Enabling and enhancing the use of ensemble numerical weather prediction in university education

Russ S. Schumacher

Department of Atmospheric Science, Colorado State University

With contributions from Nick Bassill, Brian Colle, Ryan Torn, Kevin Tyle

Research supported by NSF grant AGS-1157425

Workshop on Shaping the Development of EarthCube to Enable Advances in Data Assimilation and Ensemble Prediction
Boulder, CO
17 December 2012

Purpose

- To offer some perspectives from an early-career faculty member on how ensembles are used in university education
- To provide examples of innovative ongoing efforts in ensemble NWP at universities, and suggest how EarthCube might advance those efforts
- To discuss some of the opportunities and challenges associated with the vision for a distributed multi-university ensemble system for research and education

"The potential advantages of data assimilation science cannot be attained because currently there is a serious scarcity of young professionals and scientists with understanding and experience in data assimilation. There are examples of existing data assimilation education efforts at several universities…although these courses are good, they do not reach out to the wider pool of future professionals at the B.S., M.S., and Ph.D. levels required to support demands of the research and operational institutions for expertise in data assimilation."

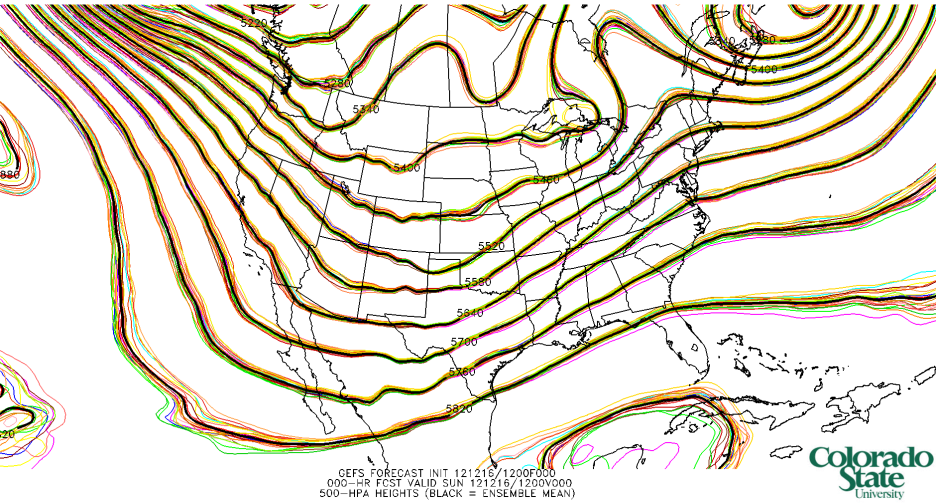
-- Vukicevic, Kalnay and Vonder Haar (2004, *BAMS*), "The Need for a National Data Assimilation Education Program"

How are students exposed to ensemble NWP and data assimilation?

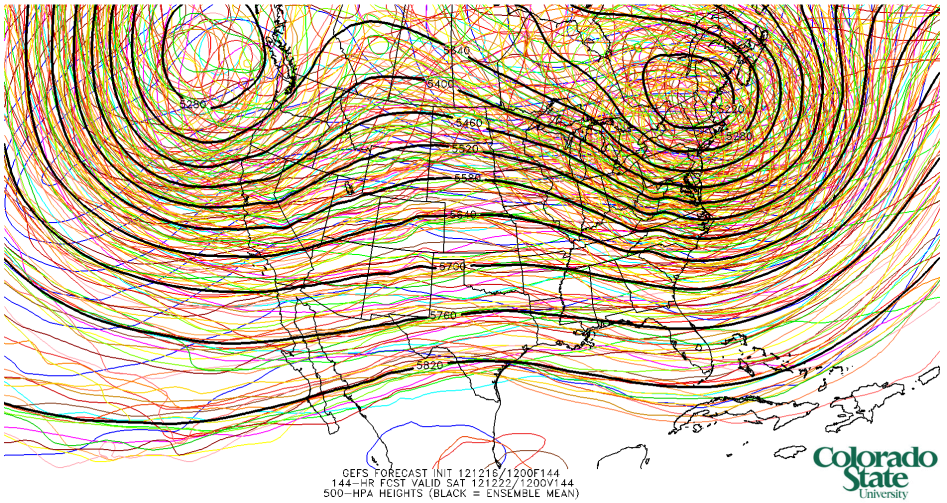
- At the undergraduate level:
  - At most universities, perhaps one formal course in NWP
  - Through weather discussions either explicitly or implicitly associated with formal courses in synoptic and mesoscale meteorology, etc.
  - Forecasting exercises like WxChallenge
  - Little exposure to data assimilation
- At the graduate level:
  - Opportunities for extensive education exist at the universities with specific expertise in these areas (i.e., working on ensemble NWP/DA for thesis research)
  - However, the broader cohort of atmospheric science graduate students may get little to no exposure to these topics

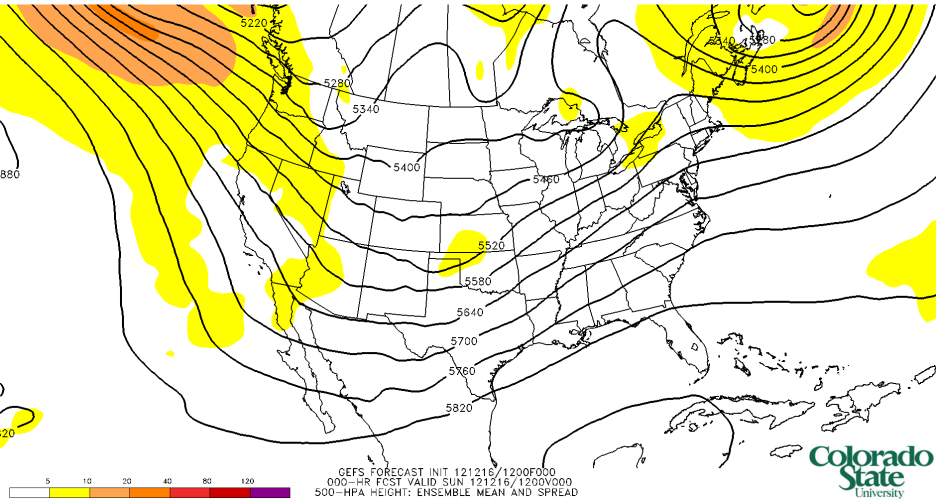
Classic illustrations of an ensemble forecast: “spaghetti” diagram and mean/spread

