Tracking and Usage of Ensemble Model Heavy Precipitation Objects at the Weather Prediction Center

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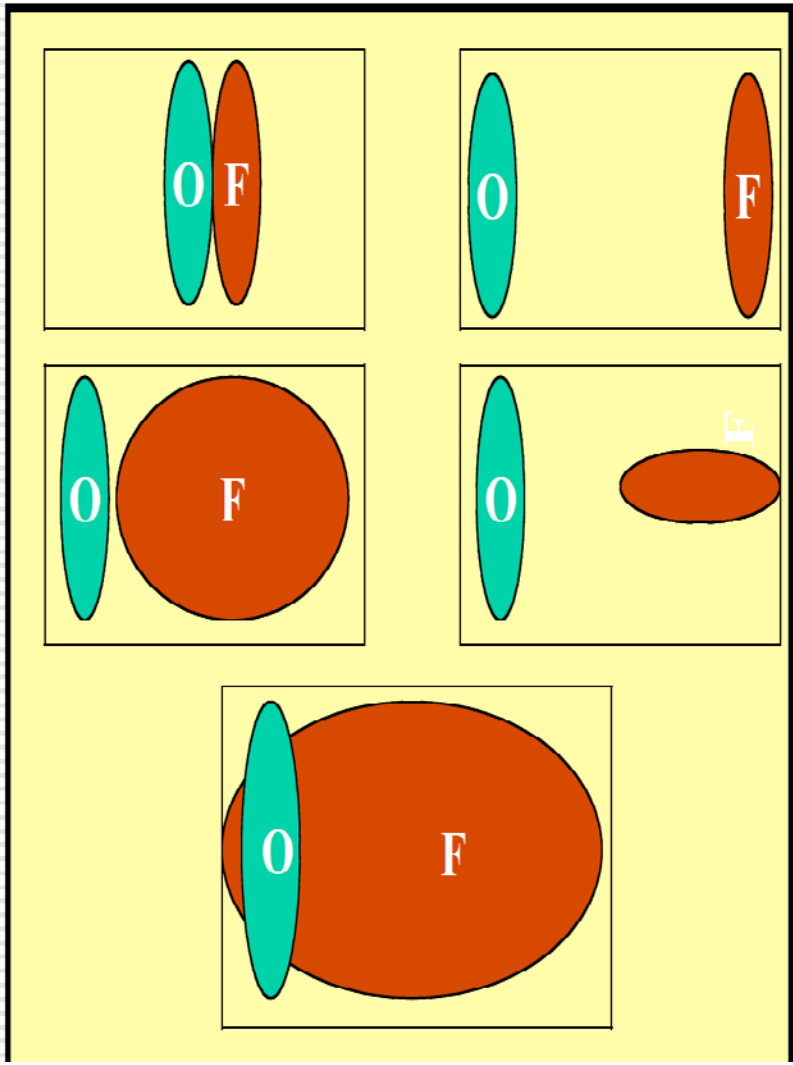
Why Track Objects?

- Output from Quantitative Precipitation Forecasts (QPF) look like coherent objects.
- Humans automatically evaluate QPF "goodness" by eye.
- Standard verification doubly penalizes models for a displaced forecast. ***A model that forecasted no object would score better***.
- Object-oriented verification of QPF objects allows for a more intuitive type of evaluation that assesses:
  1. Object centroid (i.e. displacement)
  2. Object area
  3. Object intensity
  4. Object orientation
  5. Object initiation/dissipation

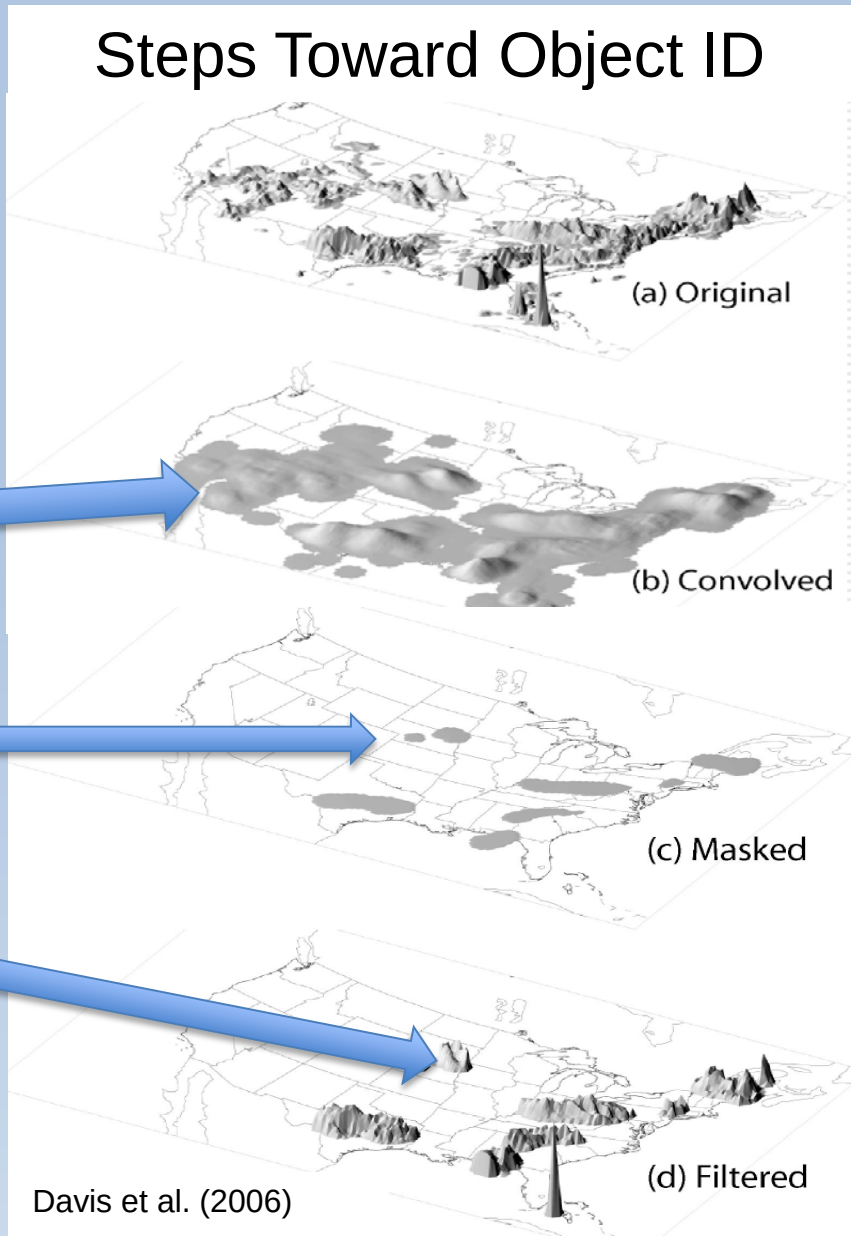
Forecast Vs Observations



Davis et al. (2006) and Gilleland et al. (2007)

Tracking QPF Objects – Identification

- The Model Evaluation Tools (METv8.1) Method for Object-based Diagnostic Evaluation Time-Domain (MTD) is used to track precipitation objects.
- The identification of precipitation objects involves 3 steps:
  1. **Convolution (smoothing)** of the raw precipitation field to remove noise and identify cohesive objects.
  2. **Masking** the precipitation data below a specified threshold to identify objects of sufficient intensity.
  3. **Filtering** (retaining) the raw precipitation data inside the objects identified and removing all other data.

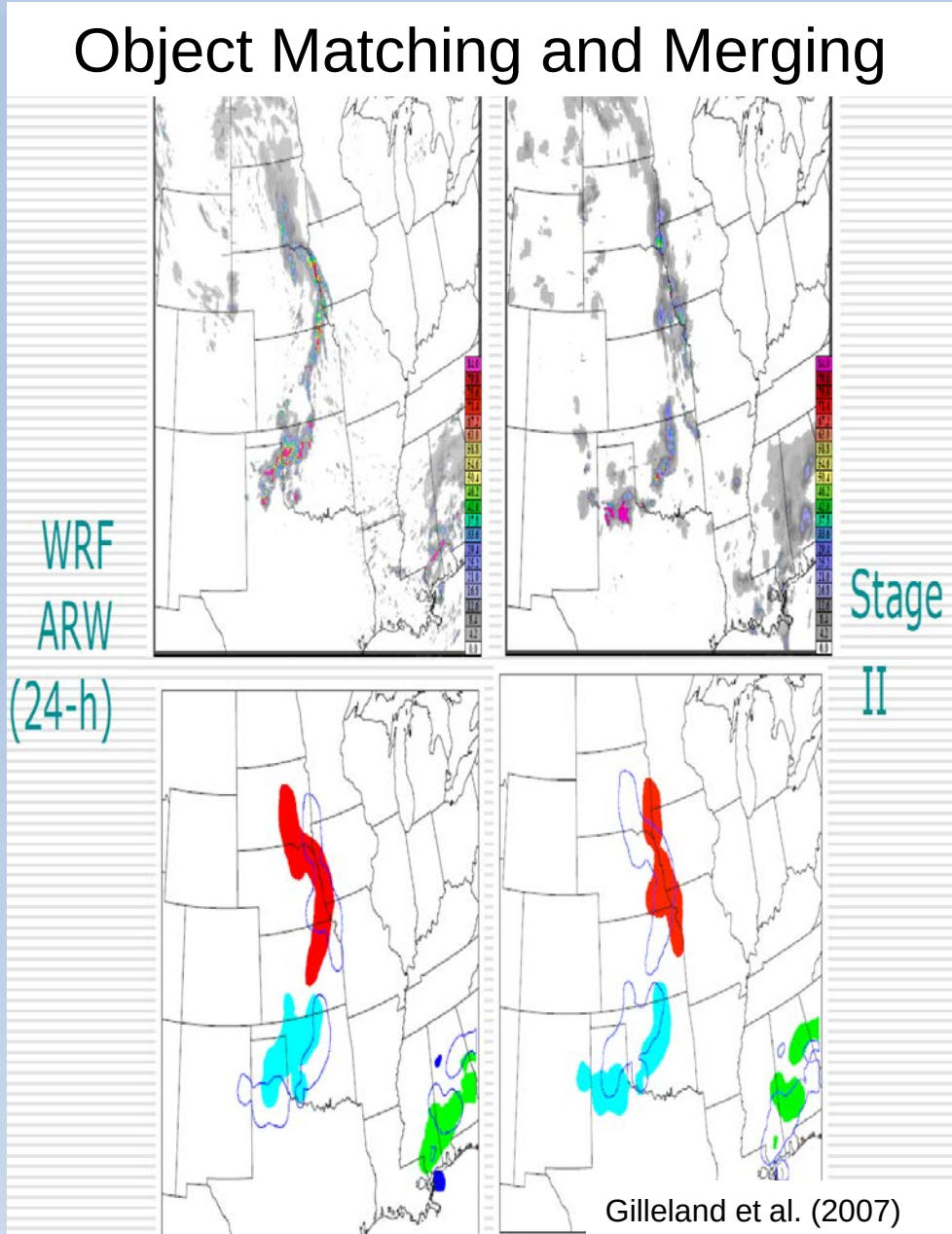


Tracking QPF Objects – Matching/Merging

- MTD compares objects within the same field and between model and observation by:

1. **<u>Merging</u> Objects**: If two objects in a forecast or observation field are close together, they are combined into one.
2. **<u>Matching (Pairing)</u> Objects:** If a forecast and observation object are similar enough, they are considered the same object. ***This is how difference statistics in object attributes are computed***.

