MACHINE LEARNING AND SEVERE WEATHER FORECASTING

A look into the role of machine learning in forecasting severe weather in the extended days 4-8 at the Storm Prediction center.

NOAA

Storm Prediction Center
Norman, Oklahoma

OVERVIEW

1 DEMISTIFY MACHINE LEARNING

2 EVENT OVERVIEW

3 MACHINE LEARNING AND THE FORECAST

4 RESULTS

DEMISTIFYING MACHINE LEARNING

WHAT KIND OF ANIMAL IS THIS?

A. BEAR
B. HORSE
C. DOG
D. CAT

WHAT KIND OF ANIMAL IS THIS?

A. BEAR

B. HORSE

C. DOG

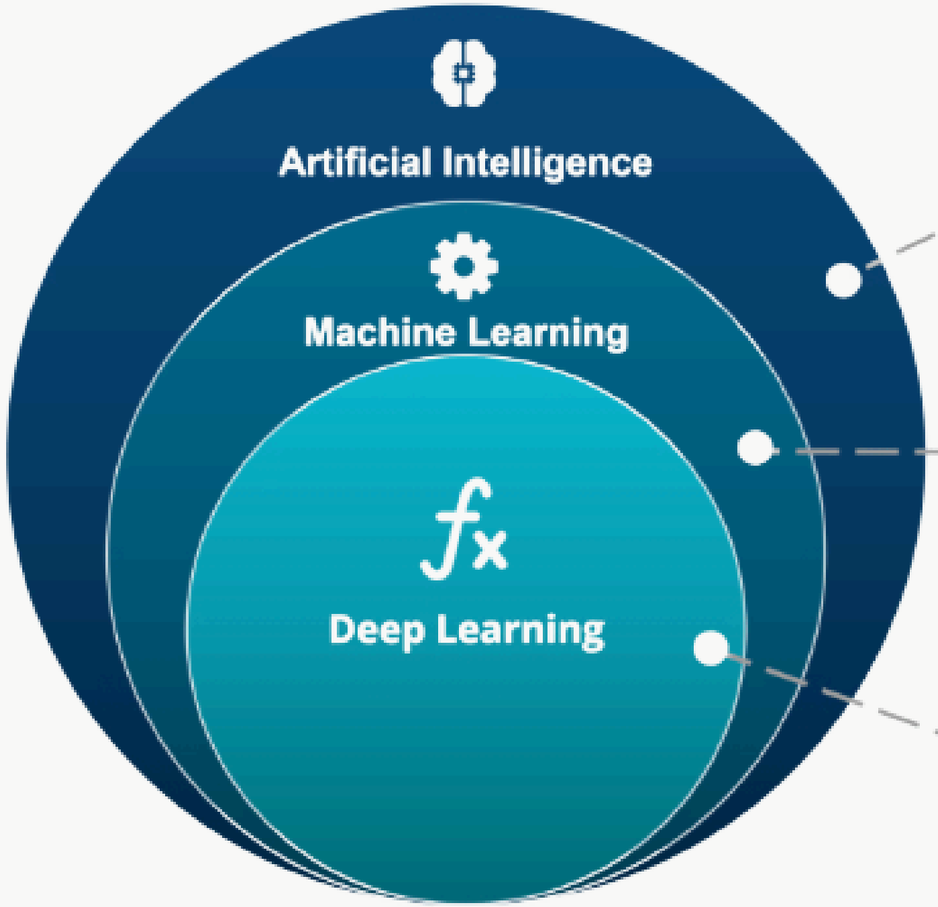
D. CAT

HOW DID YOU ARRIVE AT YOUR ANSWER?

WE HAVE BEEN TRAINED THROUGH EXPERIENCE TO KEY IN ON FEATURES AND PATTERNS TO HELP US IDENTIFY ANIMALS.

You likely considered any number of the following:

The image looked like something you had seen before.
The shape or proportions resembled a dog.
The shape had some legs, even if not the amount (or position) you might have expected...
It had a tail...maybe?
It had ears that looked like a dog's ears.



ARTIFICIAL INTELLIGENCE

A technique which enables machines to mimic human behaviour

MACHINE LEARNING

Subset of AI technique which use statistical methods to enable machines to improve with experience

DEEP LEARNING

Subset of ML which make the computation of multi-layer neural network feasible

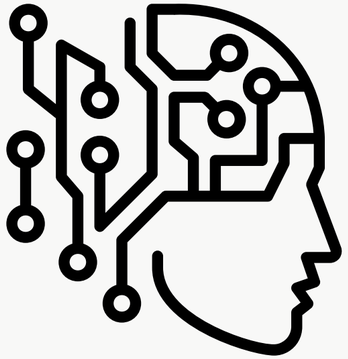
Machine Learning has more adjustable parameters compared to the sample size.

In statistical modeling, we try to keep the adjustable parameters small compared to the sample size (i.e. the number of observations).

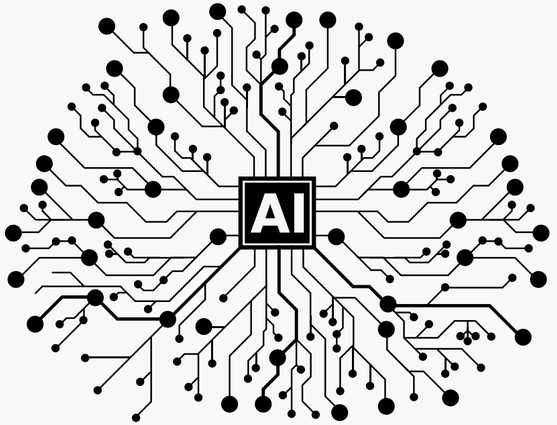
What is the tradeoff?
Better accuracy for less interpretability.

Plainly, statistics is concerned with finding connections between variables and the significance while ML is concerned with outcomes.

MACHINE LEARNING VS STATISTICAL MODELS



ARTIFICIAL INTELLIGENCE REPLACES OUR FINITE HUMAN PROCESSING CAPABILITY WITH A COMPUTER'S NEARLY INFINITE POWER AND RESOURCES.

