Heavy Precipitation Object Tracking and Forecast Tools

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‘Catastrophic flooding’ forces water rescues in Vermont after 1-in-1,000-year rainfall event

By Alisha Ebrahimji and Kara Mihm, CNN
4 minute read · Updated 11:53 PM EDT, Tue July 30, 2024

Workers clear debris amid flood damage in Lyndon, Vermont, on Tue

Vermont floods raise concerns about future of state's hundreds of aging dams

July 16, 2024 By Michael Casey, The Associated Press

A loader dumps dirt along a washed out portion of Mill Street after remnants of Hurricane Beryl caused flooding and destruction, Friday, July 12, 2024, in Plainfield, Vt. (Charles Krupa/AP)

Flash Flood Impacts in the United States

- Forecasting for heavy precipitation events remains a challenge in warning operations, which ultimately affects lives, property and transportation
- Flash Flood events account for a significant portion of the total damages and fatalities compared to other weather phenomenon (NWS, 2017 & 2023).

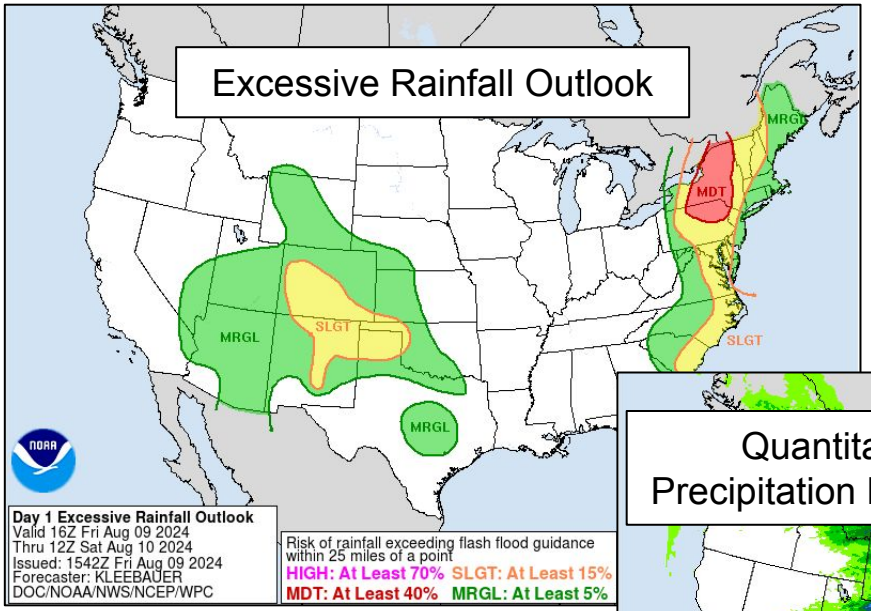
Summary of 2017 Weather Events, Fatalities, Injuries, and Damage Costs

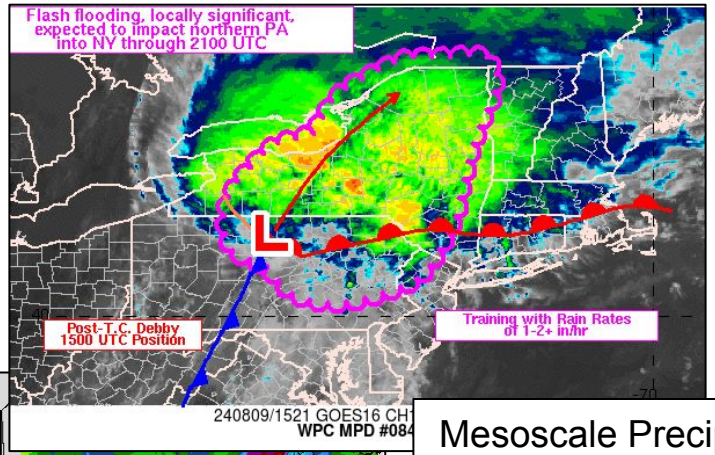
Weather Event	Fatalities	Injuries	Property Damage (million $)	Crop Damage (million $)	Total Damage (million $)
Convection					
Lightning	16	86	16.09	0.00	16.09
Tornado	35	516	631.87	17.31	649.18
Thunderstorm Wind	30	148	236.36	30.40	266.76
Hail	0	14	1,722.23	59.52	1,781.76
Extreme Temperatures					
Cold	26	3	0.00	954.13	954.13
Heat	107	176	0.01	0.00	0.01
Flood					
Flash Flood	103	8	59,118.68	62.13	59,180.81
River Flood	13	11	1,457.53	61.26	1,518.78