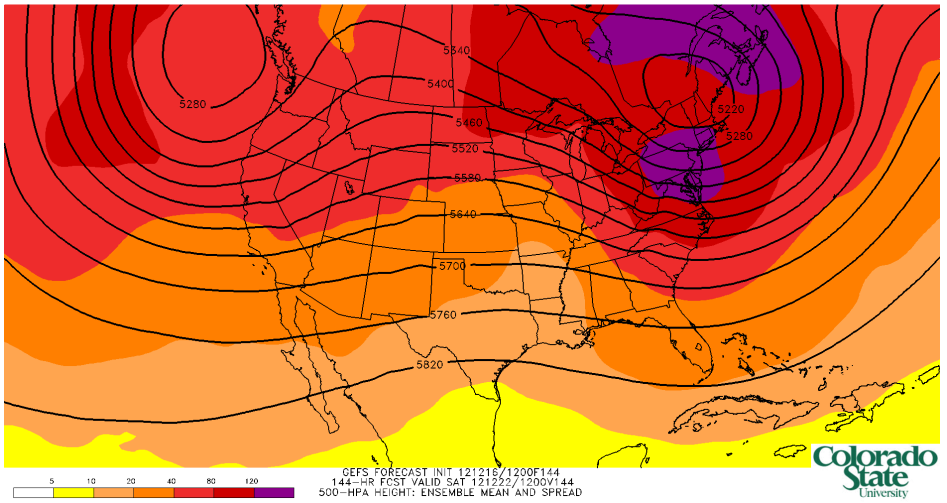
Initial time, 500-mb heights



144-hr forecast

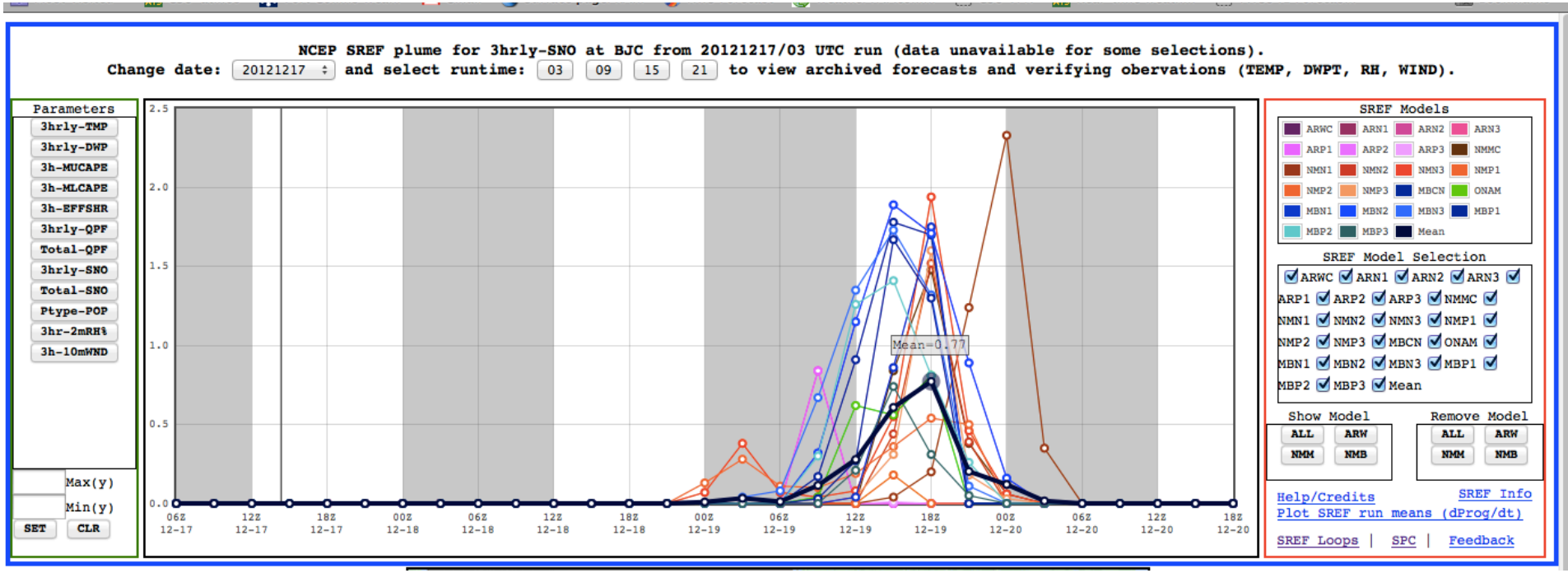






Schumacher: Ensembles in university education

Interrogation of the ensemble: the SPC's short-range ensemble "plumes"

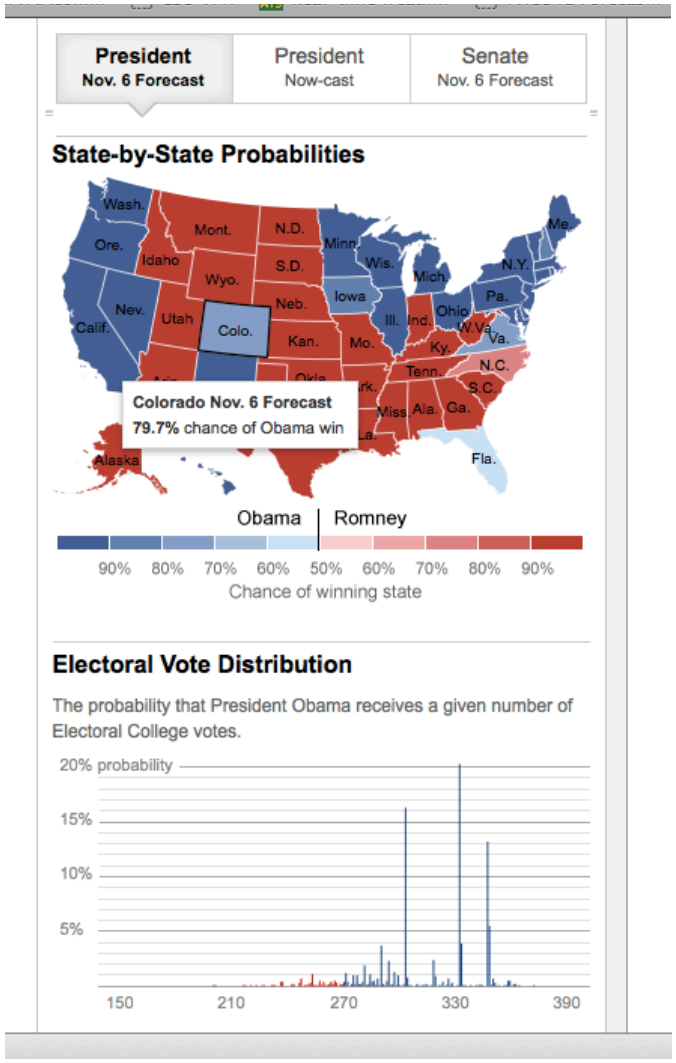


http://www.spc.noaa.gov/exper/sref/fplumes/

Challenges and opportunities

- Connecting patterns and processes in space to probabilities and spread
  - Many students look at the plume graphs and conclude that the models “don’t have any idea what’s going to happen”
  - Need to go from the “plume” to the “postage stamps” for physical reasoning
  - Objective vs. subjective interpretation
- There’s not currently a good “one-stop shop” for all of this information for operational or experimental ensembles

A non-meteorological example



Scenario Analysis

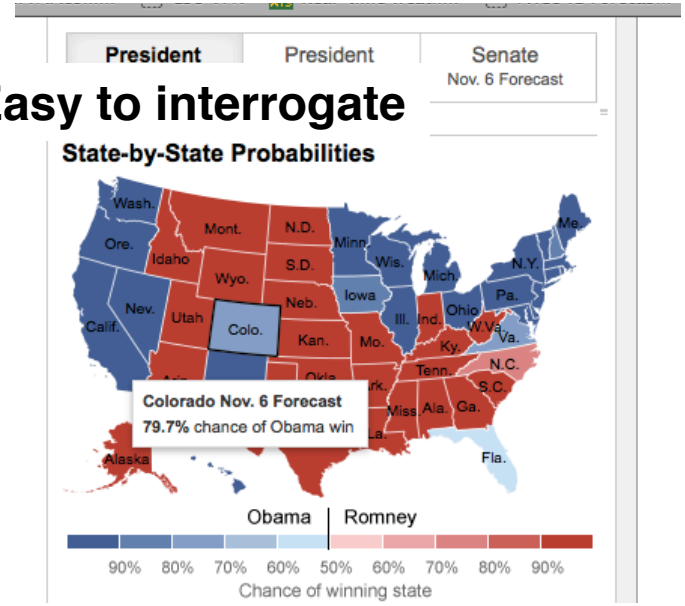
How often the following situations occurred during repeated simulated elections.

Electoral College tie (269 electoral votes for each candidate)	0.2%
Recount (one or more decisive states within 0.5 percentage points)	6.4%
Obama wins popular vote	86.2%
Romney wins popular vote	13.8%
Obama wins popular vote but loses electoral college	0.6%
Romney wins popular vote but loses electoral college	5.3%
Obama landslide (double-digit popular vote margin)	0.3%
Romney landslide (double-digit popular vote margin)	<0.1%
Map exactly the same as in 2008	0.1%
Map exactly the same as in 2004	<0.1%
Obama loses at least one state he carried in 2008	99.6%
Obama wins at least one state he failed to carry in 2008	4.2%

