Object-Based Verification Techniques for Short-Term Thunderstorm Forecasts

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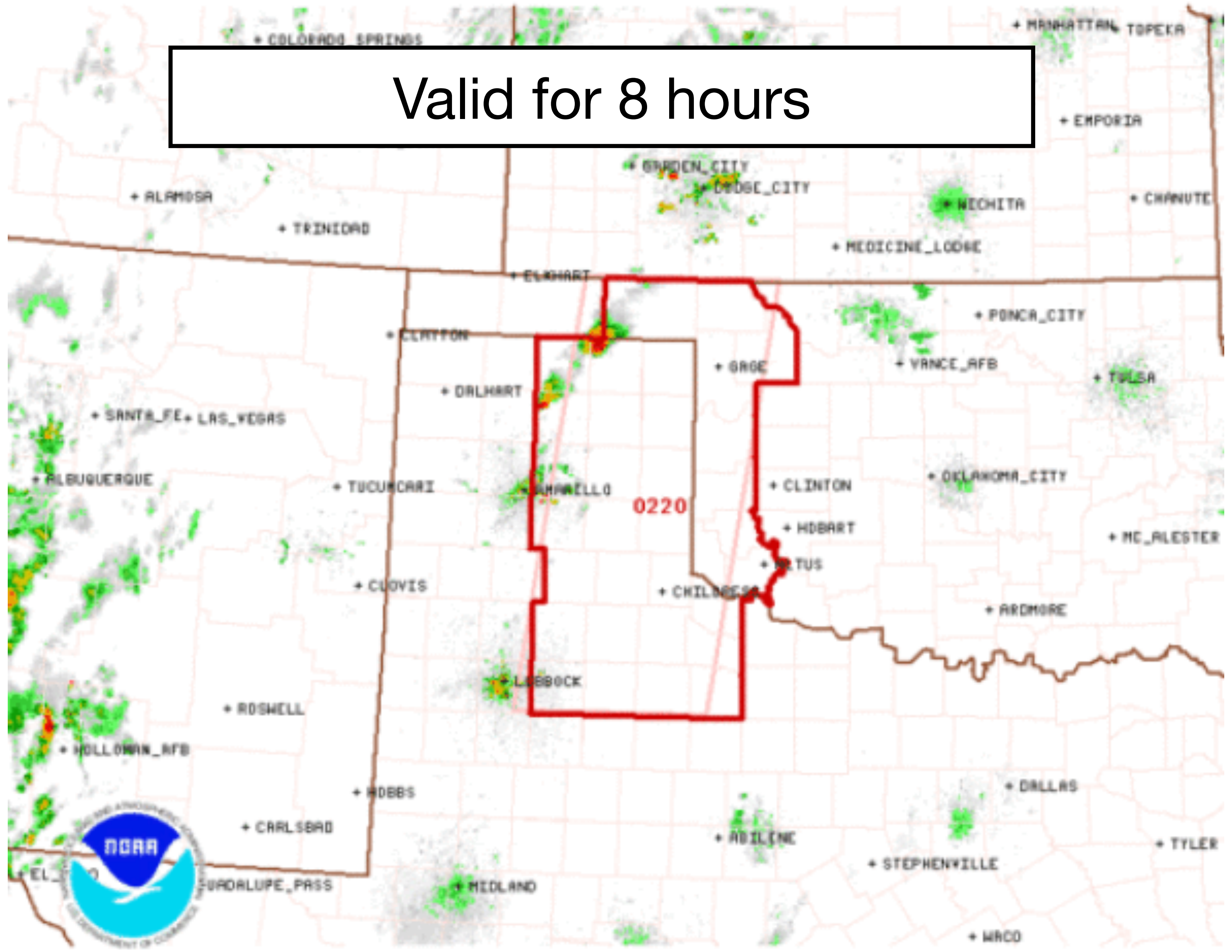
What are we trying to forecast?

We would like to provide probabilistic guidance of thunderstorm hazards on time scale between NWS watches and warnings (0-6 h) and spatial scales similar to individual convective storms (~10-50 km)

Tornado Watch

Tornadoes are *possible* in this area

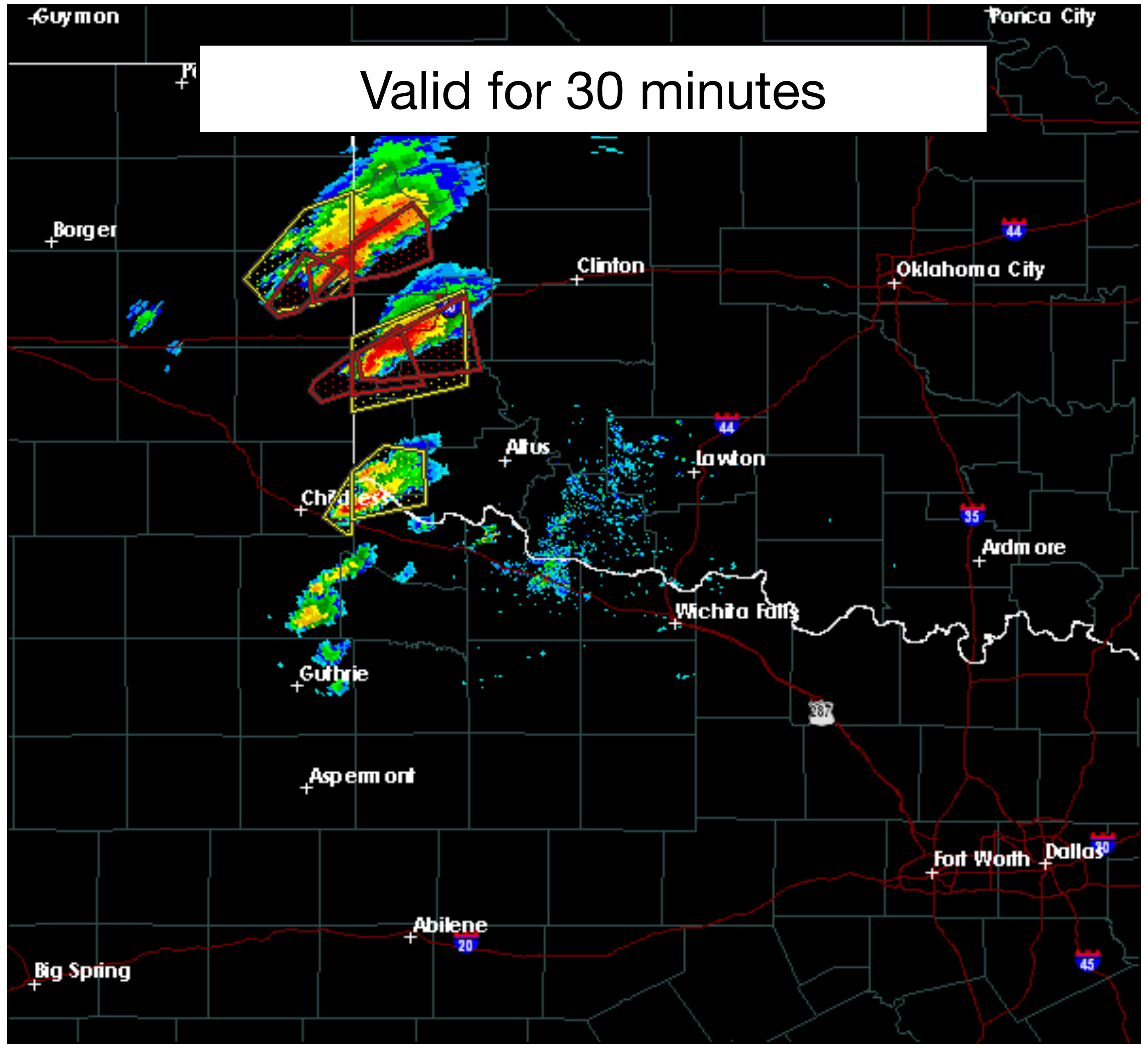


Suite of 18+ hour forecast guidance

A forecast gap of several hours exists between thunderstorm watch products and warnings

Tornado Warnings

Tornadoes are *occurring* in these areas

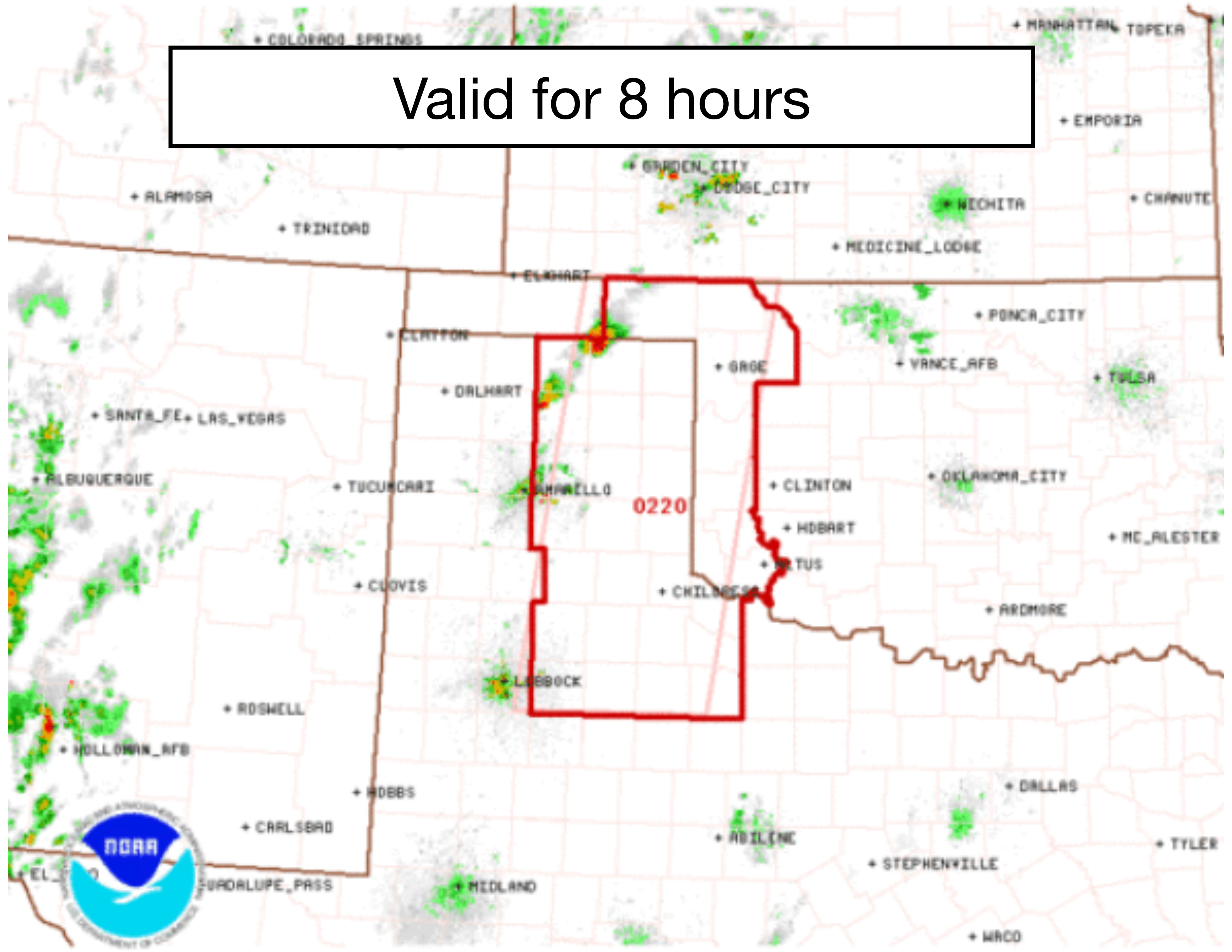


Short-term thunderstorm forecasting using the Warn-on-Forecast System (WoFS):

A convection allowing ensemble analysis and prediction system designed to provide probabilistic forecasts of thunderstorm hazards between the watch and warning scale:

