

The challenges and opportunities of being able to interrogate ensembles of numerical weather prediction models

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Along with: Greg Herman, Kevin Tyle, the Big Weather Web team



ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY

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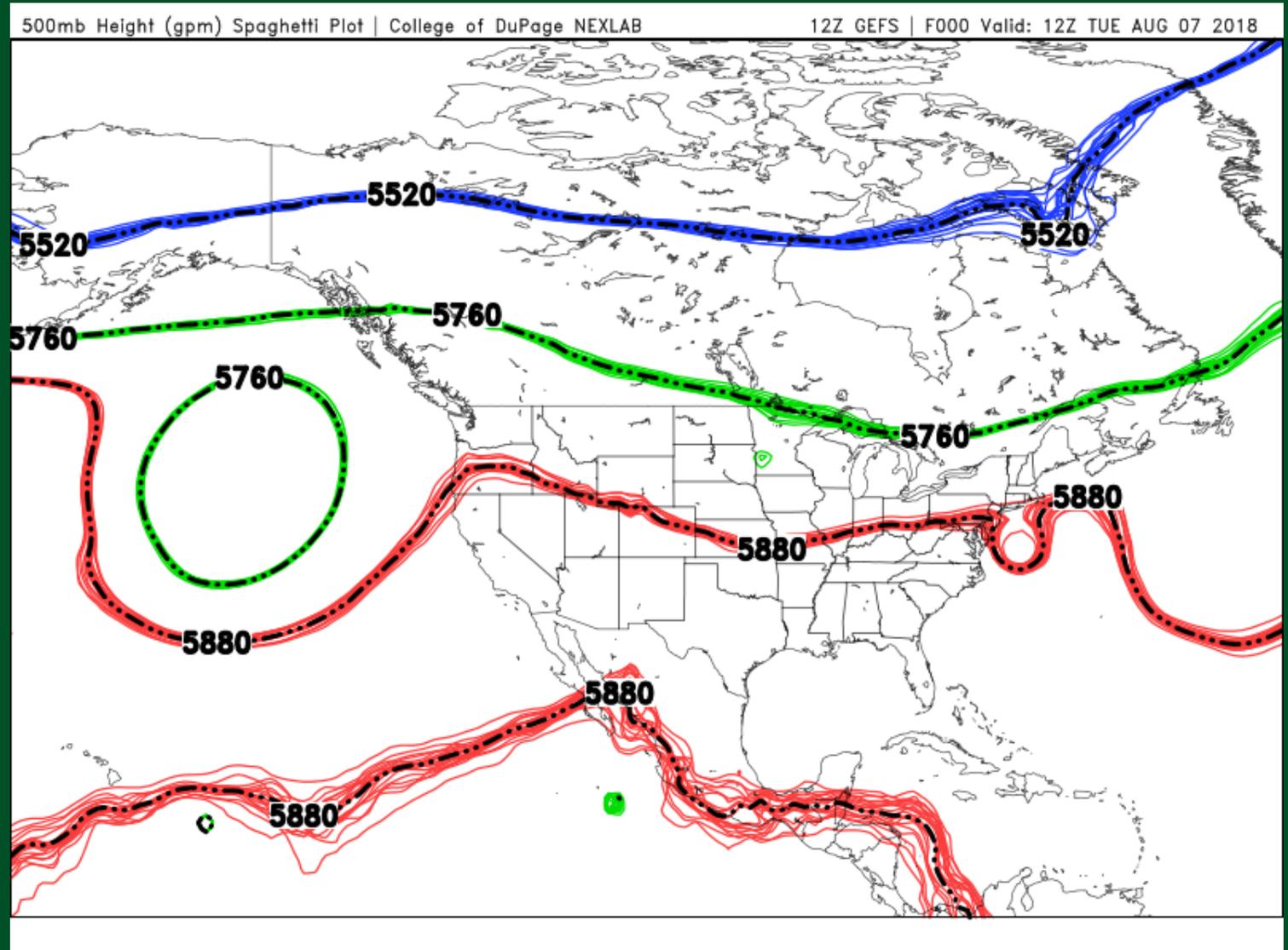
GeoDaRRS Workshop

8 August 2018

Ensemble numerical weather prediction (NWP)

Because there are inherent uncertainties in the initial state of the atmosphere; subgrid-scale processes; etc., “ensembles” of NWP models are run with slightly different initial conditions and/or model configurations

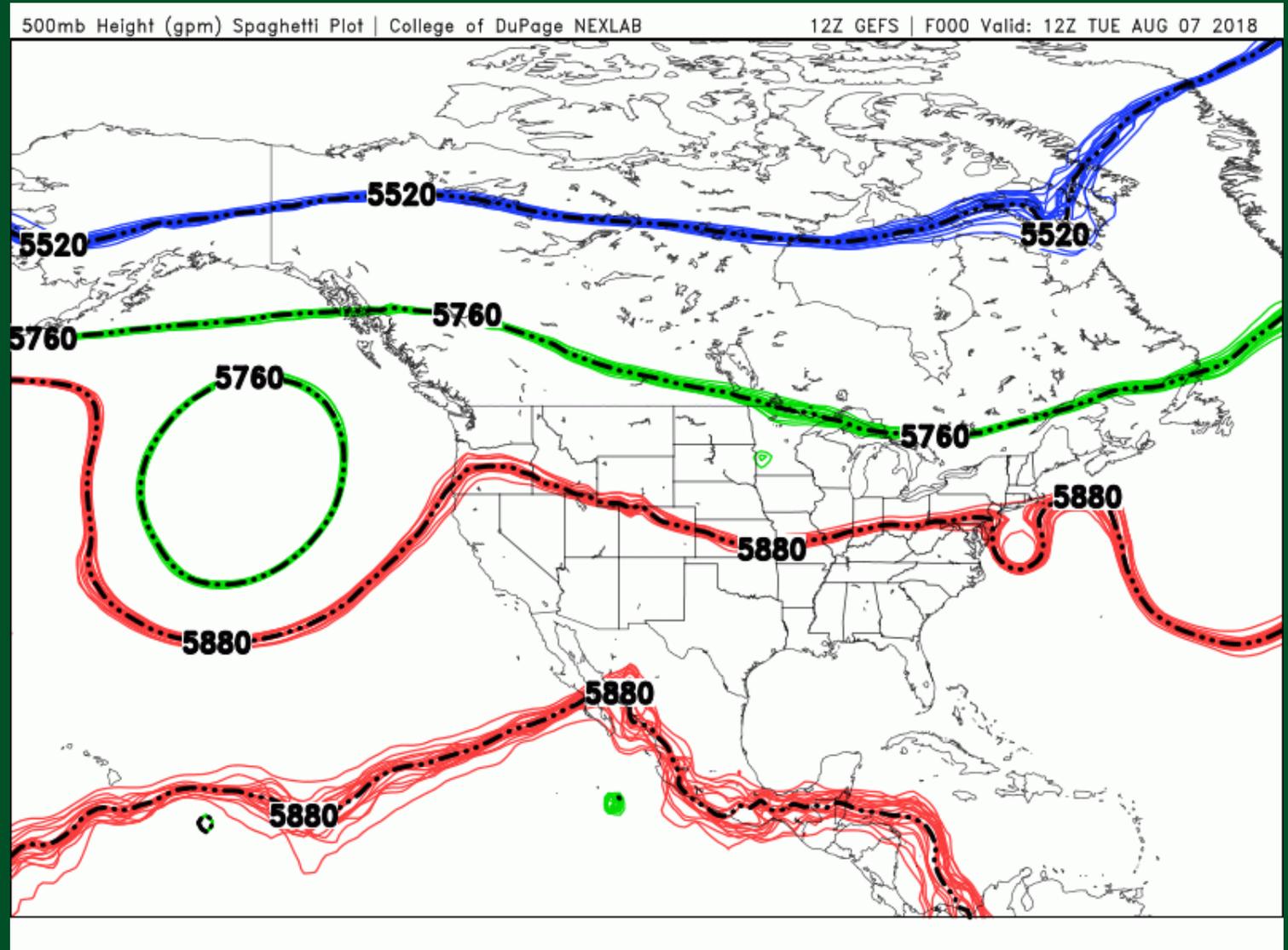
**Classic visualization:
the “spaghetti” plot**



