Using Machine Learning to Improve Prediction and Understanding of Convective Hazards

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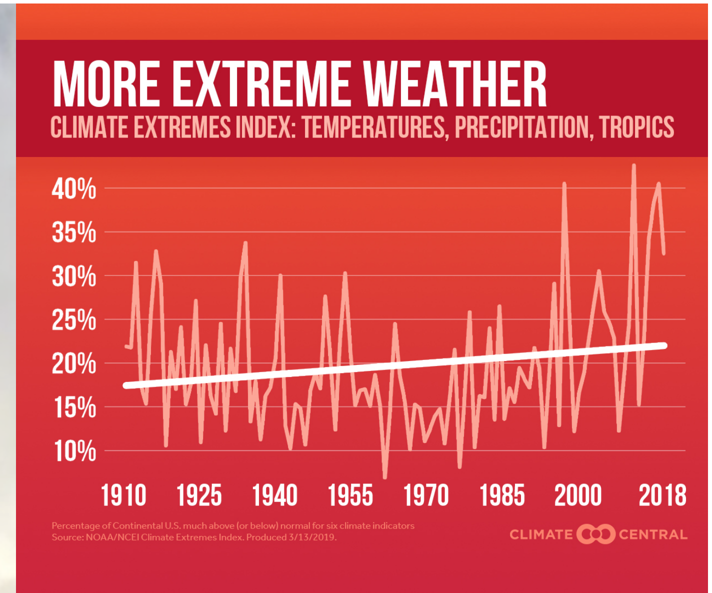
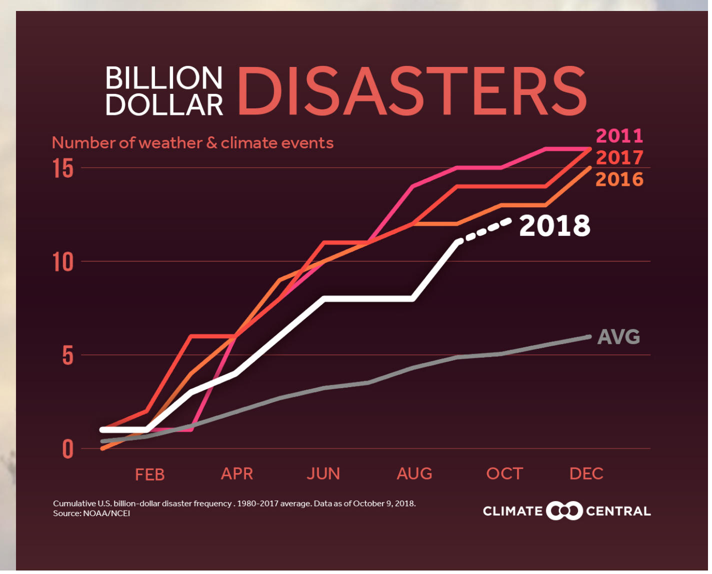
Use AI/ML to Improve Societal Resilience to Climate Change and Extreme Weather

- Wicked problems:
  - How can humans adapt to a changing climate? Where do we need to build and grow our communities? How do they need to change from current practices?
  - **How can we improve the prediction of new weather extremes?**
  - **How can we improve the adaptation of other species?** Migration patterns, land use changes, etc.
- Proposal: create a joint university, industry, and government *alpha-institute* to bring together researchers in AI/ML and climate and weather





Thank you to my students (current and former)

Will Booker
OU CS MS

Carmen Chilson
OU CS MS, now at Google

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OU, SOM MS

Katy Felkner
OU, CS and Letters BS

David Harrison
OU/CIMMS/SPC SOM PhD

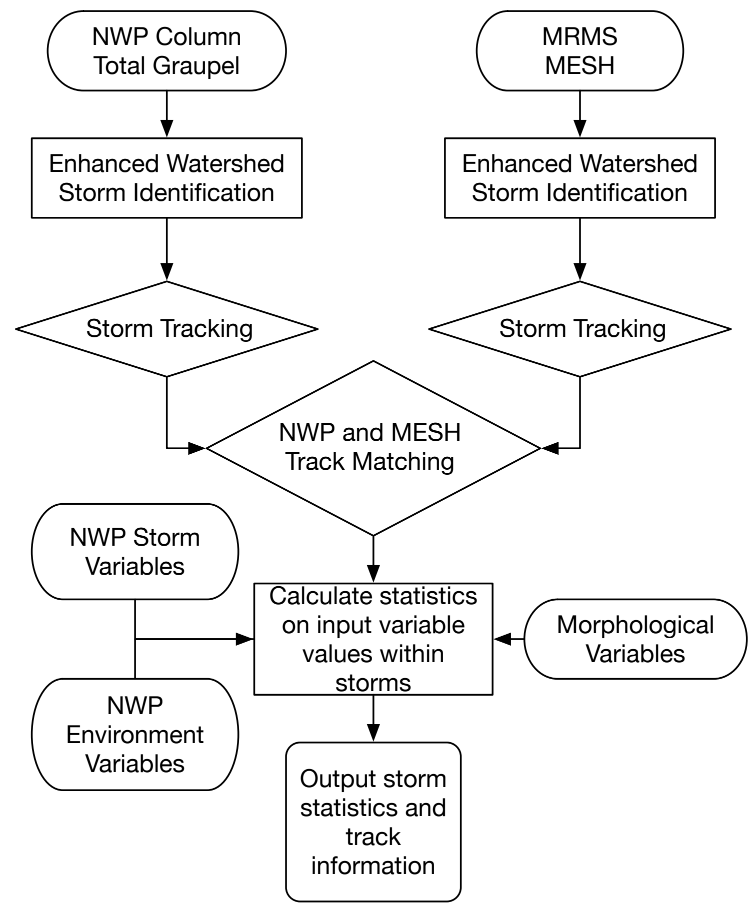
Eli Jergensen
OU, Math/Physics BS

ML for Weather Outline

- Using ML for severe weather prediction
  - Improving hail forecasting 24-48 hours in advance (traditional ML)
  - Improving nowcasting for tornadoes (deep learning/convolutional neural networks)
- Using ML to track biological species over time
  - Identifying bird roosts in non-QC radars (deep learning)

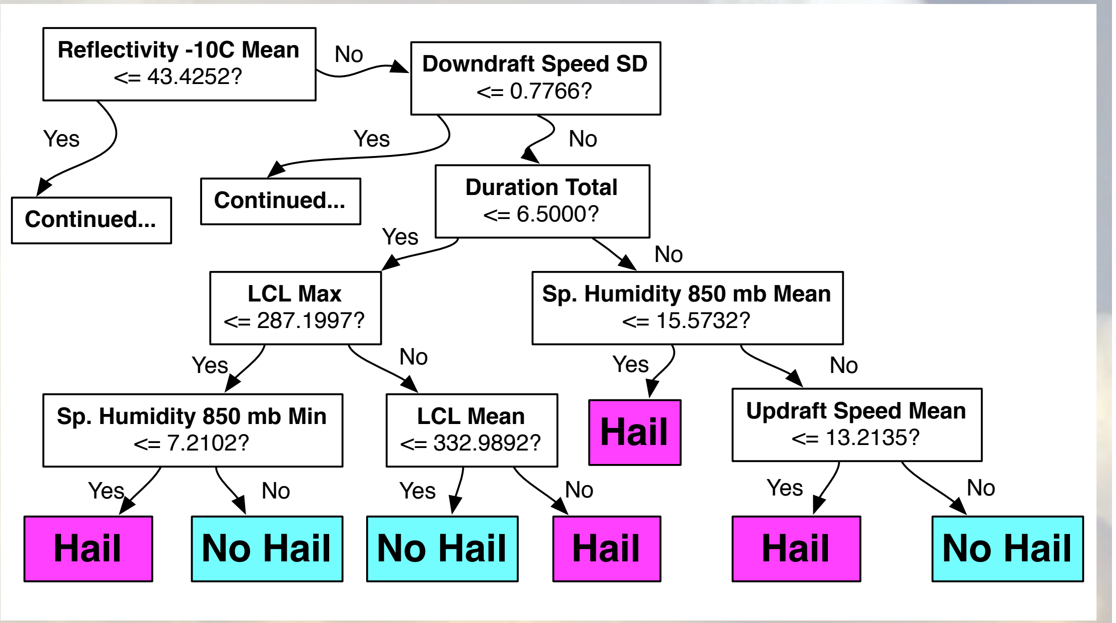
Storm-Based Hail Forecasting

- Overall steps:
  - Create training data from NWP models
  - Train ML models (random forests)
  - Prediction and evaluation
- Implemented and tested in NOAA's Hazardous Weather Testbed
- Details:
  - Gagne et al 2017, WAF
  - Burke et al, in preparation



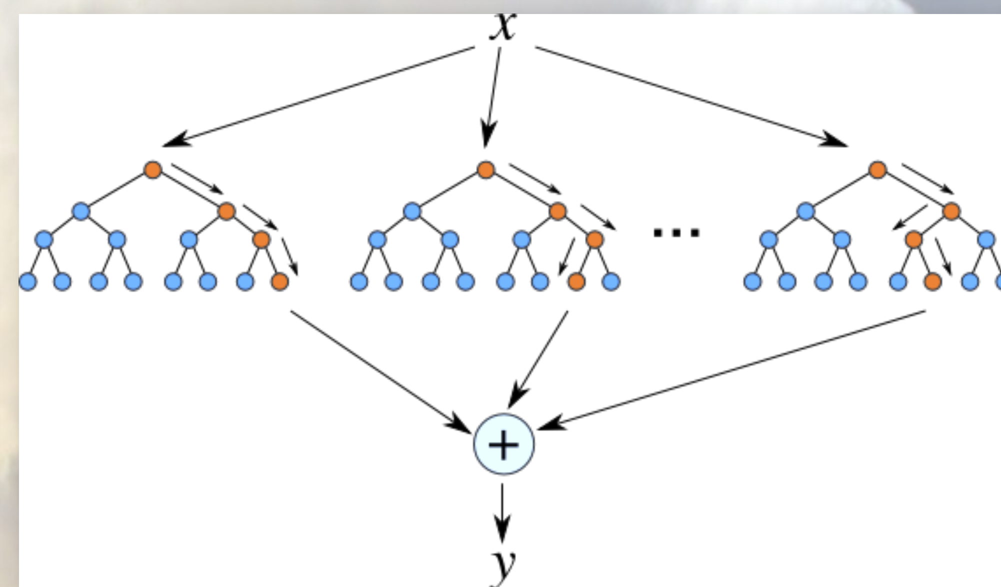
Decision Trees

- Human-readable ML model
- Can predict:
  - Class labels (hail/no hail)
  - Real-values (hail size, shape parameters)
  - Probabilities
- Demonstrated success in meteorology
  - Selective model