Summary of 2023 Weather Events, Fatalities, Injuries, and Damage Costs

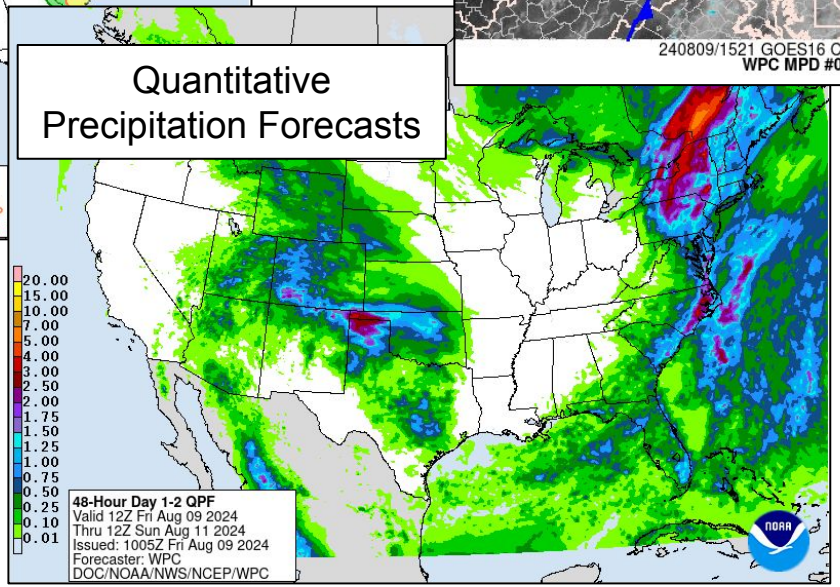
Weather Event	Fatalities	Injuries	Property Damage (million $)	Crop Damage (million $)	Total Damage (million $)
Convection					
Lightning	14	56	29.89	0.95	30.84
Tornado	86	914	1,371.05	7.25	1,378.31
Thunderstorm Wind	36	164	605.96	42.73	648.70
Hail	0	93	2,201.94	107.40	2,309.35
Extreme Temperatures					
Cold	11	8	0.01	7.28	7.28
Heat	207	1862	0.00	0.00	0.00
Flood					
Flash Flood	39	12	1,593.88	3.19	1,597.07
River Flood	31	2	495.78	8.36	504.14

Weather Prediction Center Operational Rainfall Products



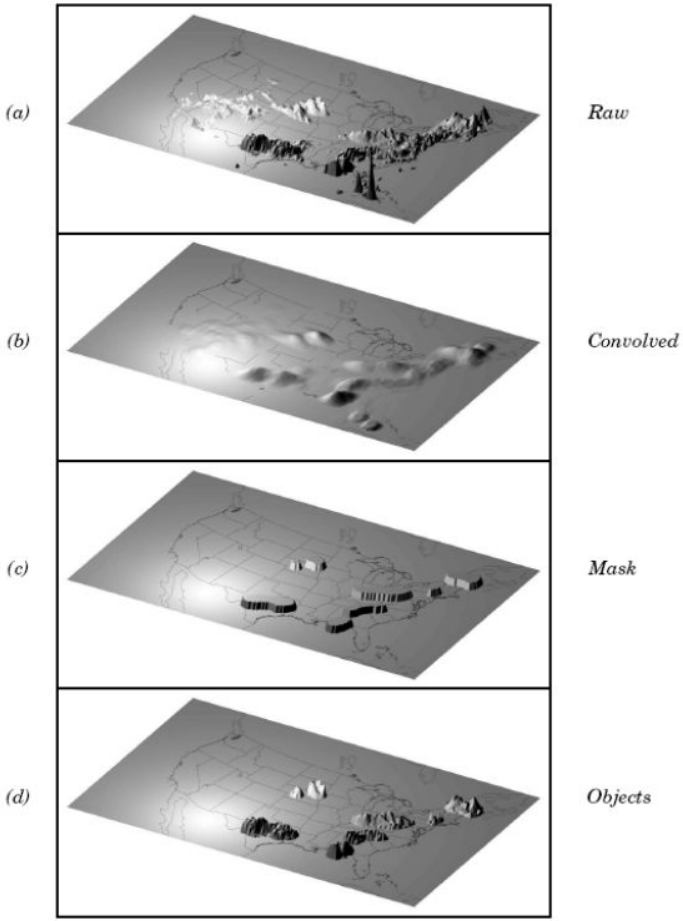


Mesoscale Precipitation Discussions



Identifying QPF Objects

- Model Evaluation Tools (MET) Method for Object-based Diagnostic Evaluation Time-Domain (MTD) is used to track precipitation objects through time.
- 3 steps to identify objects:
  1. **Convolution**: smoothing of the raw precipitation field, reducing noise to produce a cohesive field.
  2. **Masking**: Applying a particular threshold to allow for boundaries of precipitation objects to be detected.
  3. **Filtered**: Mask is placed over raw precipitation field.
- Additional steps (**Matching** and **Merging**) are taken to relate objects to one another when analyzing model and observations together, as well as separately.



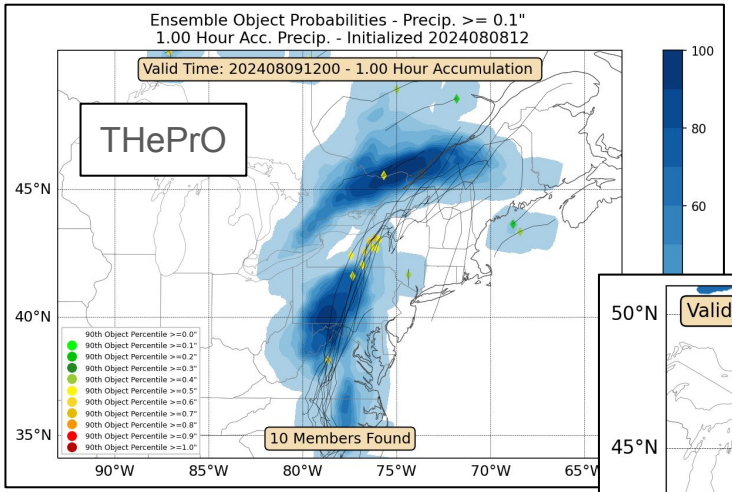
Brown et al. (2008)