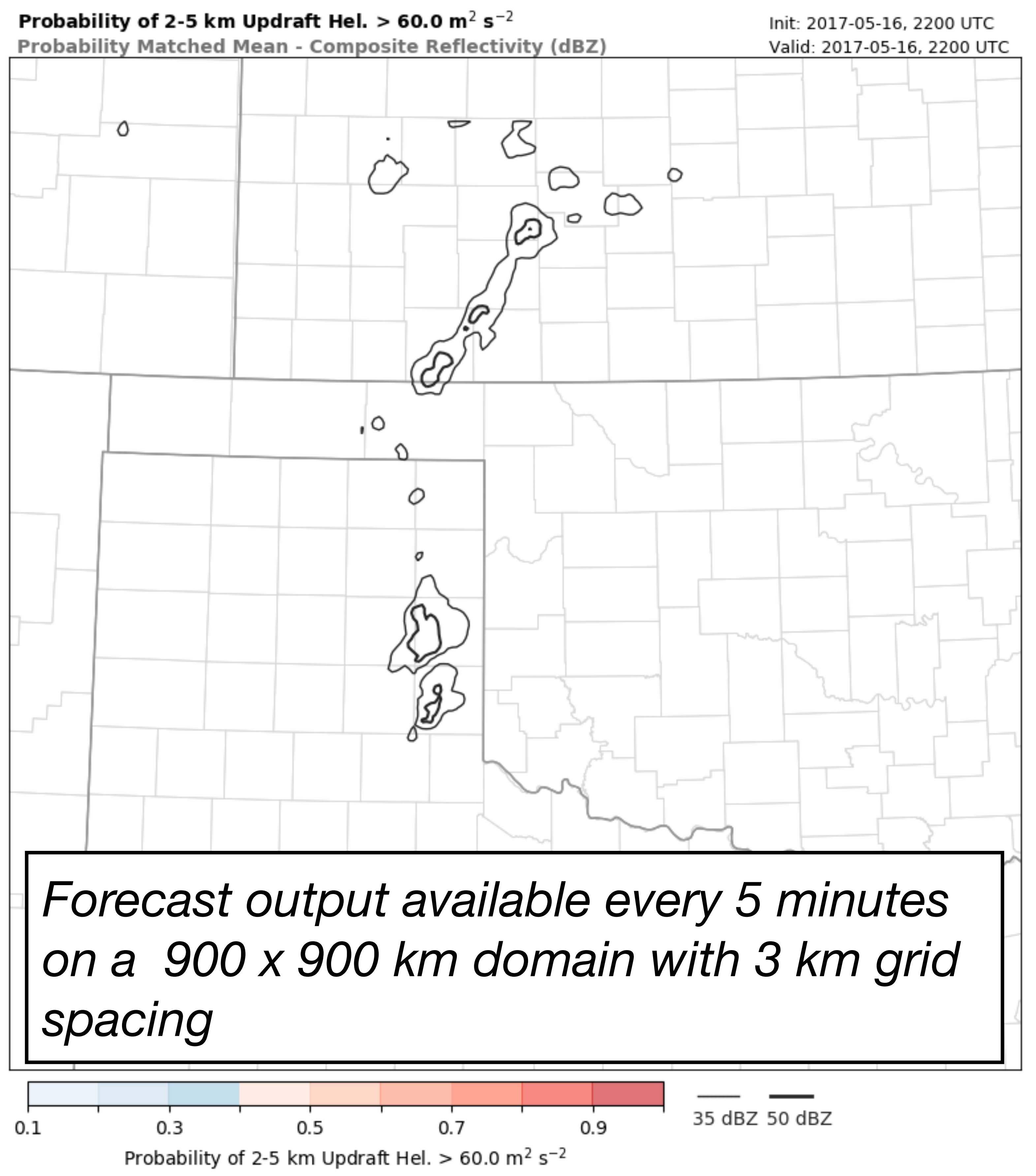
Tornado Watch

Tornadoes are *possible* in this area



Suite of 18+ hour forecast guidance

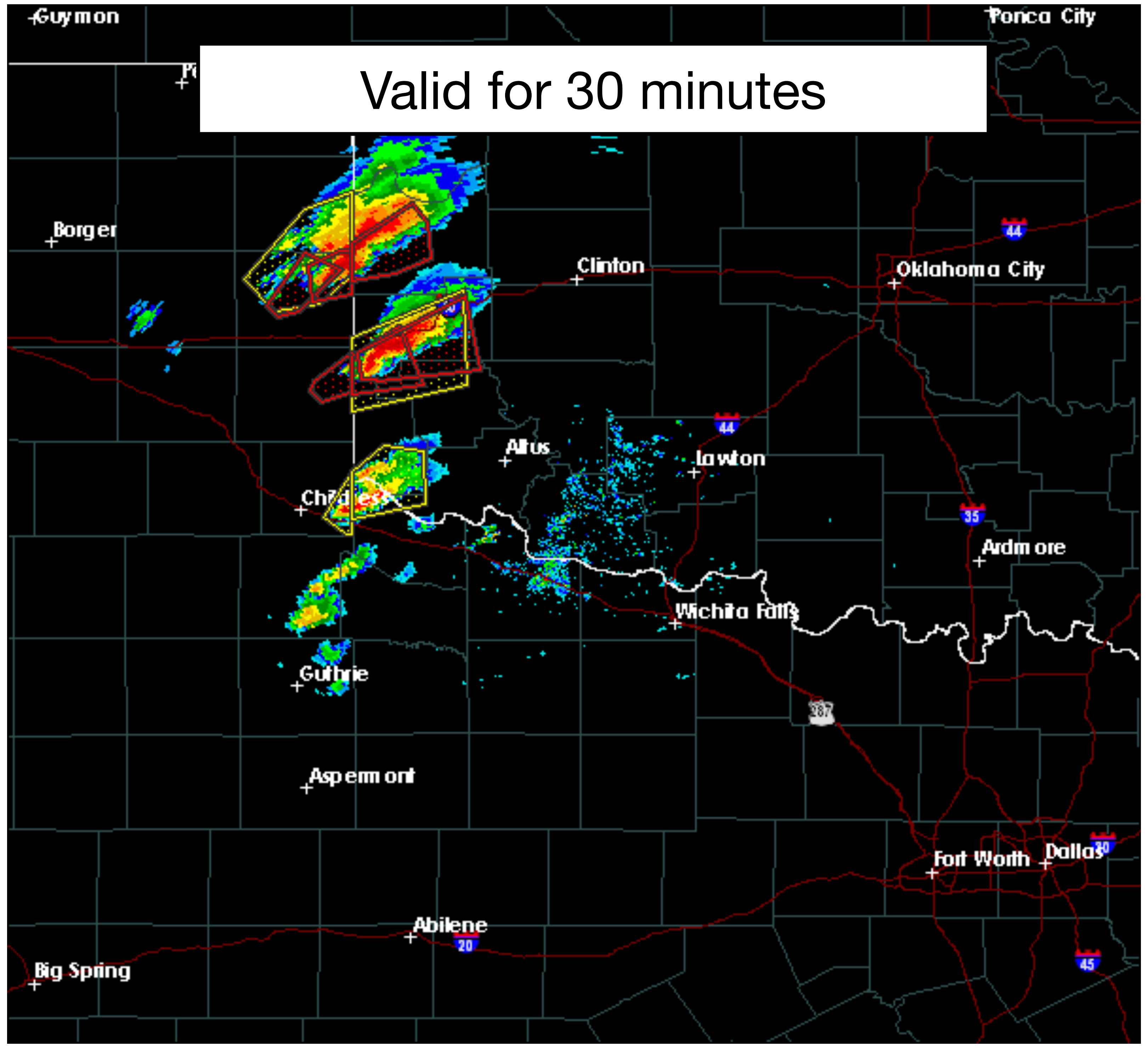
Warn-on-Forecast: 6-hr guidance



Forecast output available every 5 minutes on a 900 x 900 km domain with 3 km grid spacing

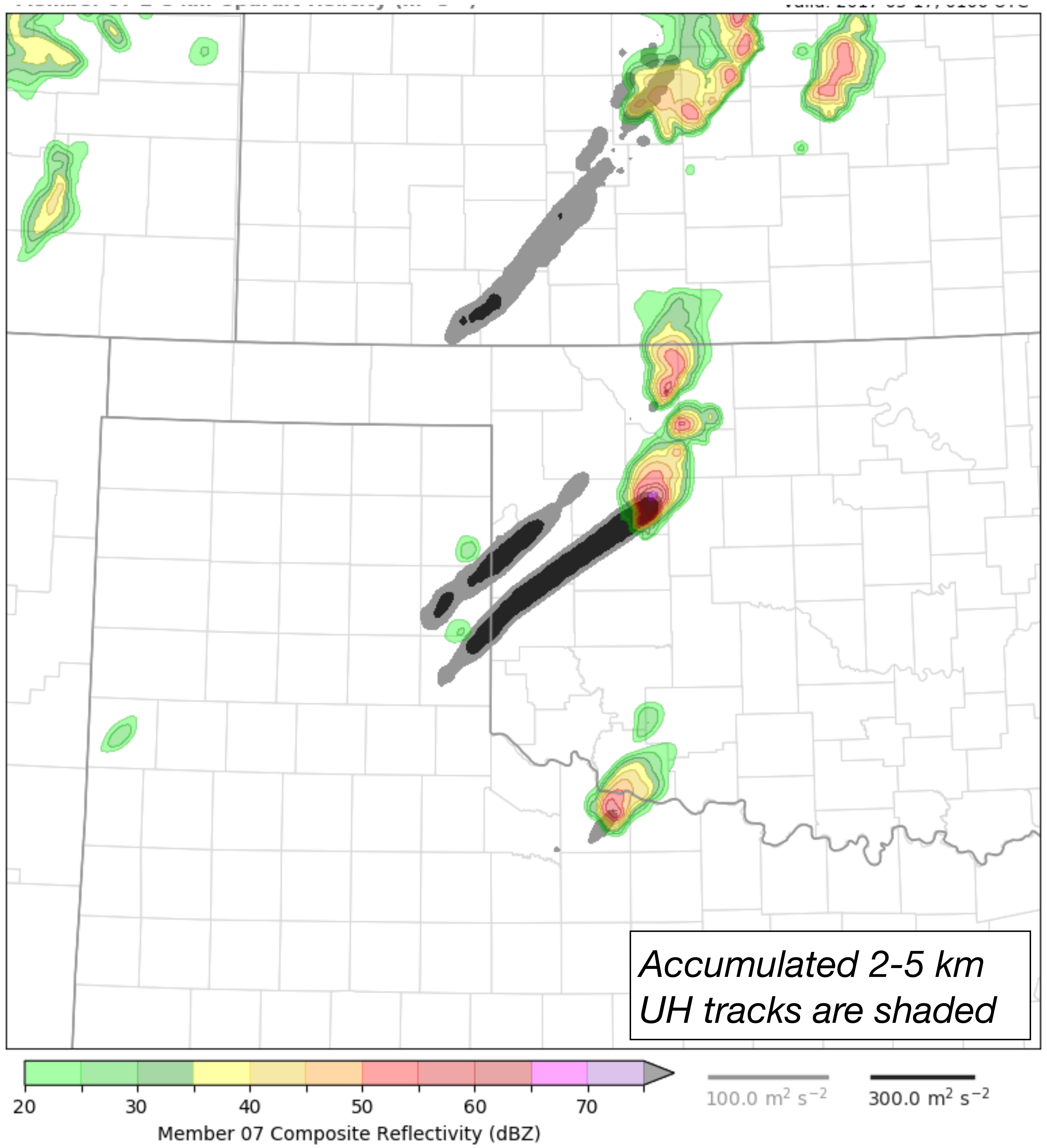
Tornado Warnings

Tornadoes are *occurring* in these areas



Forecast Dataset - Use updraft helicity swaths as surrogate for mesocyclones:

3-hr WoFS member forecast



- Updraft helicity (UH; Kain et al. 2008) is commonly used as a surrogate for severe weather (e.g. Sobash et al. 2011)
- Accumulated swaths of UH can be constructed over various time periods to serve as predicted events
- Results in a sparse field of discrete events within the forecast domain

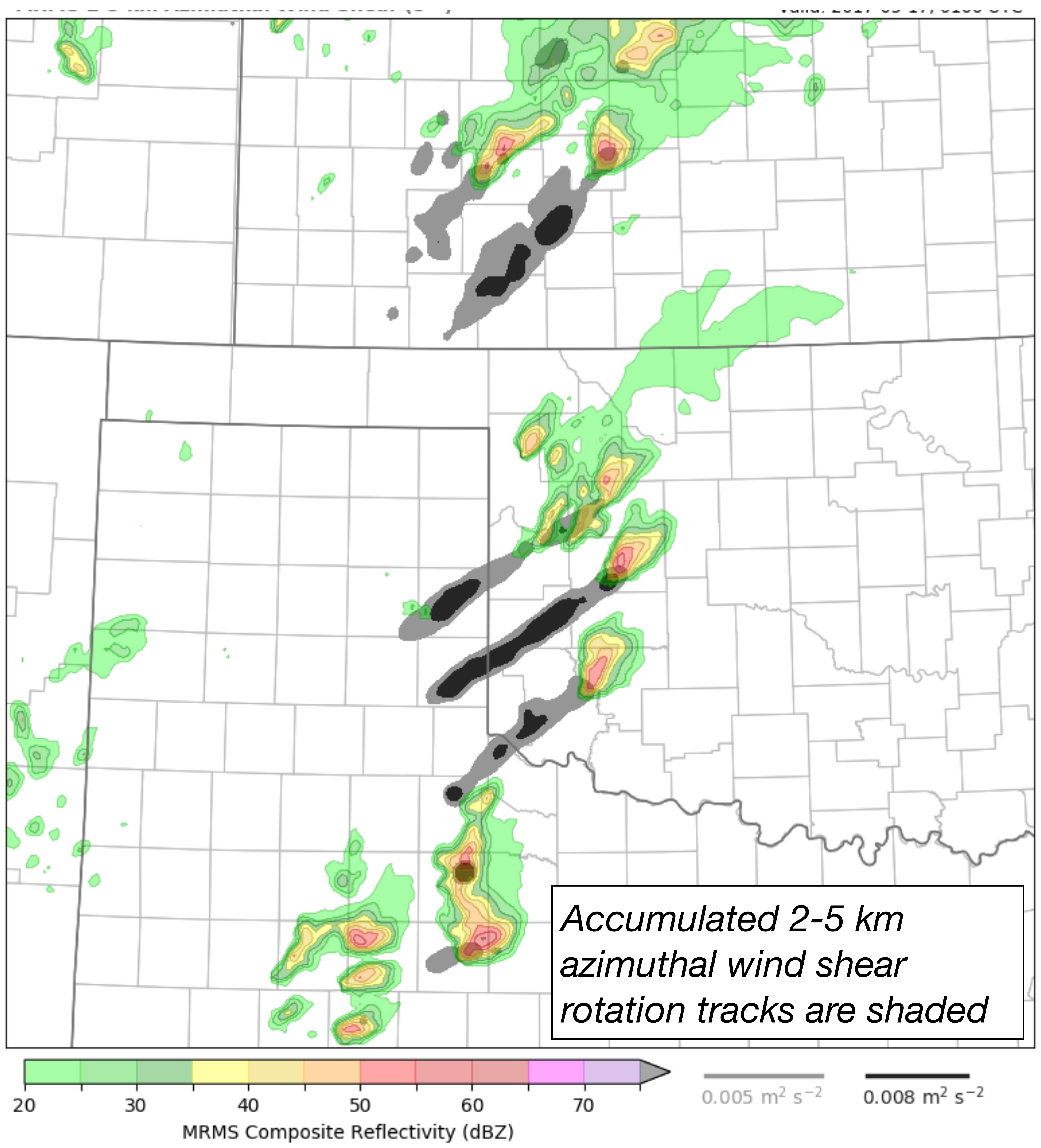
Verification Dataset - Use radar derived rotation tracks from Multi-Radar Multi-Sensor analyses:

- Mesocyclones are not fully observed without specialized observing platforms

- An imperfect proxy for mesocyclone occurrence needs to be developed as a verification dataset:
    - Local Storm Reports (LSRs) are often used as a surrogate for severe weather in next-day (24 hr) CAM verification (e.g. Sobash et al. 2011)
    - LSR databases suffer from small-scale space and time errors and nonmeteorological biases (e.g. Trapp et al. 2005; Verbout et al. 2006; Potvin et al. 2019)

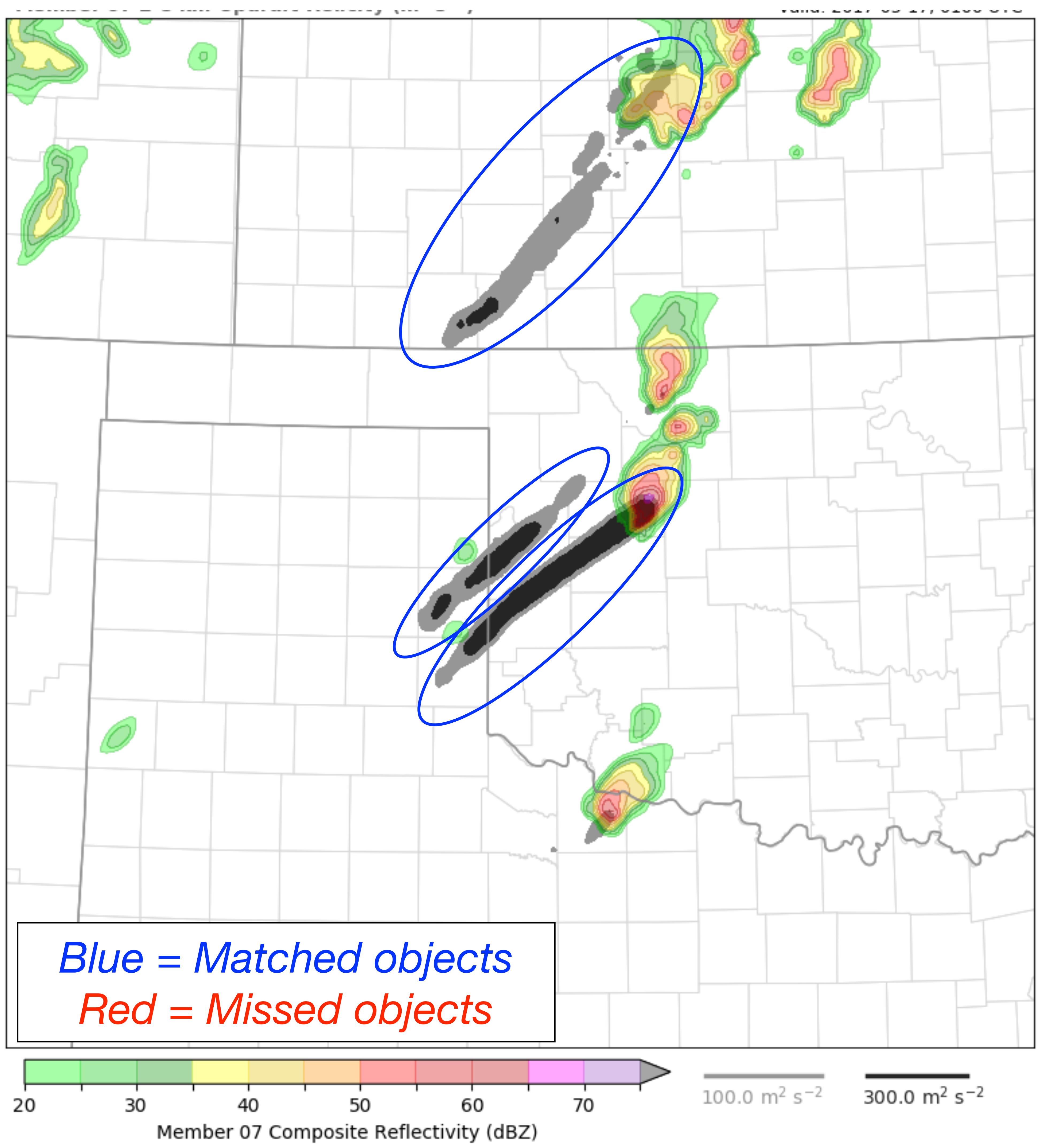
- Gridded radar azimuthal wind shear observations may be used to create rotation tracks over a similar time and space scale as UH swaths

MRMS observations

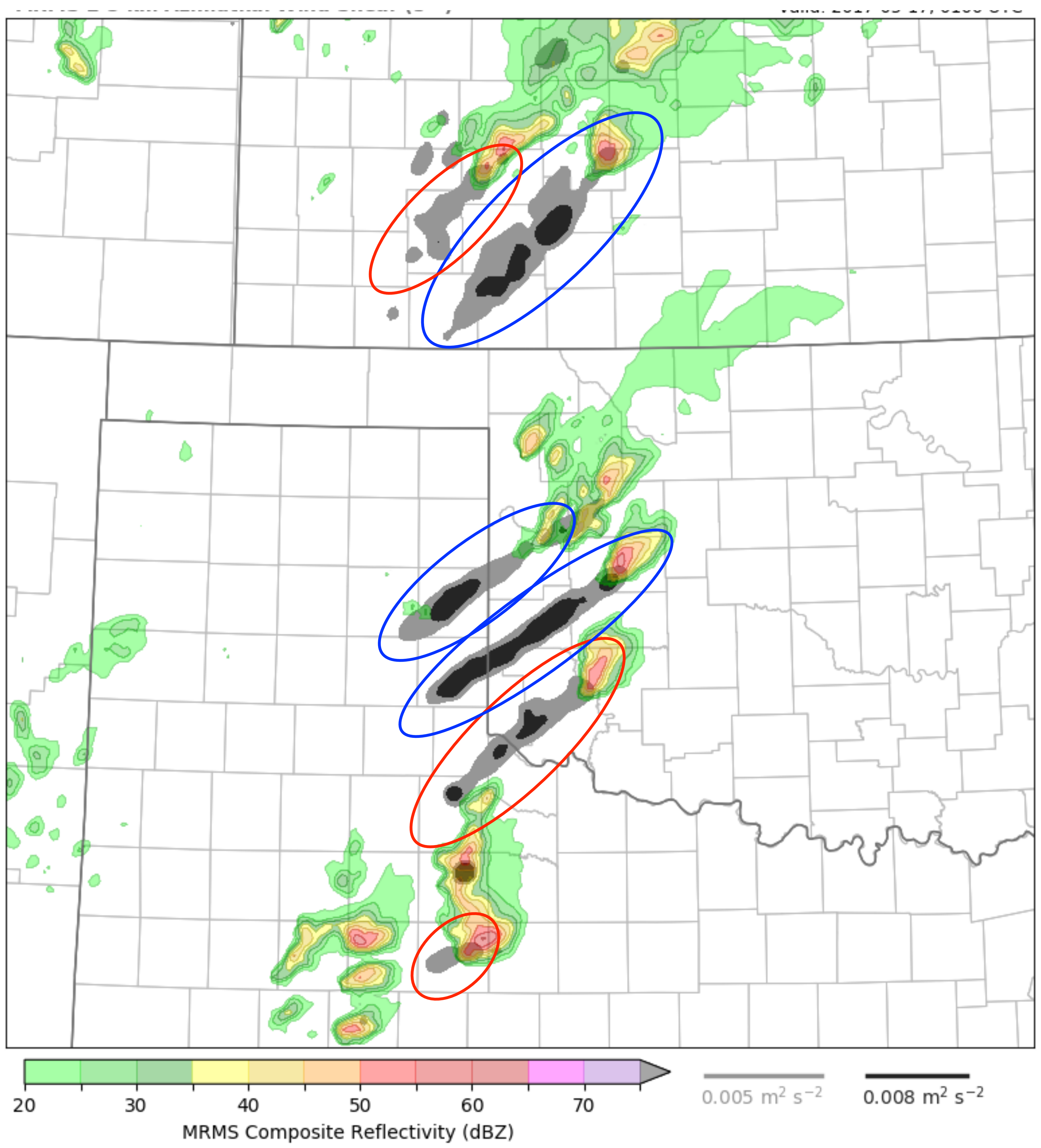


Properties of forecast and verification datasets a good fit for object-based verification

3-hr WoFS member forecast



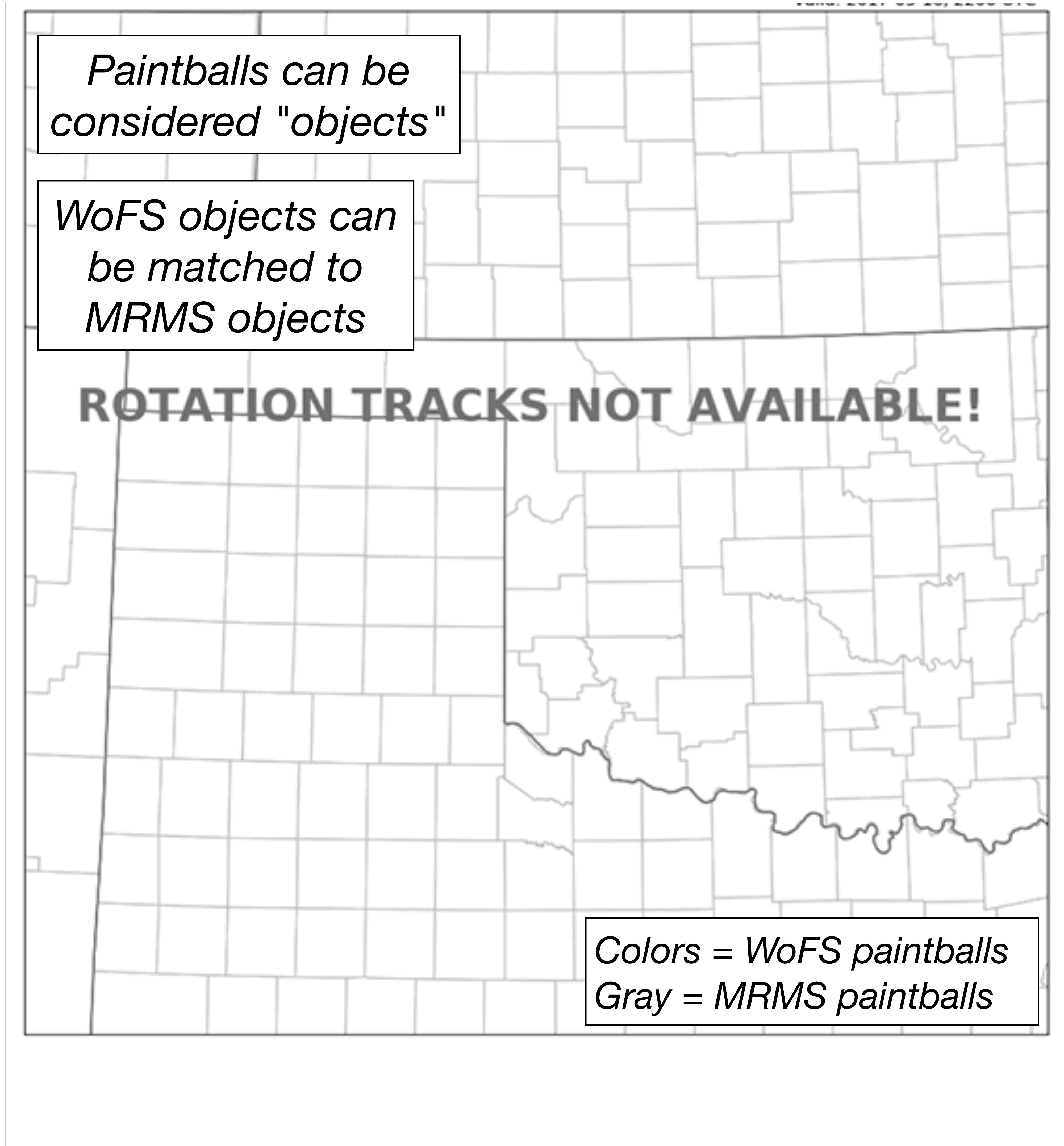
MRMS observations



Properties of forecast and verification datasets a good fit for object-based verification

- 30-min swath objects of rotation tracks can be visualized using paintball plots
- Leverages high temporal resolution of WoFS output
- Paintball plots are among the most popular forecast products based on usage by Hazardous Weather Testbed Spring Forecasting Experiment participants (Wilson et al. 2020)

