# Recent Progress in LAM-EPS Research and Implementation

## Focus on North America

Josh Hacker (jphacker@nps.edu), with contributions from many as noted on the slides.

EWGLAM/SRNWP 10 Oct 2011, Tallinn, Estonia

# Efforts at operational centers

- CMC (Canada)
- NCEP (U.S.)
- SMN (Mexico)

- U.S. Air Force Weather Agency
- U.S. Navy Fleet Numerical Meteorology and Oceanography Center (Naval Research Lab)

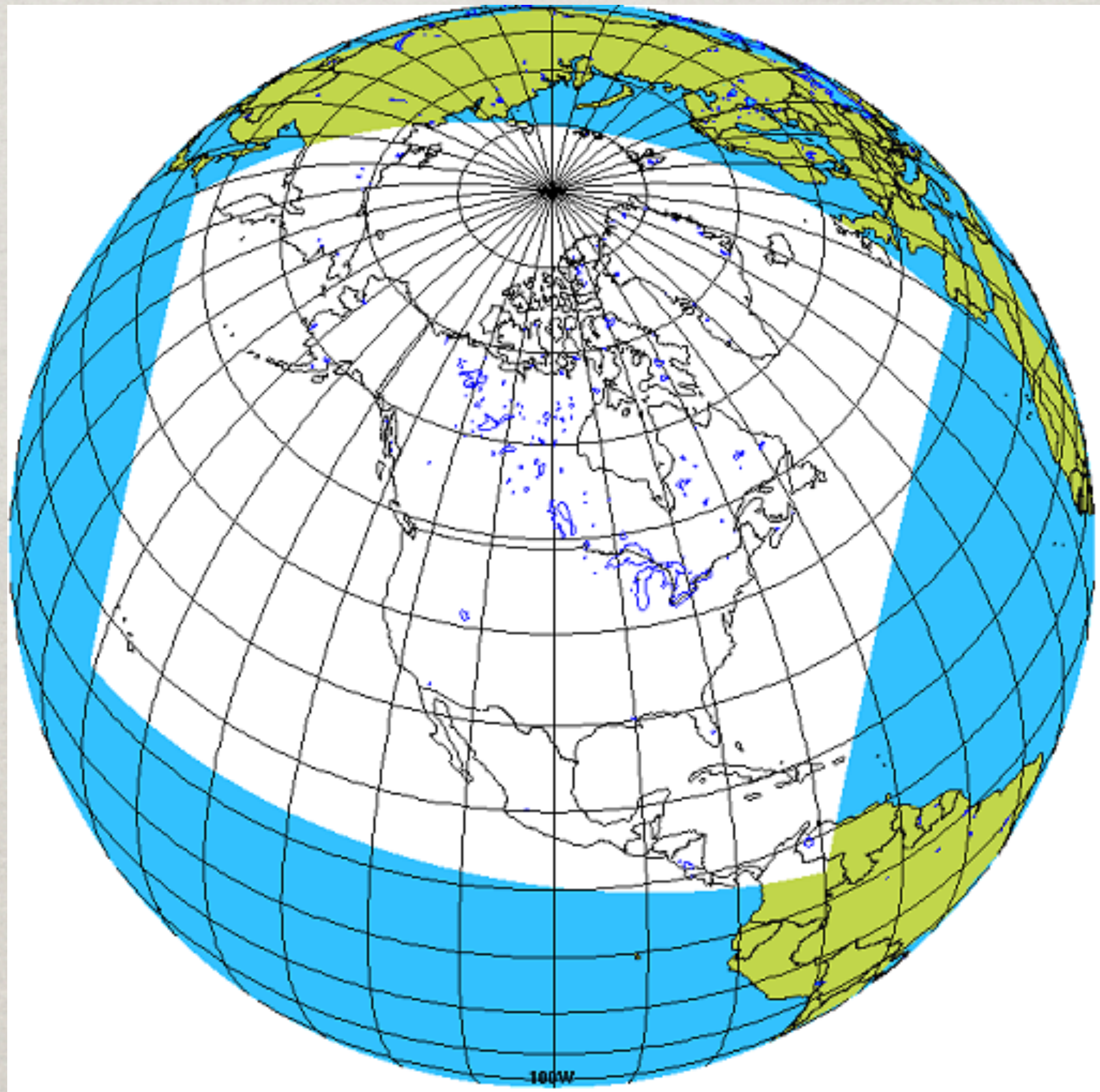
- Multi-agency ensembles

# Canadian Regional Ensemble Prediction System (REPS); operational Sept 2011

- Based on the Global Environmental Multiscale (GEM) model version 4.2 (vertical staggering à la Charney-Phillips)
- **Subgrid-scale parameterizations and horizontal grid spacing almost identical to Canadian deterministic global system (do not use multi-parameterization approach).**
- Grid spacing: 0.3° x 0.3° (280 x 287 x L28 grid points)
- REPS lid is near 10 hPa and lid nesting technique is used
  - piloting between 10 and 35 hPa
  - blending between 35 and 100 hPa
- Piloted with a 3h frequency by the global Canadian EPS with lid at 2 hPa
- Initial conditions from the global EnKF (same as global EPS)
- Lead time: 72 hours
- 20 members + one control run
- **Sources of stochasticity**
  - **Stochastic perturbations of physical tendencies**
  - **Initial conditions (global EnKF)**
  - **Boundary conditions (global EPS)**

M. Charron, R. Frenette, N. Gagnon

# The REPS domain

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# REPS: What's next?

- Better surface and near-surface model error representation by perturbing uncertain parameters and fields related to the surface scheme
- Horizontal grid spacing at 20 km in 2012
- Dedicated regional ensemble-based data assimilation (regional EnKF) in ~2013

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# NCEP SREF Planned Changes Spring 2012

I. Model Changes

1. 4-model system becomes 3-model system (remove old Eta and RSM, add NEMS-NMMB)
2. Model's horizontal resolution increases from 32km to 20km

II. IC diversity improvement

1. Use more diversity of control analyses: from 2 to 3 (add Rapid Refresh)
2. Improve IC perturbation by blending larger-scale ETR and smaller-scale BV
3. Change 2-D mask to 3-D mask to control IC perturbation size vertically

III. Physics diversity improvement

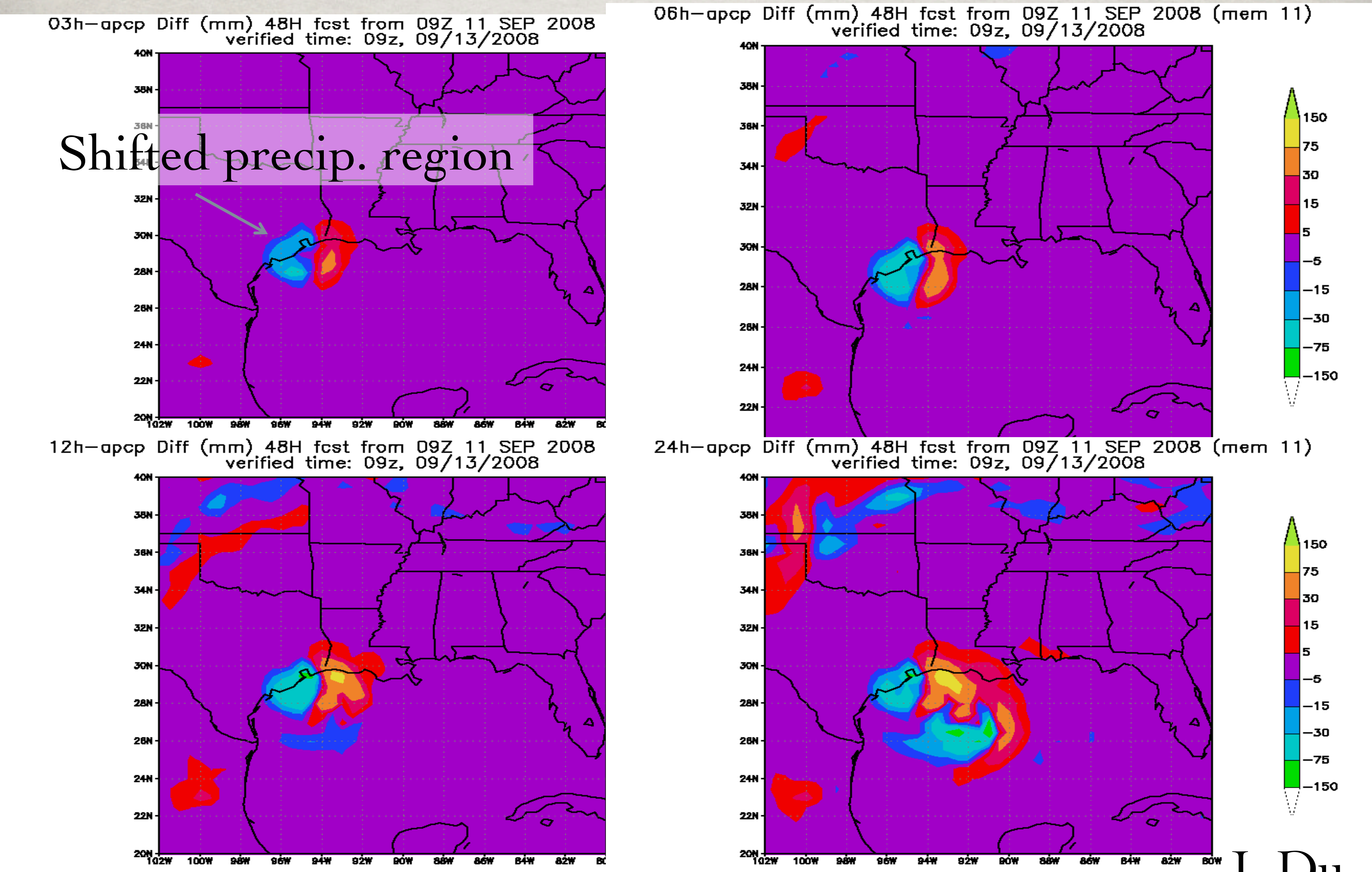
1. Add stochastic parameterization Cu physics scheme

IV. Ensemble product improvements

1. Precipitation bias correction (frequency-matching method)
2. Clustering
3. Statistical downscaling to 2.5km using hi-res analysis RTMA
4. Many new ensemble products including min/max, 10-25-50-75-90%, best/worst members, weighted-mean, extreme weather probability as well as aviation, wind energy, fire weather and convection-specific probabilistic products

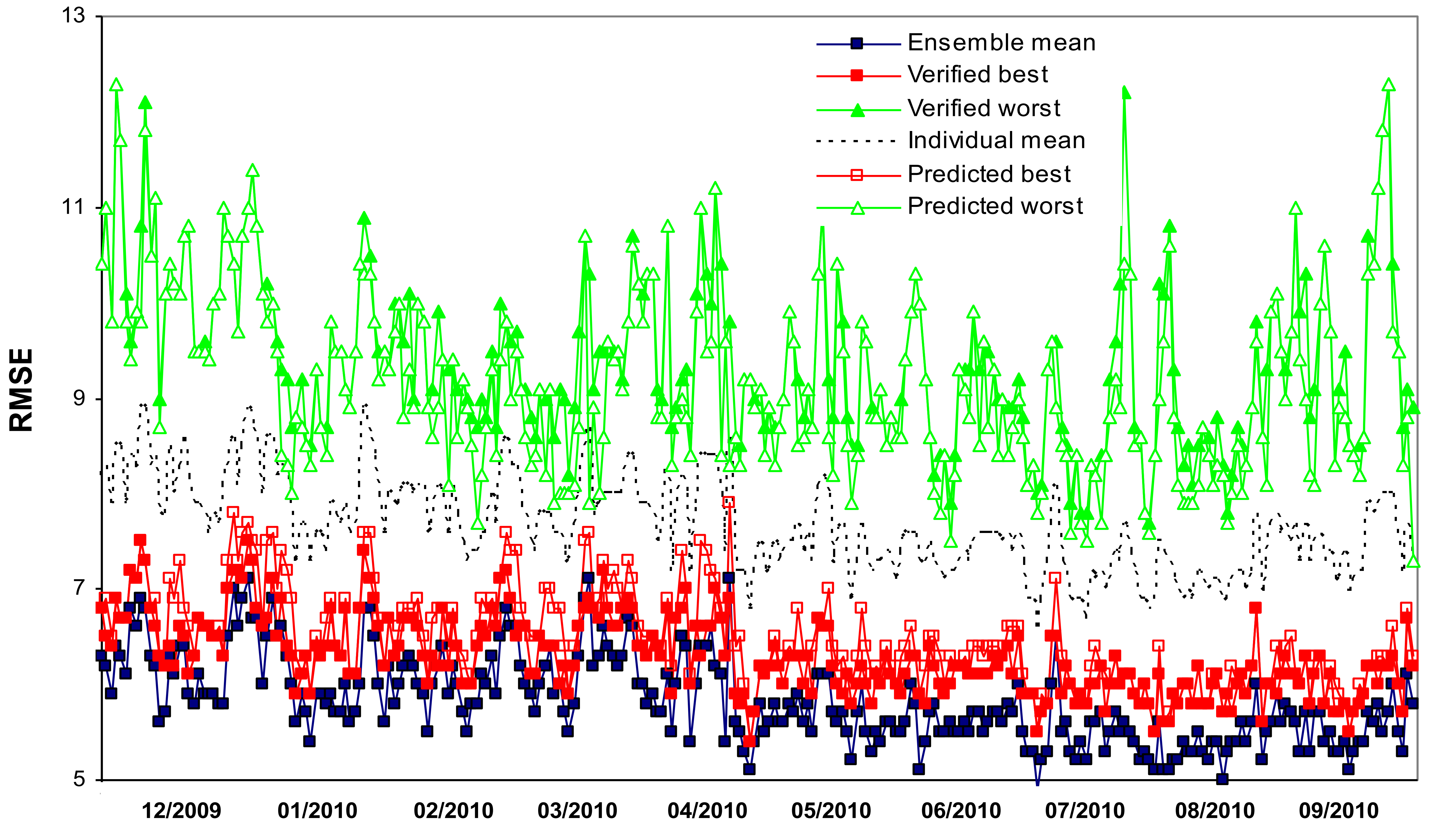
J. Du

# Difference in precipitation FCST ("exp - ctl") due to stochastic convective parameterization (Hurricane Ike)




J. Du

# Predicting individual member performances (Du and Zhou, 2011, MWR)



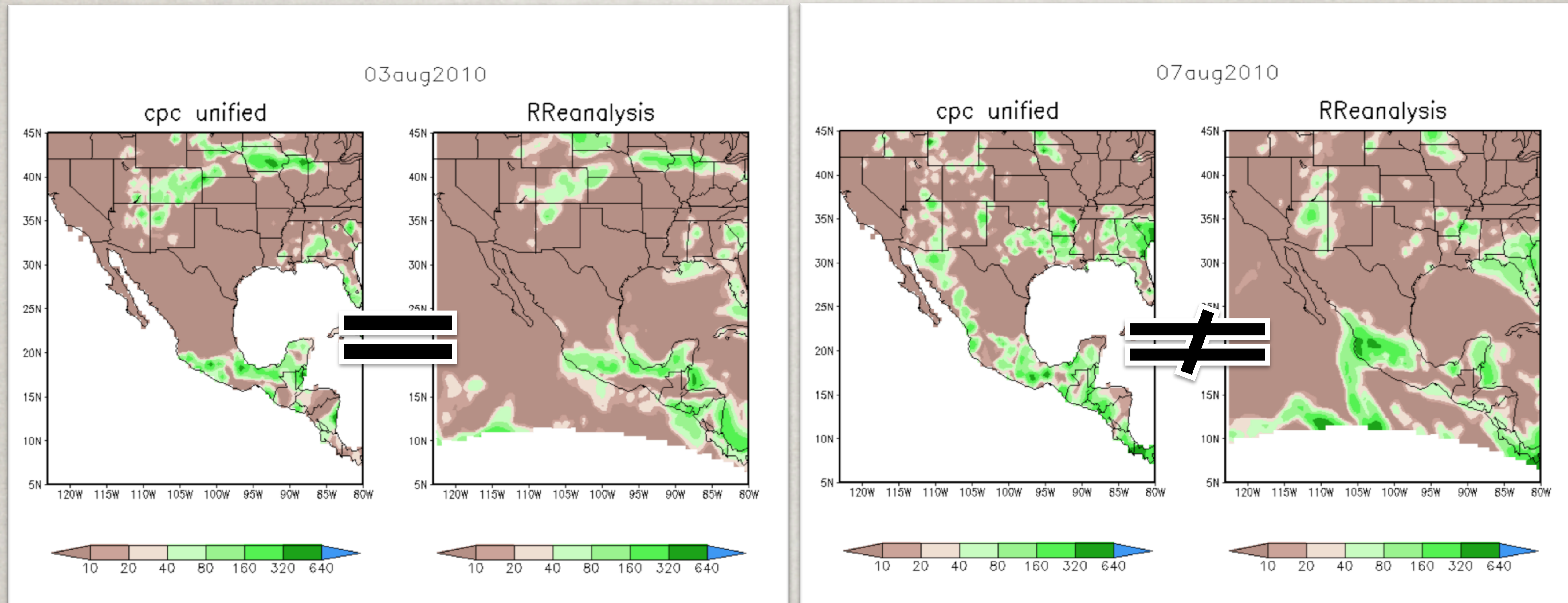

J. Du

# Mexico

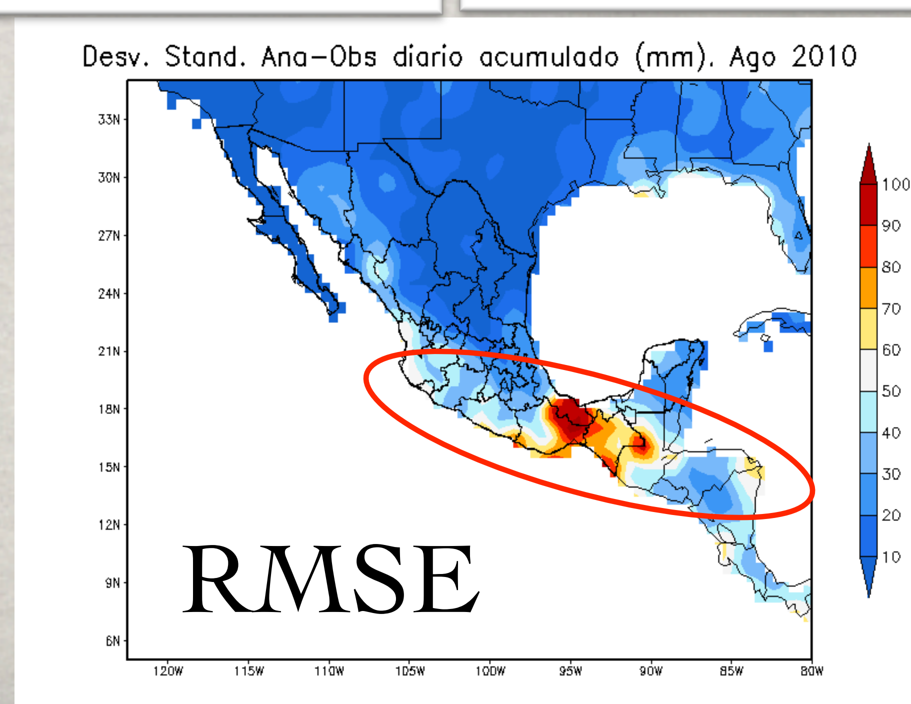
- Experiment to scope an improved and coordinated operational capability:
  - Compare the skill performance of regional forecasts systems, particularly WRF-based total precipitation, under a wide range of configurations.
  - Investigate tradeoffs between resolution and ensemble size
  - Compare the performance of WRF run in the experiment versus the performance of operational NCEP models (GFS and NAMS) available for the region.
  - Compare historical observations with the NCEP regional reanalysis, and the WRF DA, to assess the performance of the data assimilation schemes and identify regions where quality-controlled observations are required.

M. Pena

# Daily accumulated precipitation (mm): rain gage (CPC) vs Reanalysis




Analyses are problematic in this region: lack of observations and/or model problem?