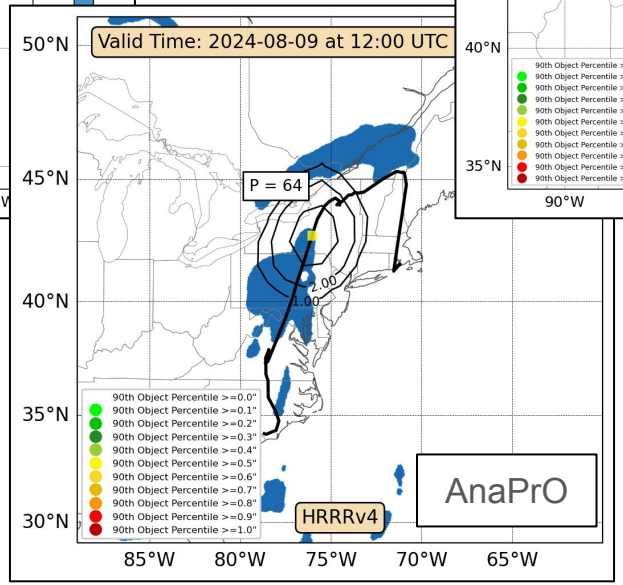
Putting these tools to use!

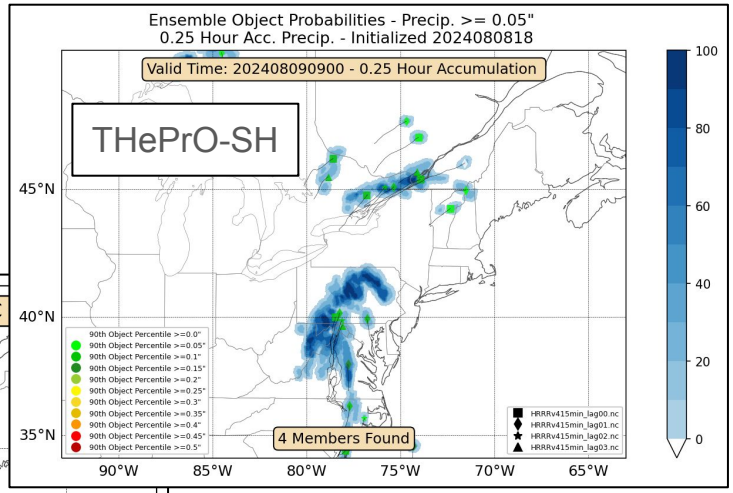
- These tools can be used in a variety of ways.
- They are widely used the Weather Prediction Center to evaluate the performance of model QPF.
    - Compared against Stage IV or MRMS QPE

- The goal of using them here is to create tools that capture uncertainty and bias within the model QPF in an operational sense.
- Can also use historical QPF object characteristics to diagnose bias and displacement within the forecasted QPF?