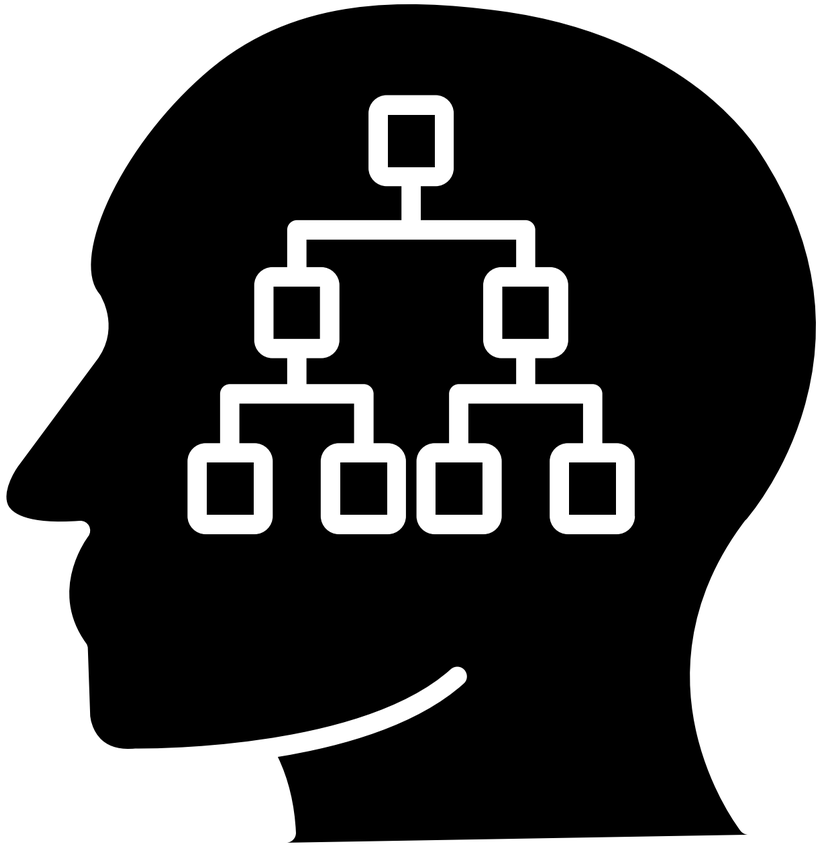


SIMPLIFYING COMPLEXITY: MACHINE LEARNING

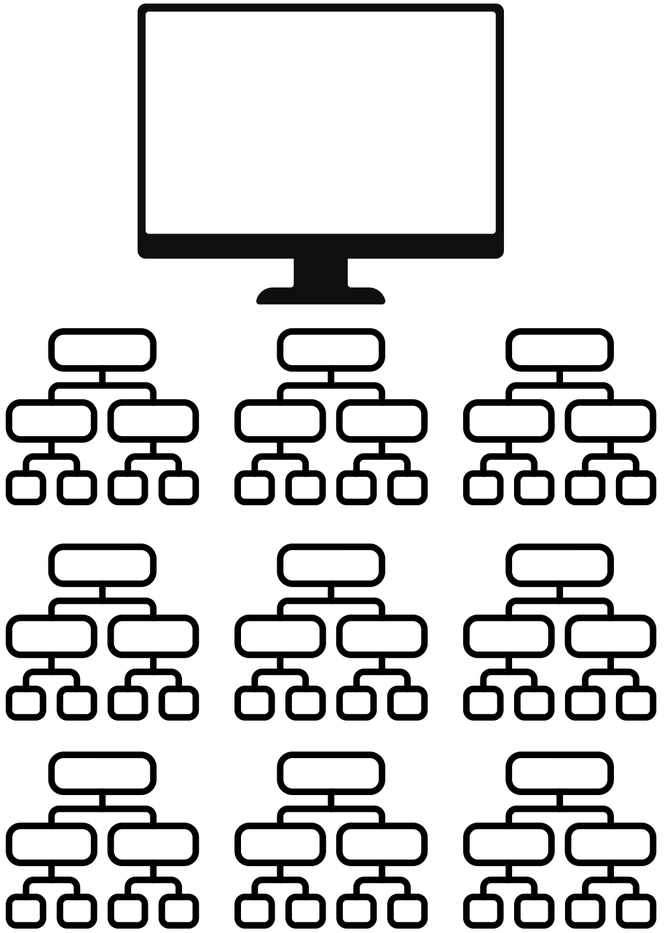
Despite some complexity in the algorithms themselves, it all boils down relating inputs to outputs

Decision Trees: How does this predictor delineate days that do have a tornado and days that don't?

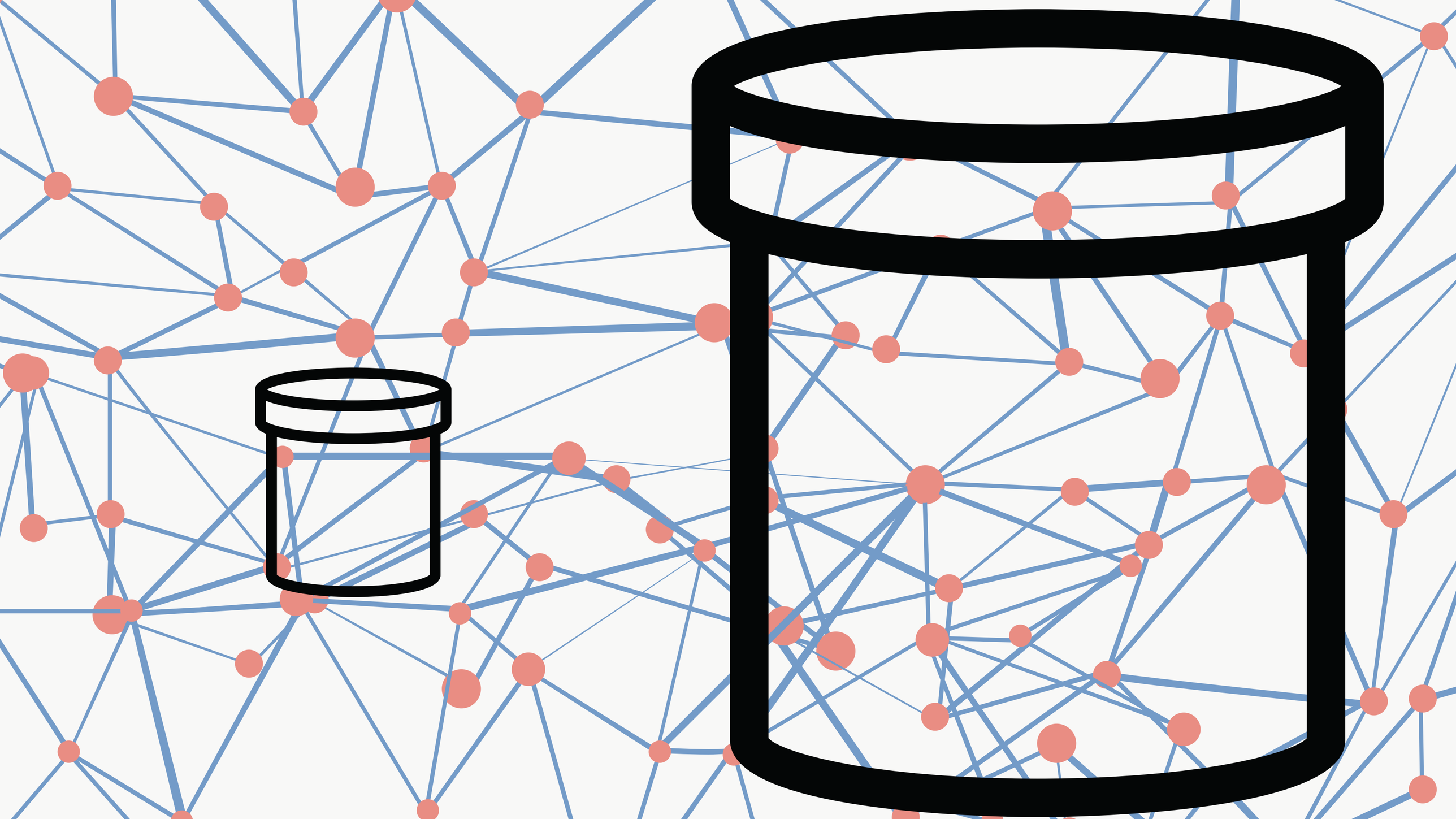
Neural Networks: How do these environmental parameters non-linearly relate to hail occurrence? Hail size?



VISUALIZING RANDOM FOREST



COMBINES MULTIPLE DECISION TREES, EACH **TRAINED** ON A RANDOM SUBSET OF THE DATA AND FEATURES, TO MAKE PREDICTION ON OUTCOMES.



How many severe events have you experienced in your lifetime?

1-5

5-10

10-20

20+

Loading...

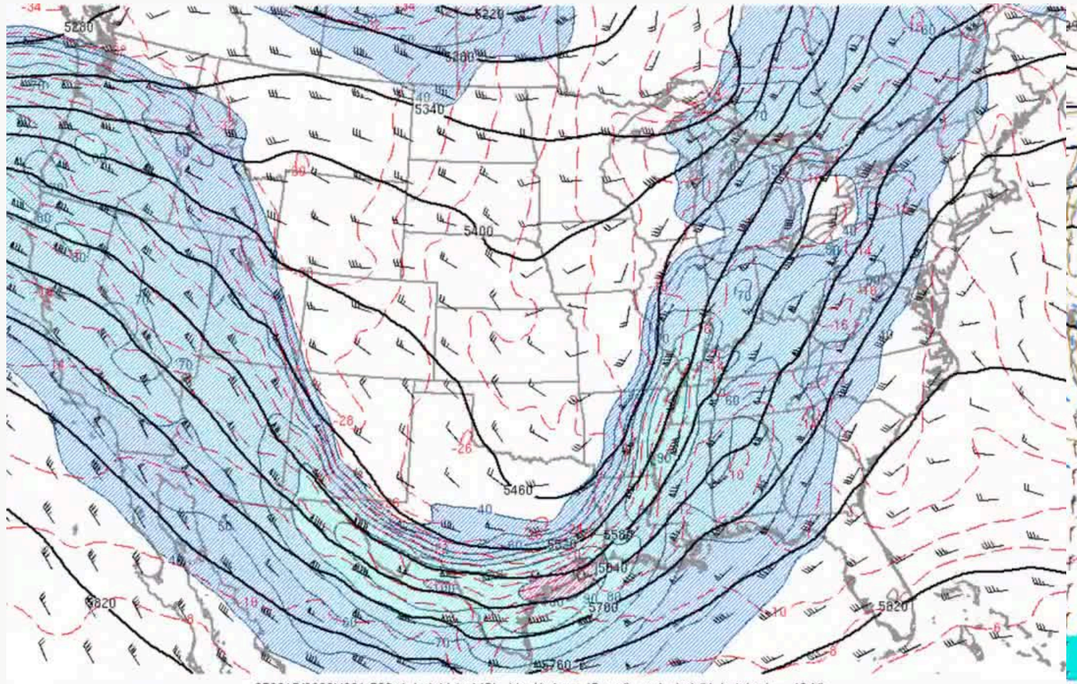
Just to name a few...