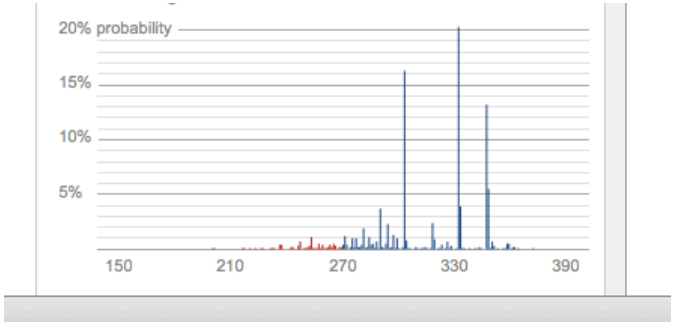
www.fivethirtyeight.com

A non-meteorological example

Easy to interrogate



Clear presentation of distribution of possible outcomes



Scenarios people might be interested in

Scenario Analysis

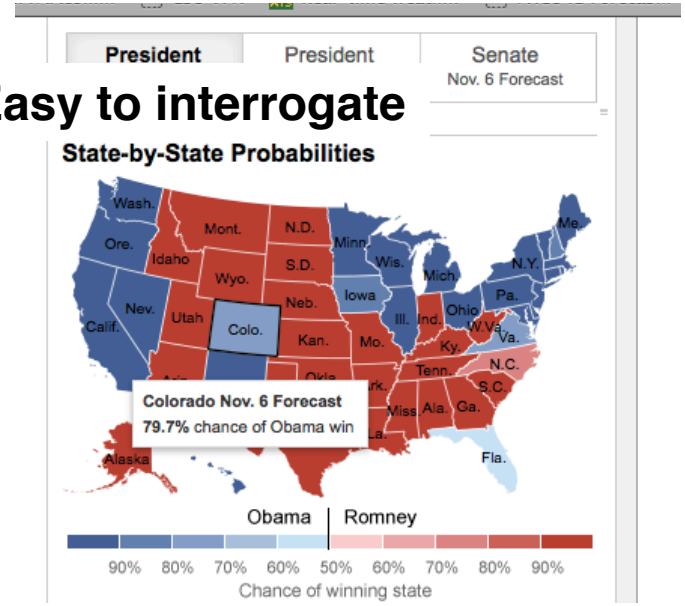
simulated elections.

Electoral College tie (269 electoral votes for each candidate)	0.2%
Recount (one or more decisive states within 0.5 percentage points)	6.4%
Obama wins popular vote	86.2%
Romney wins popular vote	13.8%
Obama wins popular vote but loses electoral college	0.6%
Romney wins popular vote but loses electoral college	5.3%
Obama landslide (double-digit popular vote margin)	0.3%
Romney landslide (double-digit popular vote margin)	<0.1%
Map exactly the same as in 2008	0.1%
Map exactly the same as in 2004	<0.1%
Obama loses at least one state he carried in 2008	99.6%
Obama wins at least one state he failed to carry in 2008	4.2%

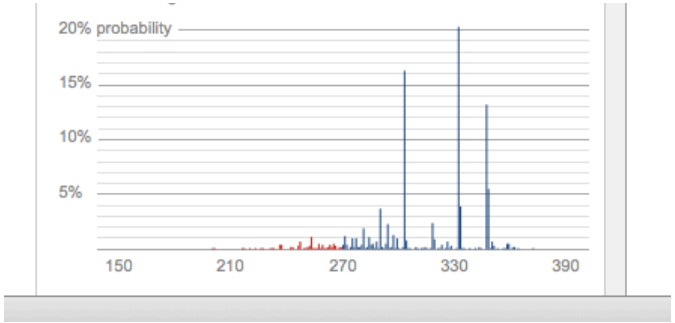
www.fivethirtyeight.com

A non-meteorological example

Easy to interrogate



Clear presentation of distribution o possible outcomes



Scenario Analysis

Scenarios people might be interested in

simulated elections.

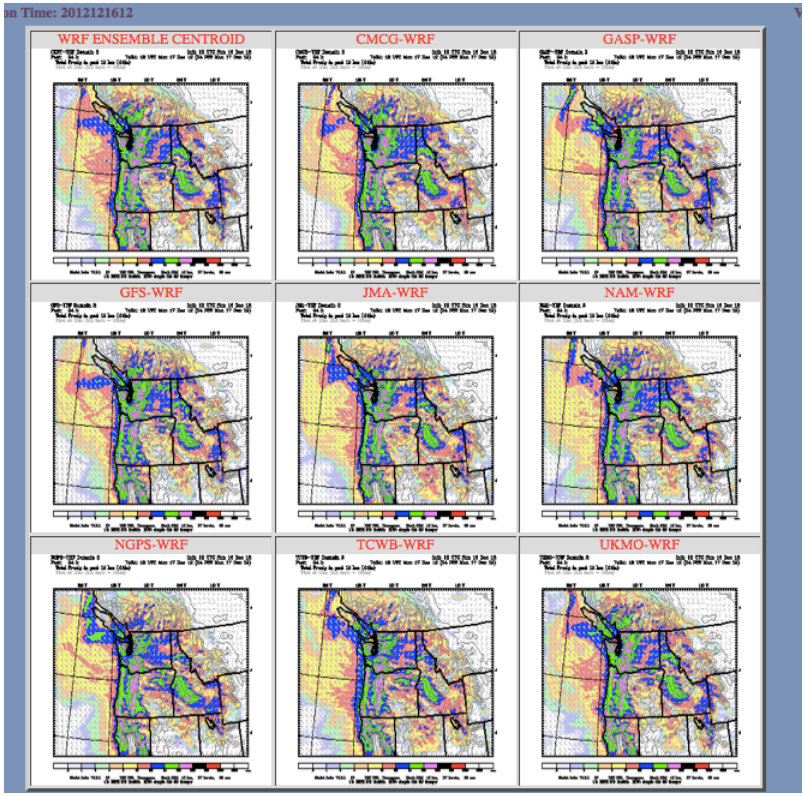
6 inches of snow	0.2%
Low temperature below 40°F	6.4%
Wind gust greater than 20 mph	86.2%
Romney wins popular vote	13.8%
Obama wins popular vote but loses electoral college	0.6%

- **Do we need tools like this for NWP ensembles?**
- **Could they be developed with existing technology?**
- **Would it be possible to enhance atmospheric science education if they existed?**
- **Can EarthCube be the framework that makes this happen?**

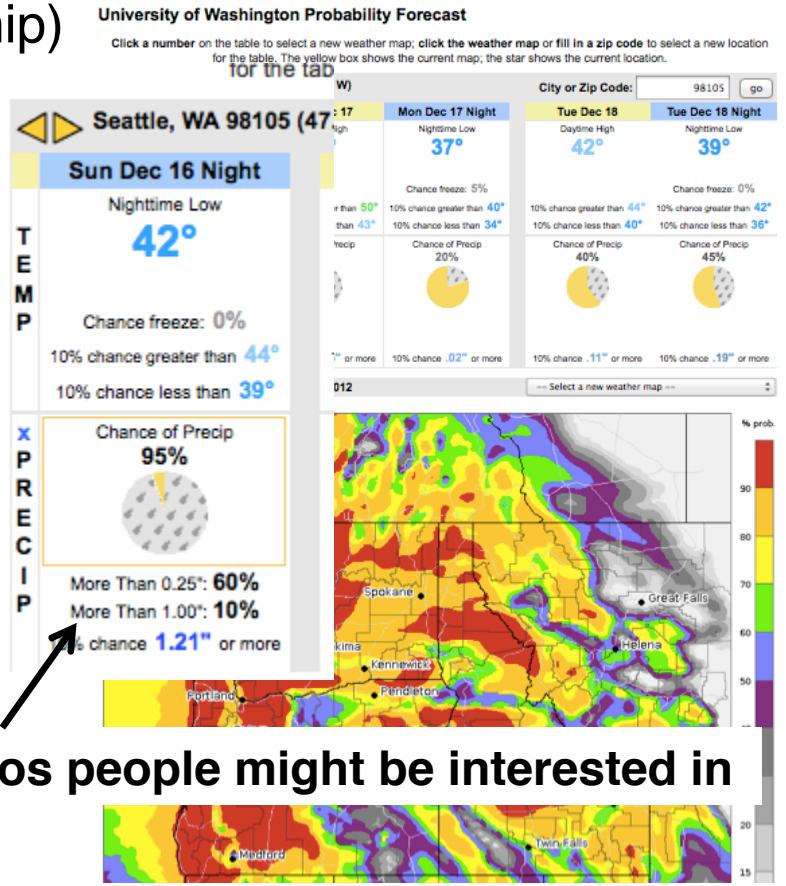
University-based ensemble NWP

- Although universities lack the major computing resources of government labs and operational centers, there is a history of real-time NWP and NWP research

