

# Potential Week-2 Skill Improvement for Multi-Model Ensemble Application

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EMC/NCEP

Presentation for 40<sup>th</sup> CDPW  
10/29/2015  
Denver, Colorado

# Highlights

- **Background**
  - **North American Ensemble Forecast System (NAEFS)**
- NAEFS Statistical Post Process (SPP)
  - Current status
  - Equal weights multi-model ensemble
  - Deficit of 2<sup>nd</sup> moment – under-dispersion
- Bayesian Model Average (BMA)
  - Concept
  - Modified BMA -2<sup>nd</sup> moment adjustment
  - Recursive Bayesian Model Process (RBMP)
- Future plan
  - Implement RBMP for NAEFS and NUOPC application

# North American Ensemble Forecast System (NAEFS)

International project to produce operational multi-center ensemble products

Bias correction and combines global ensemble forecasts from Canada & USA

Generates products for:  
Weather forecasters  
Specialized users  
End users

Operational outlet for THORPEX research using TIGGE archive

The National Oceanic and Atmospheric Administration  
of the United States,

The Meteorological Service of Canada and  
The National Meteorological Service  
of Mexico

*Recognizing the importance of scientific and technical international cooperation in the field of meteorology for the development of improved global forecast models;*

*Considering the great potential of model diversity to increase the accuracy of one to fourteen day probabilistic forecasts;*

*Noting the significant international cooperation undertaken to develop and implement an operational ensemble forecast system for the benefit of North America and surrounding territories;*

*The signatories, hereby inaugurate the North American Ensemble Forecast System at Camp Springs, Maryland, USA, on this 16<sup>th</sup> Day of November 2004.*

King, G. David L., Acting USAF (P&I)  
National Oceanic and Atmospheric Administration  
Assistant Administrator for Weather Services

Dr. Marc Denis-Evans  
Assistant Deputy Minister  
Meteorological Service of Canada