Rotation Track Paintballs

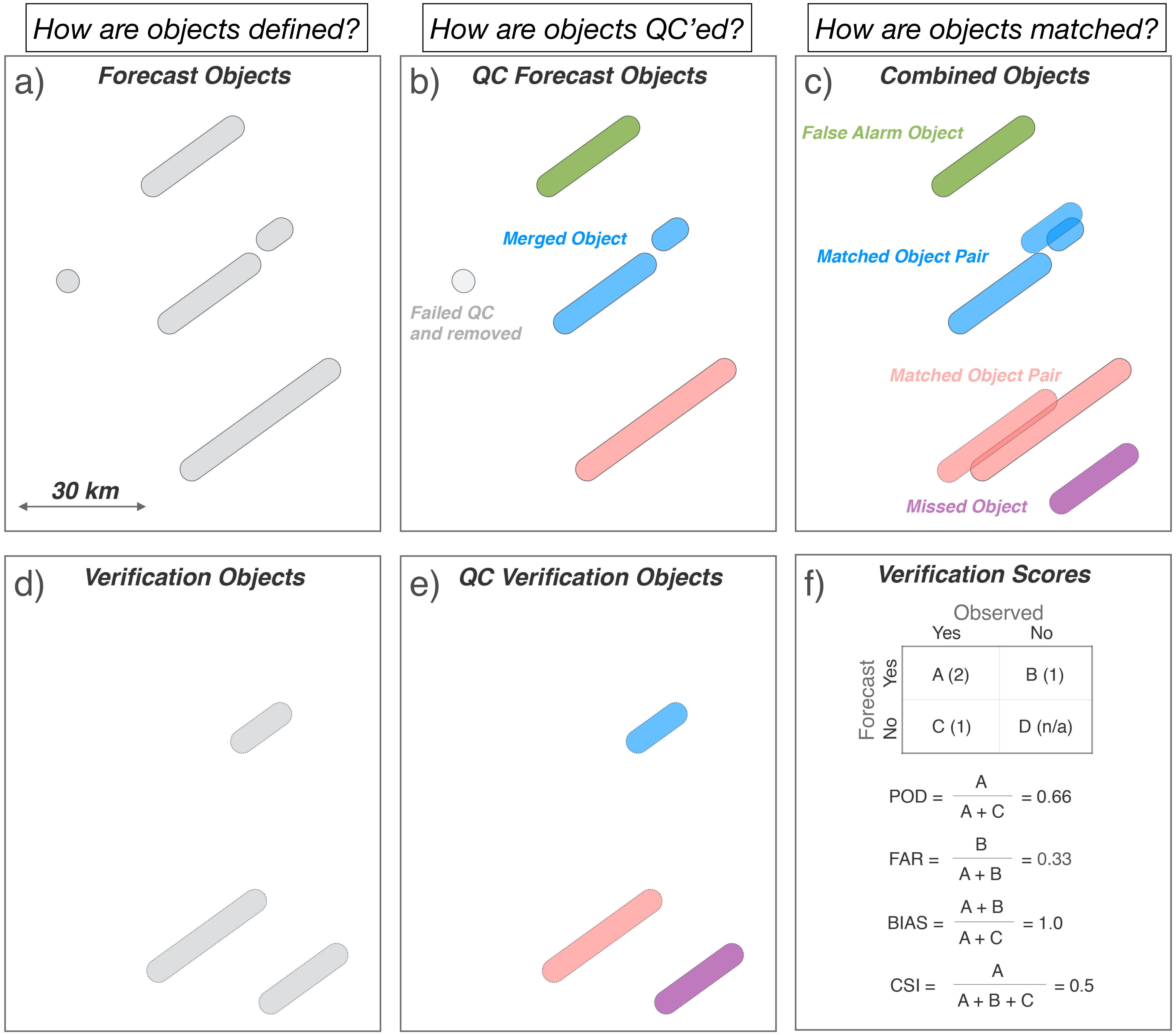


Object ID and Matching:

- Emulates MODE:
  - Apply size and continuity thresholds to rotation track objects
  - Merge nearby objects (< 12 km boundary distance)
  - Multiple forecast objects cannot be matched to the same verification object
  - Total interest score used to determine matches:

$$\mathrm{TI} = \underbrace{\left\{ \frac{\left[\frac{(\mathrm{cd}_{\max} - \mathrm{cd})}{\mathrm{cd}_{\max}}\right] + \left[\frac{(\mathrm{md}_{\max} - \mathrm{md})}{\mathrm{md}_{\max}}\right]}{2} \right\}}_{\text{Avg. of centroid and boundary displacement}} \underbrace{\left[\frac{(t_{\max} - t)}{t_{\max}}\right]}_{\text{Temporal displacement}}$$

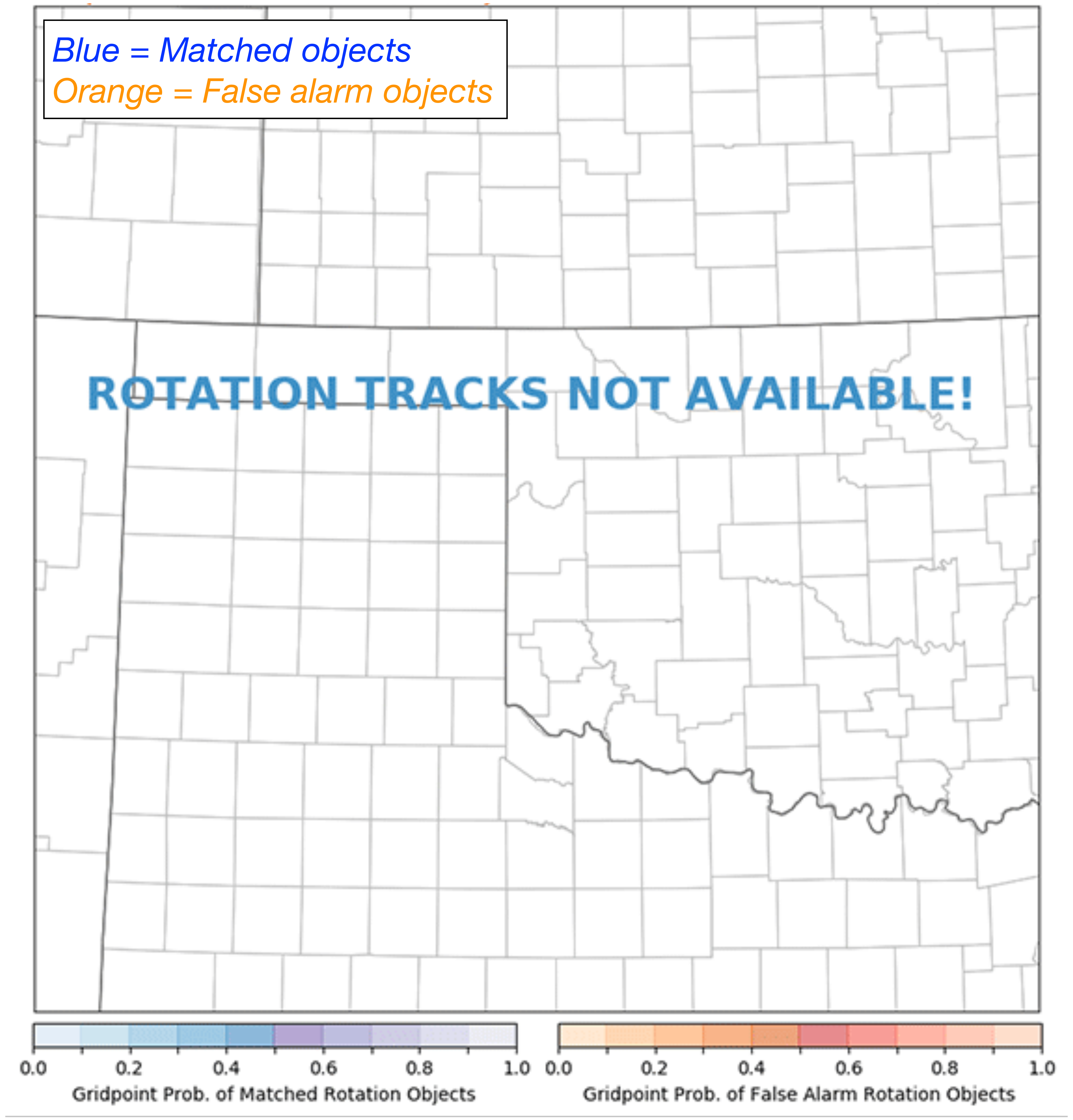
- Matching thresholds chosen to be roughly the space and time scales for a NWS warning product (cd_{max}, md_{max} = 32 km; t_{max} = 20 min)



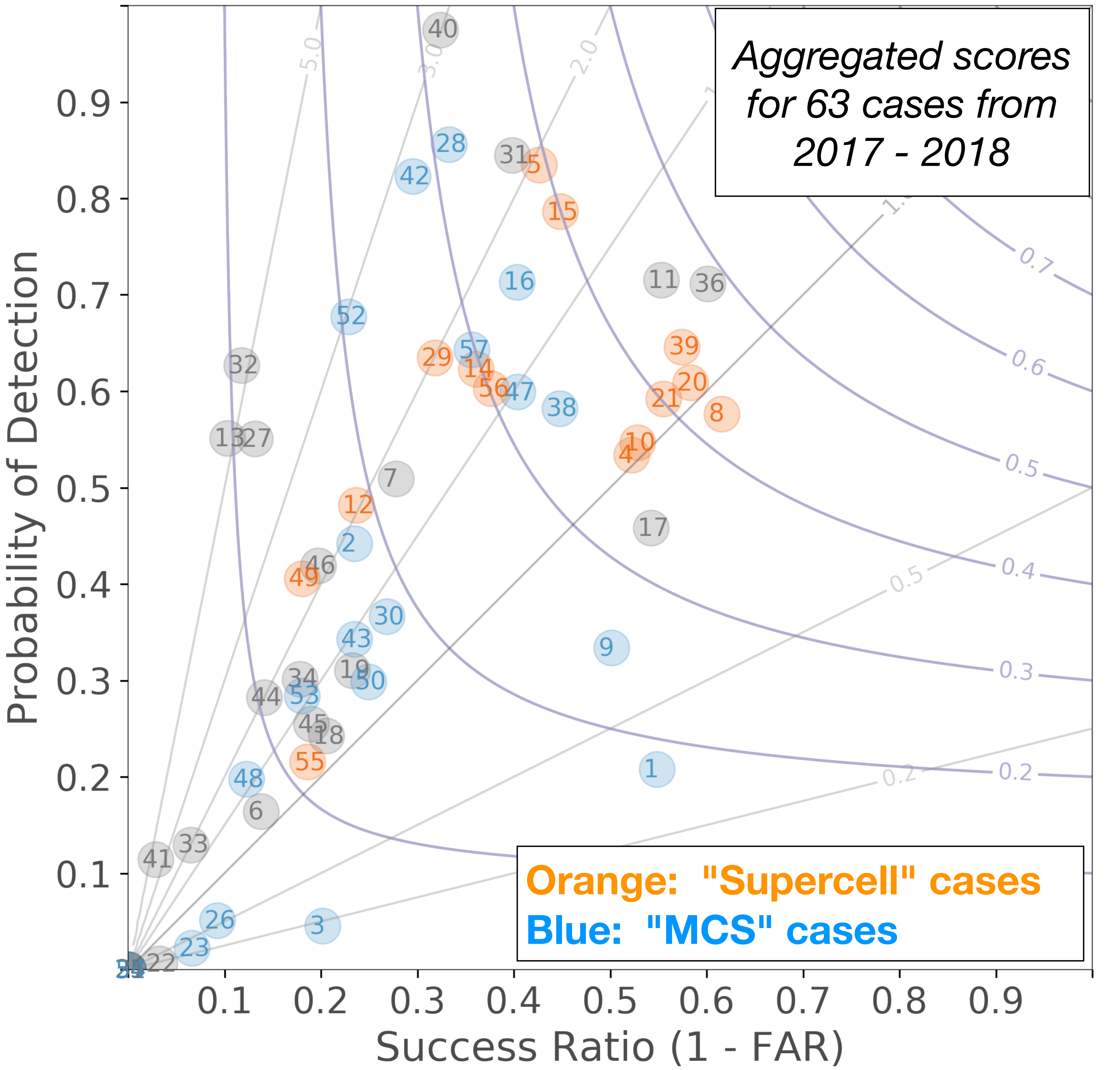
Skinner et al. (2018; Weather and Forecasting)

Deterministic WoFS rotation track verification:

WoFS rotation track object matching



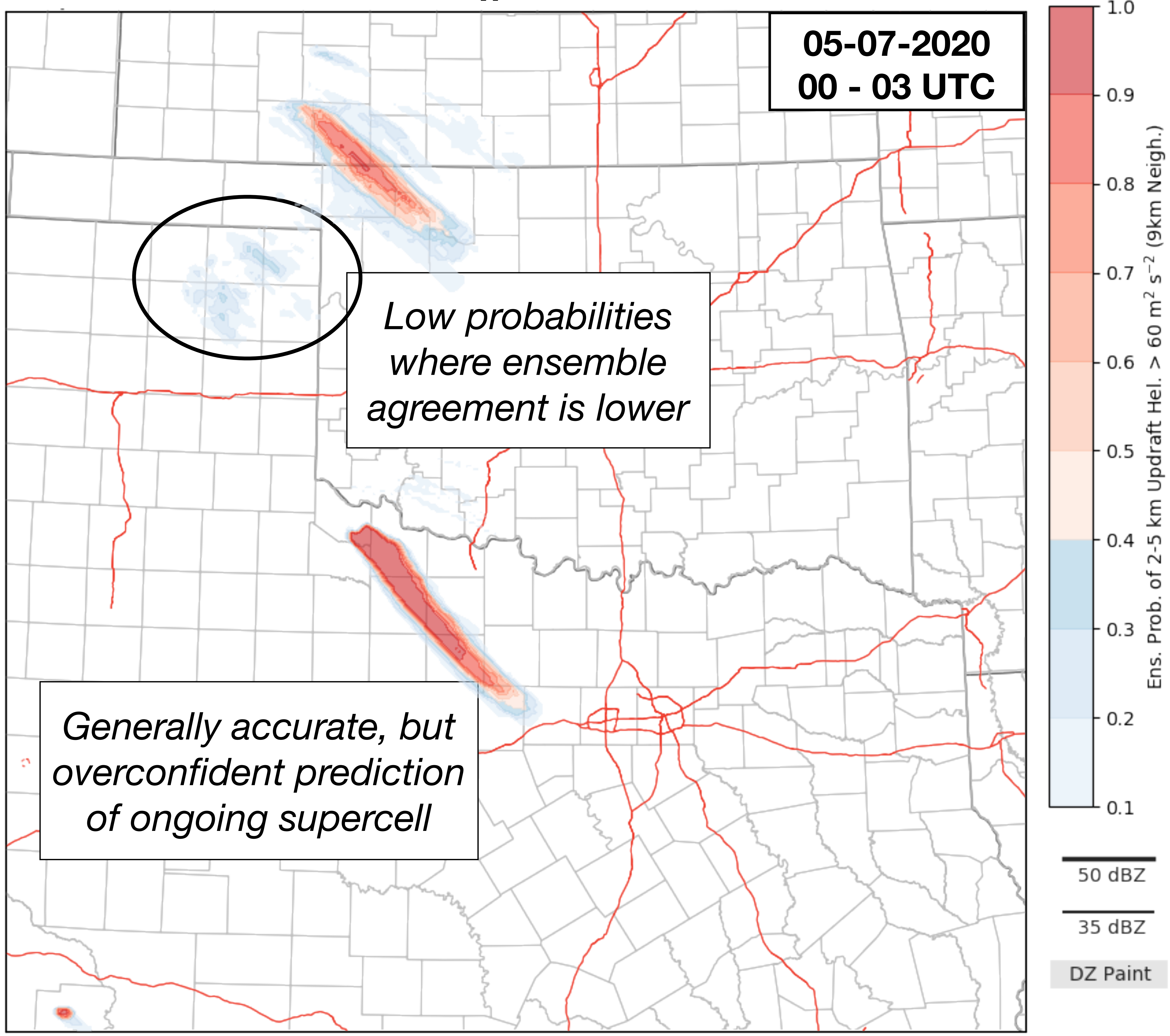
WoFS rot. track object verification (45 - 75 min)