COLORADO STATE UNIVERSITY MACHINE LEARNING FORECAST

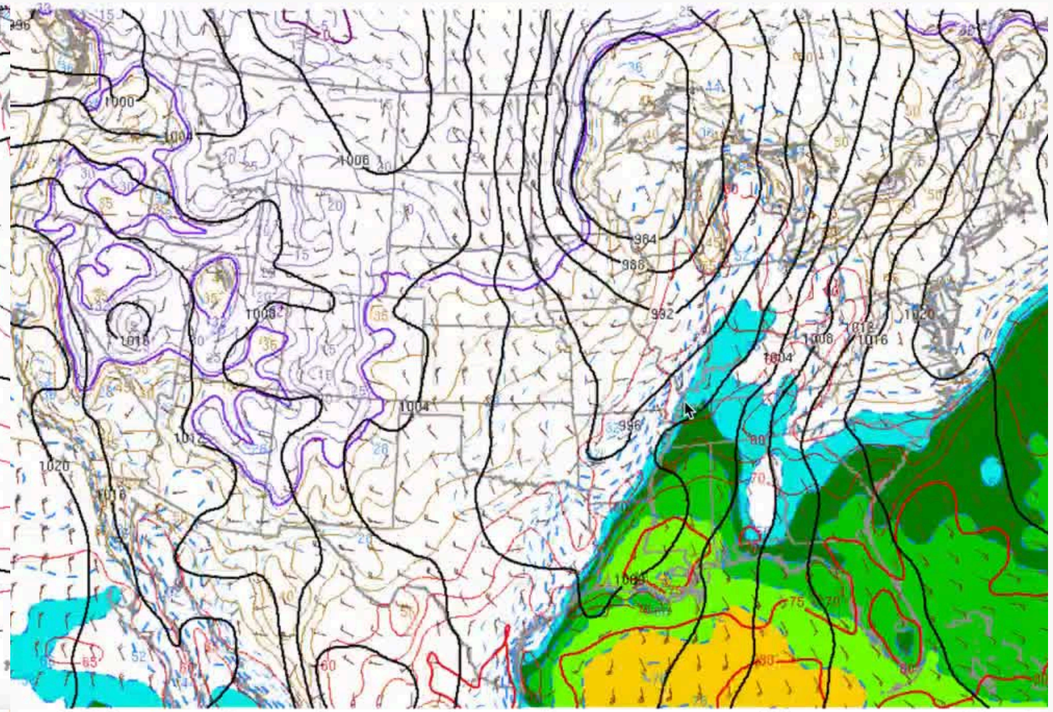
LOKEN MACHINE LEARNING FORECAST

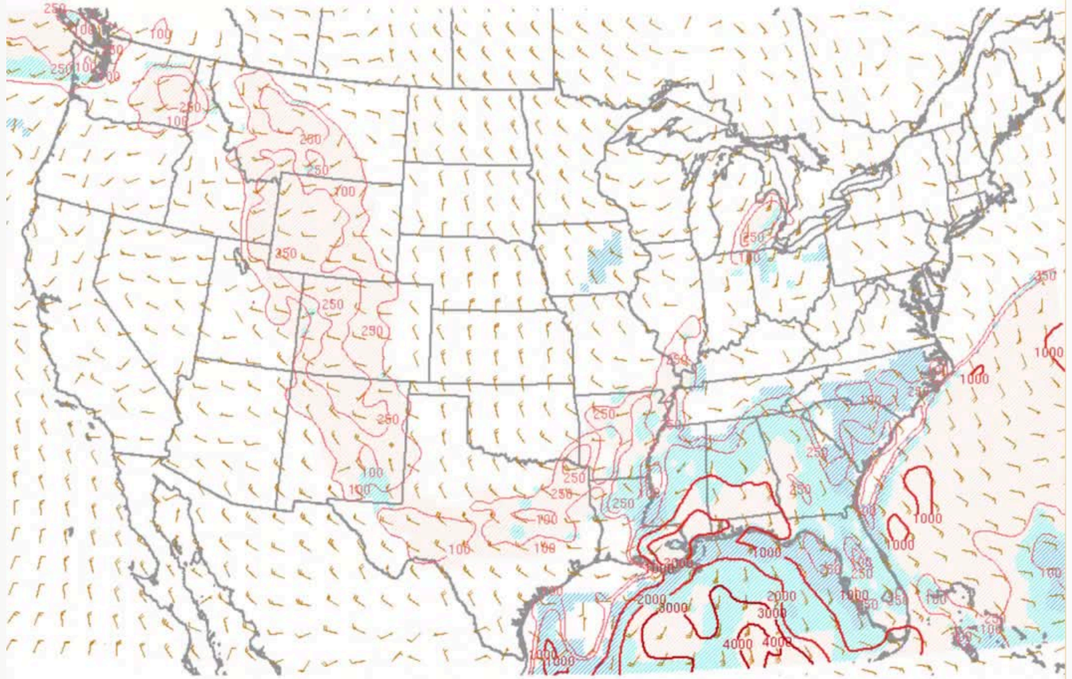
NADOCAST

GEFS MACHINE LEARNING FORECAST

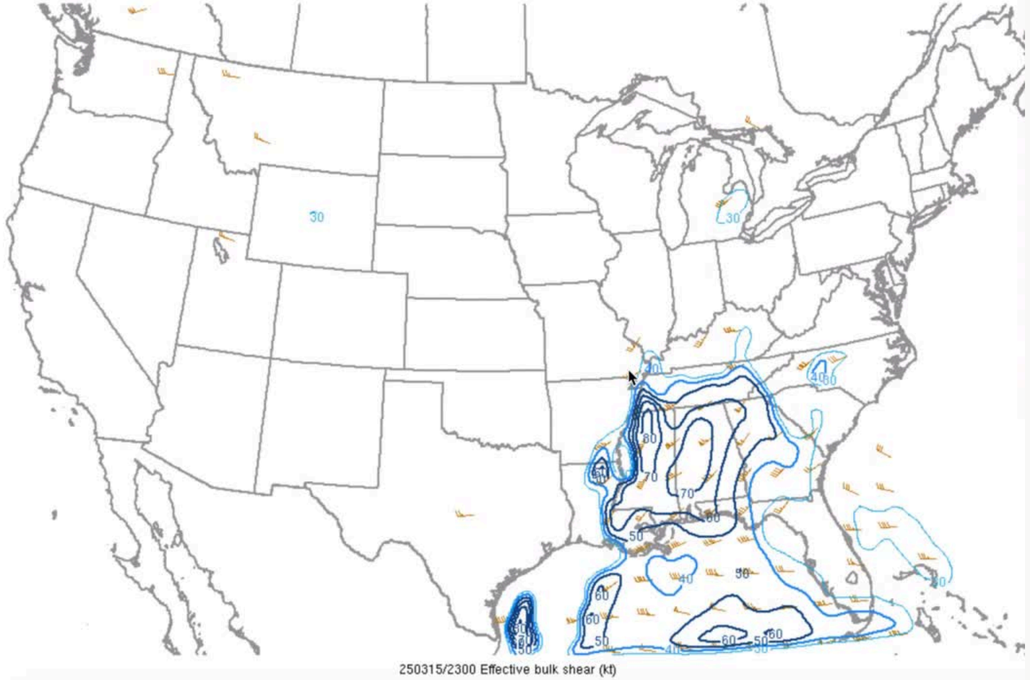


250315/0000V001 500mb height (m MSL, black), temp (C, red), and wind (kt, hatched >= 40 kt)

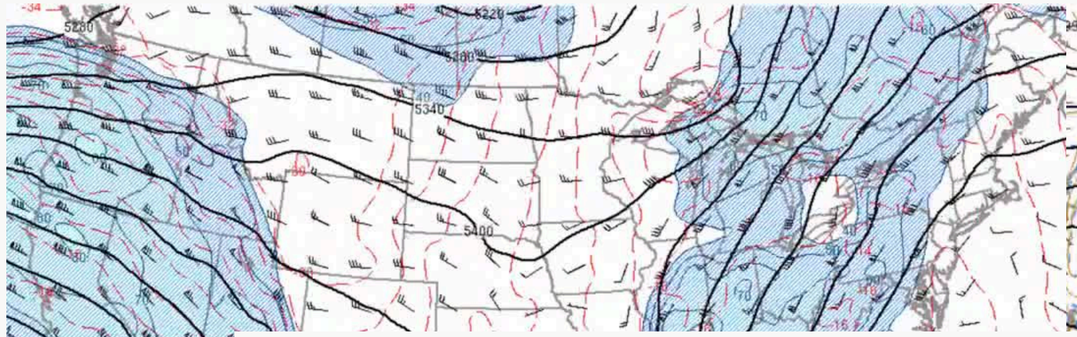


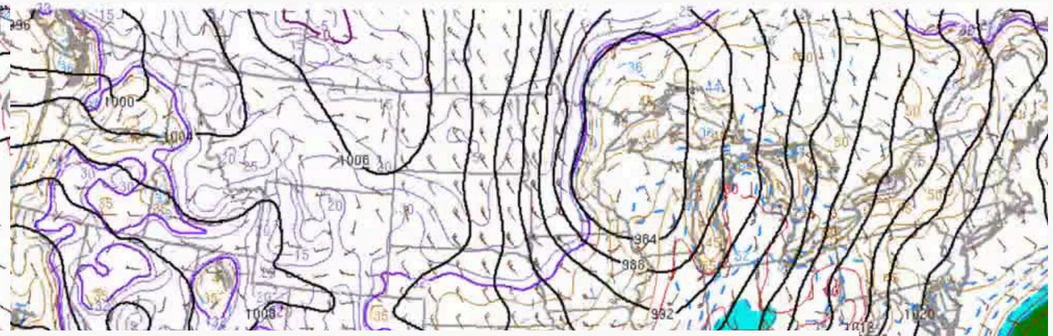


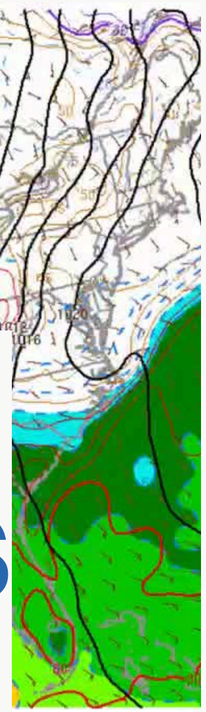
250315/2300 SBCAPE (contour) and SBCIN (J/kg, shaded at 25 and 100)