Region prone to floods

*Sample size: 31 days*

M. Pena

# US Air Force Weather Ensemble Prediction Suite (AFWEPS)

- Global Ensemble Prediction Suite (GEPS)
  - **Combination of GFS, GEM, and NOGAPS ensembles**
  - Post-processed at US Air Force Weather Agency (AFWA)
- Mesoscale Ensemble Prediction Suite (MEPS)
  - 10 members of WRF-ARW with unique physics configurations
  - Initial conditions are deterministic UM, GFS, GEM, and NOGAPS
  - 20 km northern hemisphere and tropical stripe domains to 144 hours run once per day (18Z) with online dust
  - **Seven re-locatable 4 km** (1600 km by 1600 km) domains run once per day to 54 hrs
    - **Appointed user can move domain—useful for contingency missions, tropical cyclones, severe weather outbreaks, etc**

E. Kuchera

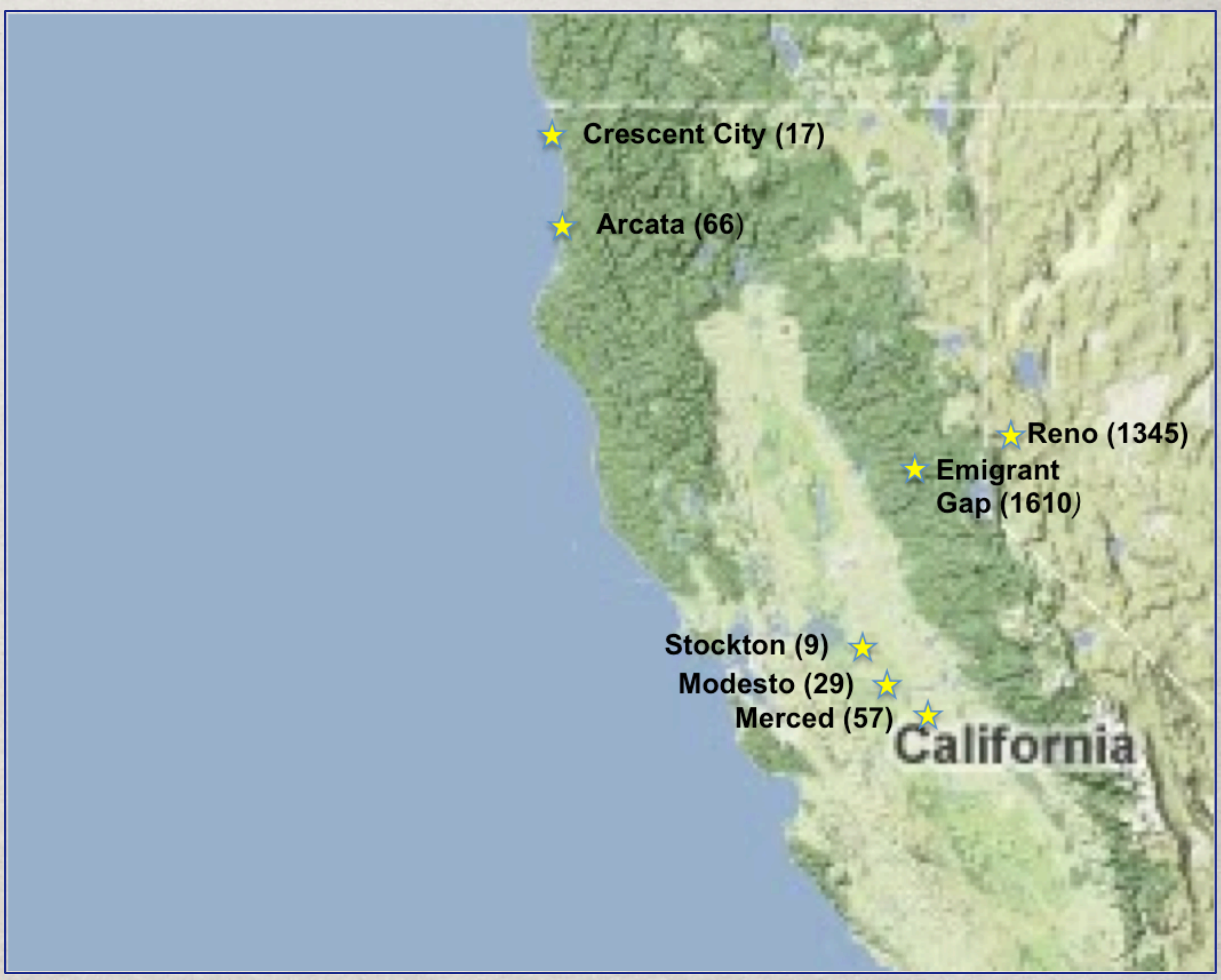
# US Air Force Weather Ensemble Prediction Suite (AFWEPS)

- Air Force Weather Tools for decision improvement:
  - Convection allowing ensembles (4 km resolution)
    - Weather uncertainty due to convection is primary problem
  - Algorithms to diagnose sub-grid scale probabilities
    - High-impact phenomena are still sub-grid even at 4 km
    - Probabilistic predictions of tornadoes, hail, visibility, wind gusts, snowfall, icing, etc
  - Inclusion of dust online inside model
    - Dust from convection is #1 problem to solve—addressed by WRF-CHEM ensemble at 4 km
    - Also working on dust source regions and uncertainties
    - Substantial improvement over current methods

E. Kuchera

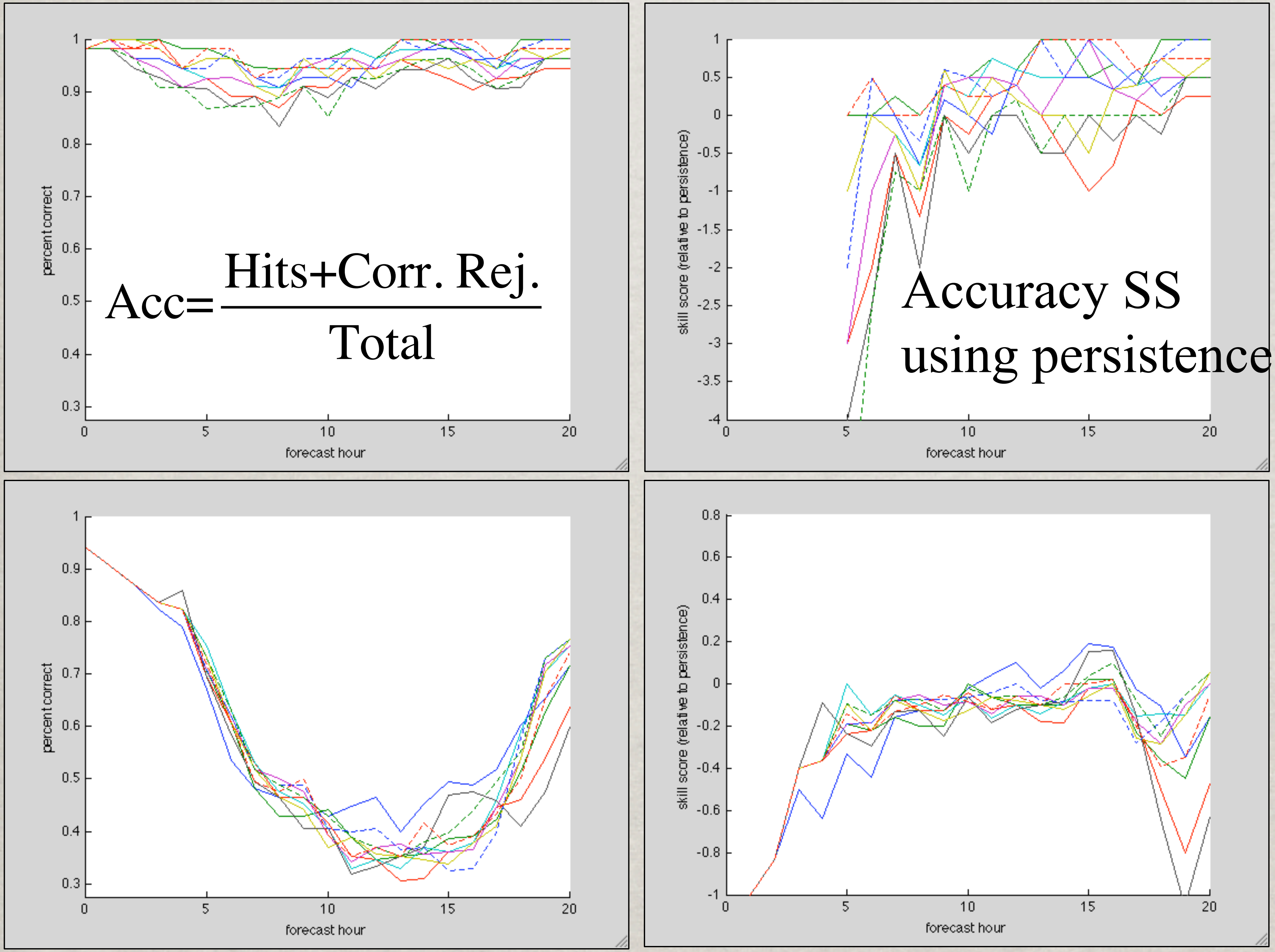
# Probabilistic fog forecast experiments with MEPS

- Visibility predictions based on explicitly forecast water content (cloud, rain, snow, ice)
- 20-h runs initialized at 00Z every 3-4 days for Nov 2008 to Feb 2009; 29 total runs
- Verification focused on seven sites
  - Represent both advection fog and radiation fog cases
  - Variety of elevations
- If visibility reduced due to precipitation, observation not included




Inner-most nest domain and verification sites (elevation in m)

# First look: individual members of simplified MEPS




$$\text{Acc} = \frac{\text{Hits+Corr. Rej.}}{\text{Total}}$$

Coastal sites (advection fog)

Valley sites (radiation fog)

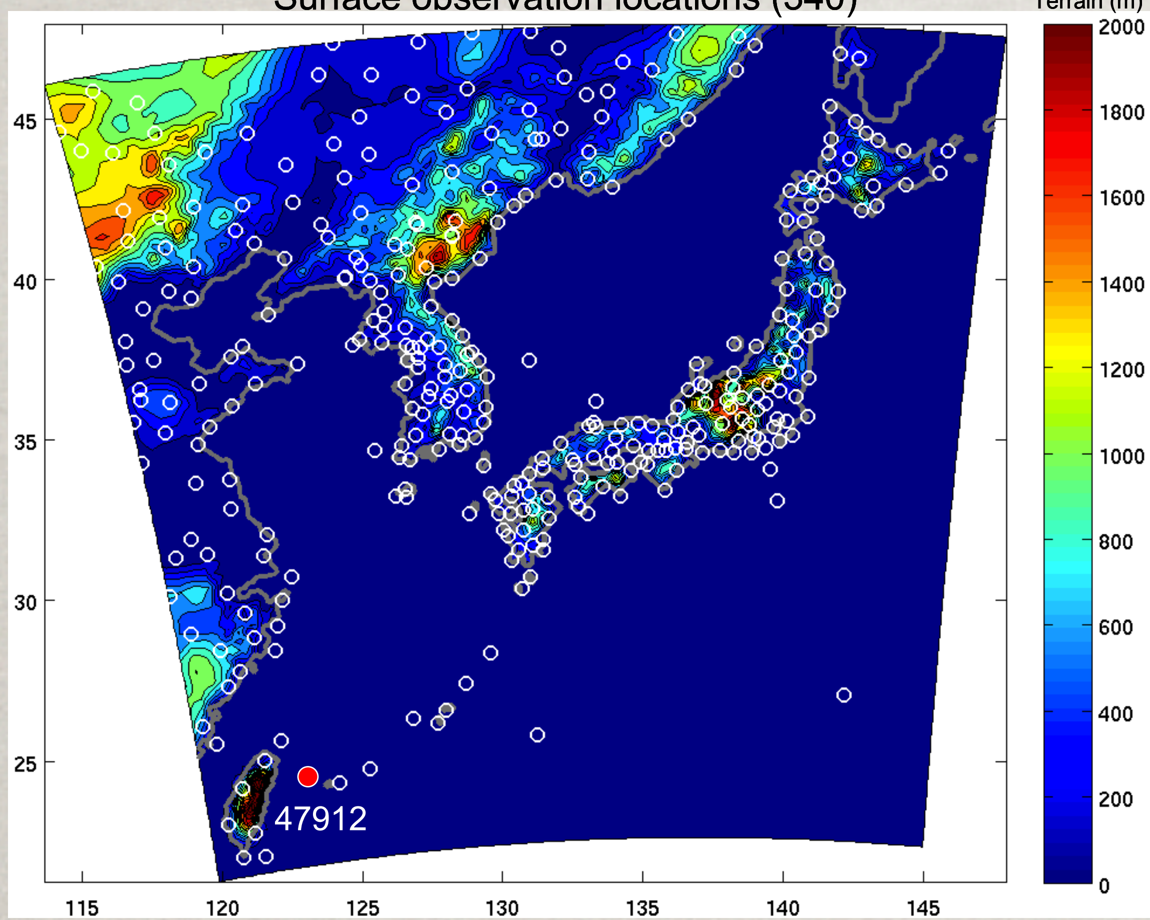
Need to explore sensitivity to thresholds on $q_c$ and extinction

# COAMPS Ensemble System (Navy)

## *Joint Ensemble Forecast System (JEFS)*

COAMPS® Ensemble JEFS Nest 2 Domain (15-km)

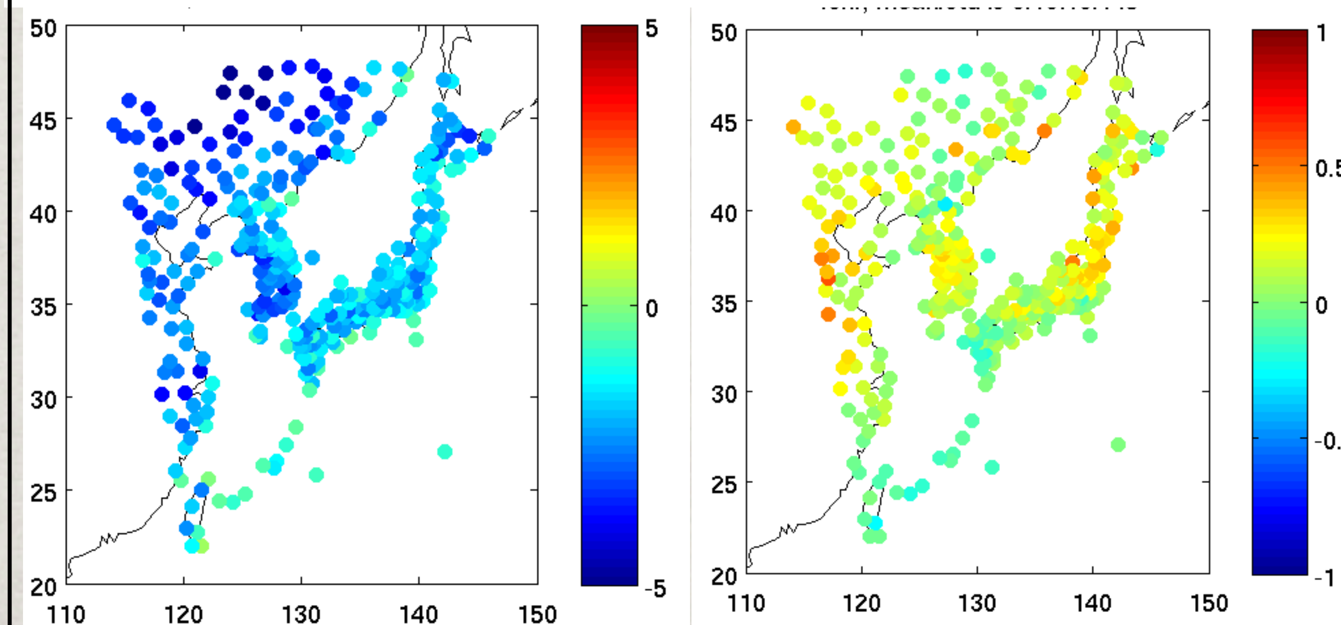
Surface observation locations (340)



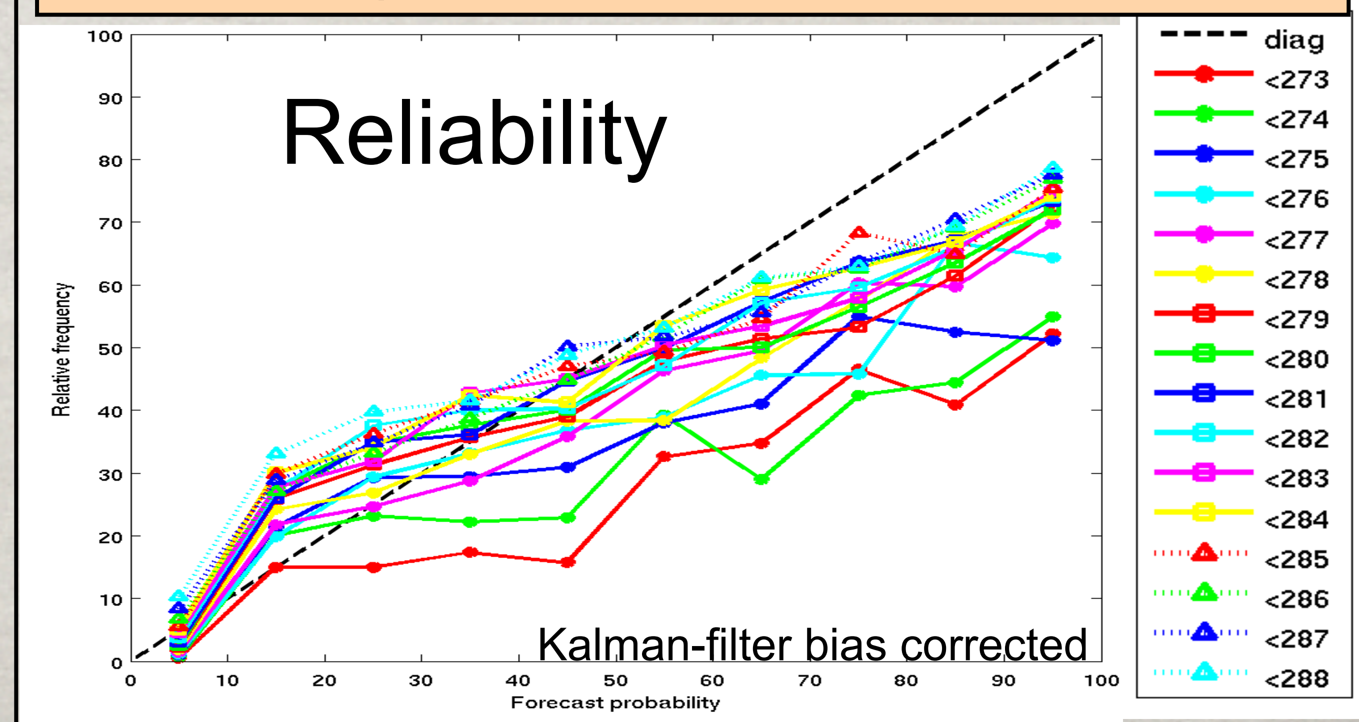

Bias reduction

Raw
(mean = -2.20°C; std = 0.95°C)

Kalman filter
(mean = 0.11°C; std = 0.14°C)



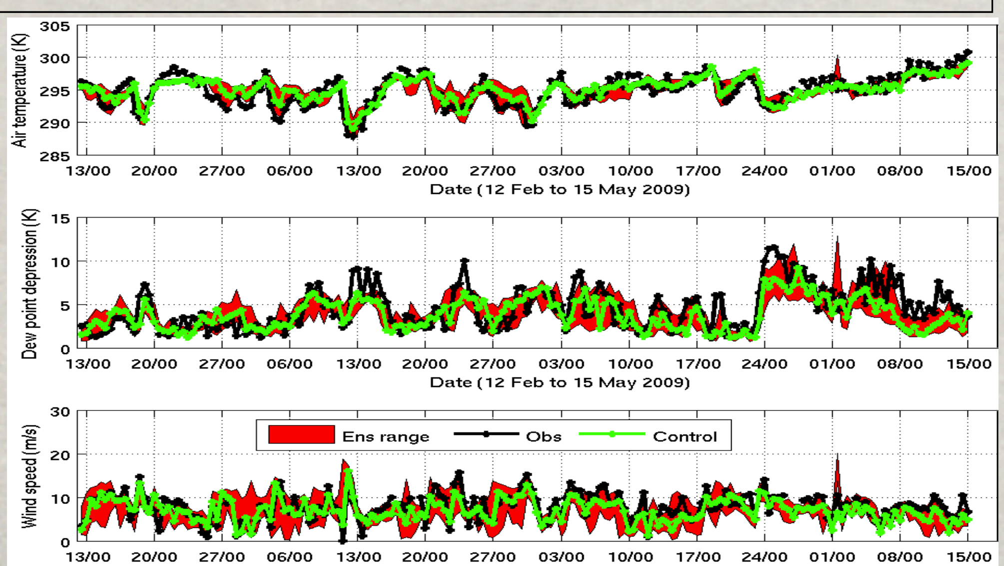

2-m air temperature: 48-h COAMPS forecasts




Sample time series

Station = 47912 Yonagunijima Island

48-h COAMPS raw forecasts



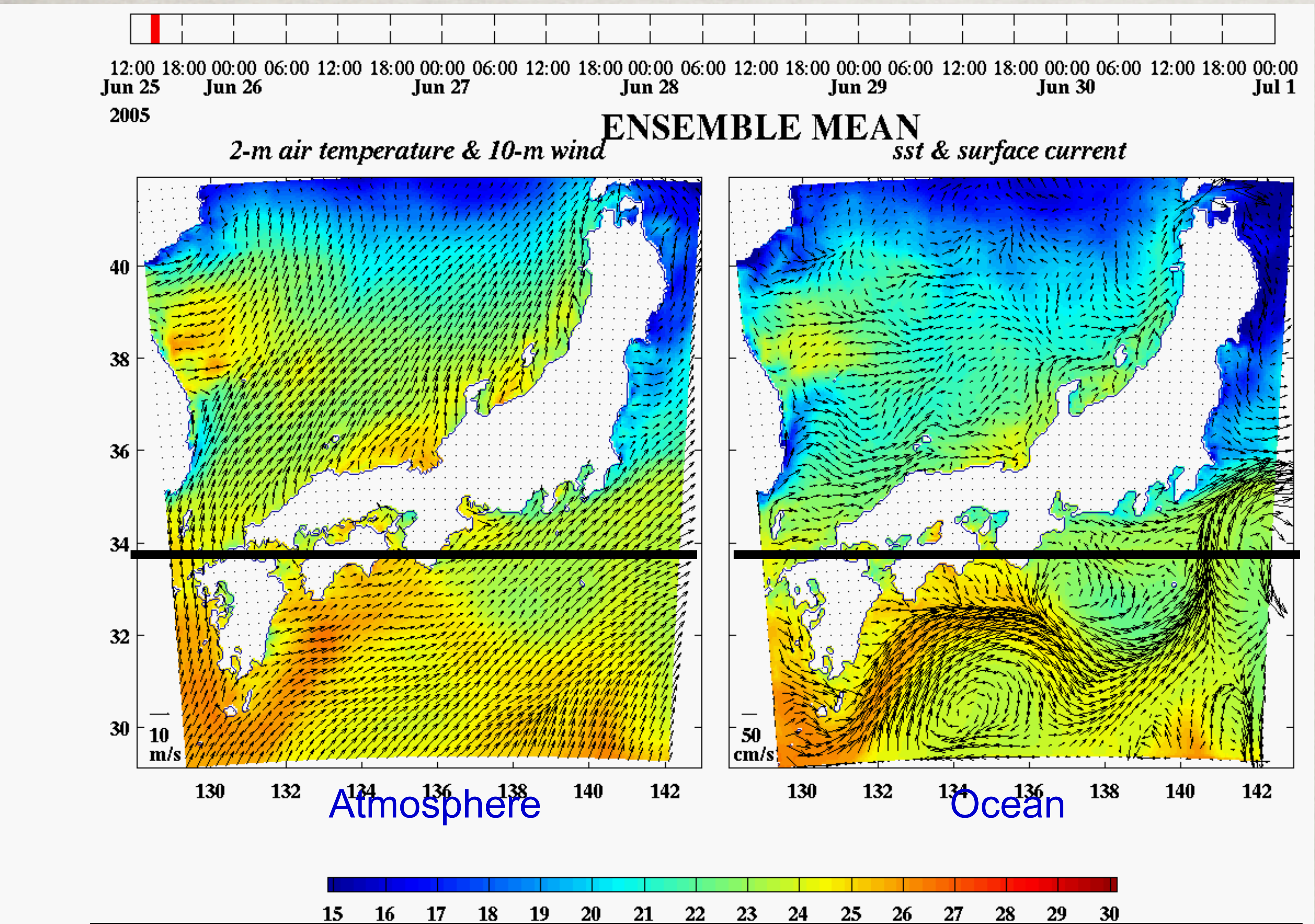

T. Holt and J. Hansen (NRL)

# COAMPS Ensembles

## High-Resolution Coupled Ensembles

**21 members (Δx=5 km), 12-h Forecasts**

25-30 June 2005

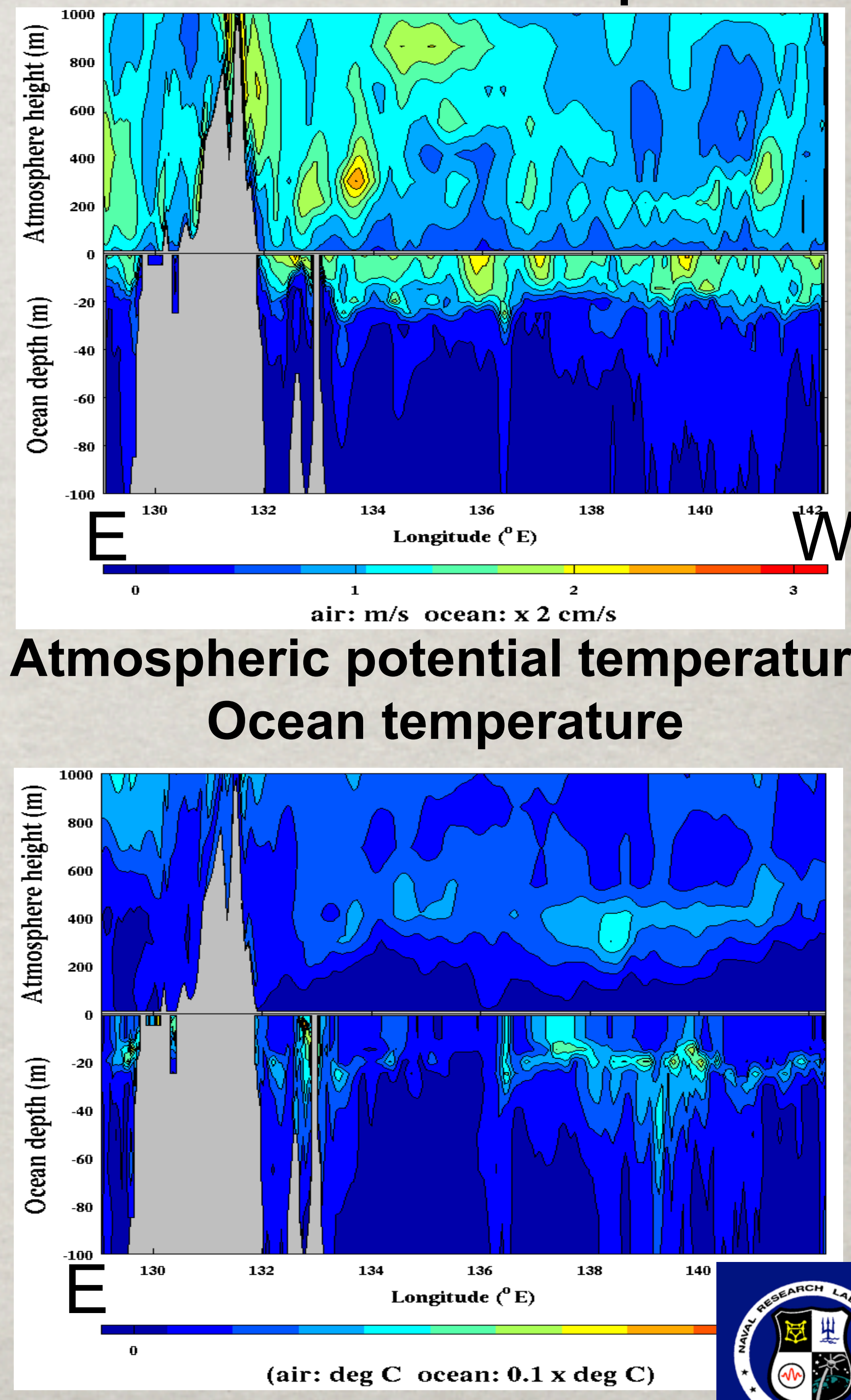



**Ensemble Spread**

21Z 27 June 2005 (9 h)