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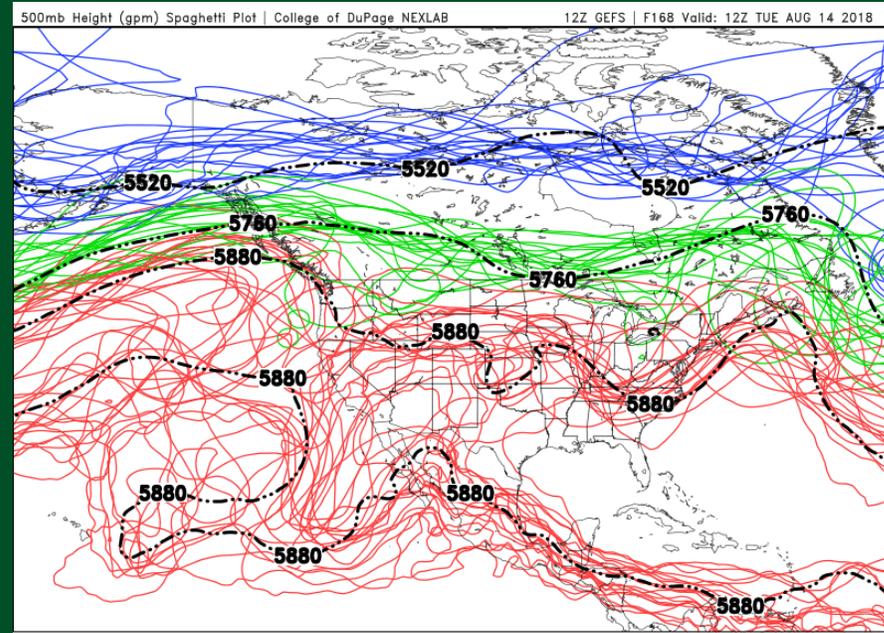
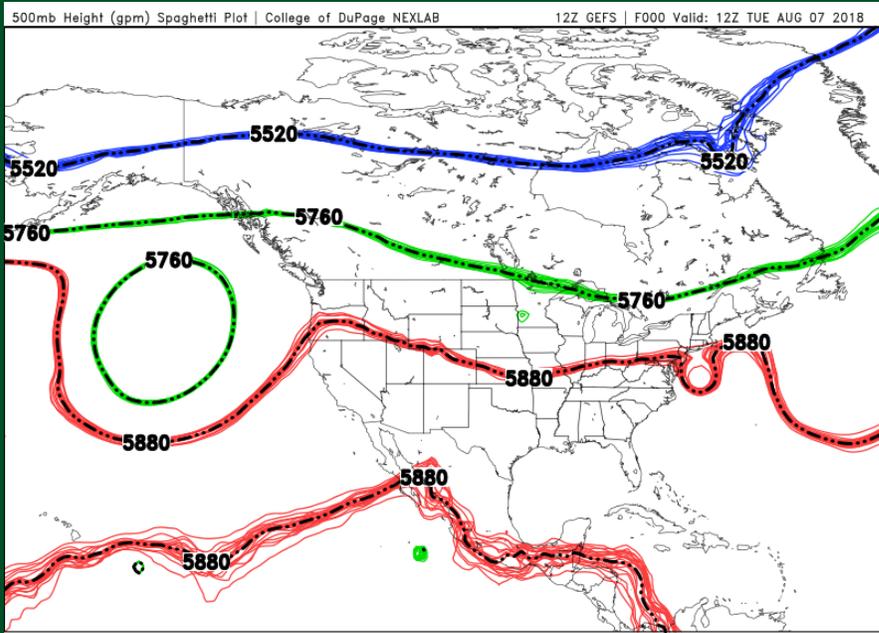
**Classic visualization:
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Ensemble NWP