250315/2300 Effective bulk shear (kt)

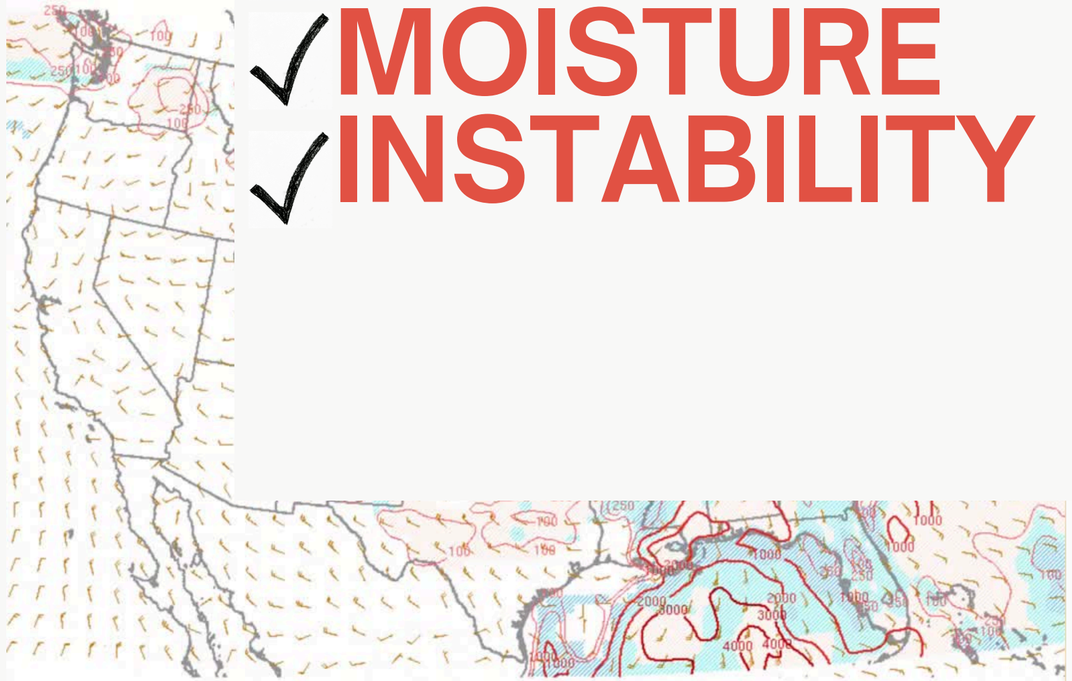




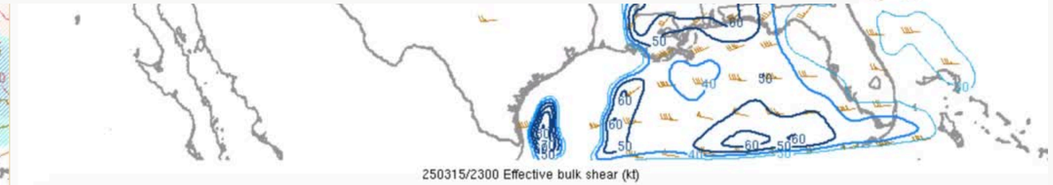


- ✓LIFT
- ✓SHEAR
- ✓MOISTURE
- ✓INSTABILITY

INGREDIENTS ARE IN PLACE



250315/2300 SBCAPE (contour) and SBCIN (J/kg, shaded at 25 and 100)



250315/2300 Effective bulk shear (kt)

CHECK THE HAND OUTS →

Understanding Severe Thunderstorm Risk Categories

THUNDERSTORMS (no label)	1 - MARGINAL (MRGL)	2 - SLIGHT (SLGT)	3 - ENHANCED (ENH)	4 - MODERATE (MDT)	5 - HIGH (HIGH)
No severe* thunderstorms expected	**Isolated severe thunderstorms possible**	**Scattered severe storms possible**	**Numerous severe storms possible**	**Widespread severe storms likely**	**Widespread severe storms expected**
Lightning/flooding threats exist with all thunderstorms	Limited in duration and/or coverage and/or intensity	Short-lived and/or not widespread, isolated intense storms possible	More persistent and/or widespread, a few intense	Long-lived, widespread and intense	Long-lived, very widespread and particularly intense

* NWS defines a severe thunderstorm as measured wind gusts to at least 58 mph, and/or hail to at least one inch in diameter, and/or a tornado. All thunderstorm categories imply lightning and the potential for flooding. Categories are also tied to the probability of a severe weather event within 25 miles of your location.

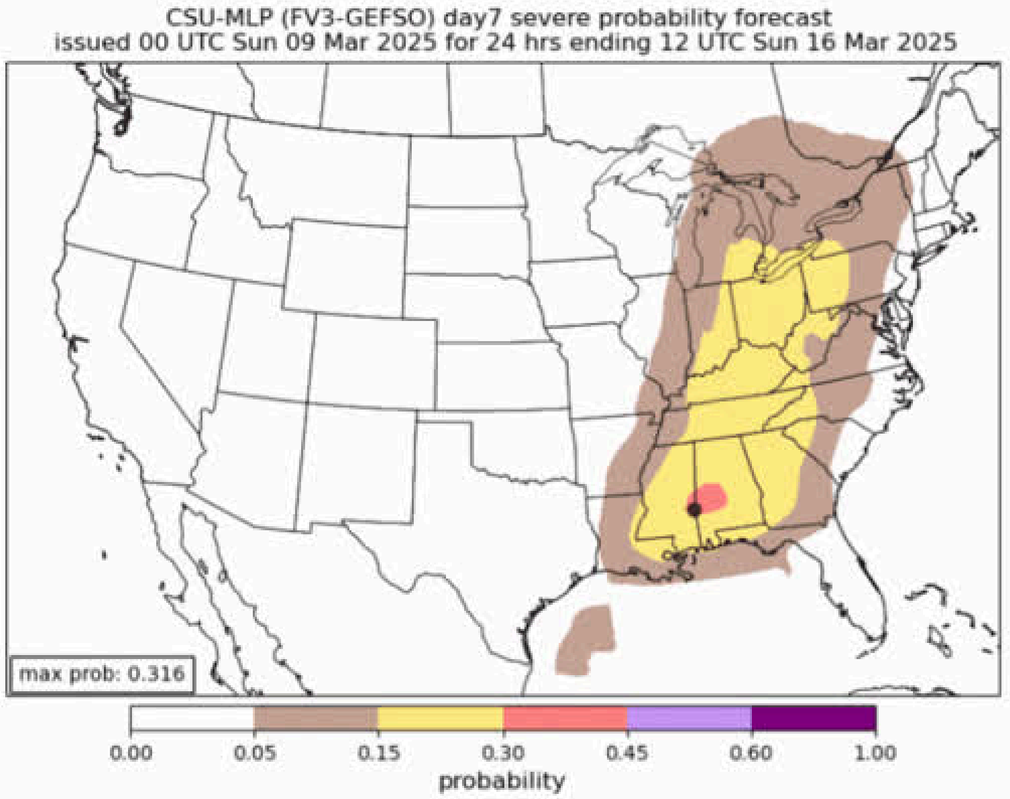
National Weather Service
www.spc.noaa.gov

