 2022-04-19
Winter Storm, Ice Storm, Heavy Snow 2022-02-04
Lakeshore Flood, High Wind, Thunderstorm Wind 2021-12-11
High Wind, Tropical Storm, Heavy Rain, Flood, Thunderstorm Wind 2020-08-04
High Wind, Coastal Flood, Lakeshore Flood, Flood, Thunderstorm Wind 2019-11-01
Hail, Flood, Thunderstorm Wind 2019-06-30
Tornado, Funnel Cloud, Hail, Thunderstorm Wind 2018-05-15
Tornado, Hail, High Wind, Thunderstorm Wind 2018-05-04
High Wind, Coastal Flood, Winter Storm, Blizzard, Heavy Snow 2018-03-02
High Wind, Thunderstorm Wind 2017-03-08
Tornado, Hail, Funnel Cloud, Thunderstorm Wind 2014-07-08
Ice Storm, Flood 2013-12-22
Hail, Lightning, Tornado, Heat, Flood, Thunderstorm Wind 2013-07-19
Funnel Cloud, Hail, Heavy Rain, Tornado, Flood, Frost/Freeze, Thunderstorm Wind 2013-05-29
Storm Surge/Tide, High Wind, Coastal Flood 2012-10-29
Winter Storm, Frost/Freeze, Heavy Snow, Coastal Flood 2011-10-29
High Wind, Storm Surge/Tide, Tropical Storm, Flood, Tornado 2011-08-28
High Surf, High Wind, Coastal Flood, Lightning, Heavy Rain, Flood, Heavy Snow 2010-03-13
Winter Storm, Debris Flow, High Wind, Heavy Snow 2010-02-25
Winter Storm, Heavy Snow 2010-02-23
Winter Storm, Ice Storm, Flood, Heavy Rain 2008-12-11
Hail, Funnel Cloud, Heat, Lightning, Thunderstorm Wind 2008-06-10
Seiche, Flood, Lake-Effect Snow, High Wind 2008-01-30
Hail, Funnel Cloud, Lightning, Flood, Thunderstorm Wind 2007-07-10
Hail, Lightning, Heavy Rain, Flood, Thunderstorm Wind 2007-06-27
Flood, Lake-Effect Snow 2006-10-12
Lake-Effect Snow, High Wind, Hail, Winter Storm, Heavy Snow, Cold/Wind Chill, Thunderstorm Wind 2006-02-17
Hail, Lightning, Rip Current, Thunderstorm Wind 2005-06-06
Winter Storm, Hail, High Wind, Heavy Snow 2003-11-13
Winter Storm, Ice Storm, Heavy Snow 2003-04-04
0
500000
1000000
1500000
2000000
Total NYS Customers Affected
Weather Phenomena Combination
Heavy Snow,
Flood, Hail, Lightning, Thund
Hail, Thund
Flood, Thund
Heavy Snow, High Wind,
High Wind,
Lake-Effect Snow,
Heavy Snow, Lake-Effect Snow,
Flood, Hail, Lightning, Thunderstorm \
Flood, Funnel Cloud, Hail, Lightning, Thunderstorm \
Flood, Hail, Thund
Flood, Hail, Heavy Rain, Lightning, Thunderstorm \
Hail, Lightning, Thund
Flood, High Wind, Thund
Flood, Heavy Snow, High Wind,
High Wind, Thund
Heavy Snow, High Wind, Lake-Effect Snow,
Lightning, Thund
Hail, Lightning, Thunderstorm \
Flood, Hail, Thunderstorm \

Numerical Weather Prediction (NWP): Weather Research and Forecasting (WRF) modeling system

“Enhancing Predictability of Weather-Caused Power Outages with NY Mesonet Observations: Demonstration on the Avangrid service territory”
(Sponsored by the New York State Energy Research and Development Authority)

Jeff Freedman, Emmanouil Anagnostou, Adam Helman, John Zack, James Rincon, June Wang, Diego Cerrai, Kingsley Udeh, Elizabeth McCabe, Jan Woodcock, and Thomas Layton

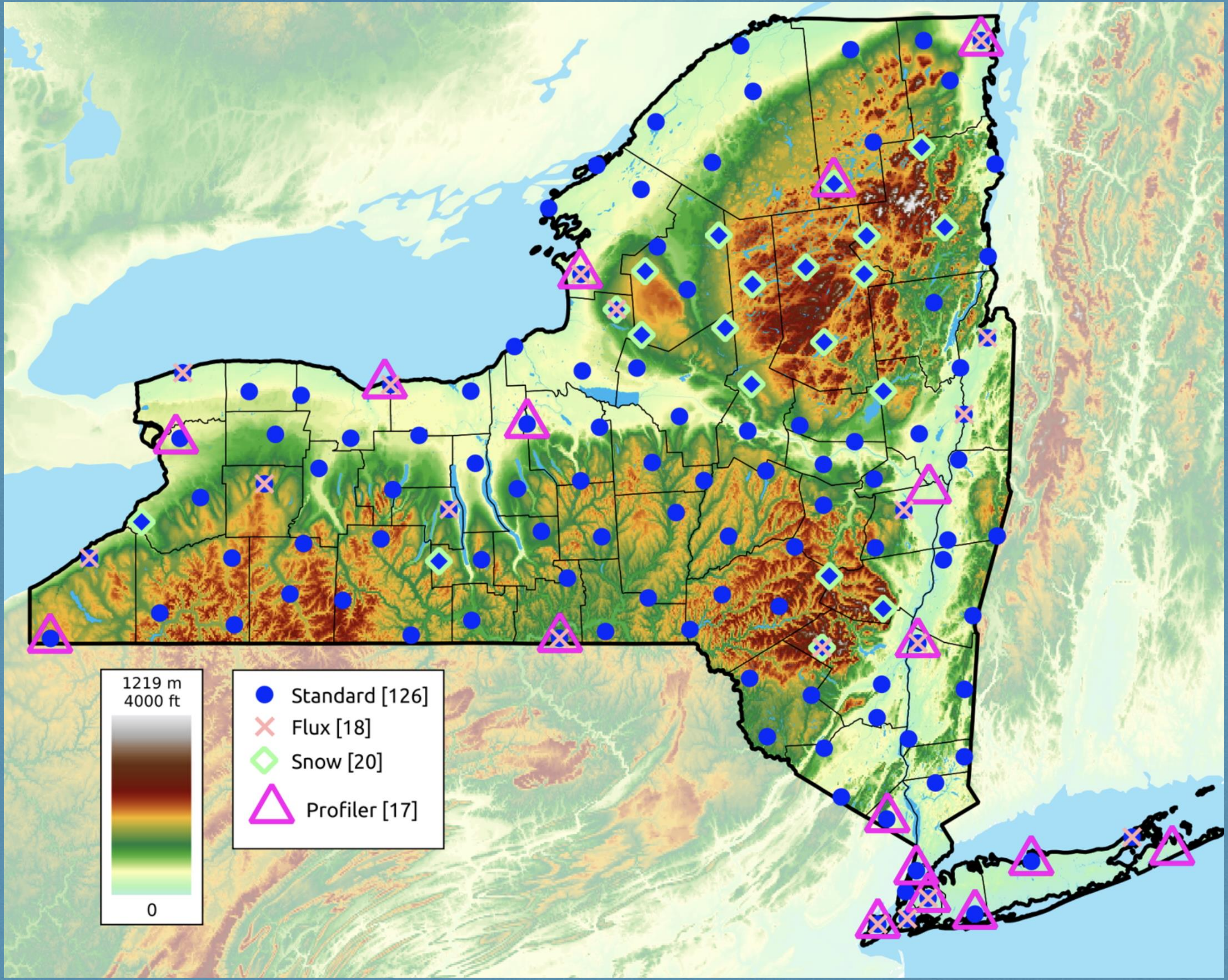
Parameterization	Scheme
Microphysics	Thompson aerosol aware
Short wave radiation	RRTMG
Long wave radiation	RRTMG
Land surface model	Rapid Update Cycle (RUC)
Surface Layer	Mellor-Yamada-Nakanishi-Niino (MYNN)
Boundary Layer	MYNN2
Moist Convection	[NONE]
Vertical levels	40 (17 below 1000 m—stretched)



UAlbany-UConn OPM model domains.
The inner nest is at 2 km resolution.