- One pioneer and leader in these efforts has been the University of Washington (under Cliff Mass's leadership)



http://www.atmos.washington.edu/~ens/uwme.cgi



Scenarios people might be interested in

http://www.probcast.com

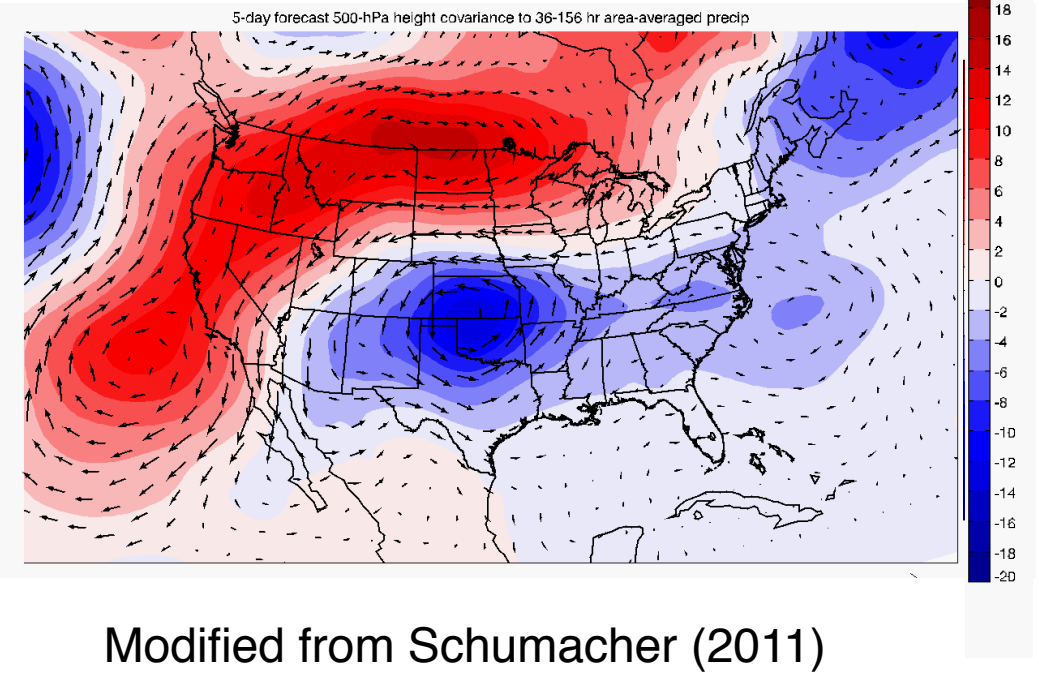
Ensemble-based synoptic analysis

- Hakim and Torn (2008) outlined “ensemble synoptic analysis”: using ensembles for quantitative diagnosis of weather systems

- Basic method: choose a forecast metric (“average precip in a lat/lon box”, or “minimum surface pressure at a point”), then project other atmospheric fields of interest onto that metric

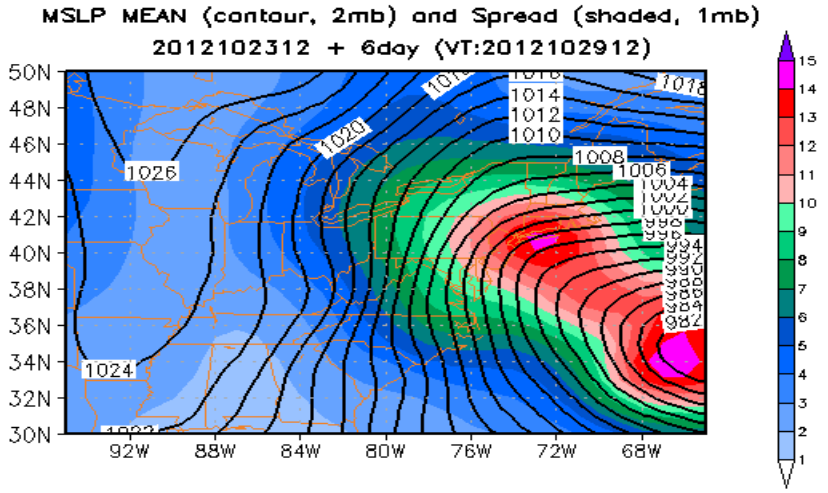
- Also used by Hawblitzel et al. (2007), Sippel and Zhang (2008, 2010), and Schumacher (2011)

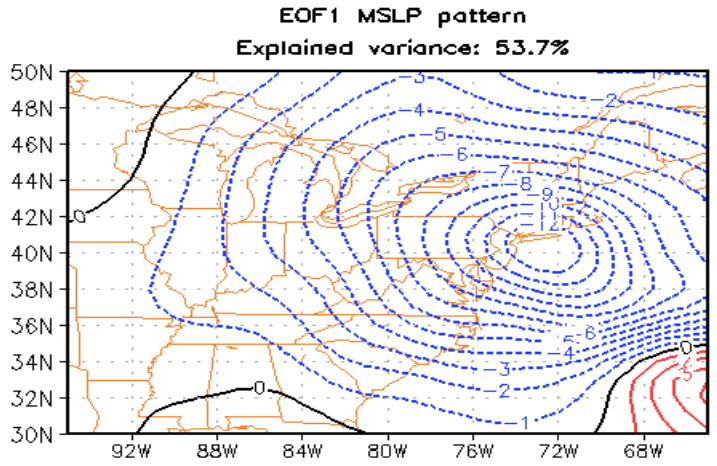
Covariance of 500-mb height and wind with area-averaged precipitation over the southern Plains – 25-30 June 2007

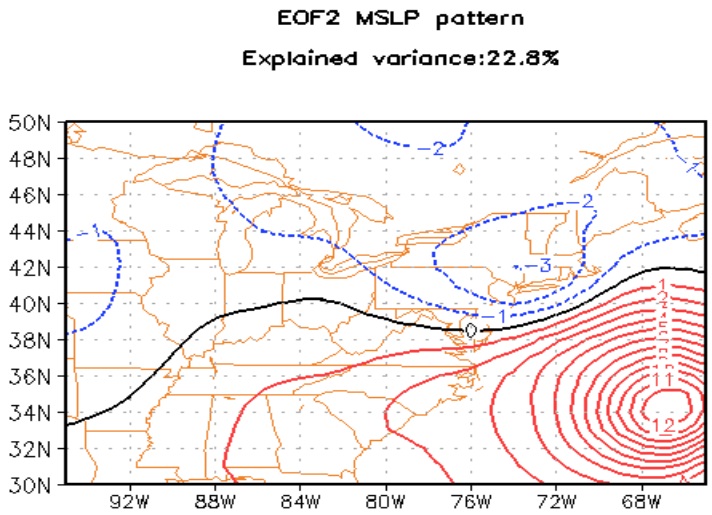


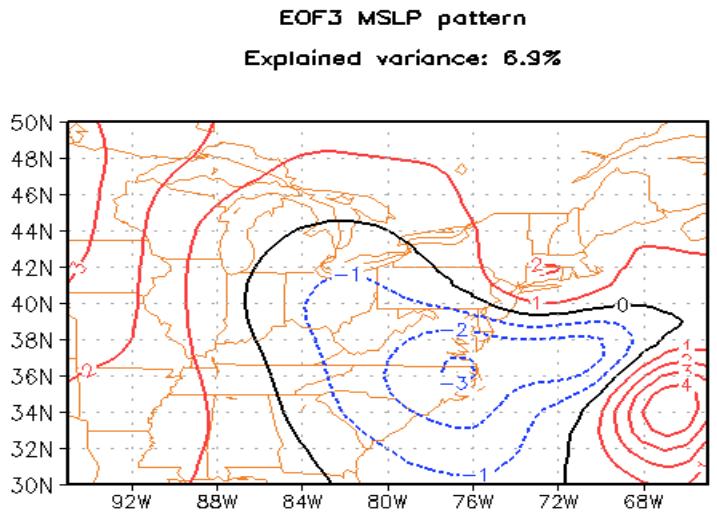
Modified from Schumacher (2011)

Brian Colle and Edmund Chang at Stony Brook: Real-time ensemble sensitivity analysis using a forecast metric represented by the EOFs of the ensemble spread





