Nowcasting hail and convective initiation using deep learning

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Outline

- Using deep learning to nowcast convective phenomena
  - Hail
  - Convective initiation
  - Updraft strength

Gridded Severe Hail Nowcasting Using 3D U-Nets, Lightning Observations, and the Warn-on-Forecast System

Tobias G. Schmidt, Amy McGovern, John T. Allen, Corey K. Potvin, Randy J. Chase, Chad M. Wiley, William R McGovern-Fagg, Montgomery L. Flora, Cameron R. Homeyer, John K. Williams

Accepted with major revisions to Weather and Forecasting

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Motivation

- Hail causes billions of dollars of damage annually
- Hail is too small to be resolved in current NWP models
- Research questions:
  - Can we use AI to improve hail nowcasting in the 0-60 min window?
  - Can we develop an approach that could scale globally?
  - Can we combine NWP predictions with observations to improve real-time predictions?

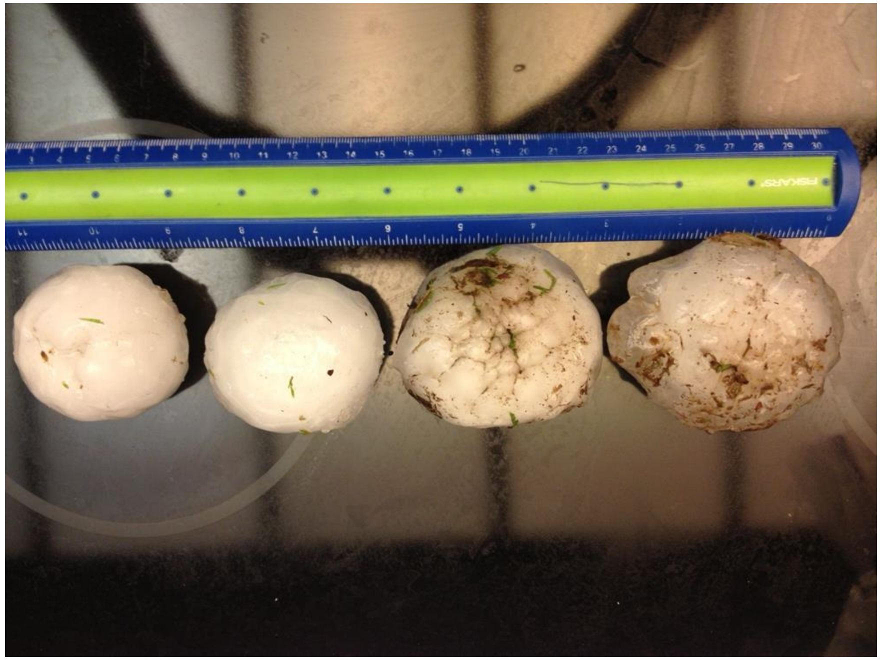
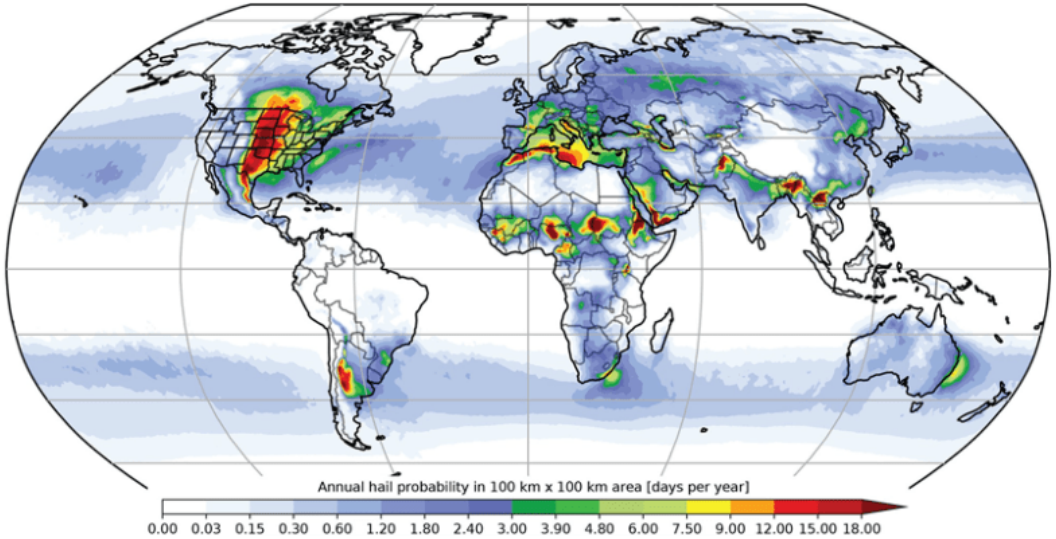


Photo credit: Amy McGovern



https://doi.org/10.1016/j.wace.2018.10.004

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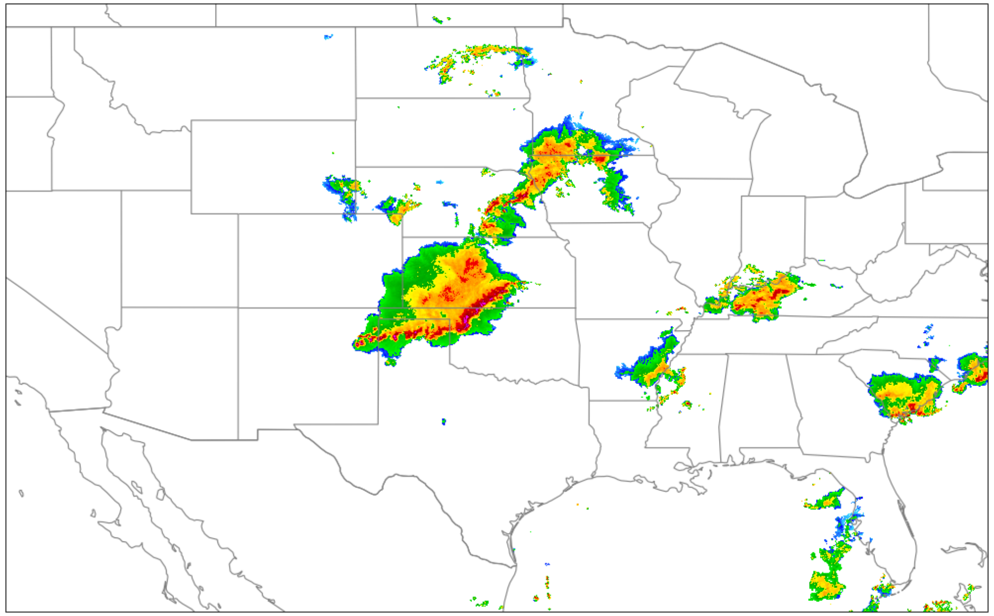
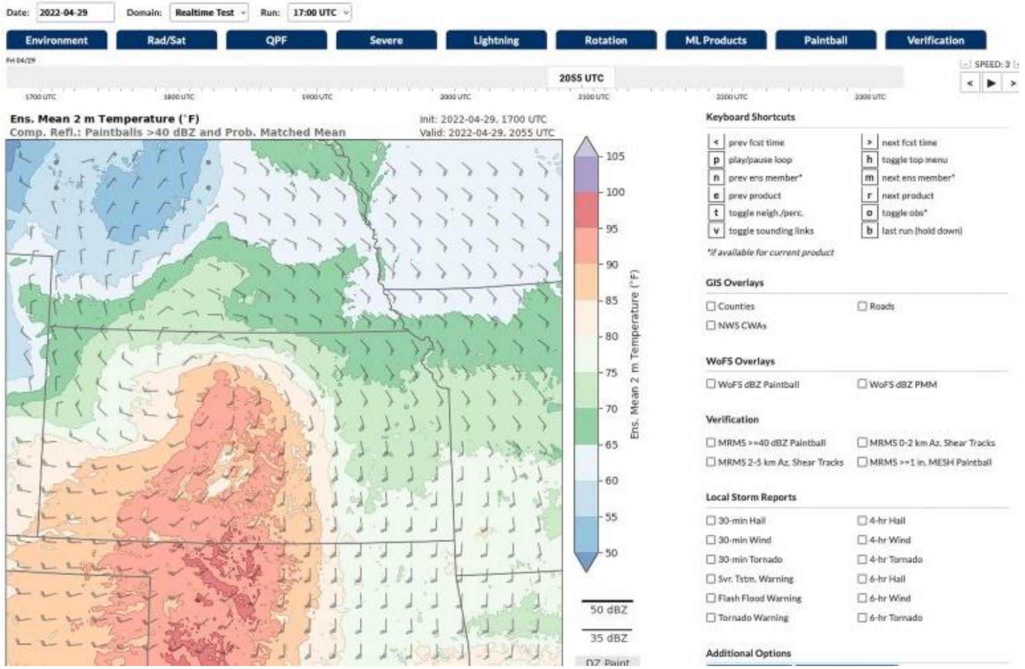
Approach

- Train a deep learning method to combine NWP output with observations to predict hail in CONUS
  - Input data:
    - NSSL's Warn on Forecast system
    - Vaisala's global lightning observations
  - Ground truth: GridRad MESH
- Deep learning method: 3D U-net