Ensembles of Trees

- Random Forests
  - Individual trees trained on bootstrap resampled subsets of data
  - Trees use subsets of attributes at each level
- Each tree votes or averages its prediction



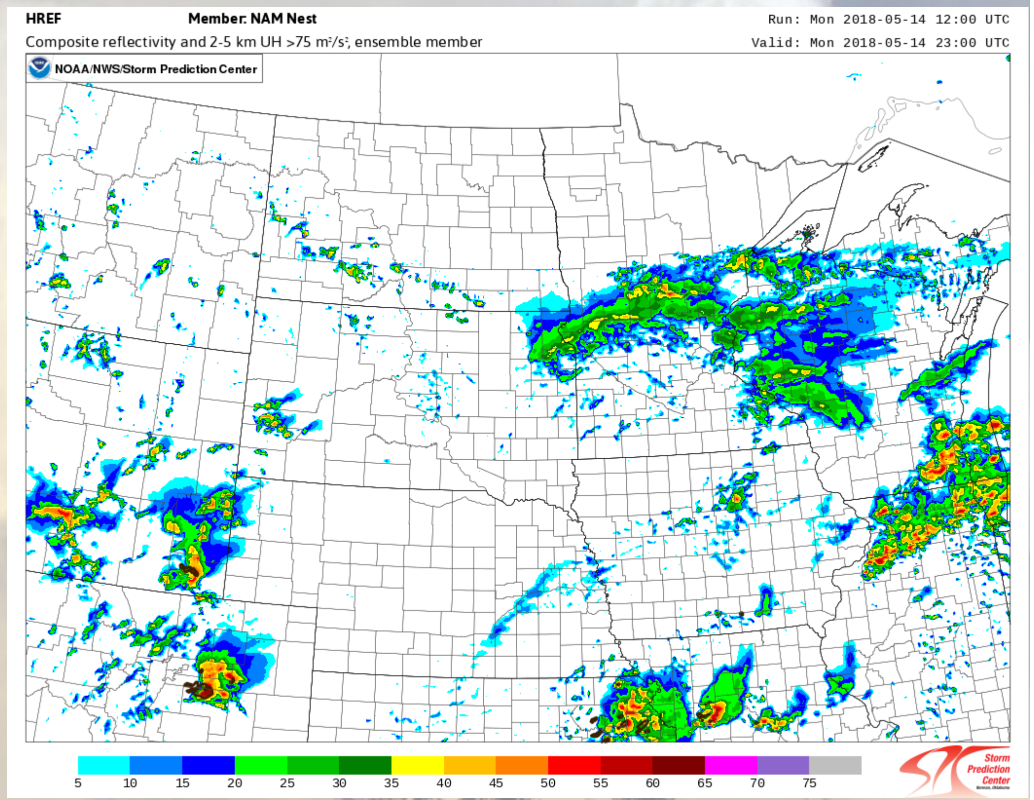
http://ncbi-hackathons.github.io/Pharmacogenomics_Prediction_Pipeline_P3/

NWP Convection Allowing Models (CAMs)

- CAMs have high spatial and temporal resolution across CONUS
  - Resolution too low to resolve hazards such as hail
  - ML can predict missing hazards and correct spatial or temporal forecast errors
- Gagne et al 2017
  - CAPS Spring Experiment ensemble
  - NCAR ensemble
- Current work (Burke et al, in preparation)
  - High Resolution Ensemble Forecast version 2 (HREFv2)
    - Operational in Storm Prediction Center (SPC)
  - High Resolution Rapid Refresh Ensemble (HRRRE, summer 2019)

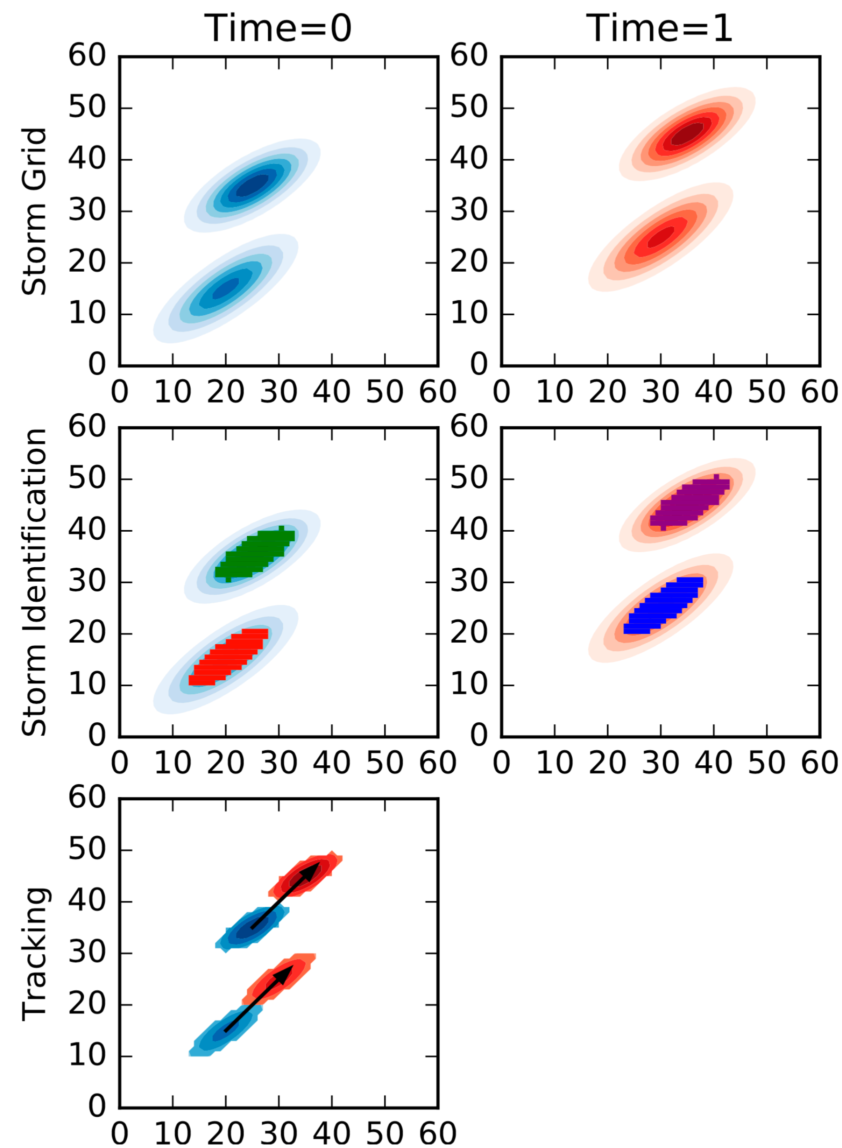
ML Input

- Extract data for each storm object/track
  - Storm data: updraft/downdraft, reflectivity, precipitation, etc
  - Environment: temperature, CAPE, wind, sounding data, etc
  - Morphological: Area, shape, etc
  - Location: Forecast hour, duration, motion
- Each CAM has slightly different data
  - ML model trained for that CAM



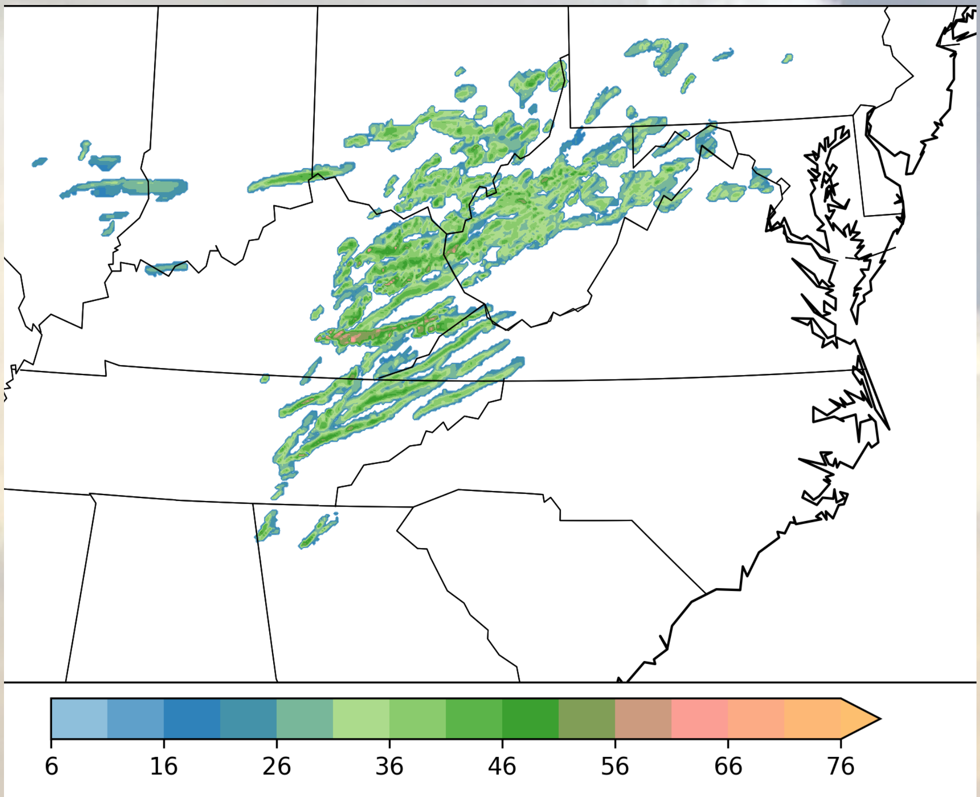
Identifying and Tracking Hail Objects

- Enhanced watershed algorithm
  - Turning pixels into objects
- HREFv2
  - Max Hourly Updraft (ms-1) > $8\frac{m}{s}$
  - Capture more than just supercells
- Observations
  - Maximum Estimated Size of Hail (MESH) > 19mm (3/4 in)