Extension to probabilistic forecasts:

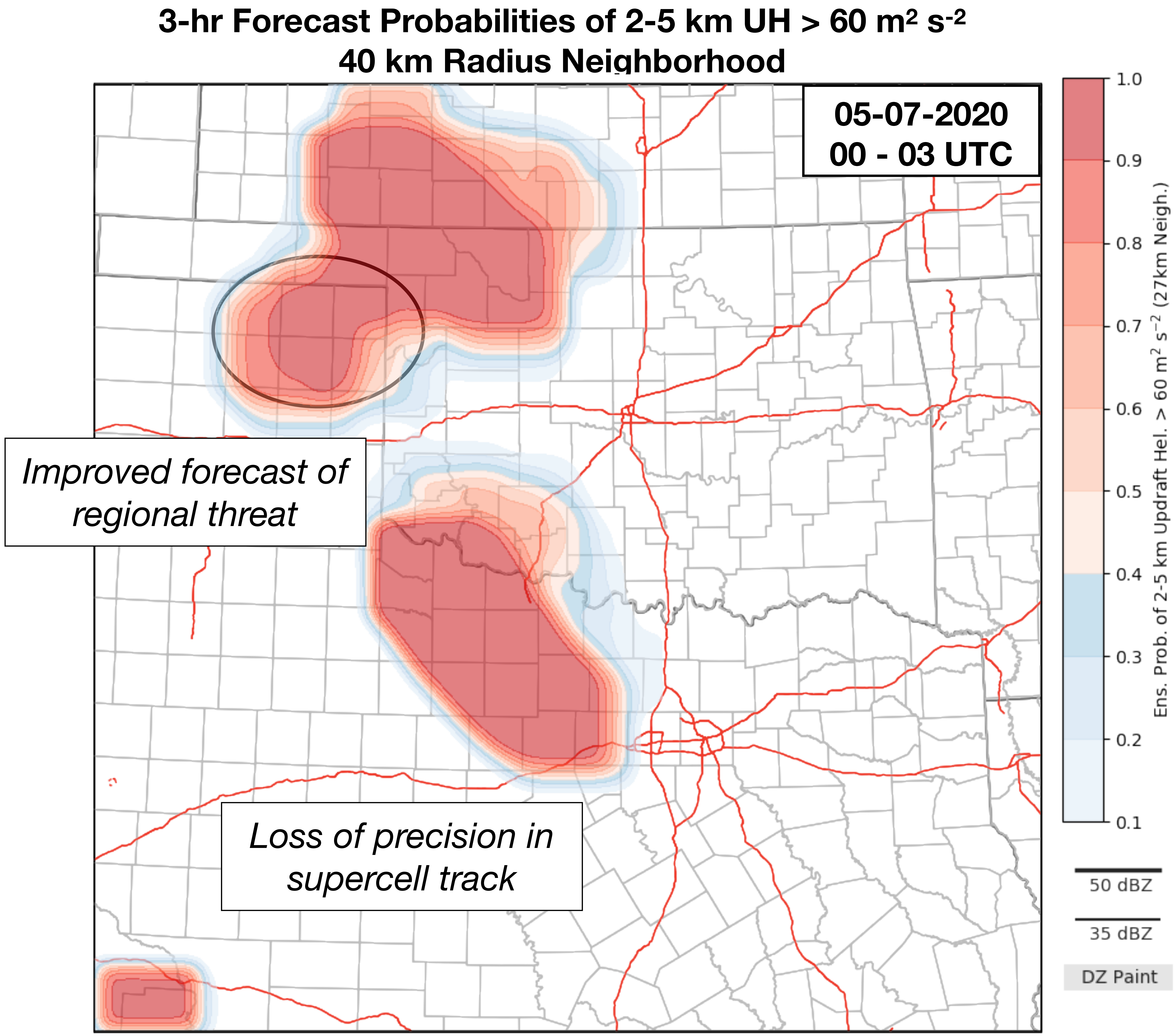
- Object-based technique only provides information on quality of deterministic forecasts
- Ensemble spread in WoFS forecasts varies for different storms in domain and is a function of storm maturity
- Complicates use of neighborhood verification measures

3-hr Forecast Probabilities of 2-5 km UH > 60 m^2 s^{-2}
No Neighborhood



Application of a "next day neighborhood" (40 km radius)

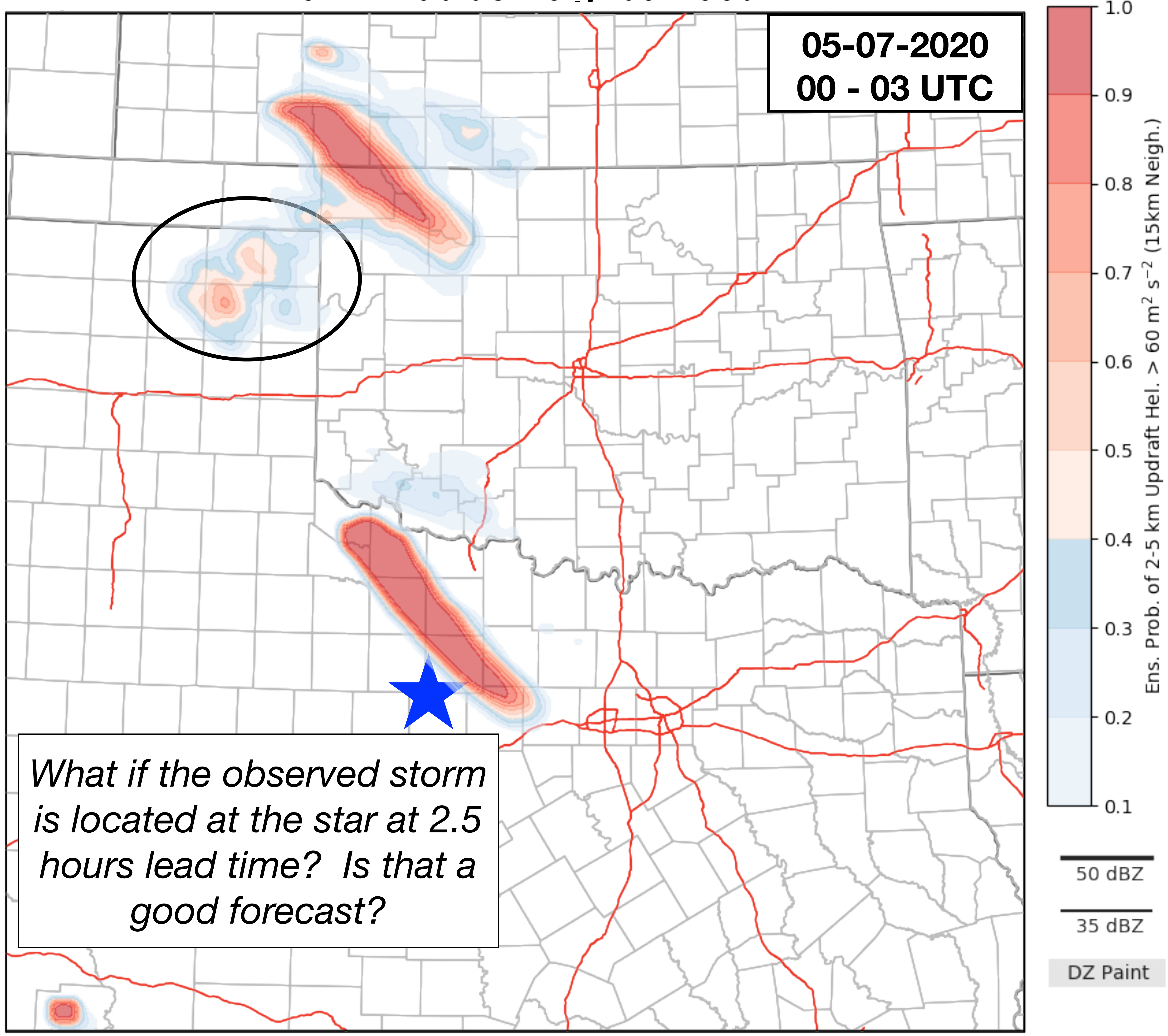
- Application of Neighborhood Maximum Ensemble Probability with a radius designed for next-day CAM verification (similar to scale of SPC outlooks - 40 km radius)
- Increases probability values where ensemble agreement is smaller
- Spreads higher probabilities over a much wider region



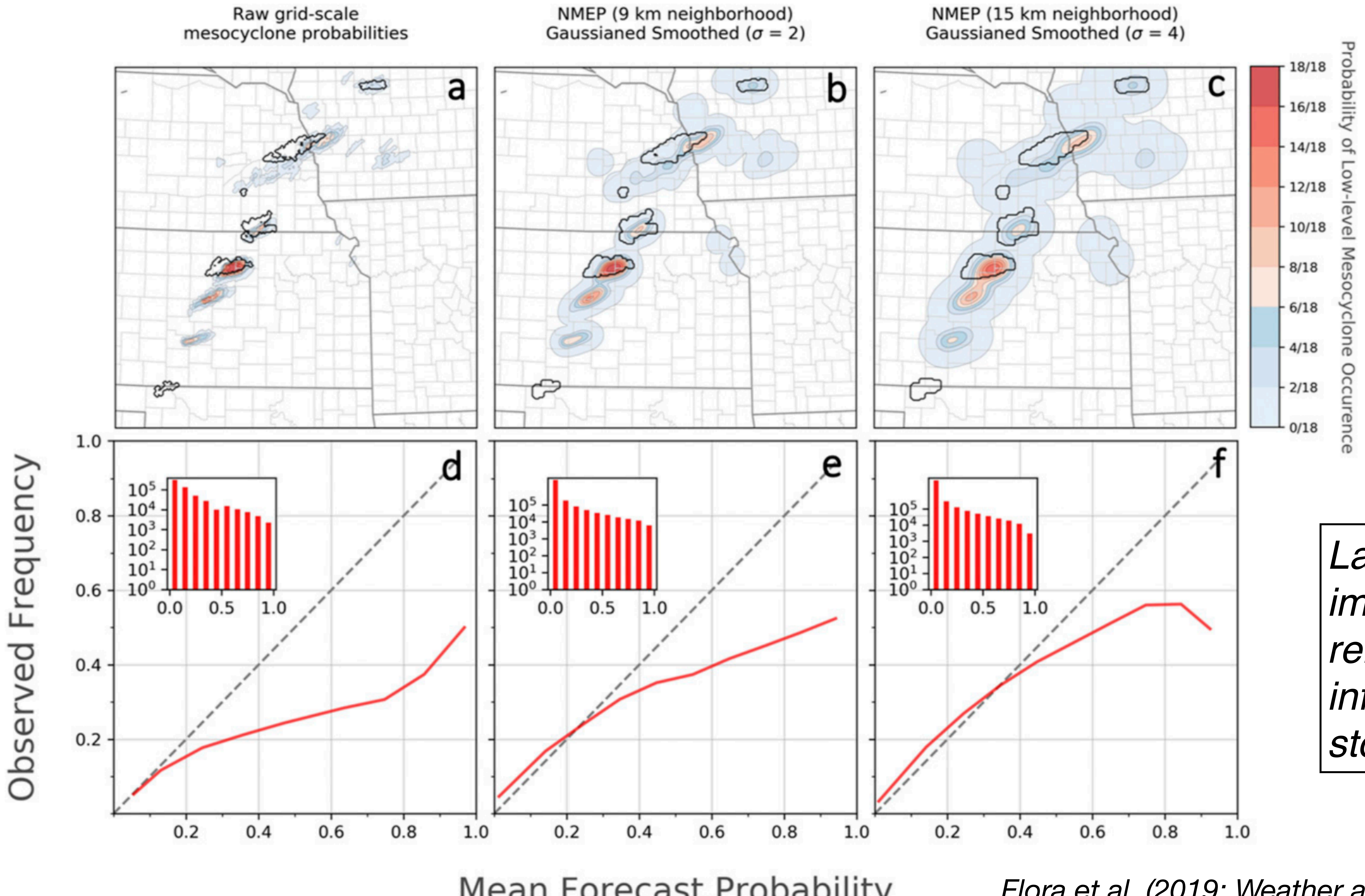
Application of a "next hour neighborhood" (7.5 km radius)