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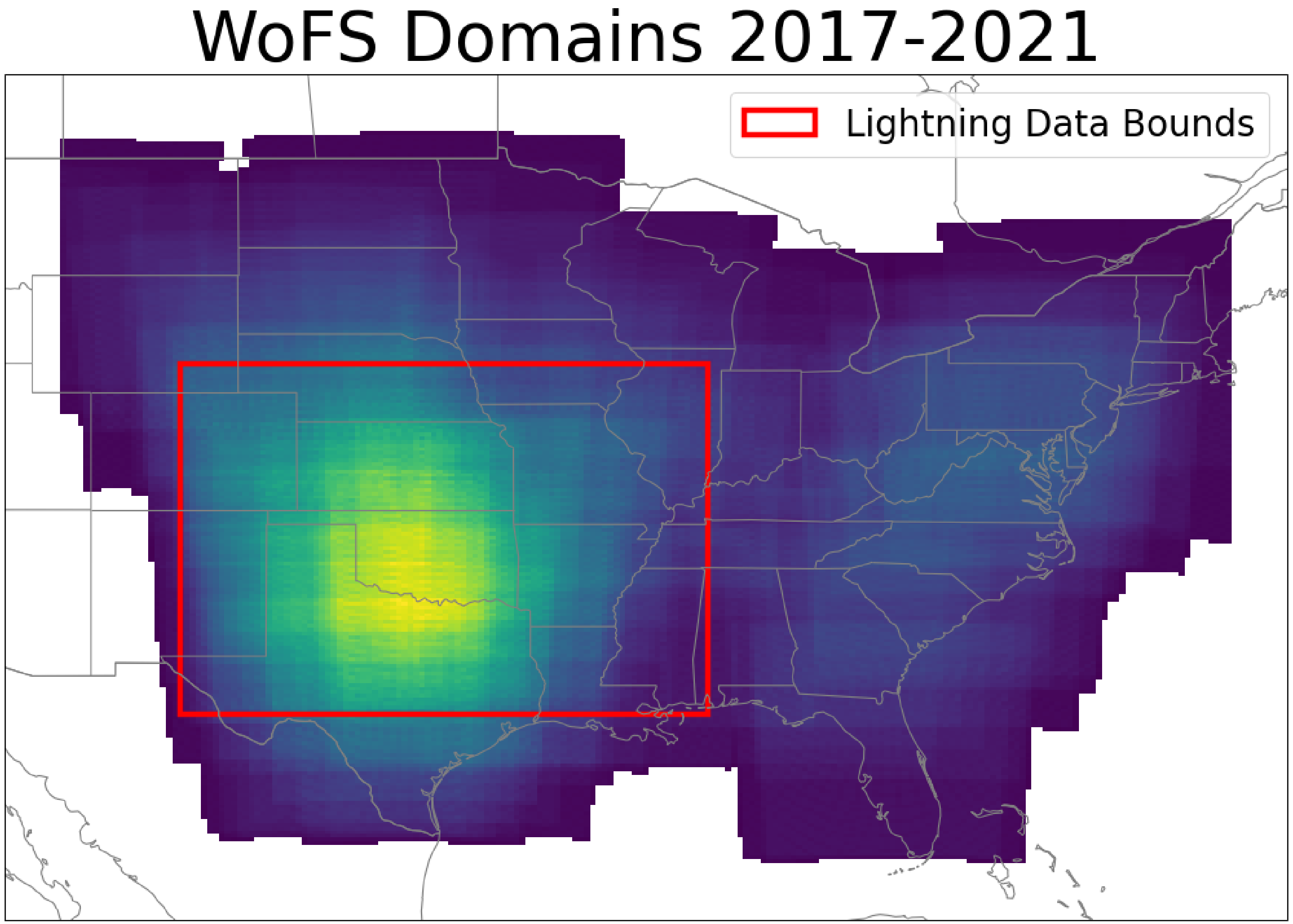
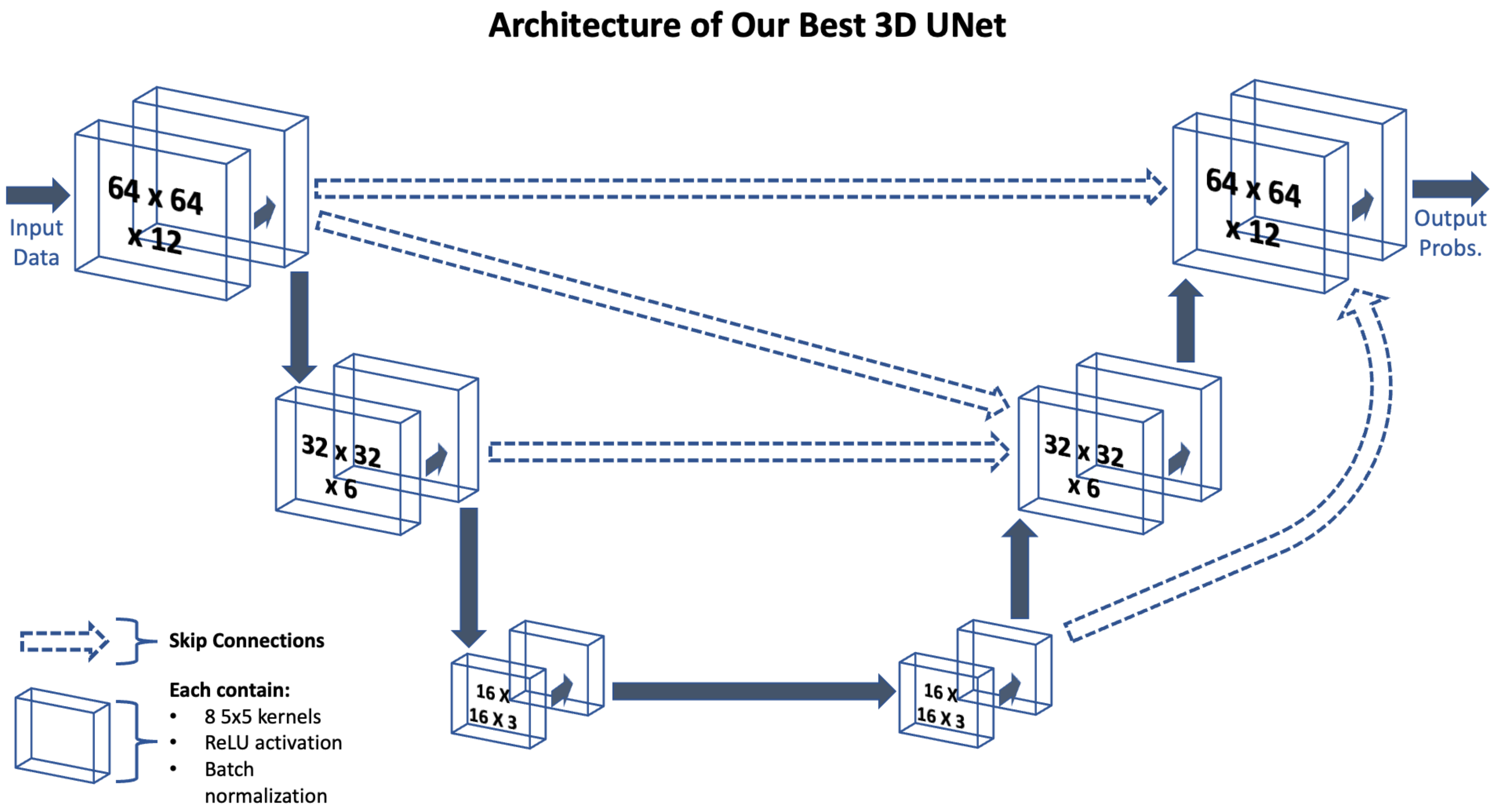
Study domain

- WoFS runs during the US spring spring season
  - High resolution (3x3 km gridcells, 5-minute time intervals)
  - Rapidly incorporates assimilated real-time observations
  - Domain moves each day to focus on area of highest severe weather probabilities
- Lightning data limited
  - Training and testing restricted to inside this area



U-net architecture



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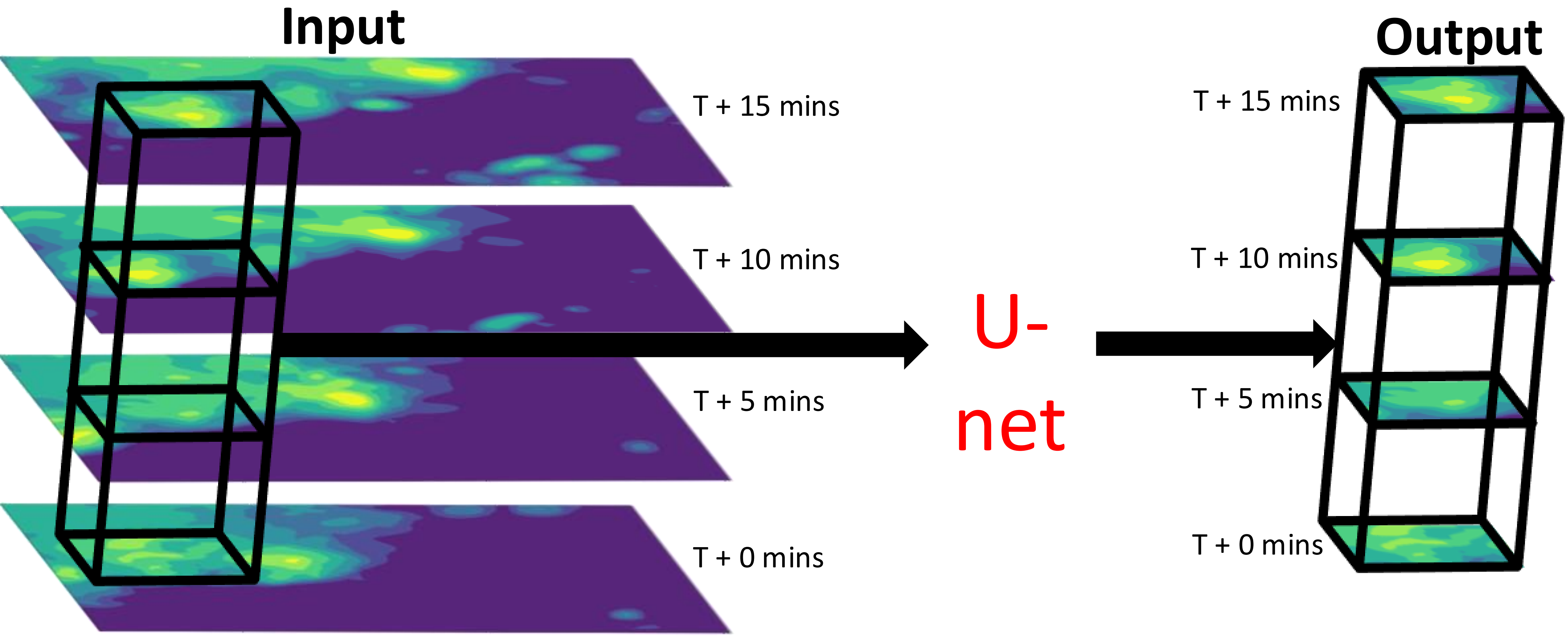
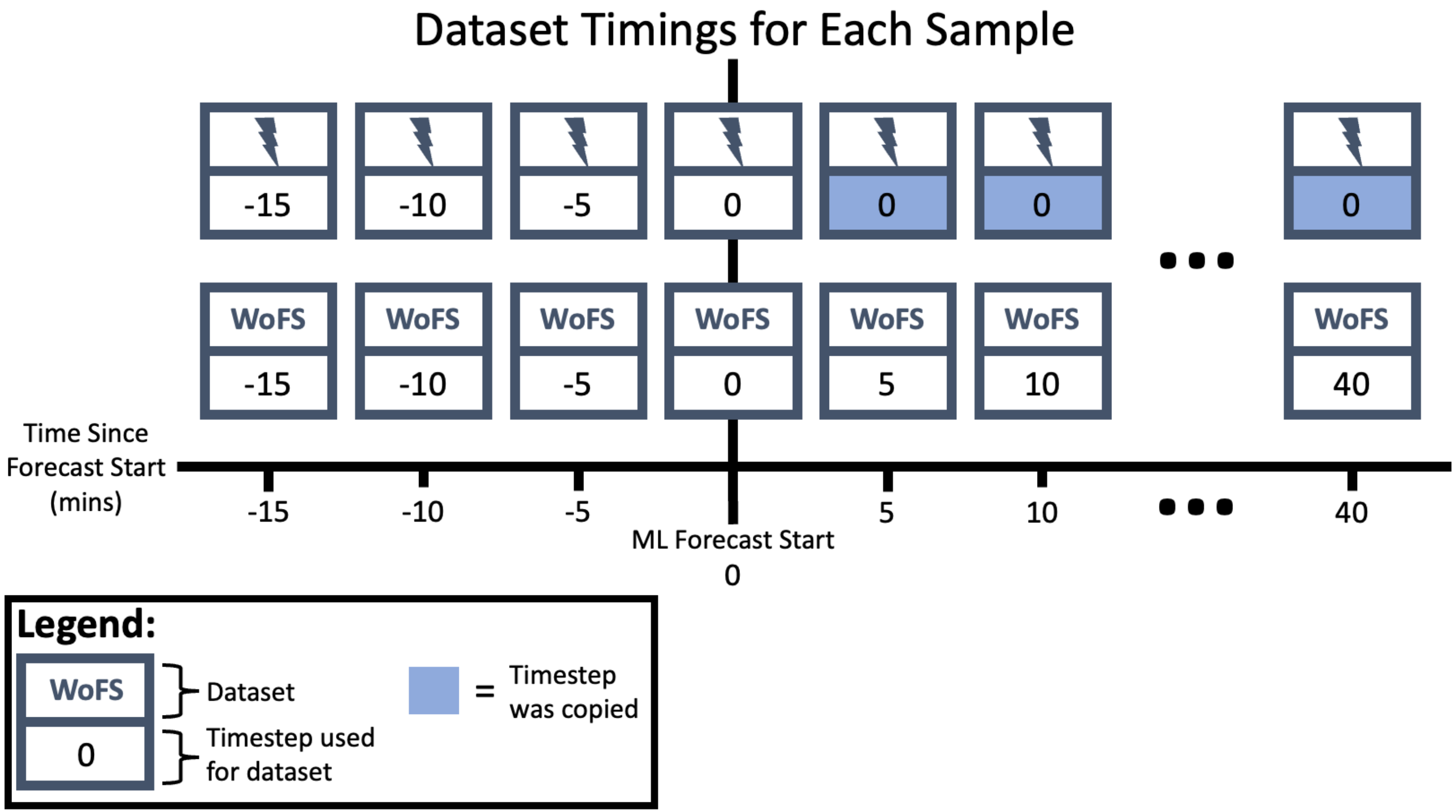
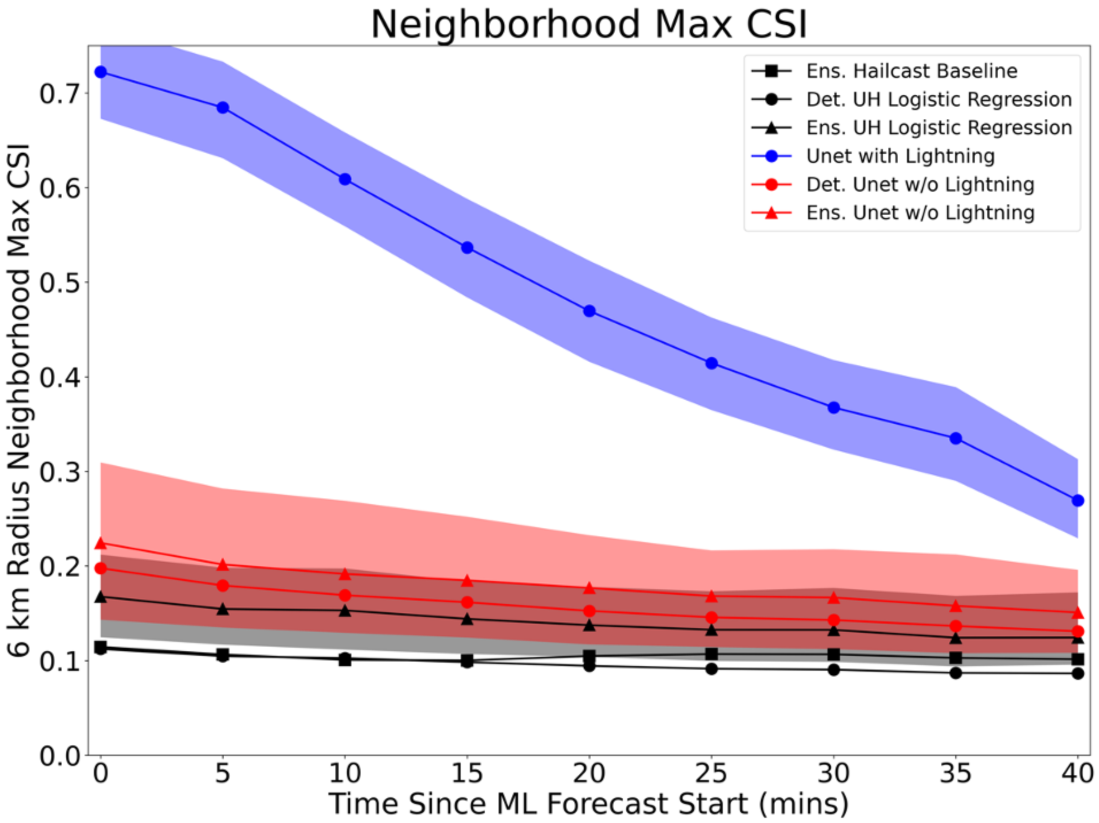
U-net architecture: handling time