NYS Mesonet
UNIVERSITY AT ALBANY

127 Standard Sites
Average spacing 27 km
At least 1 site in every county
NYC rooftop sites
1825+ sensors
1 million observations per day
2448 profiles per day

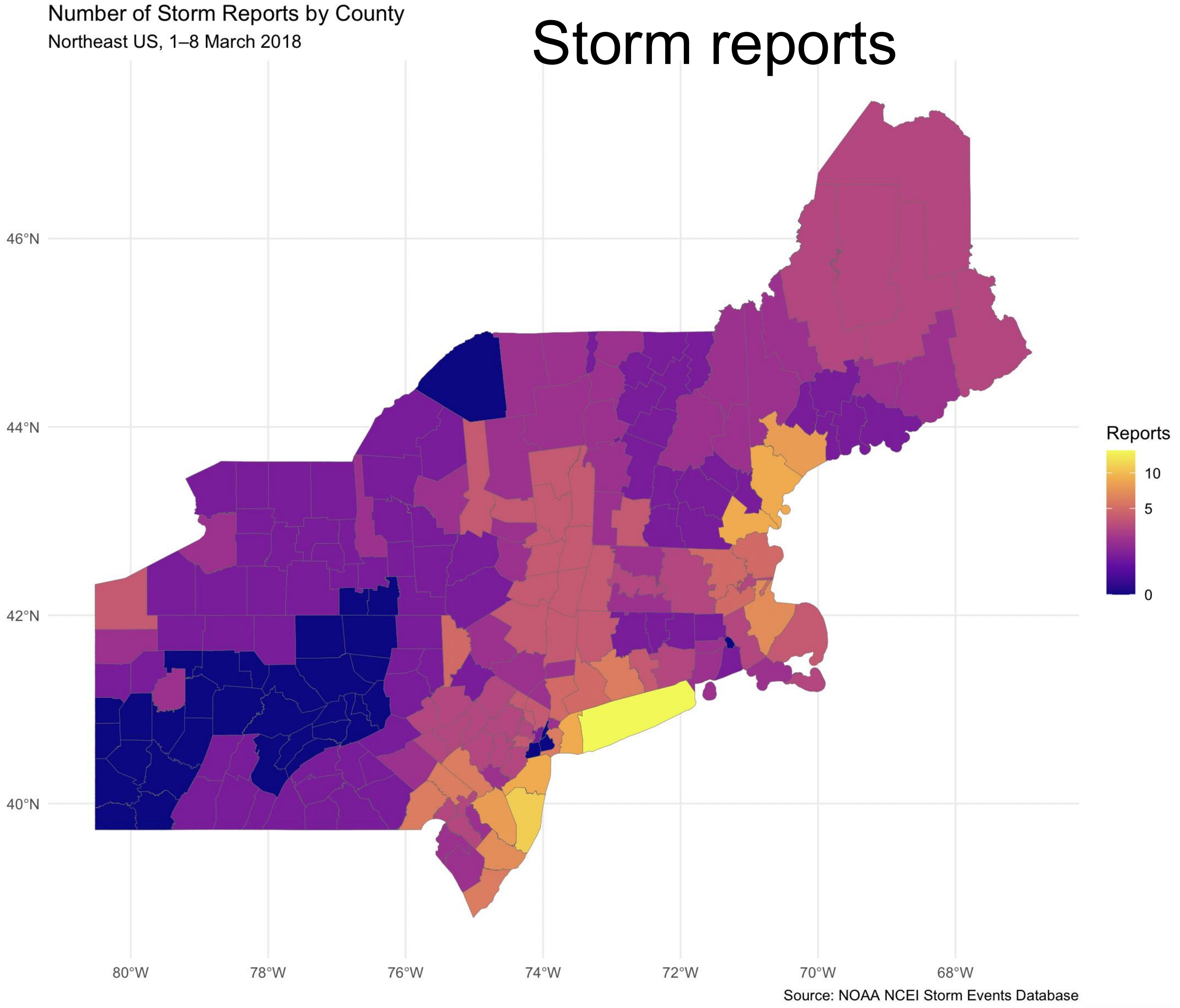


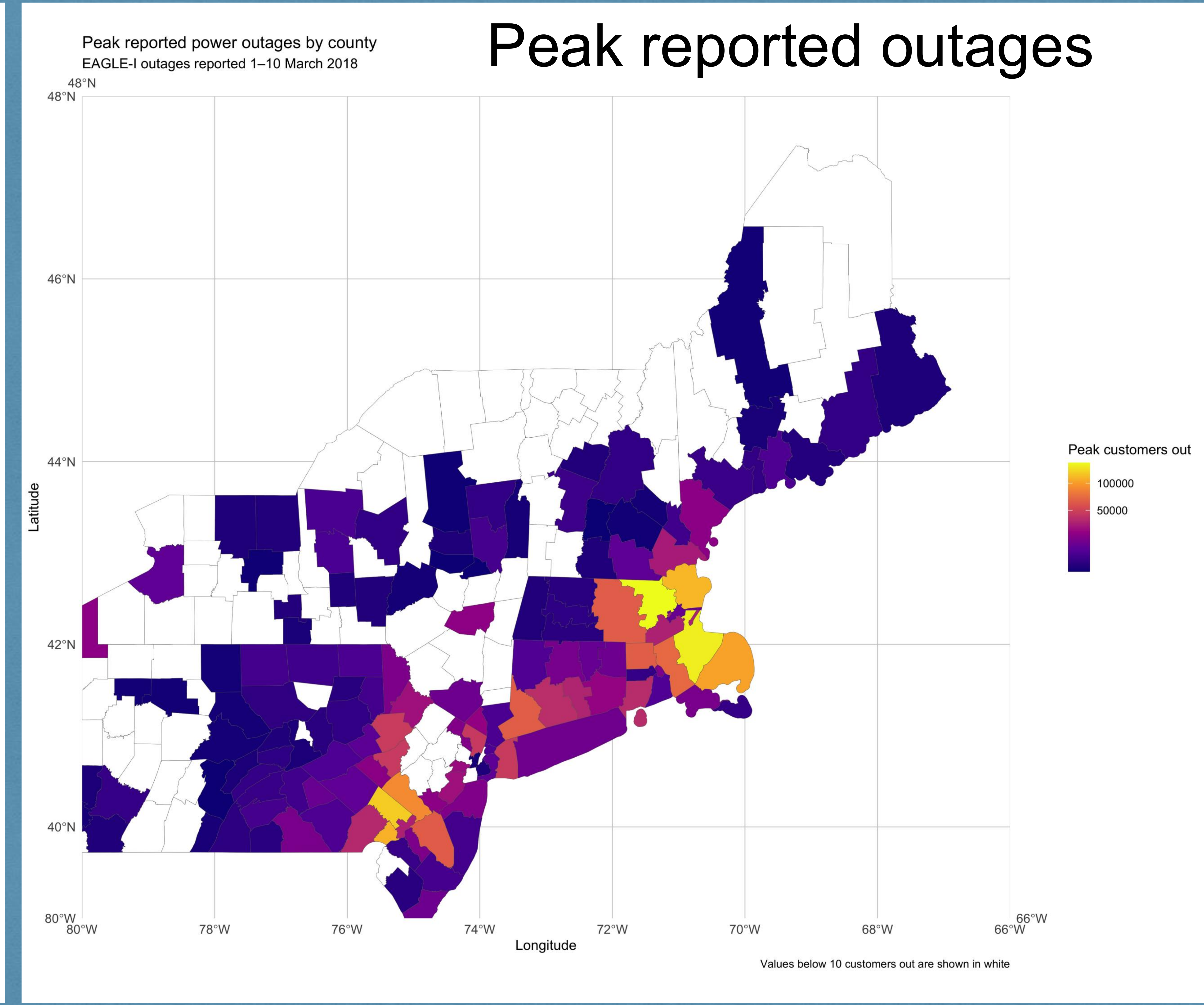
Courtesy J. Brotzge and J. Wang

NWP AI OPM Case studies

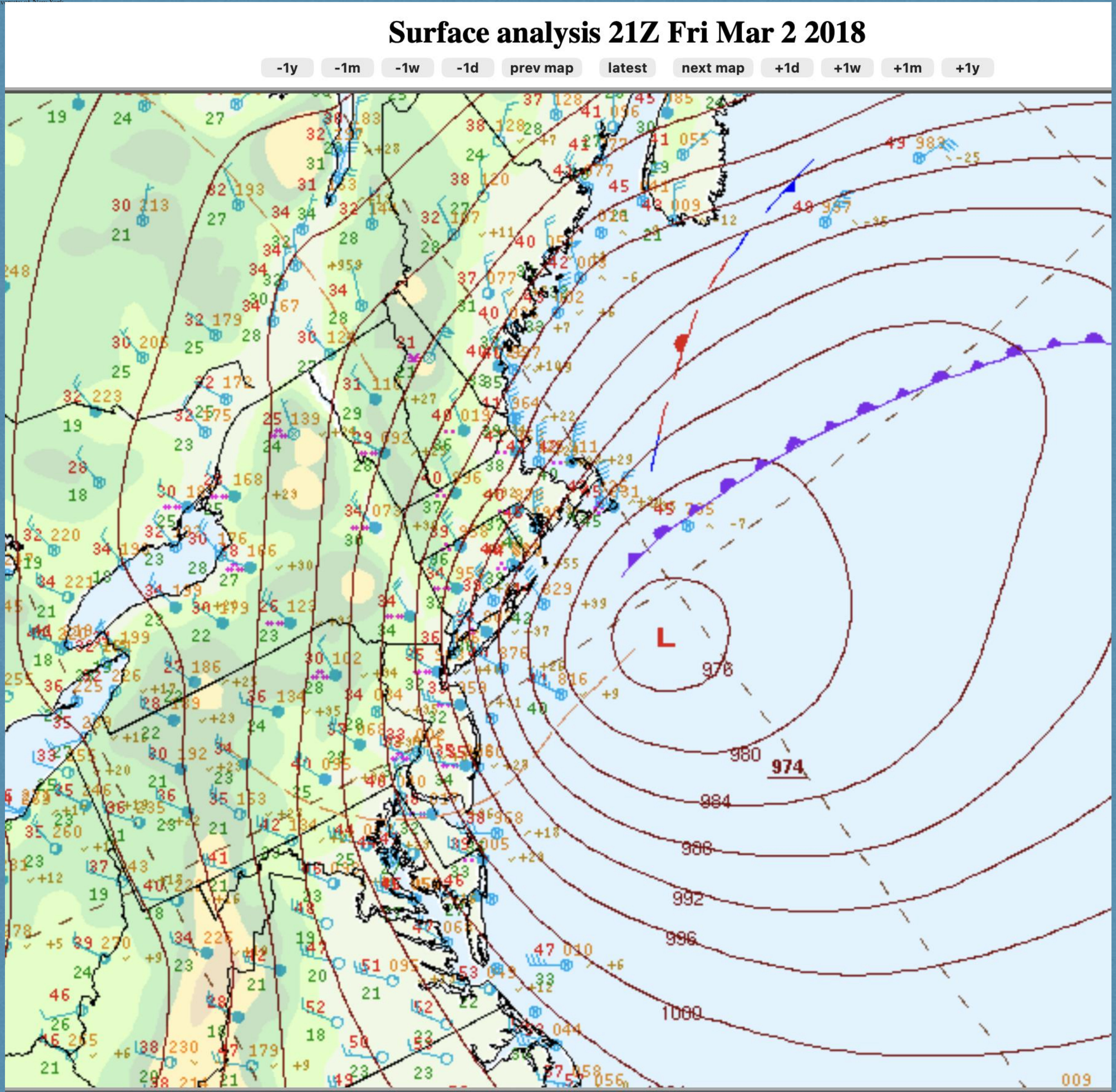
Date	Case Type	Description	#Outages (Avangrid Territories in NY)
15 May 2018	Convection	Multiple thunderstorm complexes	146,716
1 - 3 March 2018	Nor'easter	Long-duration winter storm with heavy wet snow, rain, and wind	334,322
31 October - 1 November 2019	Non-tropical system	Frontal passage with high winds	136,045
4 August 2020	Tropical system	Tropical Storm Isaias	163,613