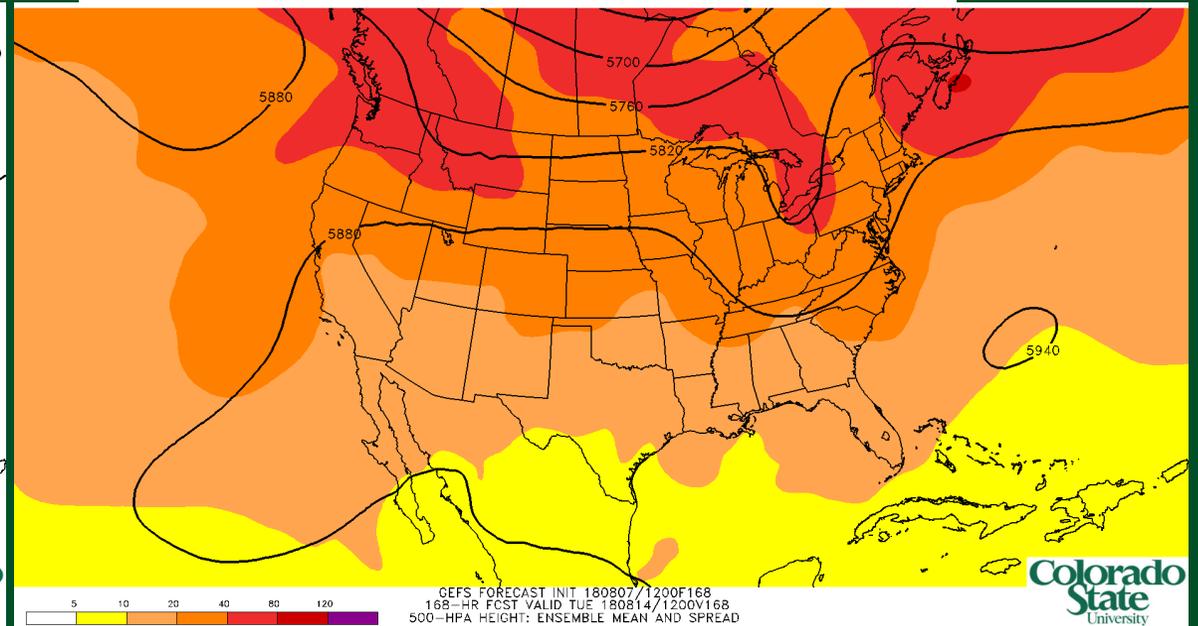
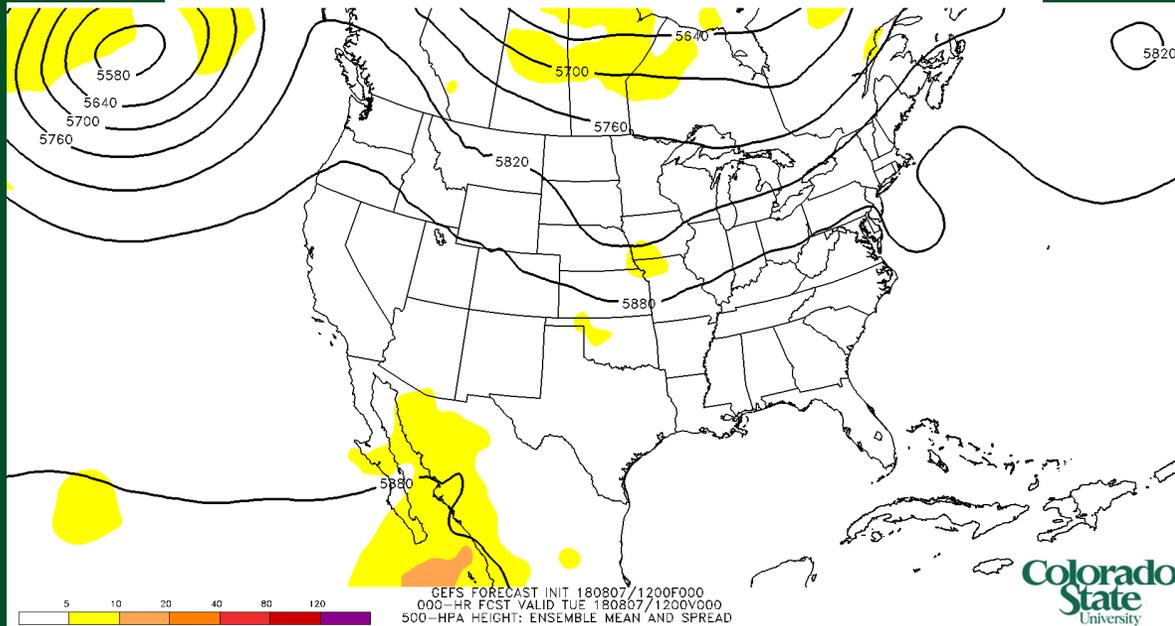
- Ensemble datasets quickly become large:
 - ECMWF ensemble prediction system, currently ‘state of the science’ for global ensembles:
 - Global grid with ~18 km grid spacing, 91 vertical levels, 51 members, tens to hundreds of variables, twice per day
- Regional ensembles at even higher resolution are being run experimentally and operationally
 - Explicit representation of convective storms, etc.

Representations are still often mostly 'static'