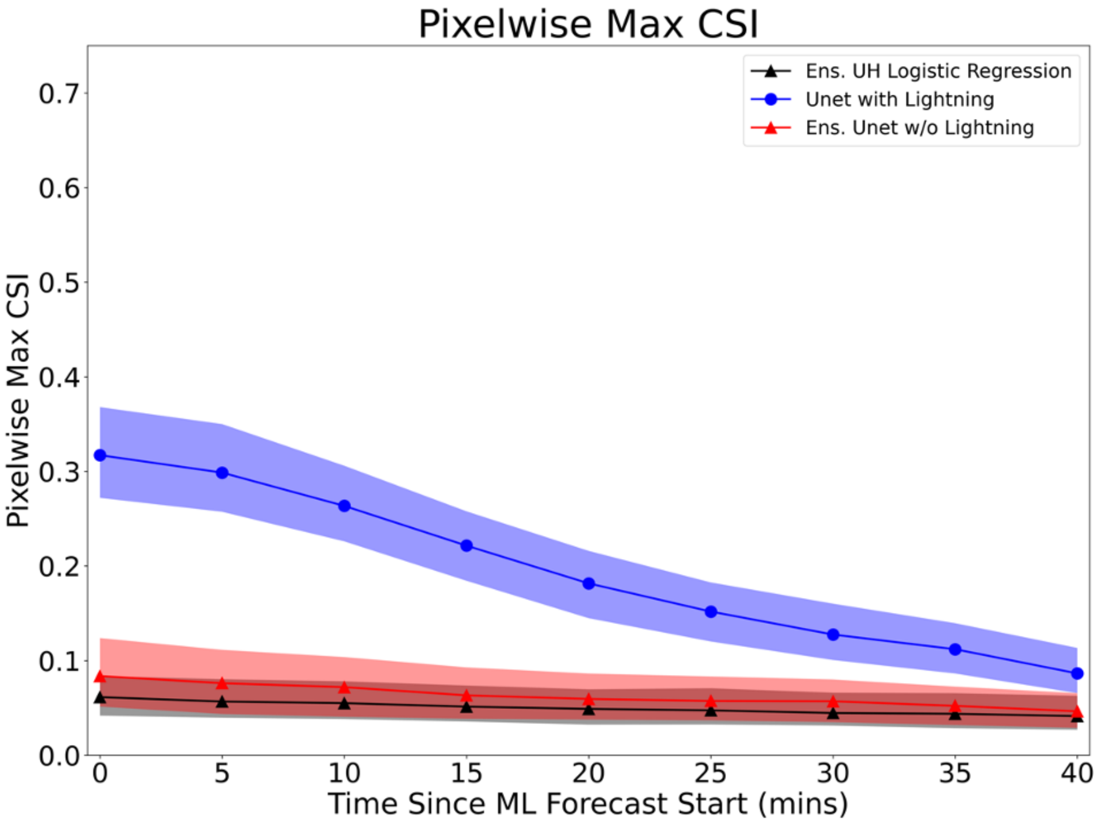


U-net architecture: handling time

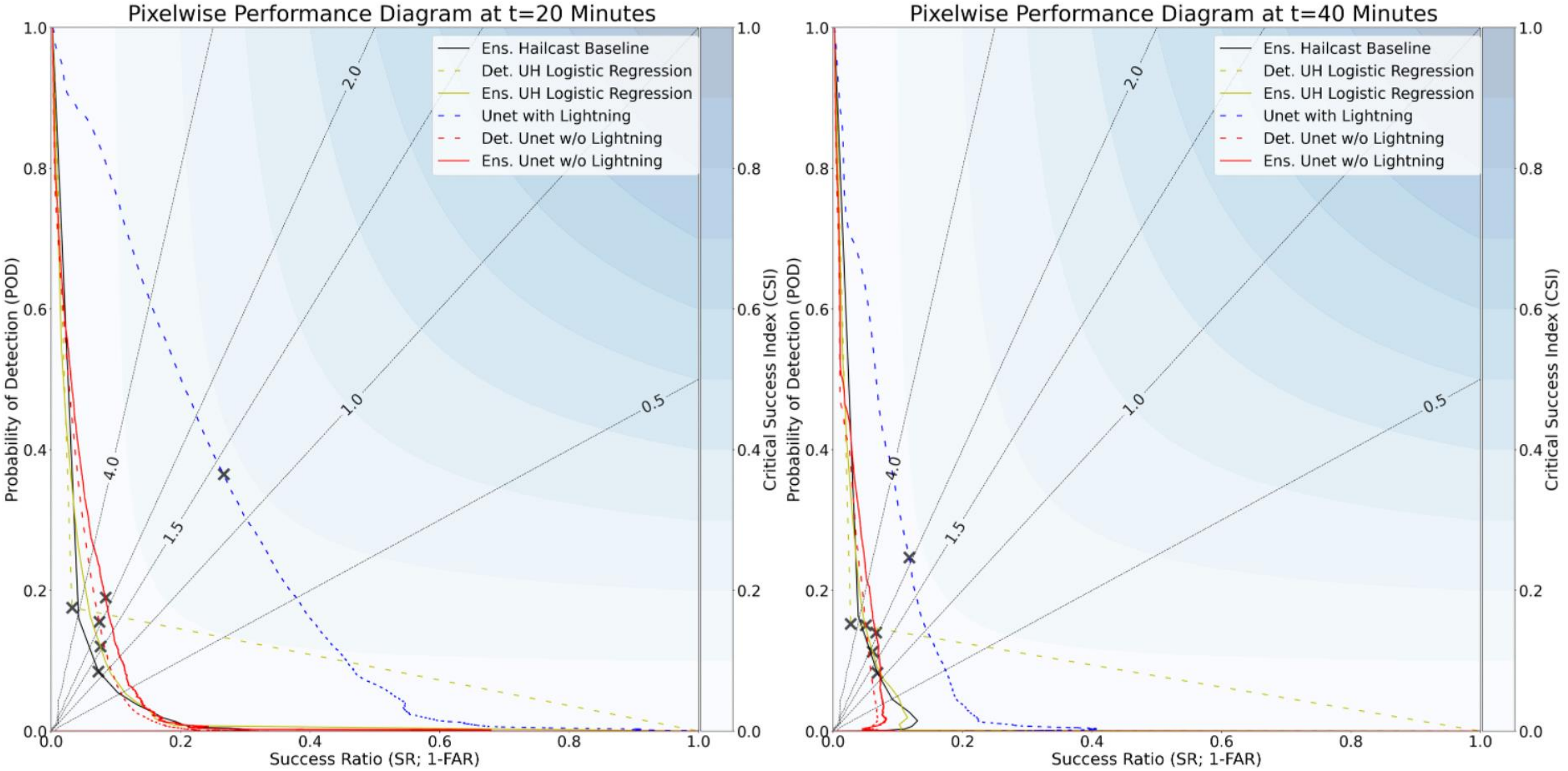


Objective verification





Objective verification



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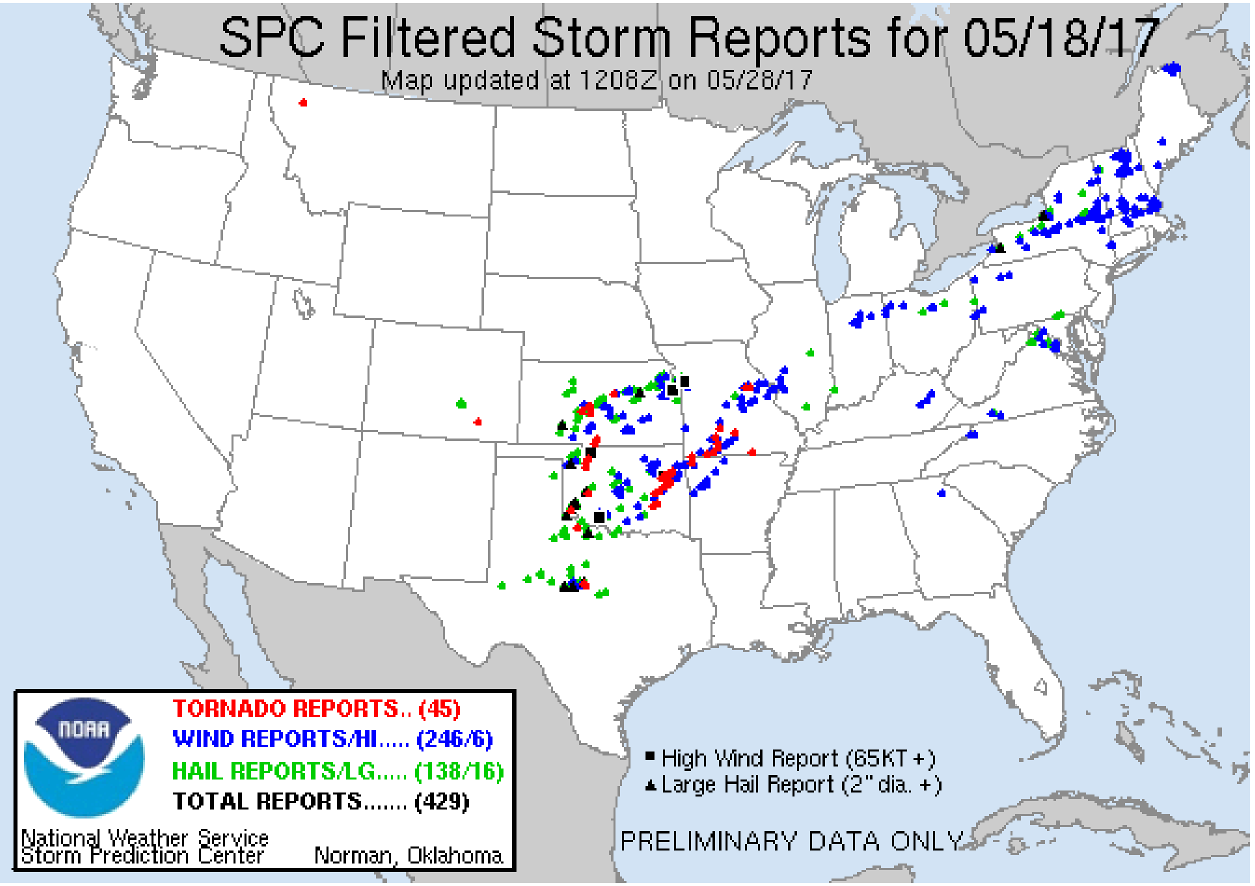
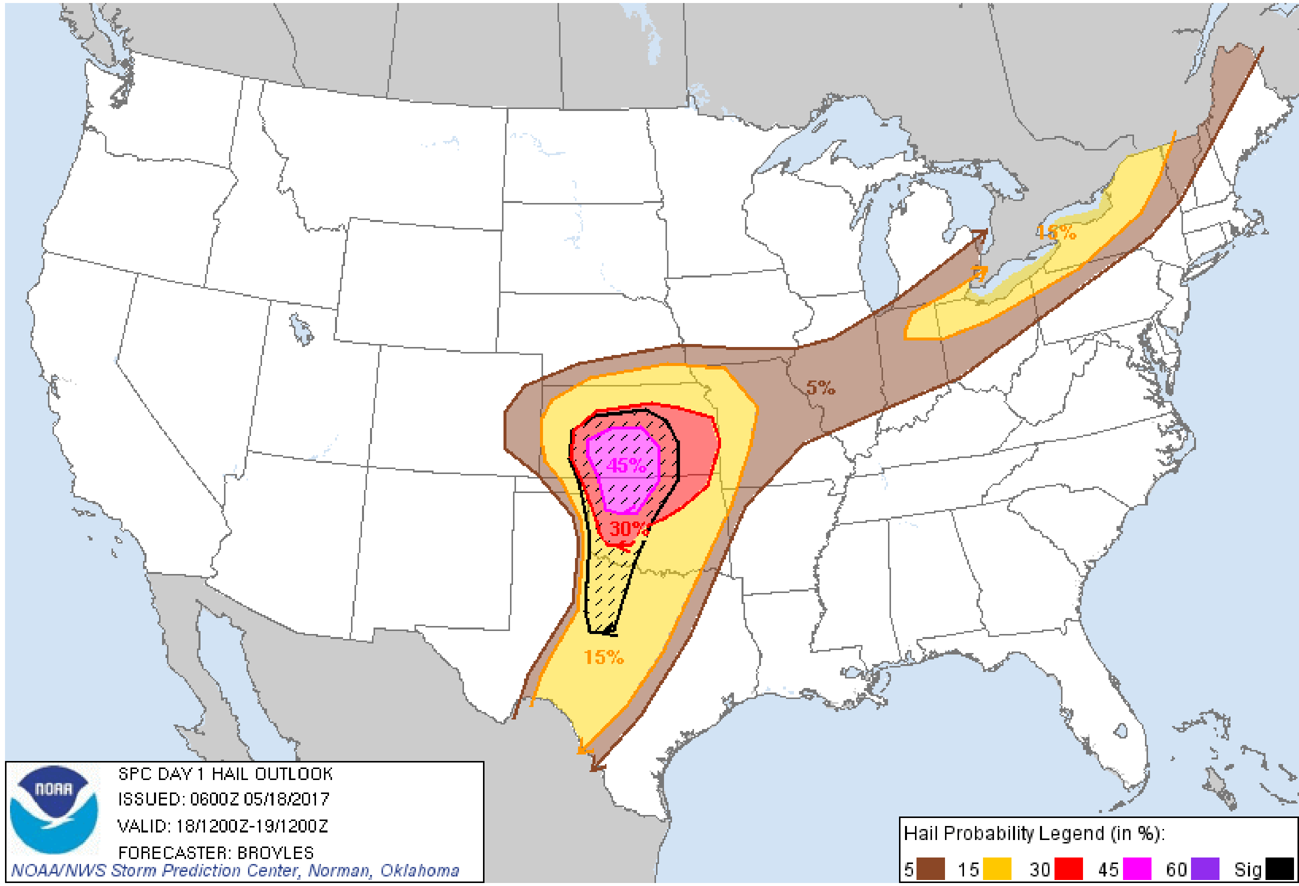
Case study: May 18, 2017





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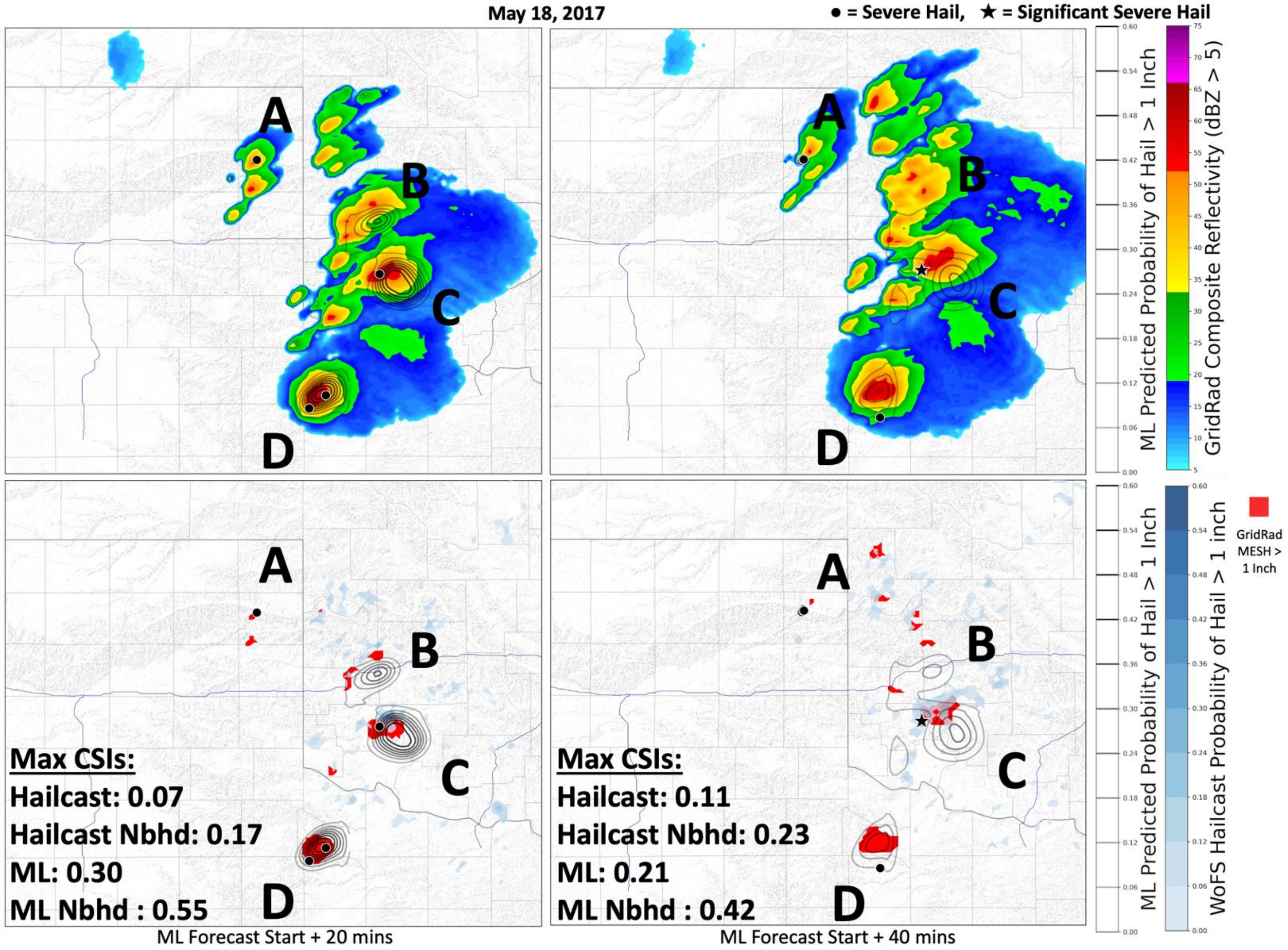

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Current and future work on hail nowcasting

- Results are very promising
- Student leading this work graduated with his MS and went to private industry
- Paper accepted with major revisions and under review again now
- Our long-term goal is to extend this (or a similar) approach globally

Using Deep Learning to Improve the Warn-On-Forecast System Prediction of Thunderstorm Location

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Chad Wiley, Montgomery Flora, Corey Potvin, Randy Chase, Tobias Schmidt, Brian Matilla, and Amy McGovern