Heavy Precipitation Object Tracking at the WPC







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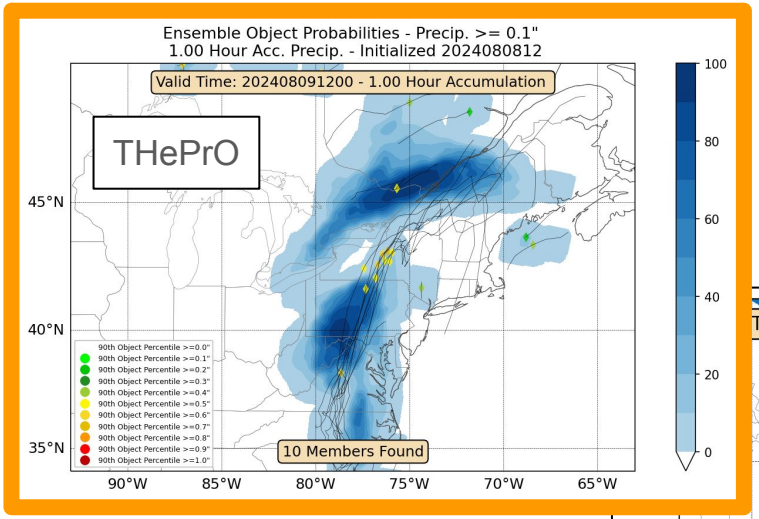
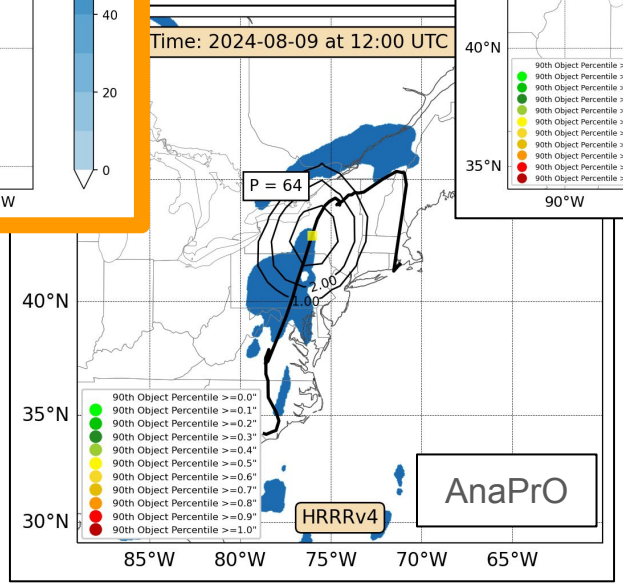
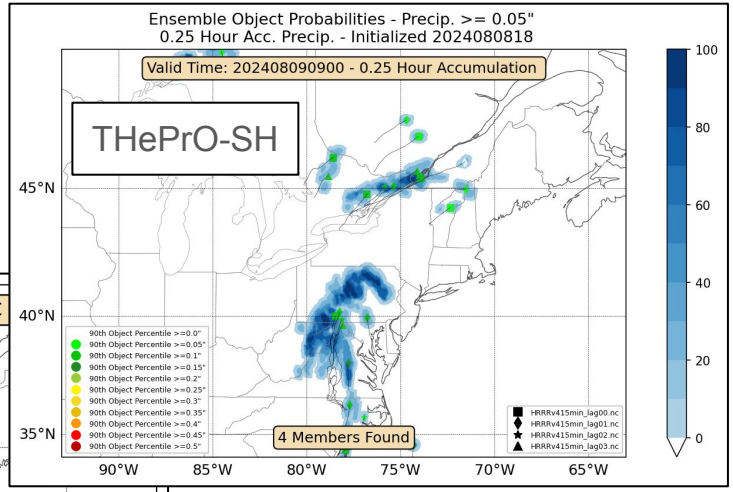
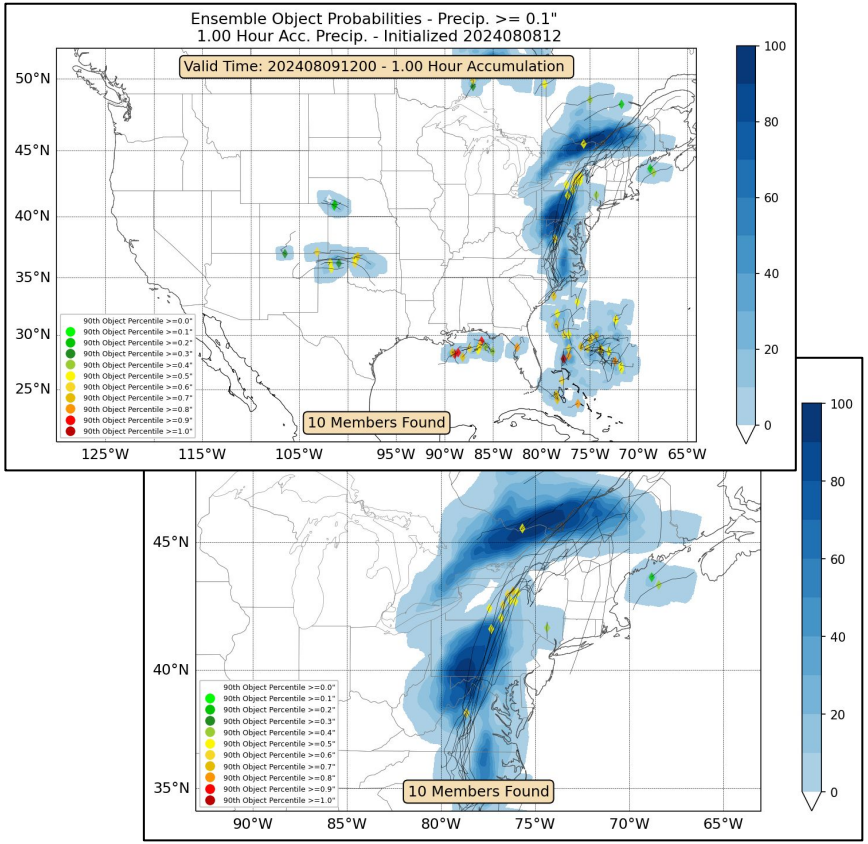




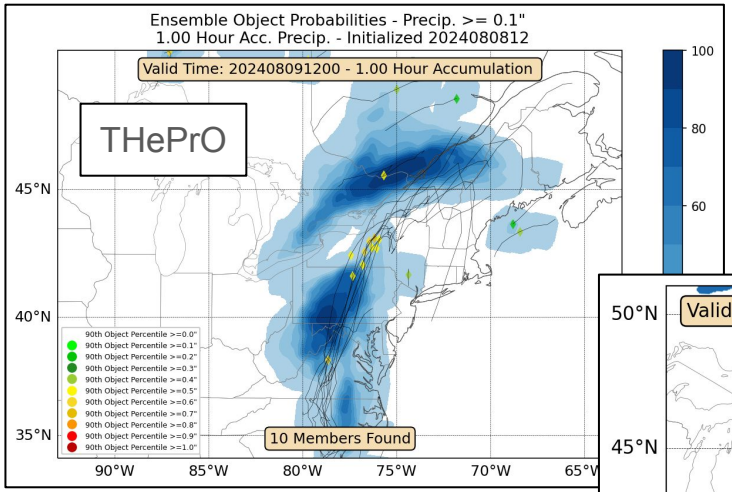


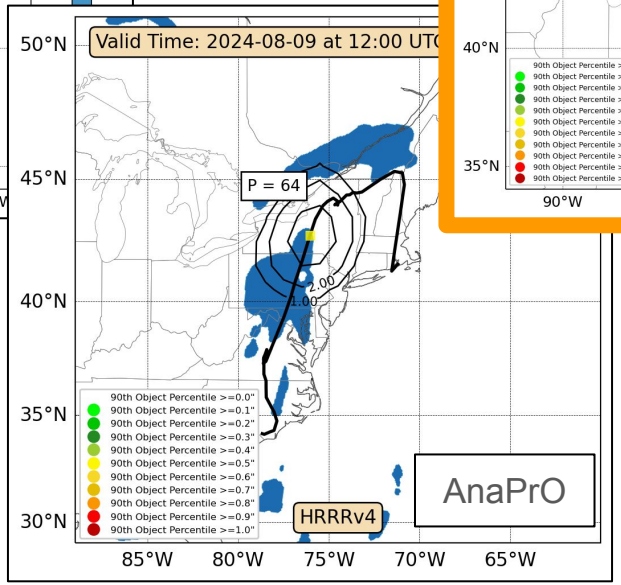
Tracking of Heavy Precipitation Objects (THePrO)