**Atmospheric u-wind component**
**Ocean u-current component**

**Atmospheric potential temperature**
**Ocean temperature**




**Maximum spread for atmospheric and oceanic temperature and winds/currents are located near atmospheric BL top & ocean ML bottom**

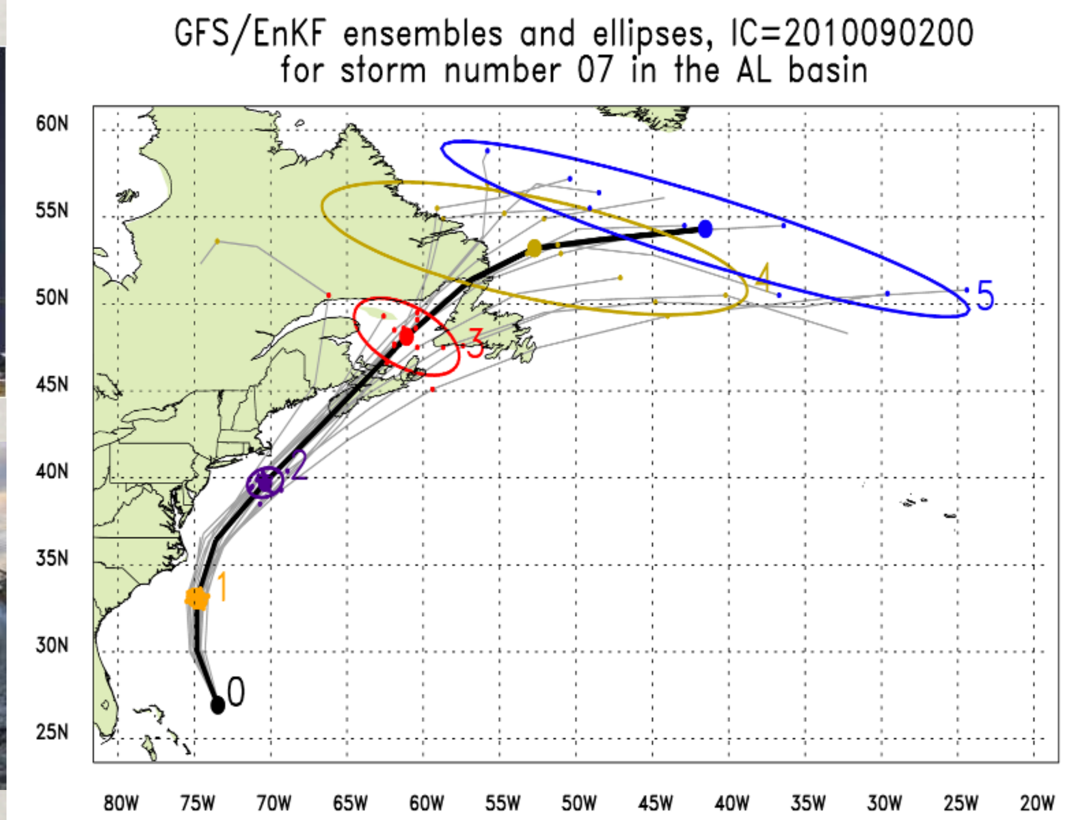
T. Holt (NRL)

# Multi-center efforts

- Ensemble Testbed (NOAA, NCAR etc.) is established to accelerate transition from research to operations (started 2011);
- North American Ensemble Forecast System (NAEFS) expanded to regional ensemble (initially combining NCEP SREF with CMC regional ensemble system, 2015, Jun Du/NCEP and Martin Charron/CMC)

# National Unified Operational Prediction Capability

- Air Force, Navy, NOAA partnership
- A managed National multi-model ensemble prediction system.
- A common modeling framework linking operations and research.
- Draw on individual partner modeling strengths.

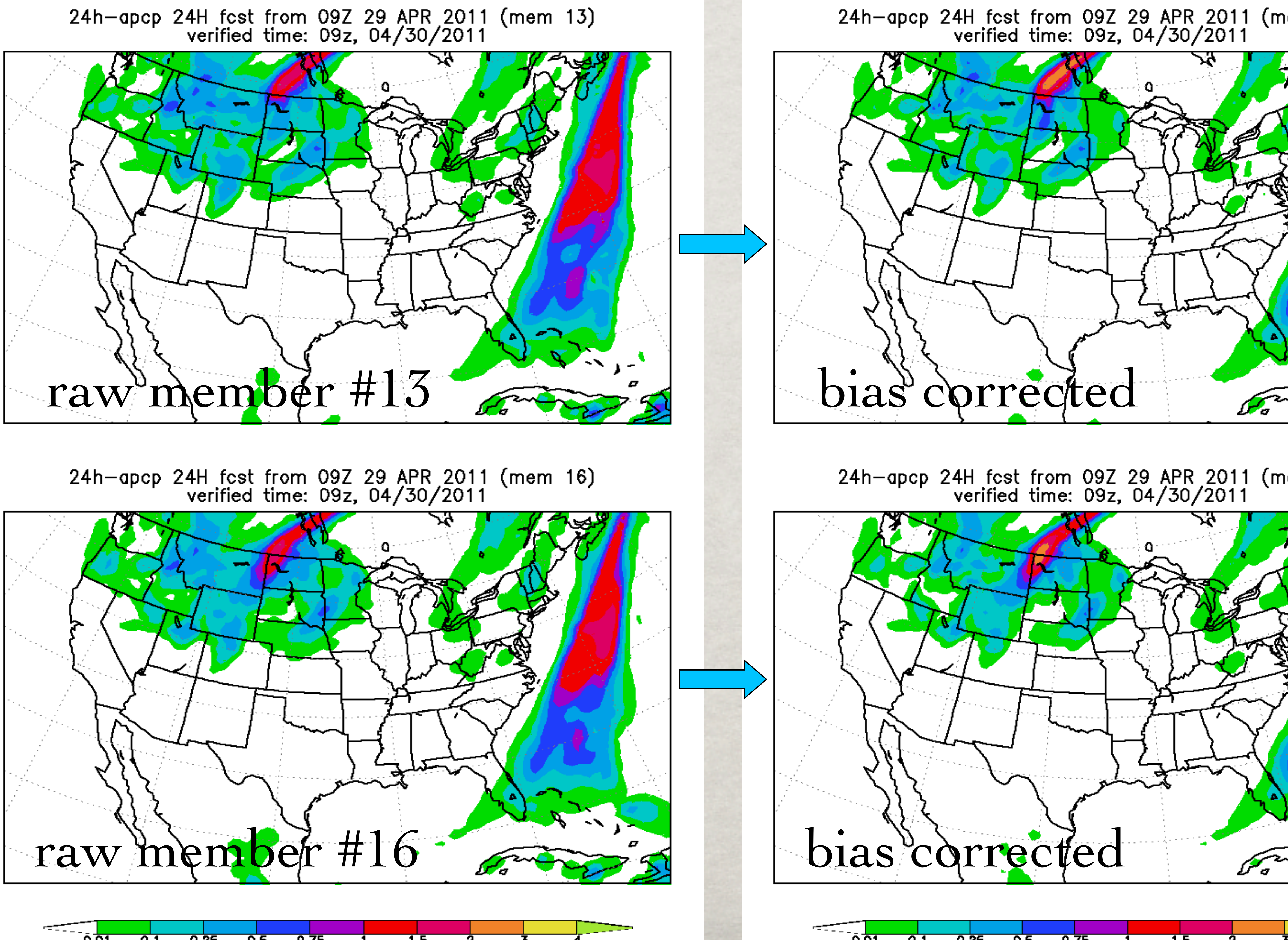



D. McCarren, S. Sandgathe

# Model Error: Calibration

- Increase in interest and activity during 2010-11
- In U.S., motivated largely by private sector and NWS forecast office needs
- Historical data set production still a challenge for mesoscale LAM-EPS
- Following example uses quantile regression (QR) as a basis to calibrate NCAR's 4DWX ensemble predictions in the desert near Salt Lake City, UT
  - What should regressors be? How does calibration change needs for ensembles size?

# NCEP: Frequency-matching corrected SREF precip - light precip reduced and heavier precip enhanced

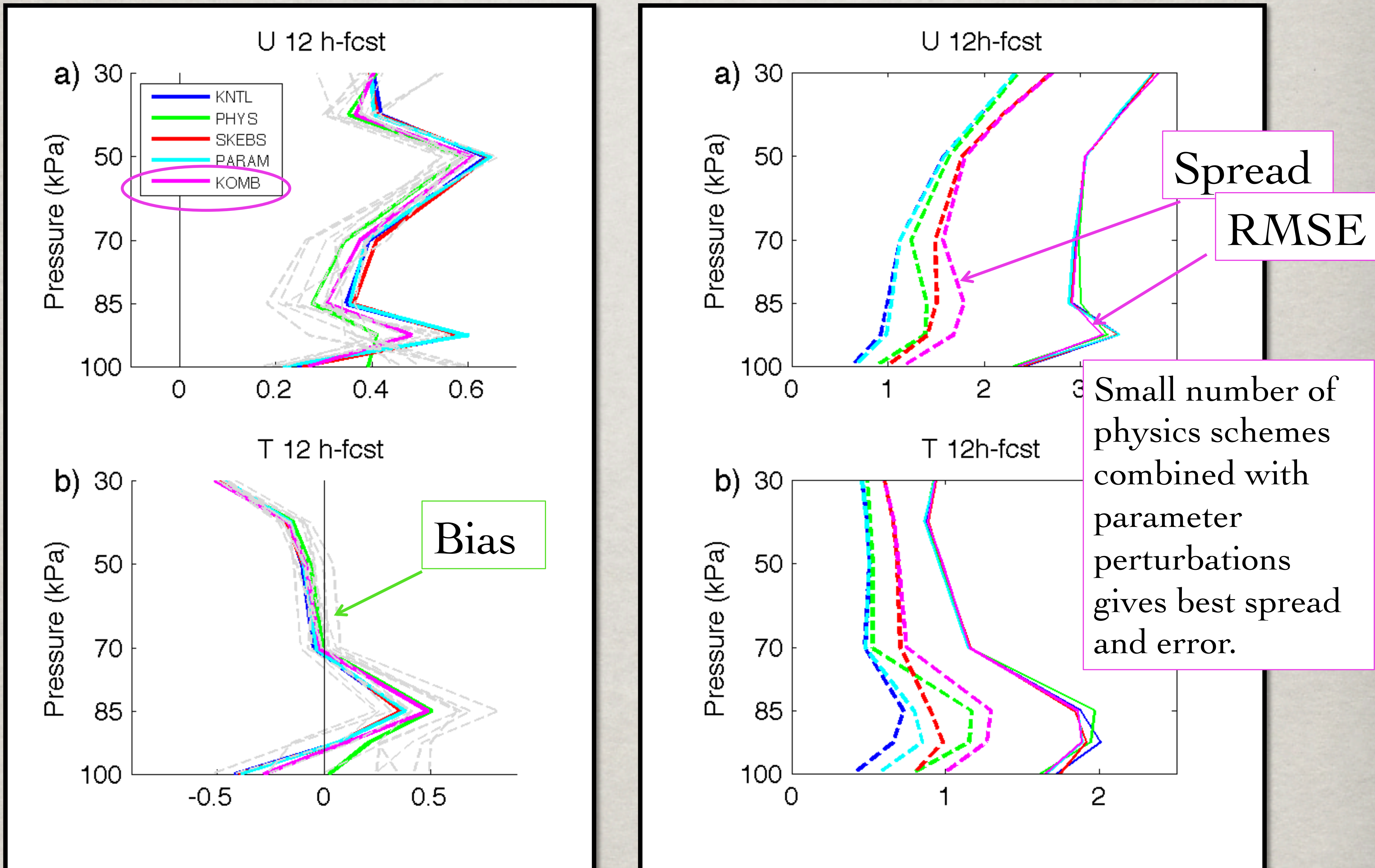



J. Du

# Model Error: Representing Uncertainty

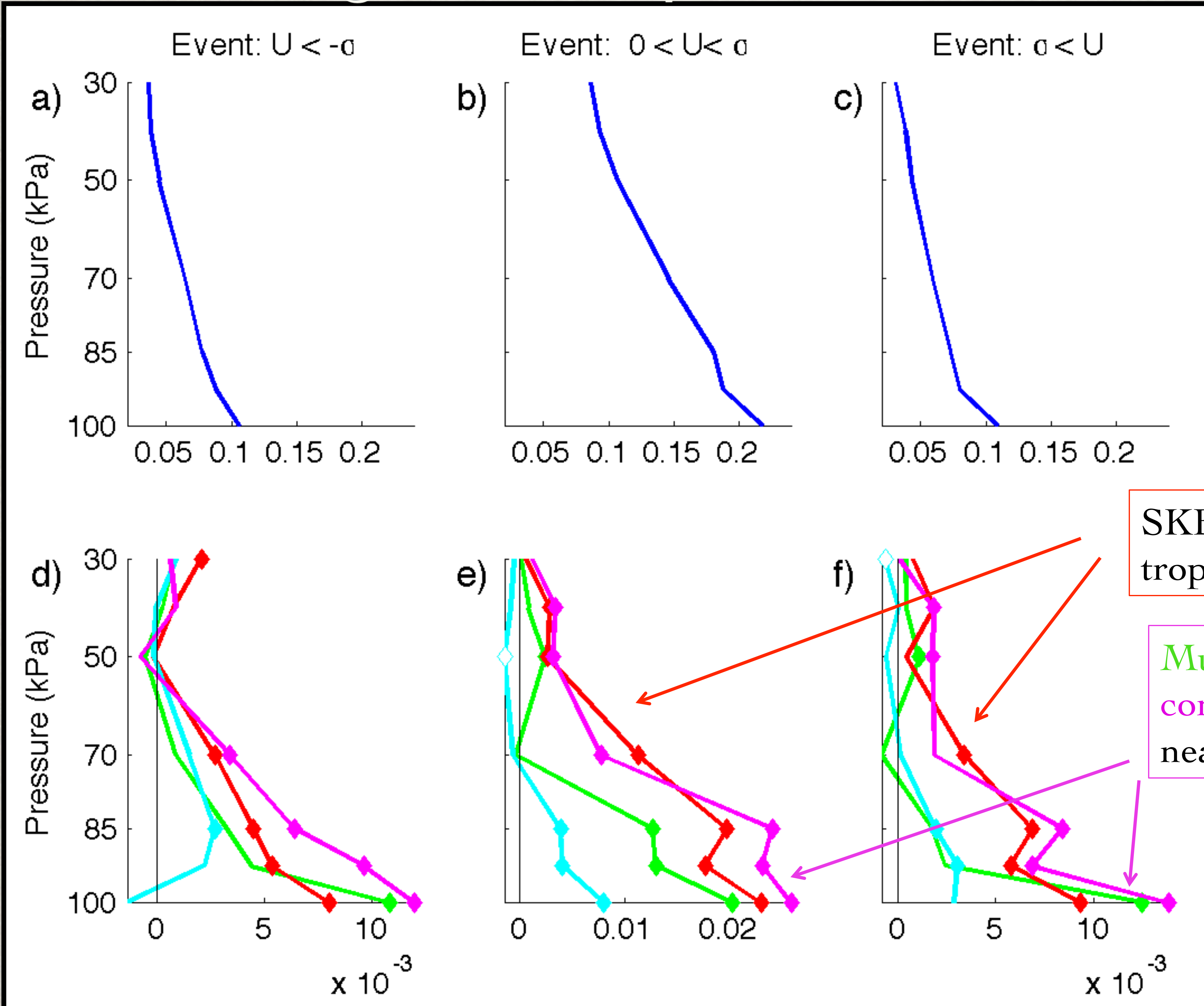
- Stochastic Kinetic Energy Backscatter Scheme now in WRF release (Berner et al. 2011).
- Primary conclusions:
  - SKEBS superior to multi-physics scheme
  - Multiple model uncertainty schemes working together give superior skill.
- Why? General guidance still lacking except where we can interpret behavior near surface and aloft.

# Including model “perturbations” in the WRF




J. Berner

# Including model "perturbations" in the WRF




Brier score and differences

SKEBS helps most in mid-troposphere

Multi-physics and combined approach helps near surface

J. Berner

# LAM ensemble filters

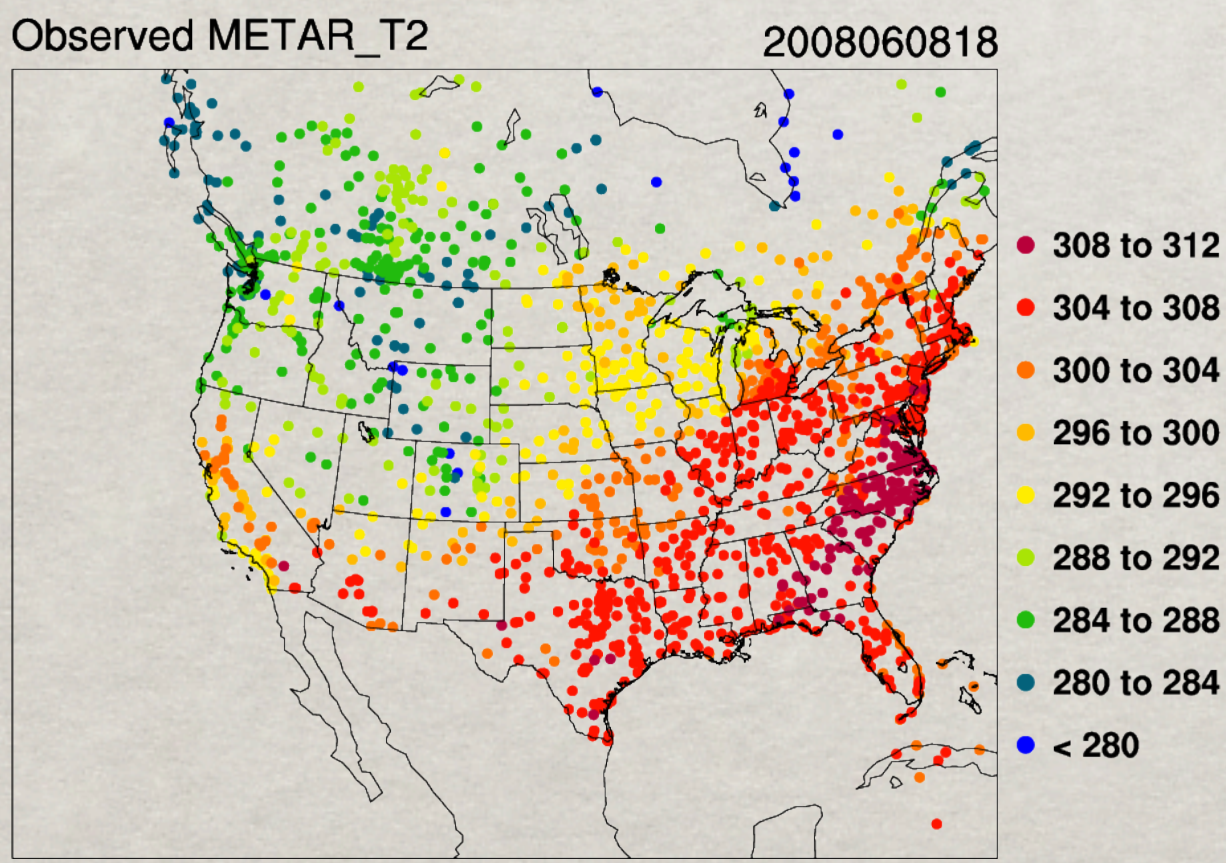
- Significant activity at universities and labs
- Emphasis on ensemble filters for ensemble production
- Ensemble filters as a tool to understand predictability and dynamics

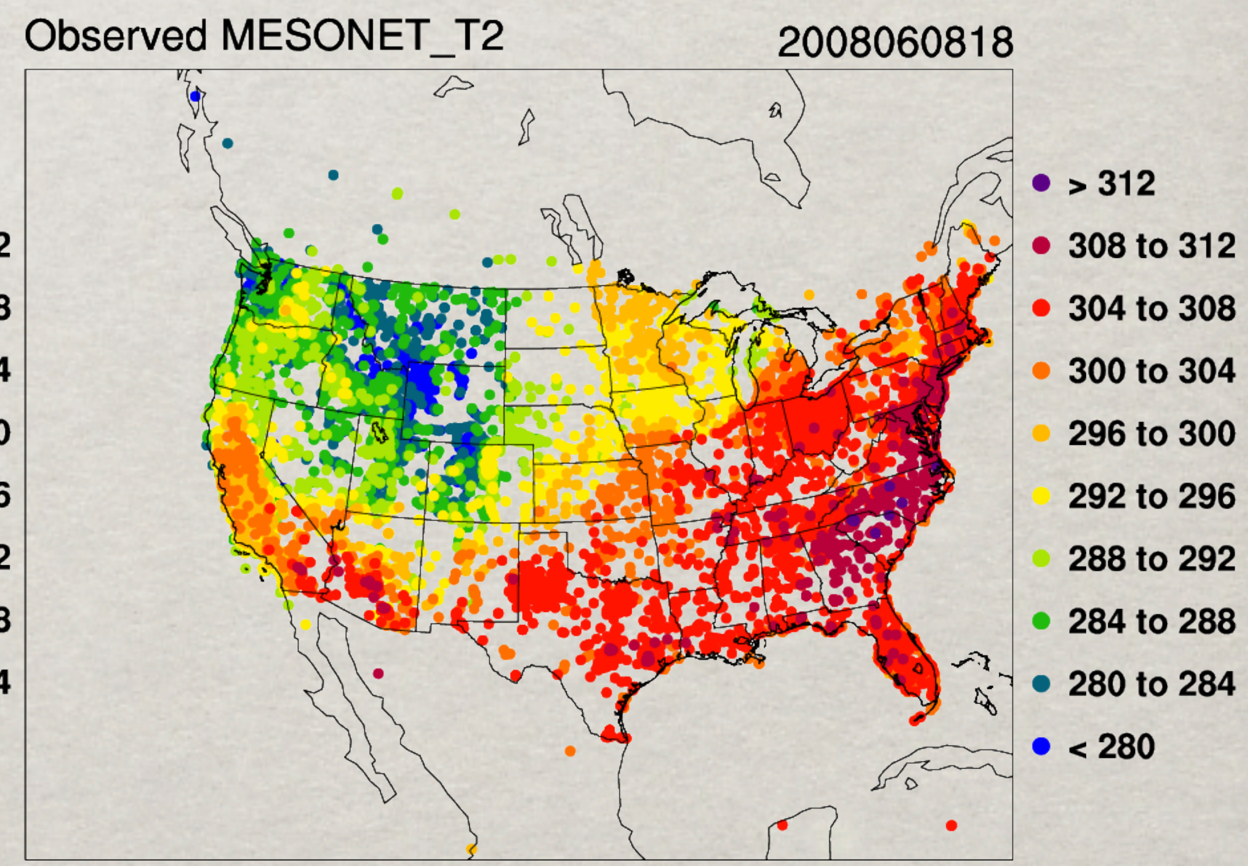
# Accounting for model uncertainty in DA

- Multiple models or schemes violate assumptions underpinning ensemble data assimilation.
    - Easy to think of situations where it might cause problems (e.g. clustering by parameterization scheme)
- Some accounting for model error surely improves mesoscale ensemble forecasts.
- Differentiate between more persistent differences between models (biases) and faster-scale differences that appear more random.