COLORADO STATE UNIVERSITY

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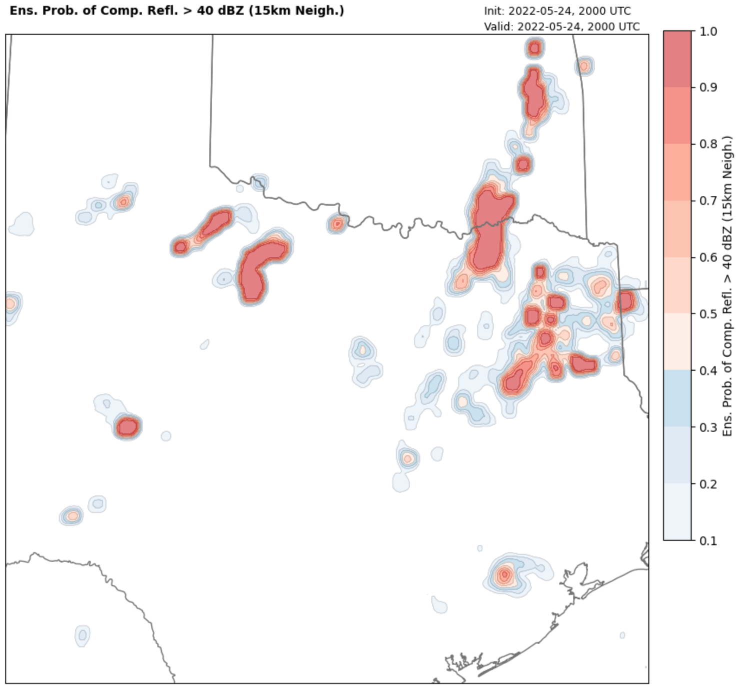
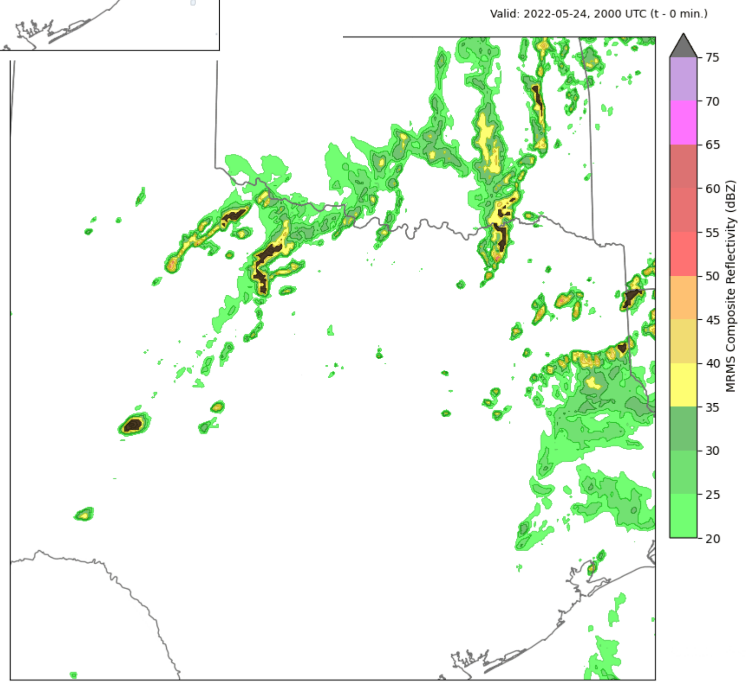
Motivation

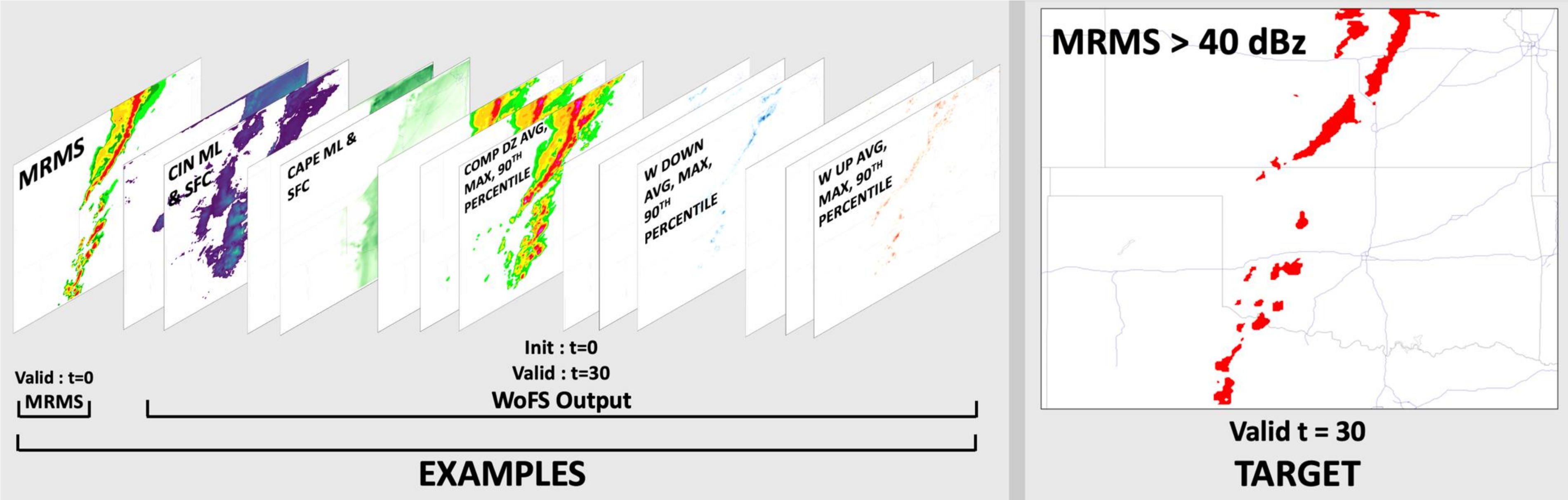
- Accurate convective initiation forecasts are important for a wide variety of impacts
  - Convective-Induced Turbulence (CIT) is responsible for about 60% of turbulence related aircraft accidents (Corman and Carmichael, 1993)
  - Public outdoor safety
- WoFS has a strong over-forecasting bias for CI



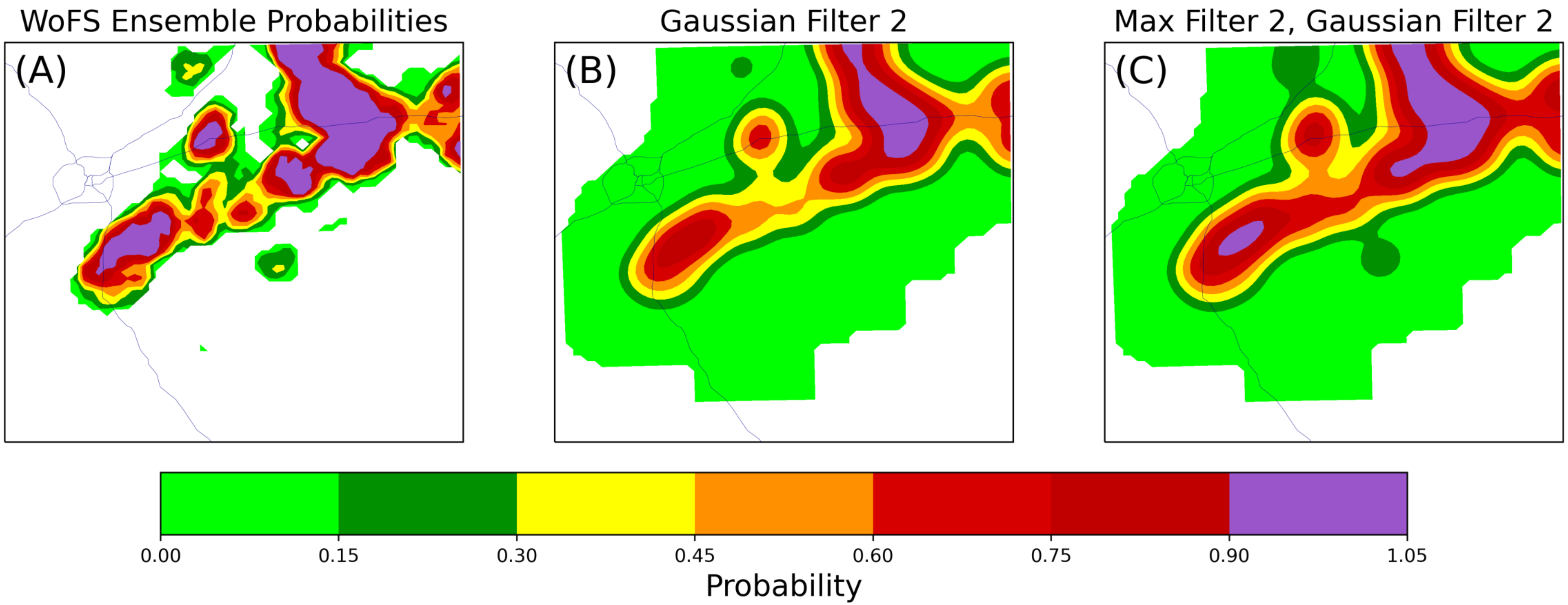


Approach

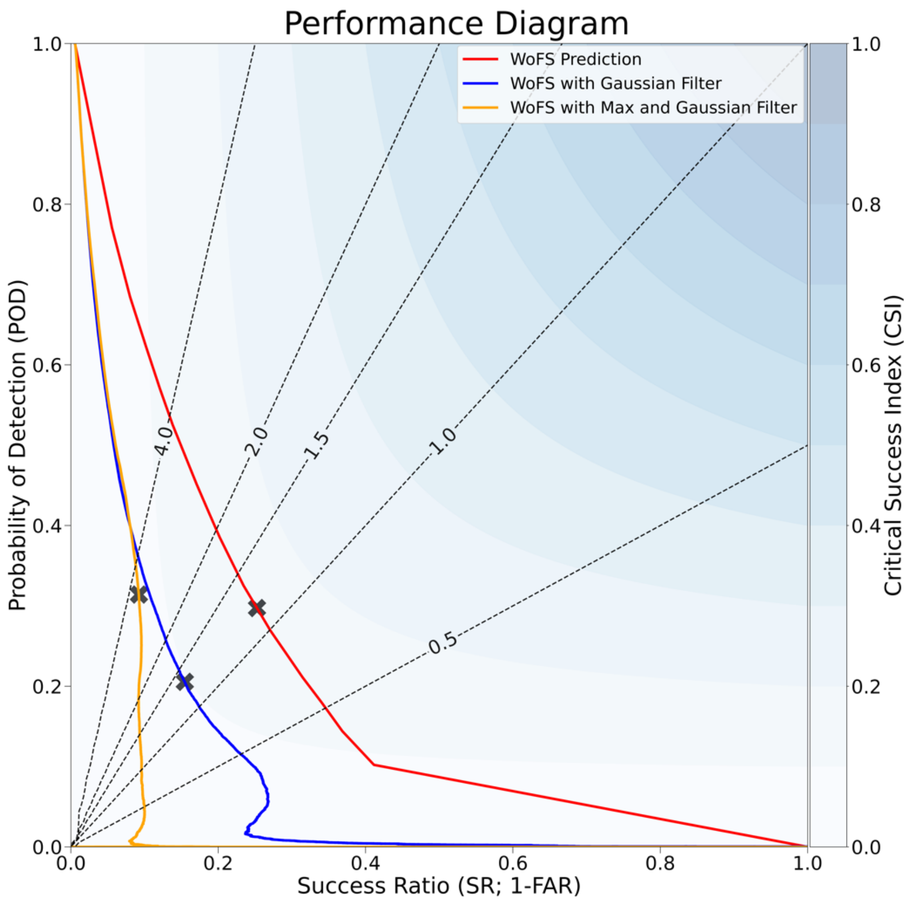
- MRMS and WoFS input to a U-net
- Training data is MRMS > 40 dBz 30 min in future
- Output probability of convection