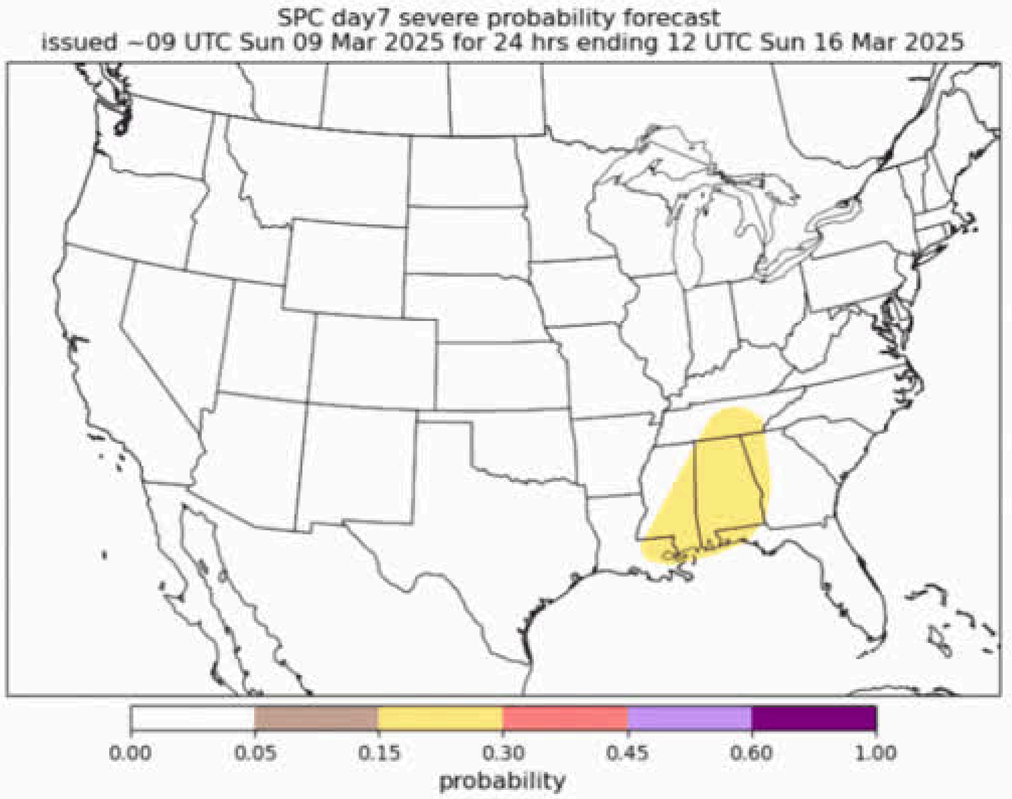
Day 1 Outlook Probability	TORN	WIND	HAIL
2%	MRGL	Not Used	Not Used
5%	SLGT	MRGL	MRGL
10%	ENH	Not Used	Not Used
10% with Significant Severe	ENH	Not Used	Not Used
15%	ENH	SLGT	SLGT
15% with Significant Severe	MDT	SLGT	SLGT
30%	MDT	ENH	ENH
30% with Significant Severe	HIGH	ENH	ENH
45%	HIGH	ENH	ENH
45% with Significant Severe	HIGH	MDT	MDT
60%	HIGH	MDT	MDT
60% with Significant Severe	HIGH	HIGH	MDT

WWW.SPC.NOAA.GOV/MISC/ABOUT.PHP

CSU MACHINE LEARNING GUIDANCE

Forecasts: Issued 20250309



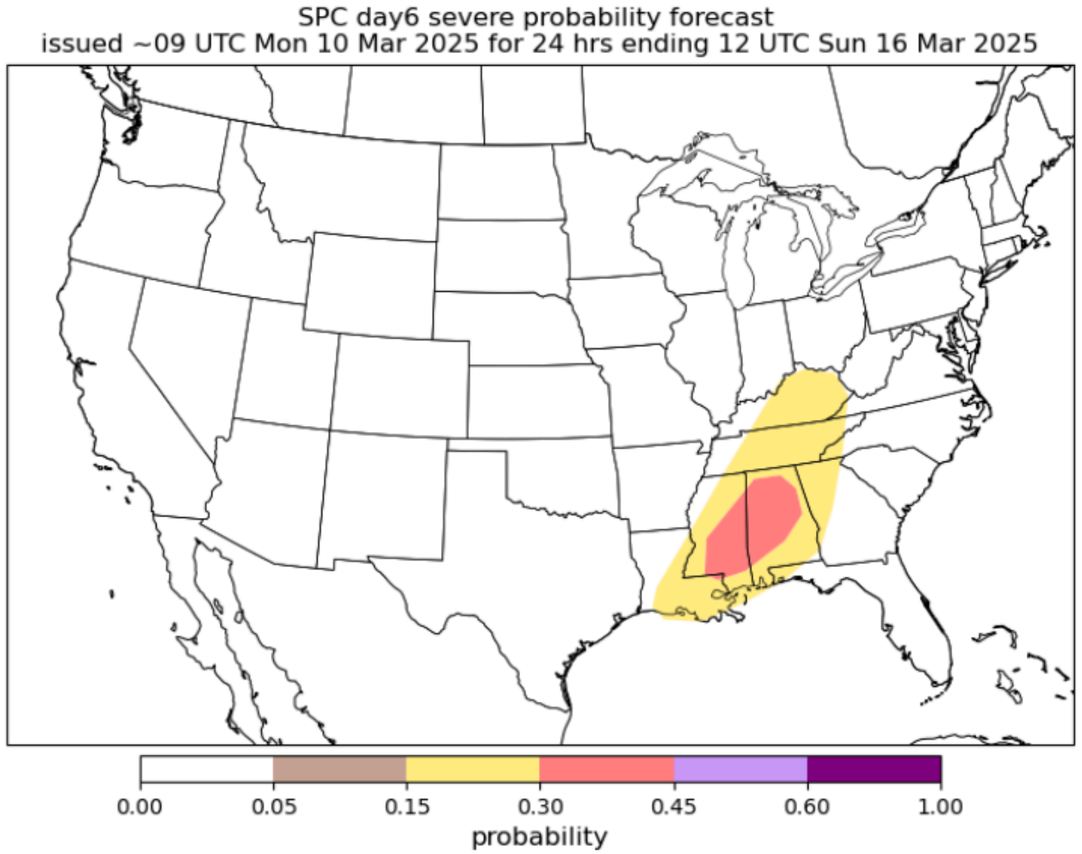


CSU MACHINE LEARNING GUIDANCE

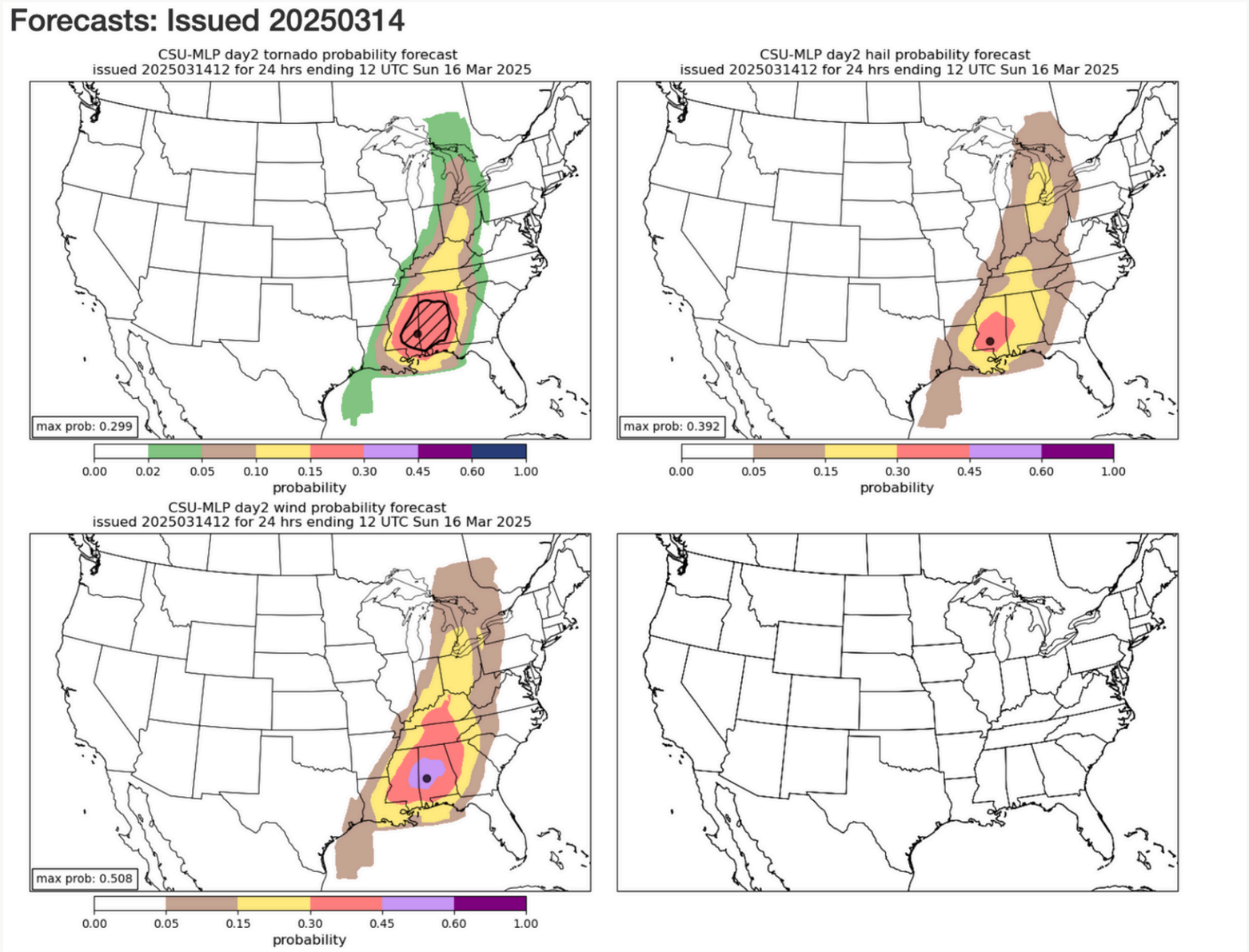
...Day 6/Fri - Mid to Lower MS Valley vicinity...