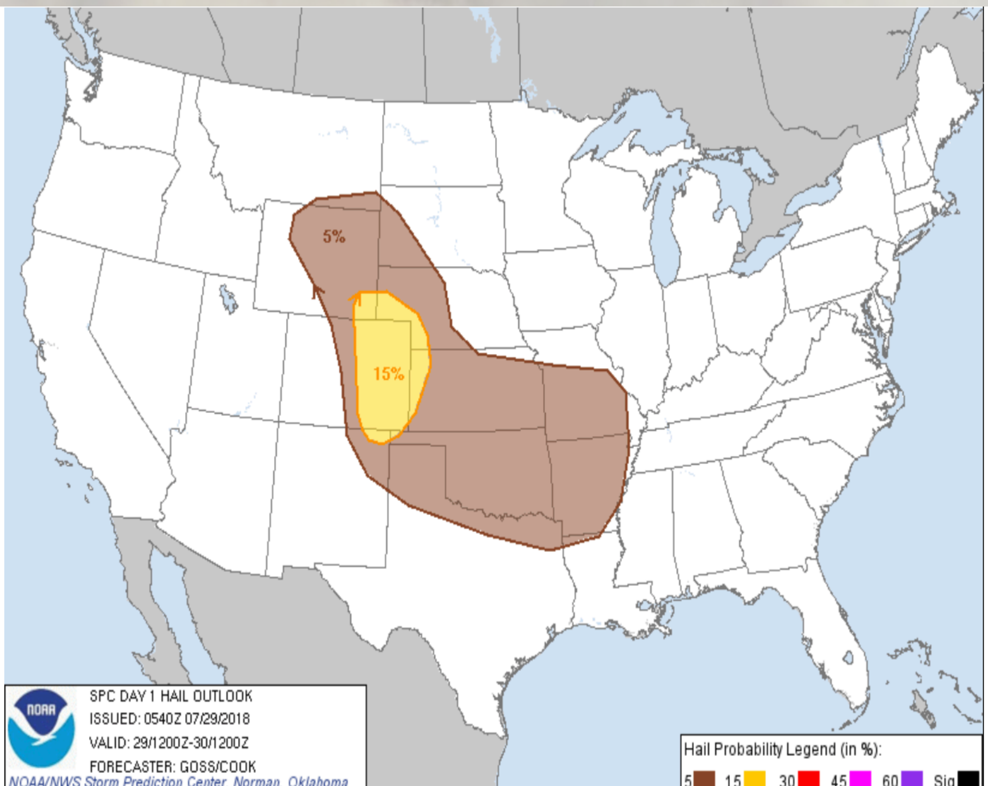


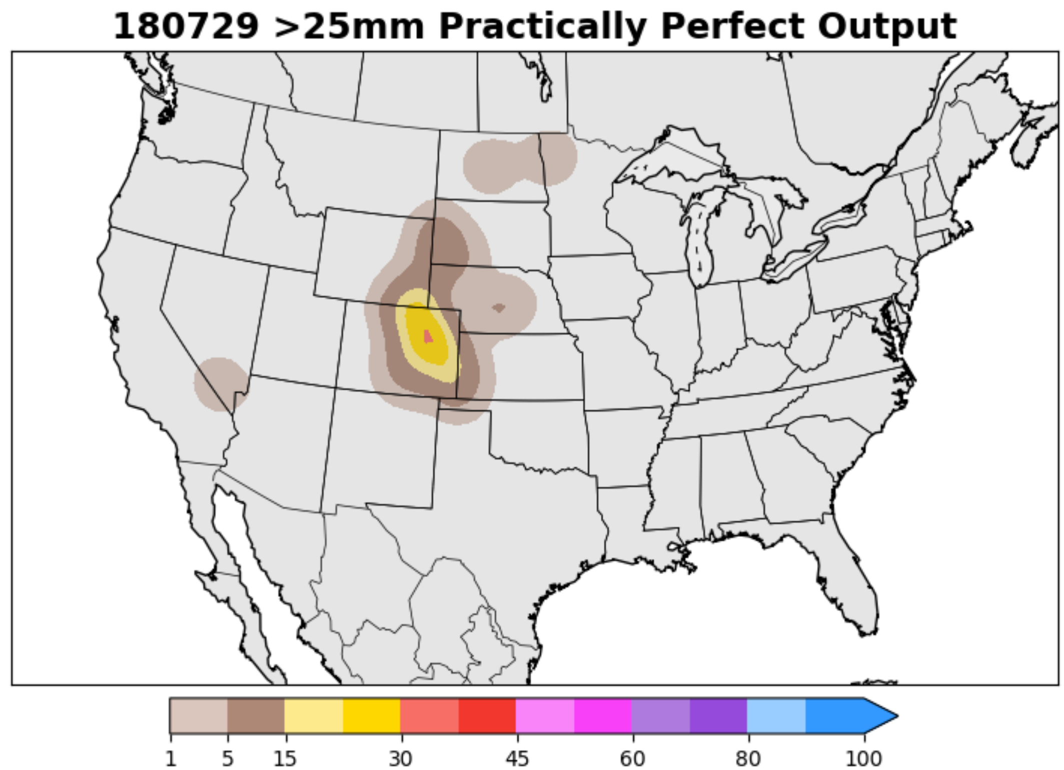
ML Hail prediction

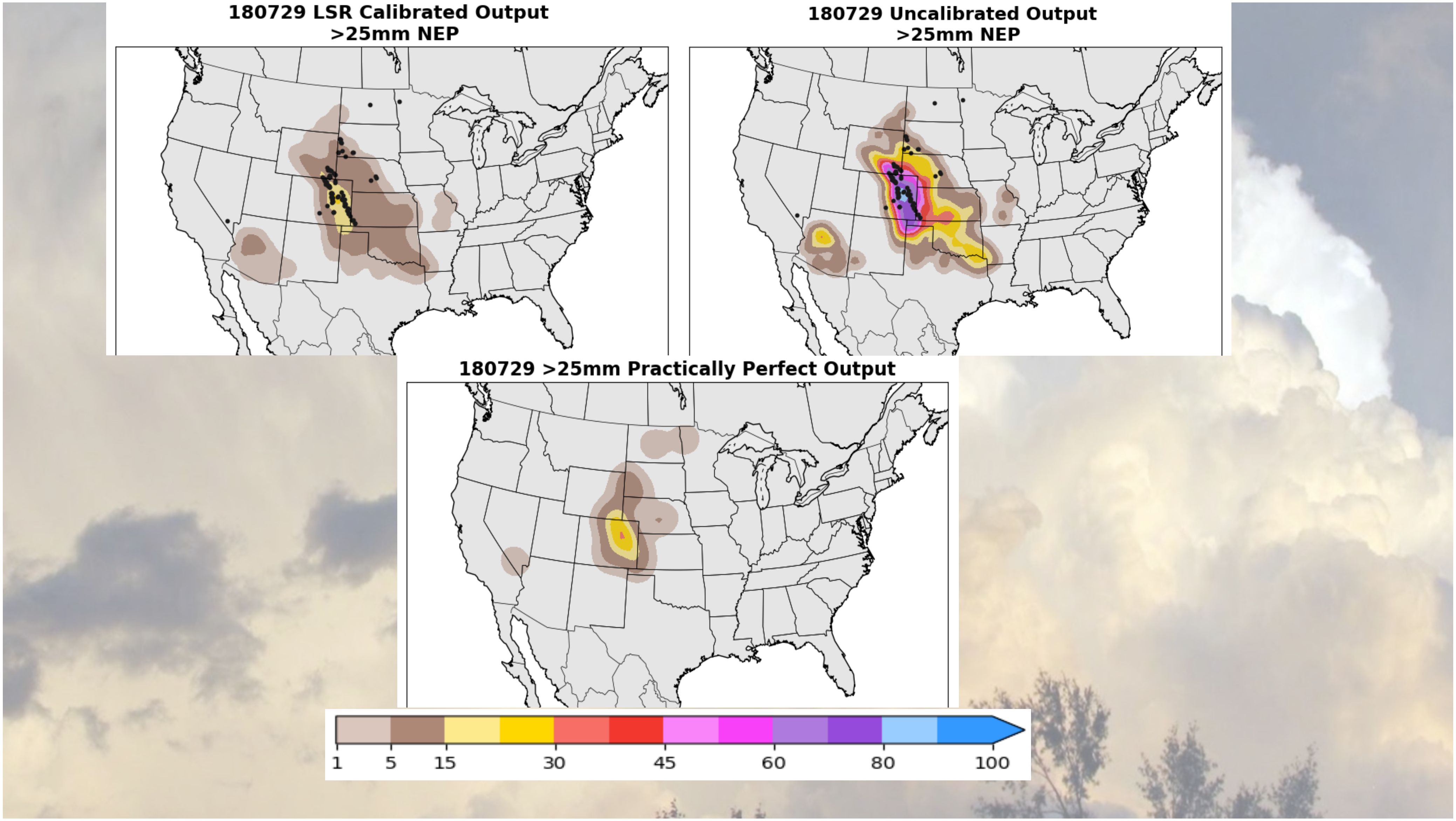
- Two step prediction
  - Hail or no hail?
- If hail:
  - Predict shape and scale parameters of gamma distribution
- Estimate ensemble neighborhood probabilities
  - Bootstrapping