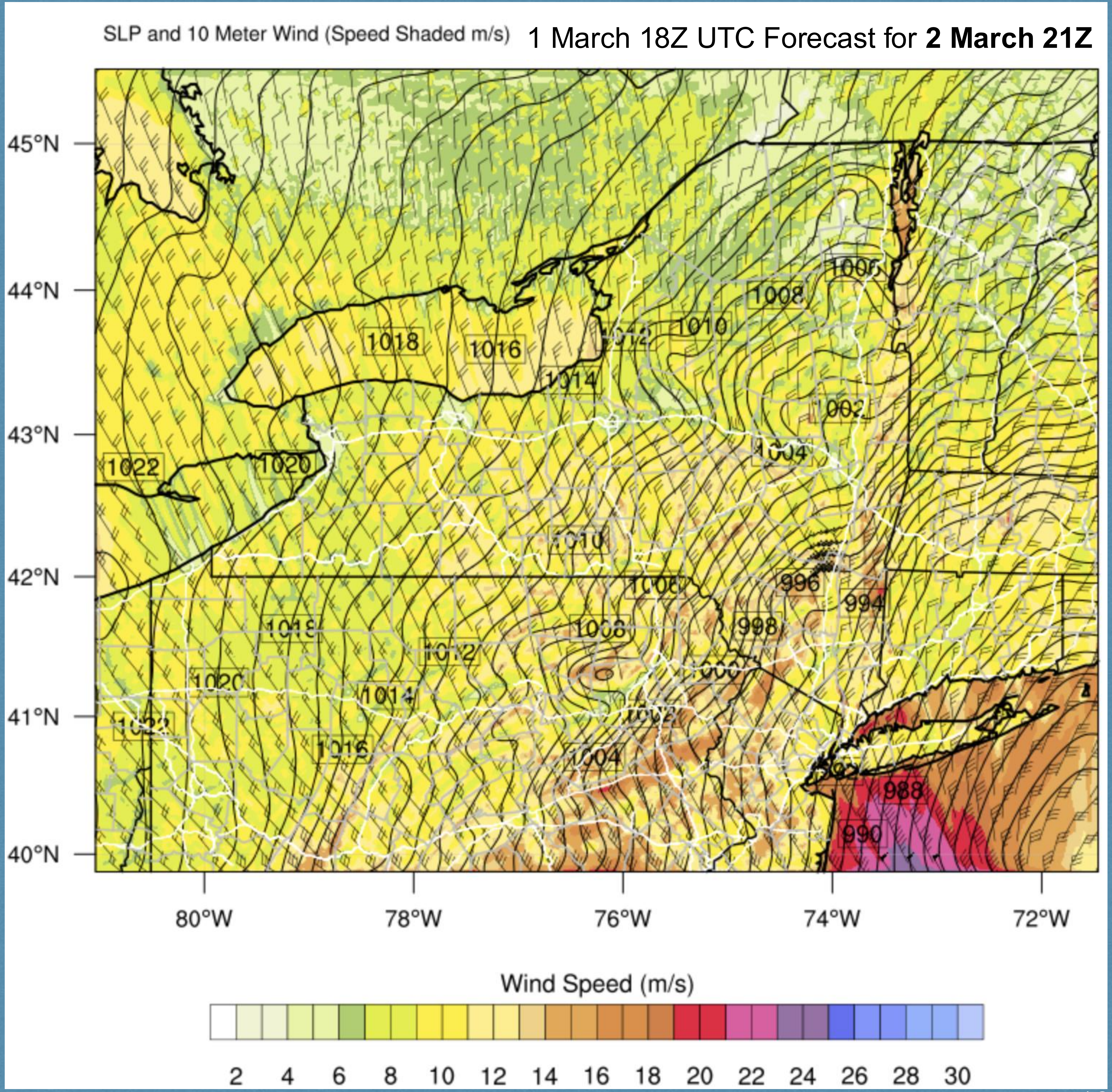
1-10 March 2018 Compound Events



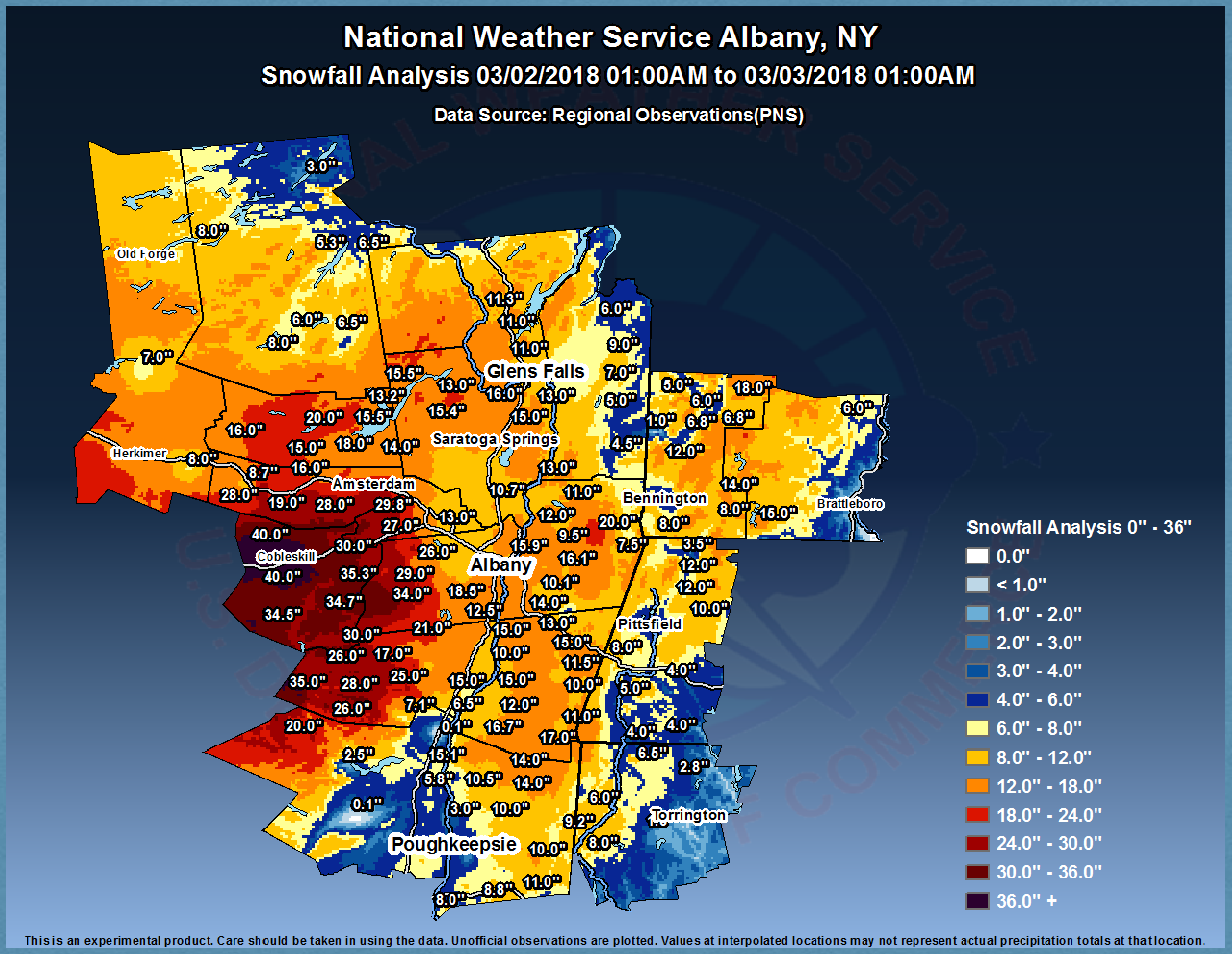


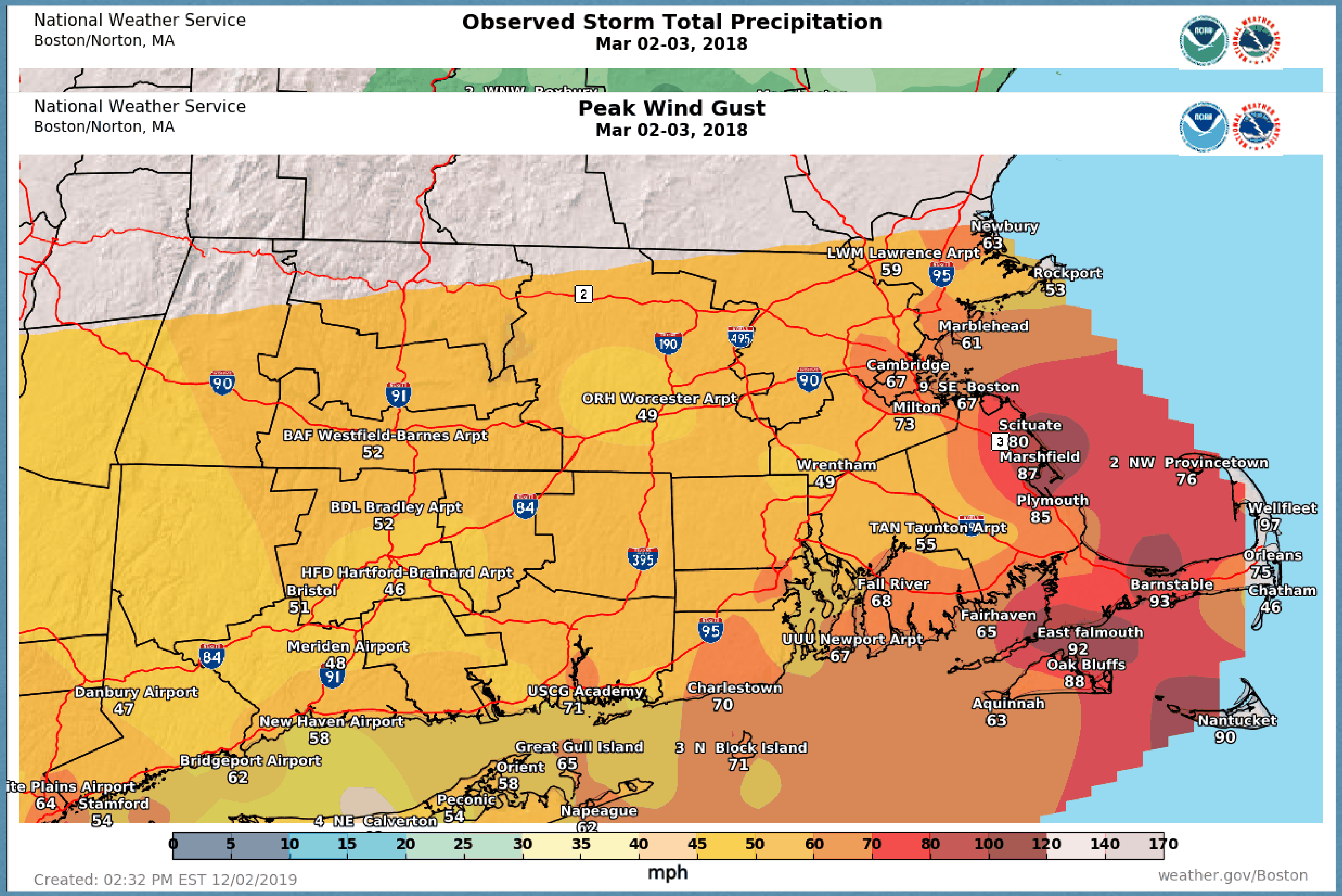
1- 3 March 2018 Compound Event (heavy snow, heavy rain, strong winds)