Dr. Michel Pielorzga  
Head of ESM  
National Meteorological Service of Mexico



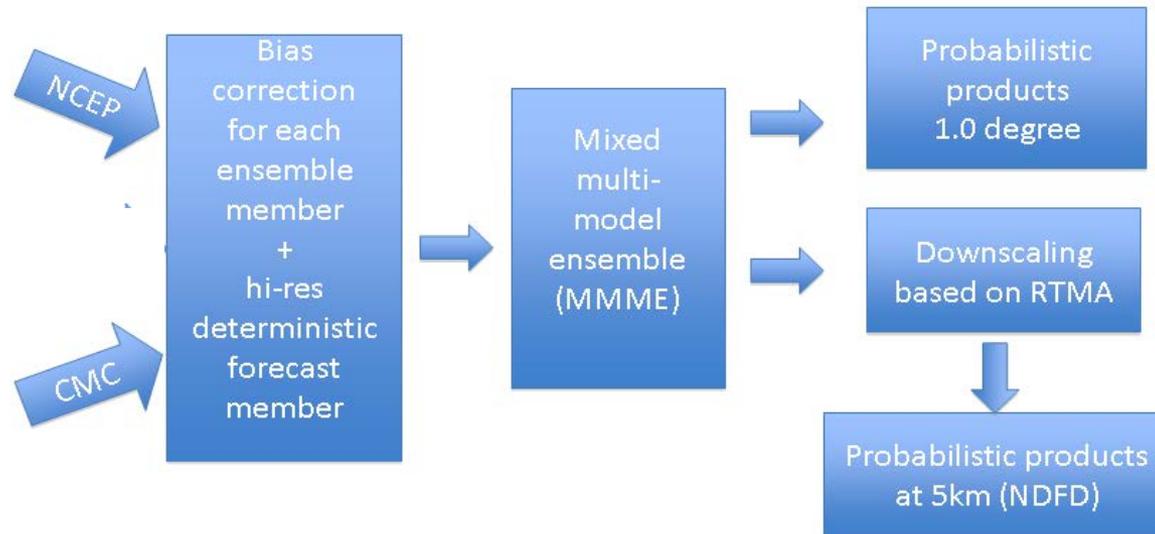
# NAEFS Milestones

- Implementations
  - First NAEFS implementation – bias correction – IOC, May 30 2006 Version 1
  - NAEFS follow up implementation – CONUS downscaling - December 4 2007 Version 2
  - Alaska implementation – Alaska downscaling - December 7 2010 Version 3
  - CONUS/Alaska new variables expansion – April 8 2014 Version 4
  - **CONUS/Alaska NDGD (2.5km/3km) and expansion – Q1FY16** **Version 5**
- Applications:
  - NCEP/GEFS and NAEFS – at NWS
  - CMC/GEFS and NAEFS – at MSC
  - FNMOC/GEFS – at NAVY
  - NCEP/SREF – at NWS
- Publications (or references):
  - Cui, B., Z. Toth, Y. Zhu, and D. Hou, D. Unger, and S. Beauguard, 2004: [\*The Trade-off in Bias Correction between Using the Latest Analysis/Modeling System with a Short, versus an Older System with a Long Archive\*](#) The First THORPEX International Science Symposium. December 6-10, 2004, Montréal, Canada, World Meteorological Organization, P281-284.
  - Zhu, Y., and B. Cui, 2006: [\*"GFS bias correction"\*](#) [Document is available online]
  - Zhu, Y., B. Cui, and Z. Toth, 2007: [\*"December 2007 upgrade of the NCEP Global Ensemble Forecast System \(NAEFS\)"\*](#) [Document is available online]
  - Cui, B., Z. Toth, Y. Zhu and D. Hou, 2012: [\*"Bias Correction For Global Ensemble Forecast"\*](#) Weather and Forecasting, Vol. 27 396-410
  - Cui, B., Y. Zhu , Z. Toth and D. Hou, 2013: [\*"Development of Statistical Post-processor for NAEFS"\*](#) Weather and Forecasting (In process)
  - Zhu, Y., and B. Cui, 2007: [\*"December 2007 upgrade of the NCEP Global Ensemble Forecast System \(NAEFS\)"\*](#) [Document is available online]
  - Zhu, Y, and Y. Luo, 2015: [\*"Precipitation Calibration Based on Frequency Matching Method \(FMM\)"\*](#). Weather and Forecasting, Vol. 30, 1109-1124
  - Glahn, B., 2013: *"A Comparison of Two Methods of Bias Correcting MOS Temperature and Dewpoint Forecasts"* MDL office note, 13-1
  - Guan, H., B. Cui and Y. Zhu, 2015: [\*"Improvement of Statistical Post-processing Using GEFS Reforecast Information"\*](#) Weather and Forecasting, Vol. 30, 841-854

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# NAEFS Statistical Post-Processing System



- **Bias correction:**
  - Bias corrected NCEP/CMC GEFS and NCEP/GFS forecast (up to 180 hrs)
  - Combine bias corrected NCEP/GFS and NCEP/GEFS ensemble forecasts
  - Dual resolution ensemble approach for short lead time
  - NCEP/GFS has higher weights at short lead time
- NAEFS products (global) and downstream applications
  - Combine NCEP/GEFS (20m) and CMC/GEFS (20m)
  - Produce Ensemble mean, spread, mode, 10% 50%(median) and 90% probability forecast at 1\*1 degree resolution
  - Climate anomaly (percentile) forecasts
  - Wave ensemble forecast system
  - Hydrological ensemble forecast system
- **Statistical downscaling**
  - Use RTMA as reference - NDGD resolution (5km/6km), CONUS and Alaska
  - Generate mean, mode, 10%, 50%(median) and 90% probability forecasts