# Observations for data assimilation

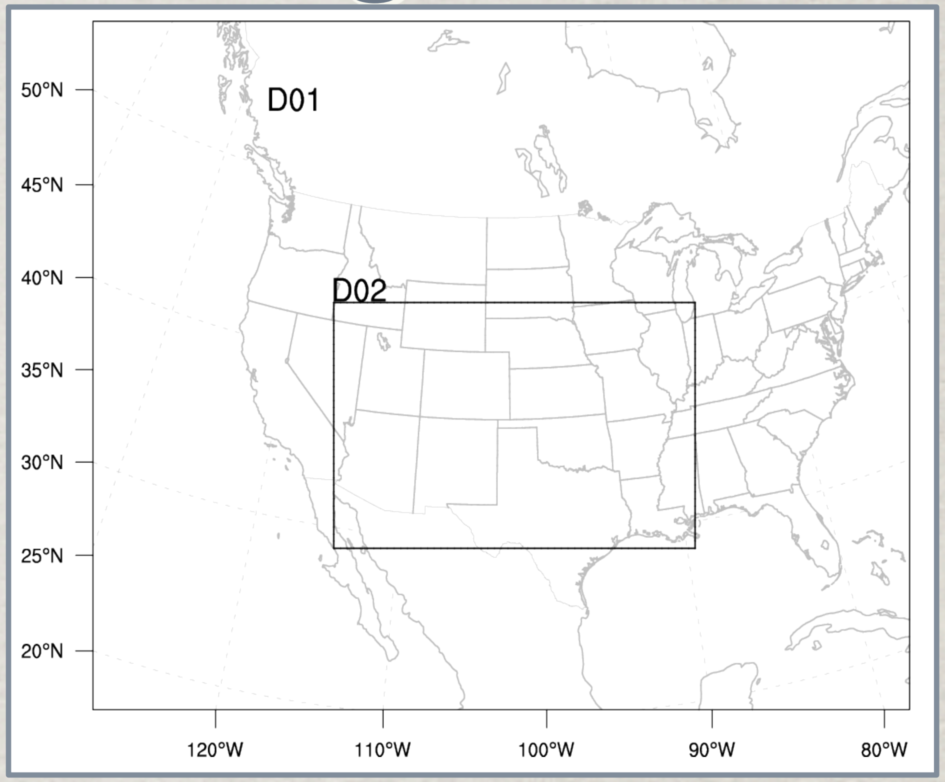
- MADIS (Meteorological Assimilation Data Ingest System)
- RAOB - u, v, t, td, surface altimeter
- METAR - u, v, t, td, surface altimeter
- Marine - u, v, t, td, surface altimeter
- ACARS - u, v, t, td
- Surface observations: metar (for assimilation) and integrated mesonet (for verification)




S.-Y. Ha

# Experiment design




<u>Grids</u>
D1: 123 x 99 (45-km)
D2: 163 x 106 (15-km)
41 levels, two-way nesting

<u>IC/LBCs</u>

- 1°x1° GFS analyses were used for initialization in both domains
- 1°x1° GFS forecasts were used to generate lateral boundaries at 45-km grid four times a day

<u>Ensemble</u>

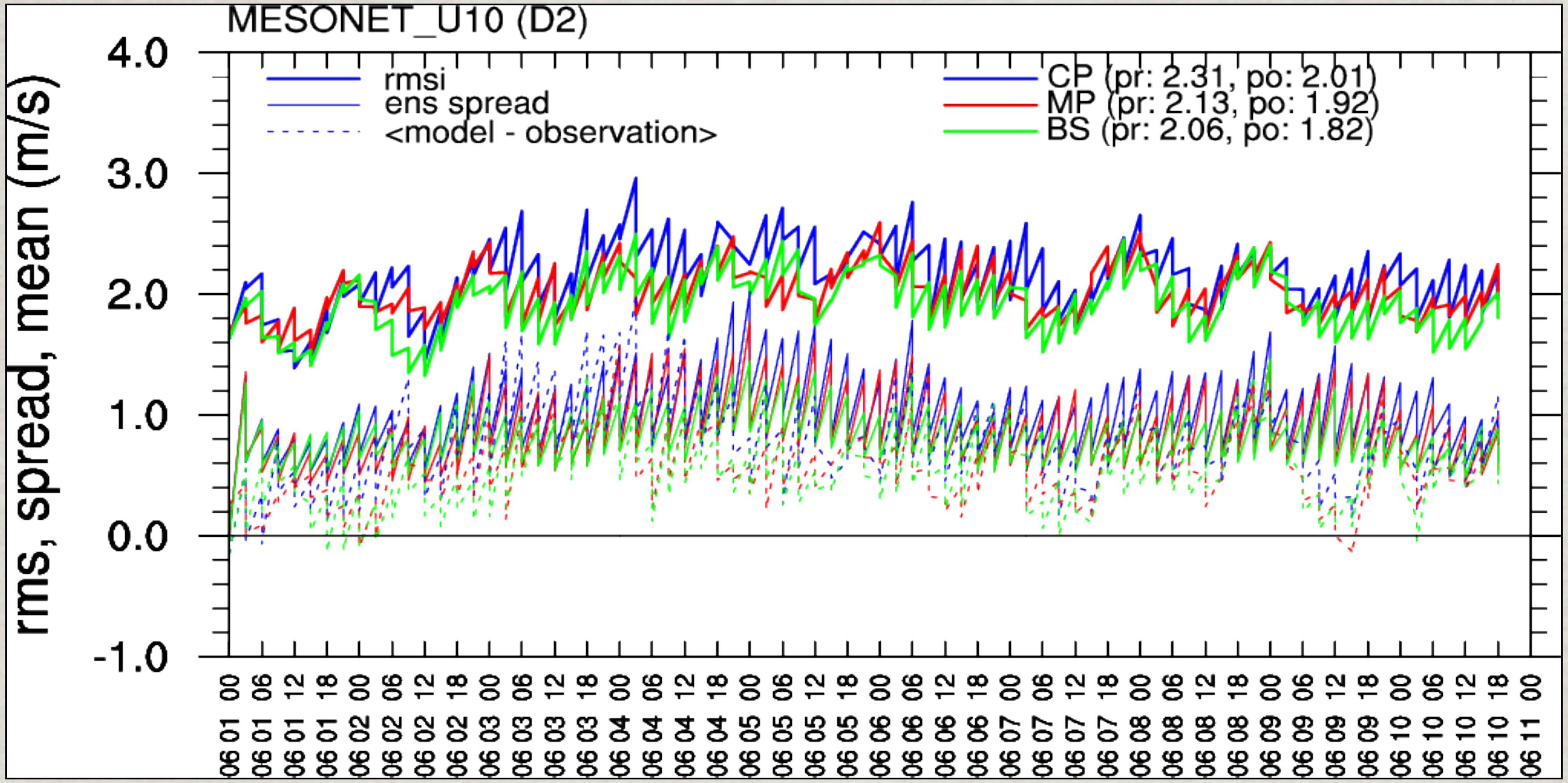
- 50-member ensemble
- WRF/DART to generate analyses and forecast

<u>Cycling period</u>: 1-10 June 2008 (3-hrly cycling)

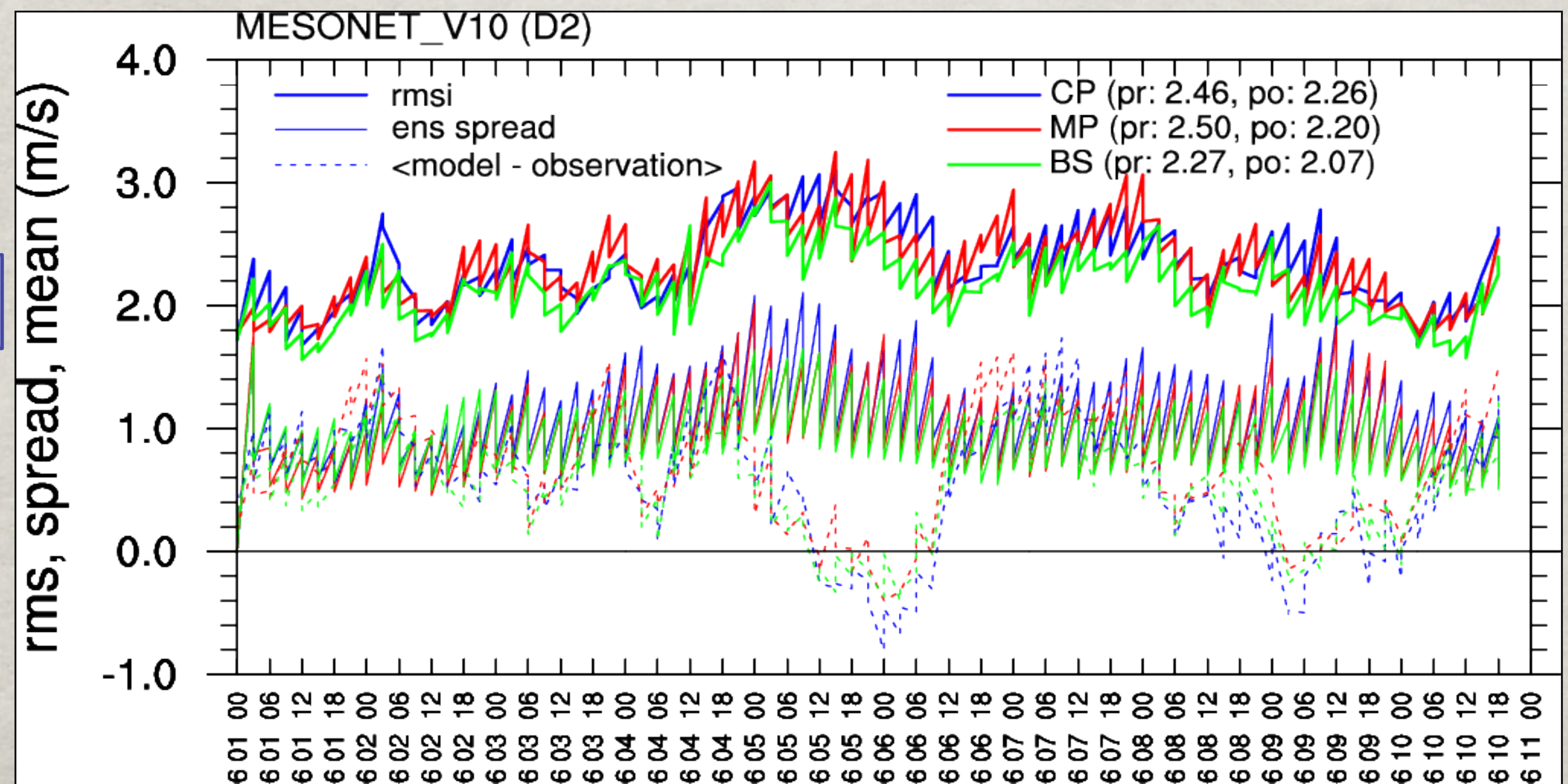
S.-Y. Ha

# Surface mesonet verification; 3-h forecast and analysis

10-m U



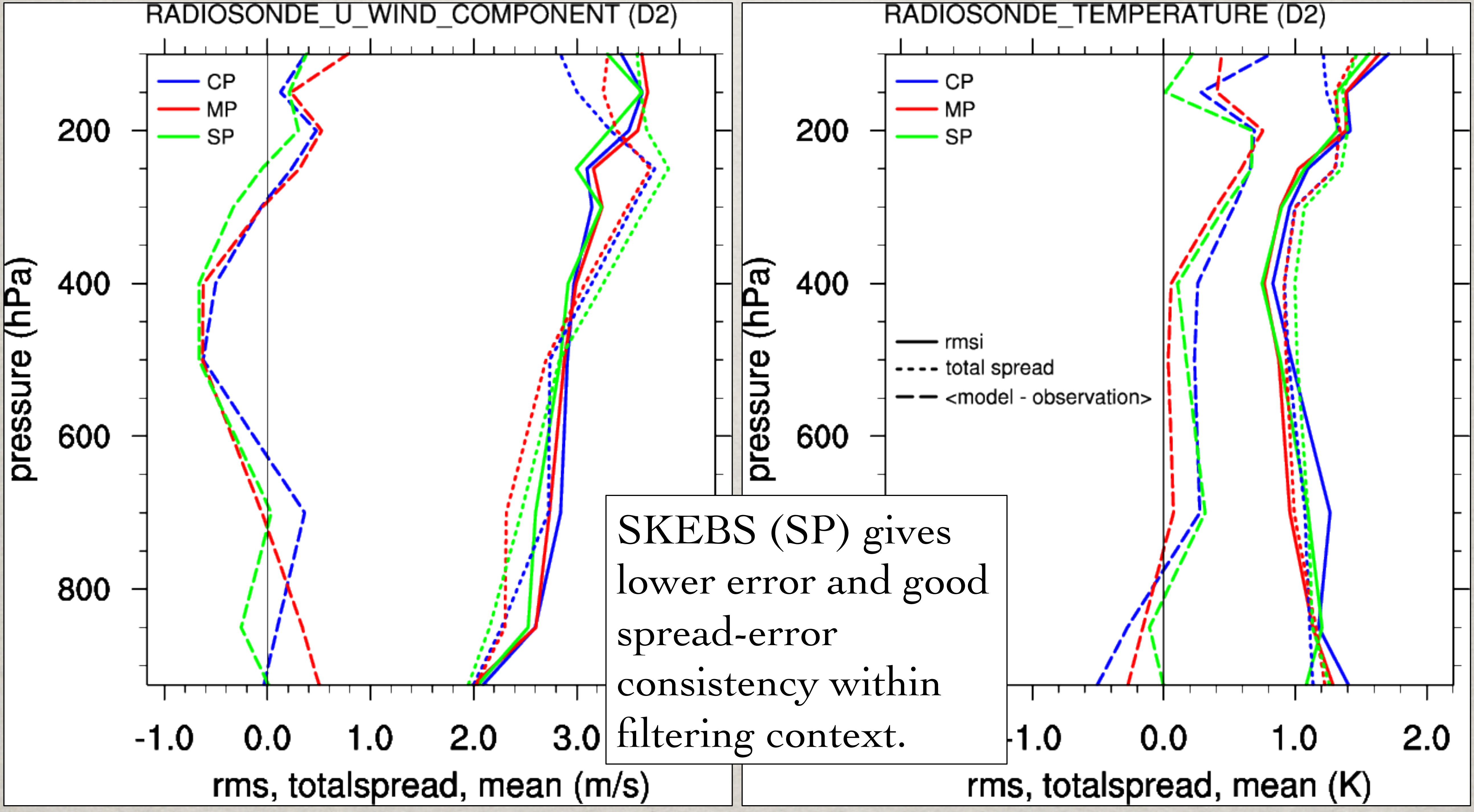

10-m V




SKEBS (BS) more skillful than multi-physics at the surface, within filtering context.

S.-Y. Ha

# Verification against radiosondes; 3-h forecast



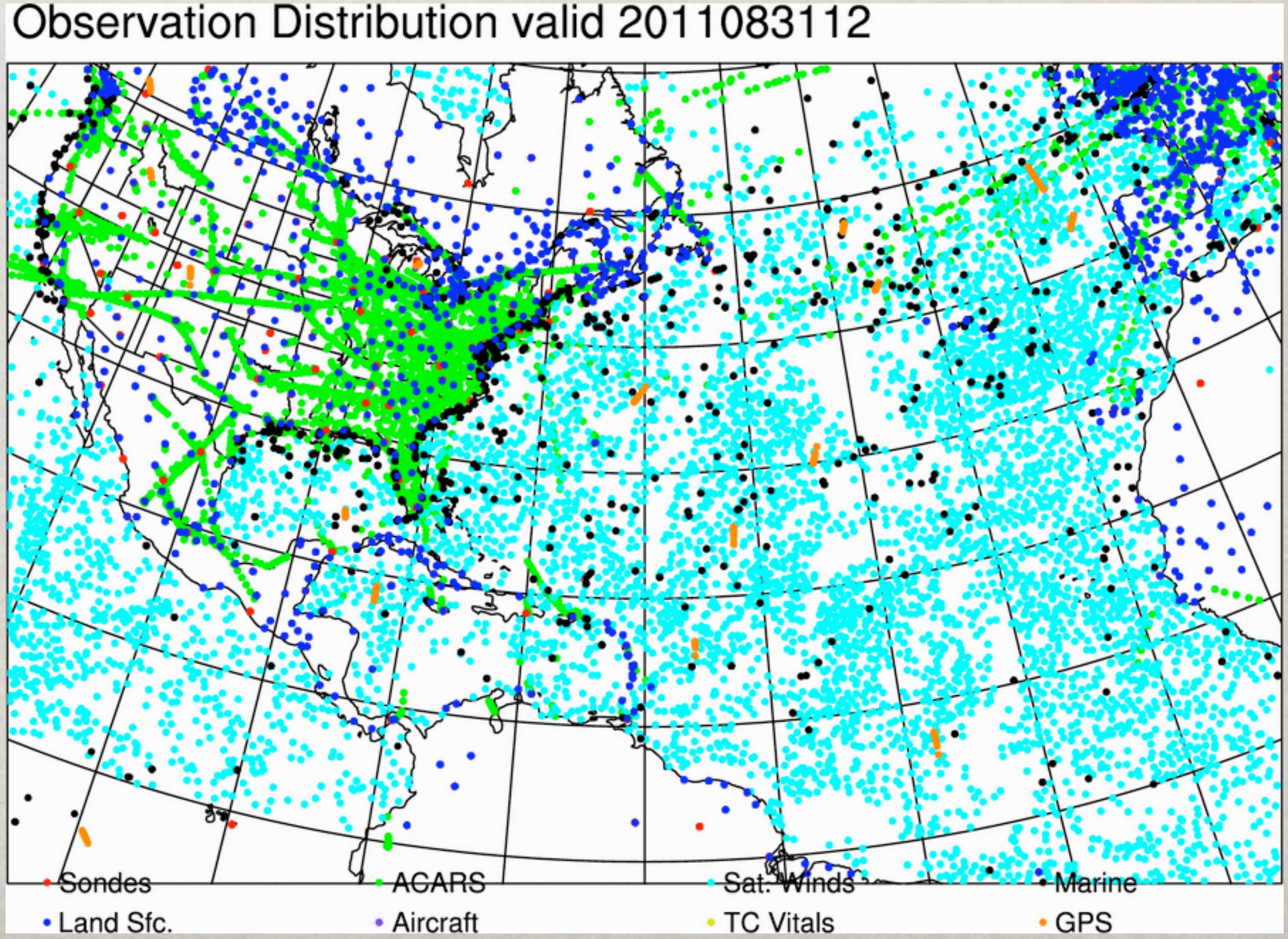

SKEBS (SP) gives lower error and good spread-error consistency within filtering context.