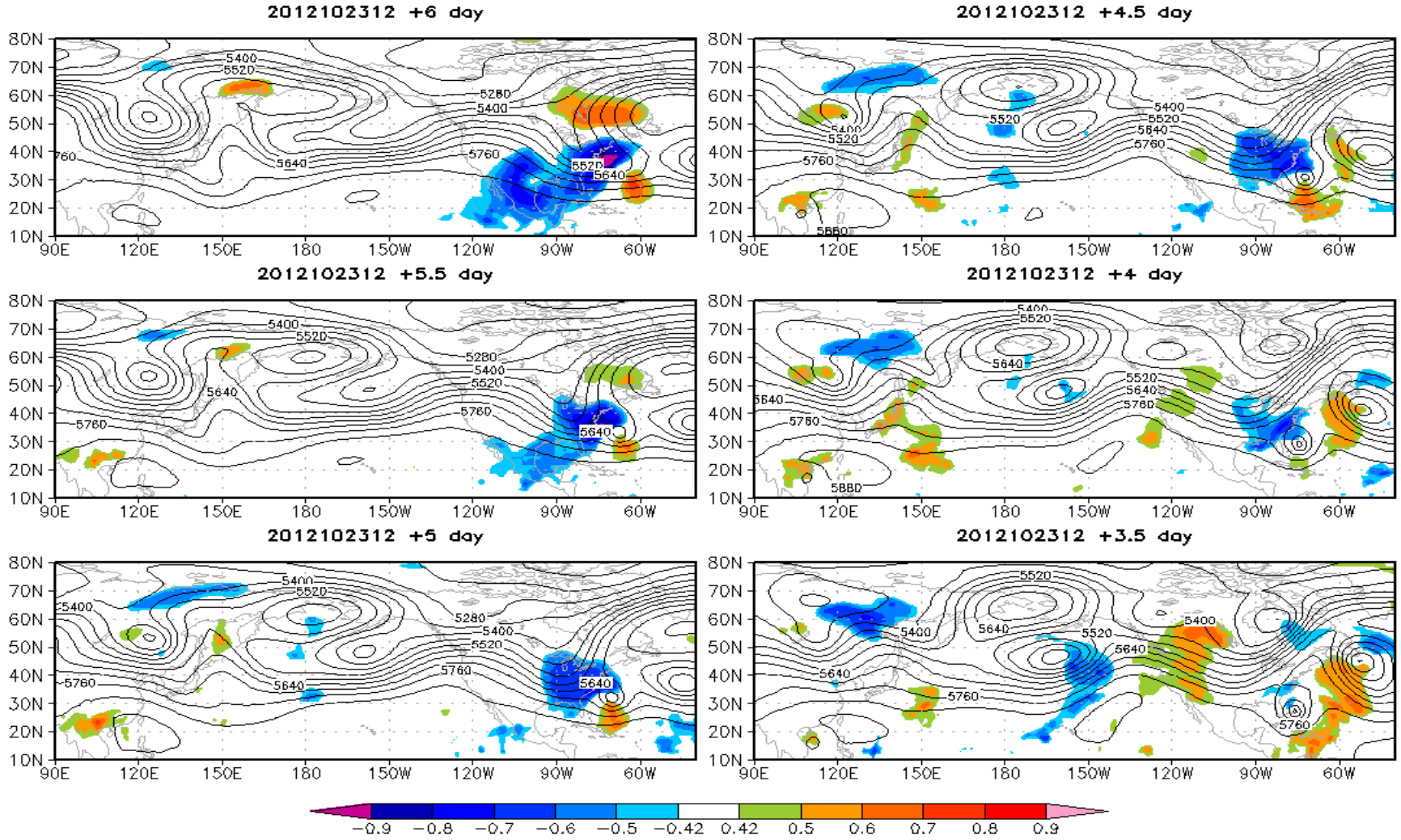




NCEP fcst, IT: 2012102312, VT: 2012102912

(slide courtesy of Brian Colle, Stony Brook Univ.)

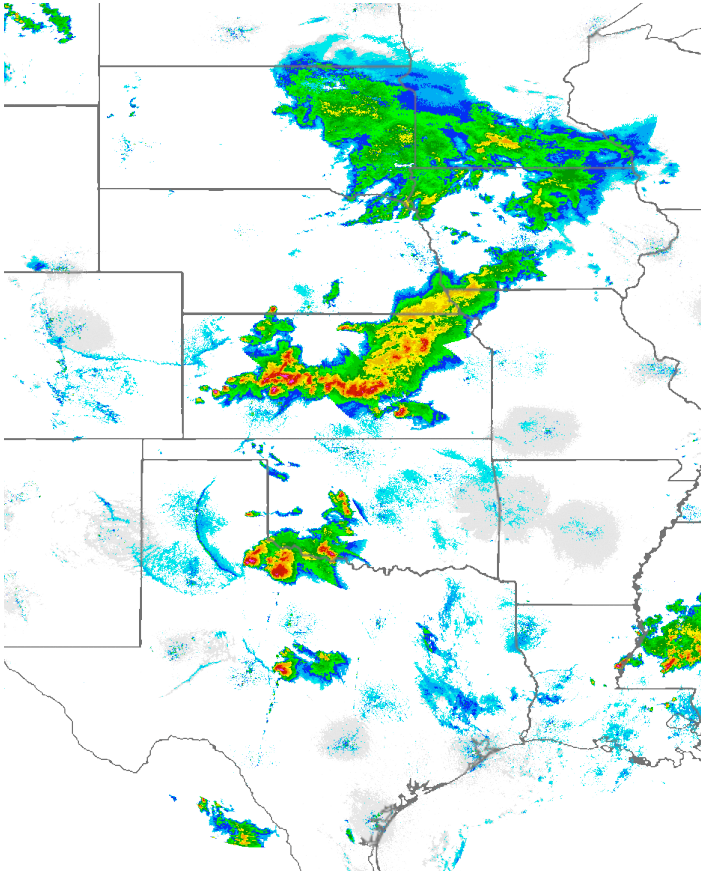
For EOF1 pattern, which represents Sandy closer to the coast, the sensitivity at day 6 originates over the eastern Pacific and western N. Amer. a few days earlier



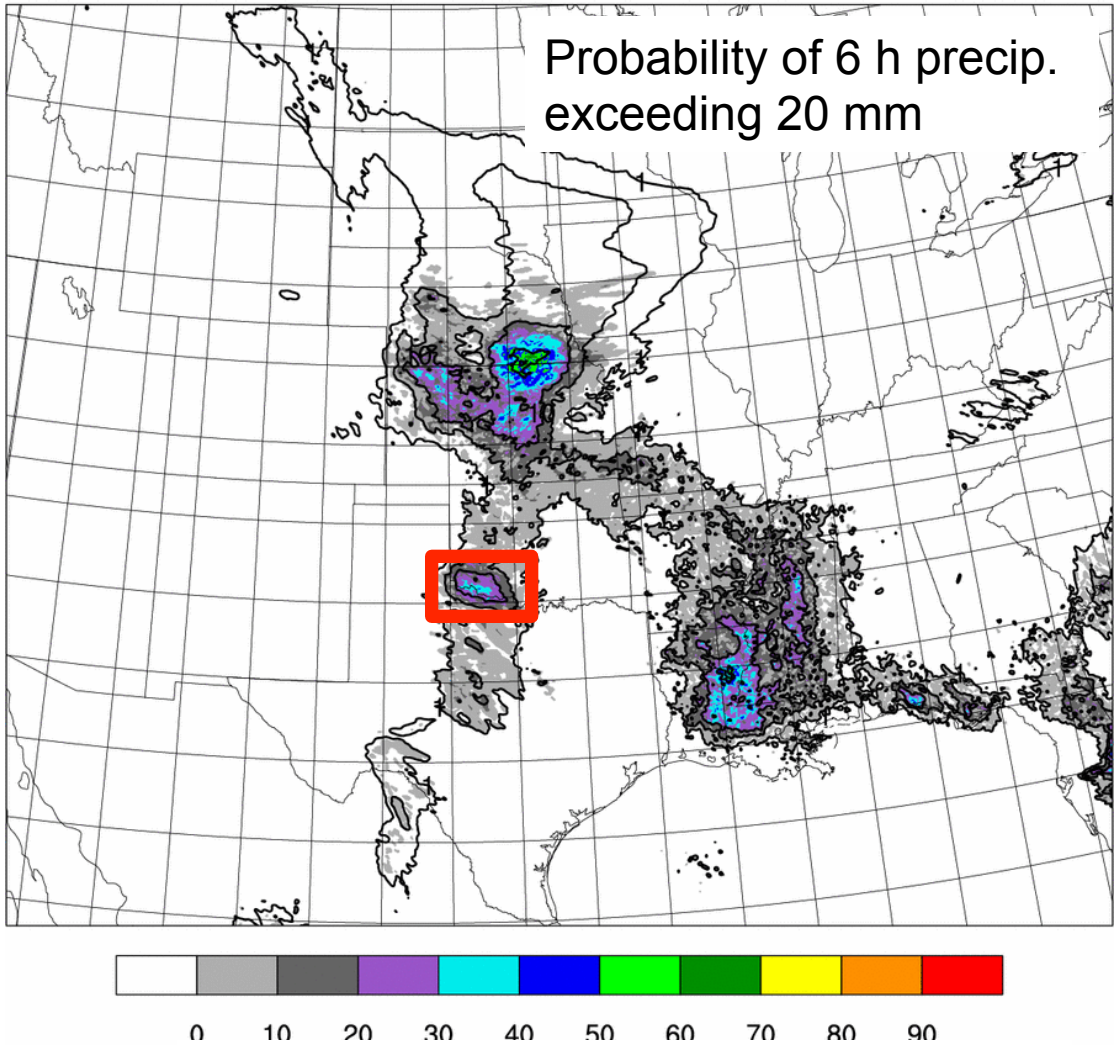
(slide courtesy of Brian Colle, Stony Brook Univ.)