# NAEFS Bias Correction (Decaying average method)

## 1). Bias Estimation:

$$b_{i,j}(t) = f_{i,j}(t) - a_{i,j}(t_0)$$

## 2). Decaying Average (Kalman Filter method)

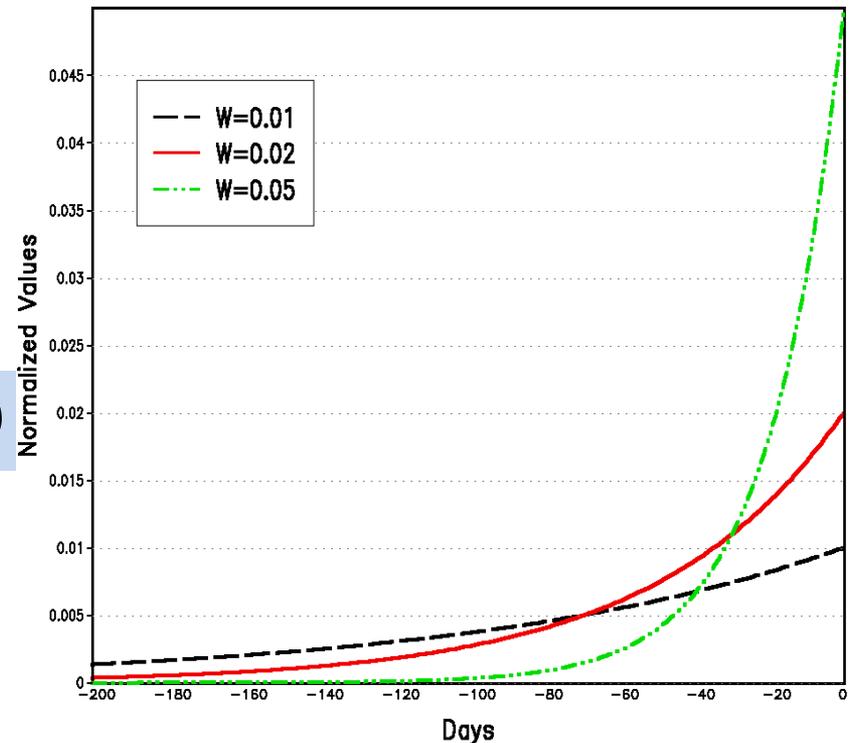
$$B_{i,j}(t) = (1-w) \cdot B_{i,j}(t-1) + w \cdot b_{i,j}(t)$$

3). **Decaying Weight:**  $w = 0.02$  in GEFS bias correction (~ past 50-60 days information)