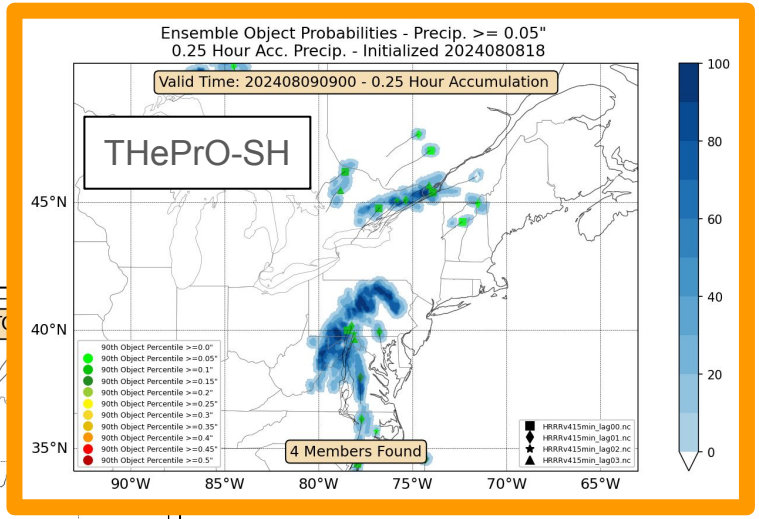
- Ensemble probability of being in a heavy precipitation object.
  - Greater than or equal to 0.1” per hour
- Location of object centroid for each ensemble member.
- 90th object percentile of hourly accumulated precipitation.
- Ensemble membership:
  - HREF includes 5 current and 5 time-lagged members (00z and 12z initializations)
  - HRRR includes 1 current and 2 time-lagged (00z, 06z, 12z, 18z initializations)



Heavy Precipitation Object Tracking at the WPC



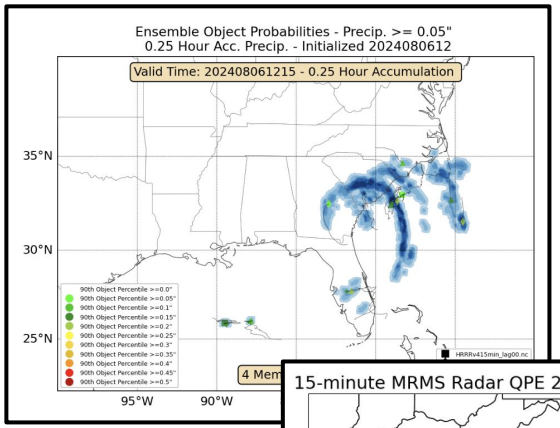


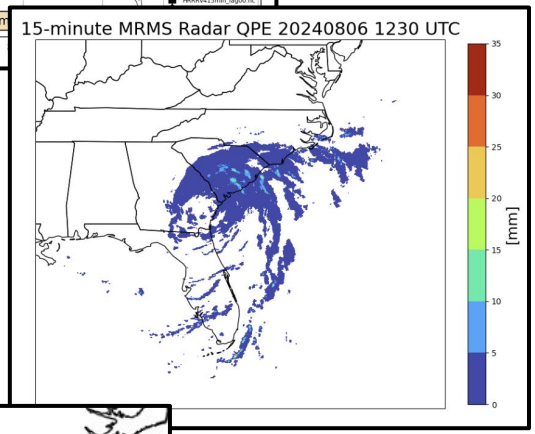


THePrO- Sub Hourly (SH)

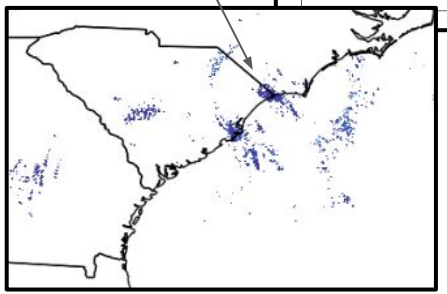
- Uses 4 member HRRR Time-lagged ensemble of 15-minute QPF
- Employs similar technique to THePrO
    - Forecasts for likelihood of heavy precipitation objects (>= 0.05” in 15-min)
- The tracking algorithm has been adapted to subhourly data to analyze smaller scale features.