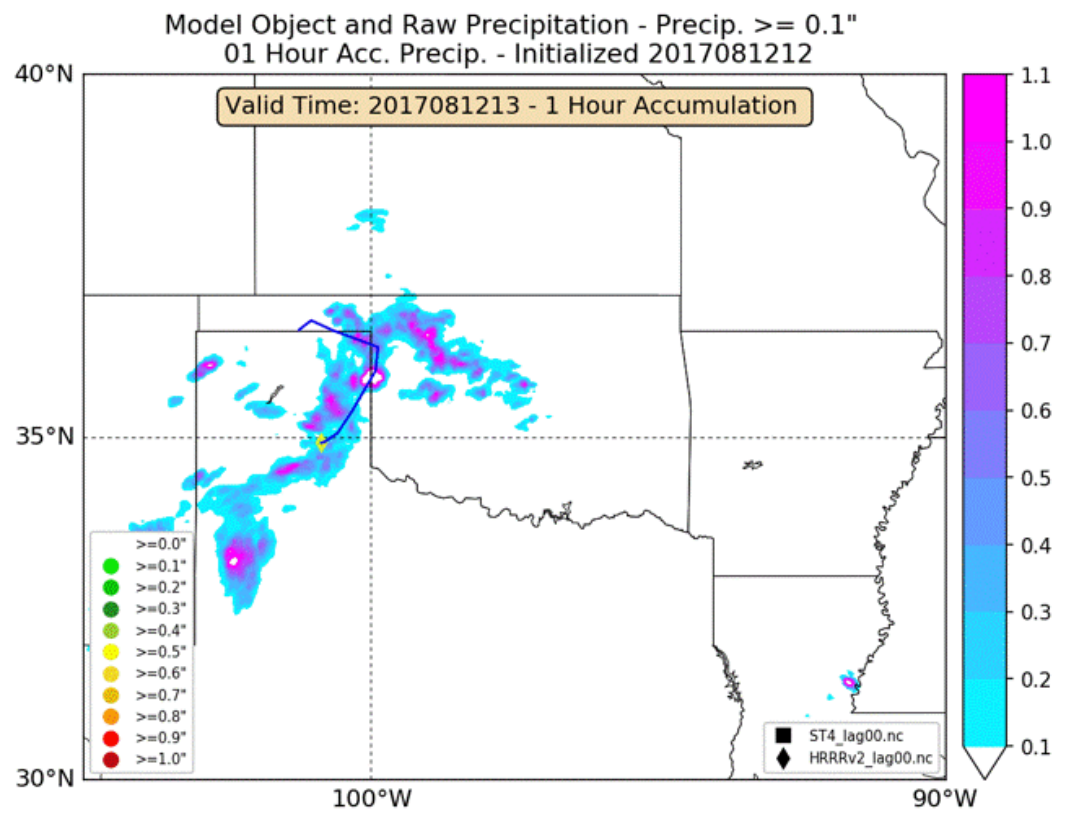
- **MTD should not simply be run "out of the box."** MTD should be tuned.



What is a Precipitation Object?

- Defining what is meant by a precipitation object is not trivial
- When isolating objects, one must consider:

1. Size of objects to be captured
2. Intensity of objects
3. Spatial/temporal separation between objects
4. Temporal resolution of the data available

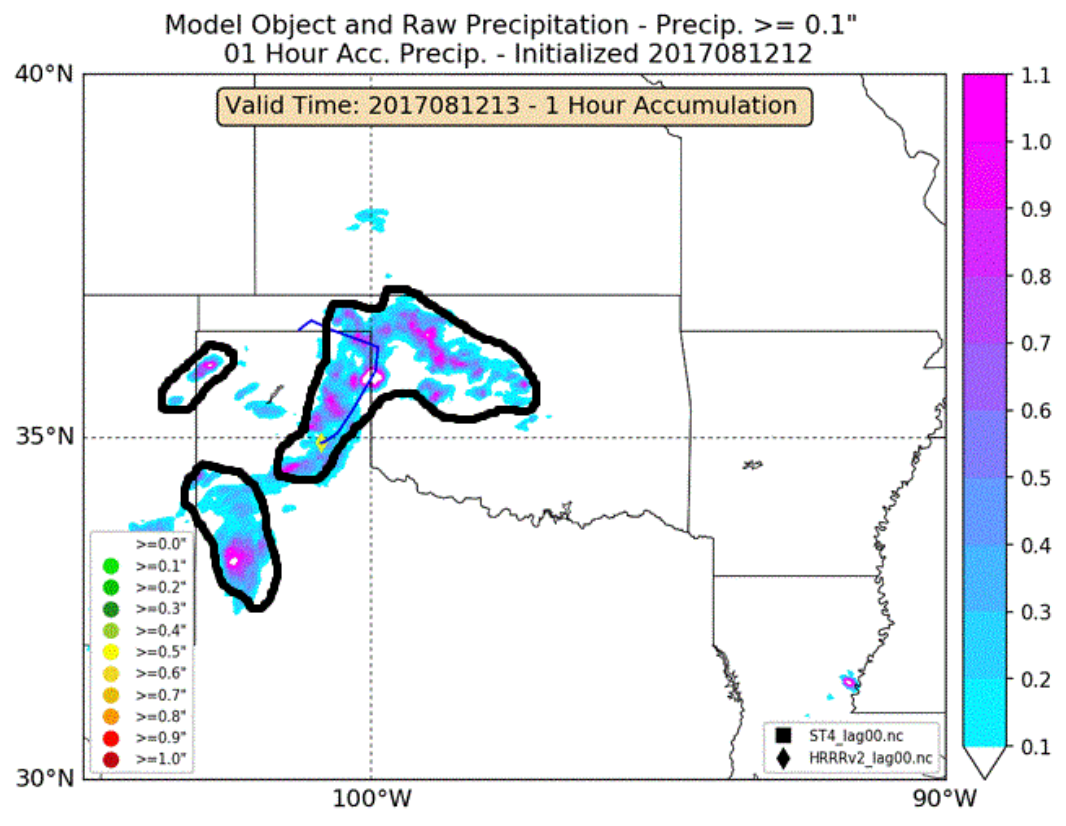


What is a Precipitation Object?

- When trying to capture more meso-alpha like heavy rain features that can lead to heavy rain, there may be only one precipitation object.

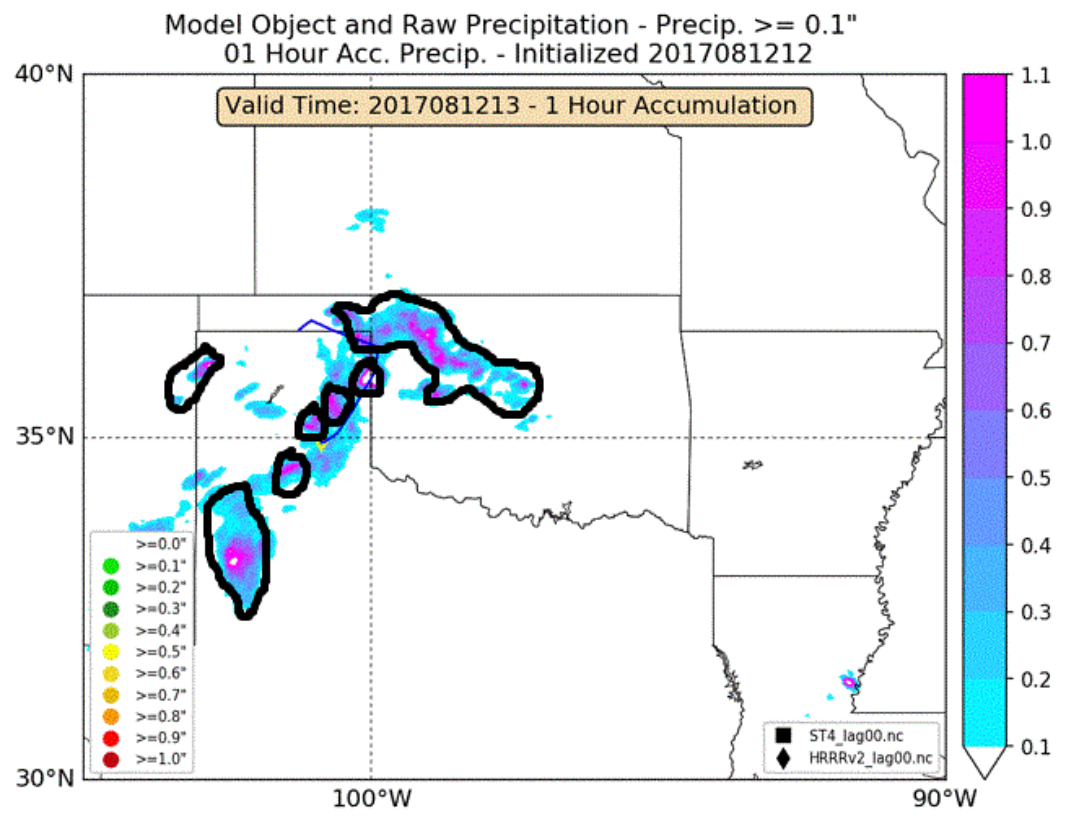
What is a Precipitation Object?

- There may be 3 objects when considering this event on the order of the meso-beta scale.
- Can one justify separating the northeast object from the southwest object given the small spatial separation?



What is a Precipitation Object?

- There may be MANY objects when looking at individual cells.
- Tracking these objects is difficult due to rapid changes in individual cells.
- For tracking, data must be available at a very high temporal resolution.
- For simplicity, our first approach will target larger mesoscale features.



Identifying QPF Objects at WPC - Overview

- The Weather Prediction Center (WPC) is transitioning towards object-based evaluation of QPF through:

A. Testbed Evaluations: Using object-based verification with participant feedback in the Flash Flood and Intense Rainfall Experiment (FFaIR).

B. Experimental Graphics: Displaying quasi-operational MTD graphics on internal websites for WPC forecasters.

C. Retrospective runs: Over a period of time, track/compare QPF and observation to gather biases in object attributes related to displacement, orientation, and intensity.