S.-Y. Ha

# Advanced Hurricane WRF Cycling Assimilation System

- WRF ARW (v3.3), 36 km horizontal resolution over basin, 96 ensemble members, DART assimilation system (http://www.image.ucar.edu/DAReS/DART/).
- Observations assimilated each six hours from surface and marine stations ($P_{sfc}$), rawinsondes, dropsondes > 100 km from TC, ACARS, sat. winds, TC position, MSLP, GPS RO

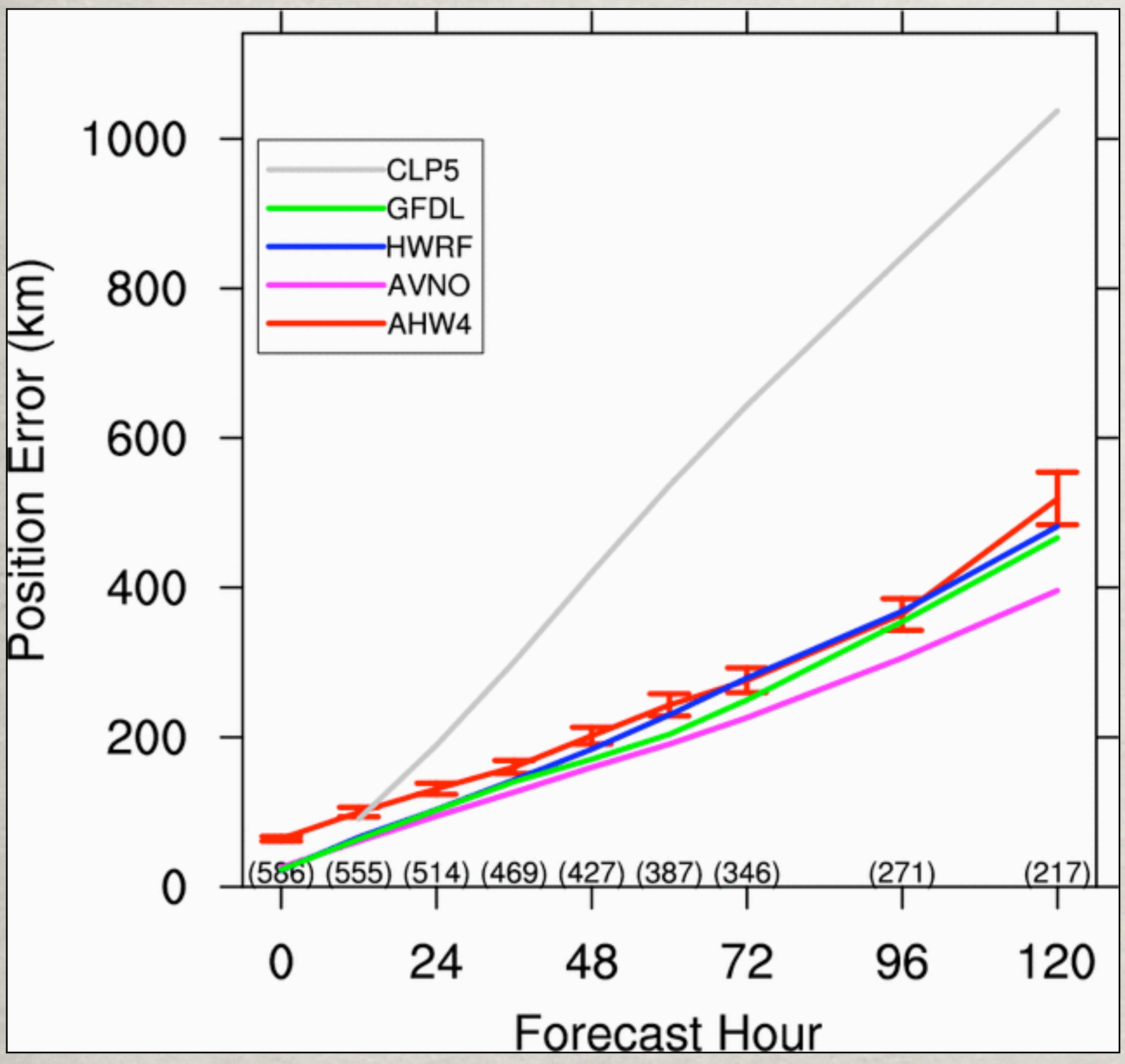
- Initialized system on 29 July 2011, continuous cycling using GFS LBC
- No vortex bogusing or repositioning, all updates to TC due to observations



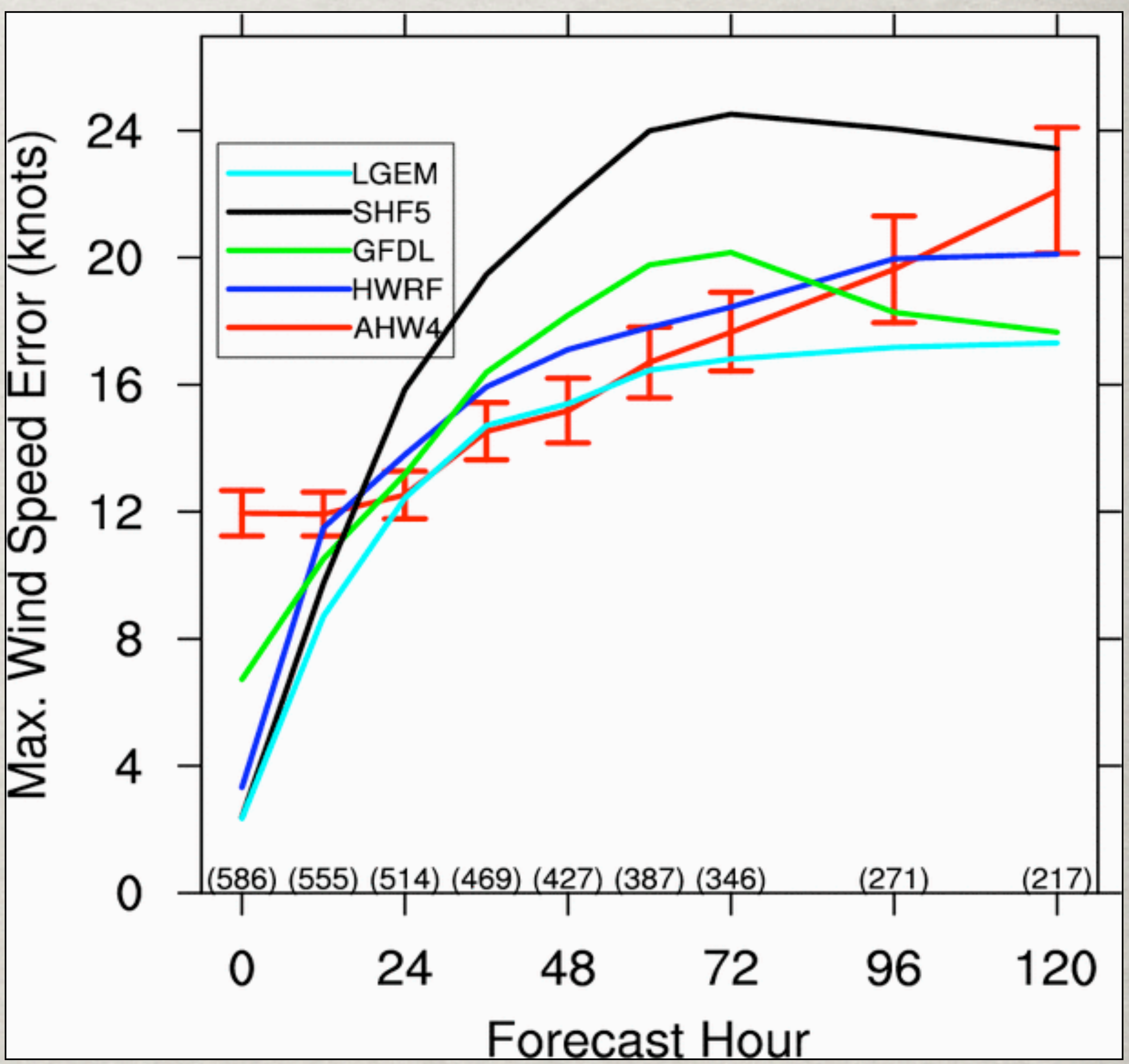

R. Torn

# 2008-2010 Retrospective Forecasts

**Track**




**Maximum Wind Speed**




R. Torn

# Opportunities!

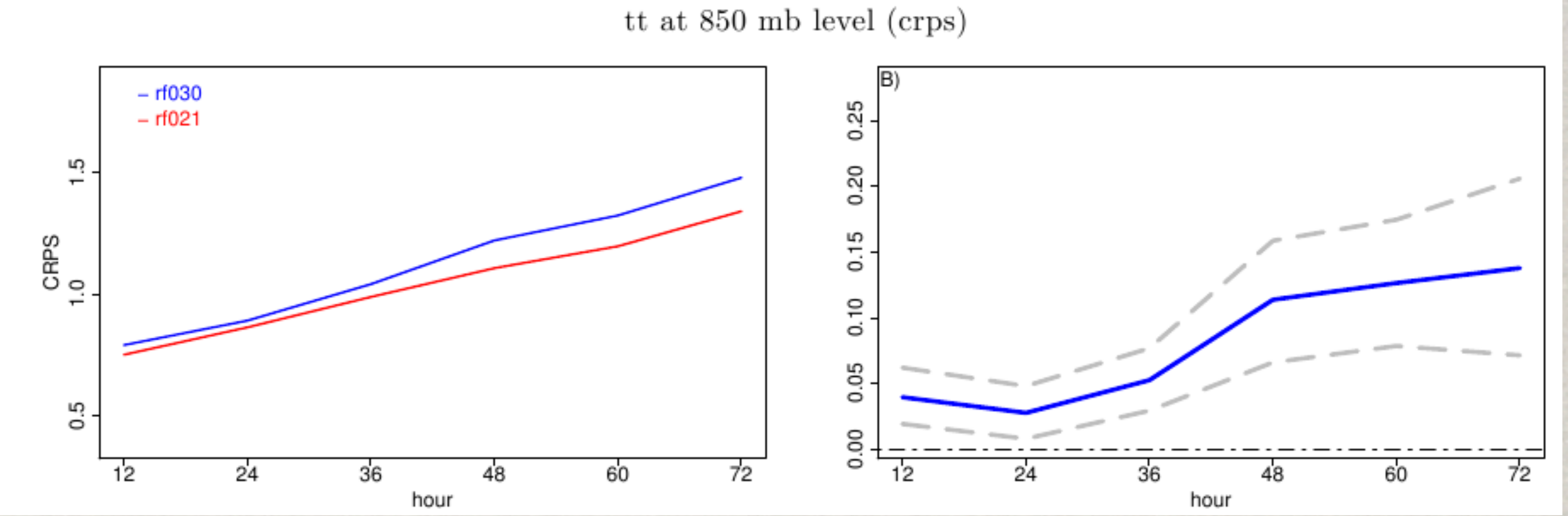
Post-docs wanted:

- Investigations of structural model error within an ensemble filter framework (at NPS)
- Predictability and observing strategies in complex terrain (at NPS)
- Marine boundary layer parameterization and ensemble data assimilation (at NCAR and/or NPS)

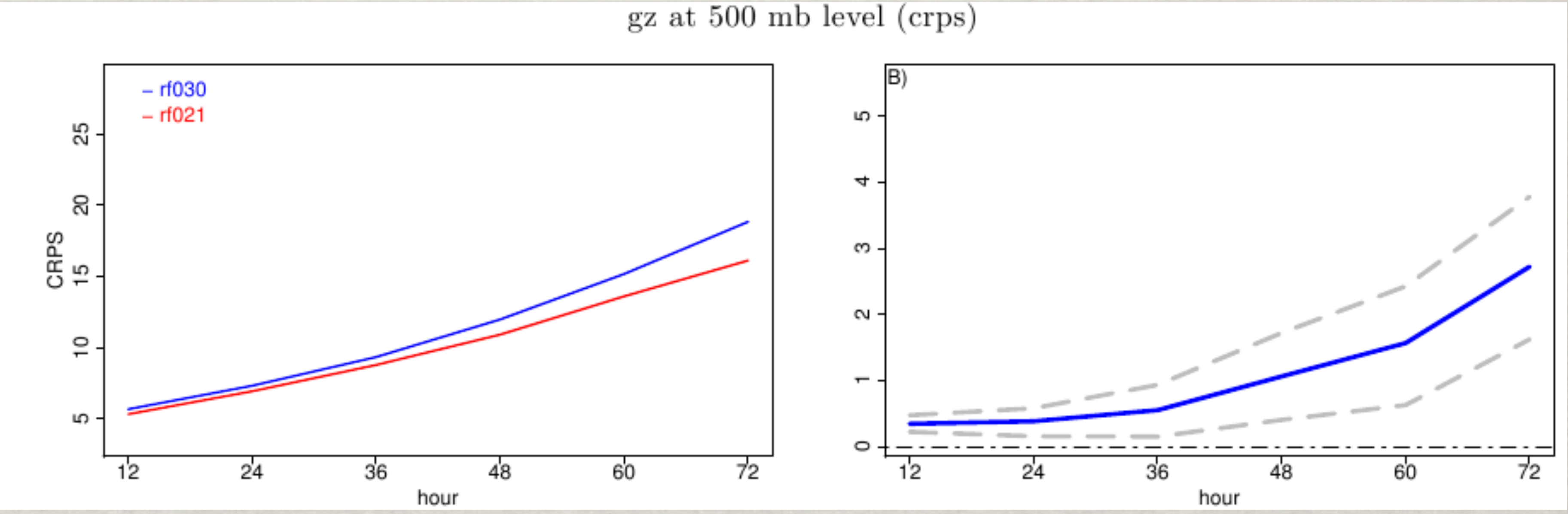
# Extras

# Verification against radiosondes
# REPS (GEM 4.2, red) vs REPS (GEM 3.2, blue)

Temperature at 850 hPa




Geopotential Height at 500 hPa




CRPS (left) and CRPS difference (with 90% confidence intervals, right) between the previous experimental REPS (blue) and operational REPS (red).

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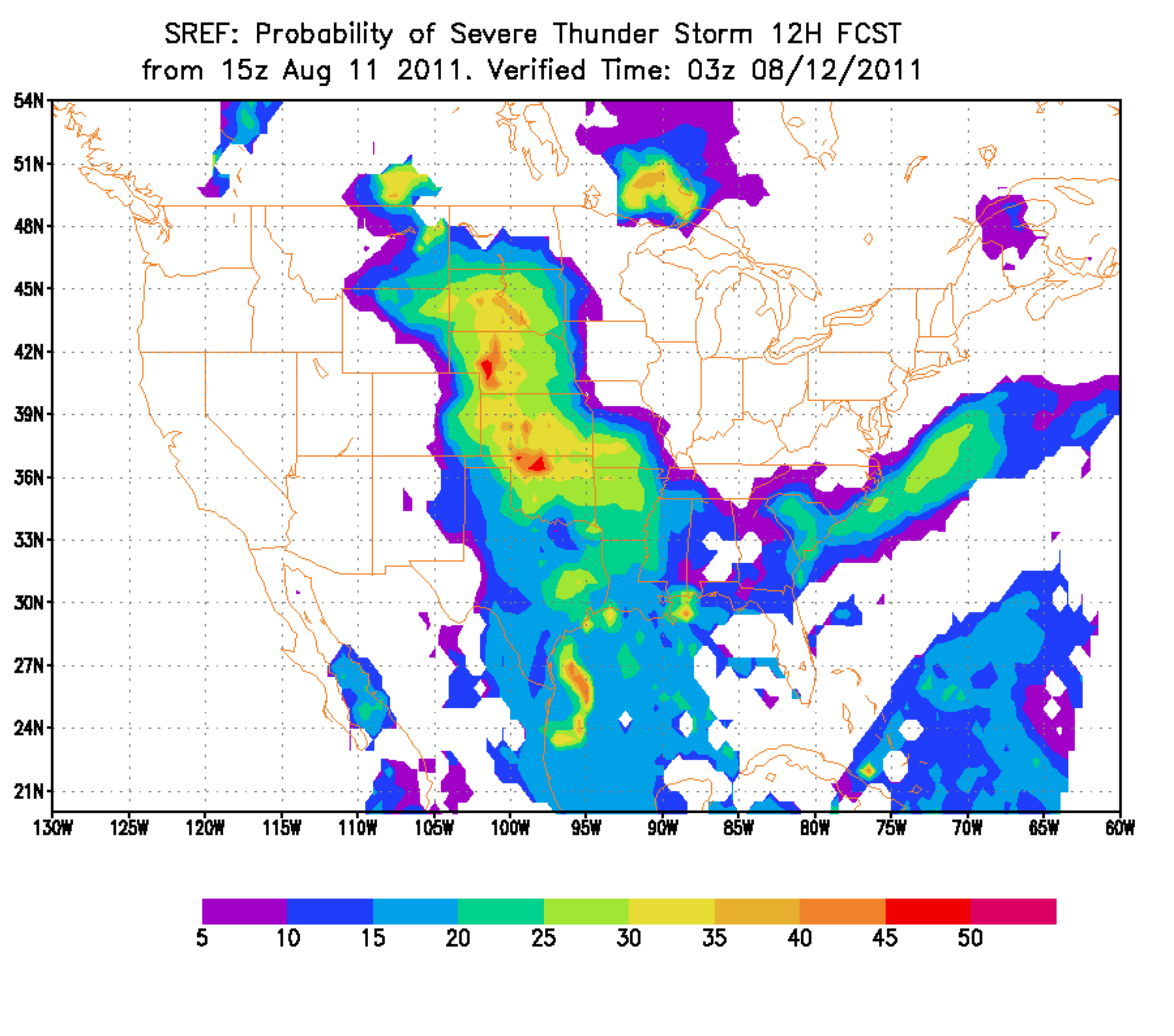
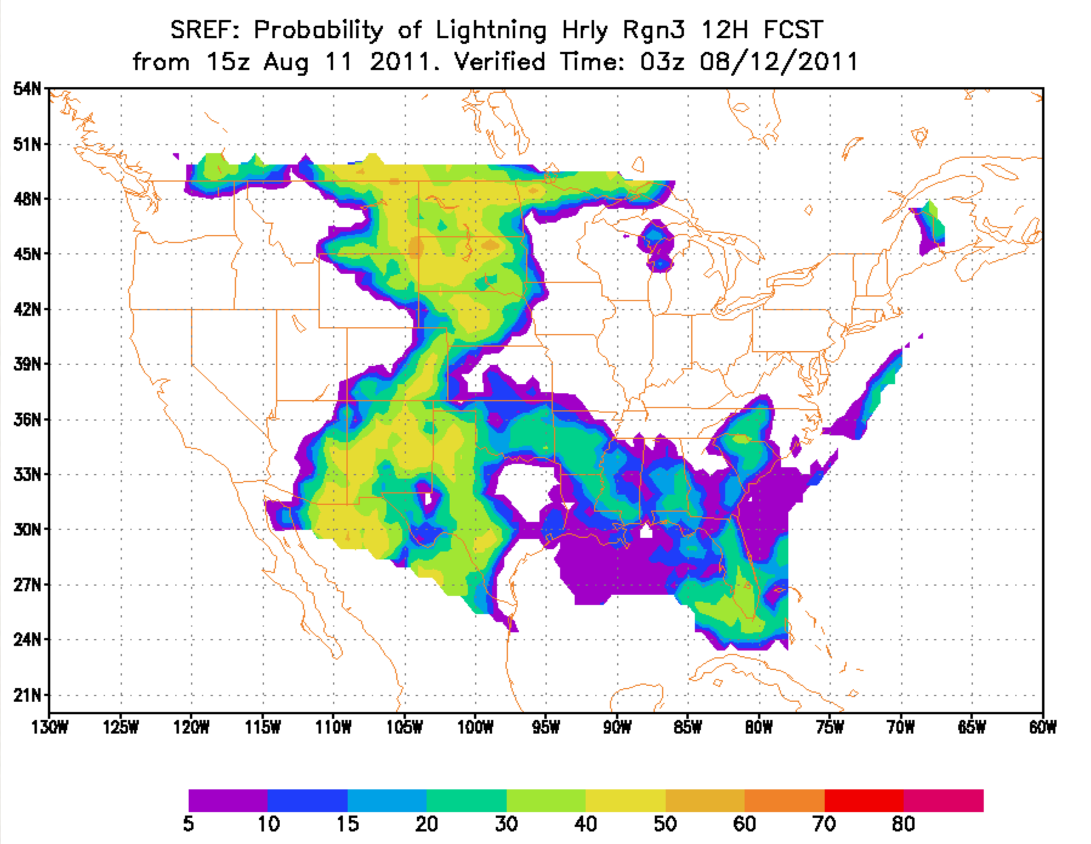
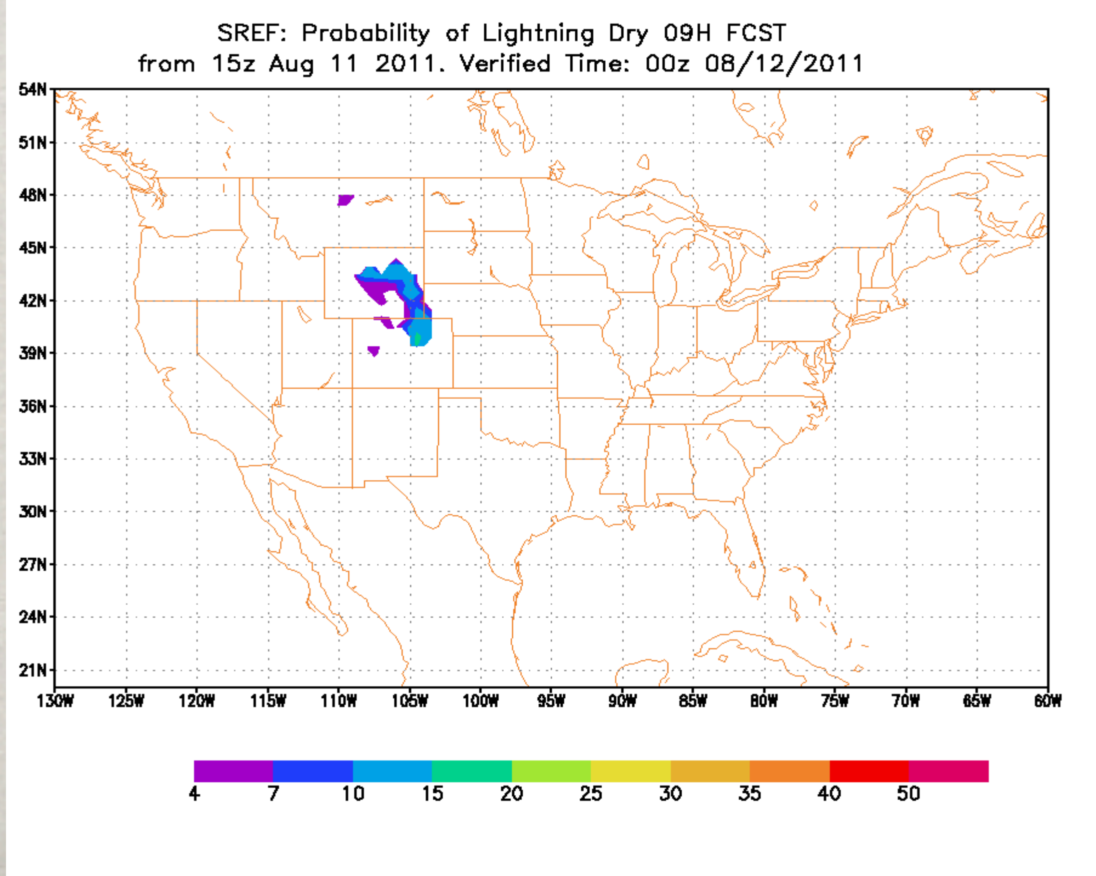
# Examples of severe thunder, lightning and dry lightning probabilistic products