- Development to provide enhanced forecasts using MRMS and mid-level rotation.
- Rotating features known to enhance precipitation efficiency (e.g. Nielsen et al. 2019)
- Mid-level rotation induces in a sustained source for ascent, which increases drop residence time and hence precipitation efficiency (e.g. Brauer et al. 2020)

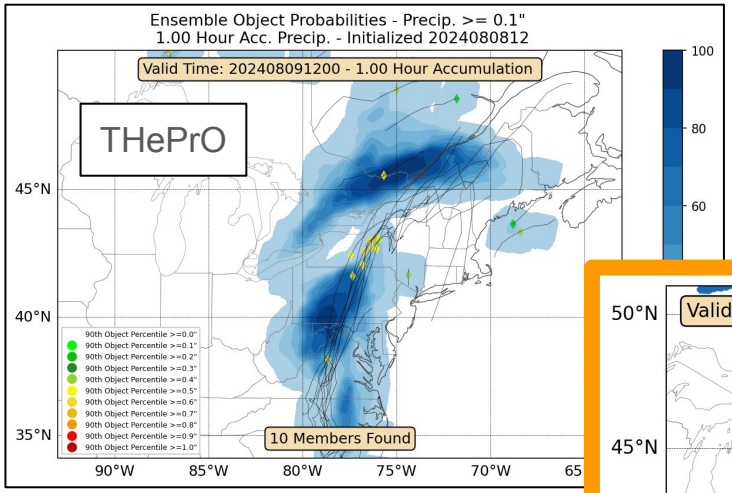


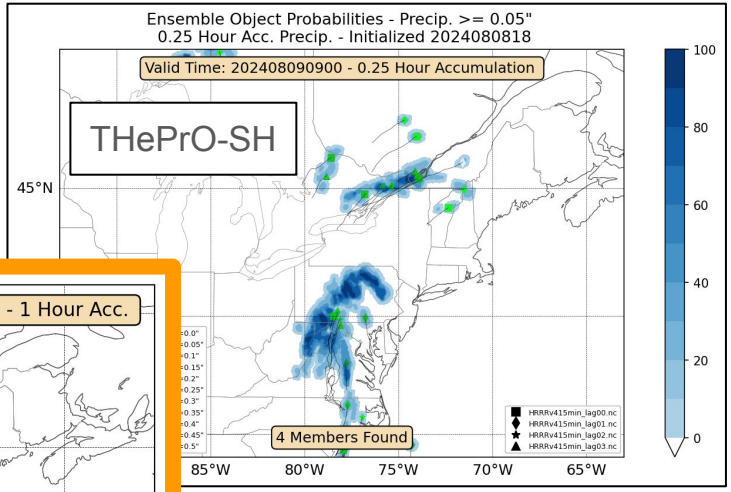


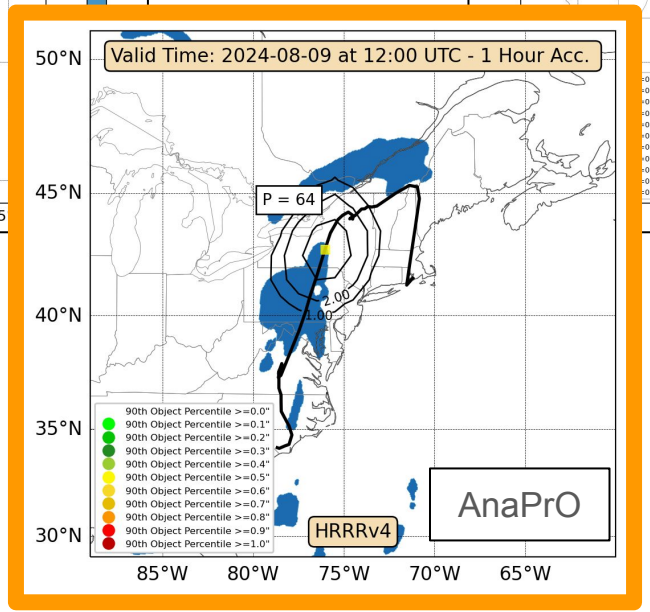
Small-scale rotating features observed on the subhourly scale in outer bands