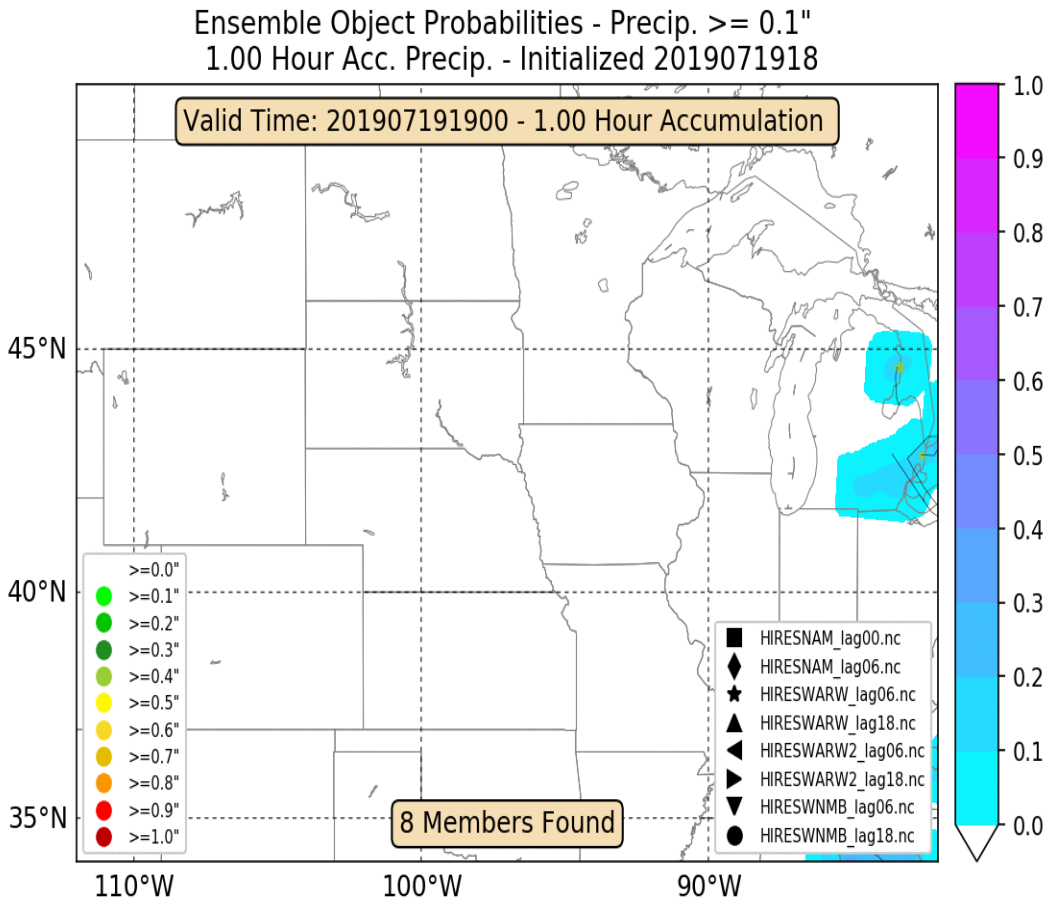
List of Trackable Ensembles

Ensemble	Resolution	Runs per day	Members	Run Length
HRRR TLE	~ 4 km	24	4 (3 time-lagged members)	15
HRRR Exp. Extended	~ 4 km	6	3 (2 time-lagged members)	24
HREFv2	~ 4 km	2	8 (4 time-lagged members)	36
NSSL (while it existed)	~ 4 km	1	9	36

B) Experimental Graphics - Warm Season QPF Internal Website

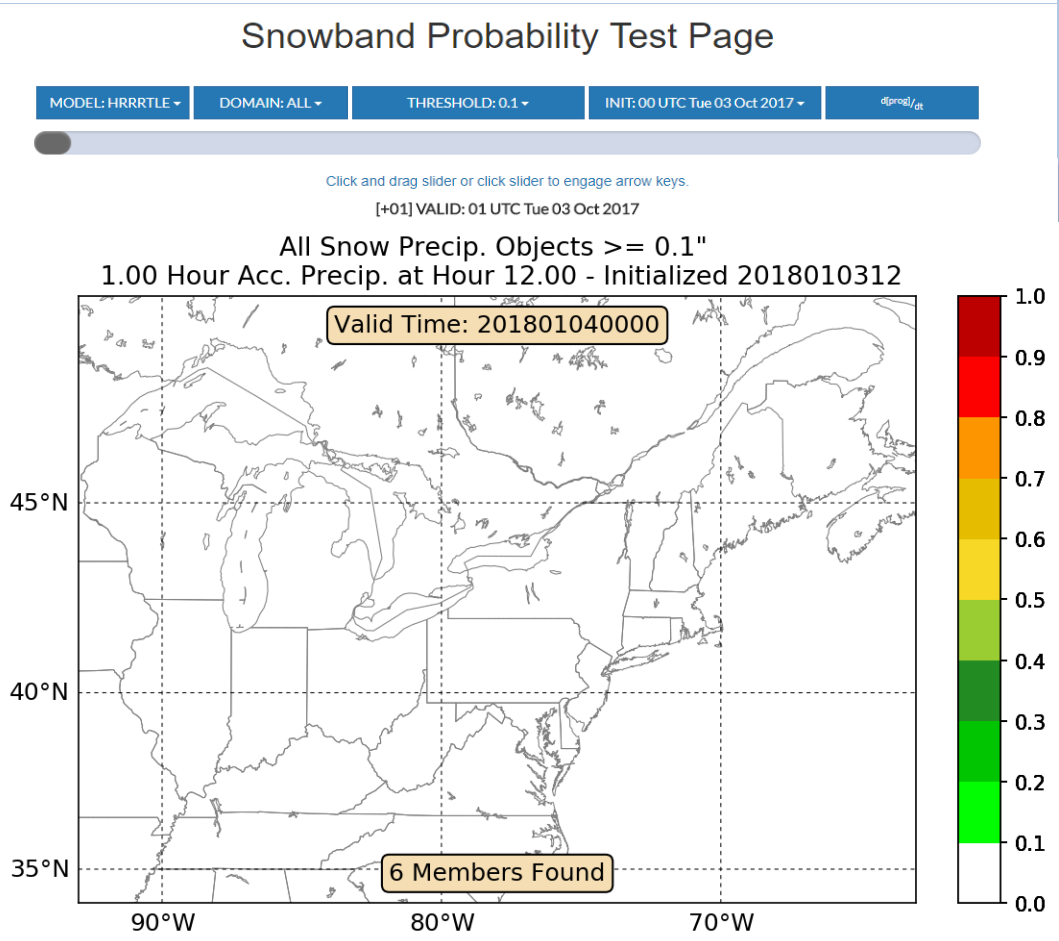
- An internal WPC Google Site has been created to display current object attributes for several ensembles.
- Users initially view a static CONUS image, with the option to zoom in on a more detailed and animated regional subplot.
- Shading denotes probability of being in an object, marker type denotes model type, and marker color denotes the 90th percentile of object intensity.

Example from Website
HREF on 18 UTC 19 July 2019



B) Experimental Graphics - Snowband Tracking Website

Example from Website
HREF on 12 UTC 03 Jan 2018

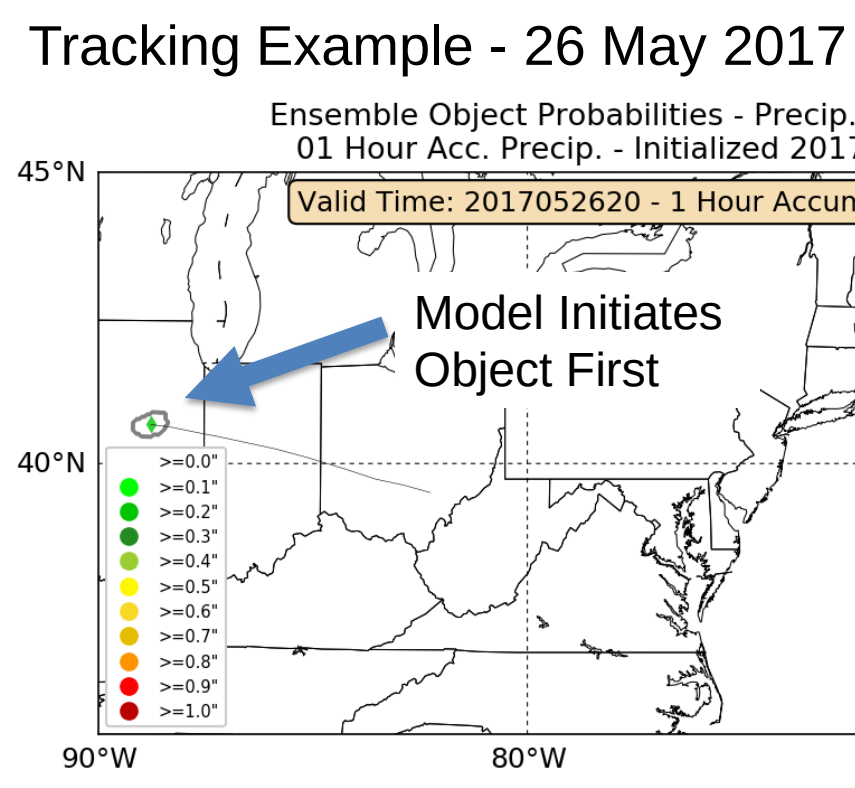


Website Work Performed by Sara Ganetis
WPC/IMSG

- QPF is masked with the categorical snow field and tracked to generate snowband images.
- Snowband objects from the 03 - 04 Jan 2018 Blizzard are shown for the HREFv2.
- The shape of the snowband object is displayed, with the border color representing 90th percentile of object intensity.
- Website interface allows for the user to specify ensemble, domain, model initialization, and model trends.

c) Retrospective Tracking – Methodology

- The HRRRv2 and HRRRv3 QPF objects exceeding 0.25" per hour are tracked and compared to the Stage IV analysis for the 2017 and 2018 warm seasons.
- Using **paired** model and observation object attributes, differences are computed in *object centroid latitude, centroid longitude, intensity, orientation, and size*.
- Using start/end time of **paired** objects, differences in *object initiation and dissipation* are calculated between model and observation.



- All difference statistics are aggregated on a 2º latitude/longitude grid.
- Only results that are statistically significant at 99% using a Student's T-test are retained.

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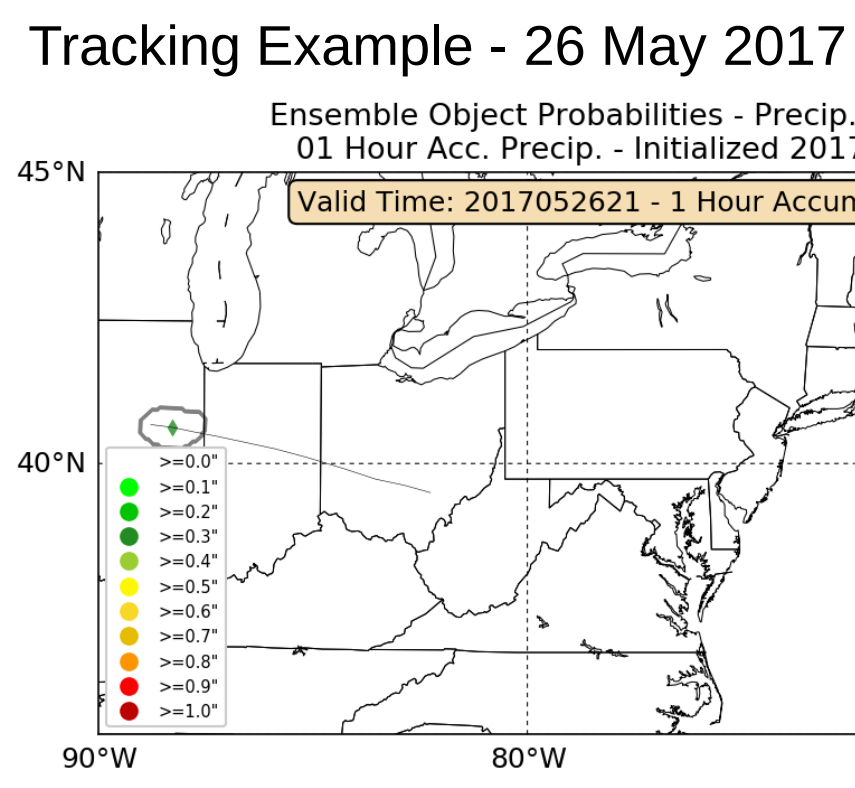

