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

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GeoDaRRS Workshop

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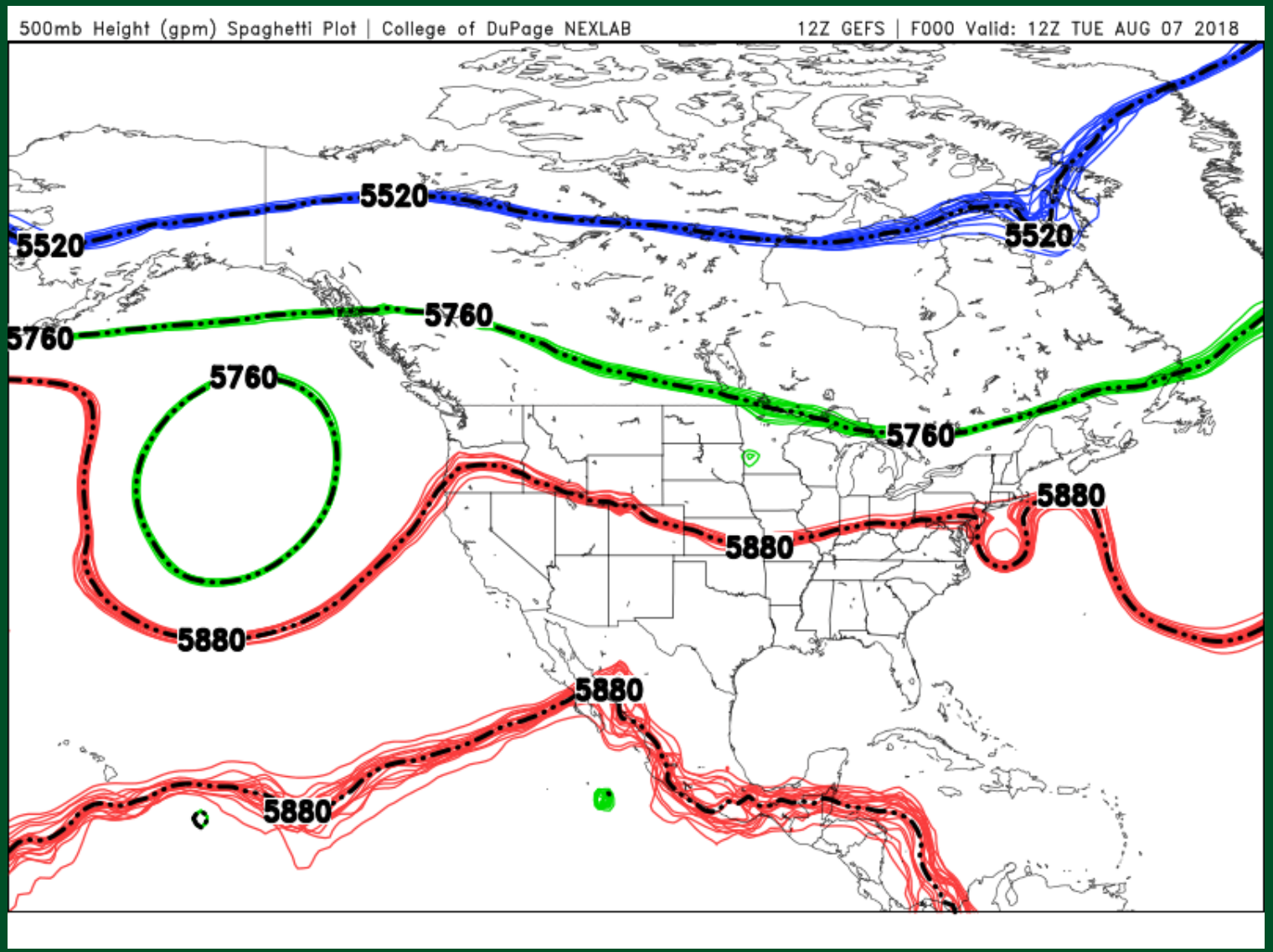
Ensemble numerical weather prediction (NWP)

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



From weather.cod.edu/forecast

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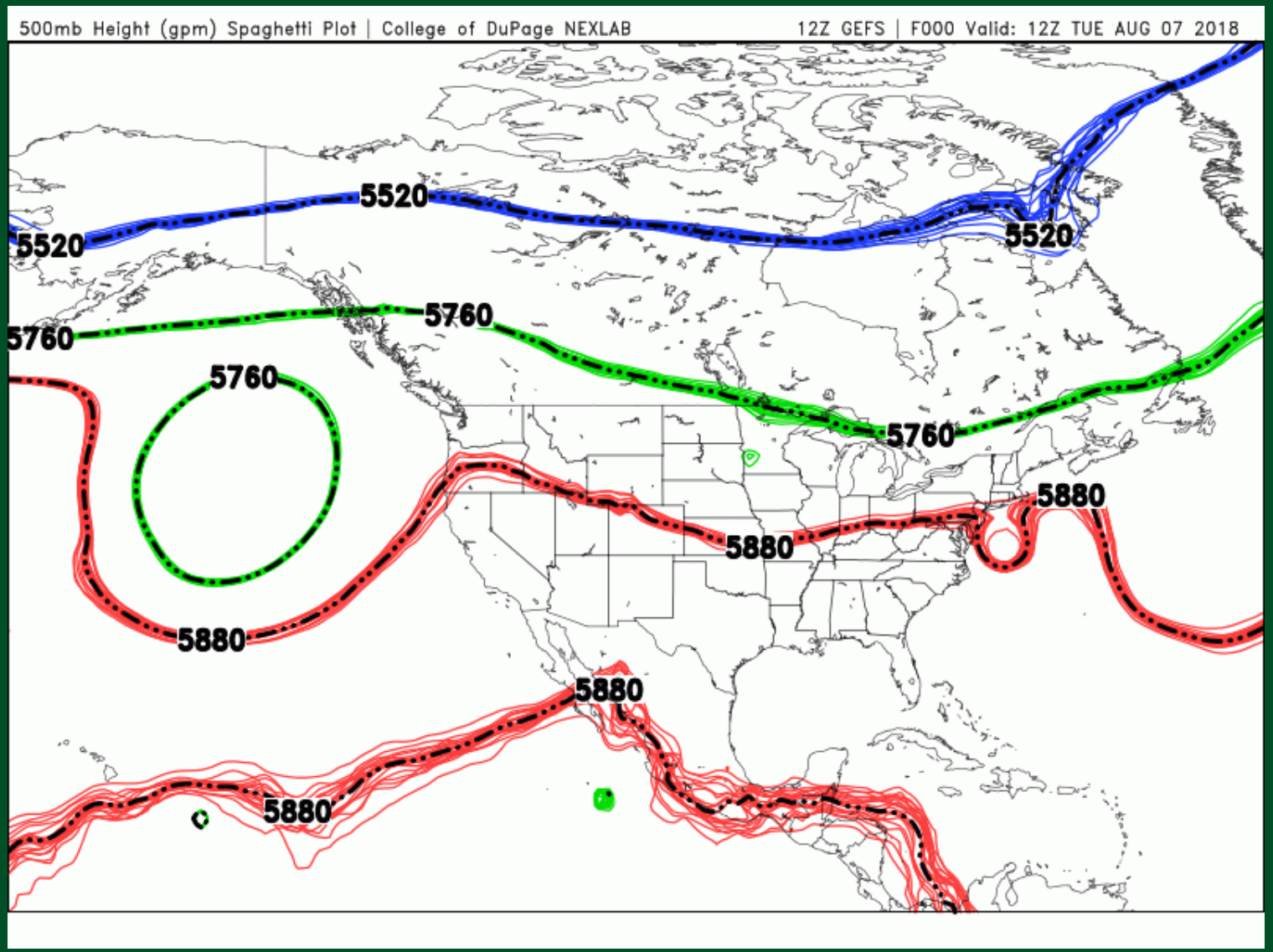