Ryan Torn at University at Albany: sensitivity analysis in a convection-allowing ensemble for the upcoming MPEX field project

Forecast Initialized
0000 UTC 30 May 2012



F027 Precipitation valid 2012053103

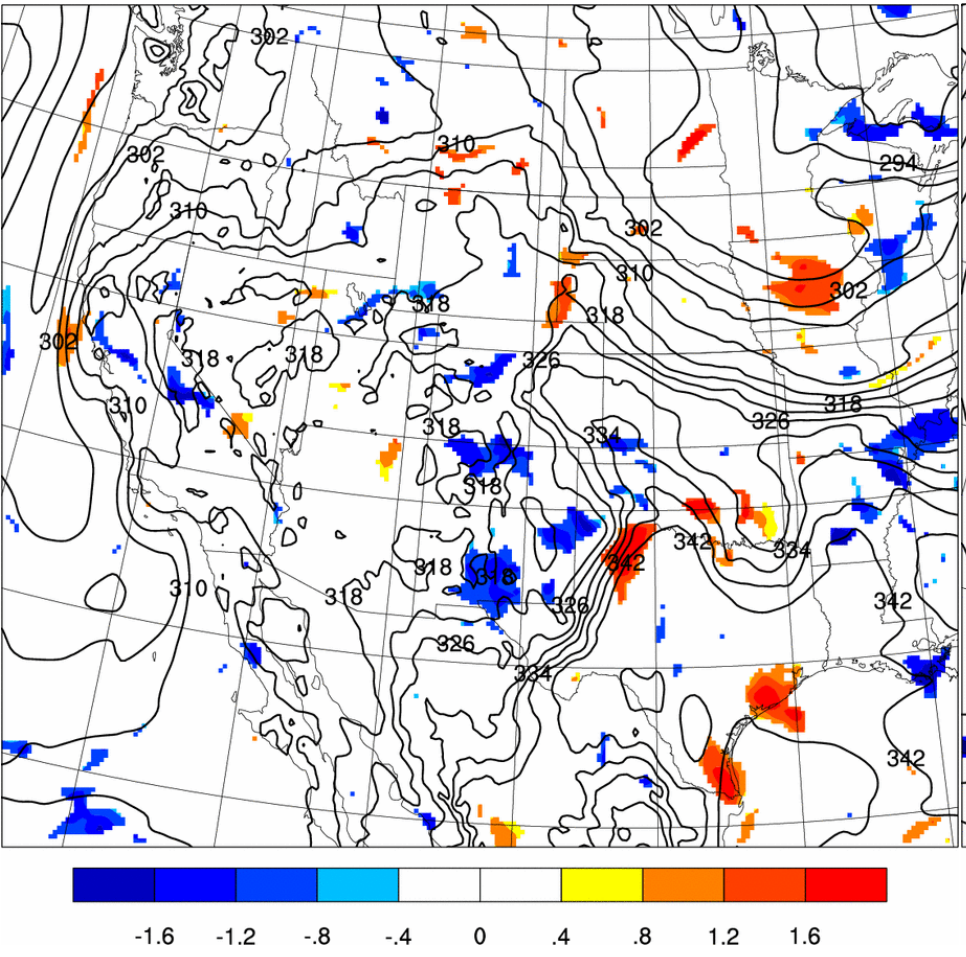


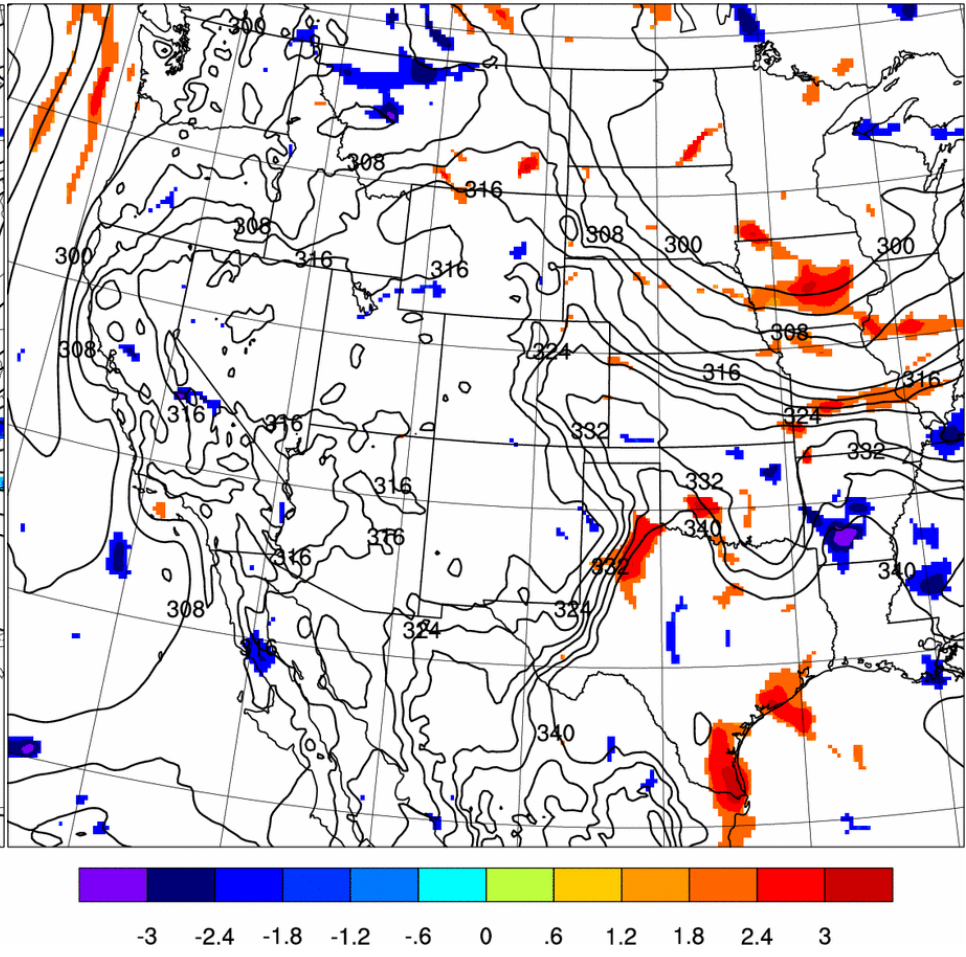
(slide courtesy of Ryan Torn, Univ. at Albany)

Sensitivity Example

Difference Between High/Low Precip. Fcst

Sensitivity to 12 h forecast





12 h forecast of theta-e at 1 km AGL

(slide courtesy of Ryan Torn, Univ. at Albany)