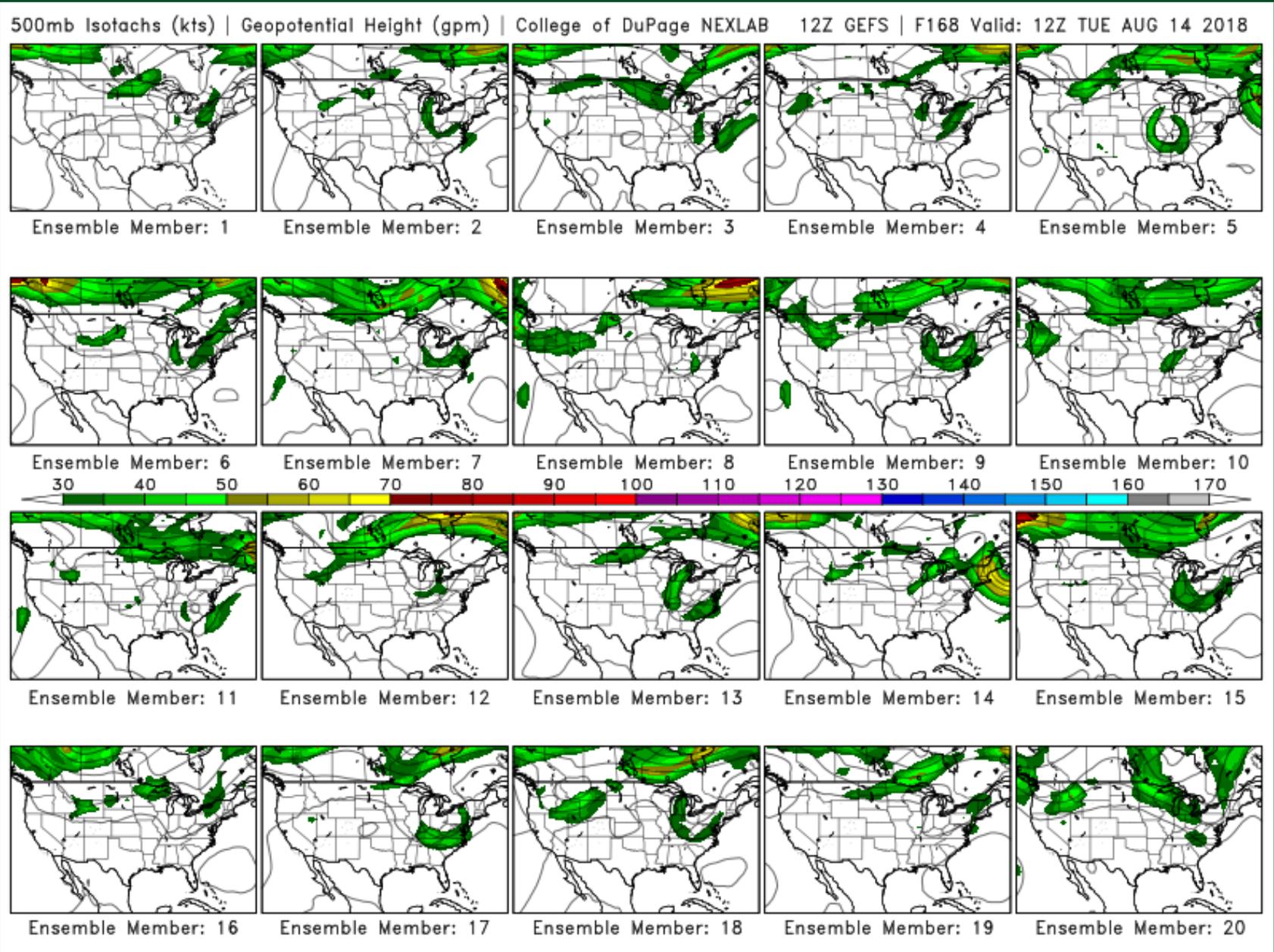


Spaghetti plots

Mean & spread

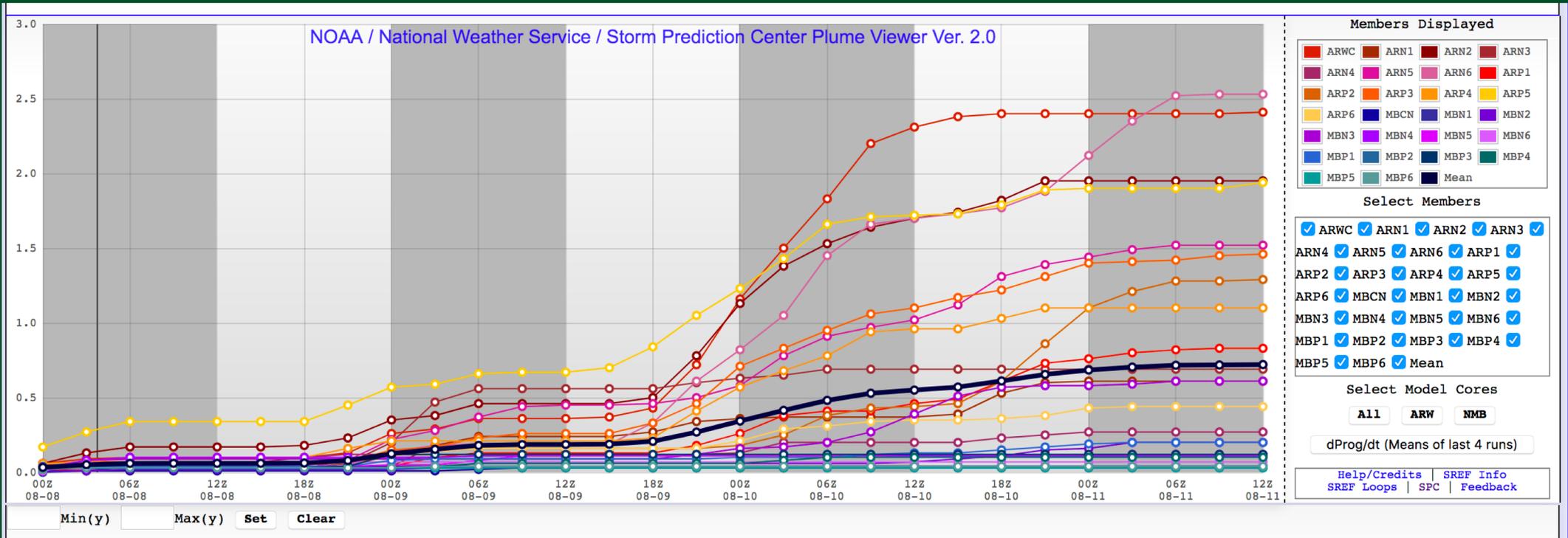


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“Postage stamps”

Interrogation of the ensemble: plume diagrams



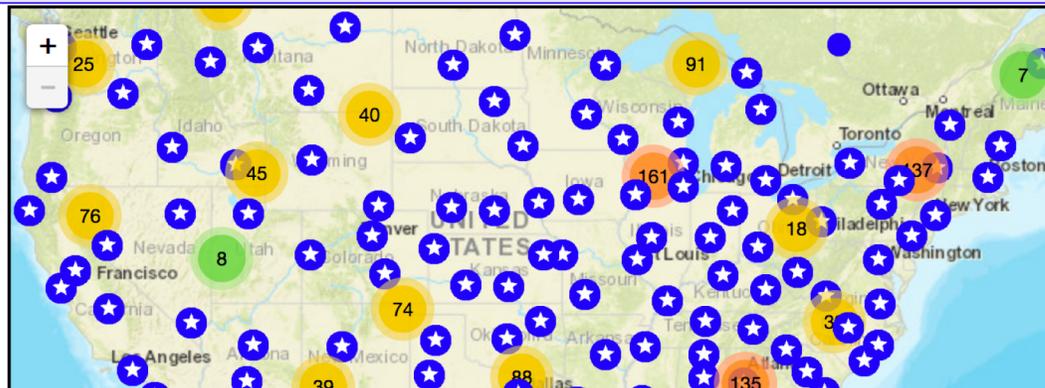
NOAA NWS Storm Pr...
 Liked 286K likes

Storm Prediction Center
 Severe Thunderstorm Watches as of 1:30 pm CDT July 27, 2018
 Severe Thunderstorm Watches 312, 313 and 314 cover much of the Eastern Seaboard from Virginia to Maine this afternoon.

Expected Hazards

- Damaging Gusts to 65 mph
- Large Hail to 1.5 inches

Watches remain in effect until 1:00pm EDT.



Tweets by @NWSSPC

NWS SPC
 @NWSSPC

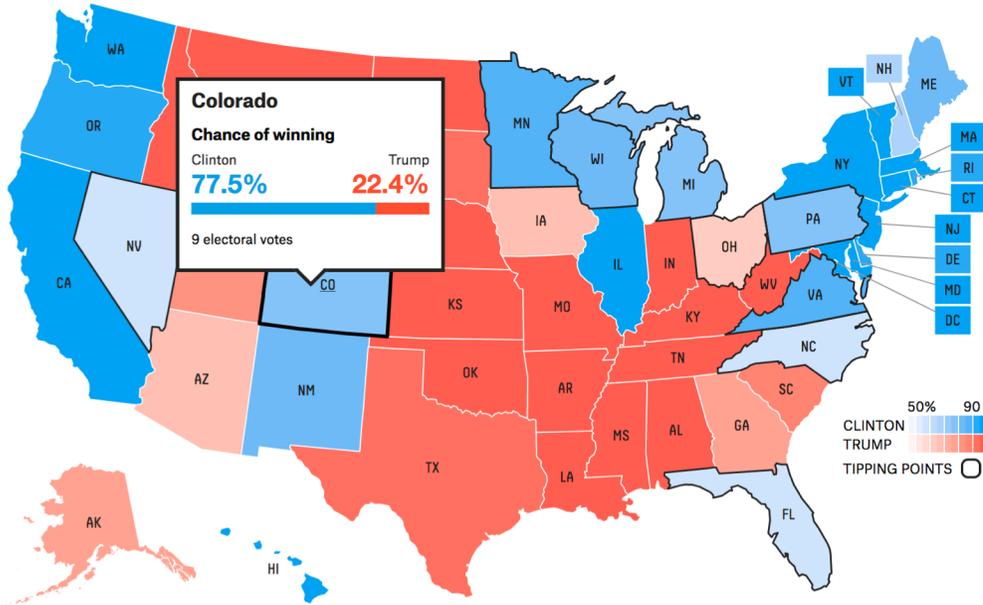
8:59pm CDT #SPC_MD 1260, #kswx #okwx #cowx #txwx #nmwx, go.usa.gov/xUAPu