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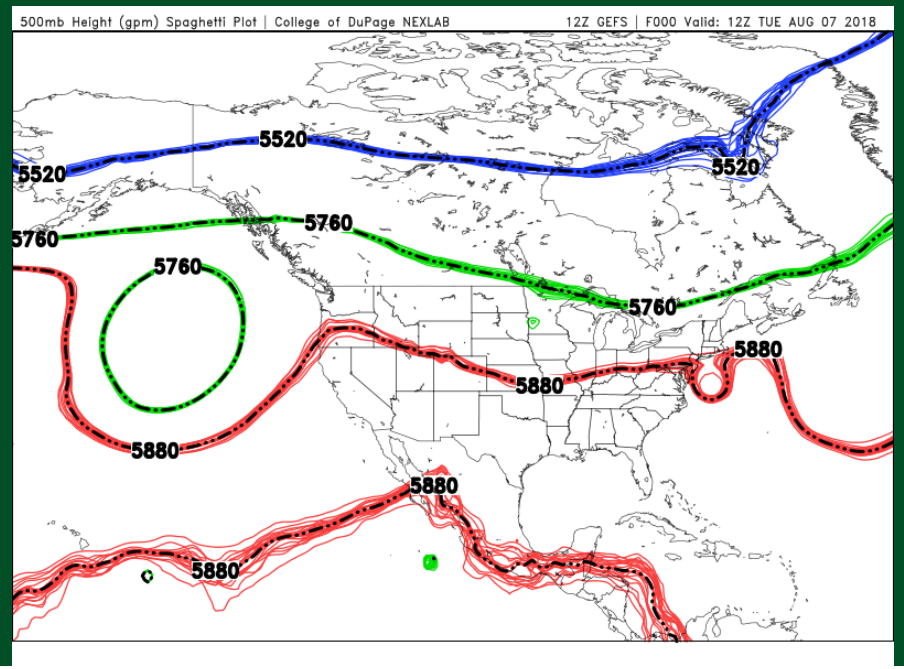
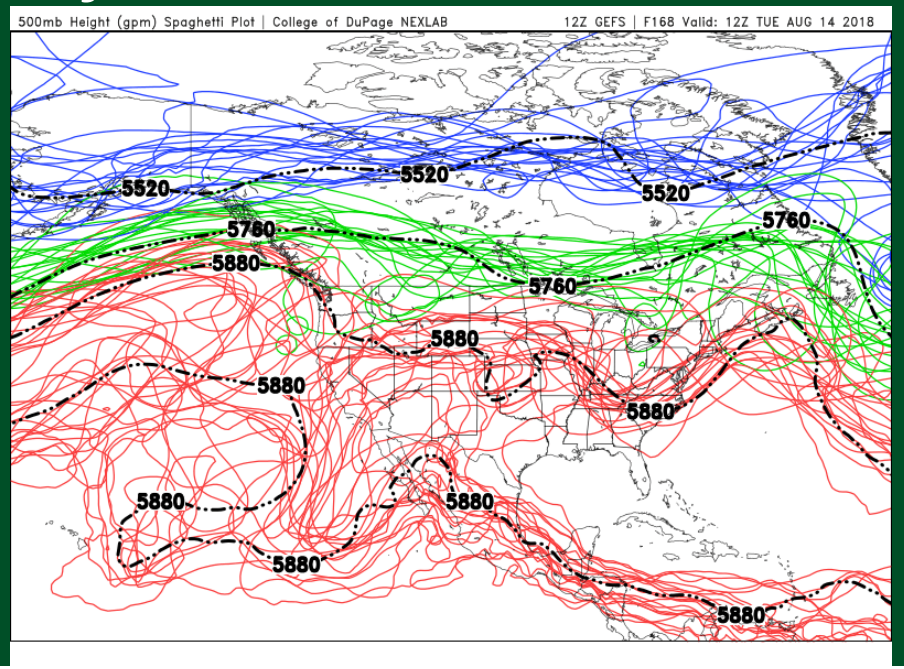
Ensemble NWP