## 4). Bias corrected forecast:

$$F_{i,j}(t) = f_{i,j}(t) - B_{i,j}(t)$$

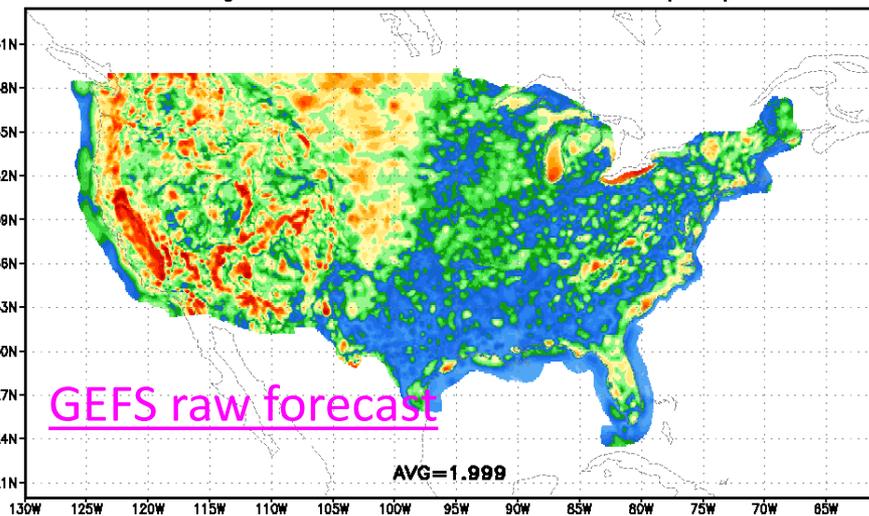
DECAYING AVERAGE WEIGHTING



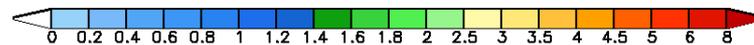
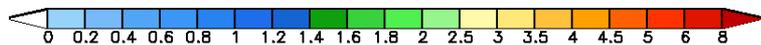
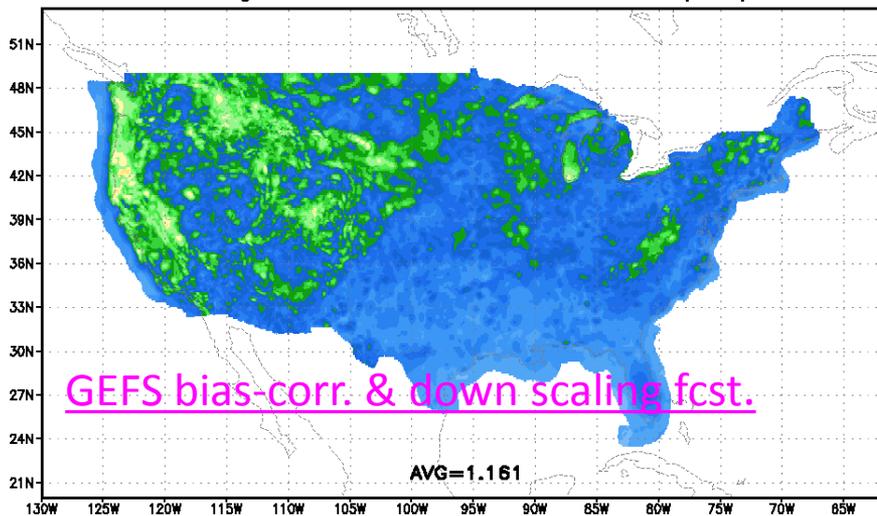
Simple Accumulated Bias

Assumption: Forecast and analysis  
(or observation) is fully correlated

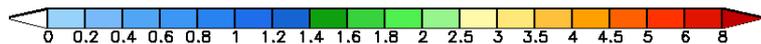
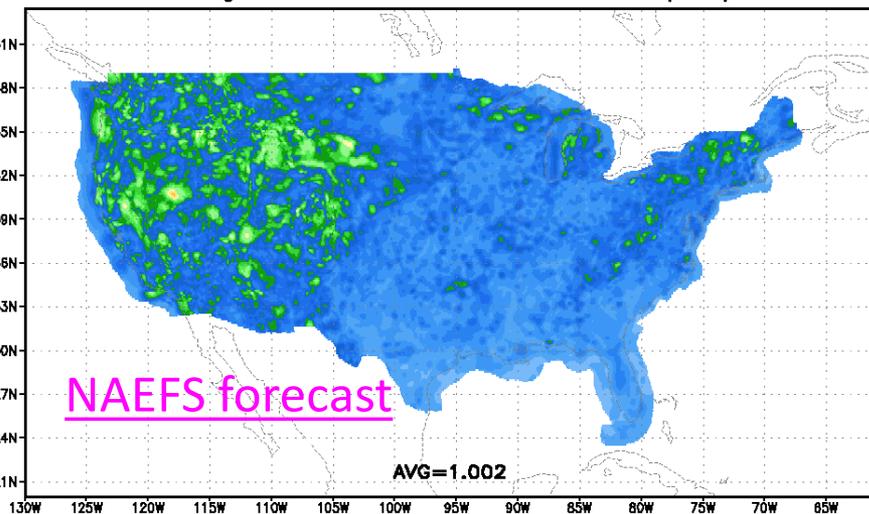
CONUS GEFS Raw Ens. Mean Absolute Error w.r.t RTMA  
2m Temperature ( shaded, K )  
Averaged From: 2007090100 to 2007093000 (12 h)



CONUS GEFS Bias Corrected Ens. Mean Absolute Error w.r.t RTMA  
2m Temperature ( shaded, K )  
Averaged From: 2007090100 to 2007093000 (12 h)