A powerful upper cyclone and attendant trough is expected to develop east across the Plains toward the MS Valley on Friday. An intense southwesterly jet (100+ kt at 500 mb) is expected to be oriented from the southern Plains to the Mid-MS Valley by Friday evening. Meanwhile, a rapidly intensifying surface cyclone will shift northeast from the central Plains to the Upper Midwest vicinity through the period. Strong southerly low-level flow ahead of this low and an attendant eastward-advancing cold front will support rapid northward transport of Gulf moisture. While details regarding quality of northward moisture transport remain, this overall pattern will be very favorable for a regional severe weather episode from late Friday afternoon into early Day 6/Sat morning.

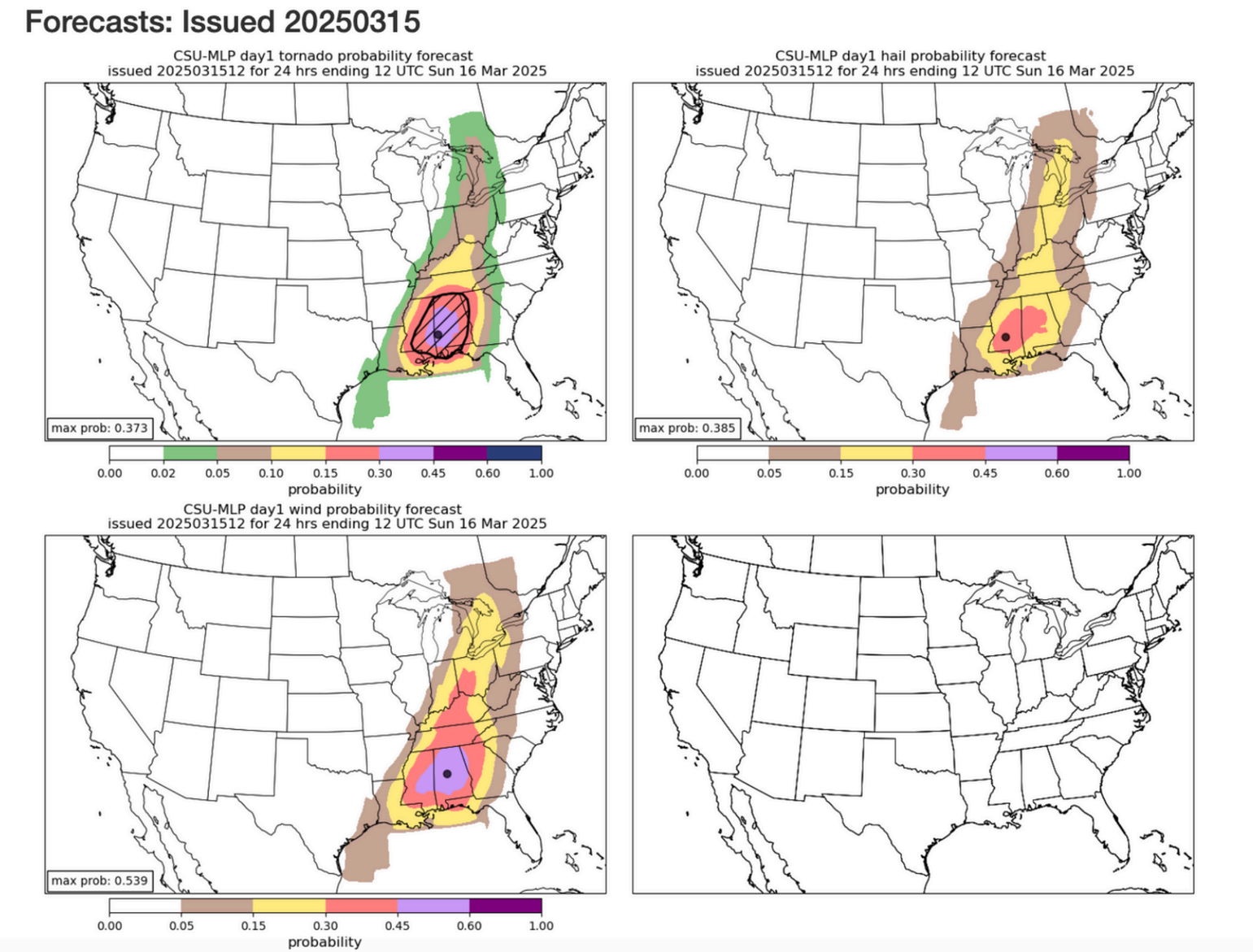
Overall, cross-model consistency has improved compared to the past couple of days, and guidance generally appears to be converging on similar solutions. When compared with the operational ECMWF, the operational GFS remains a bit further north with the placement of the low-level and upper-level cyclones, as well as northward extent of better moisture return. However, the GEFS and EPS ensemble means are quite similar. While this indicates there is still a moderate degree of spread in the north and east extent of severe potential, the envelop is narrowing, and a broad area favorable for an all-hazards severe episode is expected on Friday/Friday night, centered on the Mid to Lower MS Valley vicinity. This trends is also aligned with SPC and NSSL experimental machine learning guidance. Given uncertainties still exist regarding timing and location of key features, as well as with northward extent of deeper moisture return, this area is likely to change/shift some over the coming days as details become better resolved (and higher probabilities will likely become necessary as well).

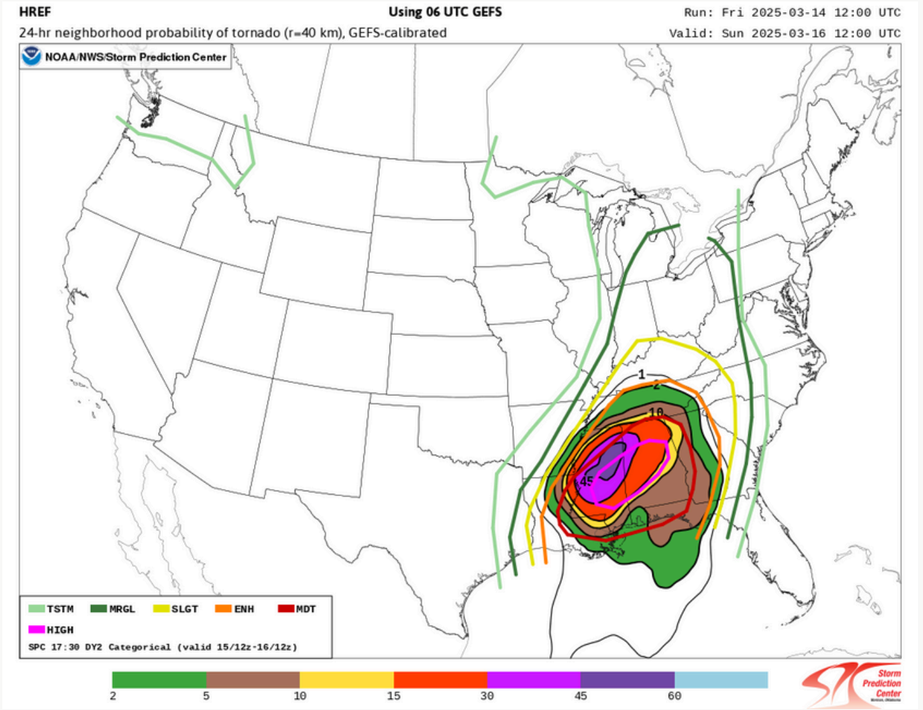


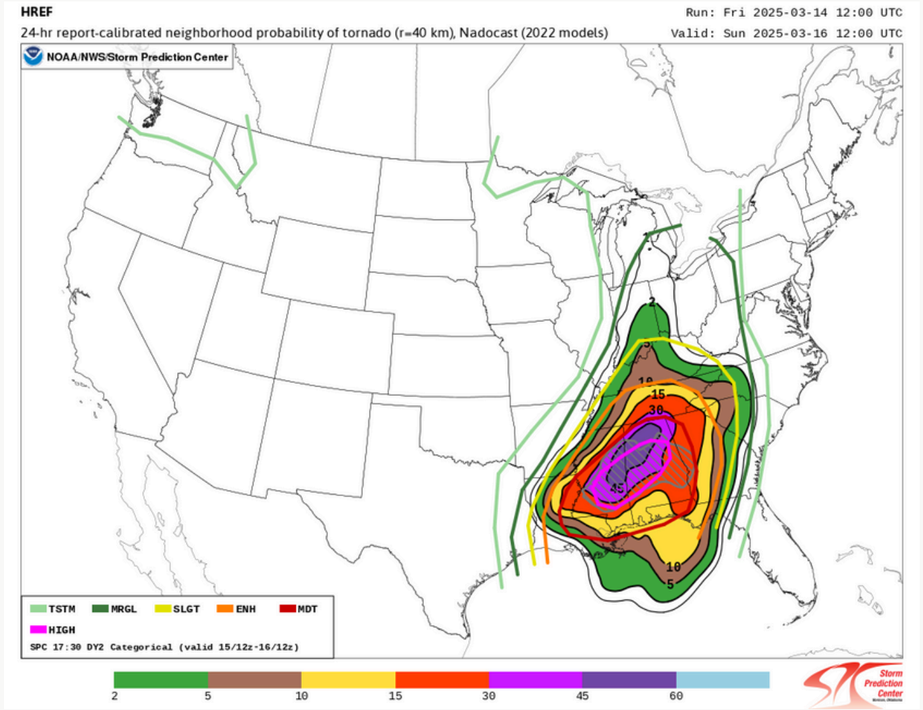
CSU MACHINE LEARNING GUIDANCE



CSU MACHINE LEARNING GUIDANCE




HREF
Using 06 UTC GEFS
Run: Fri 2025-03-14 12:00 UTC
24-hr neighborhood probability of tornado (r=40 km), GEFS-calibrated
Valid: Sun 2025-03-16 12:00 UTC
NOAA/NWS/Storm Prediction Center
TSTM MRGL SLGT ENH MDT
HIGH
SPC 17:30 DY2 Categorical (valid 15/12z-16/12z)
2 5 10 15 30 45 60
Storm Prediction Center