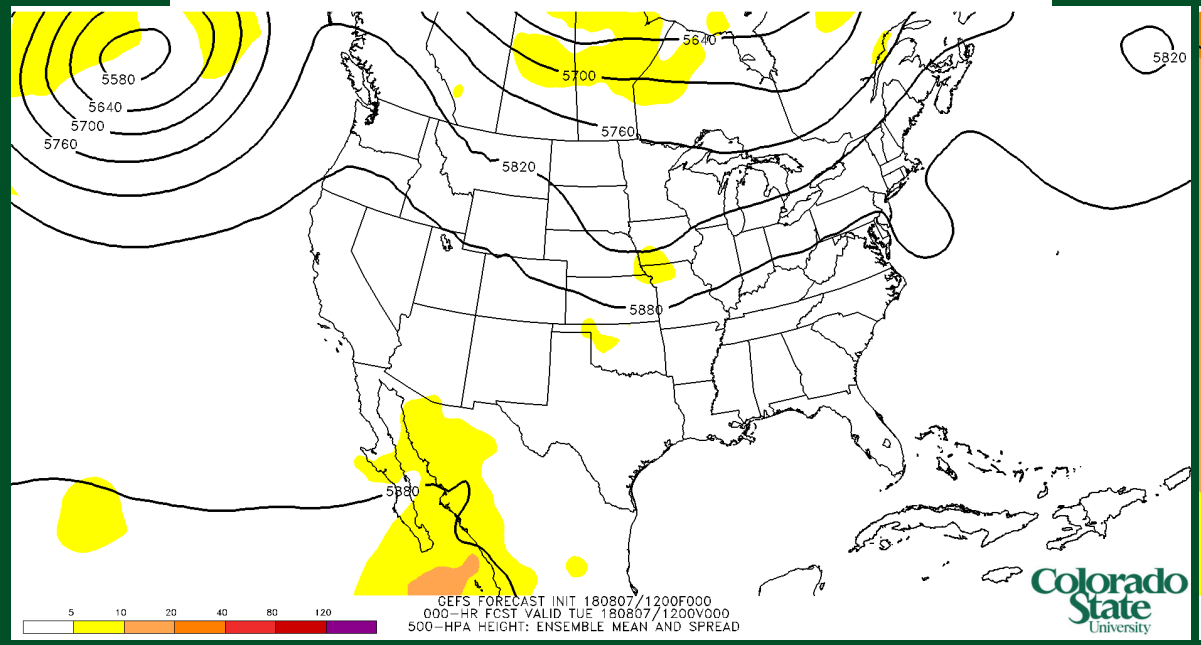
- Ensemble datasets quickly become large:
  - ECMWF ensemble prediction system, currently ‘state of the science’ for global ensembles:
  - Global grid with ~18 km grid spacing, 91 vertical levels, 51 members, tens to hundreds of variables, twice per day
- Regional ensembles at even higher resolution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

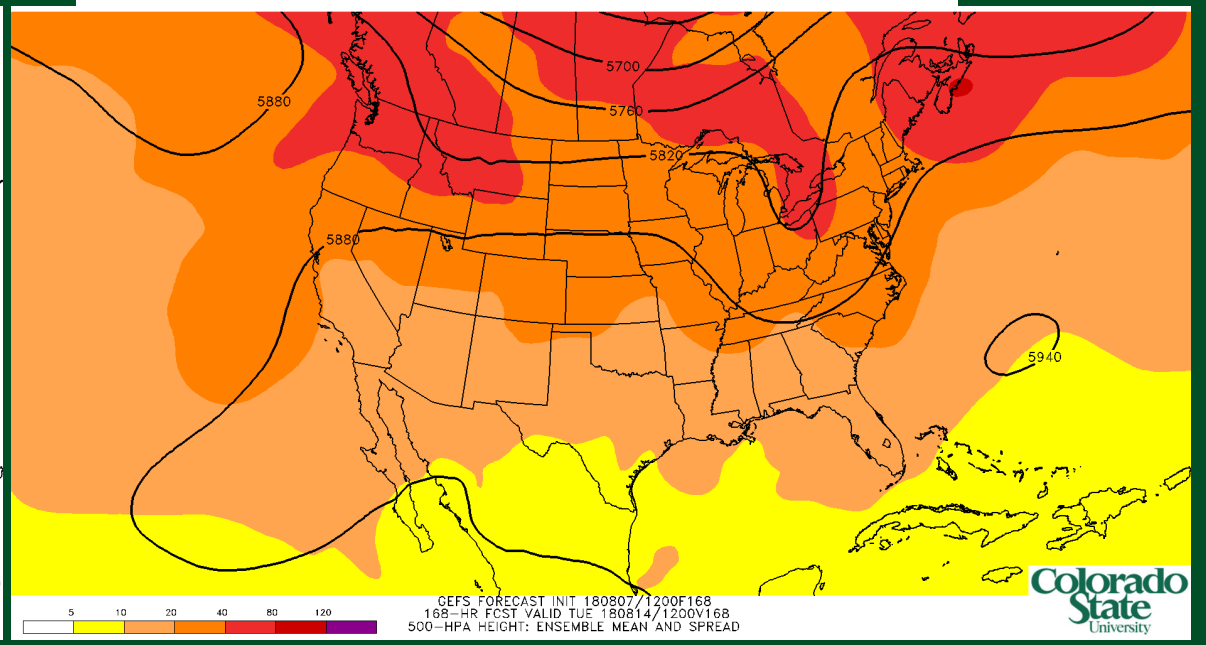
Representations are still often mostly ‘static’