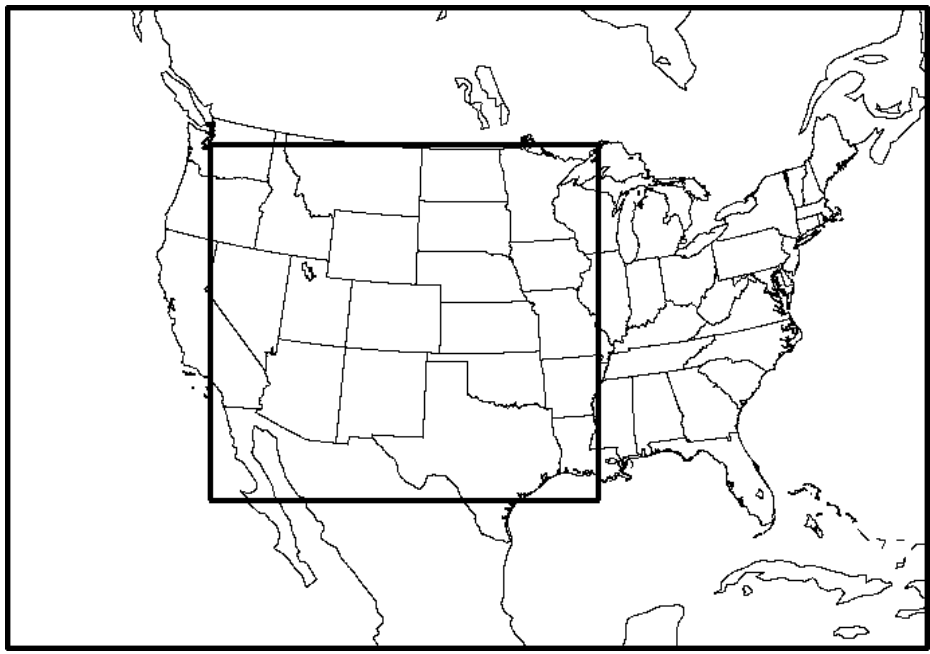
University-based NWP

- More and more universities are getting involved in real-time forecasts and NWP research, enabled by:
  - Community models like WRF
  - NOAA data and analyses (made available by Unidata)
  - Better post-processing and visualization software
  - Cheaper, faster computers and disk storage
- Regional forecasts are regularly (or semi-regularly) produced by Washington, Wisconsin, Penn State, Oklahoma, Texas Tech, Arizona, Colorado State, Illinois, UW-Milwaukee, Stony Brook, Albany, Purdue, Iowa State, North Dakota, UCLA, Millersville, Utah, Ohio State, Florida State, Texas A&M, Miami, San Jose State, Valparaiso and probably several others that I'm missing (that's 23 universities just in that list!)

Question for discussion this week: Would it make sense to “join forces” and develop a large multi-university ensemble for research and education? (and also real-time forecasting if possible)

Are university real-time forecasts any good?

- Small, cheap ensemble run at CSU on desktop machines
- Currently a 5-member WRF-ARW ensemble, with a 36-km outer grid covering most of North America, and a 12-km inner grid centered over Colorado
- Forecasts out to 60 hours, run once per day (00Z initialization)
- GFS, NAM, and WRF-VAR DA used for initial/boundary conditions, also physics diversity

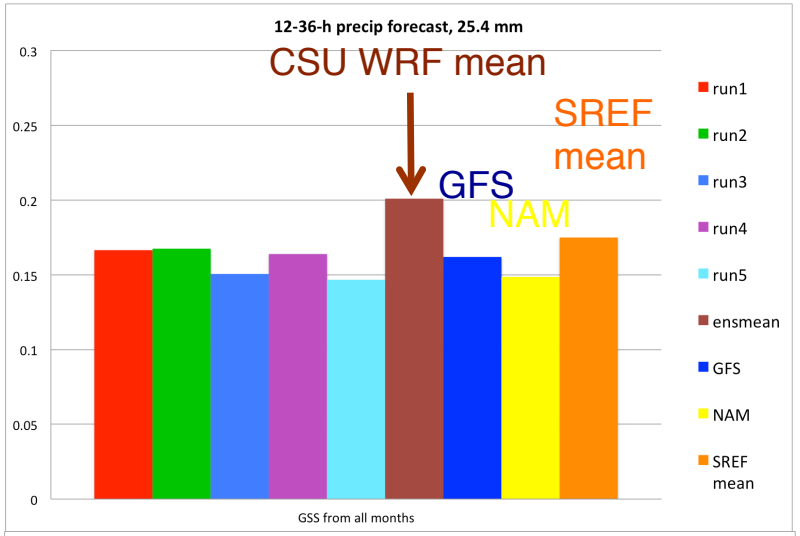


http://schumacher.atmos.colostate.edu/weather/model_compare.php

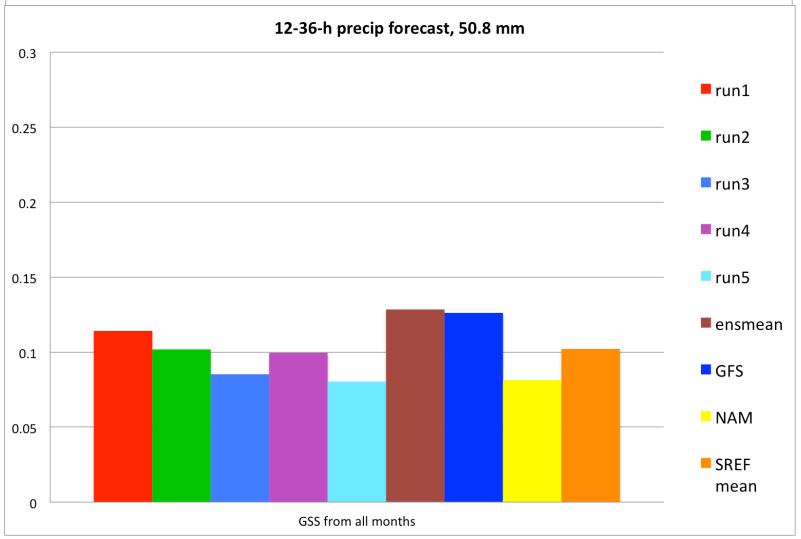
http://bit.ly/MGmNuX

24-hour Precipitation

- Over Feb-Nov 2012, CSU WRF precipitation forecasts have comparable skill to the NCEP GFS and NAM forecasts over the west-central US
- The CSU WRF ensemble mean verifies better than the SREF mean at this threshold
  - Probably in part due to better representation of topography at higher resolution; possibly also the smaller ensemble size (not enough spread)



25.4 mm (1 inch) in the 12-36-h precip forecast



50.8 mm (2 inches) in the 12-36-h precip forecast

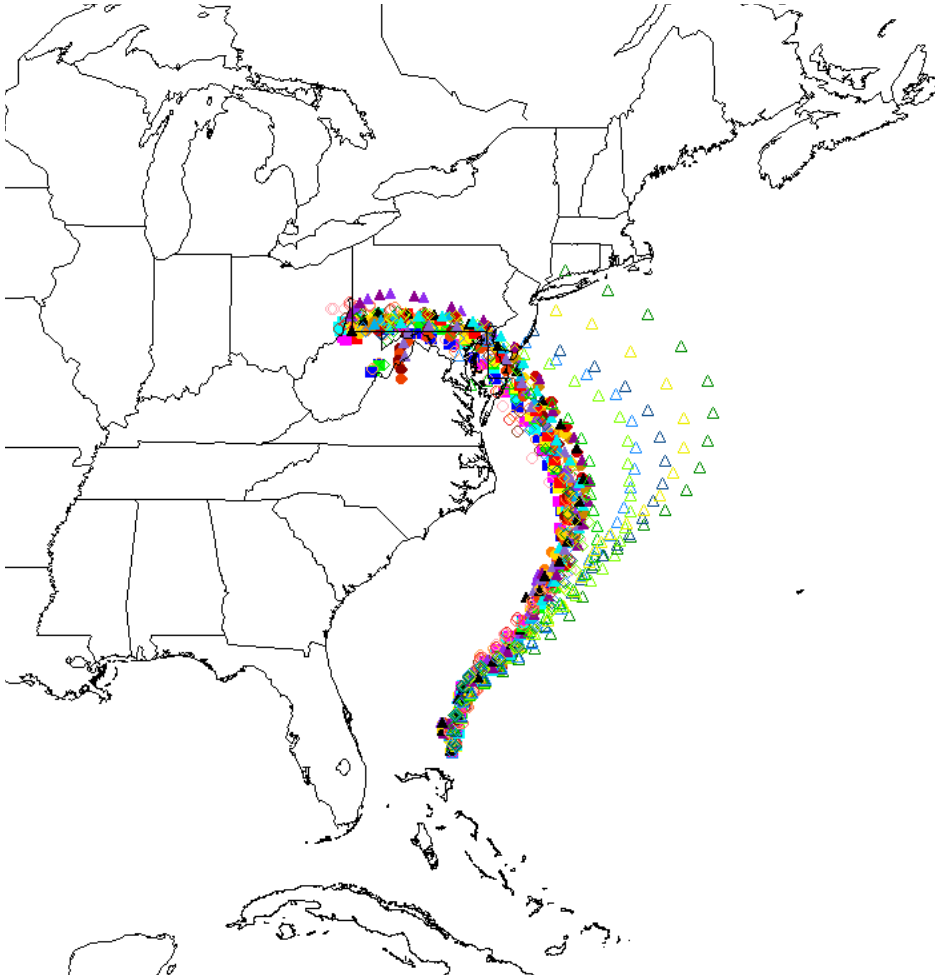
Gilbert skill score (aka Equitable Threat score) for Feb-Nov 2012, CSU WRF members and NCEP models
Higher scores are better (1 is perfect, 0 represents no skill)
Calculated for domain 2 (west-central US)