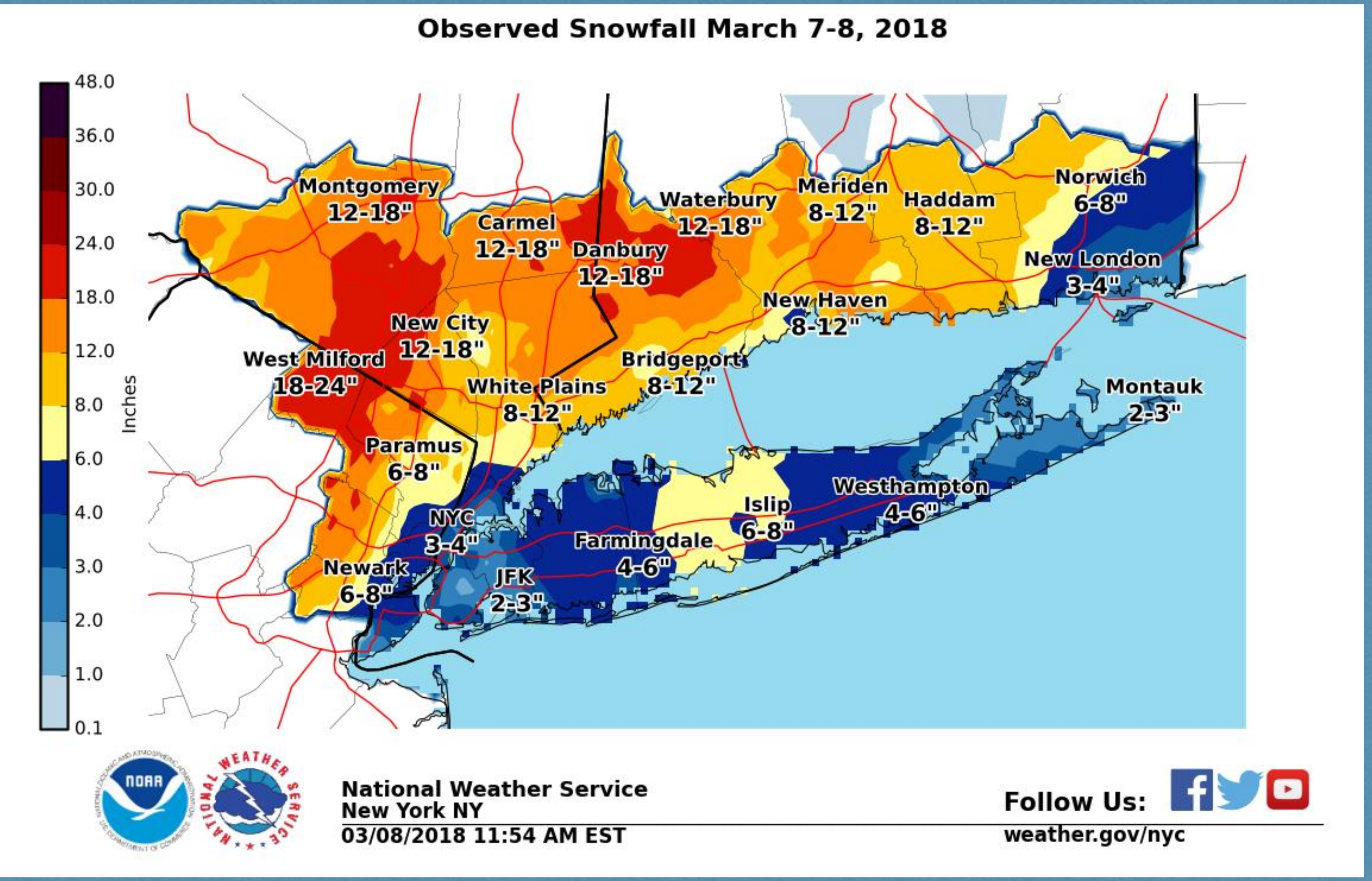


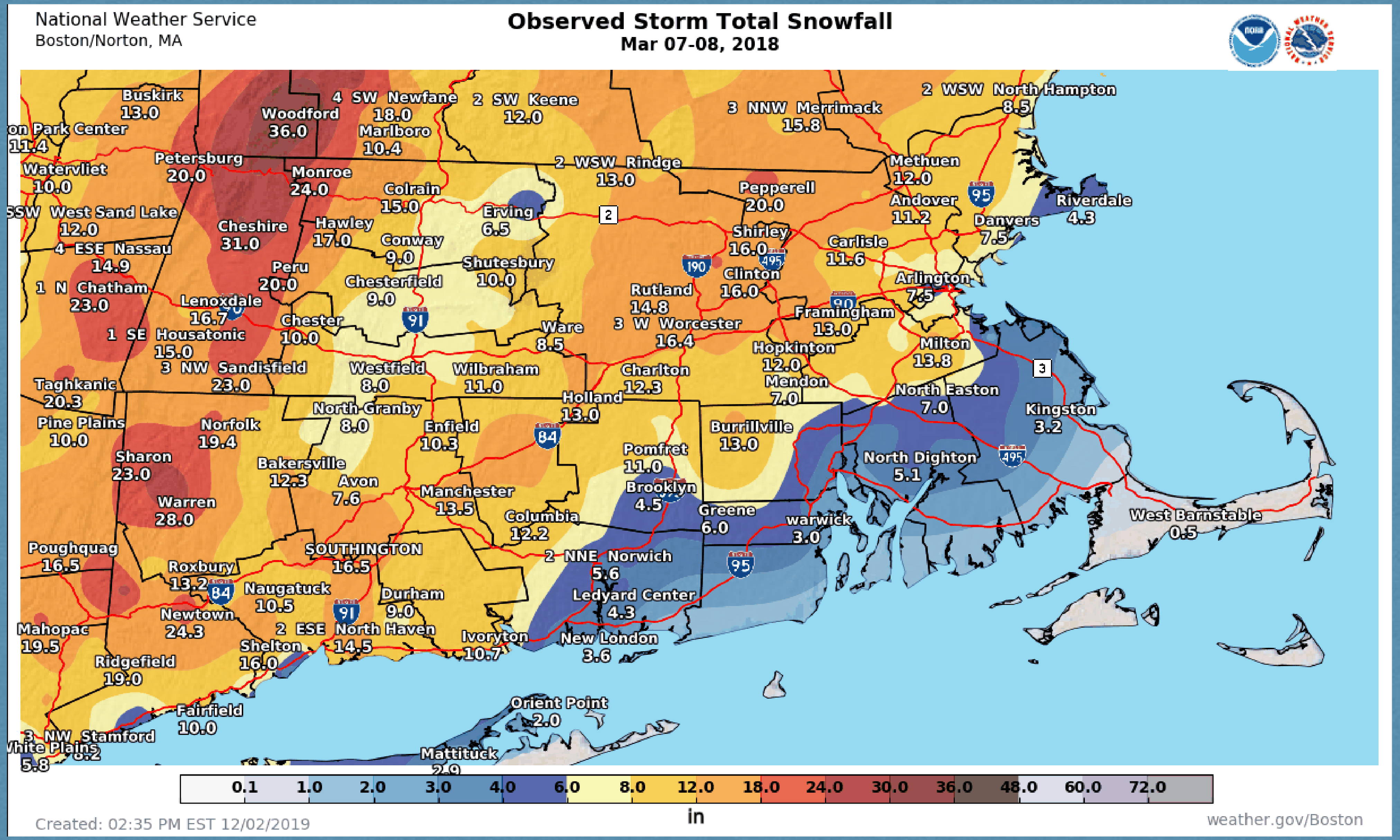
3/1-3/2018



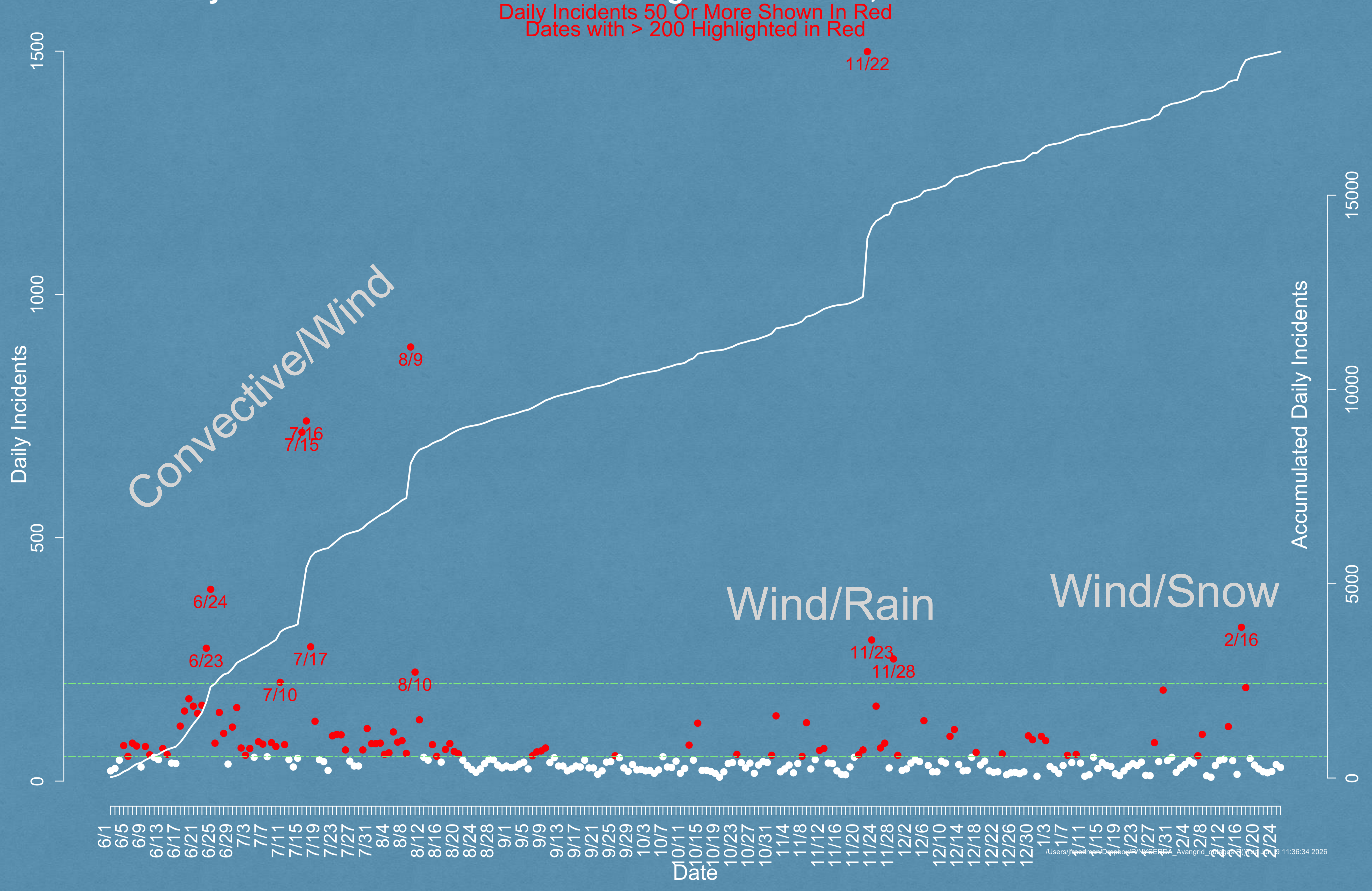


3/7-8/2018





Daily Number of Incidents in NY Avangrid Territories, 1 June 2024 - 26 Feb 2025



All WRF runs (including non-events): 346 cases

38 Thunderstorm cases

17 Rain/wind cases

13 Winter cases

Total of 68 cases with > 50 incidents

Need to minimize errors in spatiotemporal placement of forecasted winds and precipitation (rain and snow)