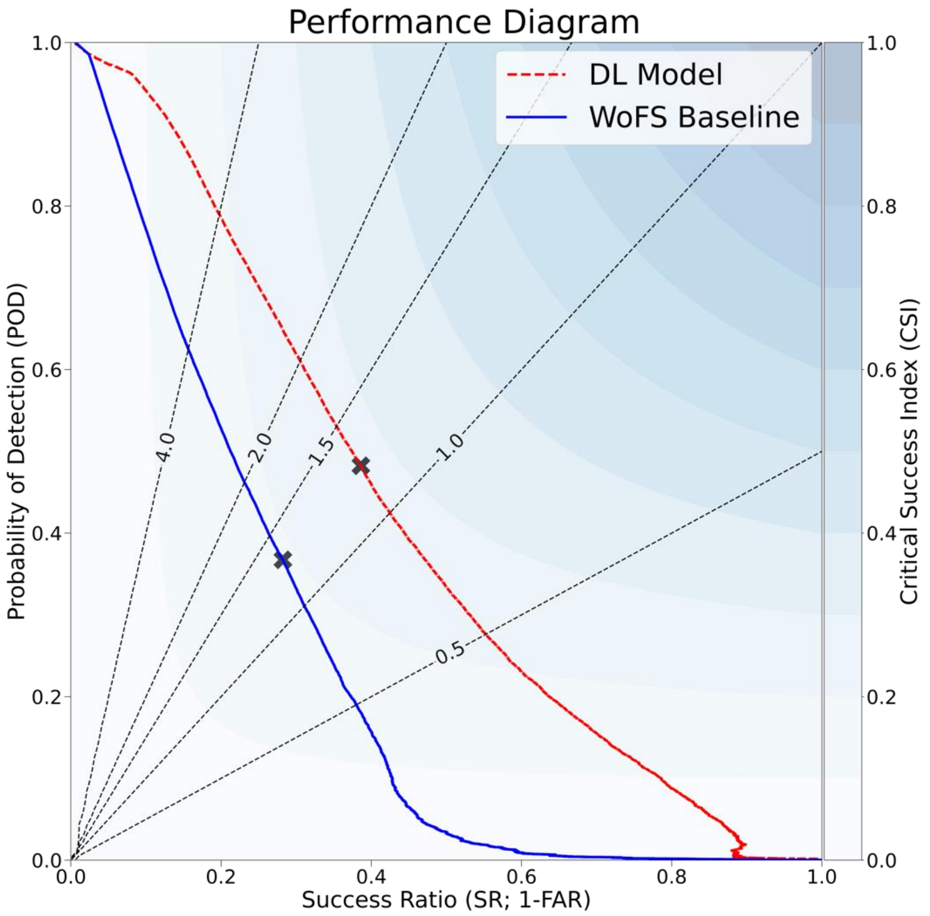


Comparison method

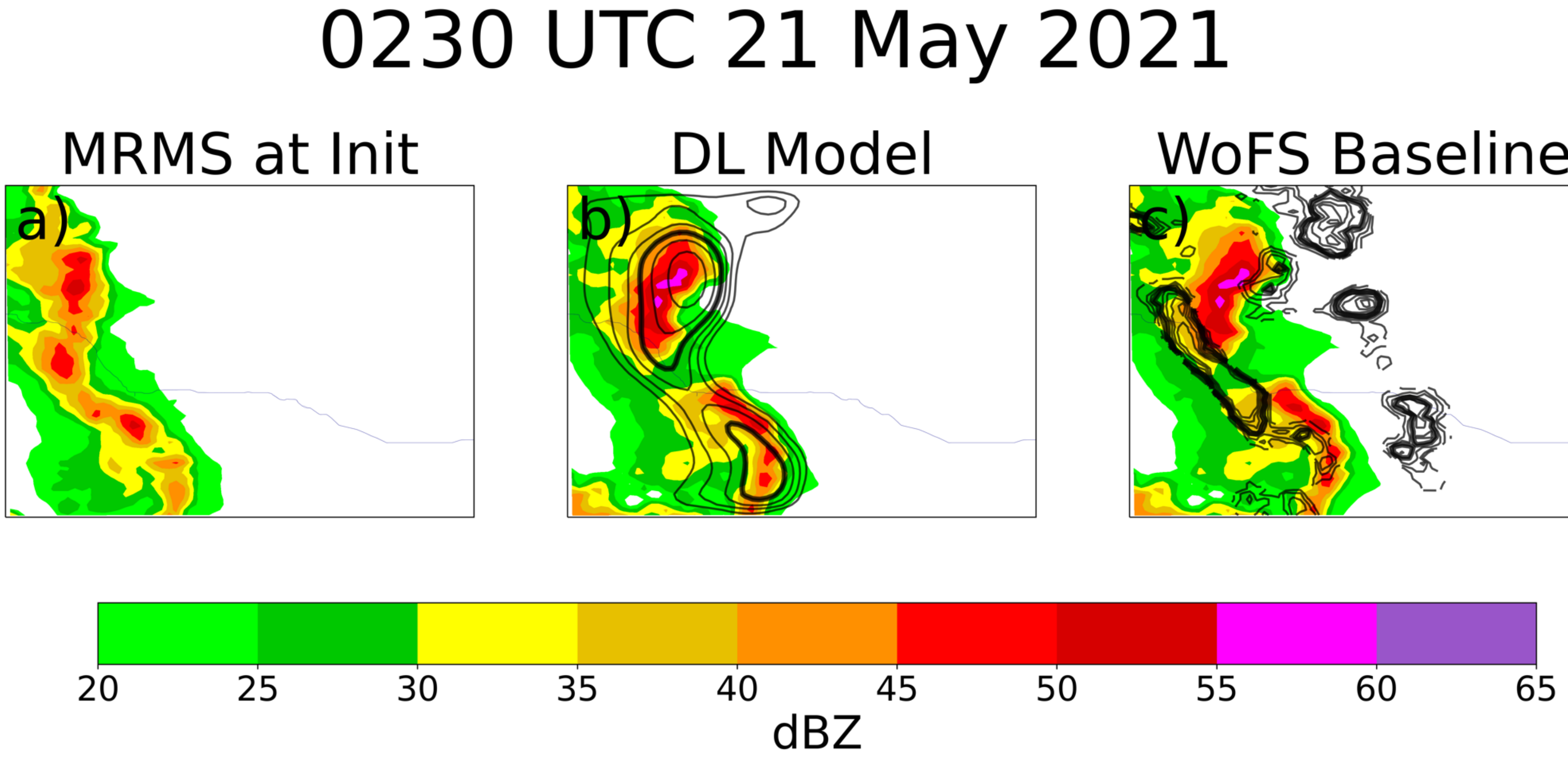


Objective performance





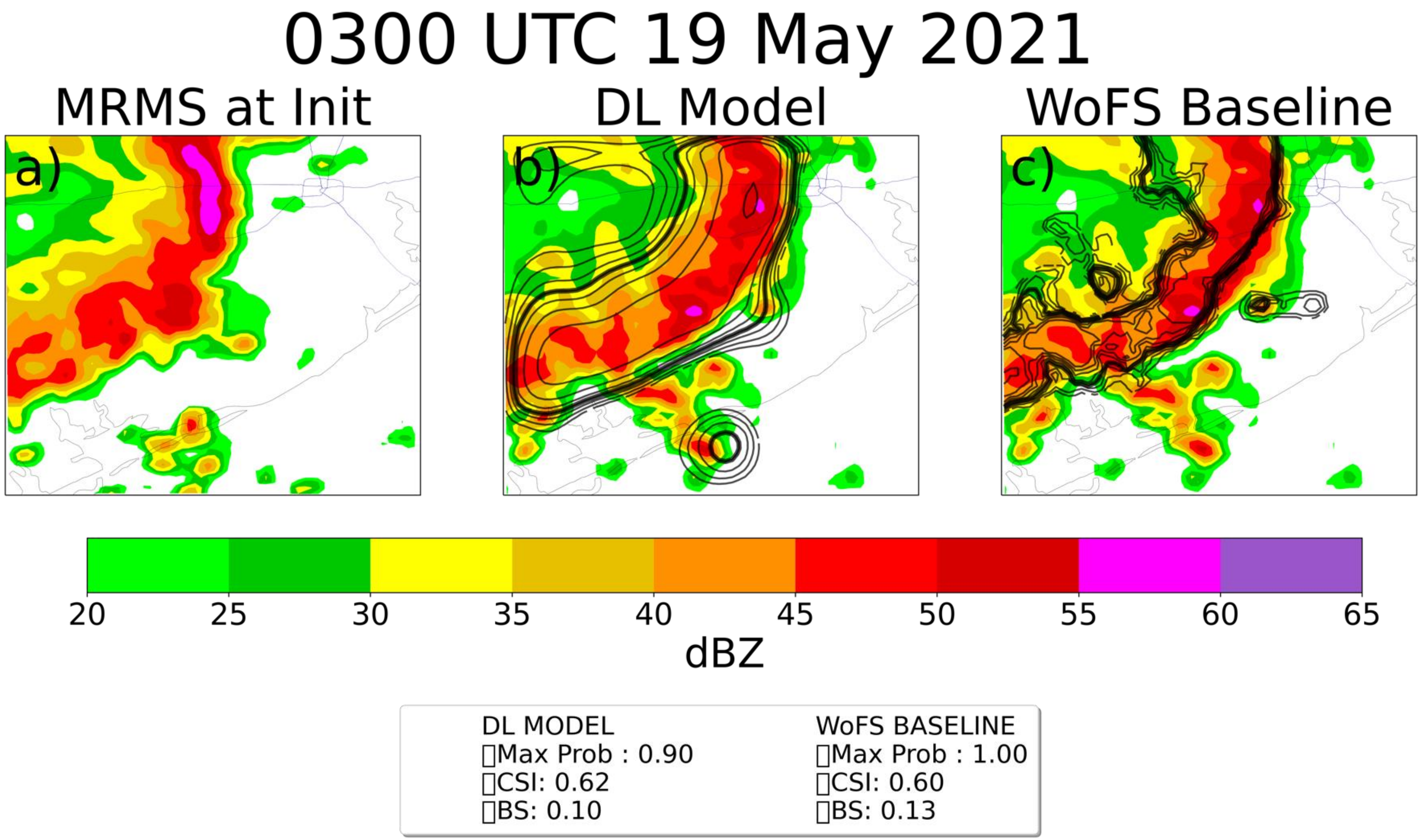
Case study: South Dakota storm



DL MODEL
Max Prob : 0.75
CSI: 0.32
BS: 0.27

WoFS BASELINE
Max Prob : 1.00
CSI: 0.03
BS: 0.63

Case study: Southeastern Texas



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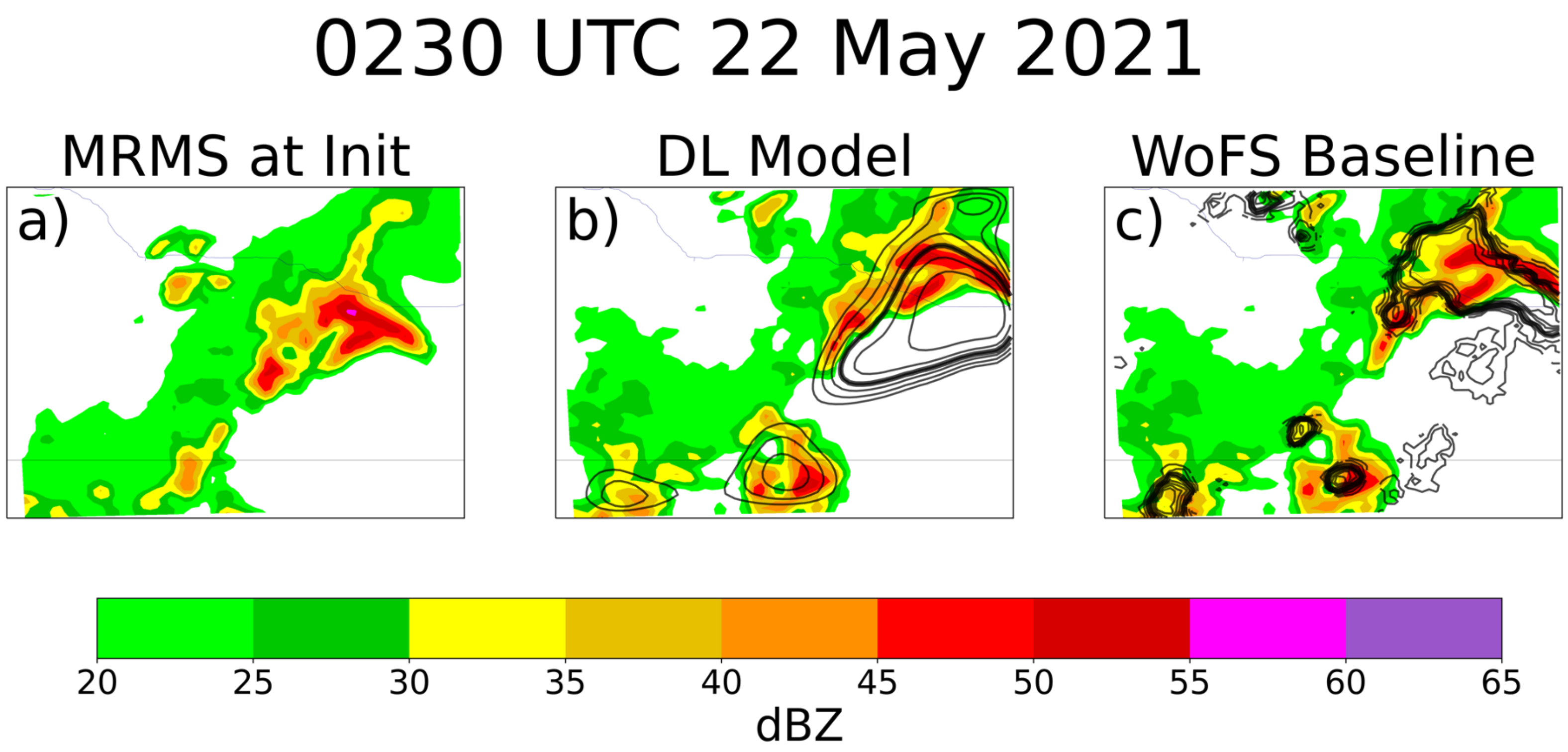
Case study: Nebraska-South Dakota



DL MODEL	WoFS BASELINE
Max Prob : 0.79	Max Prob : 1.00
CSI: 0.12	CSI: 0.23
BS: 0.35	BS: 0.27

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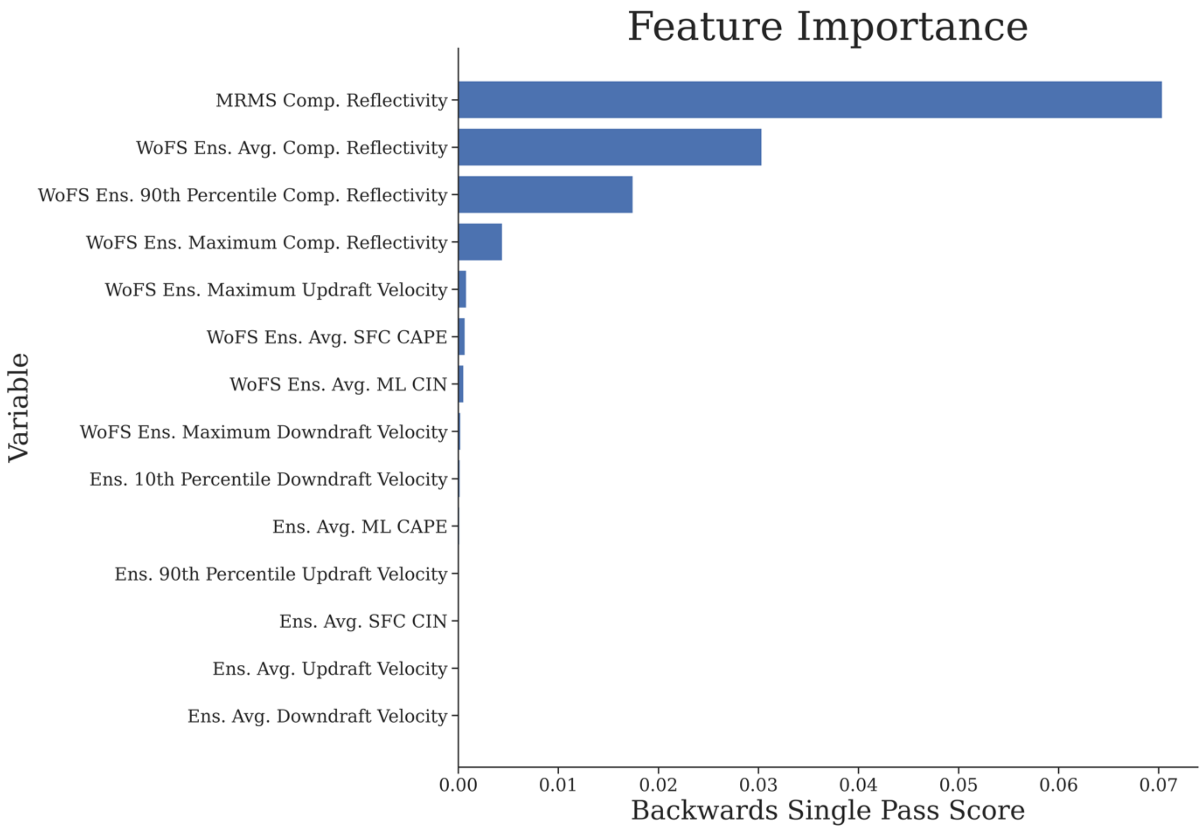
Looking inside the model

- MRMS Composite Reflectivity at initialization was the most important variable
- WoFS composite reflectivity products were also important
- Environmental variables were not important



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Current and future work on CI

- Deep learning U-Nets were able to substantially increase skill and discrimination of a 30-minute forecast of reflectivity values >= 40 dBZ
  - MaxCSI on testing dataset was raised from 0.17 to 0.27