<https://www.spc.noaa.gov/exper/sref/srefplumes/>

Challenges and opportunities

- It remains challenging (whether in a forecasting or a research setting) to connect patterns and processes identified in maps to probabilities and spread and scenarios
- Need to go from the “plumes” to the “postage stamps” for physical reasoning
- For researchers, there is often sufficient time to dig in to the ensemble output, but there’s still a lot to make sense of
- And in general you need to have the entire ensemble dataset at hand...

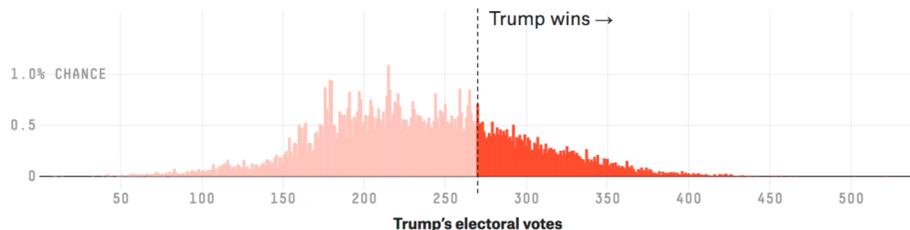
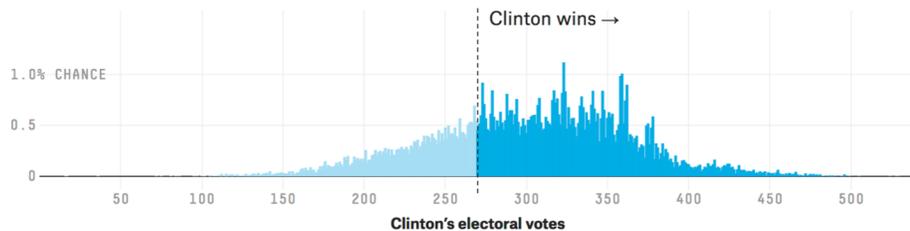
A non-meteorological example



Crazy and not-so-crazy scenarios

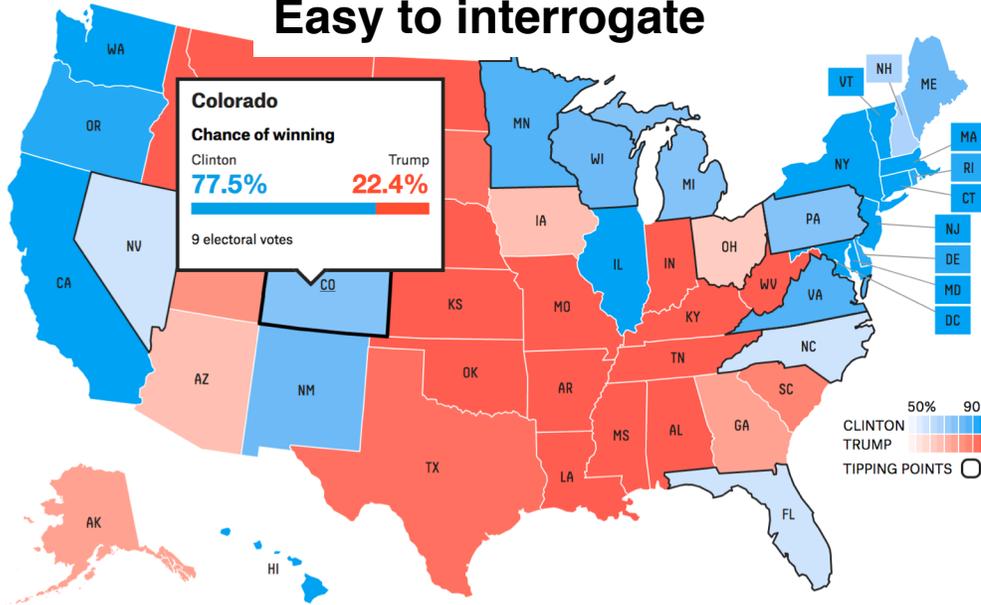
Here are the chances we'll see these election outcomes.

Electoral College deadlock <i>no candidate gets 270 electoral votes</i>	1.0%
Electoral College 269-269 tie	0.5%
Recount <i>at least one decisive state within 0.5 ppt</i>	8.3%
Clinton wins popular vote	81.4%
Trump wins popular vote	18.6%
Clinton wins popular vote but loses Electoral College	10.5%
Trump wins popular vote but loses Electoral College	0.5%
Johnson wins at least one electoral vote	0.3%
McMullin wins at least one electoral vote	13.5%
Clinton majority <i>wins at least 50 percent of the vote</i>	28.7%
Trump majority <i>wins at least 50 percent of the vote</i>	2.3%
Clinton landslide <i>double-digit popular vote margin</i>	6.1%
Trump landslide <i>double-digit popular vote margin</i>	0.3%
Map exactly the same as in 2012	0.2%
Clinton wins at least one state Mitt Romney won in 2012	71.6%
Trump wins at least one state President Obama won in 2012	85.0%



A non-meteorological example

Easy to interrogate

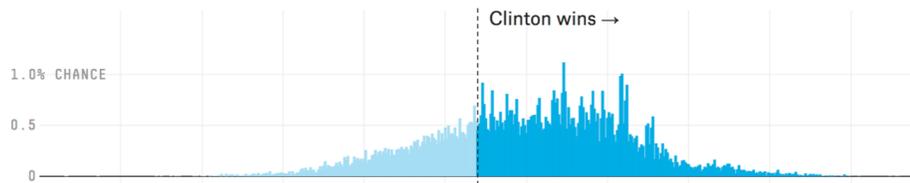


Scenarios people might be interested in

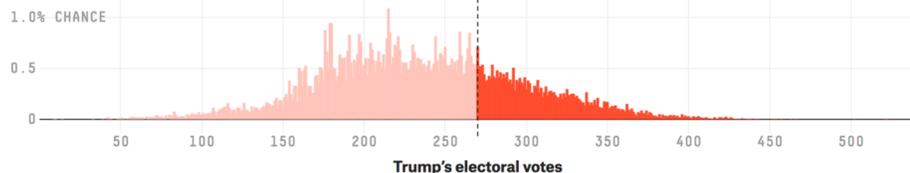
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Clear presentation of distribution of possible outcomes