HREF
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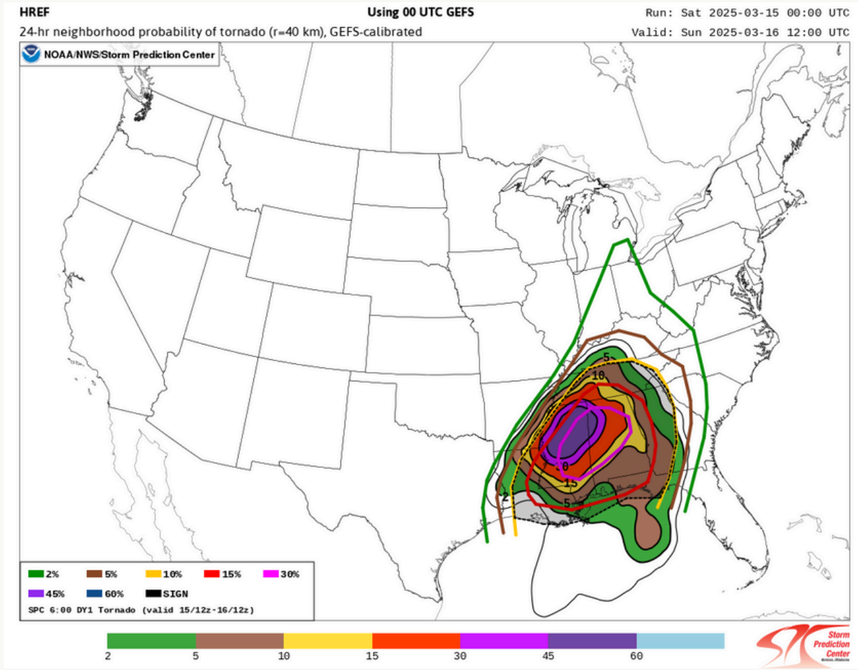
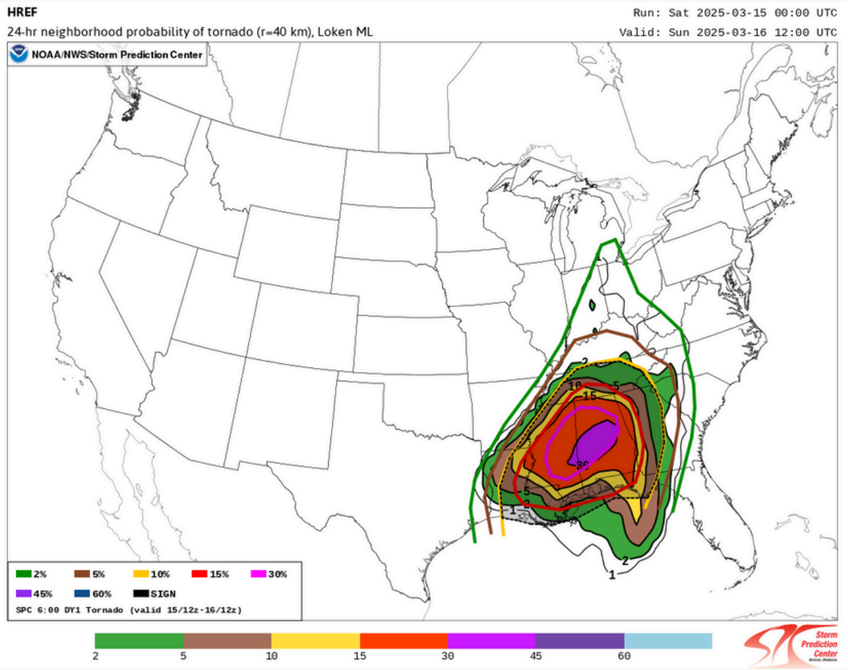
24-hr report-calibrated neighborhood probability of tornado (r=40 km), Nadocast (2022 models)
Valid: Sun 2025-03-16 12:00 UTC
NOAA/NWS/Storm Prediction Center
TSTM MRGL SLGT ENH MDT
HIGH
SPC 17:30 DY2 Categorical (valid 15/12z-16/12z)
2 5 10 15 30 45 60
Storm Prediction Center

D2 INITIAL


HREF
Using 00 UTC GEFS
Run: Sat 2025-03-15 00:00 UTC
24-hr neighborhood probability of tornado (r=40 km), GEFS-calibrated
Valid: Sun 2025-03-16 12:00 UTC
NOAA/NWS/Storm Prediction Center
2% 5% 10% 15% 30%
45% 60% SIGN
SPC 6:00 DY1 Tornado (valid 15/12z-16/12z)
2 5 10 15 30 45 60
Storm Prediction Center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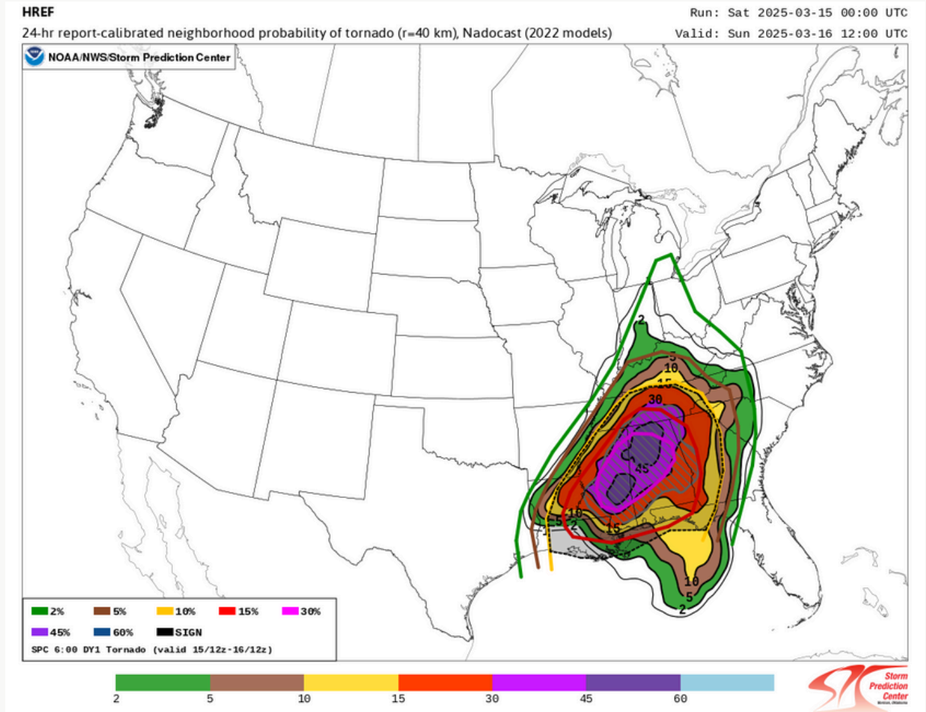
24-hr neighborhood probability of tornado (r=40 km), Loken ML
Valid: Sun 2025-03-16 12:00 UTC
NOAA/NWS/Storm Prediction Center
2% 5% 10% 15% 30%
45% 60% SIGN
SPC 6:00 DY1 Tornado (valid 15/12z-16/12z)
2 5 10 15 30 45 60
Storm Prediction Center


HREF
Run: Sat 2025-03-15 00:00 UTC
24-hr report-calibrated neighborhood probability of tornado (r=40 km), Nadocast (2022 models)
Valid: Sun 2025-03-16 12:00 UTC
NOAA/NWS/Storm Prediction Center
2% 5% 10% 15% 30%
45% 60% SIGN
SPC 6:00 DY1 Tornado (valid 15/12z-16/12z)
2 5 10 15 30 45 60
Storm Prediction Center

D1 INITIAL

Does the human forecaster add value?

Yes

No

Loading...

HISTORICAL CONTEXT

1900s

Forecasts occasionally mentioned the potential for severe weather, Weather Bureau policy continued to **prohibit use of the word "tornado" in forecasts.**

The ban on the word "tornadoes" was lifted in 1938, very few forecasts made mention of tornadoes during the 1940s.