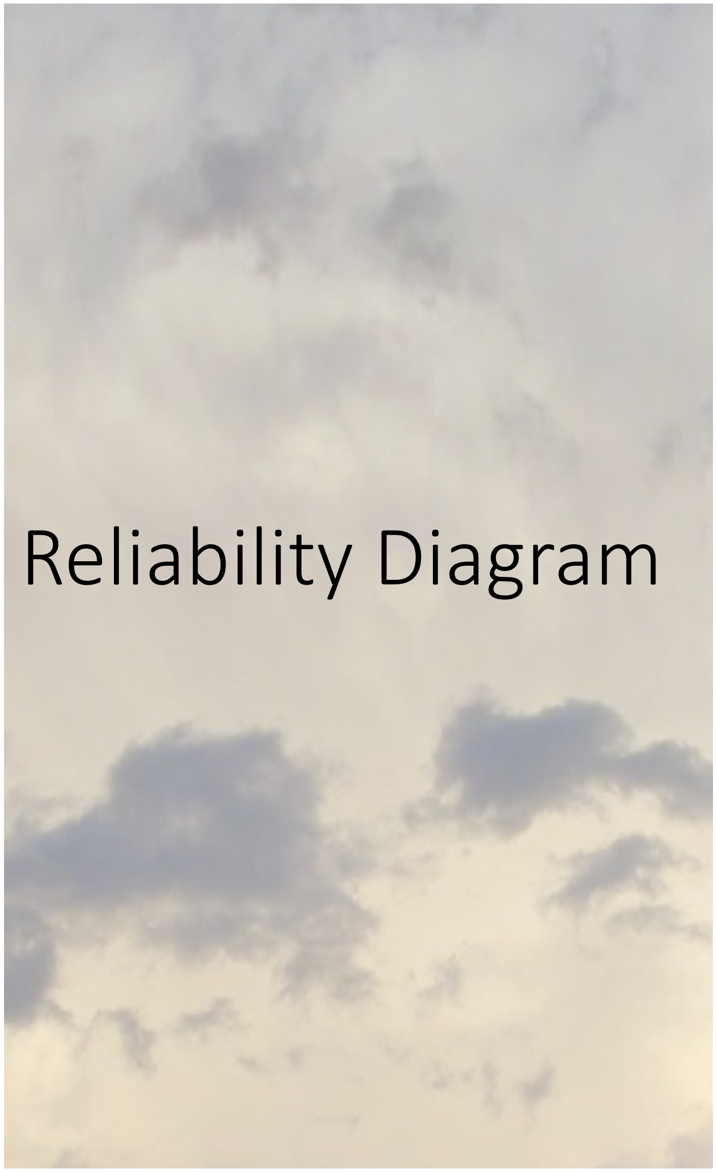
Case Study: High-End Hail Day

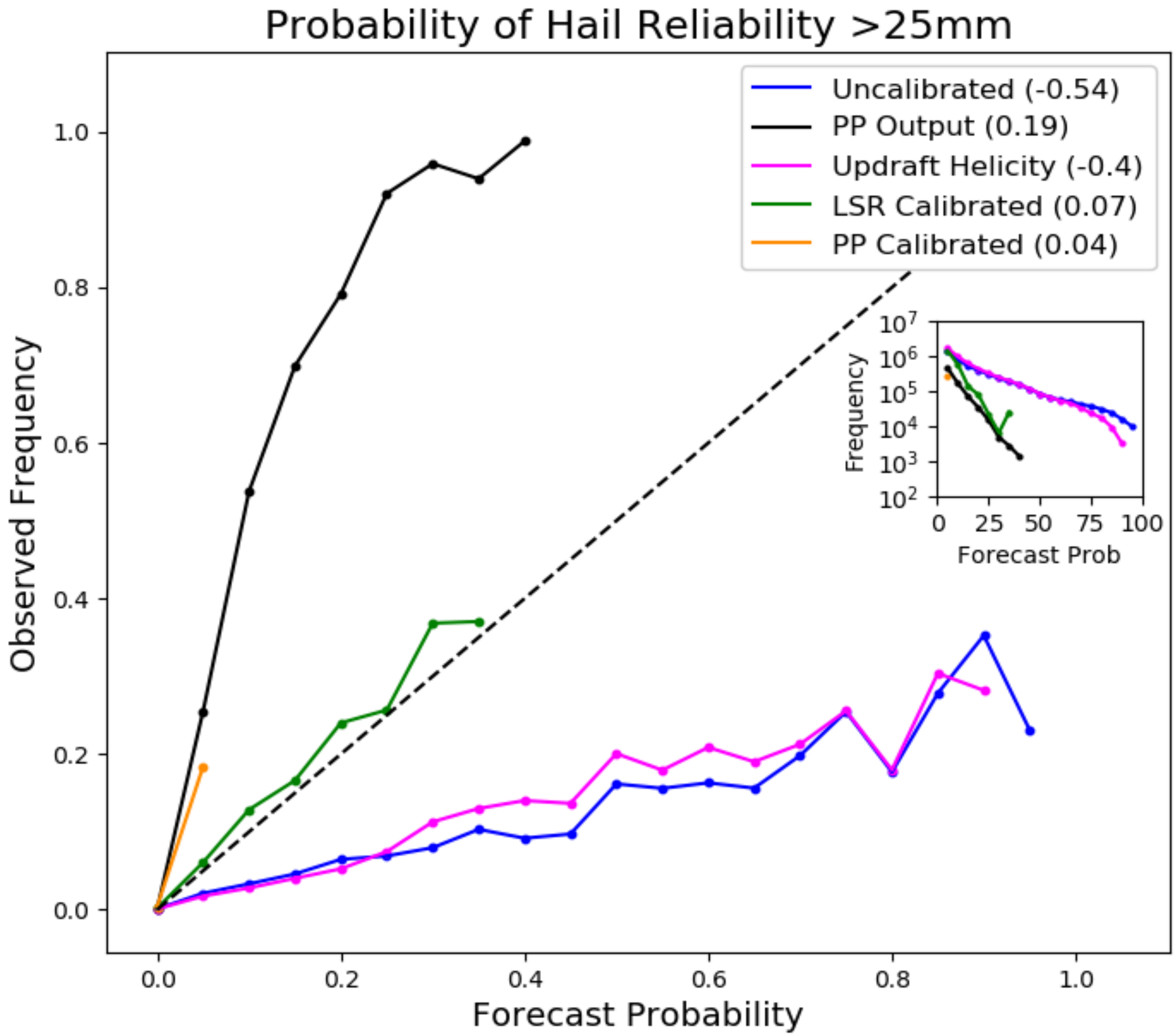





180729 LSR Calibrated Output
>25mm NEP
180729 Uncalibrated Output
>25mm NEP
180729 >25mm Practically Perfect Output
1
5
15
30
45
60
80
100