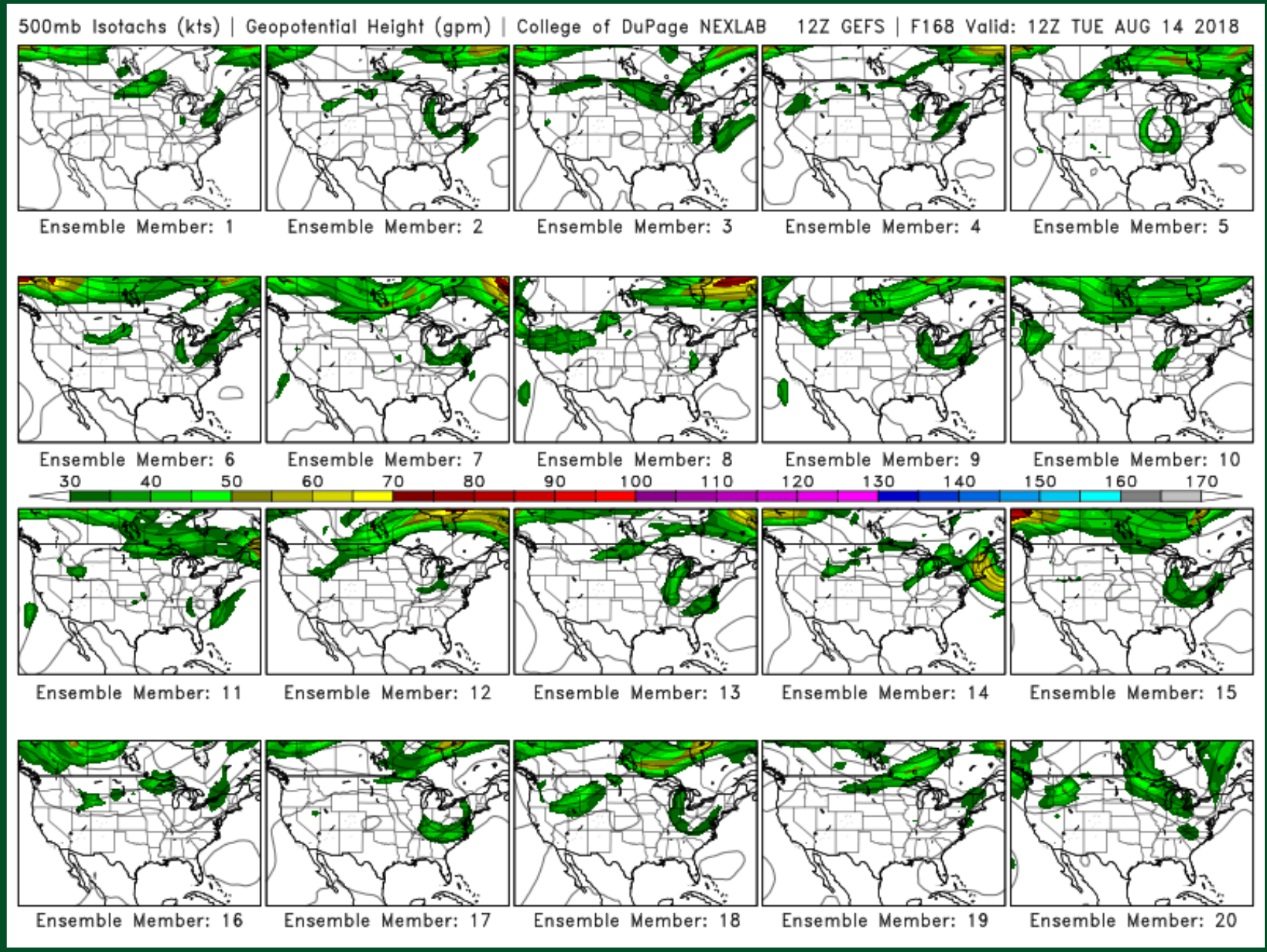
Spaghetti plots





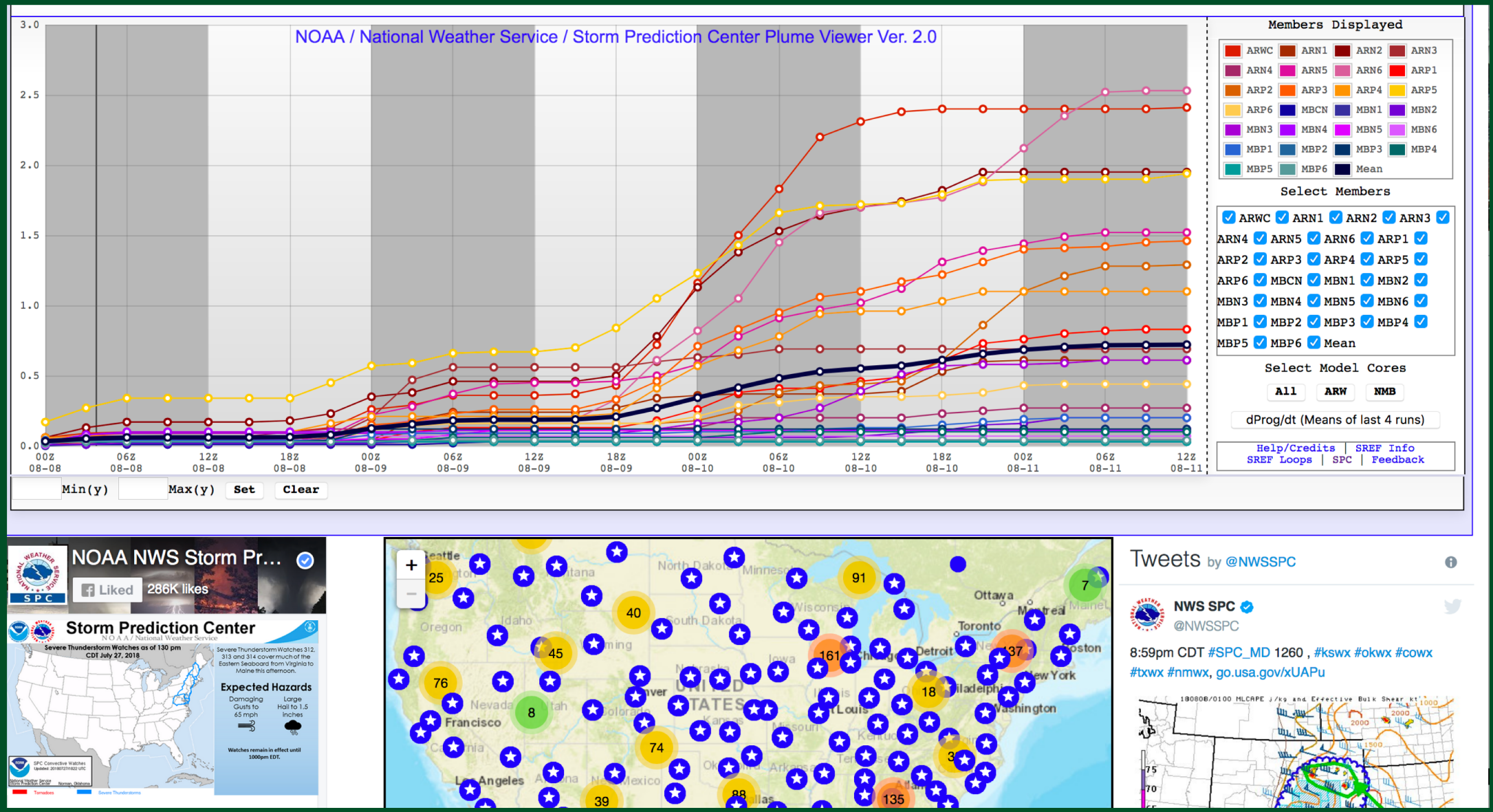
Mean & spread

Representations are still often mostly ‘static’