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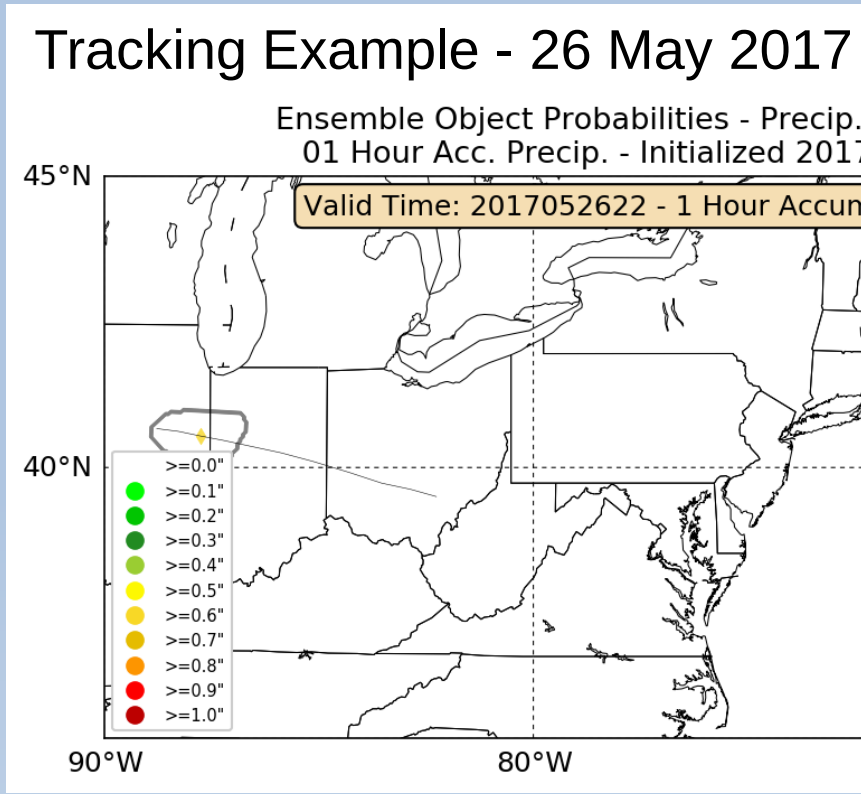

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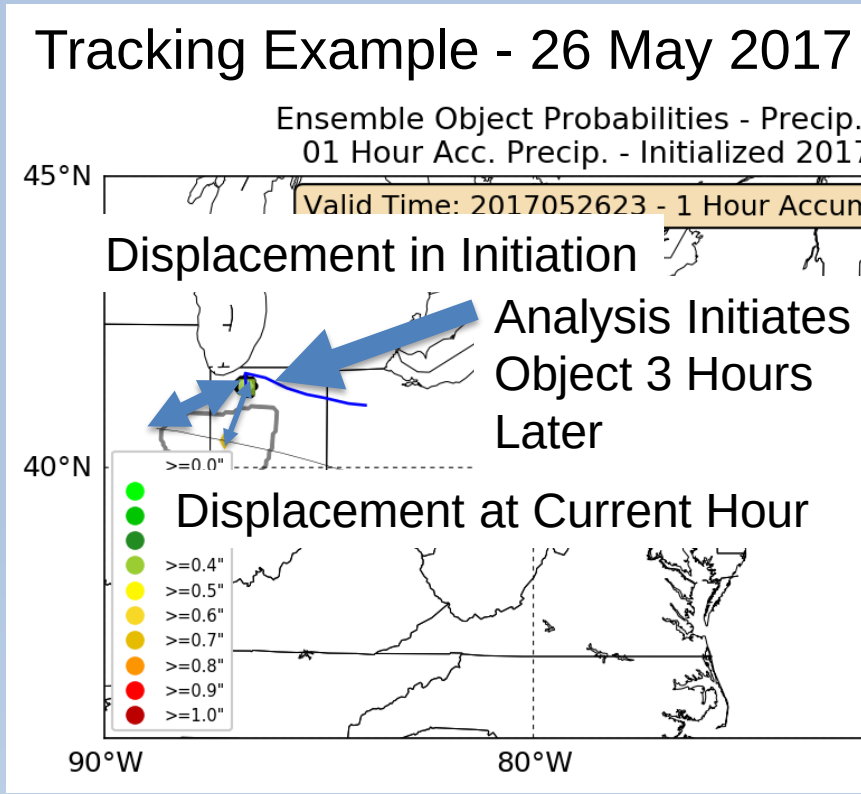

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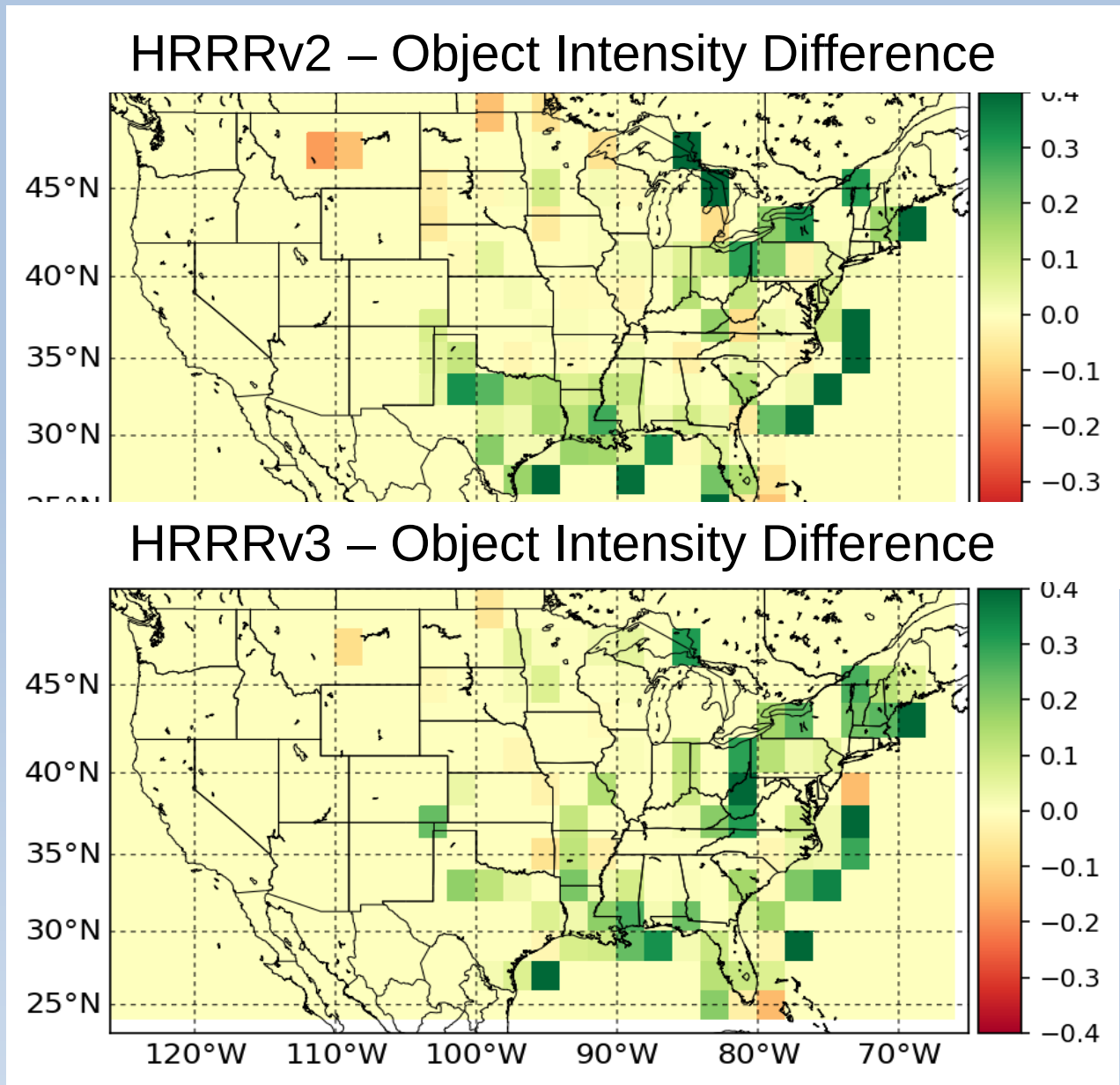
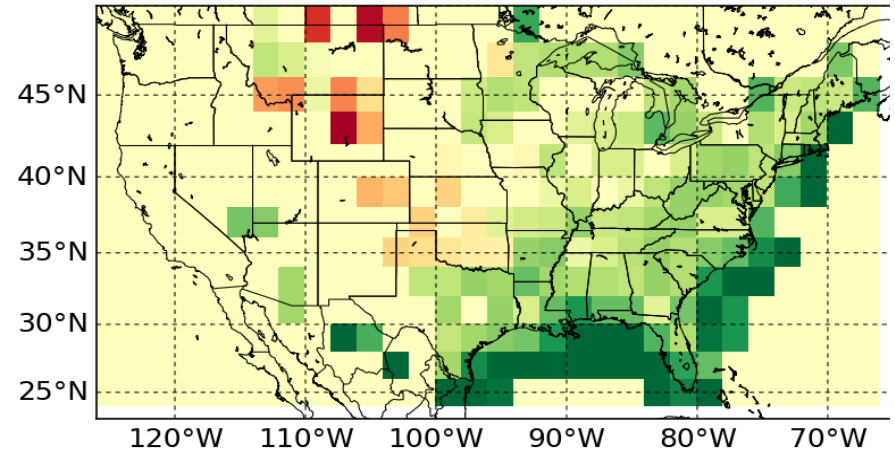
Paired Object Intensity Difference 2017 and 2018 Warm Seasons

- Both versions of the HRRR have a wet bias in the Eastern U.S.
- There is a slight dry bias in the HRRRv2 over the Northern Plains extending back into Montana.