Reliability Diagram





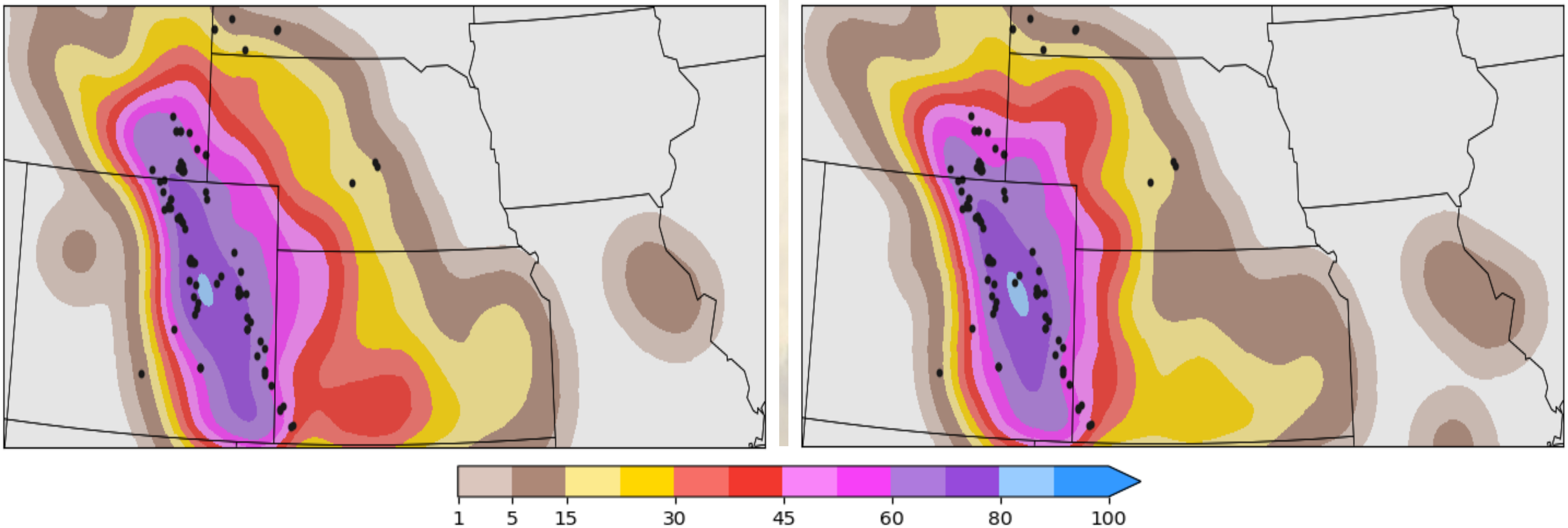
Regions

- Train regional models by weighting CONUS storms

Case Study: Central Plains Sector

180729 CONUS Trained Output
>25mm NMEP

180729 Sector Trained Output
>25mm NMEP



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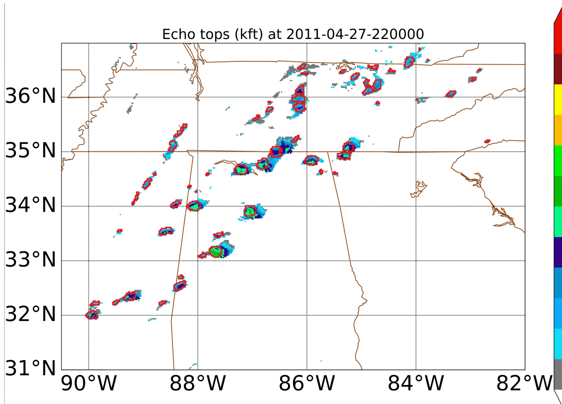
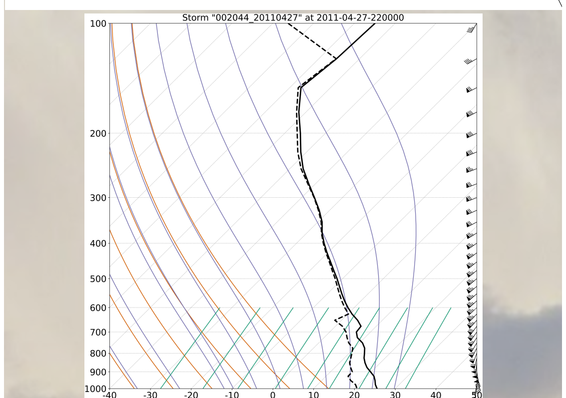
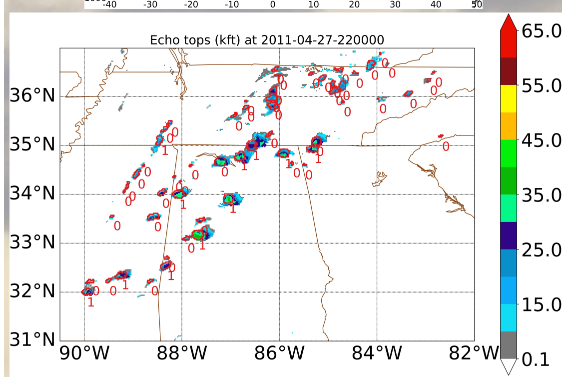
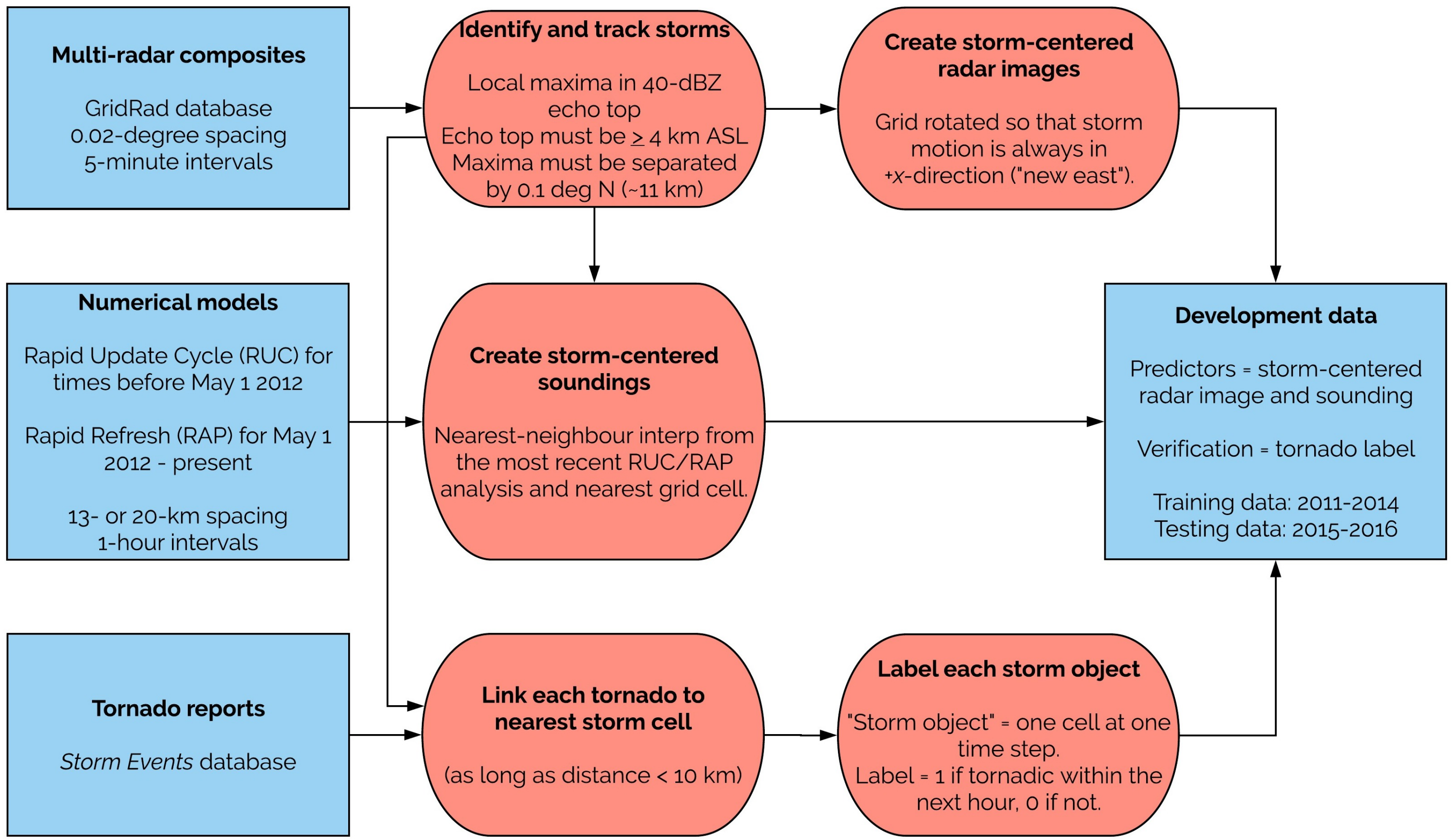
Tornado Prediction with Deep Learning