1948-1950

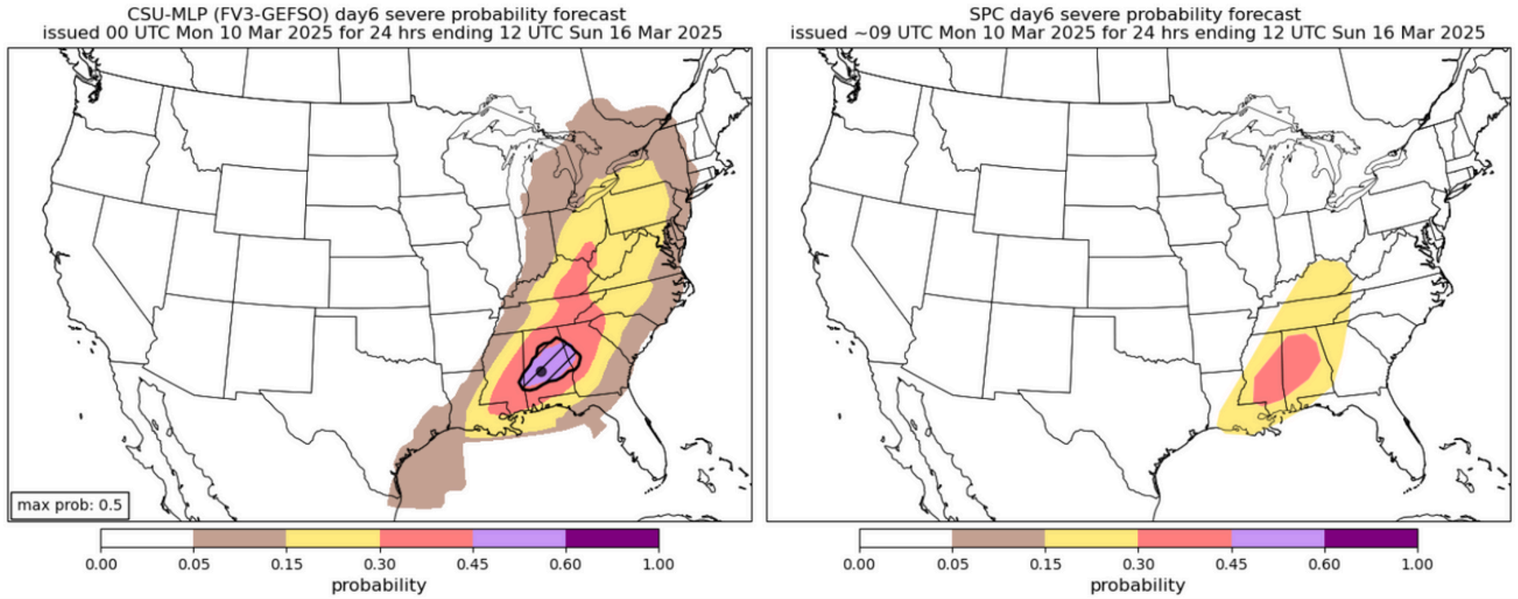
Based on earlier research and on their own investigation of the conditions that produced a damaging tornado at Tinker Air Force Base in Oklahoma City on 20 March 1948 --- Air Force weather officers **E. J. Fawbush and R. C. Miller successfully predicted the occurrence of another tornado at the base five days later on 25 March.**

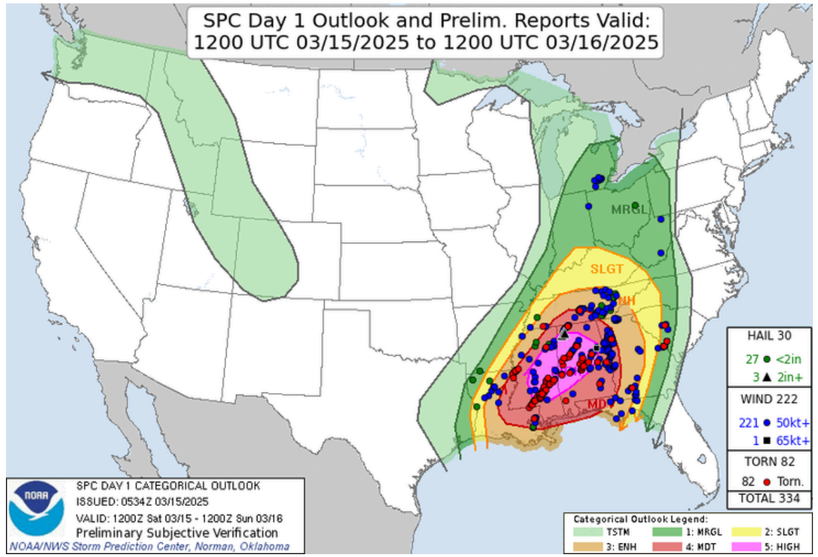
The forecast's accuracy drew considerable attention; soon the officers were responsible for Air Force tornado prediction over much of the central United States.

D6 MACHINE LEARNING VS SPC FORECASTER

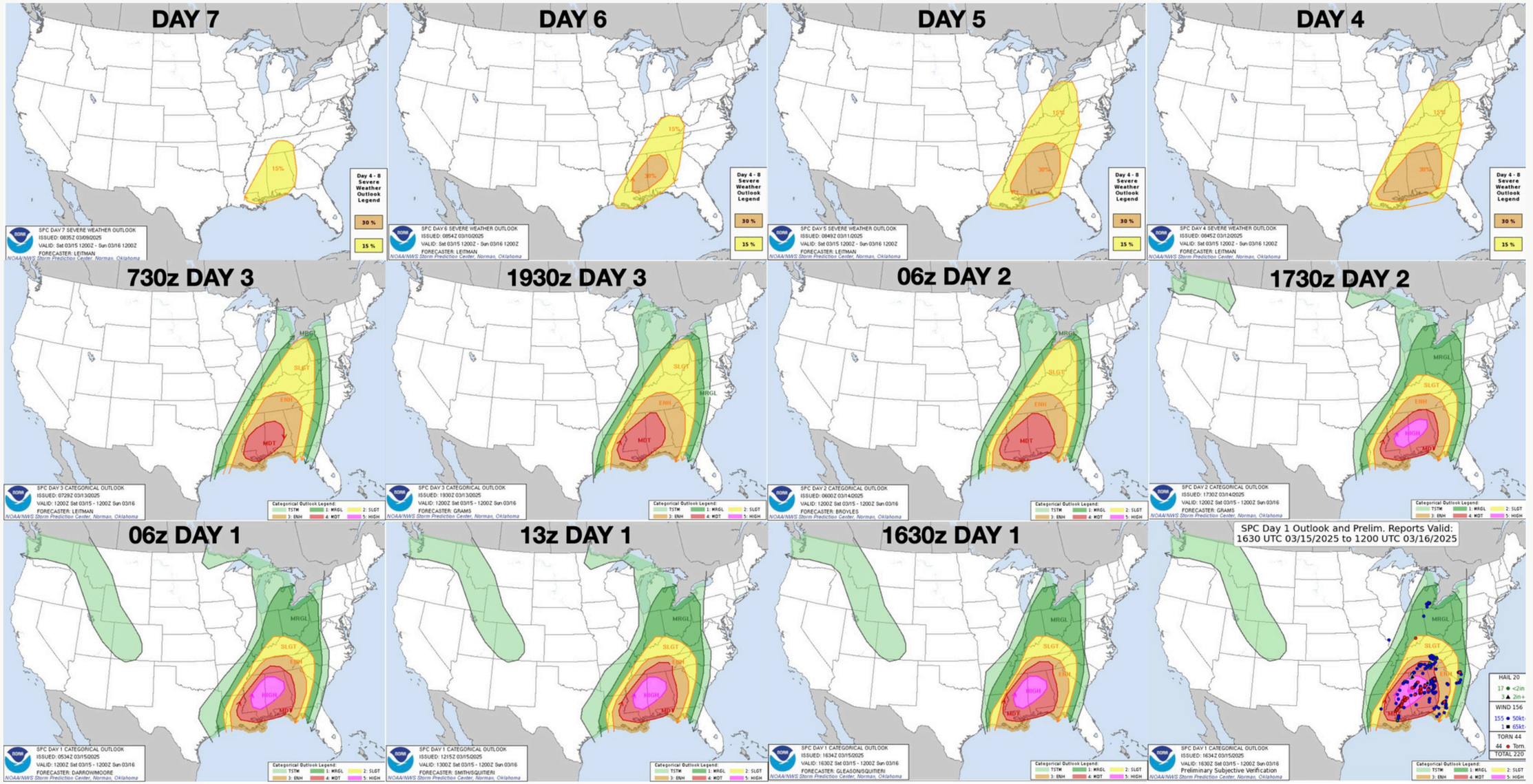
Strengths lie in **earlier** detection and increasing confidence in severe threat across a **broad area.**

Forecasts: Issued 20250310





DAY 1 OUTLOOK



Outlook sequence and preliminary storm reports for March 15, 2025