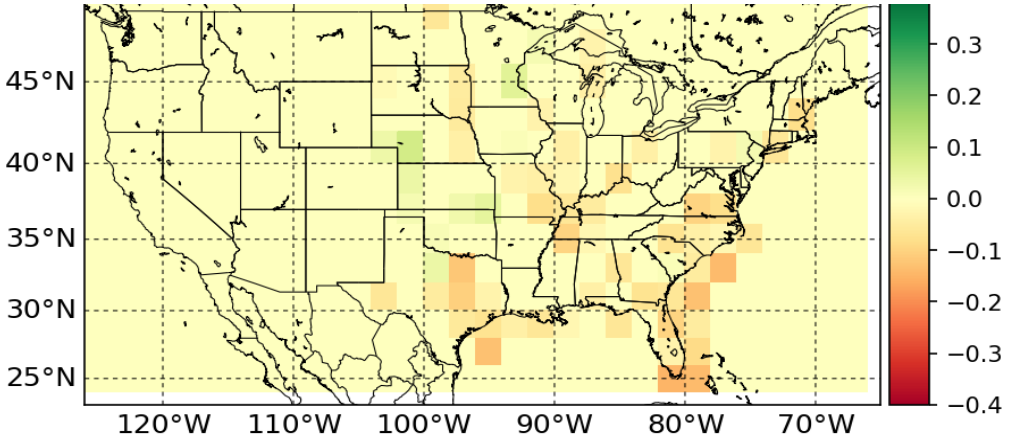


Paired Object Intensity Difference 2017 Versus 2018

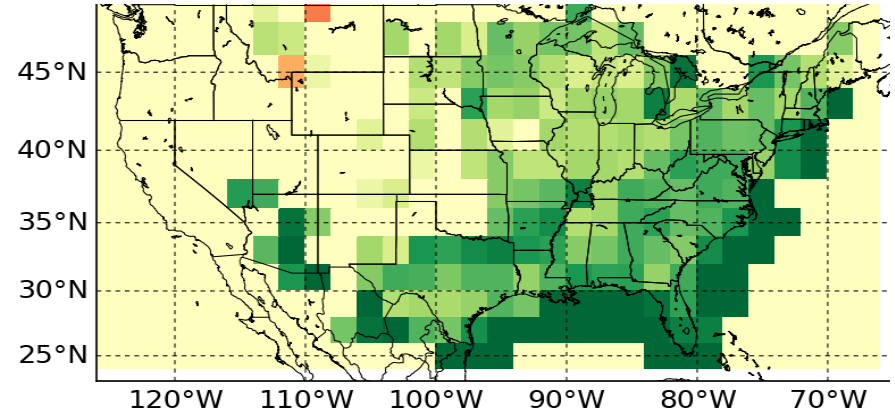
2017 – HRRRv2



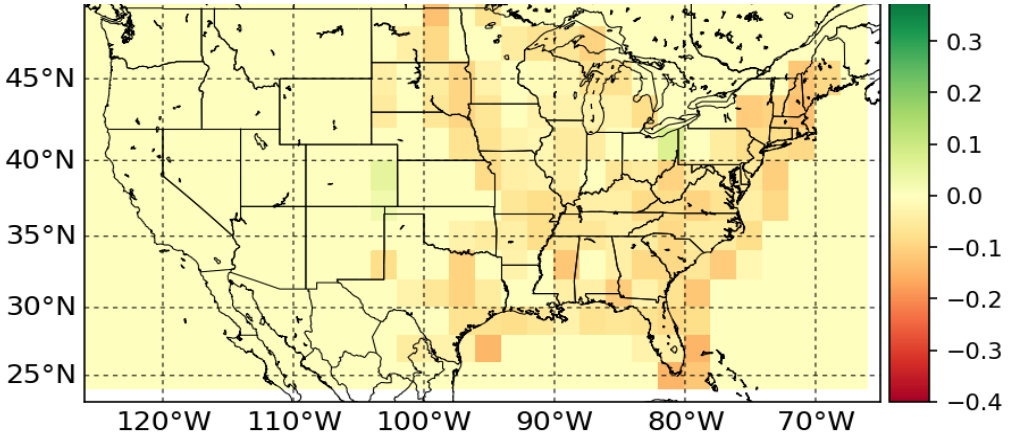
2018 – HRRRv2



2017 – HRRRv3



2018 – HRRRv3

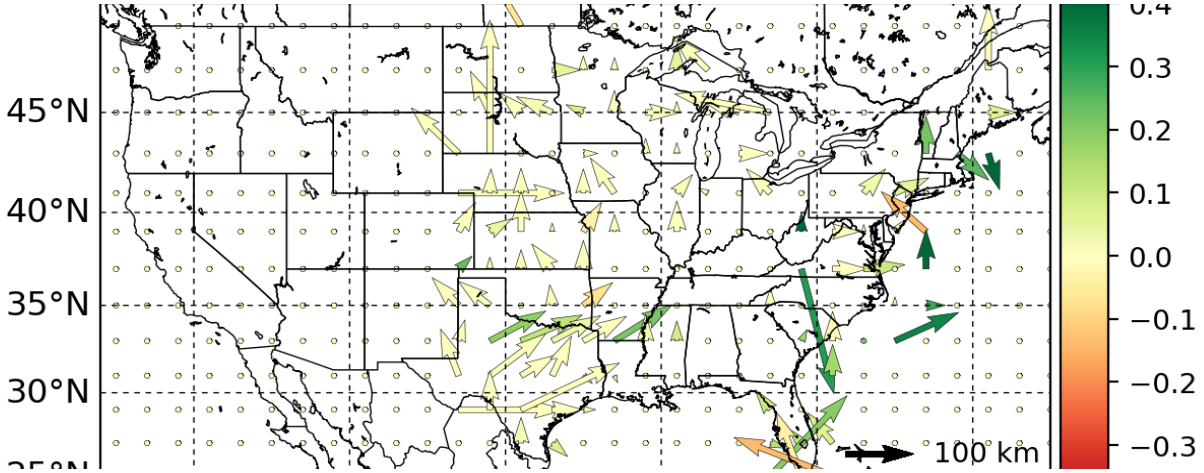


- There was a wet bias for the HRRR during the 2017 warm season but not for the 2018 warm season.

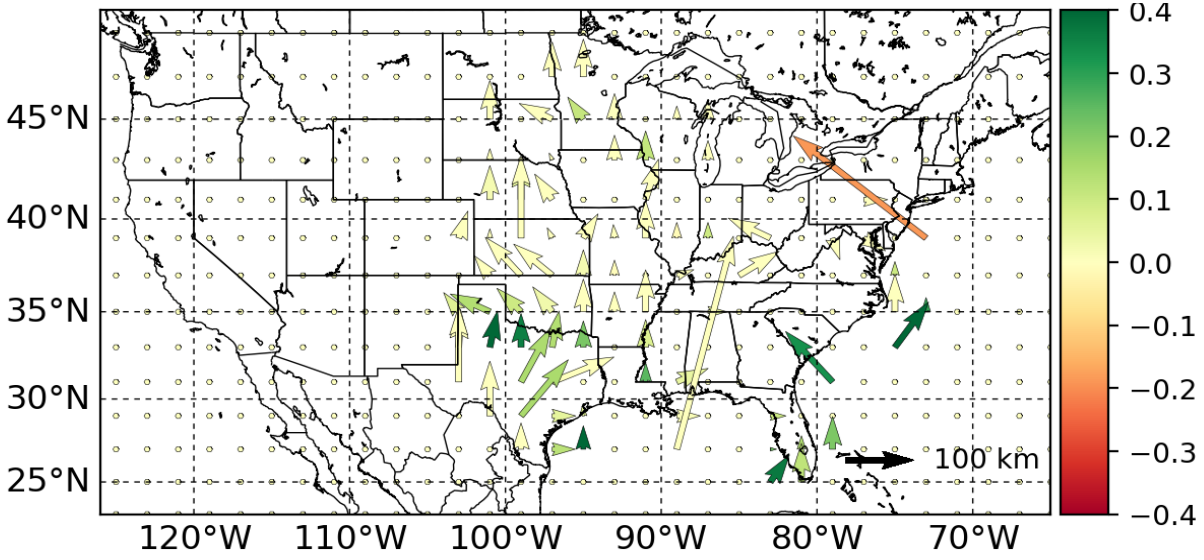
Paired Displacement Difference 2017 and 2018 Warm Seasons

- HRRRv2 and HRRRv3 has a north and northeast displacement bias over the Plains and Mid-west.
- High resolution models displacing heavy precipitation to the north has been noted by WPC forecasters.

HRRRv2 – Object Displacement Difference

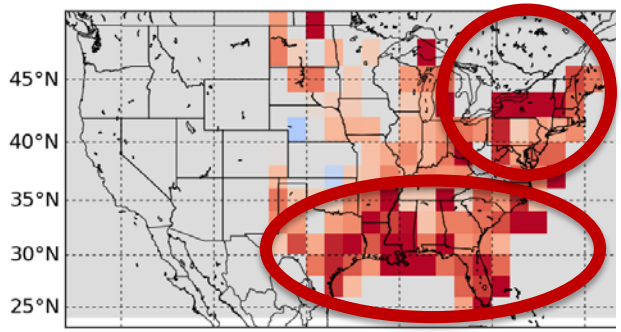


HRRRv3 – Object Displacement Difference

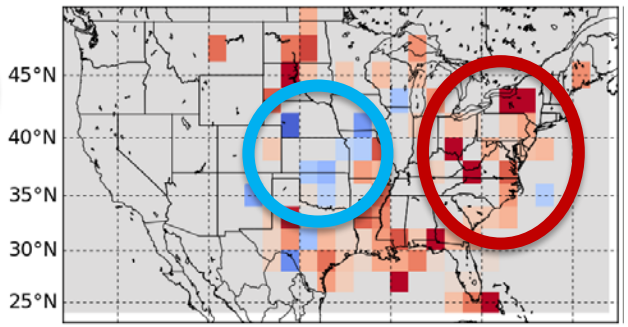


Paired Object Area By Forecast Hour HRRRv2 and HRRRv3

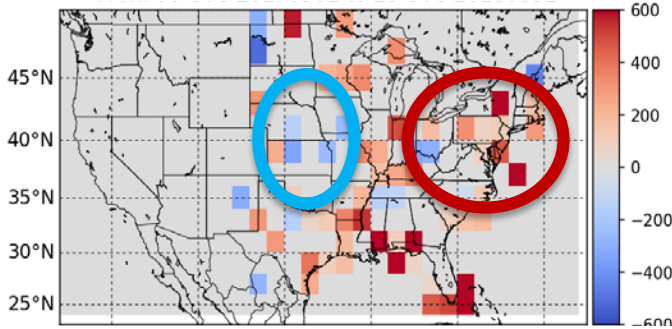
HRRRv2 Area Difference
Forecast Hours 1 to 6



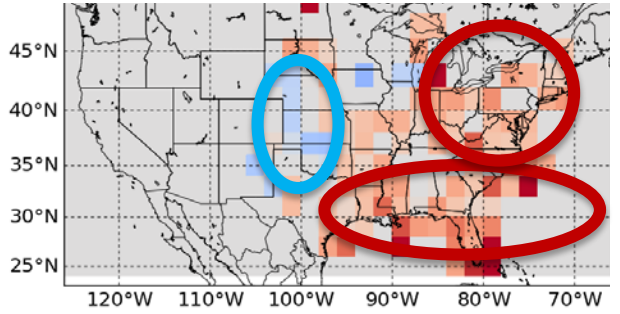
HRRRv2 Area Difference
Forecast Hours 7 to 12



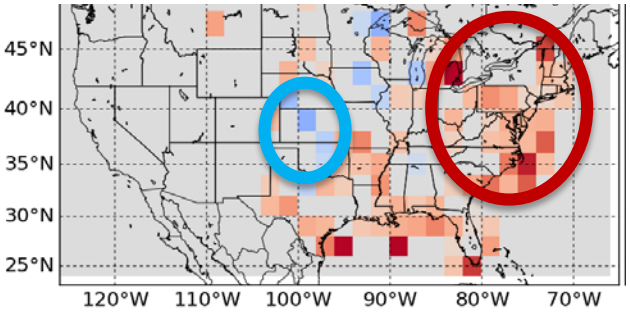
HRRRv2 Area Difference
Forecast Hours 13 to 18



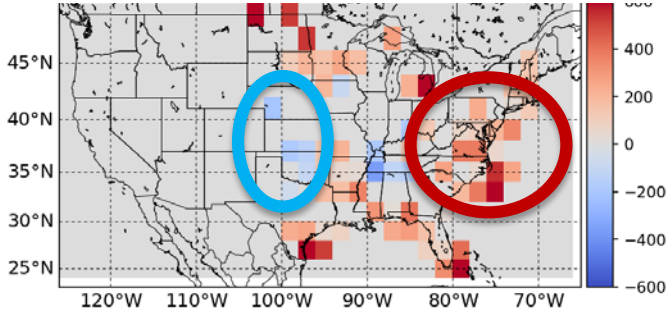
HRRRv3 Area Difference
Forecast Hours 1 to 6