NCAR ensemble (2015-2017)

ensemble.ucar.edu

NCAR Ensemble Forecasts

Initialized: 00 UTC Tue 16 May 2017

Surface / Precip

Upper-Air

Severe

Winter

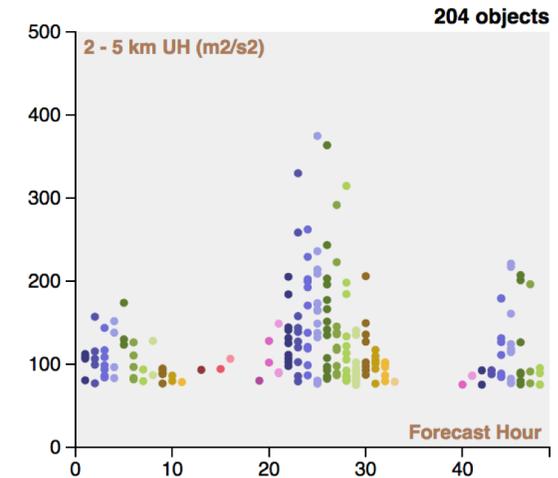
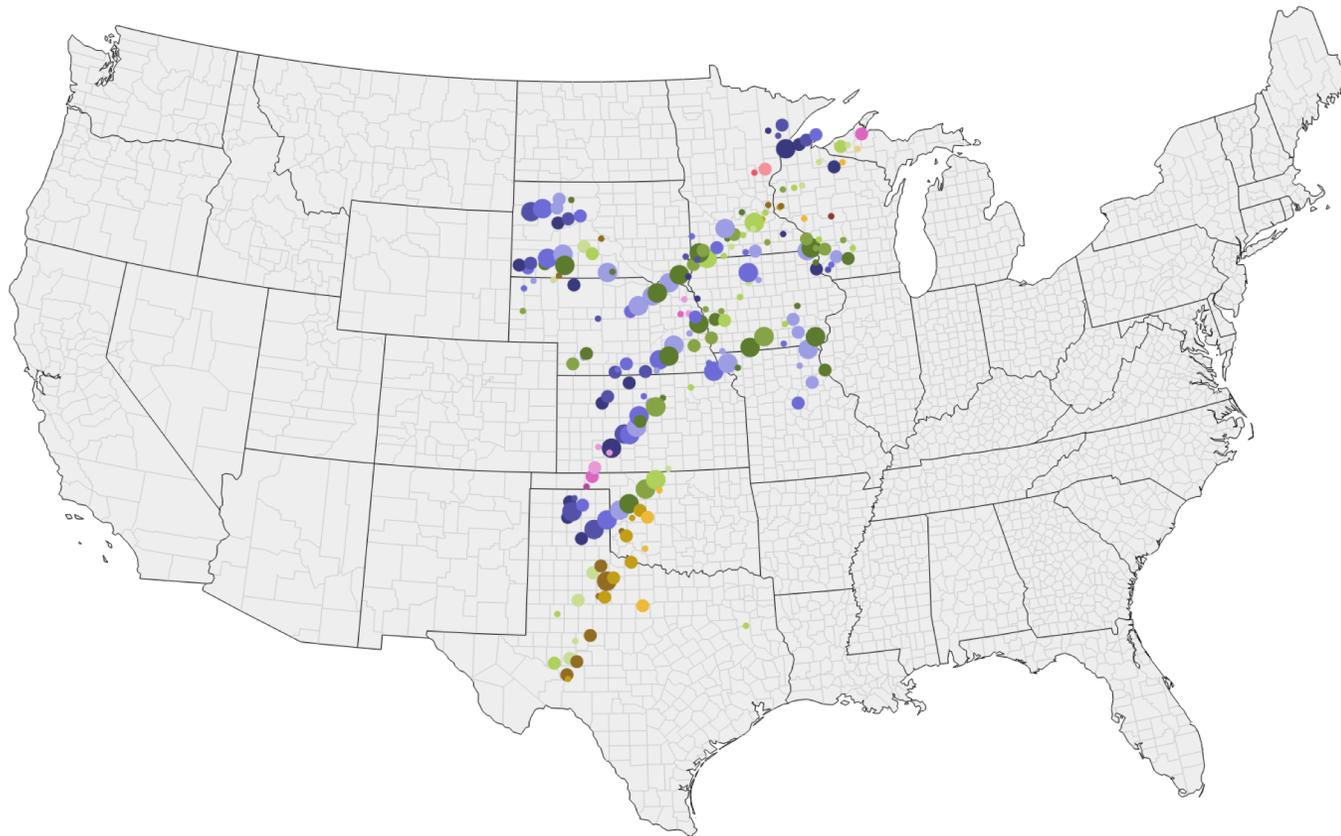
Hourly-Max

Domains

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

- Mem 1
- Mem 2
- Mem 3
- Mem 4
- Mem 5
- Mem 6
- Mem 7
- Mem 8
- Mem 9
- Mem 10

Drag, zoom, and hover to interrogate storms



Scatterplot Fields --- select x-axis

- | | |
|--------------------------|---------------|
| 2 - 5km Updraft Helicity | SBCAPE |
| 0 - 3km Updraft Helicity | SBCIN |
| Col. Int Graupel | 0 - 6km Shear |
| Max 10-m Wind Speed | 0 - 1km Shear |
| Max Updraft | SBCL Height |
| Max Downdraft | 0 - 3km SRH |
| Thomp. Hail | 1km Vorticity |
| Forecast Hour | Member |

Storm Filters Show All Storms

- | | | |
|---------------|---------------|-------------------|
| UH >= 75 | UH >= 150 | WSPD >= 50kts |
| HAIL >= 1" | HAIL >= 2" | RVORT >= 0.013s-1 |
| Tracks >= 3hr | Tracks >= 6hr | |
| FHR 0-12 | FHR 12-36 | FHR 36-48 |

Color Filters Reset

- | | | |
|---------------|----------|--------|
| Forecast Hour | Duration | Member |
|---------------|----------|--------|

The “Big Weather Web”



- Effort to develop new methods for sharing ensemble NWP output across universities, improving reproducibility, and incorporating ensembles into education
- We ran a 47-member ensemble across 7 different universities
 - 20-km grid spacing over the US

bigweatherweb.org

Principal Investigators:

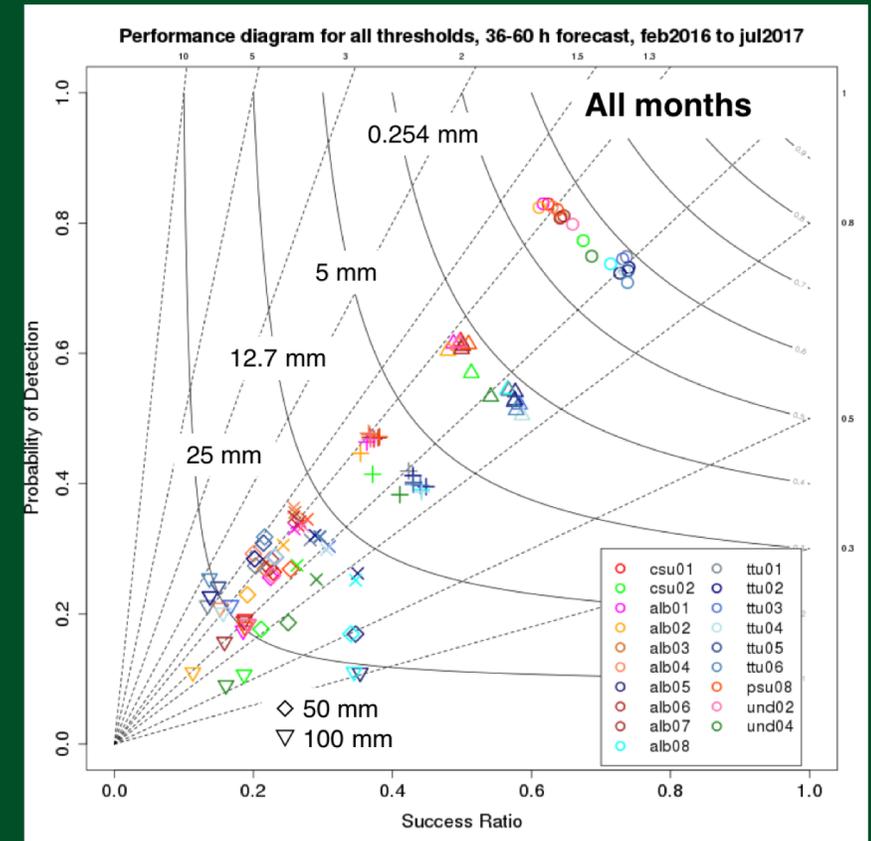
-  [Carlos Maltzahn](#) (lead)
-  [Mohan Ramamurty](#)
-  [Gretchen Mullendore](#)
-  [Brian Ancell](#)
-  [William Capehart](#)
-  [Clark Evans](#)
-  [Robert Fovell](#)
-  [Steven Greybush](#)
-  [Russ Schumacher](#)

Senior Personnel:

-  [Joshua Hacker](#)
-  [John Exby](#)
-  [Kate Fossell](#)
-  [Kevin Tyle](#)

The “Big Weather Web”

- What to do with the ensemble output originating from the different universities?
- We tried several possible solutions, but settled on the NSF Jetstream cloud
 - Allowed for automated collection of the model output, storage, and analysis
 - Dockerized versions of model and analysis code can be put on the cloud as well
- Dataset can be used for numerous research and education applications,
 - One we’ve explored is identifying biases in different model configurations

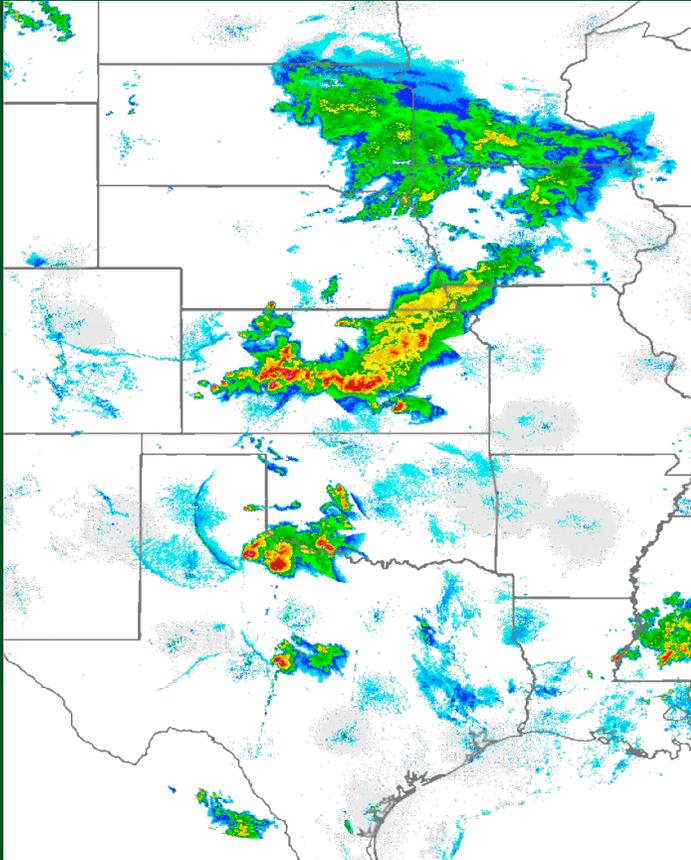


What is needed?

- Methods for interrogating ensemble output in spatial, temporal, and ensemble dimensions
 - Preferably all in the same framework
 - Ideally, without having the entire ensemble dataset stored locally
 - Both interactive interrogation and high-quality visualizations
- Many groups have made important accomplishments in this direction, but they tend to be supported for grant-length time periods rather than being long-term sustainable efforts