“Postage stamps”

Interrogation of the ensemble: plume diagrams

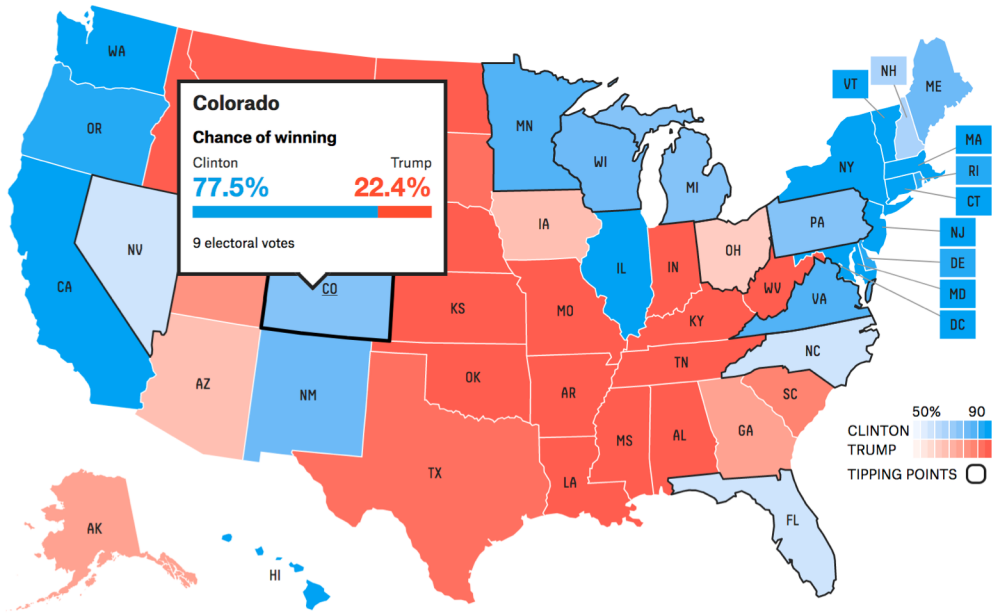


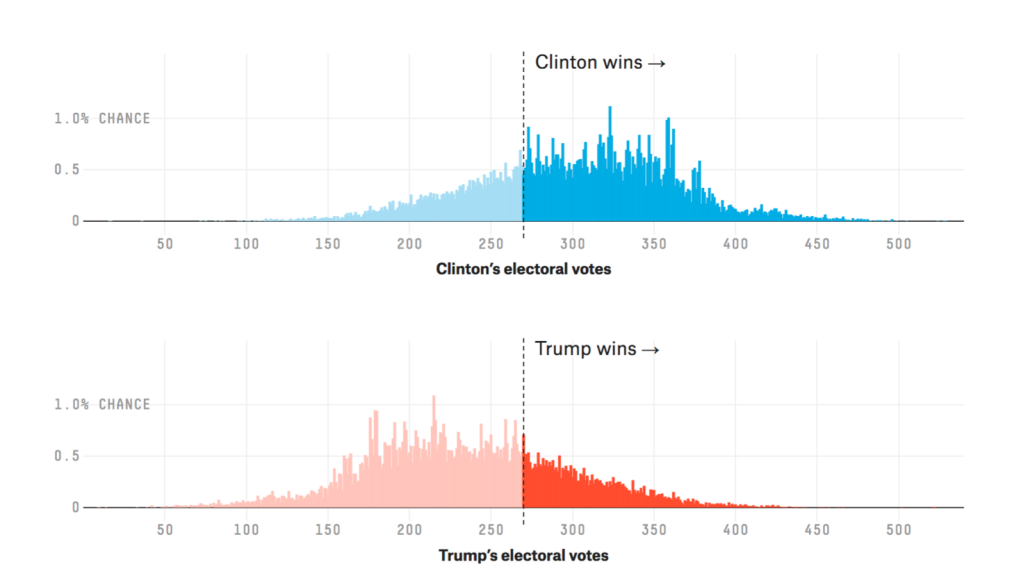
https://www.spc.noaa.gov/exper/sref/srefplumes/

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

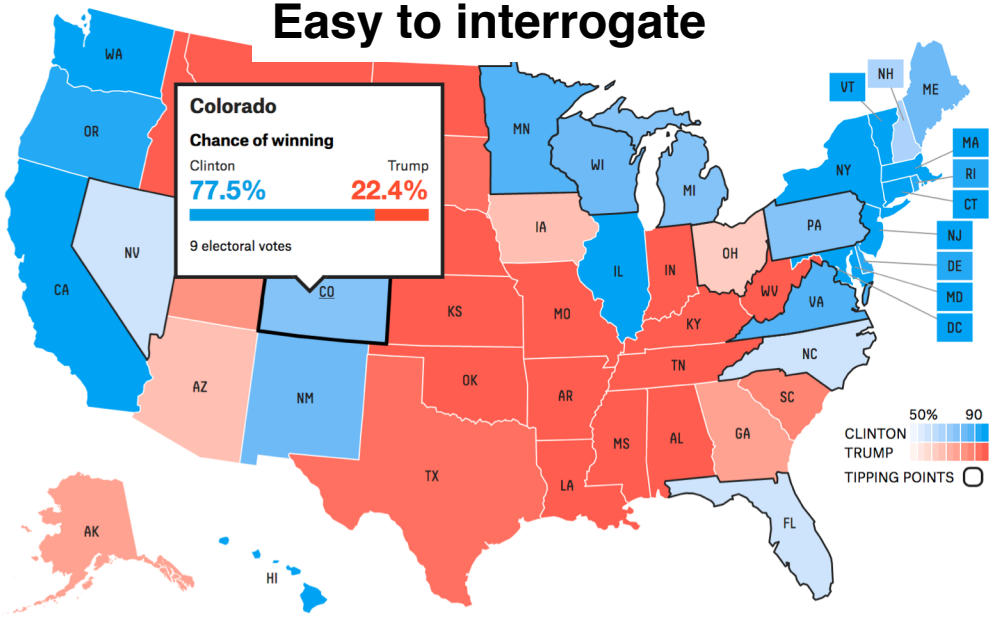
Here are the chances we'll see these election outcomes.