- MRMS Composite Reflectivity greatly impacted the performance and helped in cases of poorly initialized storms
- Student leading this work also graduated and went to private industry

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Machine learning estimation of storm updrafts

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Randy J. Chase, Kayla Hoffman, Dan Stechman, Cameron Homeyer, Corey Potvin and Amy McGovern

Chase, R. J., A. McGovern, C. R. Homeyer, P. J. Marinescu, and C. K. Potvin, 2024: Machine Learning Estimation of Maximum Vertical Velocity from Radar. *Artif. Intell. Earth Syst.*, **3**, 230095, https://doi.org/10.1175/AIES-D-23-0095.1.

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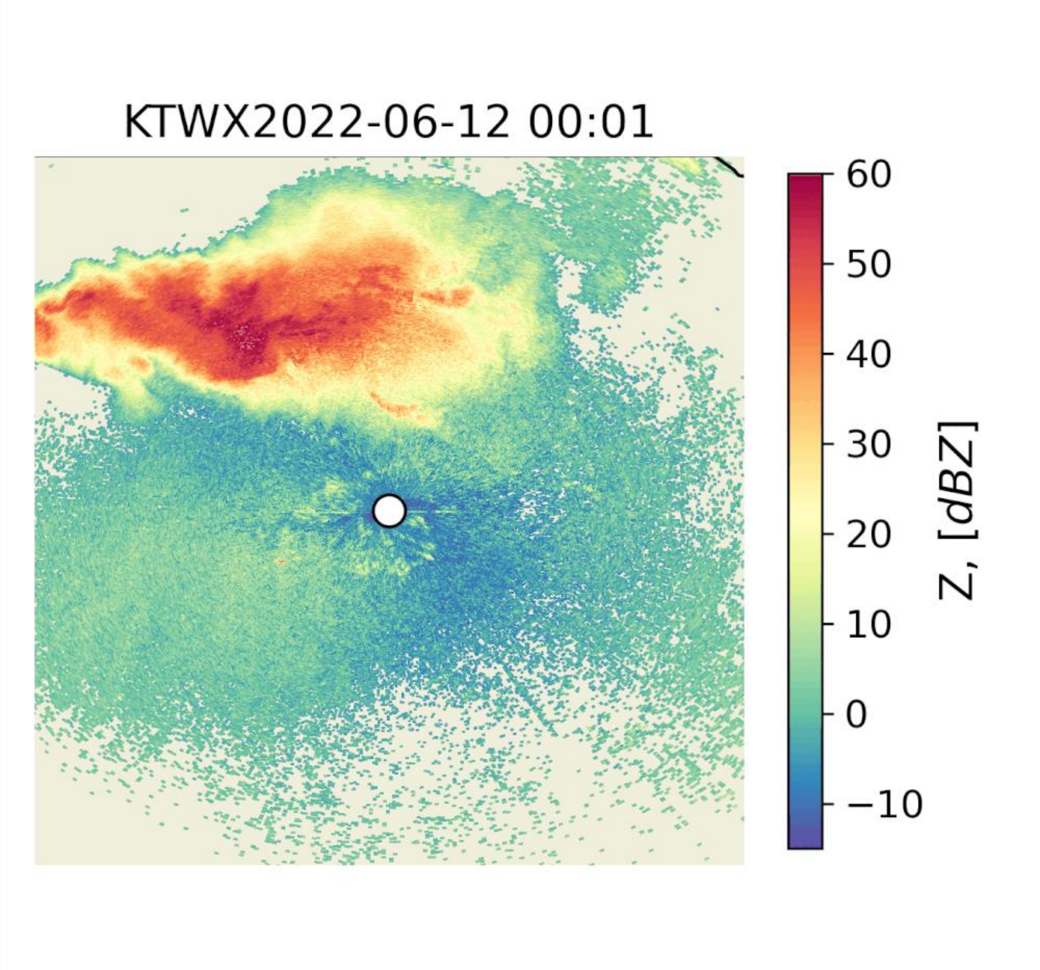
Estimating Vertical Velocity from Radar

- The NEXRAD system is underutilized (e.g., most only use low level scans)
- Physics retrievals of updrafts (i.e., multi-dop) are costly, baselines are not good and low level data is often missing
- CAMs can provide updraft info but are also unavailable in real-time
- Can we use AI/ML to estimate updrafts in real-time?