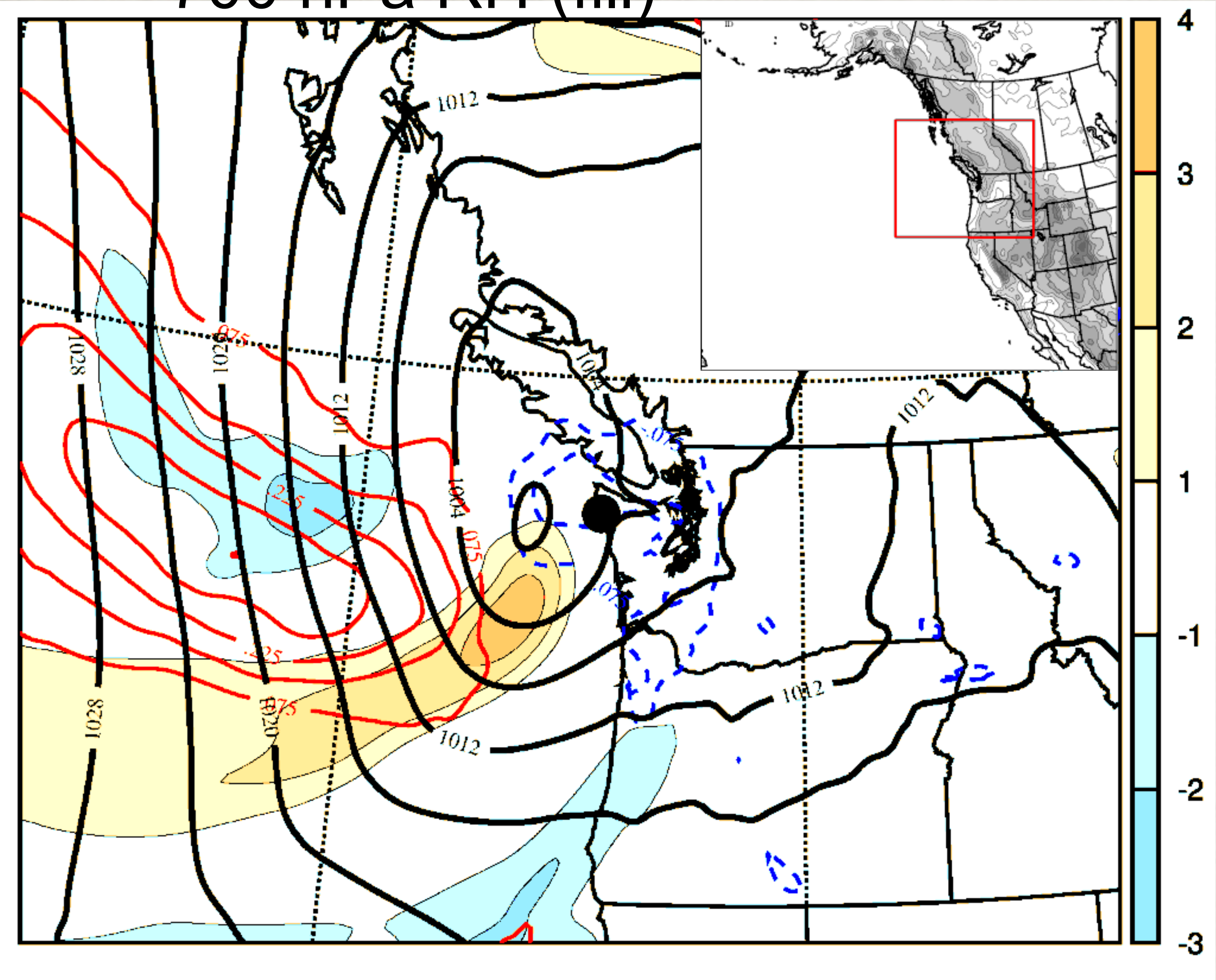




J. Du

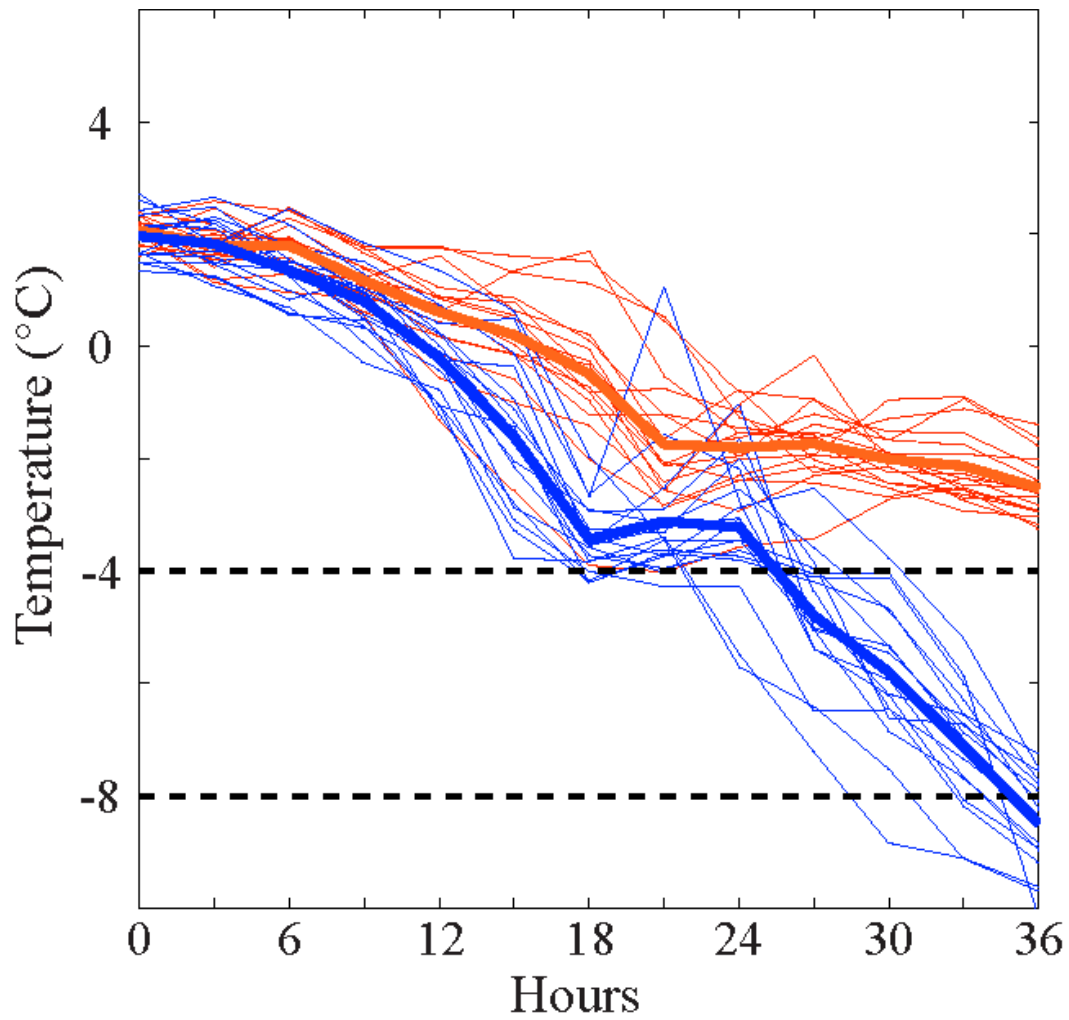
# Ensemble Data Assimilation and Predictability
## *Application of COAMPS EnKF to Pacific NW Snowstorm*

100-member EnKF Data Assimilation System (27 and 9-km)

Covariance between SLP and
700 hPa Temp (contours)
700 hPa RH (fill)




Puget Sound 850 hPa Temp
17 Warm and Cold Members



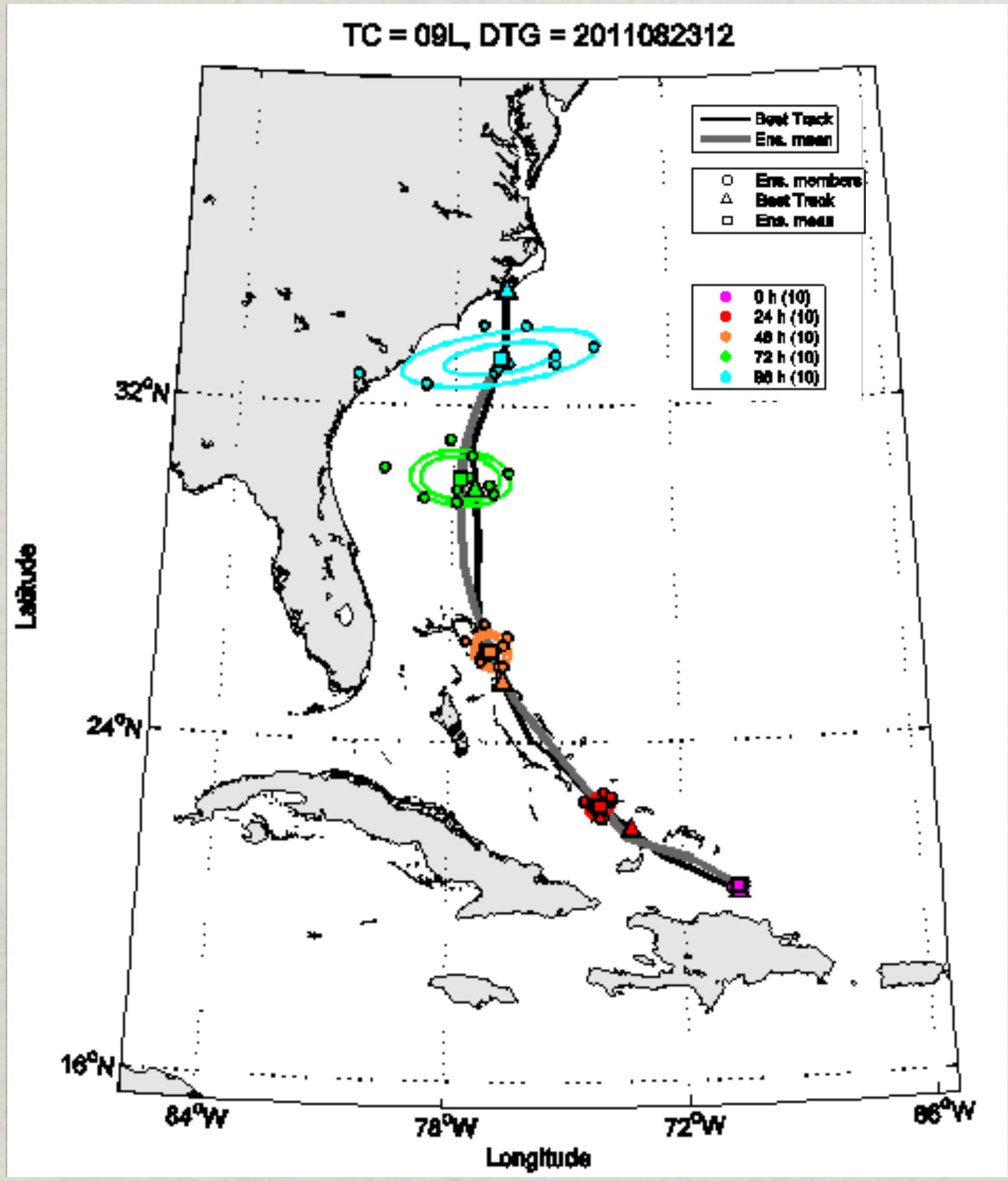

- Flow dependent mesoscale covariances
- Mesoscale cyclogenesis (500 km difference in low position)
- Rapid error growth; 36-h temperature differences of 6°C.

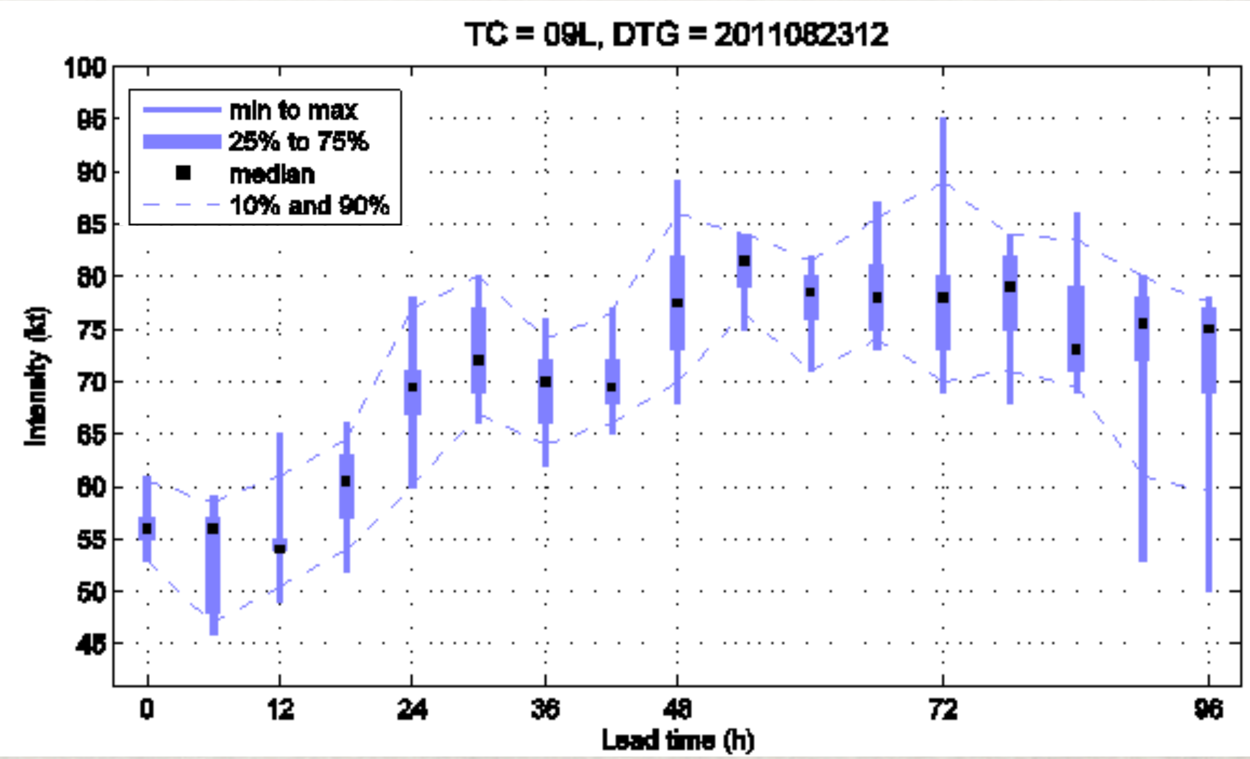
A. Reinecke and J. Doyle (NRL)

# COAMPS-TC

## *Irene Ensemble Forecasting*

10 Member 5-km Resolution Ensemble System (COAMPS-TC DART)




TC position from individual ensemble members every 24 h and ellipses that encompass the 1/3 and 2/3 ensemble distributions.

Median, minimum, maximum, and 10% and 90% distributions are shown

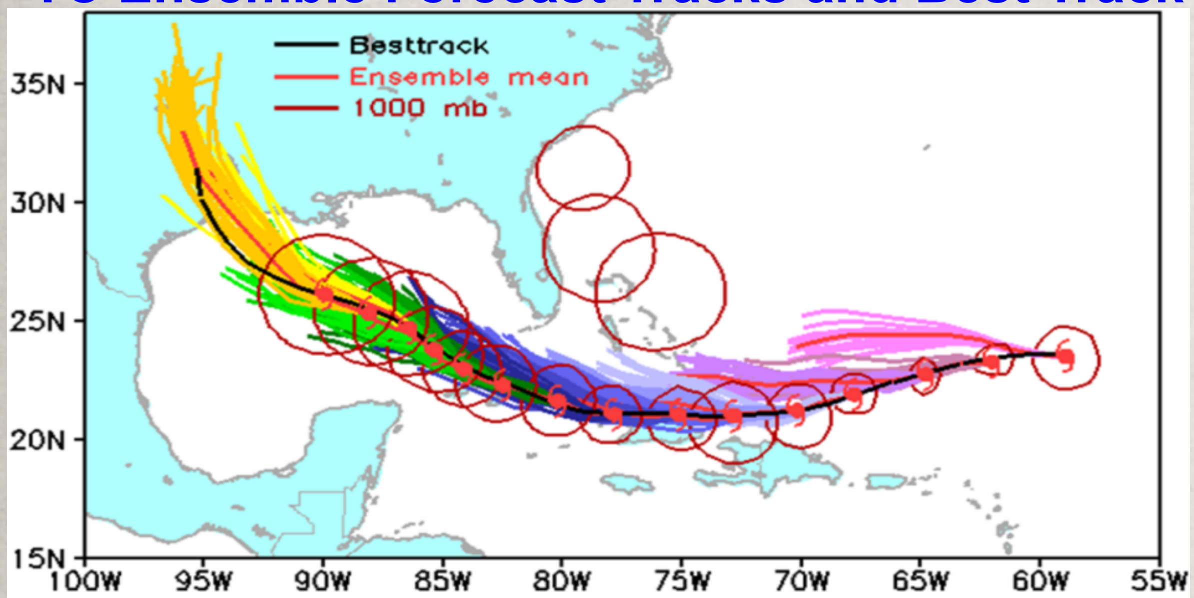
**COAMPS-TC DART Ensemble System Tested in Real Time in 2011. The System Performed Well during the Landfall of Hurricane Irene.**

A. Reinecke and J. Doyle (NRL)

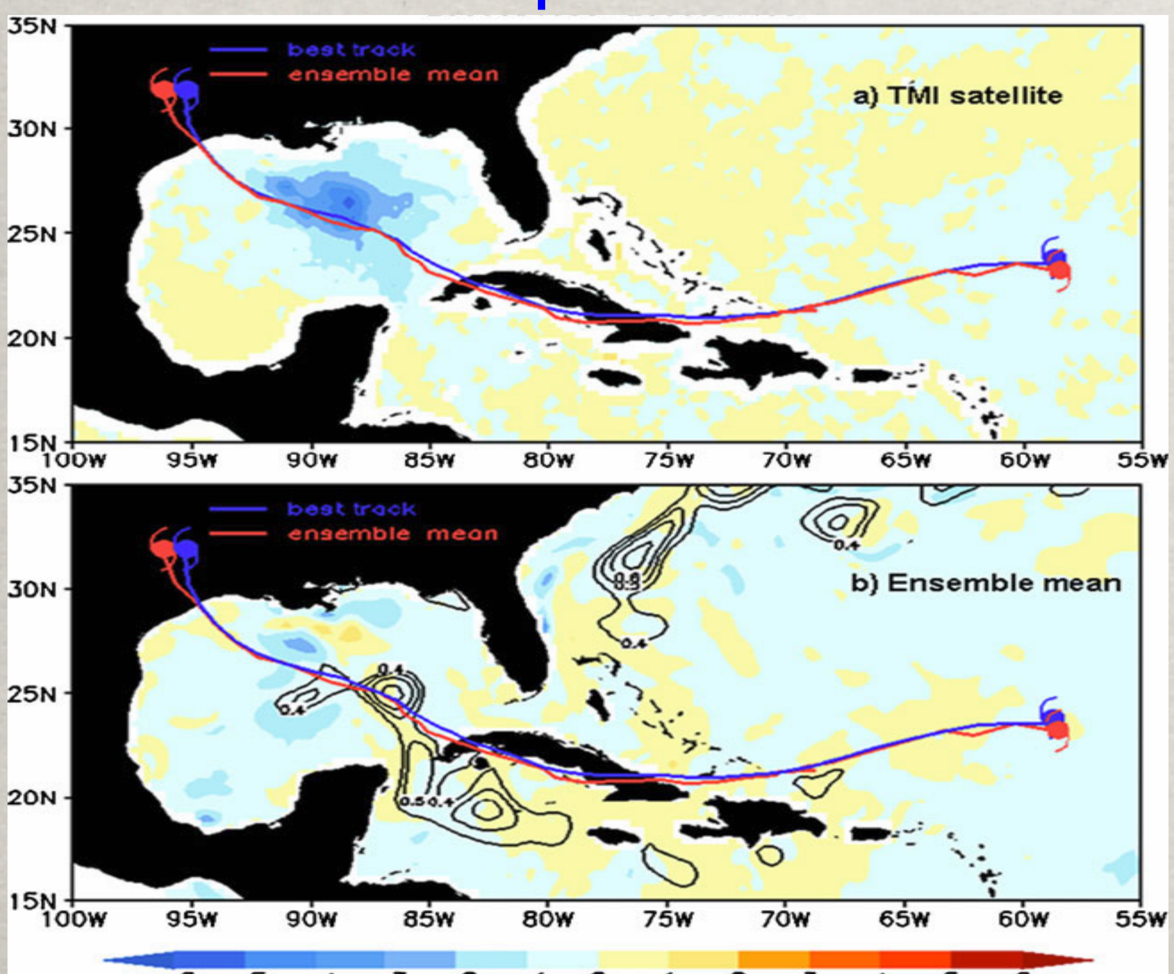
# COAMPS-TC Coupled Ensembles

## *2-Way (Air-Ocean) Coupled Forecasts of Ike*

### TC Ensemble Forecast Tracks and Best Track



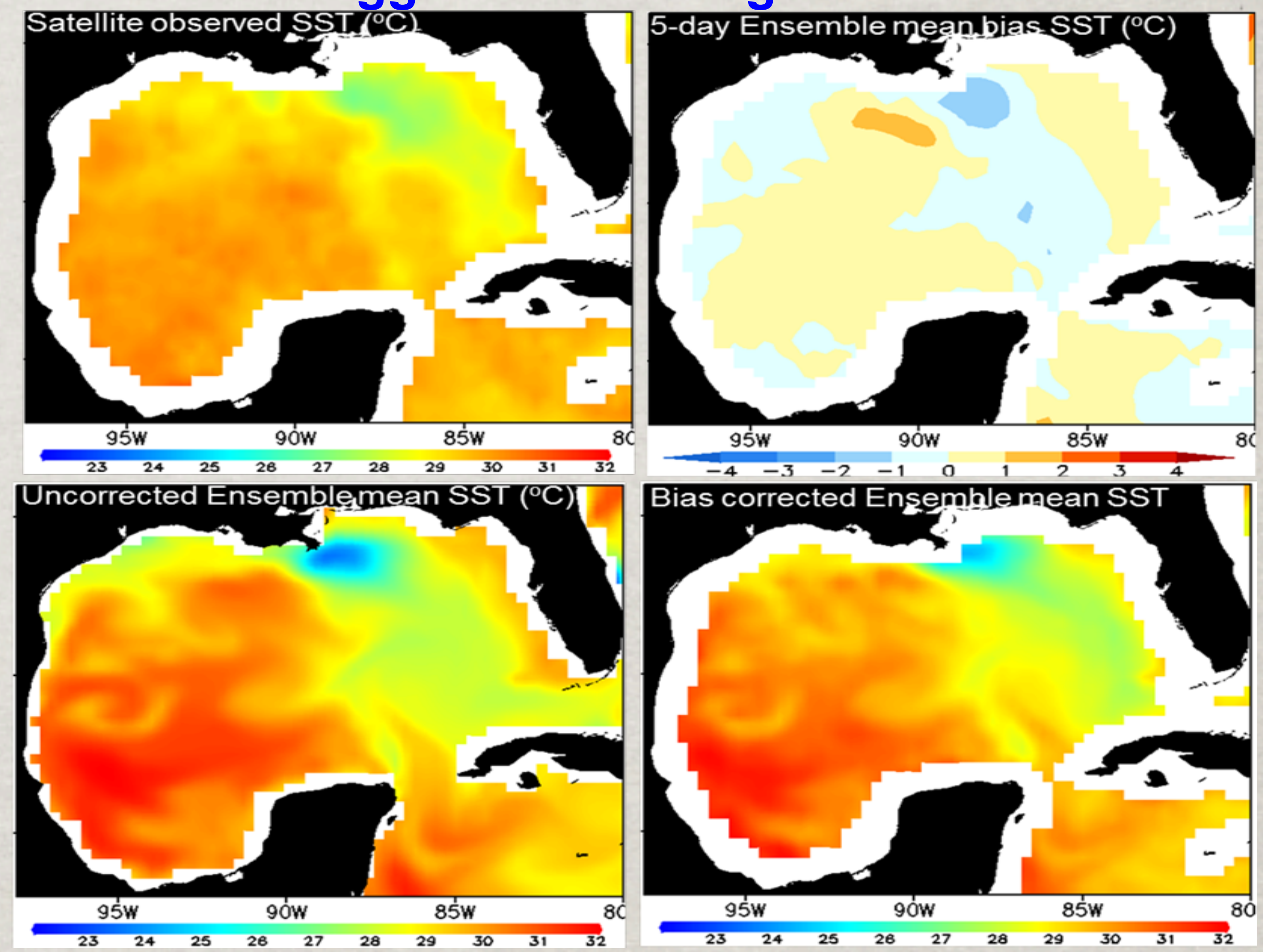

### Sea Surface Temperature Difference




X. Hong and T. Holt (NRL)

### Ensemble Forecast Bias Correction

#### Lagged bias average method




- Atmos: 81 km & 27 km; Ocean: 27 km
- The ensemble forecast can provide reasonable uncertainty information
- The ensemble mean shows a similar location for the SST decrease as observed
- Bias correction is able to improve the ensemble mean SST

# National Unified Ensemble

- Common output formats
- Same forecast times
- 73 common variables
- Products being developed to support mission needs
- Future development being coordinated by a tri-agency management committee

D. McCarren, S. Sandgathe

# Where We Are

- Well Established Tri-Agency Partnership
- Initial Operational Capability of National Unified Ensemble in January 2011
- Software architecture and interoperability standards part of latest release of the Earth System Modeling Framework.