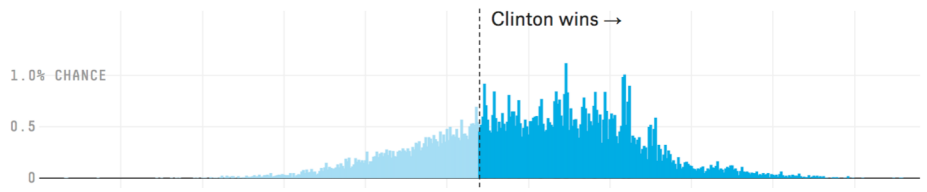
Electoral College deadlock no candidate gets 270 electoral votes	1.0%
Electoral College 269-269 tie	0.5%
Recount at least one decisive state within 0.5 ppt	8.3%
Clinton wins popular vote	81.4%
Trump wins popular vote	18.6%
Clinton wins popular vote but loses Electoral College	10.5%
Trump wins popular 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 wins at least 50 percent of the vote	28.7%
Trump majority wins at least 50 percent of the vote	2.3%
Clinton landslide double-digit popular vote margin	6.1%
Trump landslide double-digit popular vote margin	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%

fivethirtyeight.com

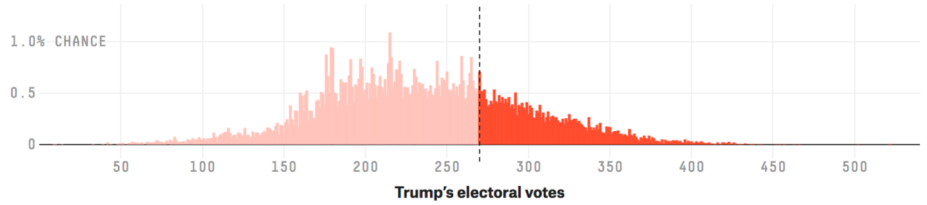
A non-meteorological example

Easy to interrogate





Clear presentation of distribution of possible outcomes



Scenarios people might be interested in

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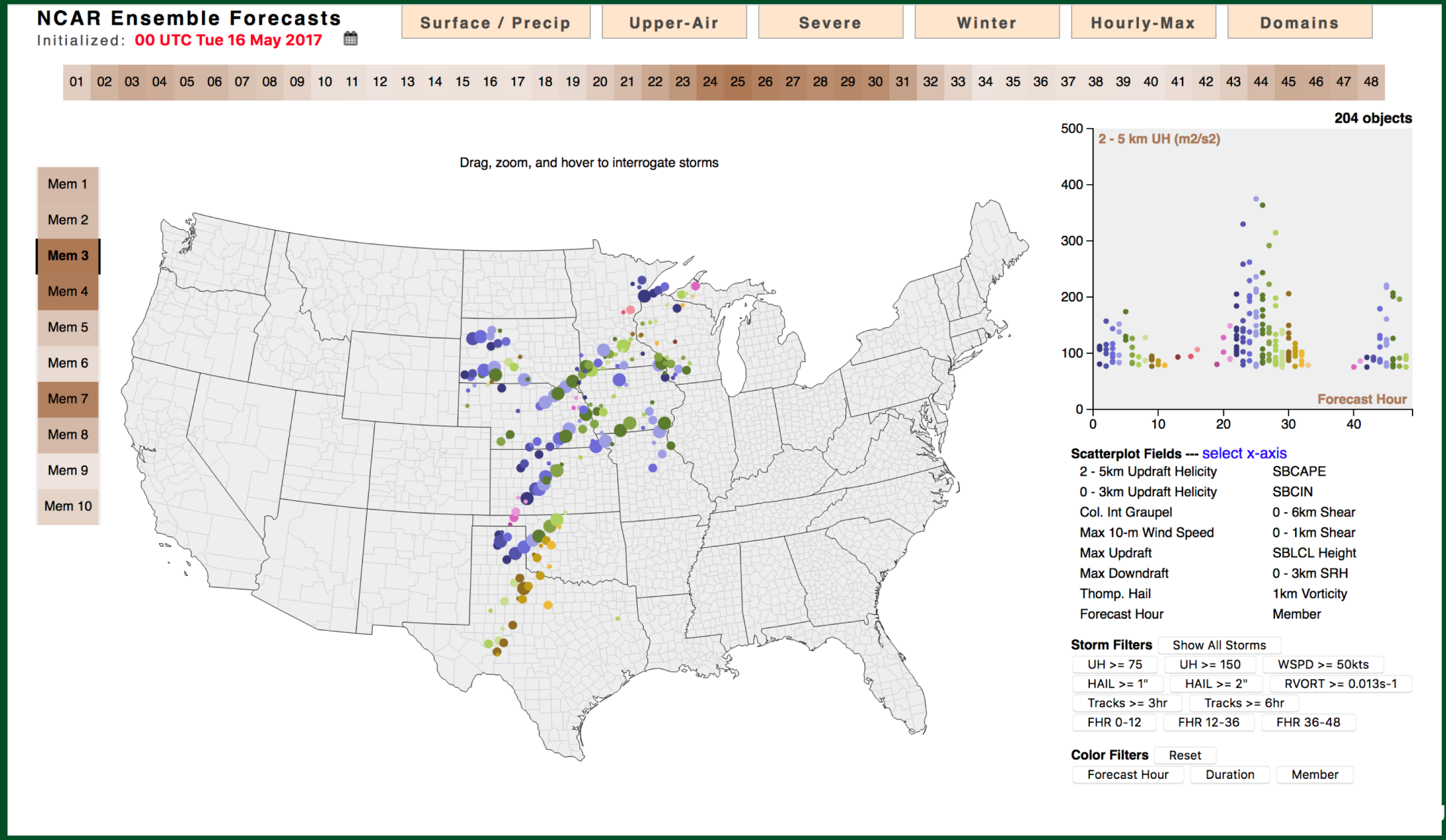
NCAR ensemble (2015-2017)