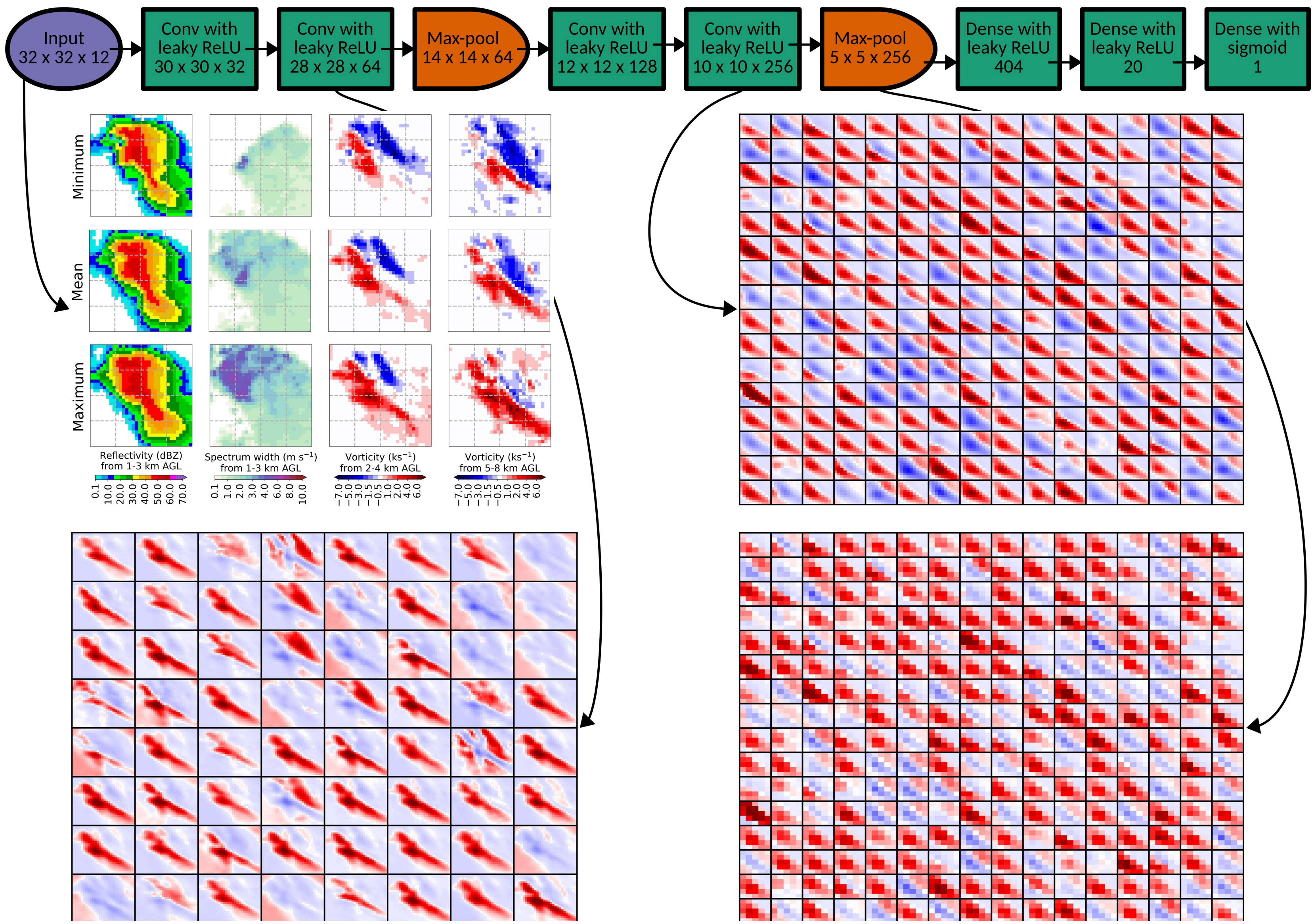






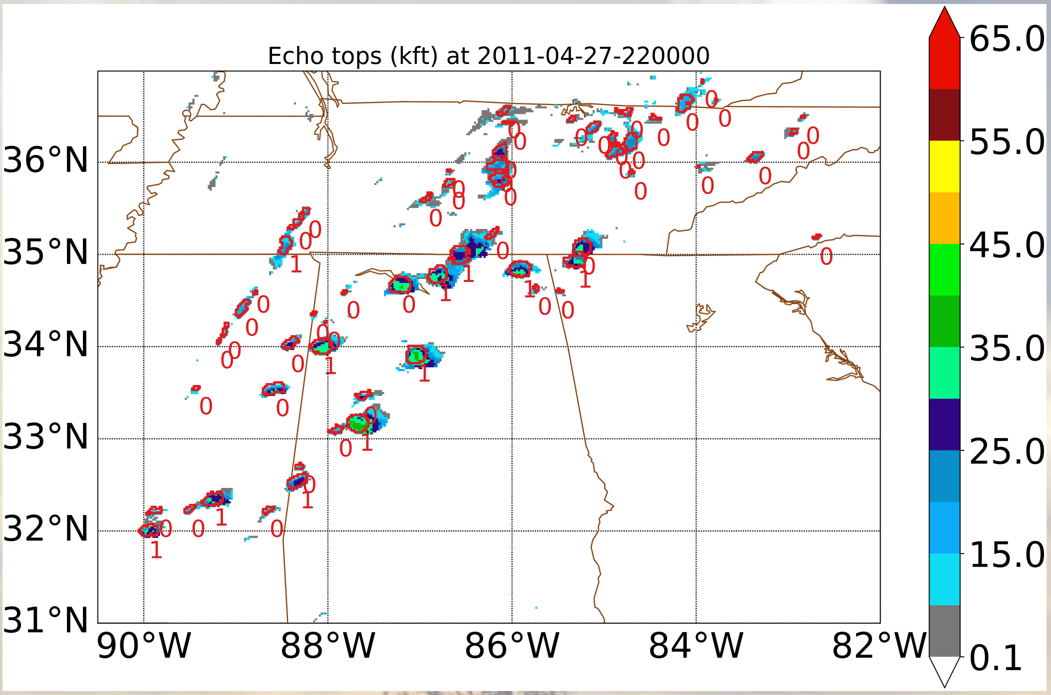


CNN architecture

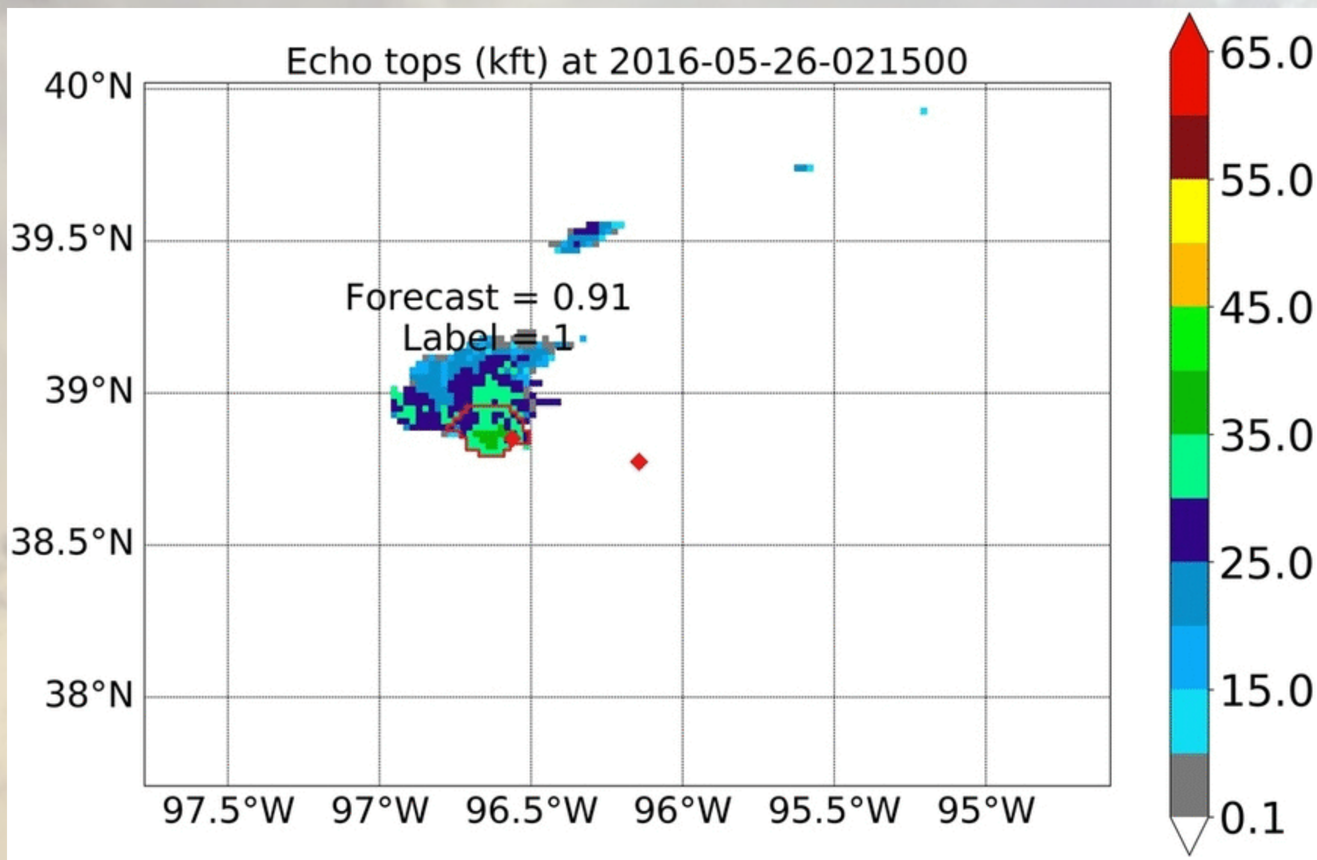


Tornado Experimental Data

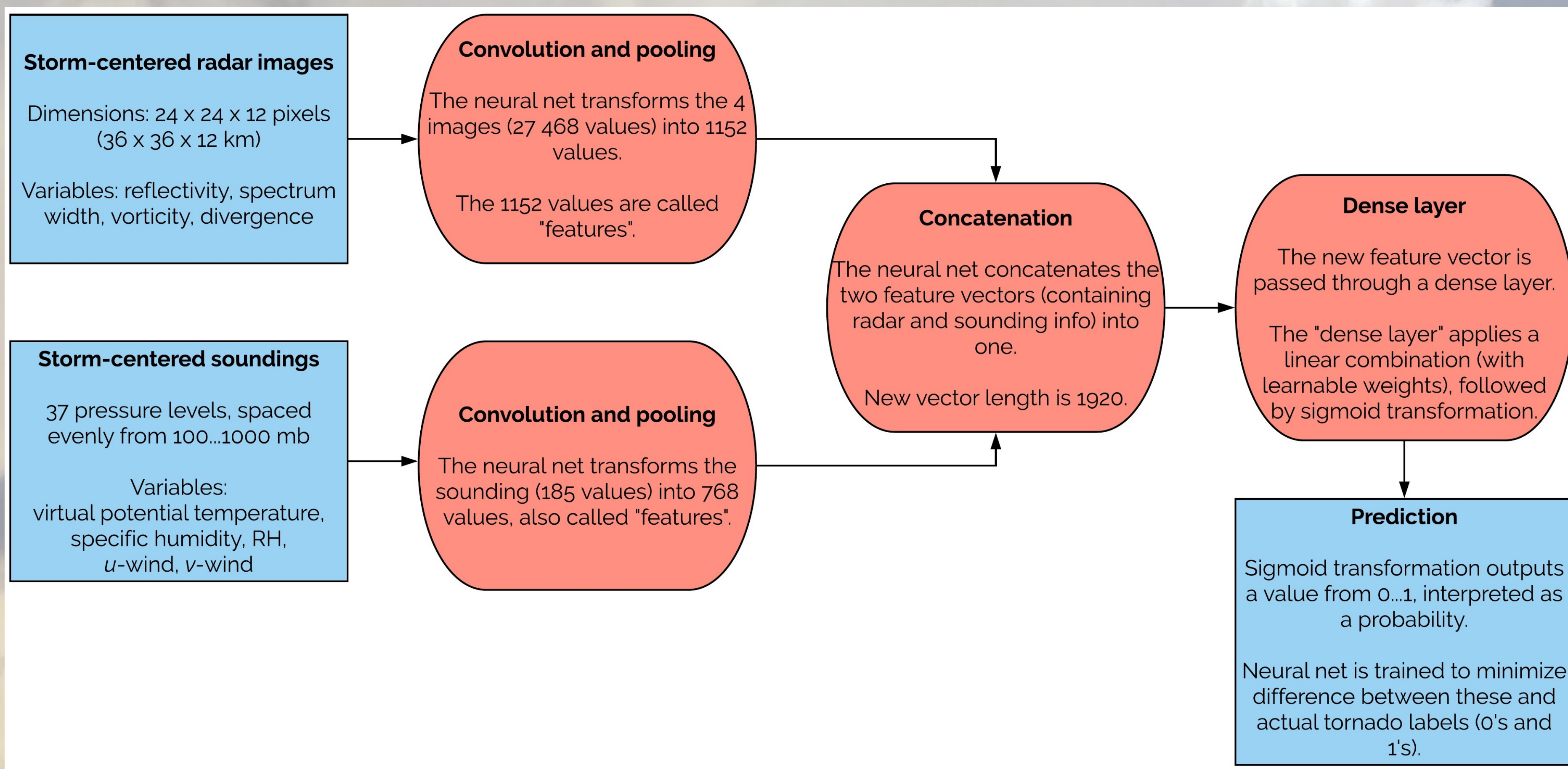
- 1 storm object = 1 storm cell at one time step
- Training set: 2011-14
  - Tornadic objects: 8385
  - Non-tornadic (no tornado in the next hour): 447,922
  - Downsample non-tornadic to 50/50
- Testing set: 2015-16
  - Tornadic: 1420
  - Non-tornadic: 39,639