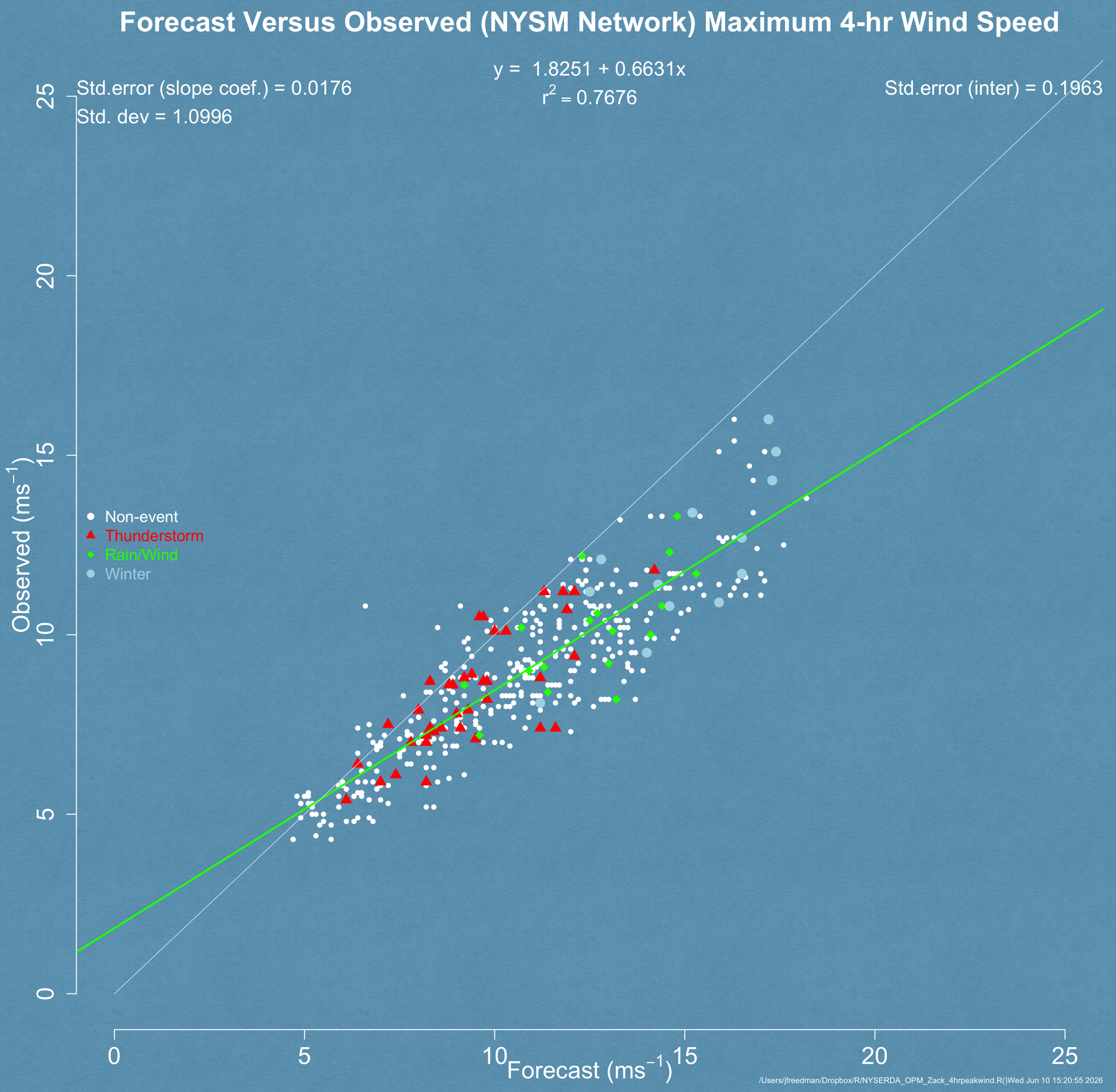
Specifically:

1. ***Maximum 4-hr average 10-m wind speed;***
2. Maximum 10-min average 10-m wind speed;
3. **Maximum 10-m wind gust;**
4. Total event precipitation;
5. ***Maximum 1-hr precipitation rate***; and
6. ***Total event snowfall***

Key takeaway: Max 4-hr wind speed

WRF tends to over predict gusts—an issue related to station siting and surface roughness.