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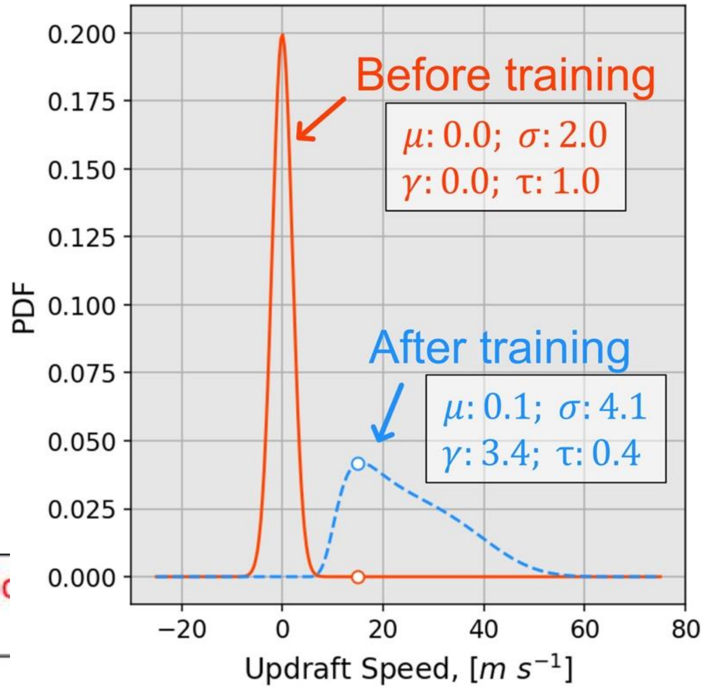
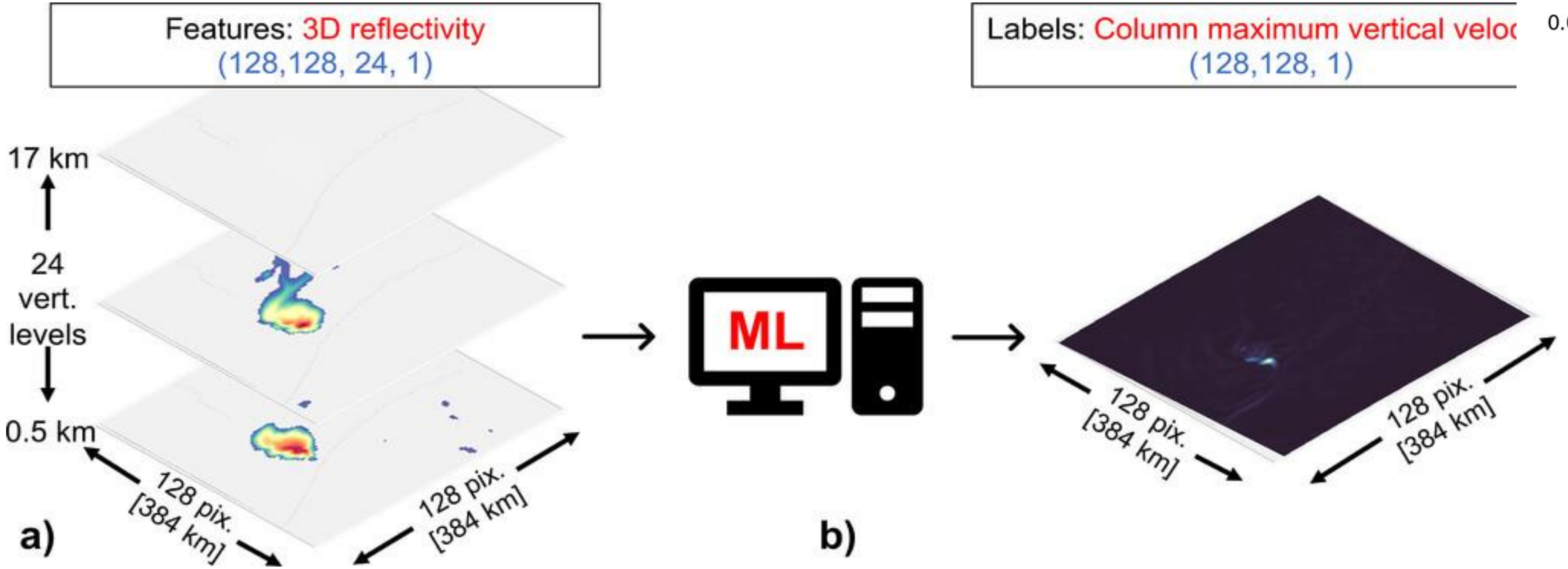
Approach

- U-net trained on WoFS to predict distribution of values





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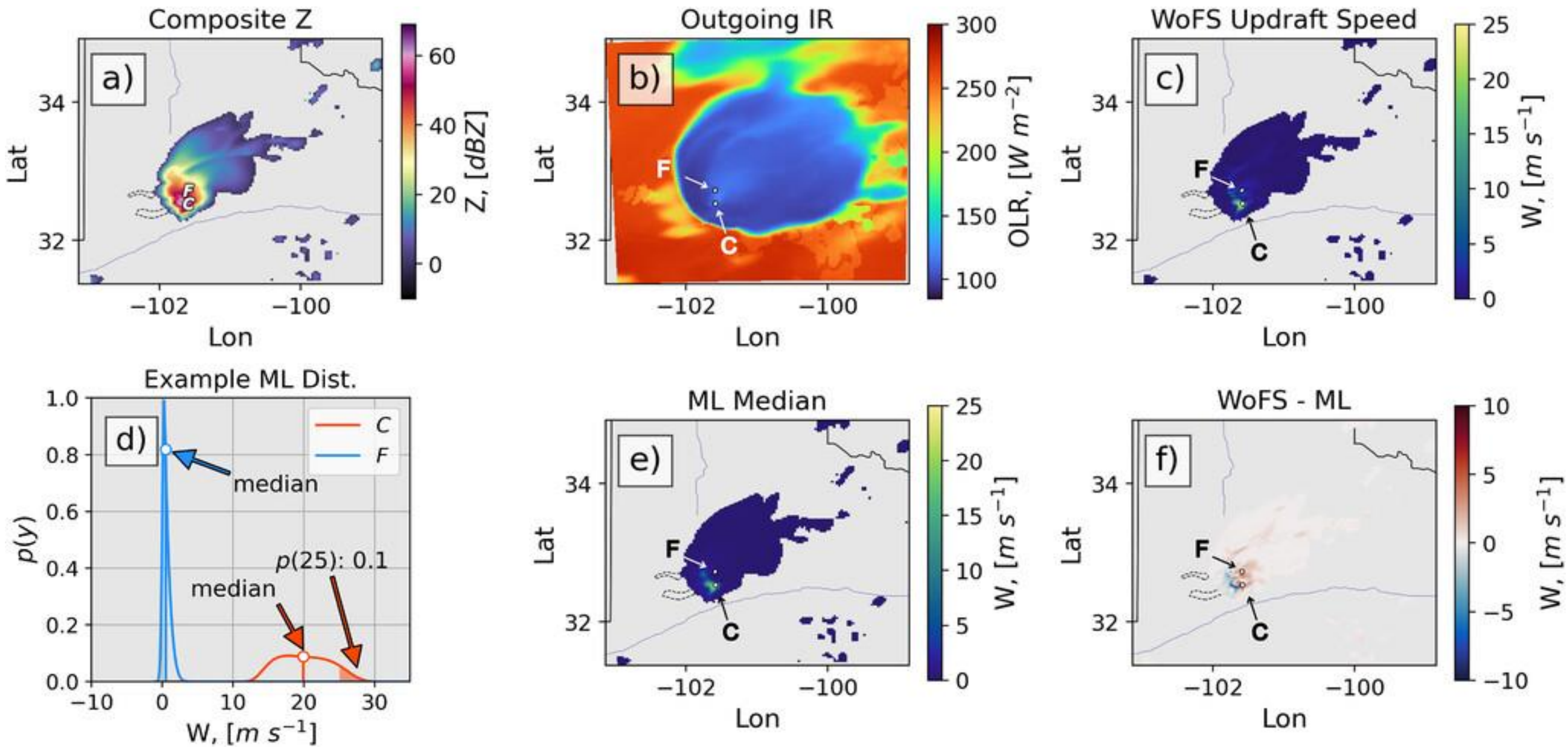
Case study: WoFS evaluation April 30 2019 TX



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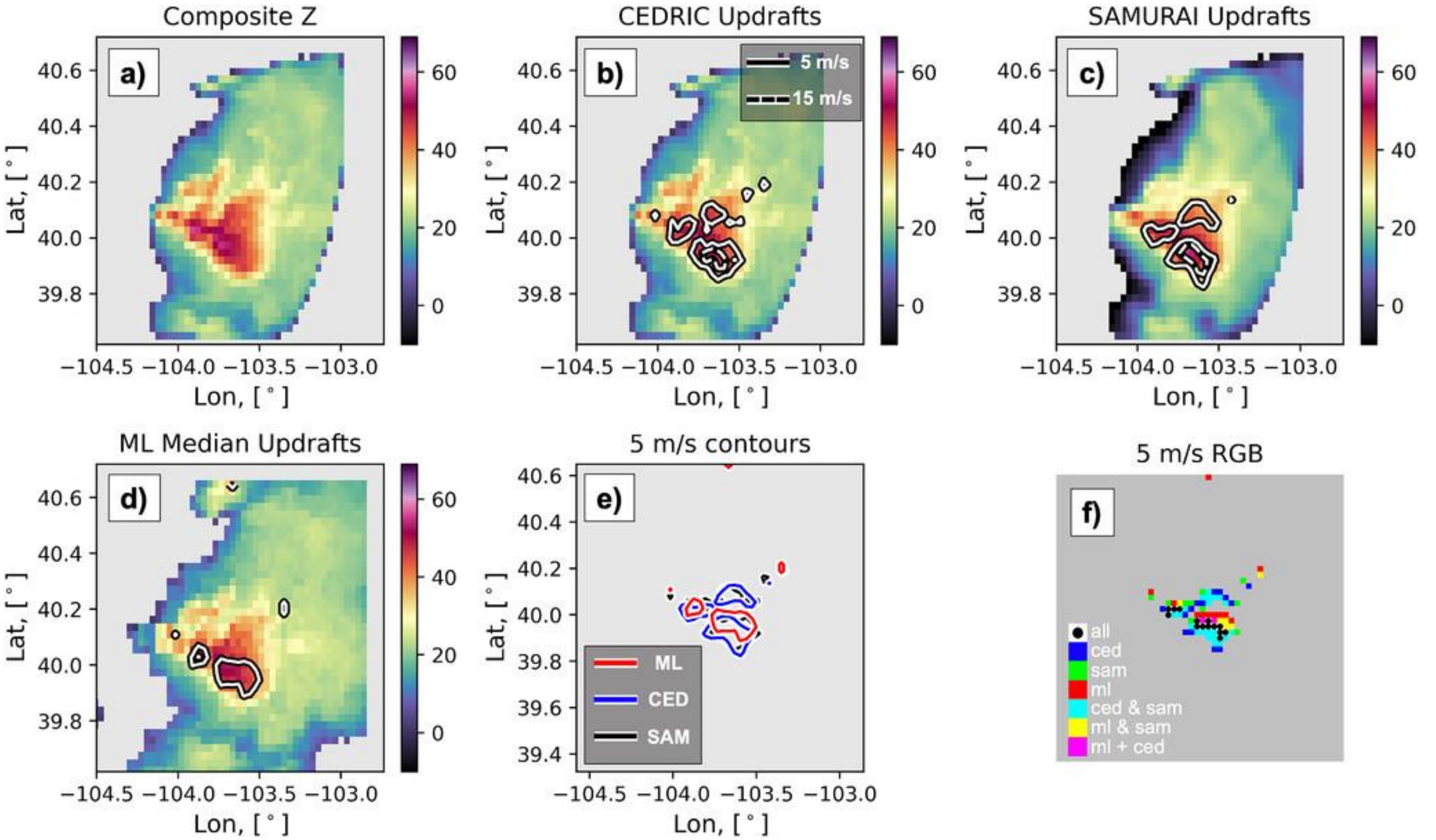
Case study: Eastern Colorado 26 May 2017

- Estimates from ML are close to the observed retrieved data
- Strong promise of ML to do this in real-time
- Now let's use this data to improve understanding of storm evolution



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AI2ES is developing *novel, physically based* AI techniques that are demonstrated to be *trustworthy*, and will directly improve *prediction, understanding, and communication* of high-impact weather and climate hazards, directly improving climate resiliency.

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