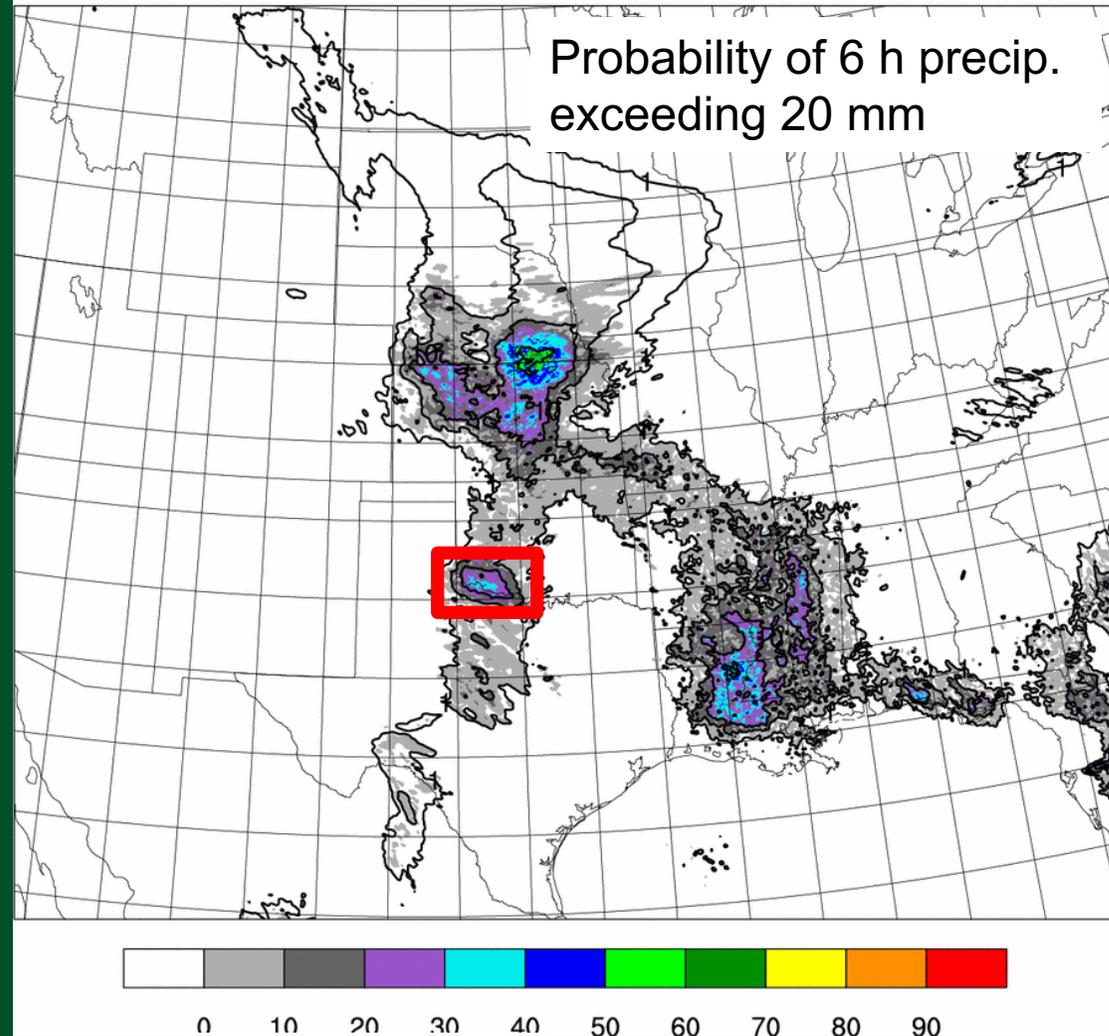
Sensitivity analysis in convection-allowing ensembles

Forecast Initialized
0000 UTC 30 May 2012



Observed reflectivity on 0000
UTC 31 May 2012

F027 Precipitation valid 2012053103

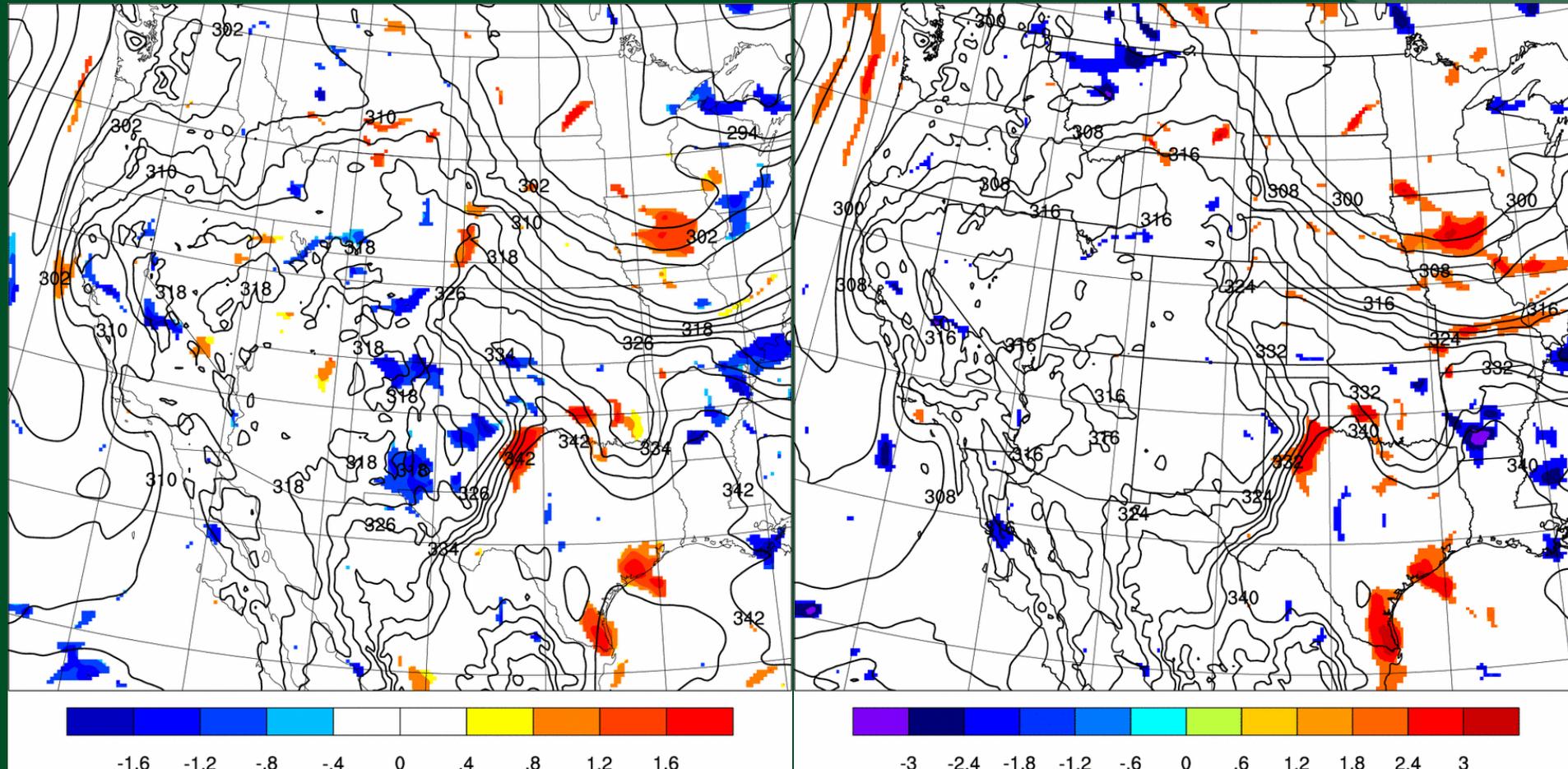


(Ryan Torn et al.)

Sensitivity Example

Difference Between High/Low Precip. Fcst

Sensitivity to 12 h forecast



12 h forecast of theta-e at 1 km AGL

(Ryan Torn et al.)