- Small neighborhoods provide a balance between spreading information in low confidence events while preserving precision of high confidence events
- Underdispersion in WoFS creates trade off between reliability and precision
- A highly confident 0-3 h forecast of a mesocyclone with small spatial errors (< ~50 km) is useful to most end users
- Goal is to apply object-based methods to probability swaths to quantify forecast consistency while maintaining spatial specificity

3-hr Forecast Probabilities of 2-5 km UH > 60 $m^2 s^{-2}$
7.5 km Radius Neighborhood



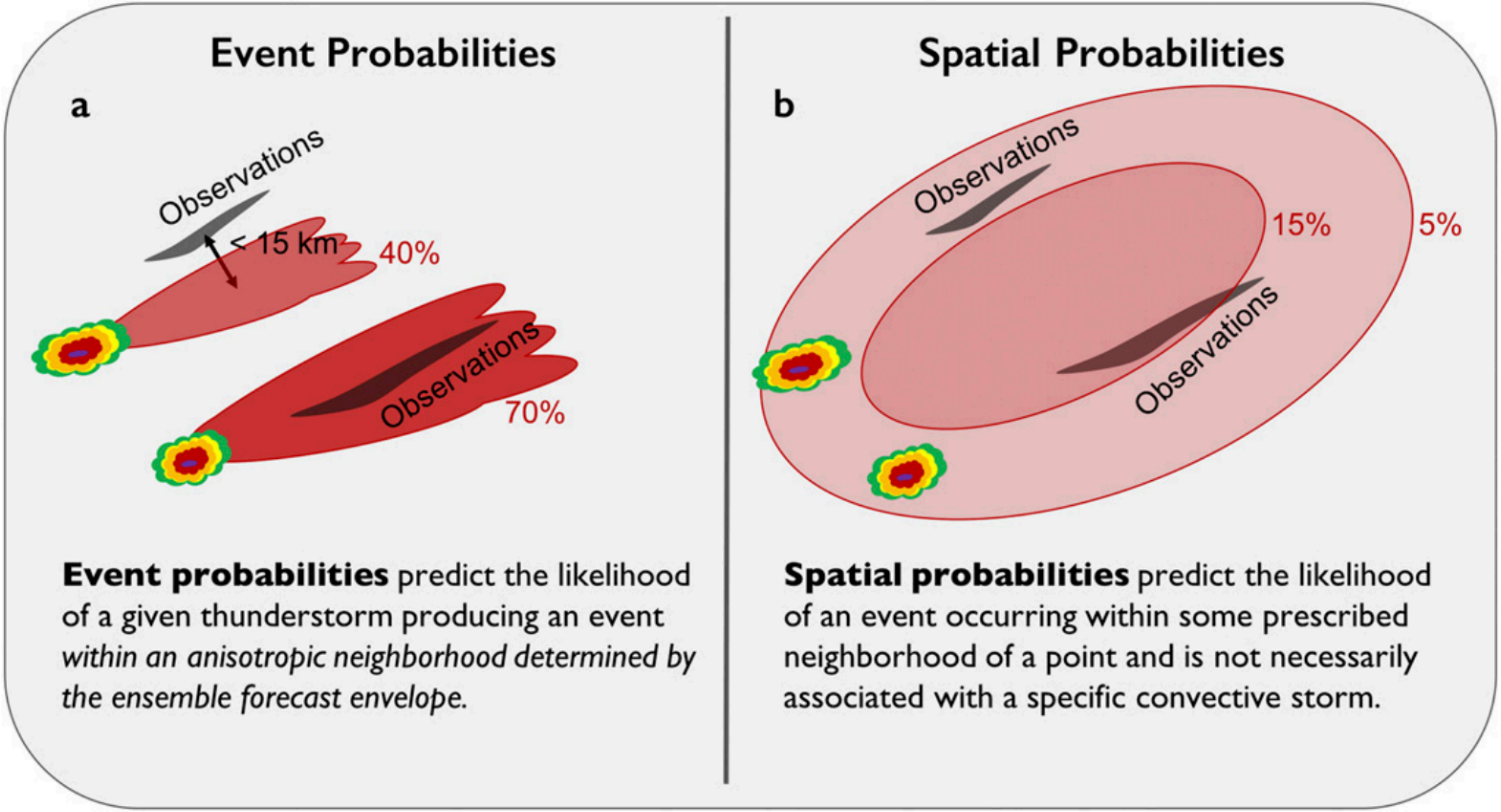
Relationship between neighborhood size and grid scale reliability:



Larger neighborhoods improve forecast reliability, but information on individual storm tracks is lost

Flora et al. (2019; Weather and Forecasting)

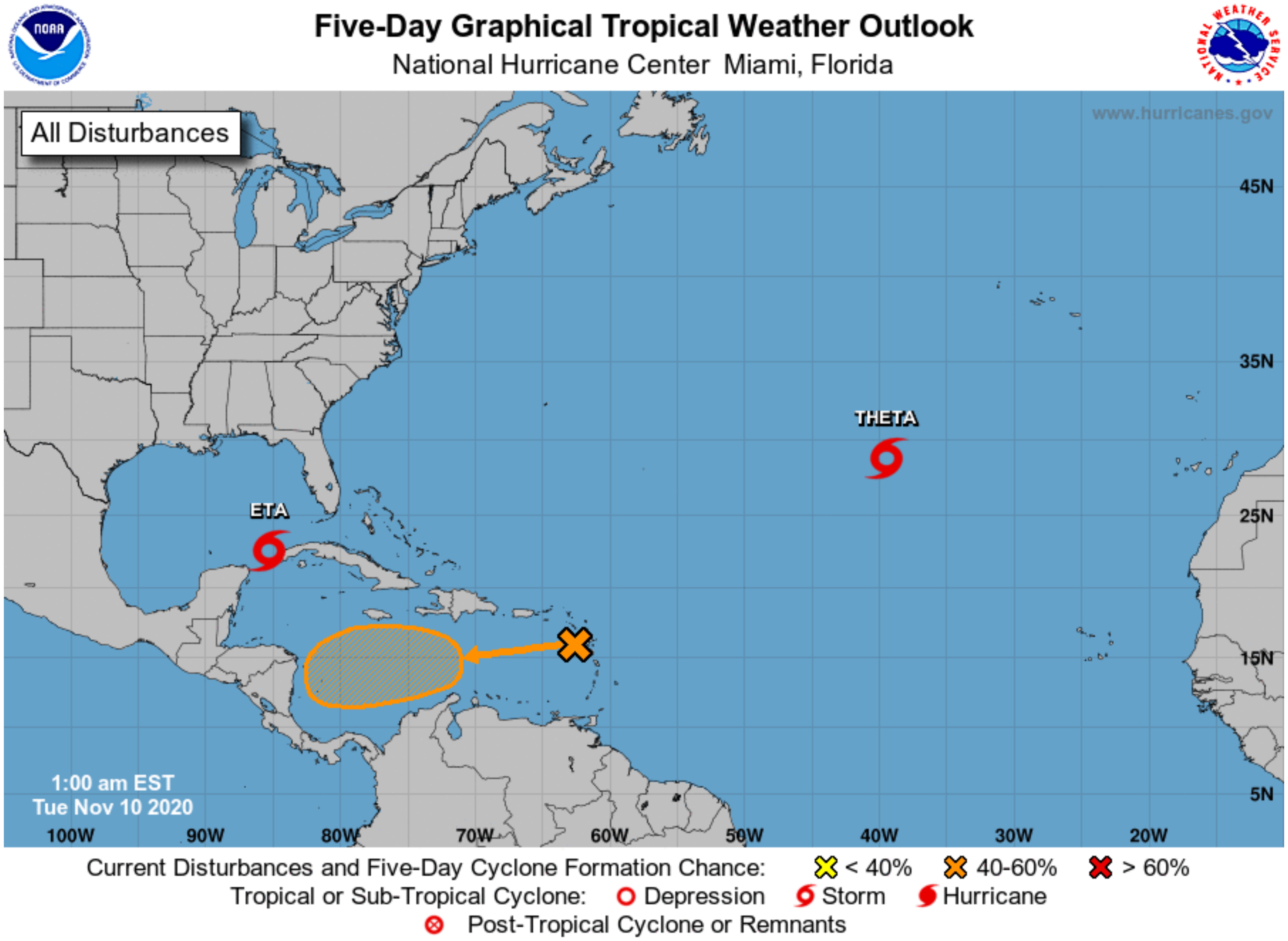
Motivates development of event based probabilities:



Flora et al. (2019; Weather and Forecasting)

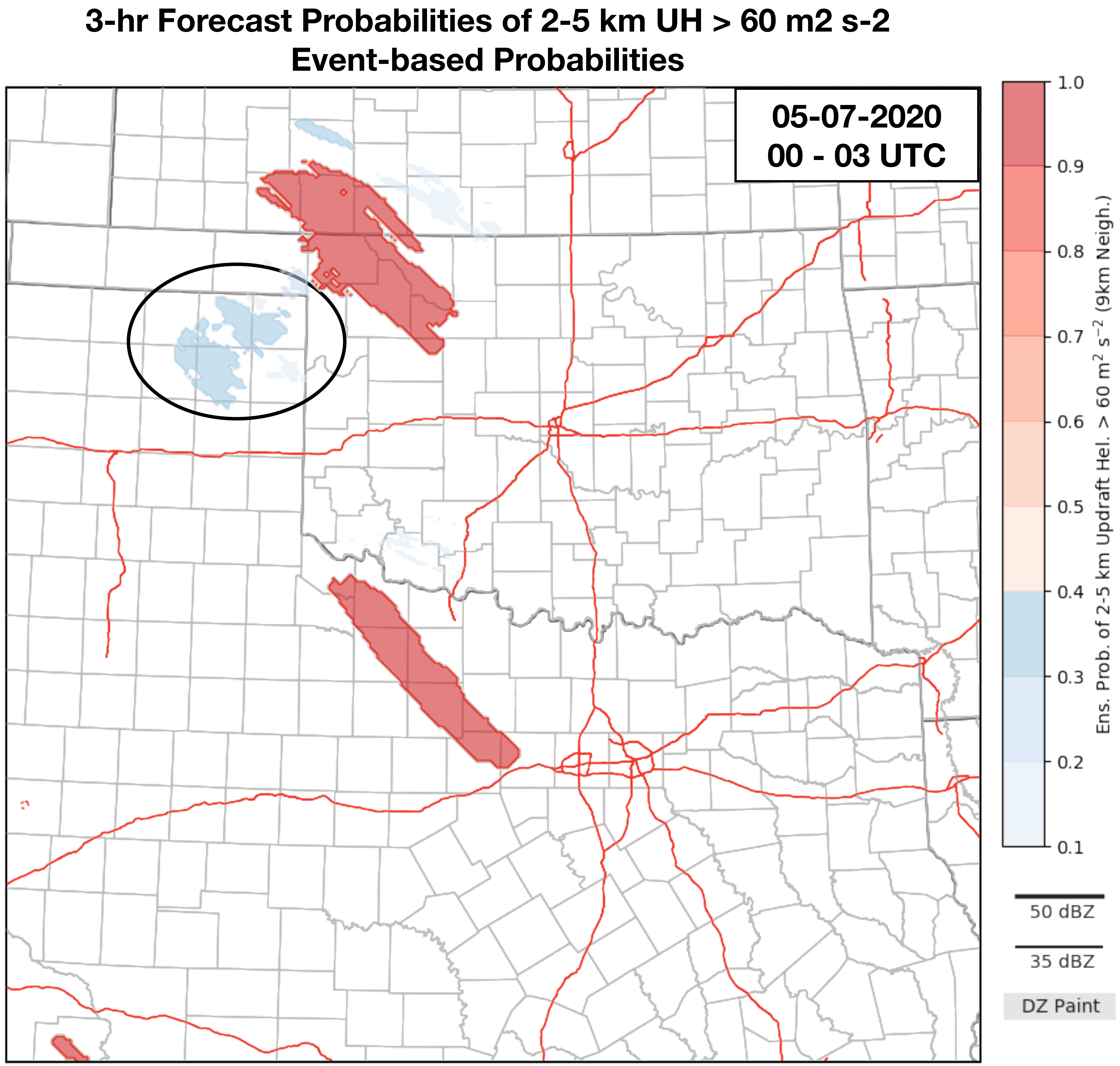
Motivates development of event based probabilities:

- Concept is similar to National Hurricane Center predictions of tropical cyclogenesis:



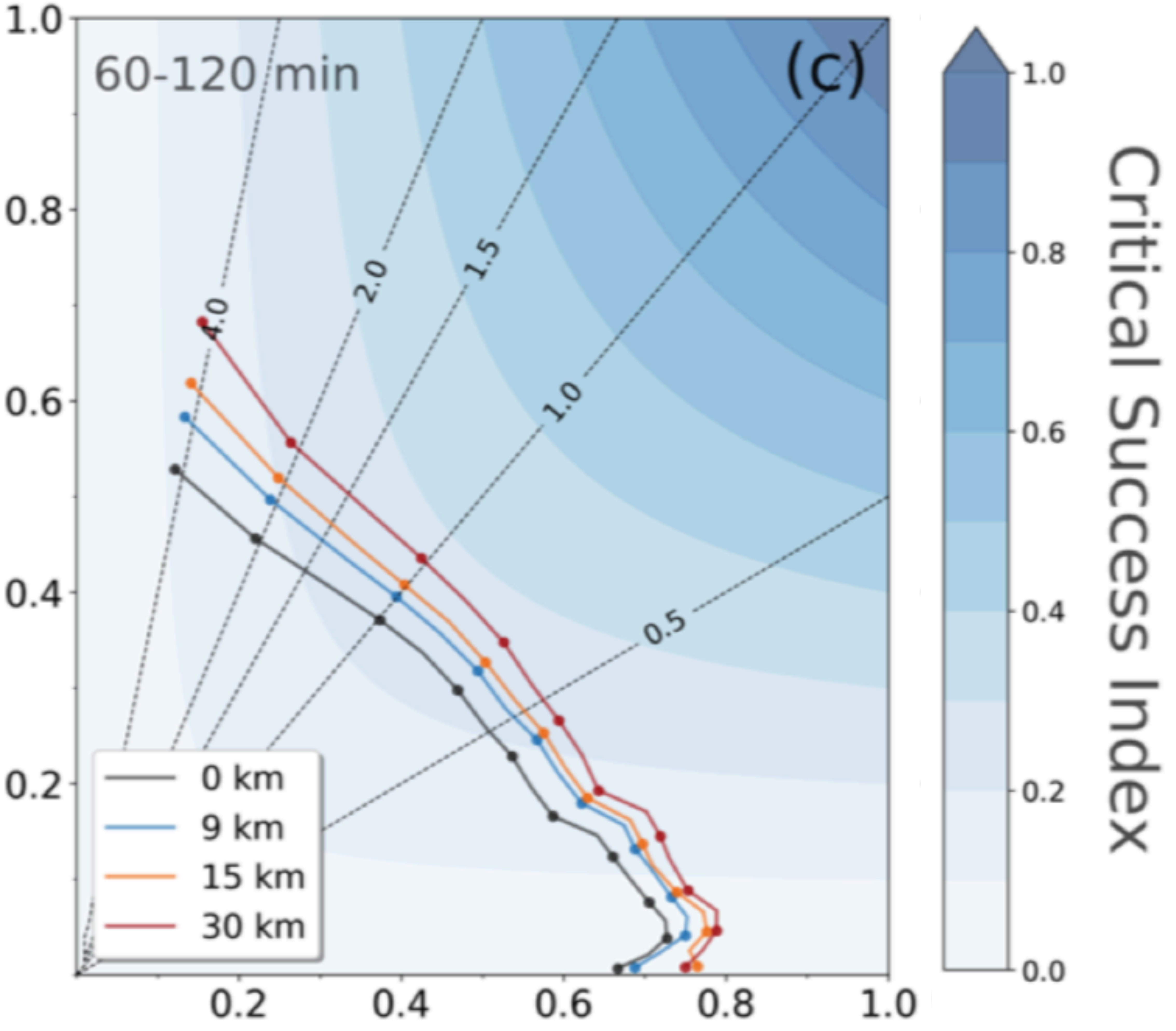
Methodology for event-based probabilities:

- Calculated as the percentage of ensemble members predicting UH swaths within a contiguous region
- No neighborhood
- Enhanced watershed algorithm (Lakshmanan et al. 2009) used to identify object boundaries
- *Advantages:*
  - *Provides probabilistic guidance in format similar to paintball plot*
  - *Reliability may be calculated through object matching to radar-derived proxies*
- *Disadvantages:*
  - *Many tunable parameters in object ID and matching*
  - *Complex storm modes complicate object identification*

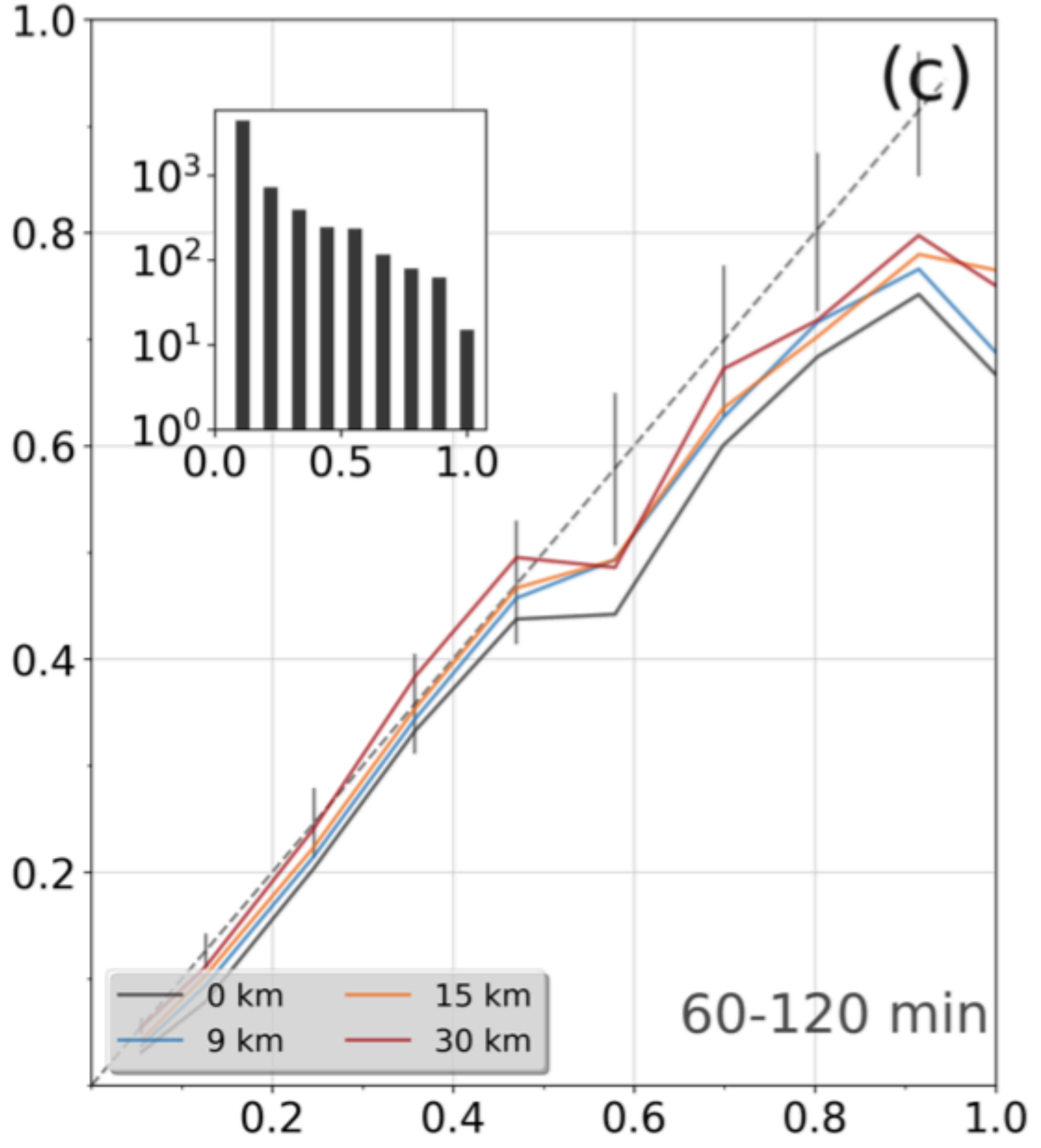


Verification of 1-2 hr, event-based mesocyclone forecasts (63 cases in 2017-2018)

- *Highest CSI for probability threshold of ~20%*
- *Missed events during ensemble spin up limit POD*



- *Reliable forecasts up to 50% probability*
- *Slight overproduction bias for higher probabilities*

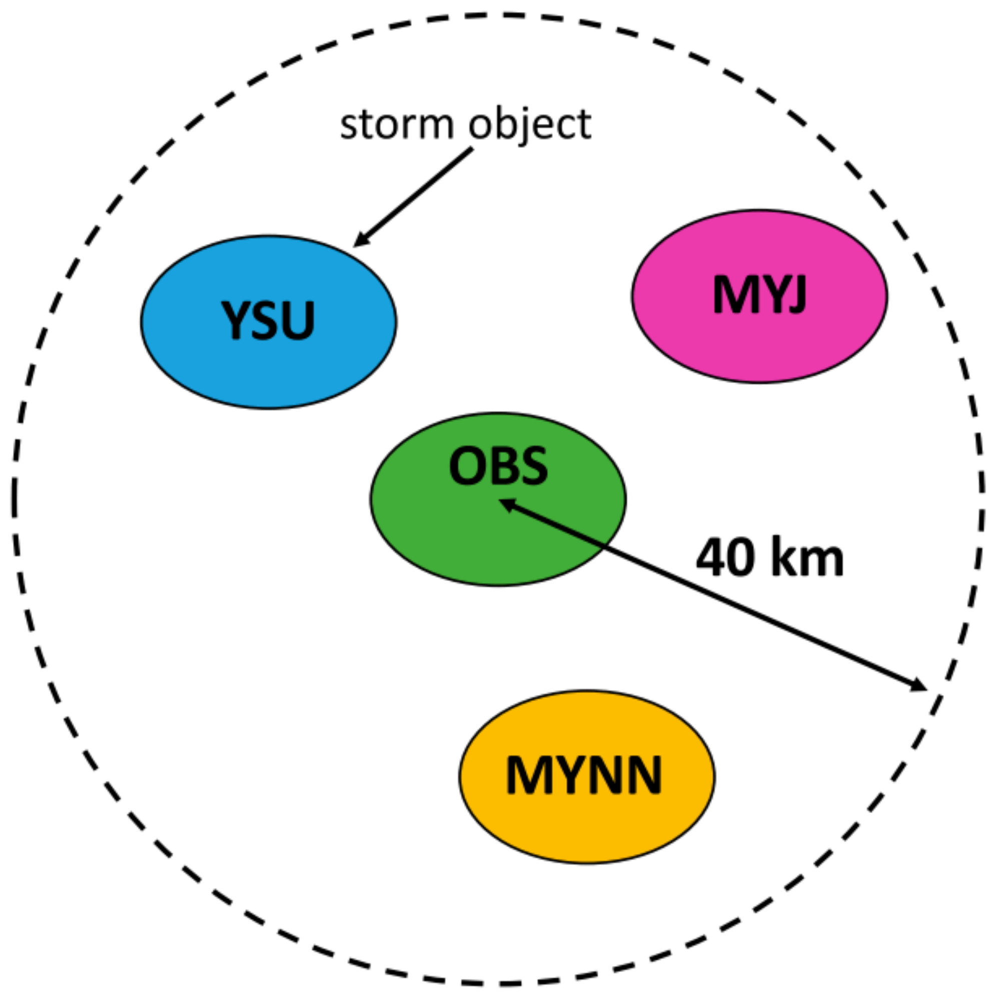


Flora et al. (2019; Weather and Forecasting)

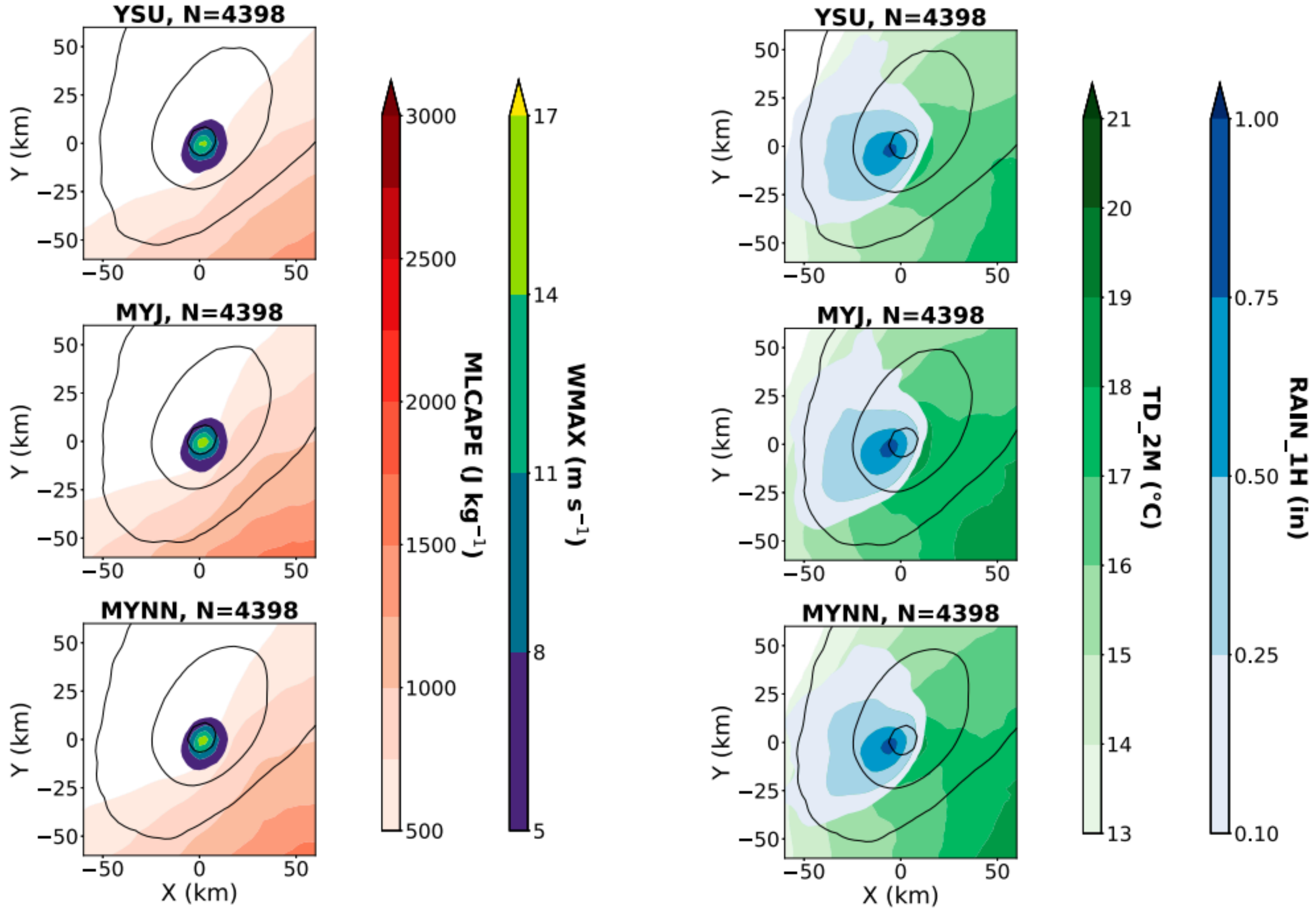
Applications to point-based verification:

- The near-storm environment modulates the intensity and evolution of thunderstorms
- However, sparse observation networks rarely collect observations in most pertinent regions

- Object matching allows composite thunderstorm objects to be created using probability matching
- Composite objects verified against observations in a storm-relative framework



Composite WoFS thunderstorm objects for different Planetary Boundary Layer schemes

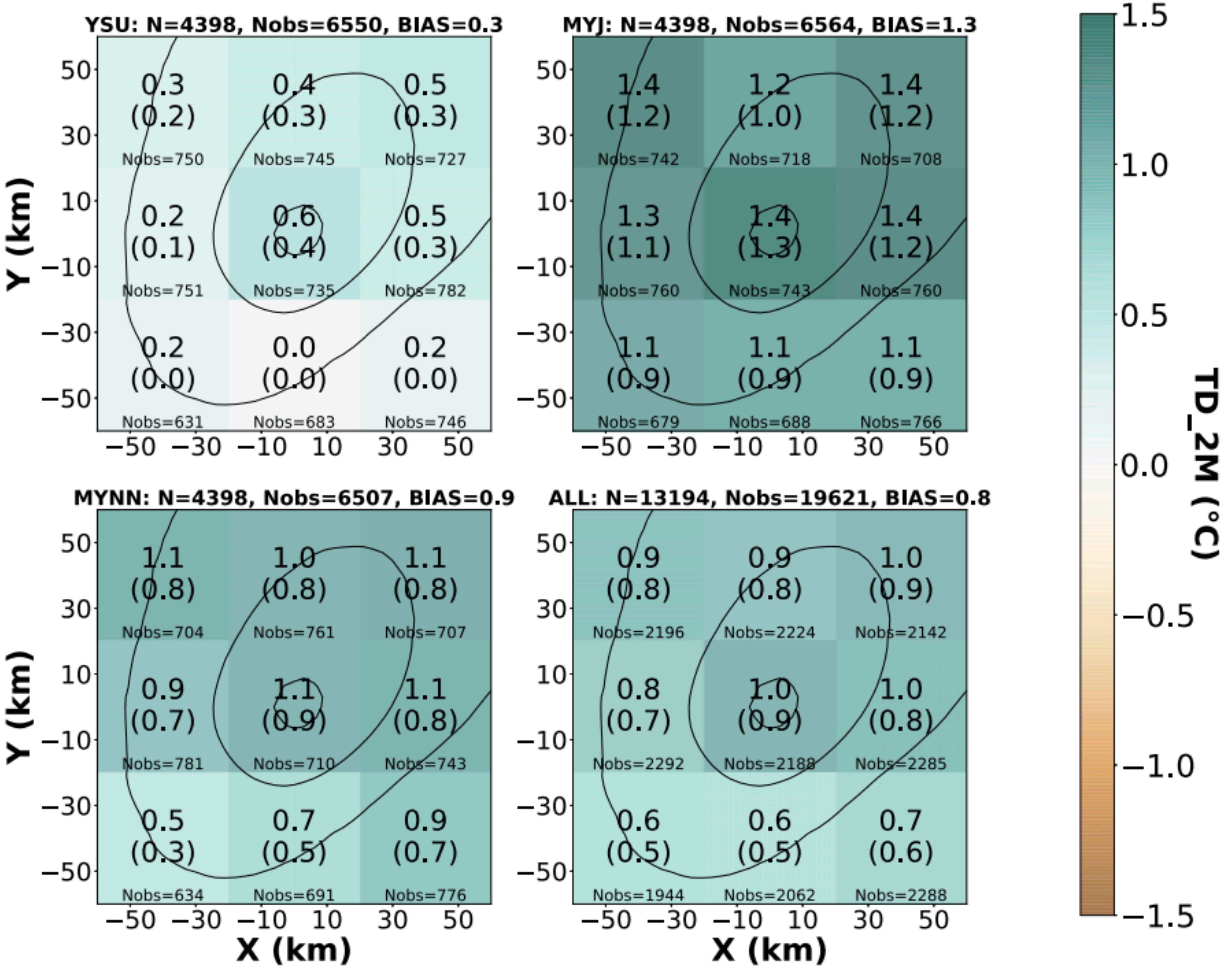


Potvin et al. (2020; Monthly Weather Review)

Applications to point-based verification:

Near-storm ASOS verification of WoFS dewpoint temperature:

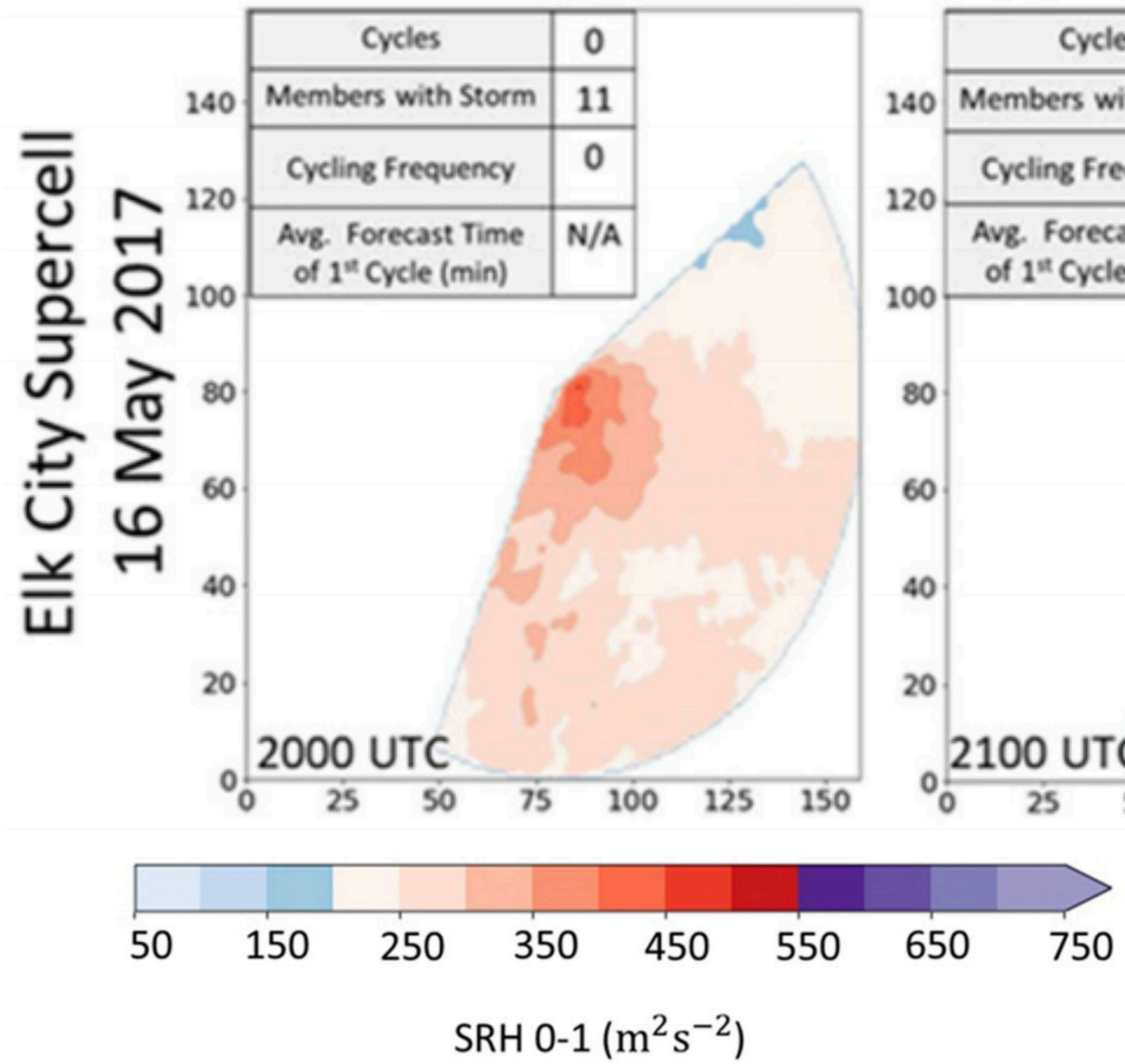
- Compositing allows large samples to be collected of observations near relatively rare phenomena
- Used to quantify near- and intrastorm biases in surface temperature and dewpoint across 3 PBL schemes used by WoFS



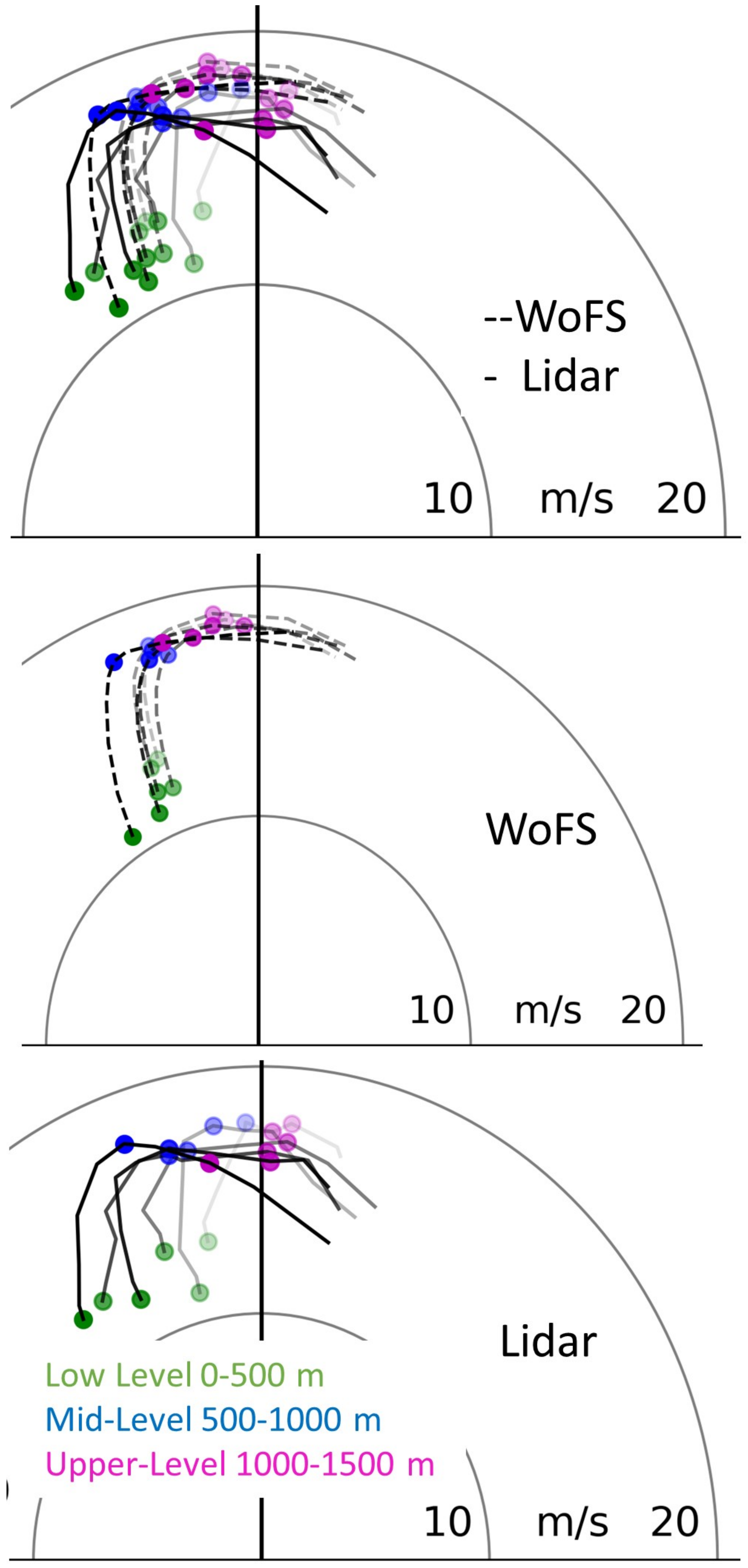
Potvin et al. (2020; Monthly Weather Review)

Applications to point-based verification:

- Compositing allows the extent to which storms modify their environment to be quantified
- Prediction of storm modification can be verified using specialized observations from field experiments



Britt et al. 2020 (Weather and Forecasting)



Courtesy Jordan Laser

Conclusions:

- Object-based verification provides an intuitive method for verifying short-term forecasts of thunderstorm hazards that emulates end users interpretation of guidance (Skinner et al. 2018)
- Identification of event-based probabilities extends object-based methods to probabilistic forecasts (Flora et al. 2019)
- Matching across ensemble members allows composite storm objects to be created and verified against point observations in a storm-relative framework (Potvin et al. 2020)

https://wof.nssl.noaa.gov/realtime

Ongoing/Future Research:

- Integration of techniques into MET+/MODE
- Development of object identification techniques for different storm modes
- Use of event based probabilities as input into machine learning models (Flora et al. 2020)
- Evaluating the impacts of reduced horizontal grid spacing on mesocyclone forecasts (Lawson et al. 2020)
- Quantification of the impacts of ensemble spin up on forecast quality

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