Heavy Precipitation Object Tracking at the WPC

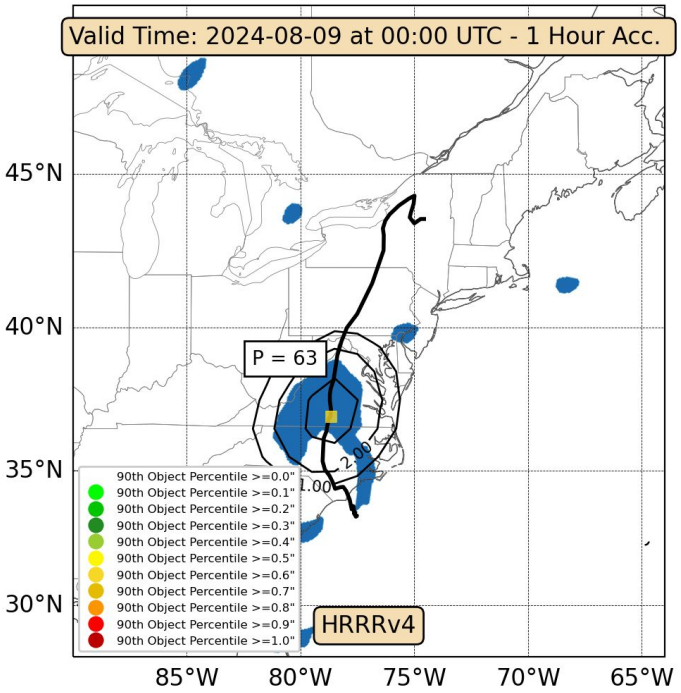




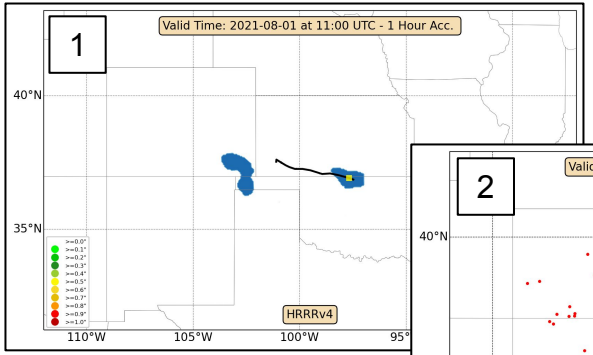


Analog Forecasting of Precipitation Objects

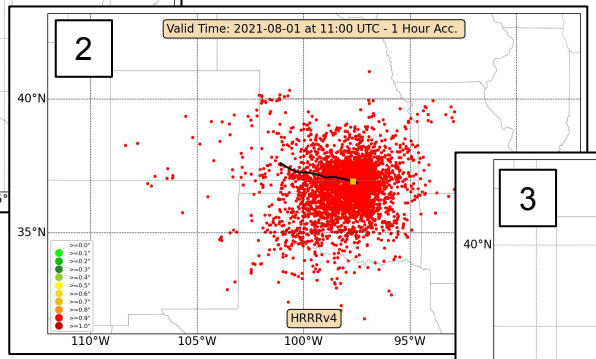
- Extension of the THePrO by providing displacement information.
- Provides neighborhood probabilities for likelihood of object centroid falling within 40 km.
- Uses a retrospective archive to capture location bias of similar events.
- Provides centroid track and probability of heavy rainfall object occurring for given forecast.
- Is run for extended runs of HRRRv4
    - (00z, 06z, 12z, 18z initializations)



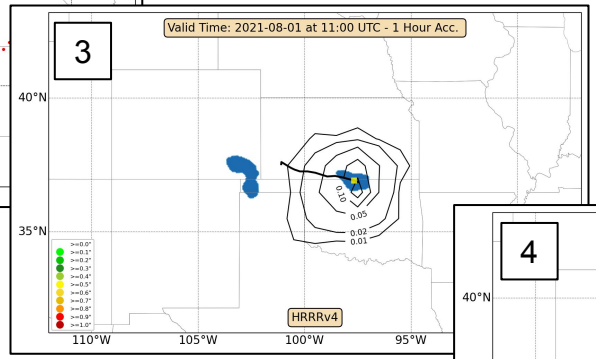
AnaPrO Demonstration



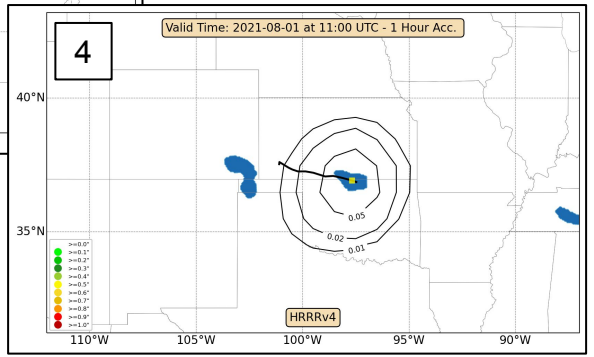
1. Precipitation object is found using THePrO technique.



2. Forecast object is linked to retrospective archive.



3. “Uncentainty cloud” is calculated using similar historical objects.

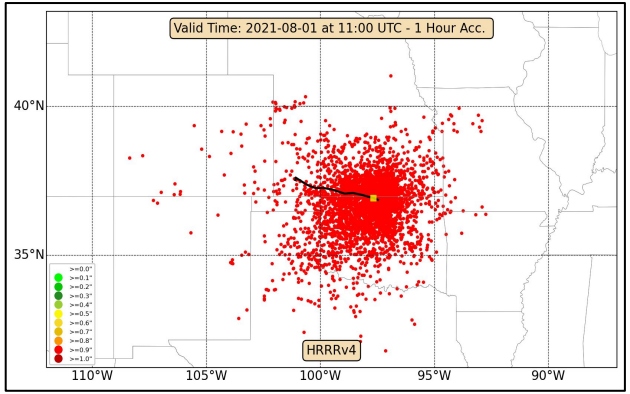


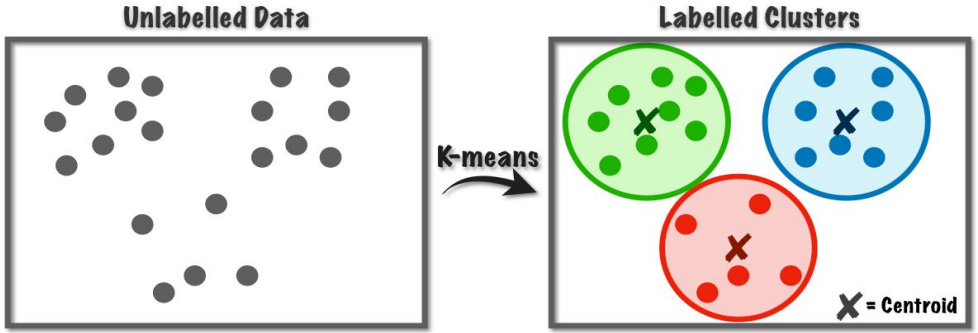
4. Gaussian filter is applied to probabilities to decrease noise.