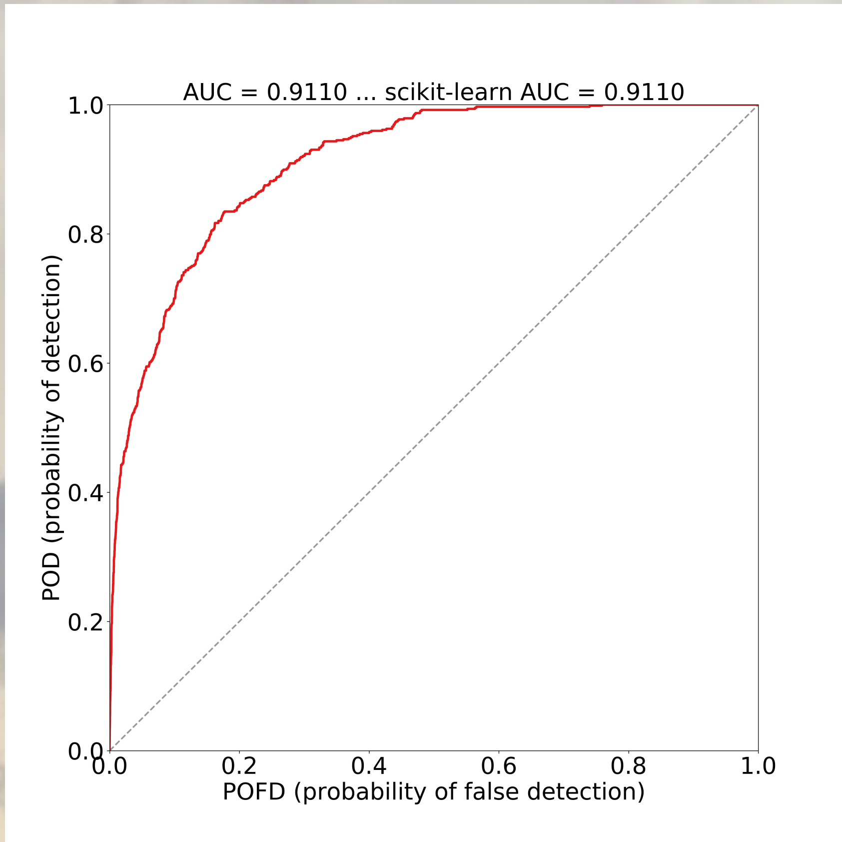
Tornado Labels

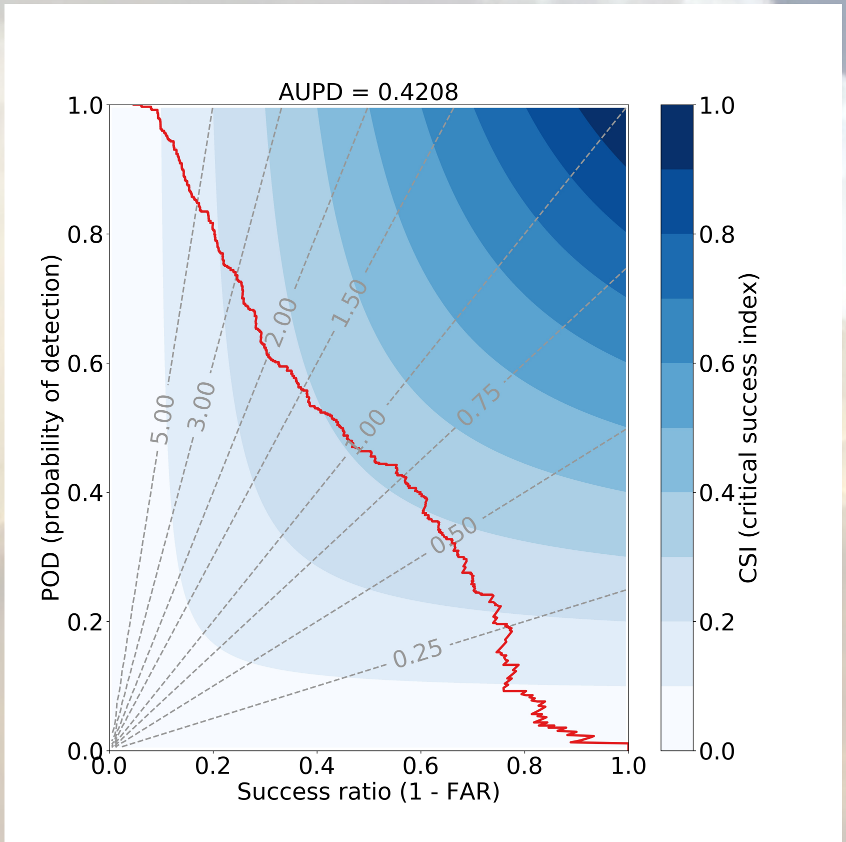


Convolutional Net Architecture



ROC and Performance





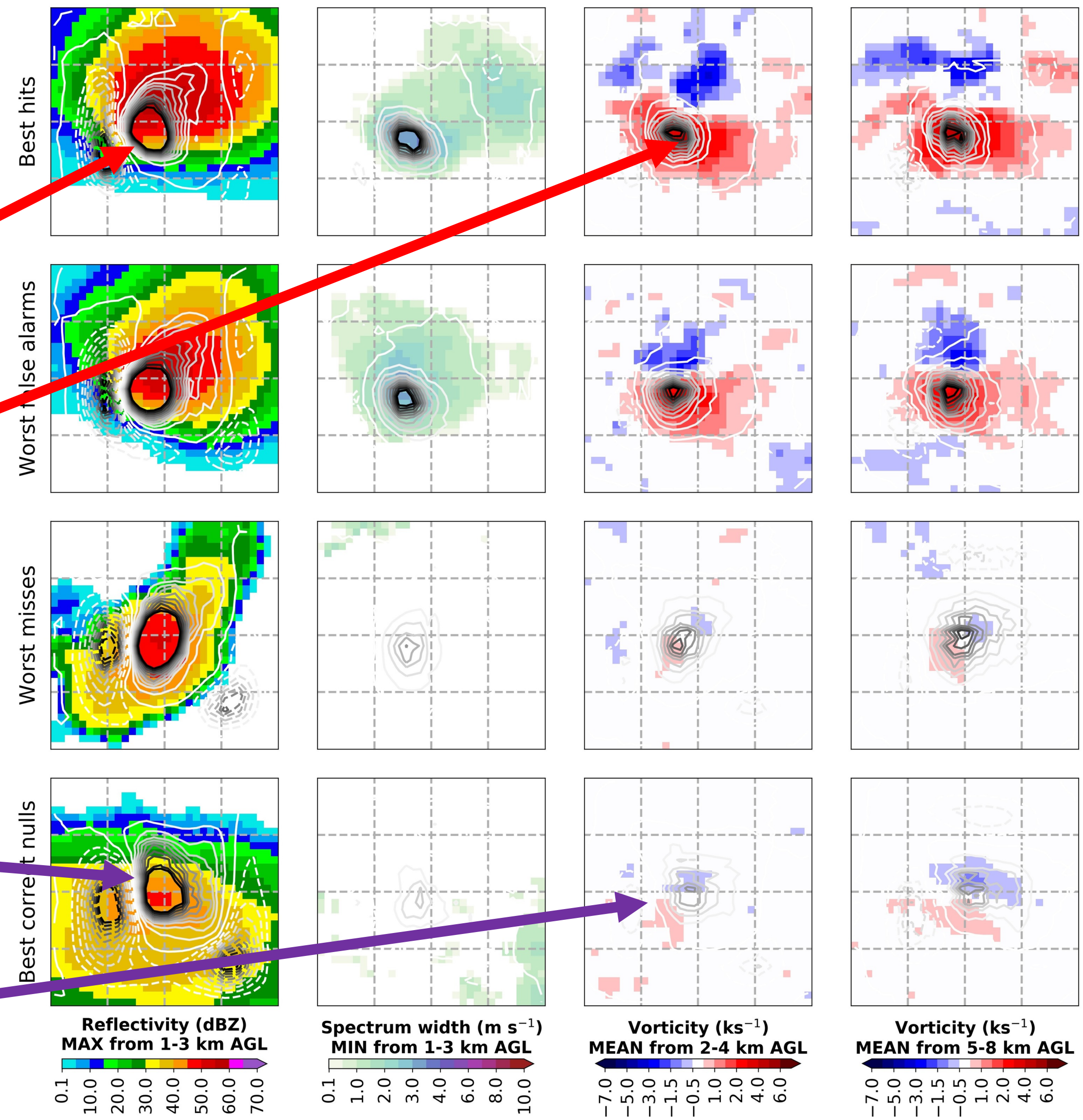
What the model is learning: Saliency

Strong reflectivity core
with hints of a hook

Region of
vorticity near
”hook”

Disorganized storm
with weak reflectivity

No strong
vorticity



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Why Study Bird Roosts?

- Purple Martins and Swallows roost in large colonies visible on the radar
- Important for ecological conservation (Shipley et al. 2017)
- Reasons to study birds roosts and migration (Bauer et al. 2017)
  - Wind turbine collision
  - Habitat deterioration
  - Pest control
  - Crop damage
  - Dispersal of pathogens

Tree Swallow by Prem Balson

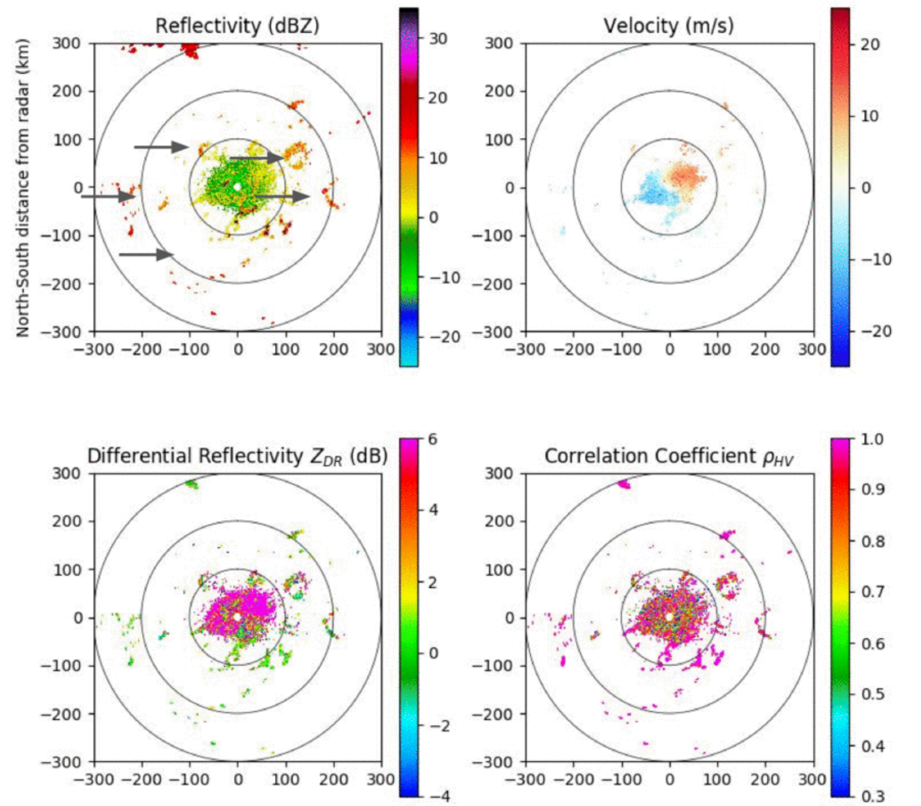
Purple Martin by Greg Homel, Natural Elements Productions

https://sheywicklundphotographs.com/2014/07/20/hundreds-of-purple-martins/

NEXRAD RADAR DATA

- Data:
  - Level 2 NEXRAD data
  - 0.5° scan
- Roosts most visible at sunrise
- Products used (when available):
  - Reflectivity
  - Velocity
  - Correlation Coefficient (dual-pol)
  - Differential Reflectivity (dual-pol)