HRRRv3 Area Difference
Forecast Hours 7 to 12



HRRRv3 Area Difference
Forecast Hours 13 to 18



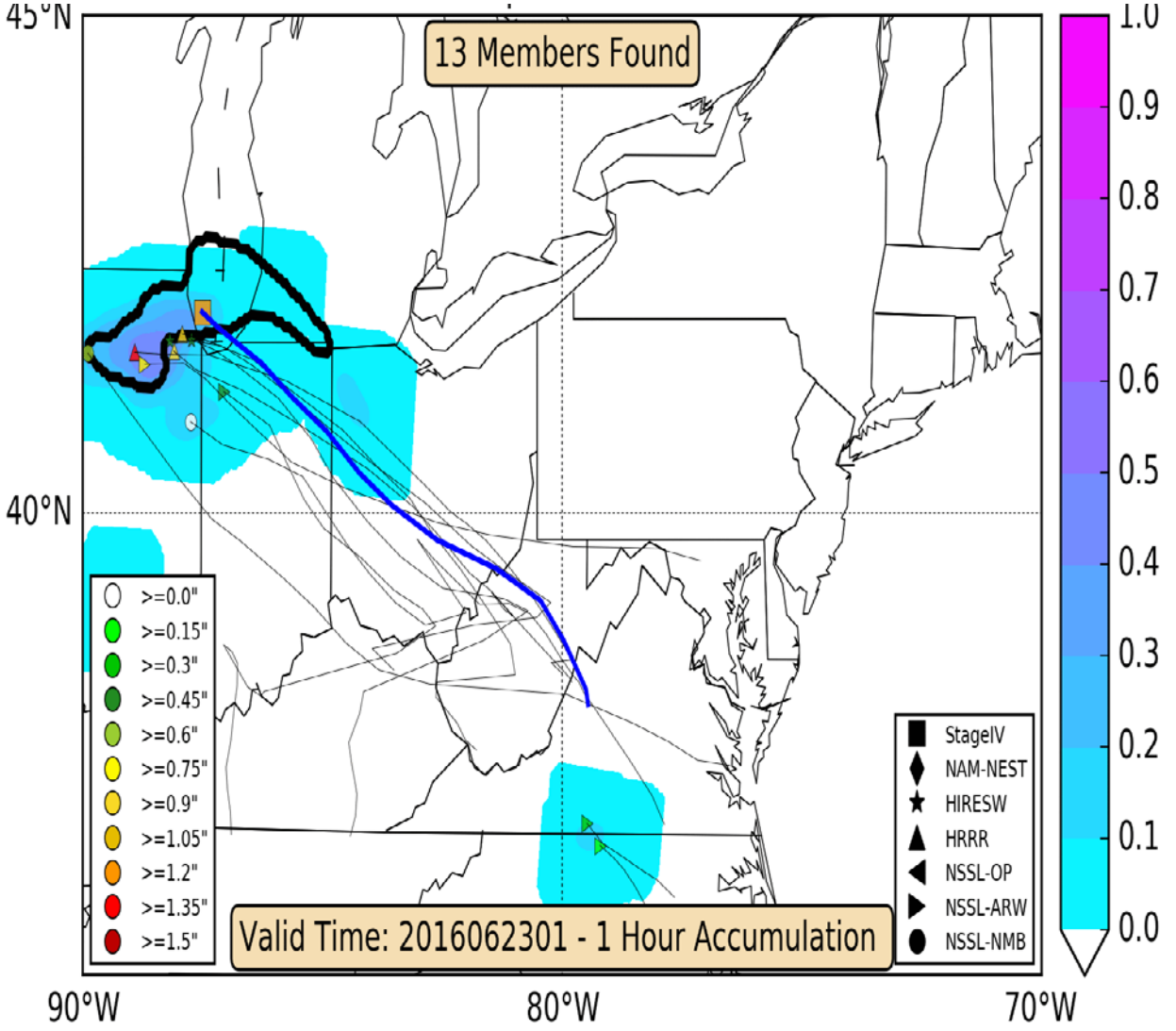
- The Central Plains have a negative object area bias. This develops in the HRRRv2 after forecast hour 6 and exists for all forecast hours of the HRRRv3.
- The positive object bias lingers in the Northeast United States for later forecast hours.

~~For earlier forecast hours, the HRRRv2 and HRRRv3 have a positive object area bias in the Eastern and Southern U.S.~~

What is a Precipitation Object? - Revisited

- Many flooding events are associated with different precipitation objects training over the same area.
- Hourly temporal resolution doesn't always properly separate these objects.
- Tracking precipitation objects at a higher temporal resolution may allow for better tracking of objects.

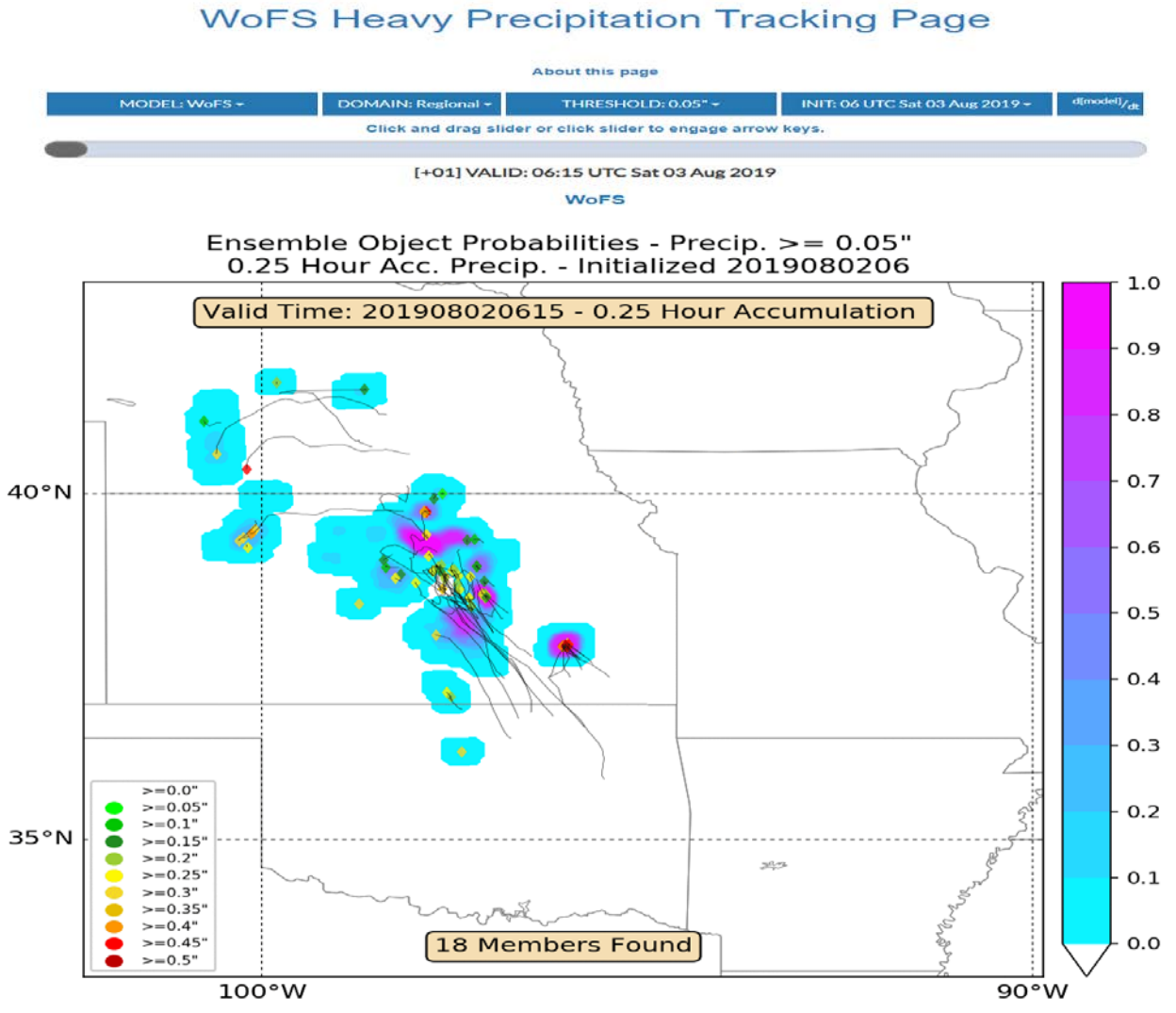
Ensemble Object Probabilities > 0.25"
1-hour Acc. Precip. - 20160623



What is a Precipitation Object? - Revisited

- WoFS (Warn on Forecast System) can be used to address this temporal resolution issue by tracking 15-minute accumulated precipitation.
- Requires revisiting “What is a precipitation object?” on smaller time scales.
- MET tracker was reconfigured to track smaller scale features.

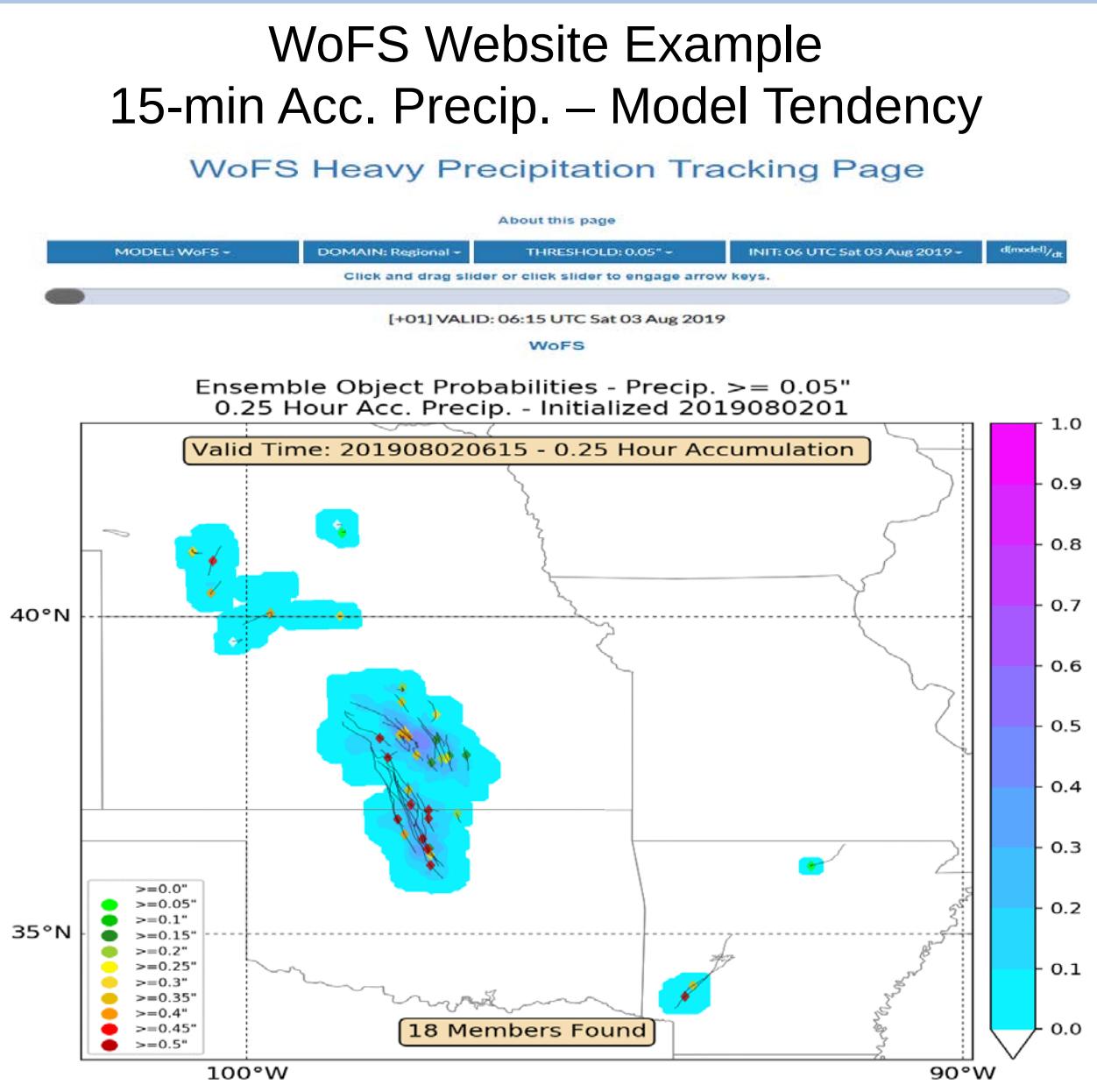
WoFS Website Example
15-min Acc. Precip. – 20190802 at 06 UTC



What is a Precipitation Object? - Revisited

- WoFS was also used to identify model tendency by WPC MetWatch forecasters in real-time.
- Trends were used to assess confidence and trends associated with intensity and placement.