- National R&D agenda for advancing global NWP presented to American Meteorological Society Meeting – January 2011

D. McCarren, S. Sandgathe

# Future

## Next Generation Prediction Capability

- New modeling techniques to improve predictive skill
- Exploit interoperability architecture for a fully coupled system: land, ocean, ice, wave, atmosphere, space, ecosystem.
- Exploit emerging computing capabilities
- Improved inter-annual to decadal predictions

***Earth System Prediction Capability (ESPC)***

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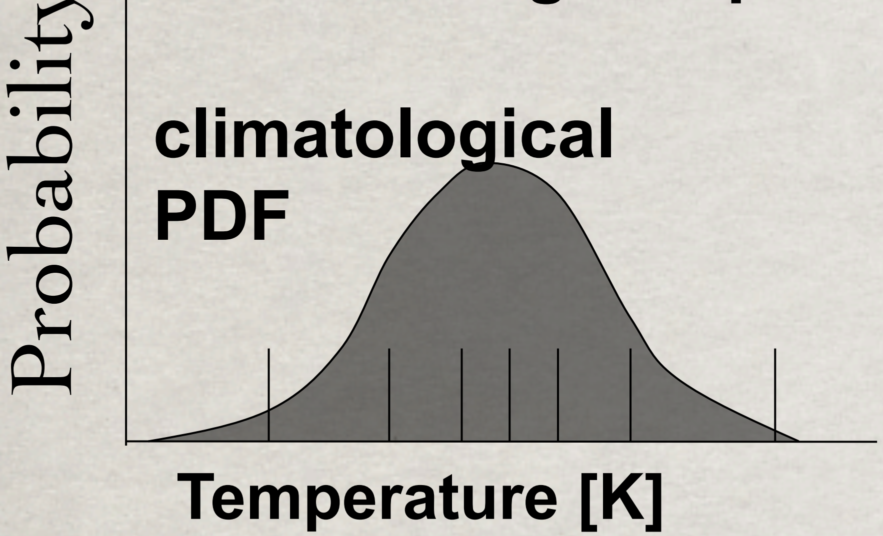
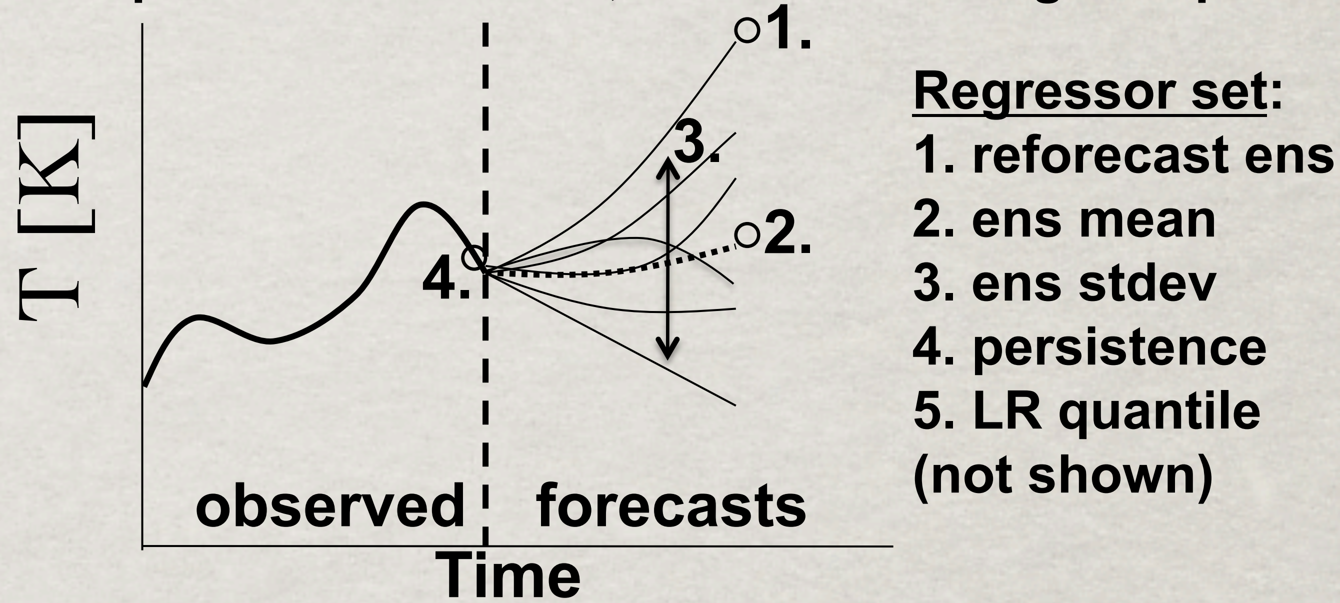
**Step I: Determine climatological quantiles**

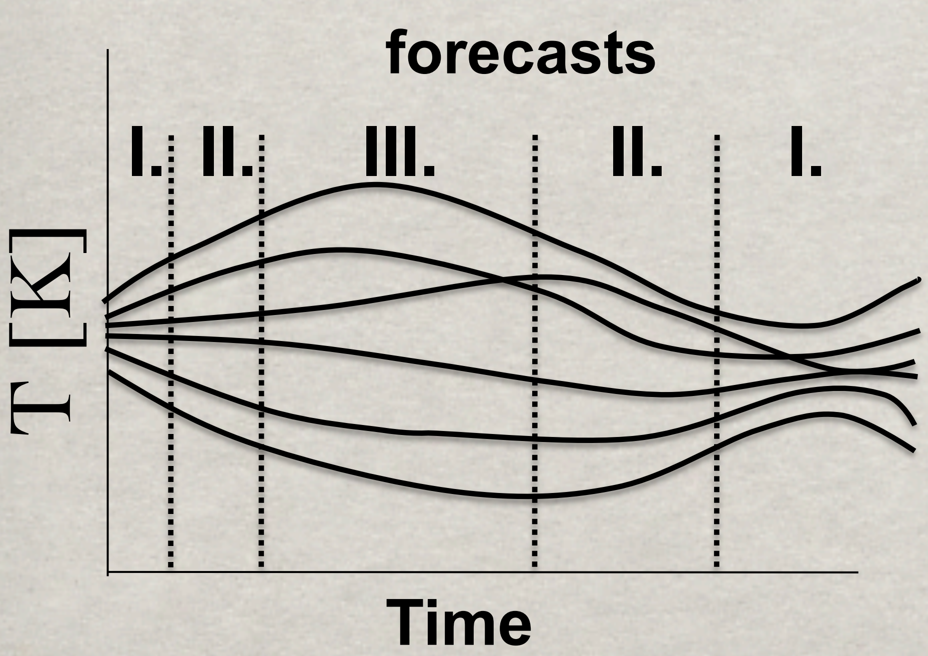



**Step 2: For each quan, use forward step-wise cross-validation to select best regress set**

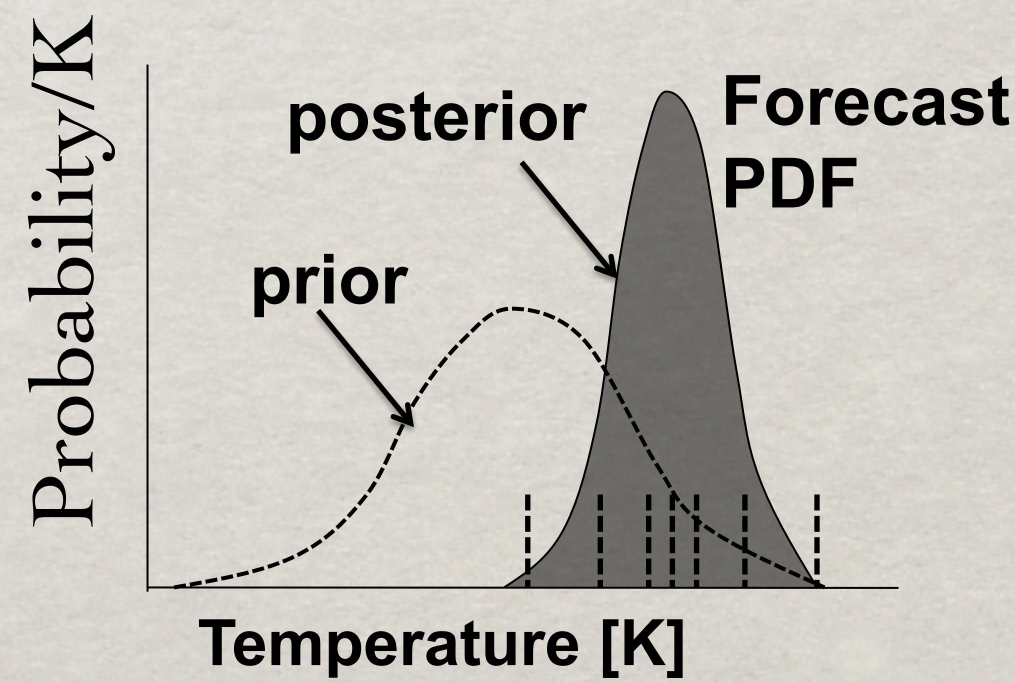
**Selection requires: a) min QR cost function,**
**b) binomial distrib at 95% confidence**
**If requirements not met, retain climatological “prior”**




**Step 3: segregate forecasts based on ens dispersion; refit models (Step 2) for each range**




**Final result: “sharper” posterior PDF represented by interpolated quans**

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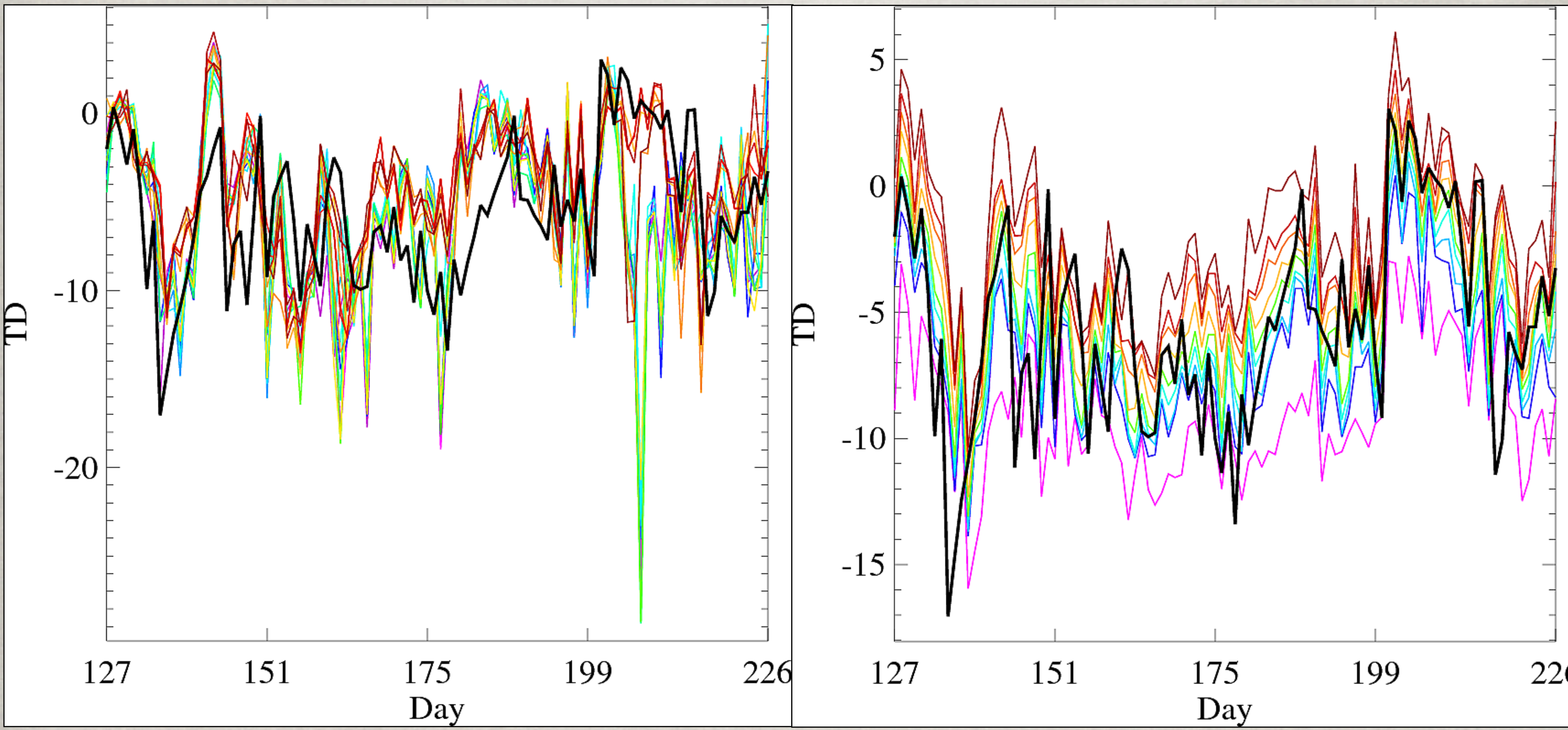
# 42-hr dewpoint calibration

Station DPG S01

Before Calibration | After Calibration

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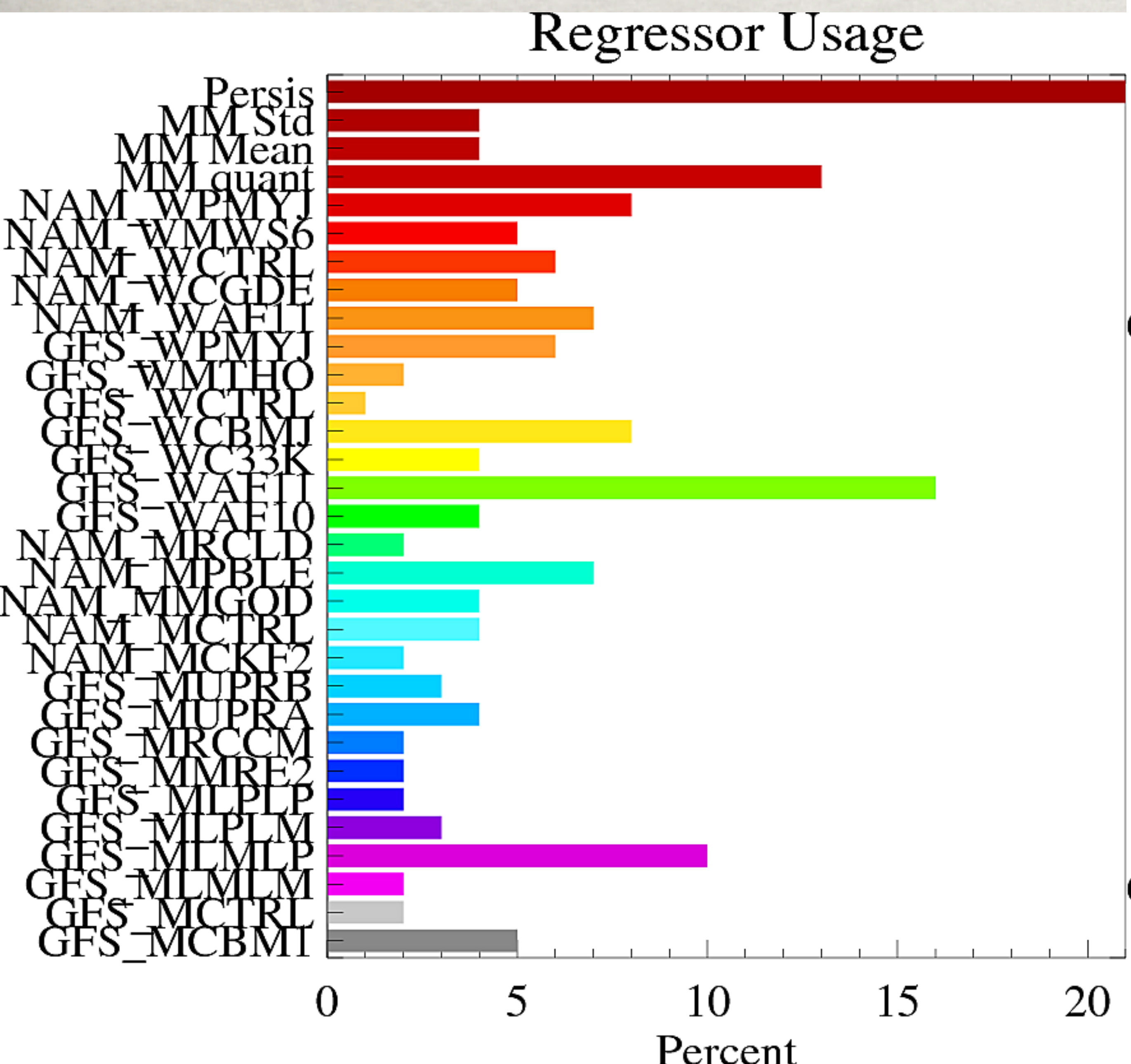
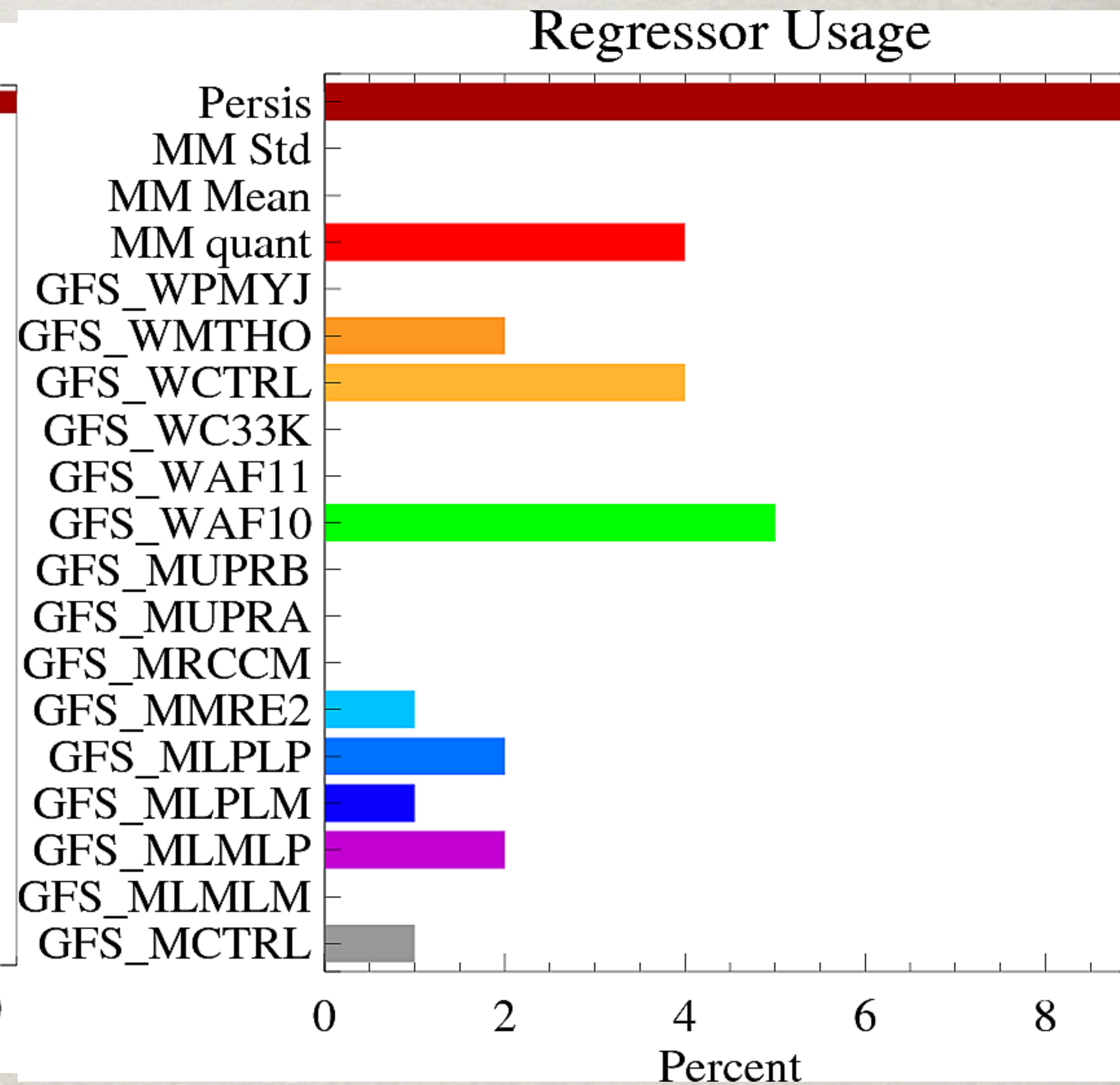
# Significant calibration regressors