University-based ensemble

- This small ensemble is not state-of-the-science by any means, but it shows that they can provide some useful information
- If each university running a similar ensemble (or even a single run) contributed their output, a mesoscale “grand ensemble” would be possible that would require relatively few new resources
- Could engage a large part of the atmospheric science university community, from large research institutions to small undergraduate institutions

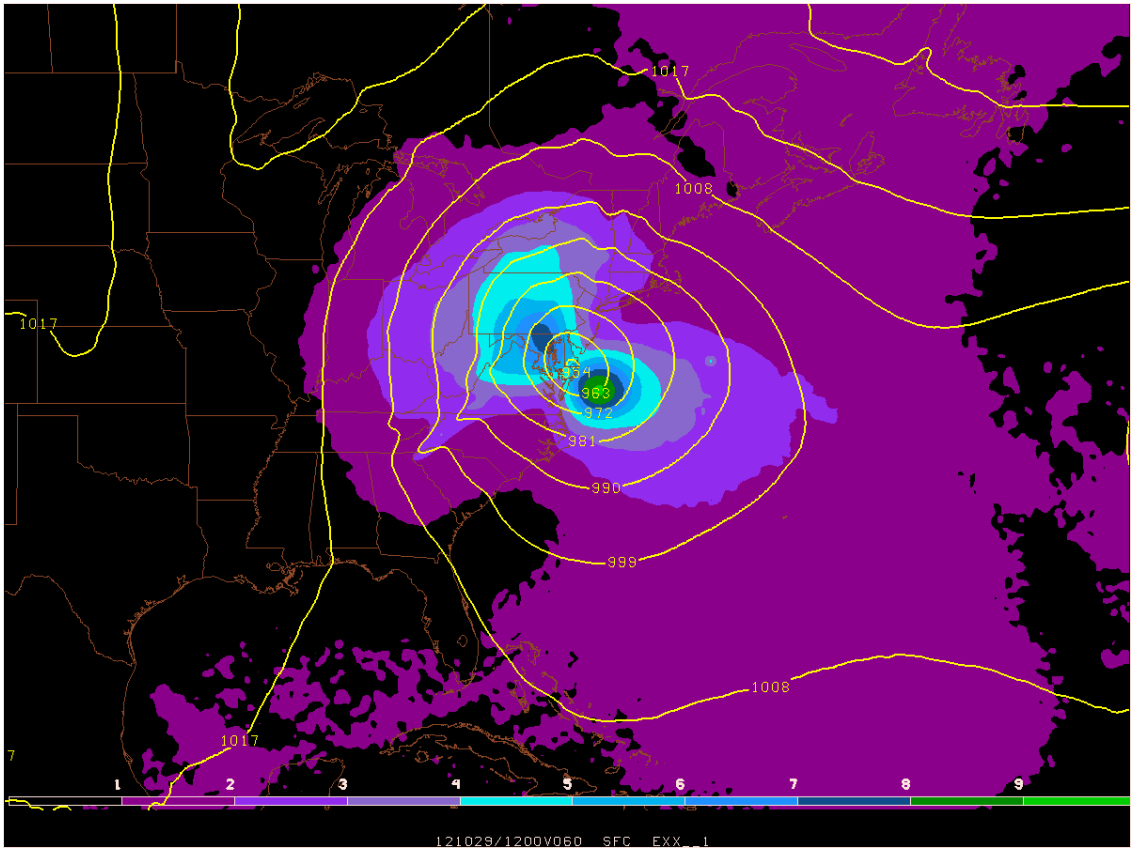
Pilot project for Superstorm Sandy

- 36-member ensemble run between CSU, University of Wisconsin (Nick Bassill) and University at Albany (Kevin Tyle)
- WRF-ARW ensemble at 30-km grid spacing over eastern North America and the western Atlantic
- Initial and lateral boundary conditions from GFS – only physics diversity for this test
- 84-h forecast initialized 0000 UTC 27 October (72 h prior to landfall)
- This configuration could easily be run in a timely manner on desktop machines



MSLP mean and spread at t=60

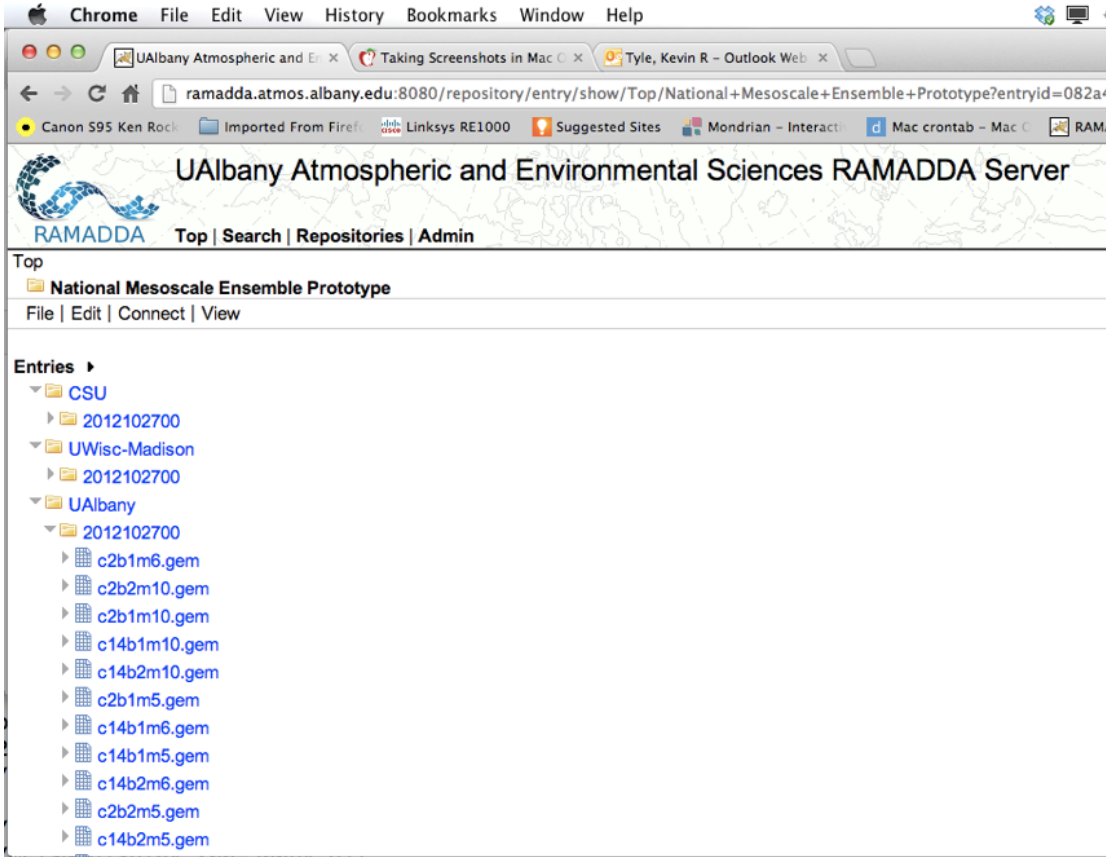
- Most spread in this ensemble was in the forward speed of the storm – several members were too fast, others quite accurate



(image from Nick Bassill, Univ. of Wisconsin)

Workflow, questions, and challenges

- Each set of runs uploaded to Albany's RAMADDA server, processed into an ensemble
- Initial configuration takes coordination and standardization among all participants
- How to store and access data if the ensemble gets into the hundreds of members and/or higher resolution?



(image from Kevin Tyle, Univ. at Albany)

Summary, conclusions, and points for discussion (1)

- Formal university courses in ensemble NWP exist and are expanding, but are still fairly limited
- University research is developing innovative methods for running, analyzing, and working with ensemble data, and this provides great opportunities for enhancing education
- Real-time model forecasts at universities can provide value, and a multi-university large ensemble is feasible with few additional resources
- Additional tools are needed for easy diagnosis, processing, and visualization of ensembles for use in the classroom

Summary, conclusions, and points for discussion (2)

- What specific capabilities should EarthCube include to enhance ensemble-based research and education?
- Is a large multi-university mesoscale ensemble a good idea? If so, what should its focus be? (not likely to be actual operational prediction, but instead research and education) How would the configurations be determined? Would there be support for this effort from NSF, Unidata, etc.? How could EarthCube help facilitate this effort?
- What educational activities or initiatives are needed to enhance research and education on ensemble NWP and DA at universities?