WoFS Website Example
15-min Acc. Precip. – Model Tendency



Conclusions

The Model Evaluation Tools (MET) tracker can successfully identify and track regions of heavy rain and snow (depending on the scale).

Object-oriented verification has been performed for the High Resolution Rapid Refresh (HRRR) versions 2 and 3 during the 2017/2018 warm seasons. In general:

- The HRRR exhibits a wet bias in the 2017 warm season but a slight dry bias in the 2018 warm season.
- Over most of the Plains and Mid-west, the HRRR displaces heavy precipitation objects too far north and northeast.
- The HRRR produces objects that are too large across the eastern CONUS, with objects slightly too small in the Central Plains.

A similar verification study will be performed with the WoFS in the near future.

Sensitivity Studies: Methodology

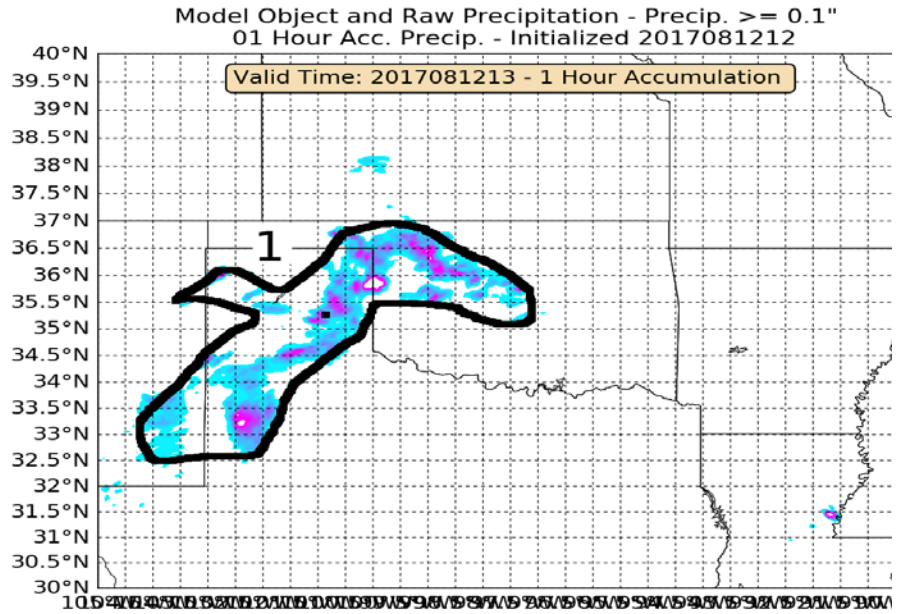
- 15 sensitivity studies are performed by tuning parameters controlling:
  1. **Convolution radius**: Smoothing
  2. **Space centroid distance**: Importance of spatial separation for matching and merging
  3. **Time centroid delta**: Importance of temporal separation
- Four active cases are selected:
  1. *12 UTC on 21 July 2017*
  2. *12 UTC on 26 July 2017*
  3. *12 UTC on 05 Aug 2017*
  4. *12 UTC on 12 Aug 2017*
- Tracker performance is evaluated **subjectively** by-eye and **objectively** using common error metrics.
- **Purpose is to optimize the tracker, not evaluate the forecast.**

Sensitivity Studies

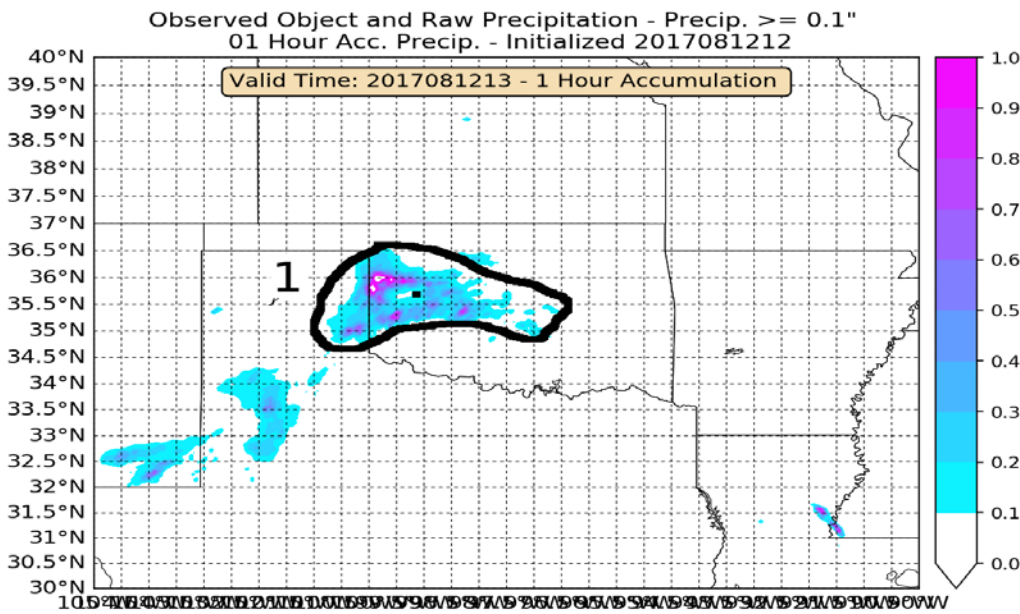
Sensitivity Study Name	Convolution Radius (km)	Space Centroid Weight	Time Centroid Weight
Test 1	16	13	40
Test 2	24	13	40
Test 3	32	13	40
Test 4	16	32	32
Test 5	24	32	32
Test 6	32	32	32
Test 7	16	44	23
Test 8	24	44	23
Test 9	32	44	23
Test 10	16	40	13
Test 11	24	40	13
Test 12	32	40	13
Test 13	16	23	44
Test 14	24	23	44
Test 15	32	23	44

Sensitivity Studies: Creating the "Observed" Objects By-eye

Hand Drawn - Model



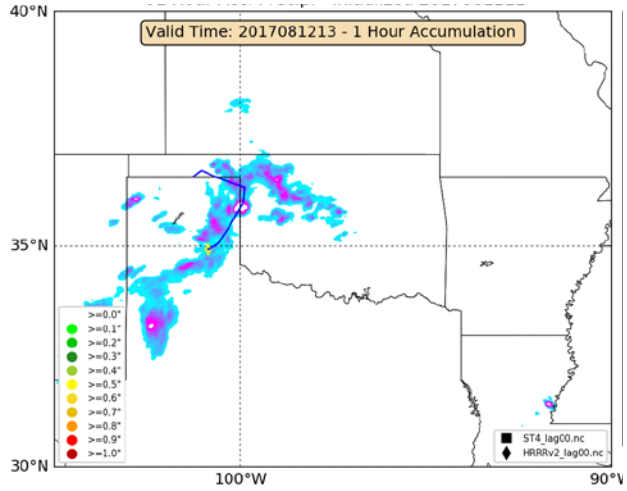
Hand Drawn - Observation



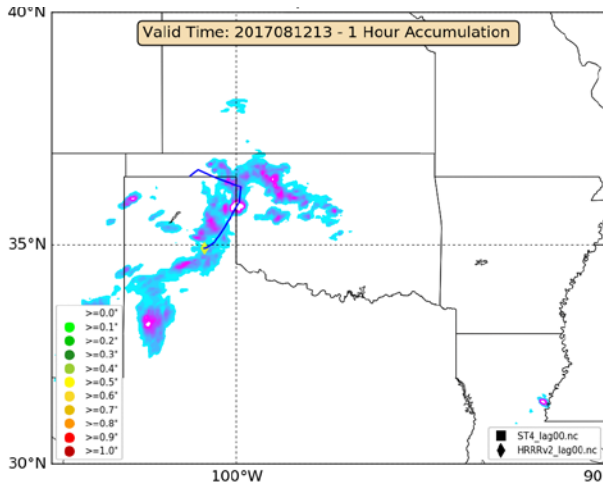
- To verify these cases, the object convex hull and centroid location were identified by-eye for the High Resolution Rapid Refresh (HRRR) model and Stage IV (rainfall analysis).
- Objective verification includes latitude/longitude displacement for False Alarm Ratio (FAR), Hit Rate (HIT), Critical Success Index (CSI), Frequency Bias, Mean Error (ME), and Mean Absolute Error (MAE).