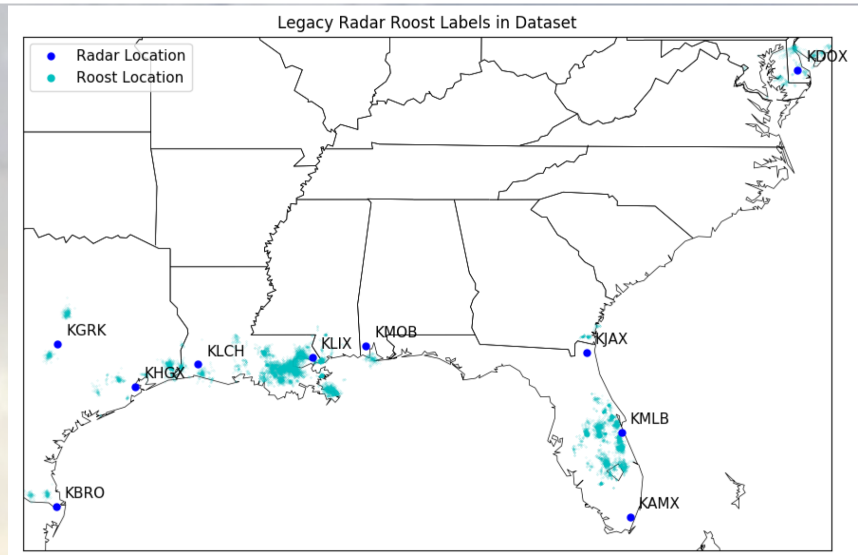
Roost at sunrise

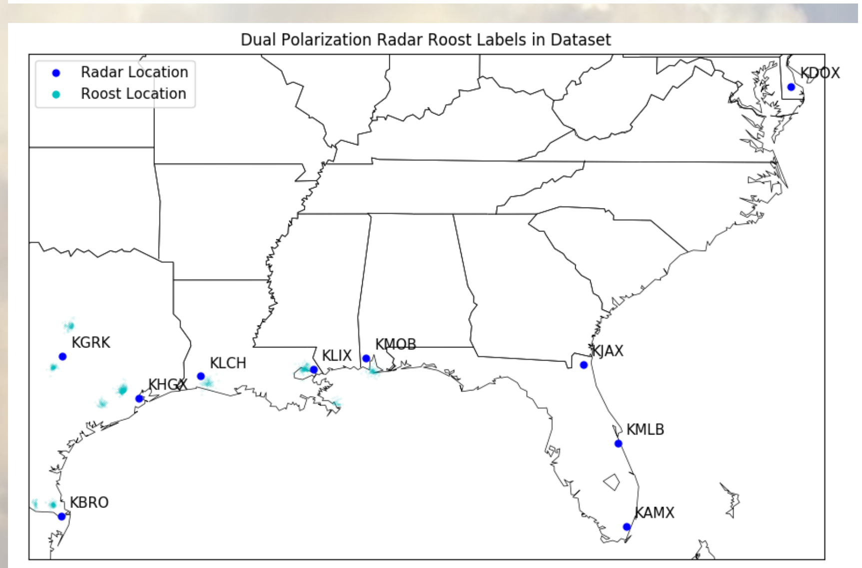


Dataset

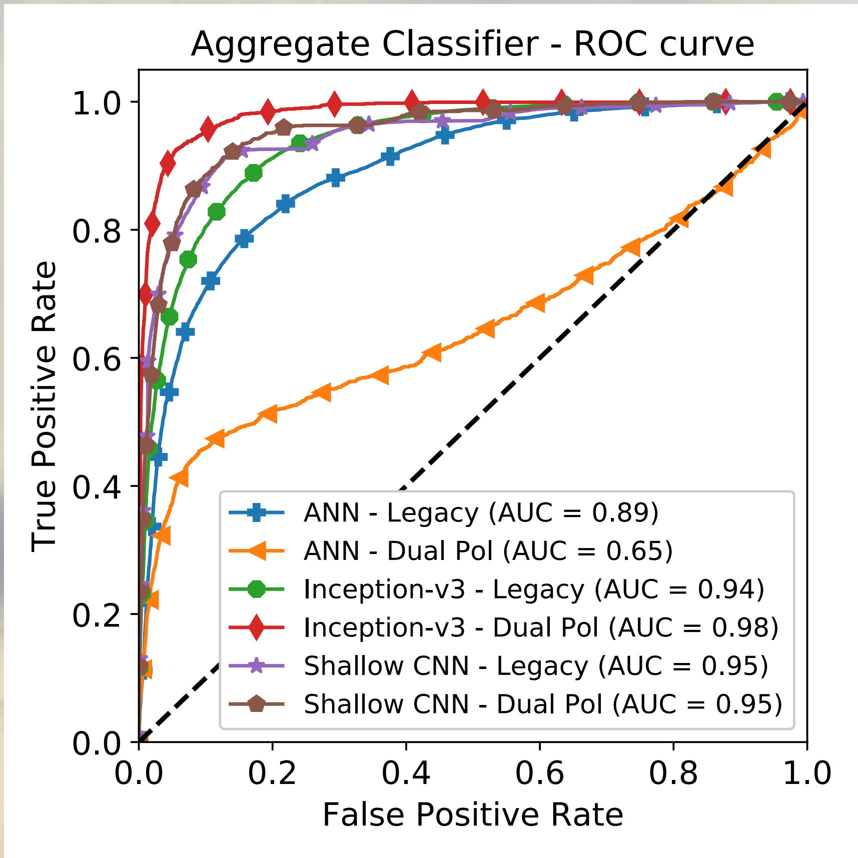
- Labels: Roost and No Roost
- Two sets of radar data: legacy and dual-pol
- 10 different radars: KAMX, KBRO, KDOX, KGRK, KJAX, KHGX, KLCH, KLIX, KMLB, and KMOB
- Hand-labeled data from OU and UMass Amherst

	Roost	No Roost
Legacy	11,112	19,939
Dual-pol	1,346	10,806

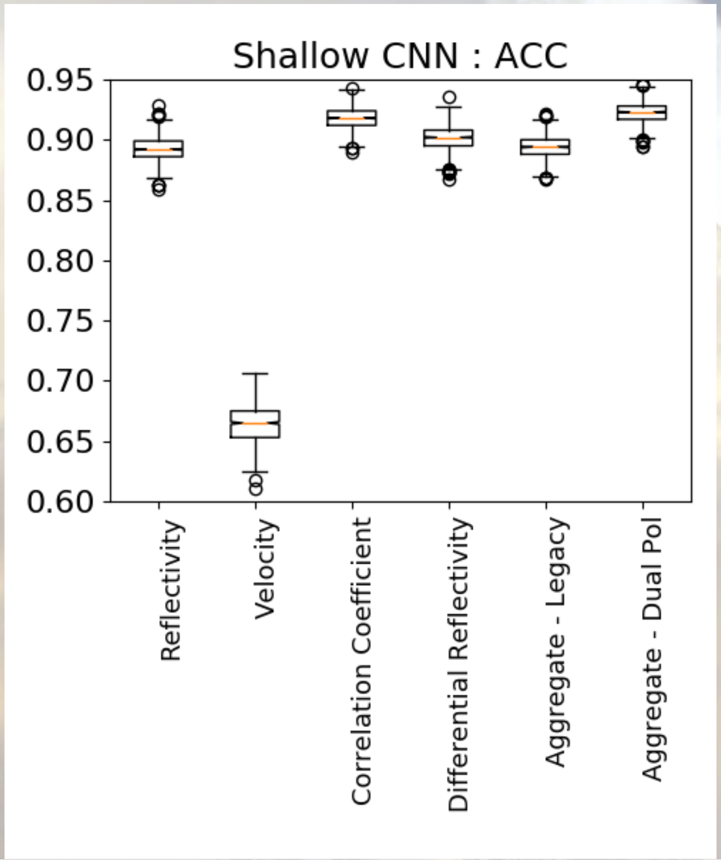




Results



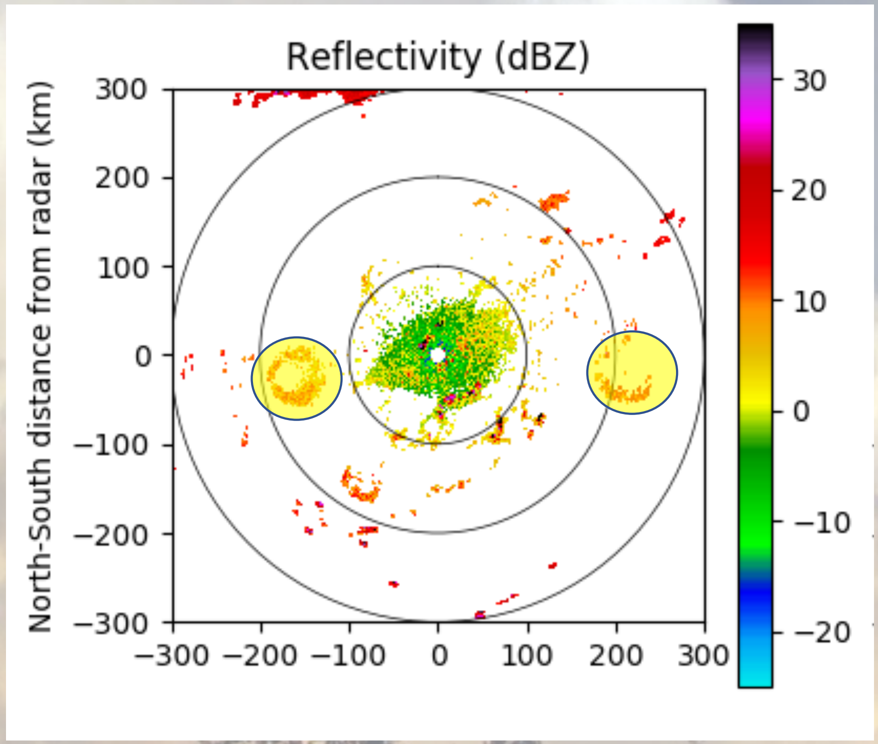
Aggregate Classifier - ROC curve
True Positive Rate
False Positive Rate
0.0
0.2
0.4
0.6
0.8
1.0
ANN - Legacy (AUC = 0.89)
ANN - Dual Pol (AUC = 0.65)
Inception-v3 - Legacy (AUC = 0.94)
Inception-v3 - Dual Pol (AUC = 0.98)
Shallow CNN - Legacy (AUC = 0.95)
Shallow CNN - Dual Pol (AUC = 0.95)



Shallow CNN : ACC
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
Reflectivity
Velocity
Correlation Coefficient
Differential Reflectivity
Aggregate - Legacy
Aggregate - Dual Pol

Current and Future work on Roosts

- Identify locations of bird roosts
- Track changes in behavior over time
- Mitigate risk



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- Funding was provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA16OAR4320115, U.S. Department of Commerce.

- **I’ve got an open PhD position right now!**

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- Contact me: Amy McGovern amcgovern@ou.edu