ensemble.ucar.edu



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

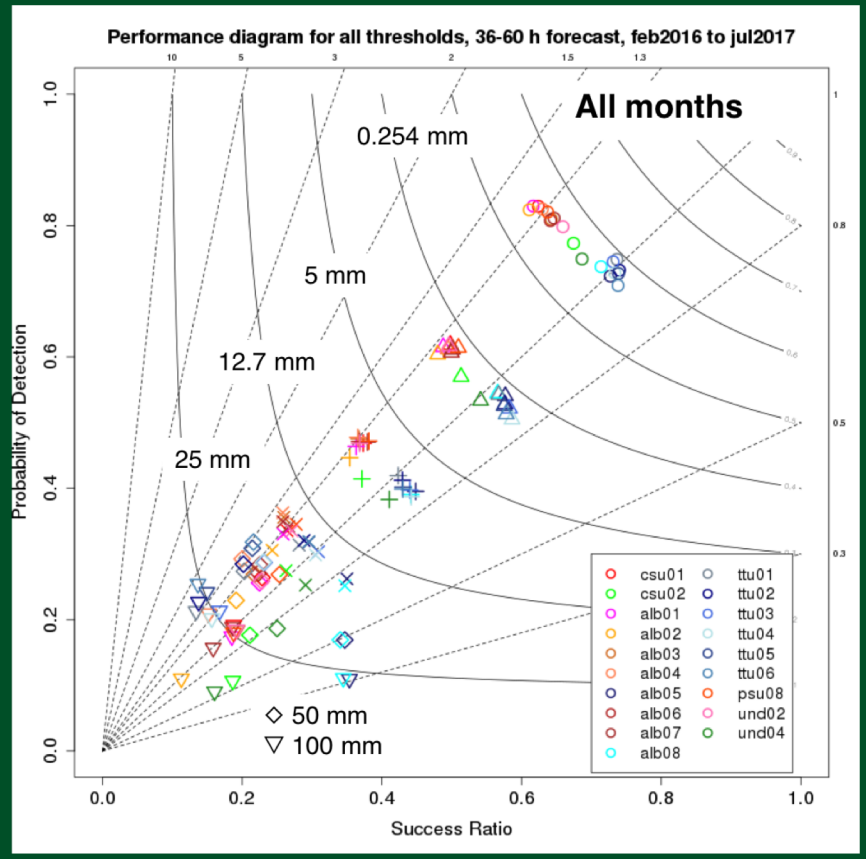
John Exby

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

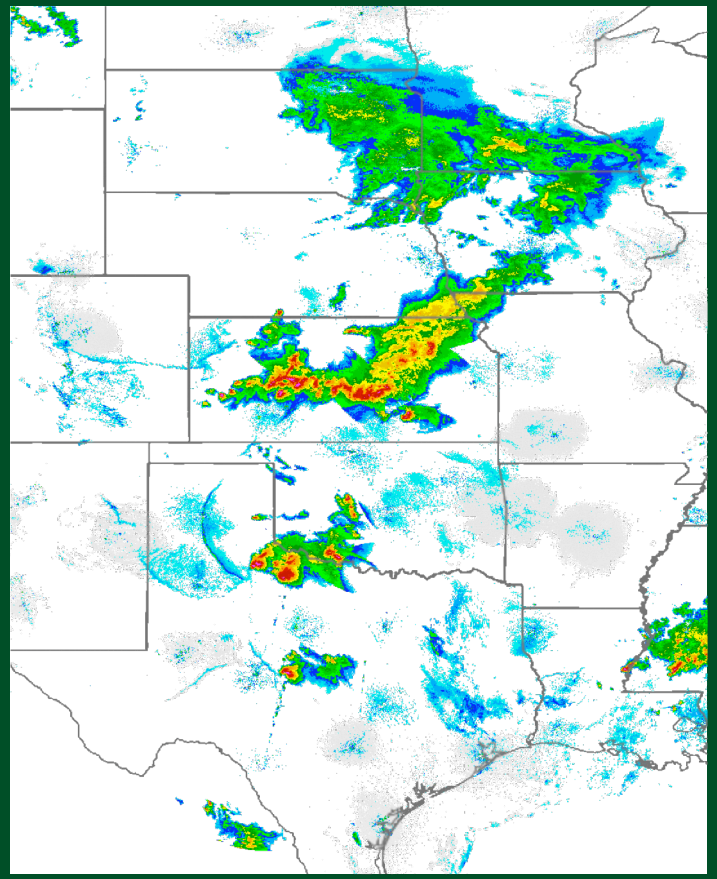


What is needed?