WRF does correctly differentiate the relative magnitudes of the gusts by event type.



<u>Key takeaway: Max 1-hr wind gust</u>

WRF tends to over predict gusts—an issue related to station siting and surface roughness.

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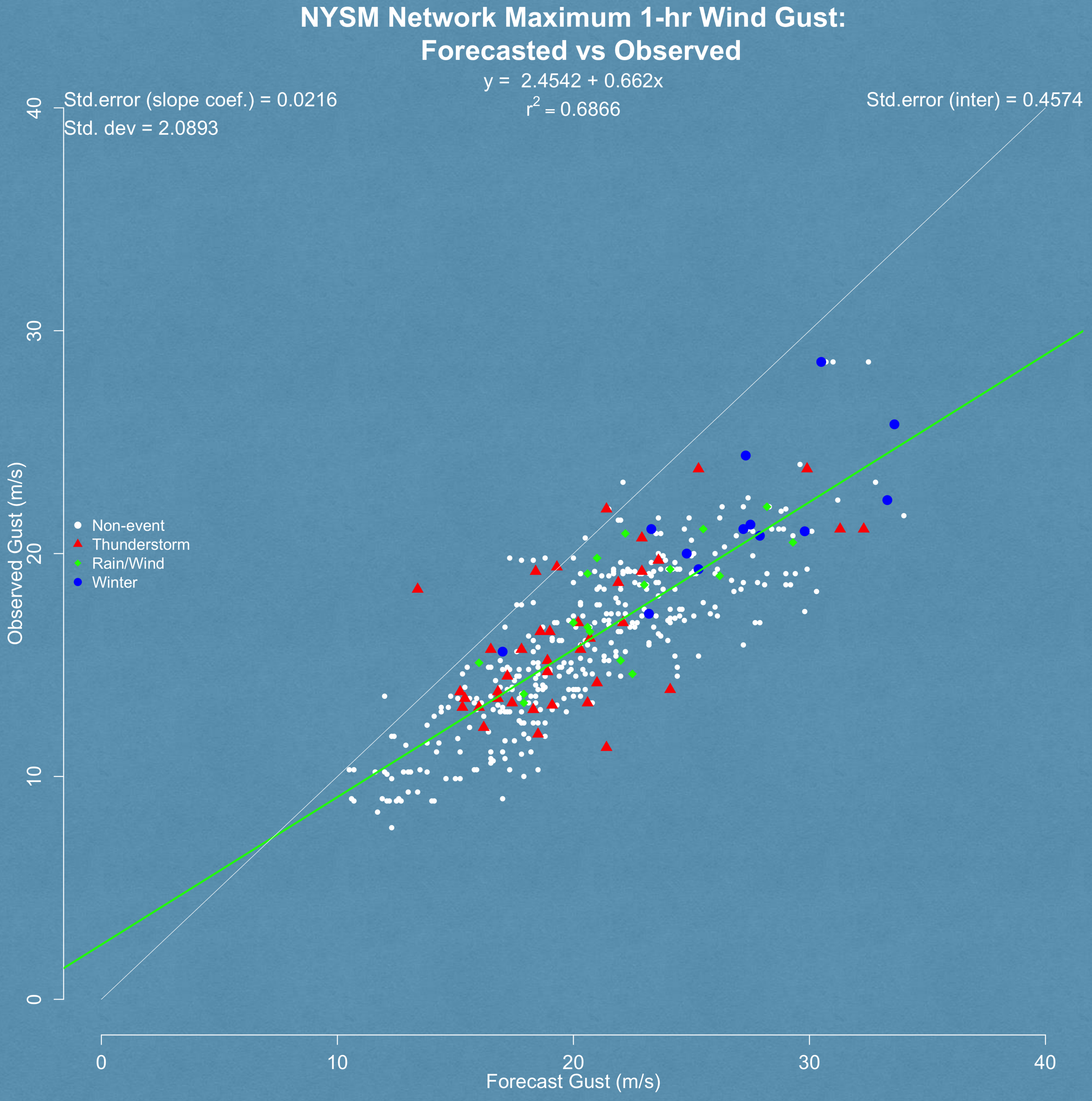


Total Precipitation (mm)

Key takeaway

1. Large spread in forecasted versus observed total precipitation for each case(48 hr period). Especially true for Thunderstorm events—convective-type storms tend to be more difficult to forecast in space and time, given the smaller scales involved.

2. Less spread in the Rain/Wind and Winter cases, consistent with the larger atmospheric and spatial scales involved in generating these types of storms. For the more significant events (total precipitation > 12.7 mm or 0.5 in), NWP performance is quite good, with higher hit rates and lower false alarms, especially for Rain/wind and Winter storms.