AnaPrO Retrospective Machine Learning (ML)

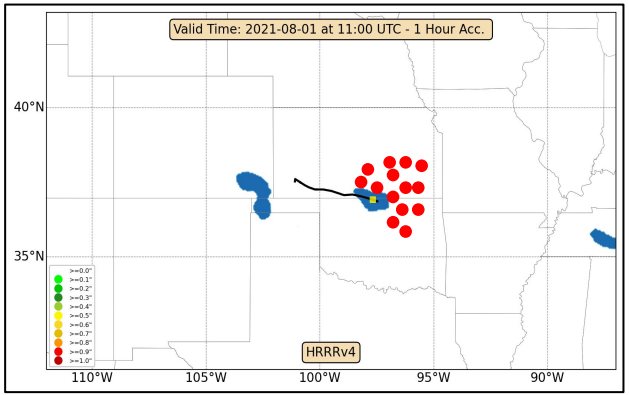
- To improve product's skill and reliability, we use k-Means clustering to further limit historic objects to include only those that share similar features and storm modes
- Storm modes (eg. Pulse Storm, Supercell, Tropical, etc.) move and behave uniquely and require different synoptic conditions
- k-Means clustering is a unsupervised ML method that can group data points together that share similar attributes

Current Analysis

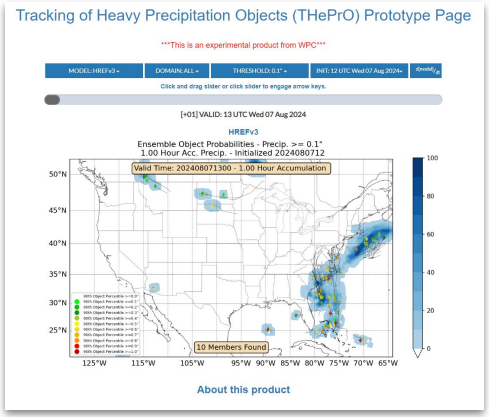


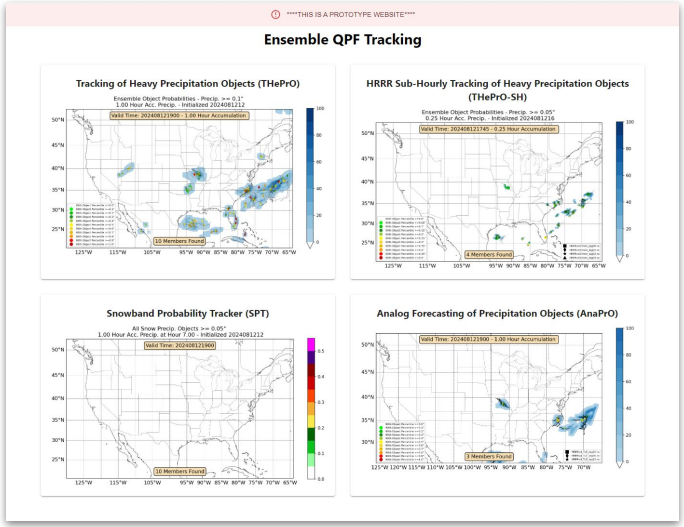


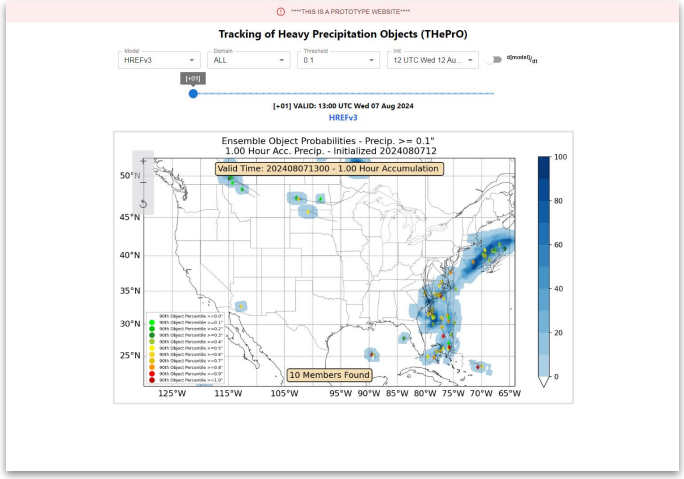
Clustered Analysis Example



Web development







Existing Web Pages:

- THePrO
- THePrO-SH
- SPT
- AnaPrO

New webpage(s) are currently in development that improve upon the relatively simple interfaces above. These new pages will allow for similar viewing of static images, as well as a new interactive map view.

Some New Features:

- Pre-loading of images for smooth scrubbing
- An easier to use product selection menu
- Zoomable images
- Responsive design that scales to browser window or device size
- Interactive map view (in development)

Development Task Summary

- Development of object-based tools aims to communicate model uncertainty and bias of CAMs for operational forecasts.
- Focused on improving these tools through the inclusion of other meteorological data.
- Machine learning will provide a filter for a retrospective archive for the AnaPrO to capture similar events.
- Upgrading how we communicate this analysis through enhancing the web pages user interface.

AnaPrO Retrospective Component

- Consider similar historic objects
  - 2020 - 2022
  - +/- 4 degrees lat/lon
  - +/- 1 month
  - +/- 12 forecast hours
- For all objects that meet this criteria, map the historic object location to the current object location
- Compare historic object's observed displacement to generate probabilities