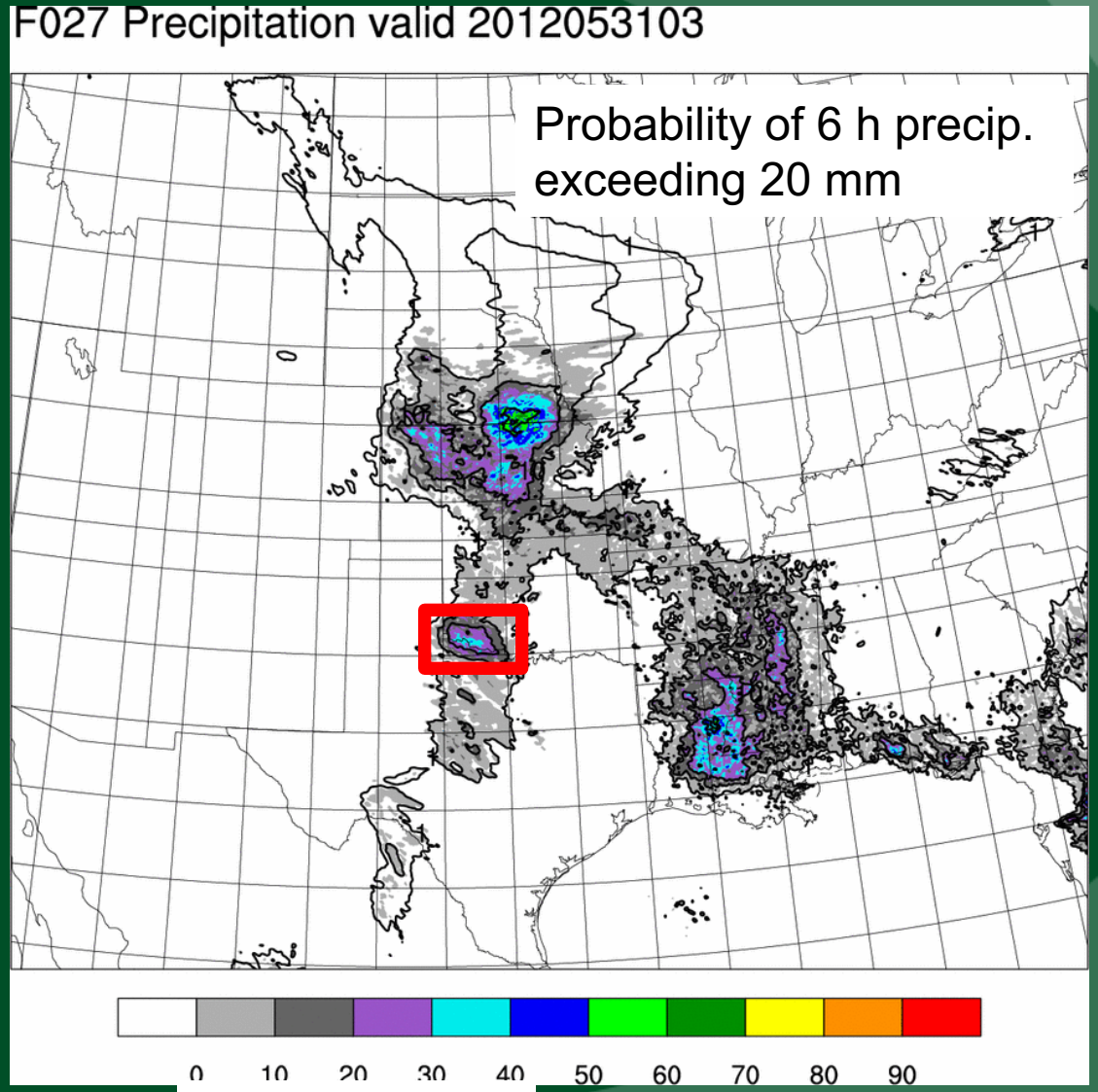
- Methods for interrogating ensemble output in spatial, temporal, and ensemble dimensions
  - Preferably all in the same framework
  - Ideally, without having the entire ensemble dataset stored locally
  - Both interactive interrogation and high-quality visualizations
- Many groups have made important 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

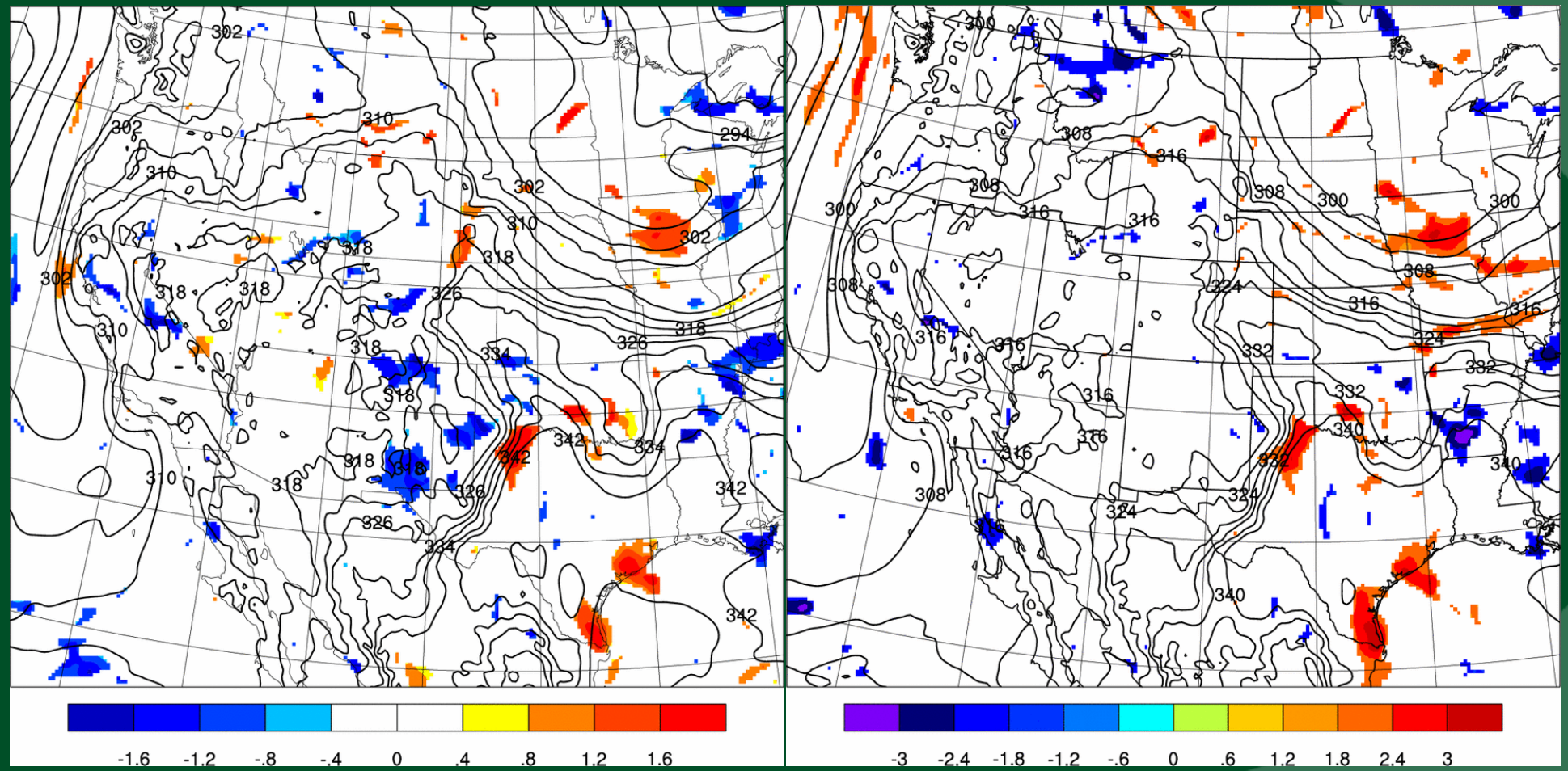


(Ryan Torn et al.)

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.)