## Station DPG S01

### 3hr Lead-time




### 42hr Lead-time

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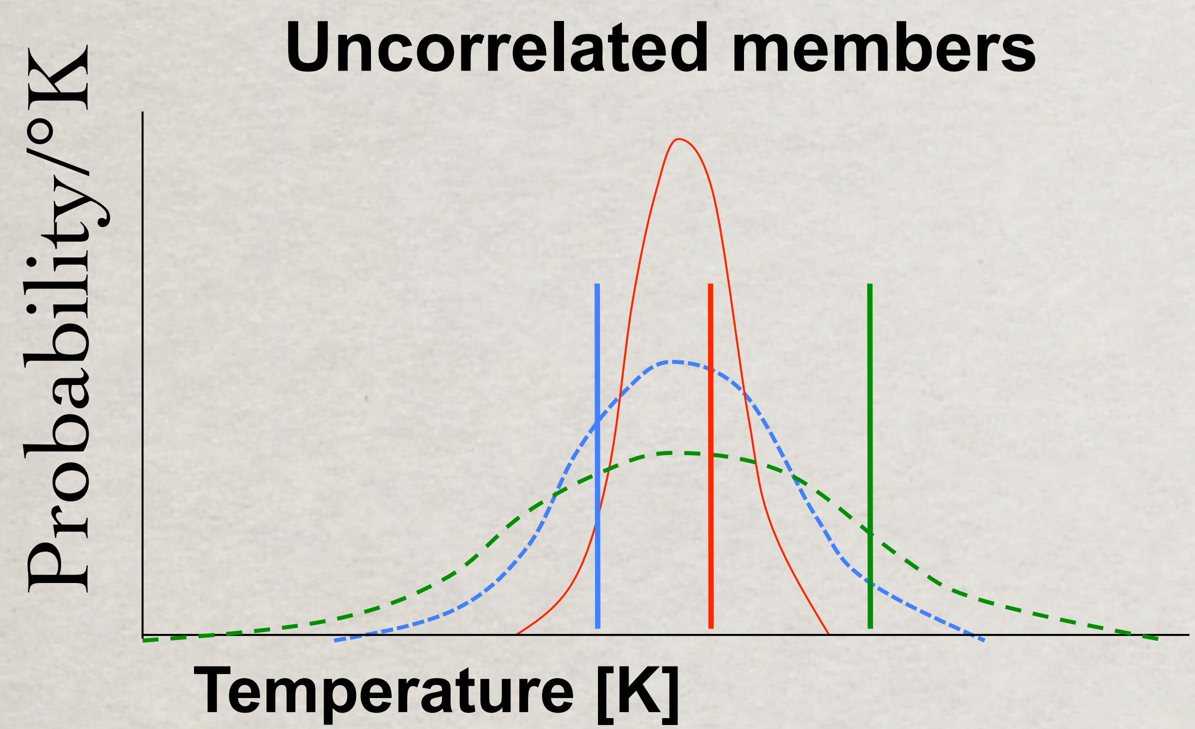
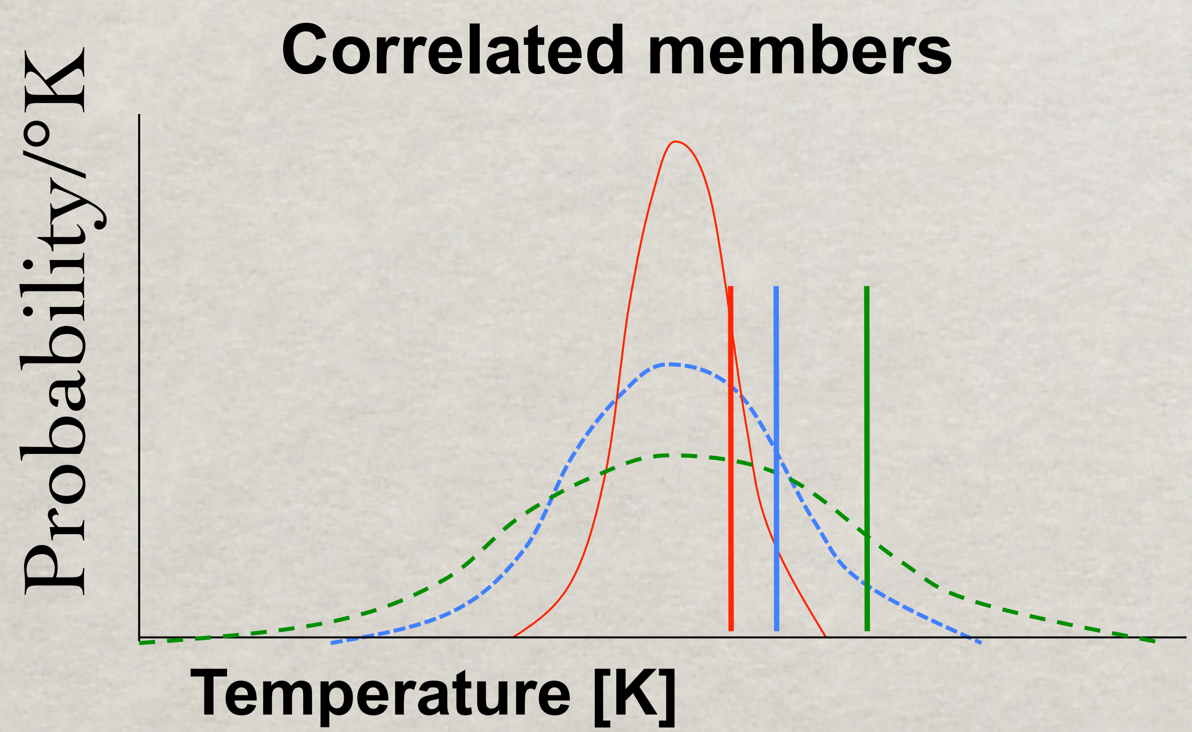
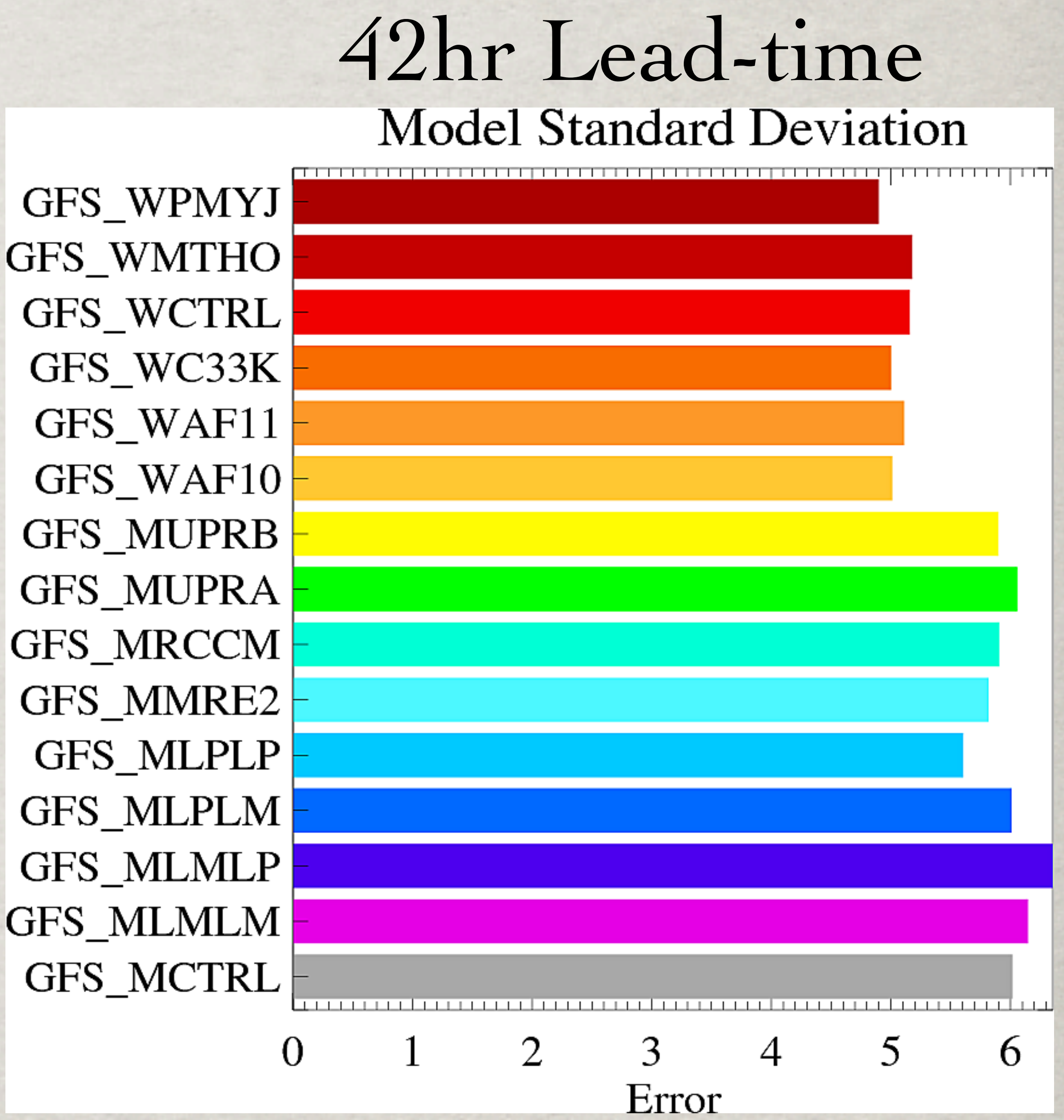
# Member contributions




- More members improve mean of PDF if error growth less than linear *and* members are uncorrelated
- For perfectly-correlated ensembles, *any* additional member degrades skill

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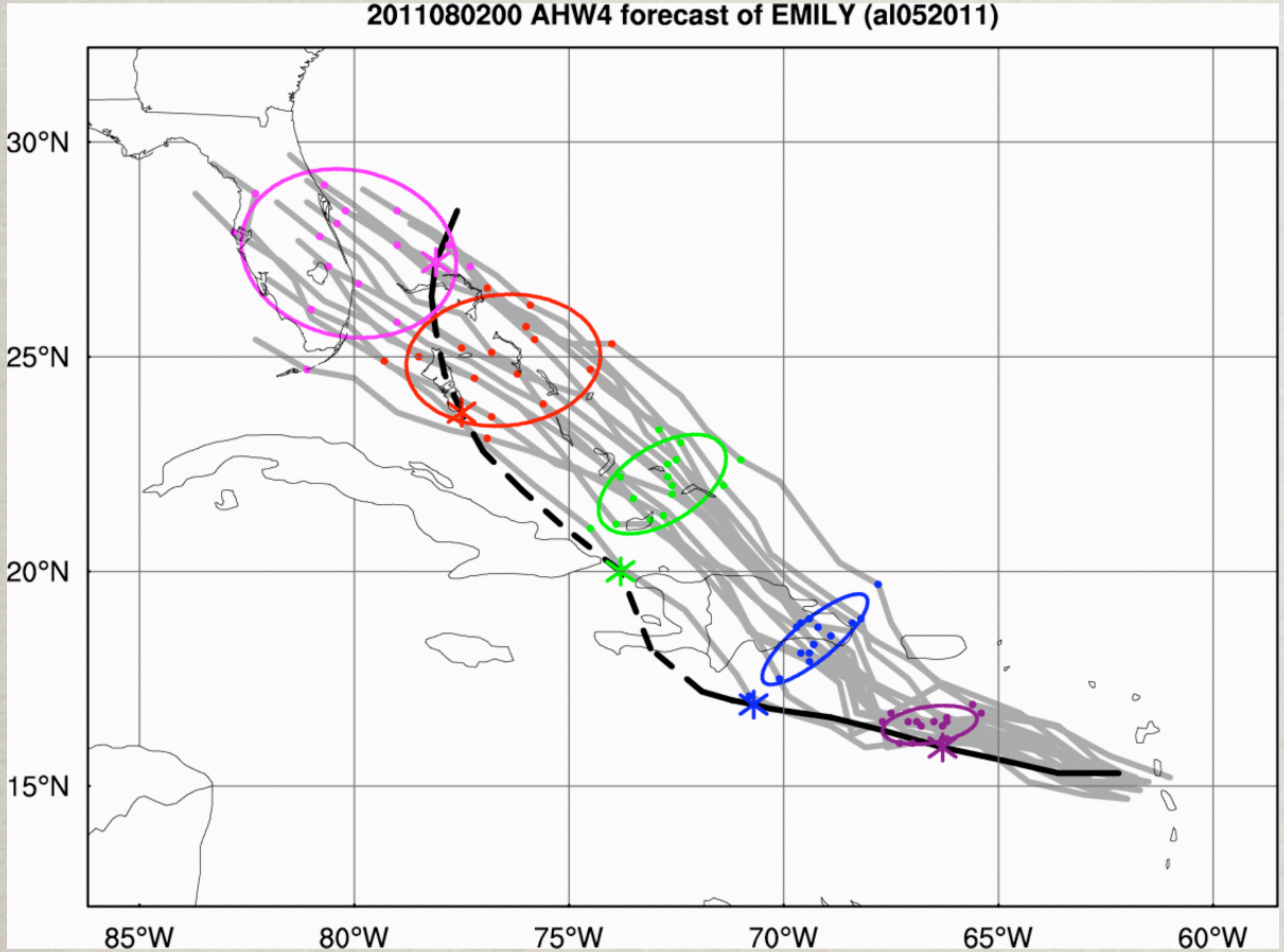
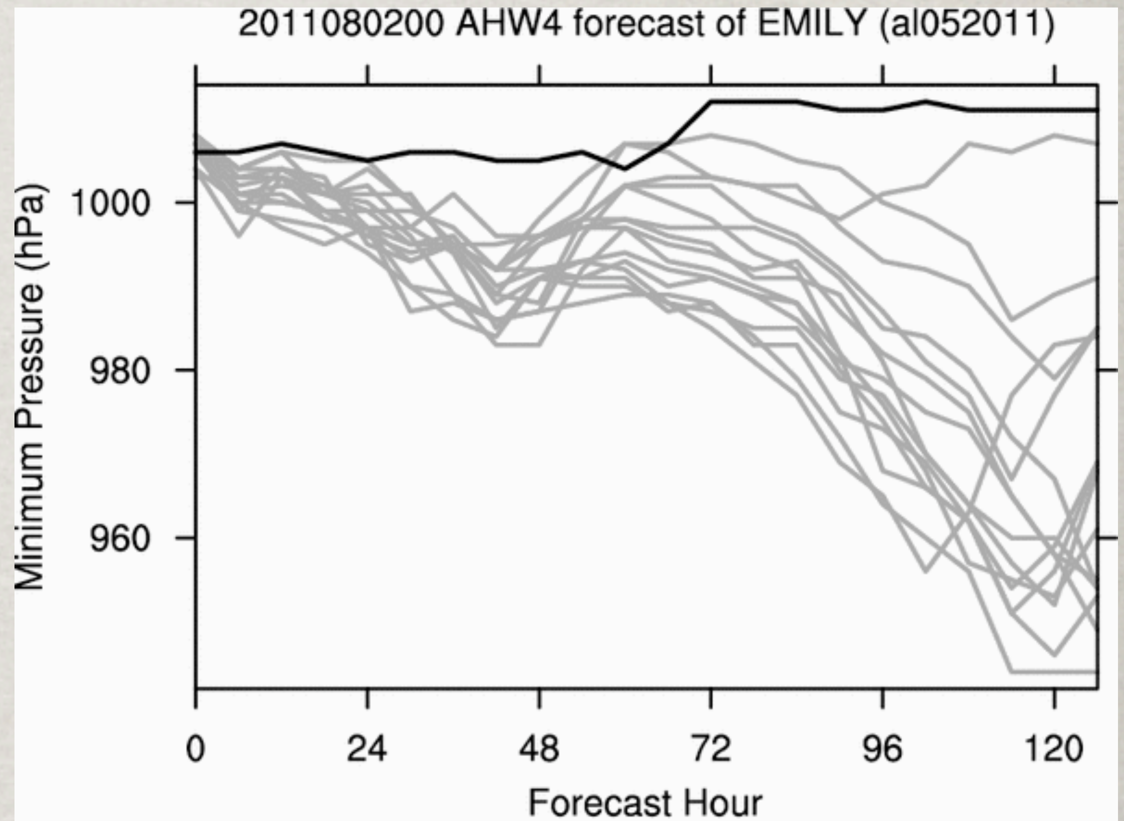
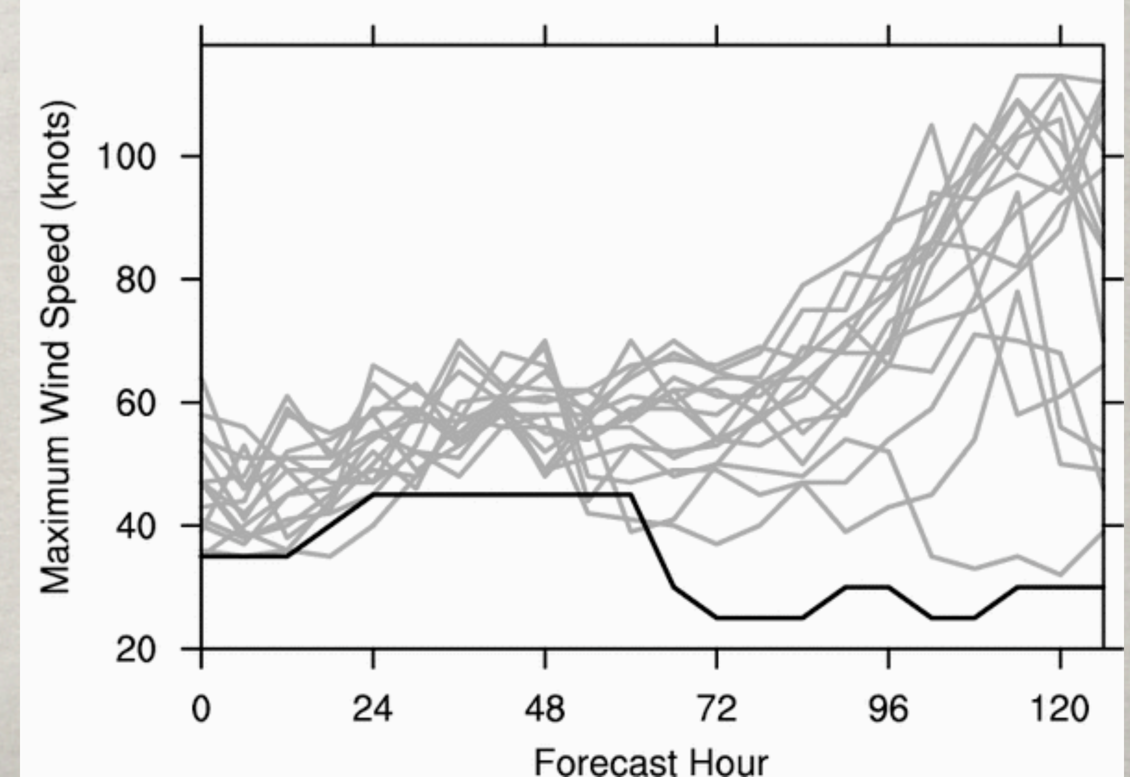
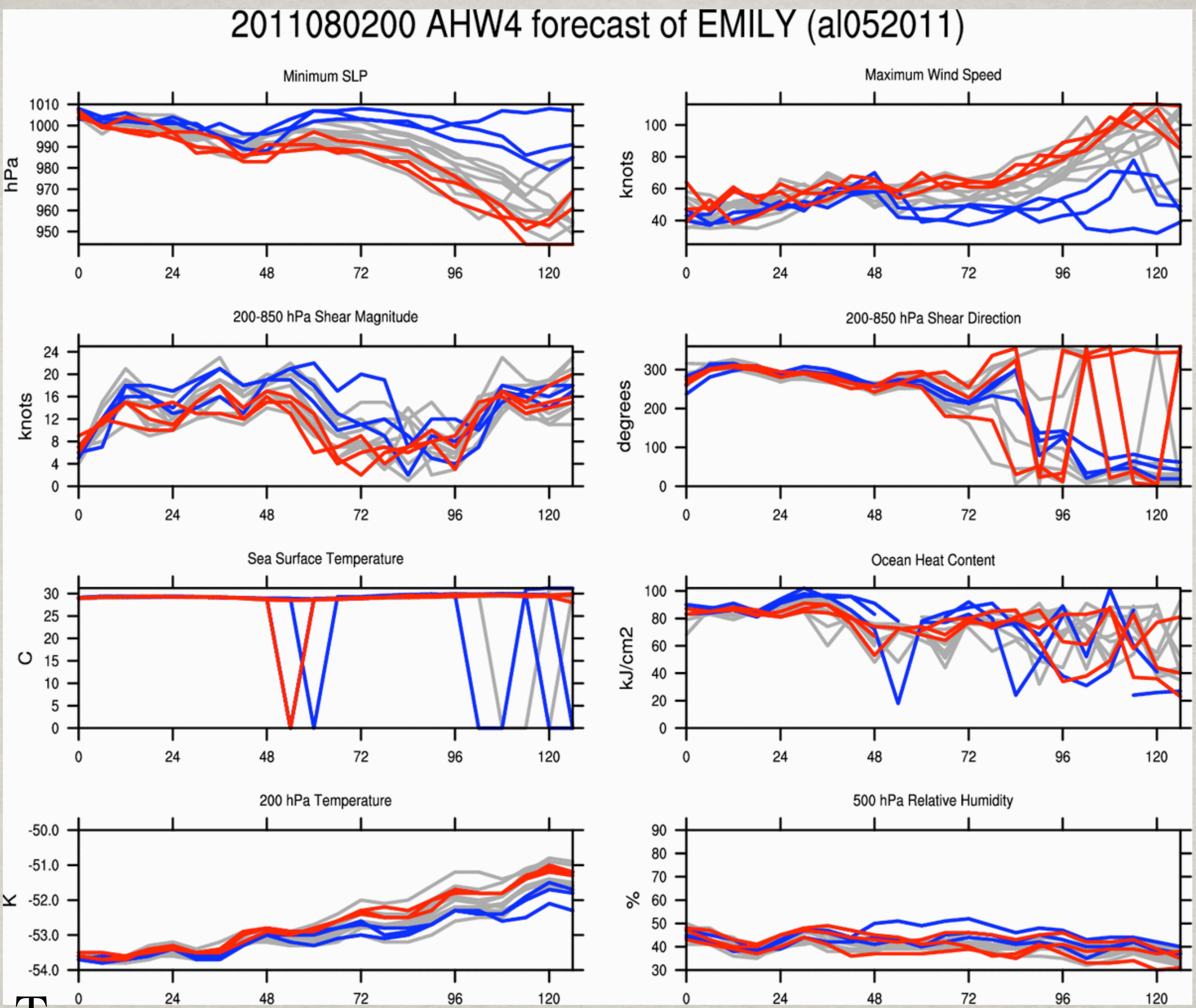
# 0000 UTC 2 Aug. Ensemble




R. Torn


2011080200 AHW4 forecast of EMILY (al052011)
Minimum SLP
hPa
Maximum Wind Speed
knots
200-850 hPa Shear Magnitude
knots
200-850 hPa Shear Direction
degrees
Sea Surface Temperature
C
Ocean Heat Content
kJ/cm2
200 hPa Temperature
K
500 hPa Relative Humidity
%

R. Torn