Sensitivity Studies: HRRR Tracker Performance 12 to 13 August 2017

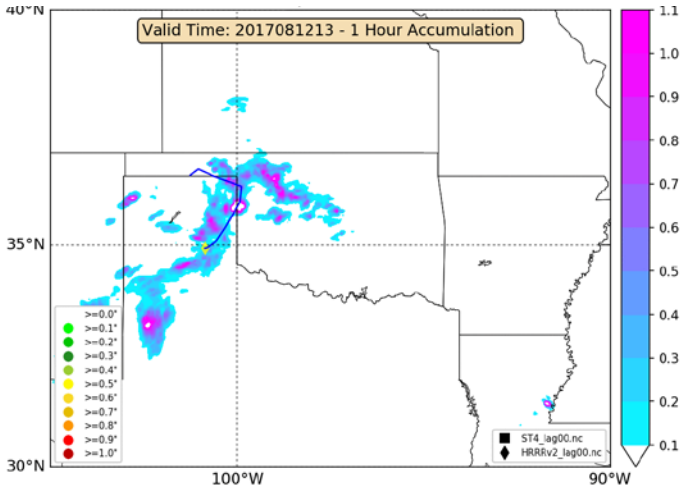
Test 2



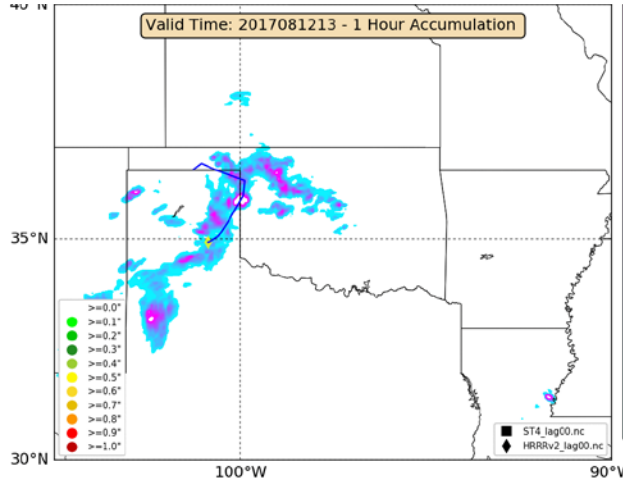
Test 5



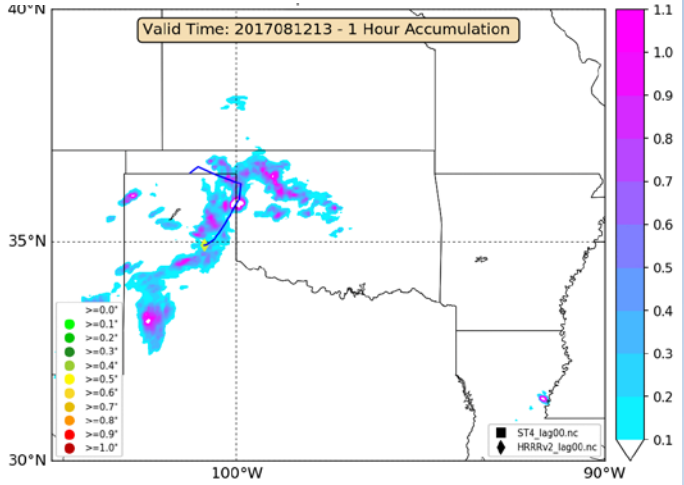
Test 8



Test 11



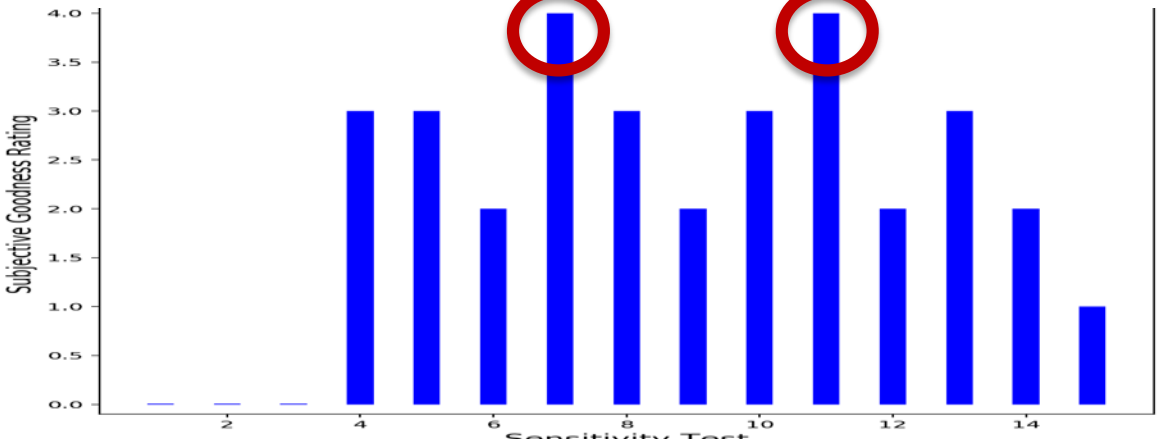
Test 14



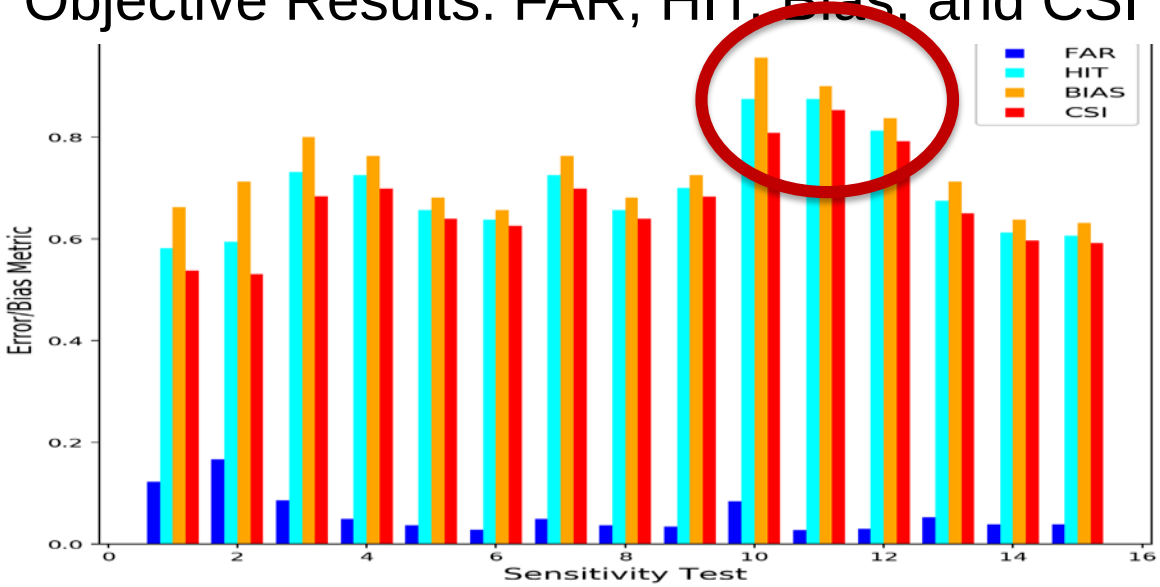
- Test 2 and 14 perform poorly due to merging of far away objects (off the map) in later forecast hours.
- Tests 5, 8, and 11 perform well by-eye.

Sensitivity Tests: Bulk Verification Results Objective Vs Subjective

Subjective Results: By-eye Measure of "Goodness"



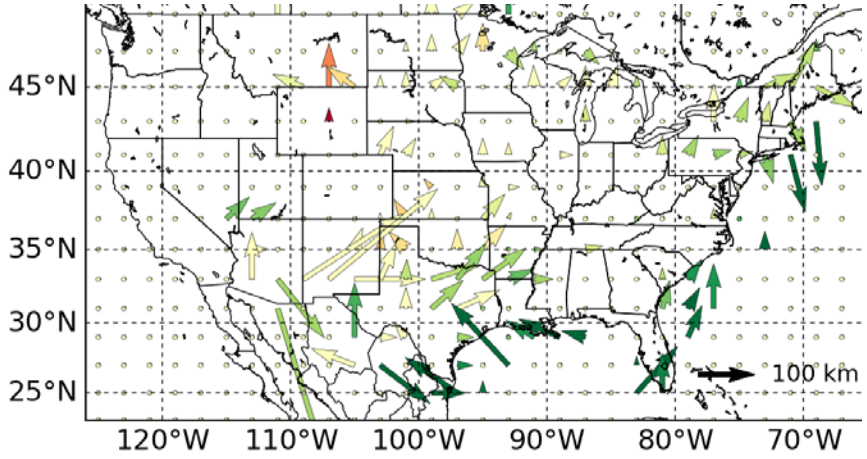
Objective Results: FAR, HIT, Bias, and CSI



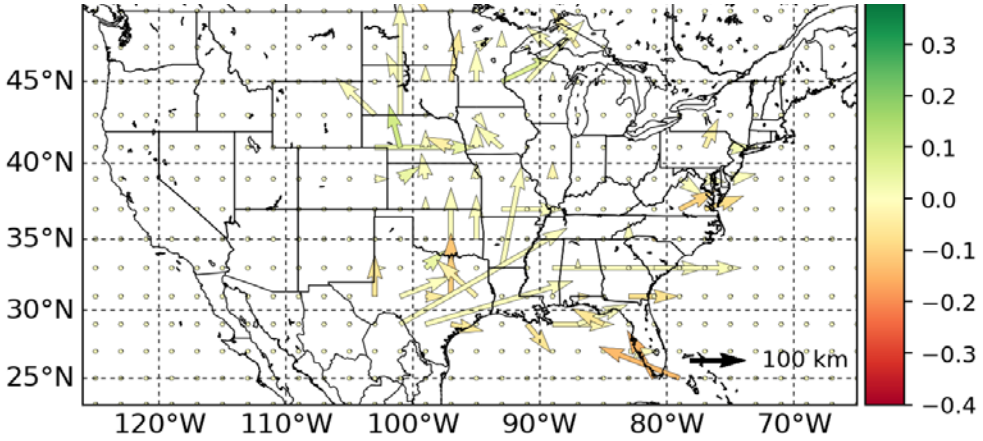
- Tests 7 and 11 perform best subjectively.
- Test 11 is selected for the retrospective runs because it performs well with all objective metrics.

Paired Displacement Difference 2017 Versus 2018

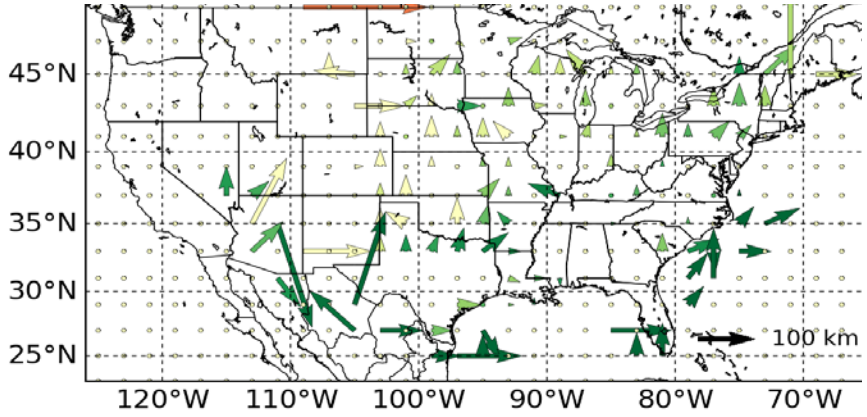
2017 – HRRRv2



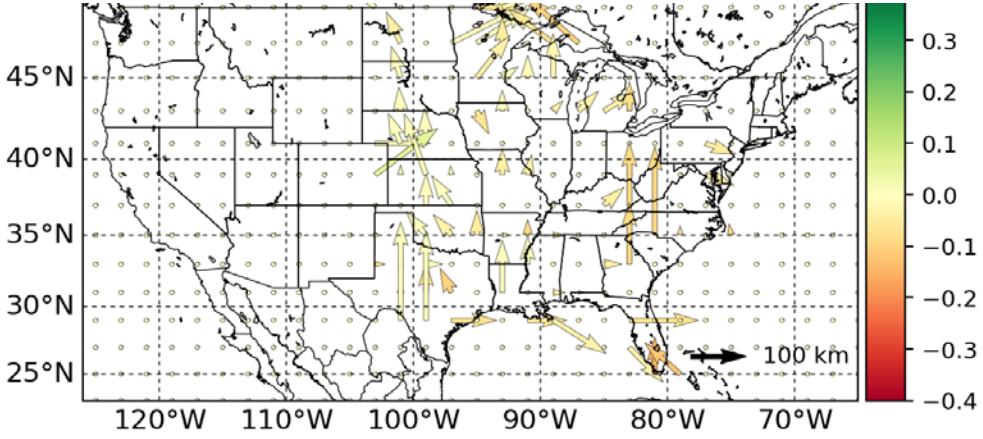
2018 – HRRRv2



2017 – HRRRv3



2018 – HRRRv3



- The northward displacement bias is present in both seasons and versions of the HRRR.