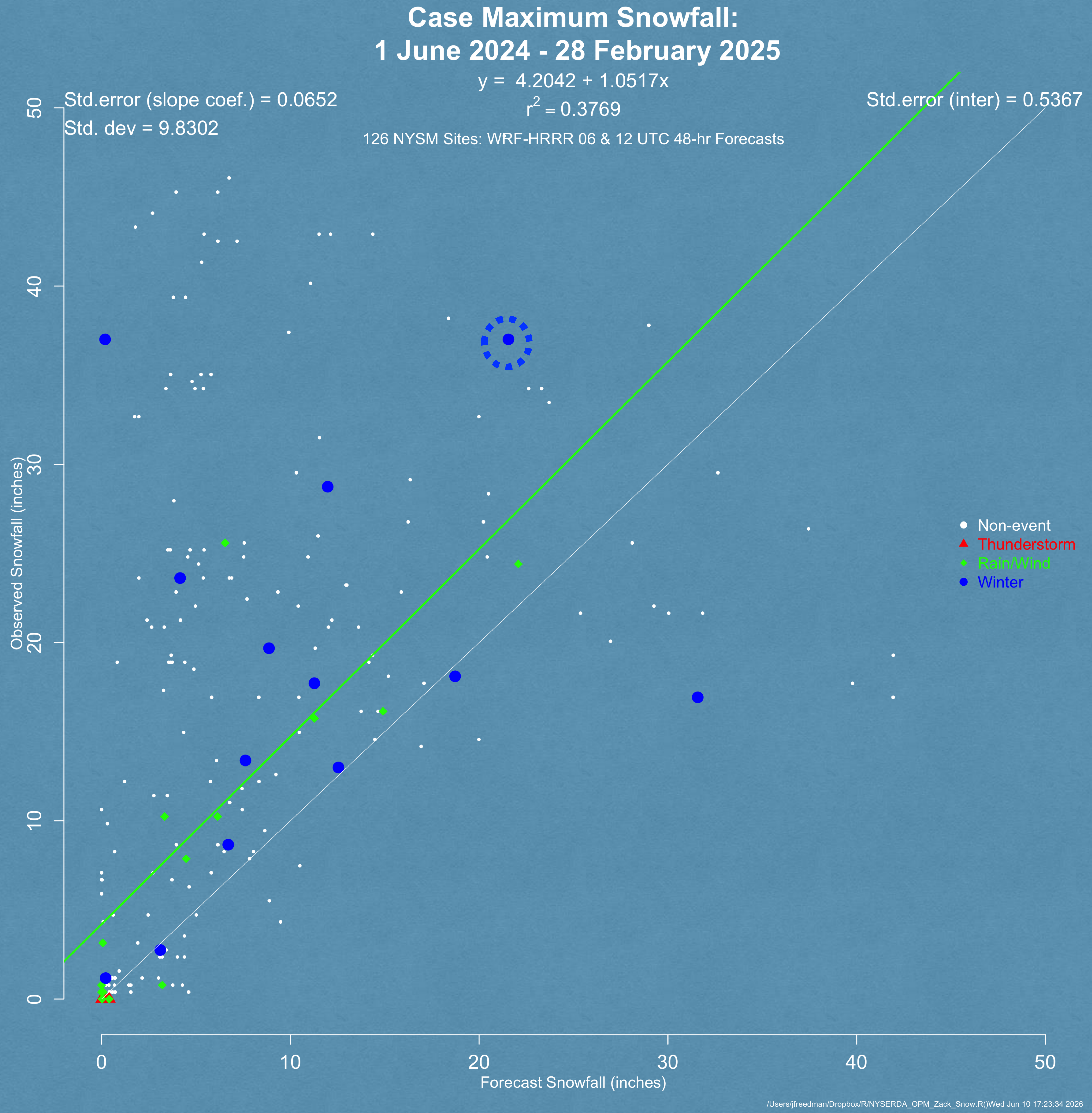
Variable: Total Precipitation (mm)					
Parameter	**All Cases**	**Non-event**	**TS**	**RainWind**	**Winter**
# of Fcsts	**432**	**364**	**38**	**17**	**13**
Mean Obs Max (mm)	29.10	25.67	60.86	29.92	30.94
Mean # Sites >12.7 mm	17.5	14.4	40.8	27.2	23.3
Mean # Site > 25.4 mm	6.8	5.0	20.4	15.4	7.2
Bias (mm; Site Max)	0.03	-0.12	1.61	-0.07	-0.29
MAE (mm; Site Max)	4.06	3.36	11.25	3.38	3.51
RMSE (mm; Site Max)	6.23	5.23	16.90	4.70	5.09
Bias (mm; Case Max)	0.15	-1.34	17.53	-3.26	-4.66
MAE(mm; Case Max)	12.12	10.80	28.27	5.44	10.19
Correlation (Sites)	0.387	0.385	0.305	0.505	0.515
Hit Rate (>12.7 mm)	0.64	0.60	0.68	0.89	0.67
FA Rate (12.7 mm)	0.38	0.41	0.38	0.13	0.32
Bia Ratio (>12.7 mm)	1.03	1.02	1.09	1.03	0.99
CSI (>12.7 mm)	0.46	0.42	0.48	0.79	0.51
Hit Rate (>25.4 mm)	0.51	0.48	0.51	0.80	0.48
FA Rate (>25.4 mm)	0.48	0.48	0.55	0.26	0.41
Bias Ratio (> 25.4 mm	0.99	0.92	1.14	1.07	0.81
CSI (> 25.4 mm)	0.31	0.33	0.31	0.62	0.36

Key takeaway—case max snowfall

Performance for the Winter and Rain/Wind cases is reasonable despite large errors resulting several intense large lake effect snow events (e.g., more than five feet of snow was observed in narrow 5-10 mile wide bands downwind of Lakes Erie and Ontario in multiple events

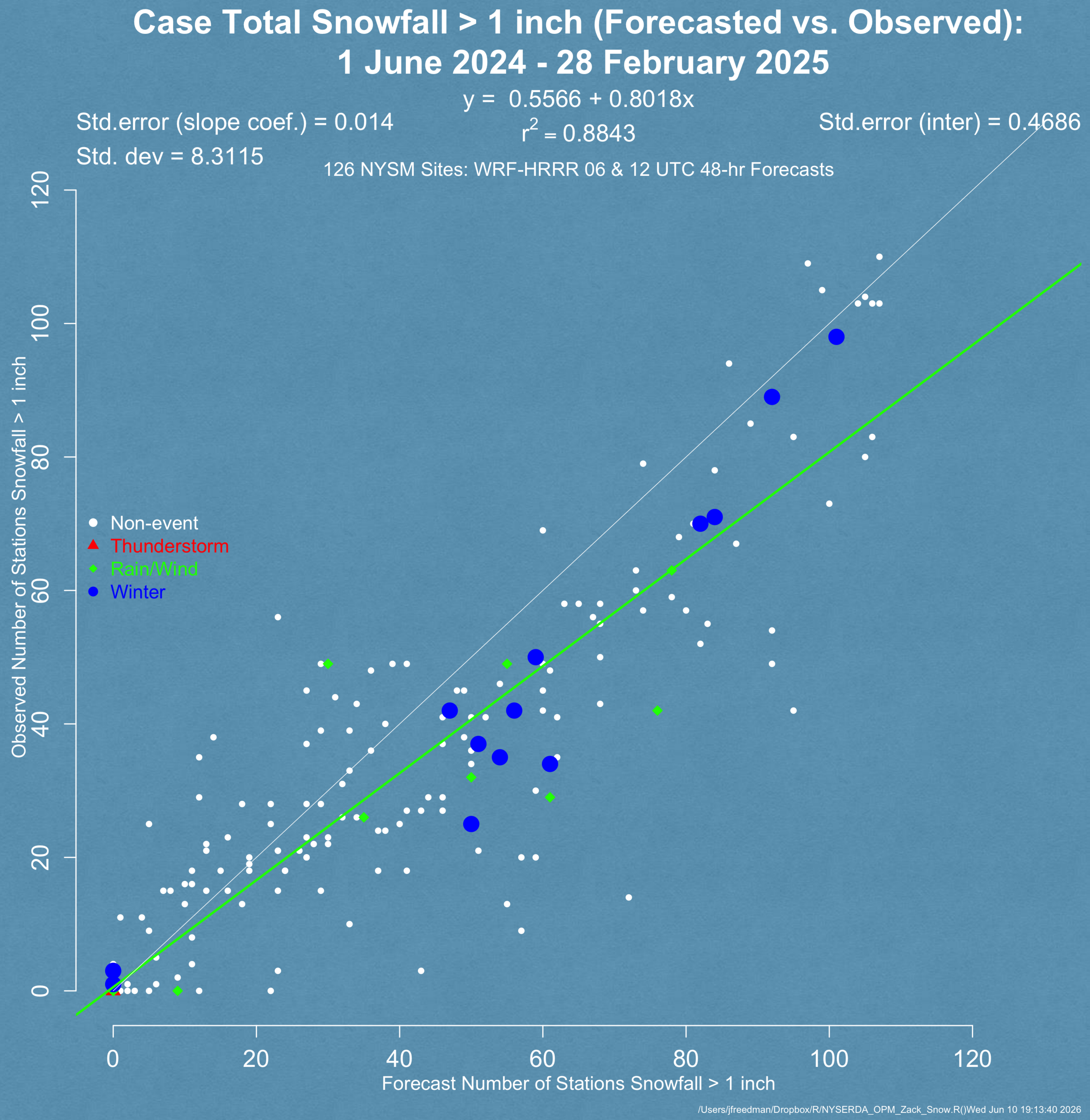
Generally non-events, given the nature of type of snowfall typically associated with lake effect (dry and fluffy) and the localized aspect of these events.

Exception was the event of 11 – 13 December 2024, where strong winds (gusting to 50+ MPH or > 22 ms^{-1}) after the passage of a frontal system (a Rain/Wind event) accompanied the subsequent development of persistent lake effect snow bands—well-captured by NWP (circled blue dot).



Key takeaway—total snowfall > 1”

Overall, WRF performed well when examining the number of stations forecasted to experience > 1 inch of snowfall compared with observations (r^2 of 0.88).



Conclusions

1. Damaging (and largest power outage events) weather events tend to be of a compound nature (at least in the Northeast US);
2. Large-scale events forecasted well by optimized NWP (WRF);
3. Convective and lake-effect snow events can be problematic due to spatiotemporal aspects of these systems; and
4. Work continues!

Thank You!