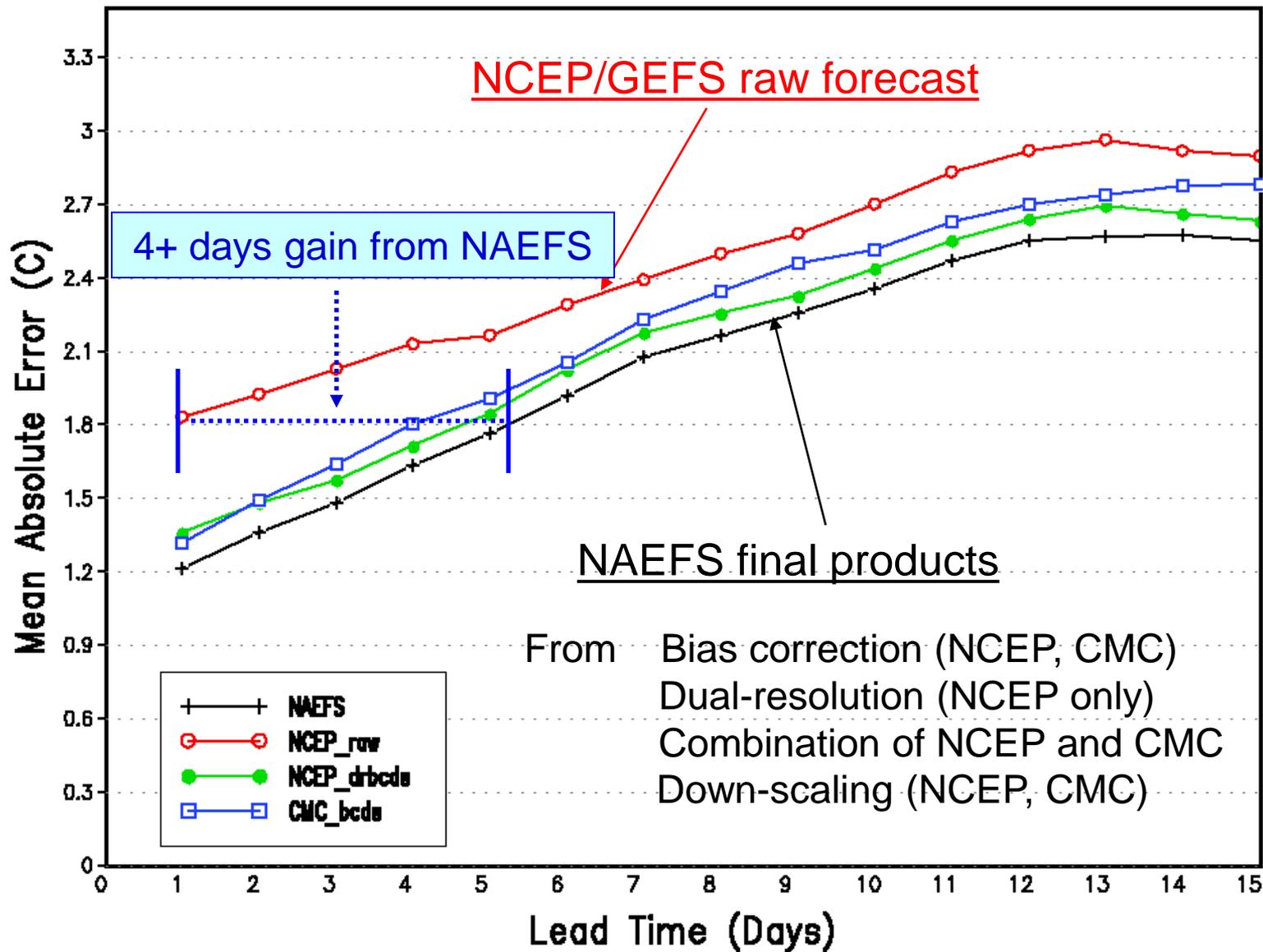


Averaged From: 2007090100 to 2007093000 (12 h)

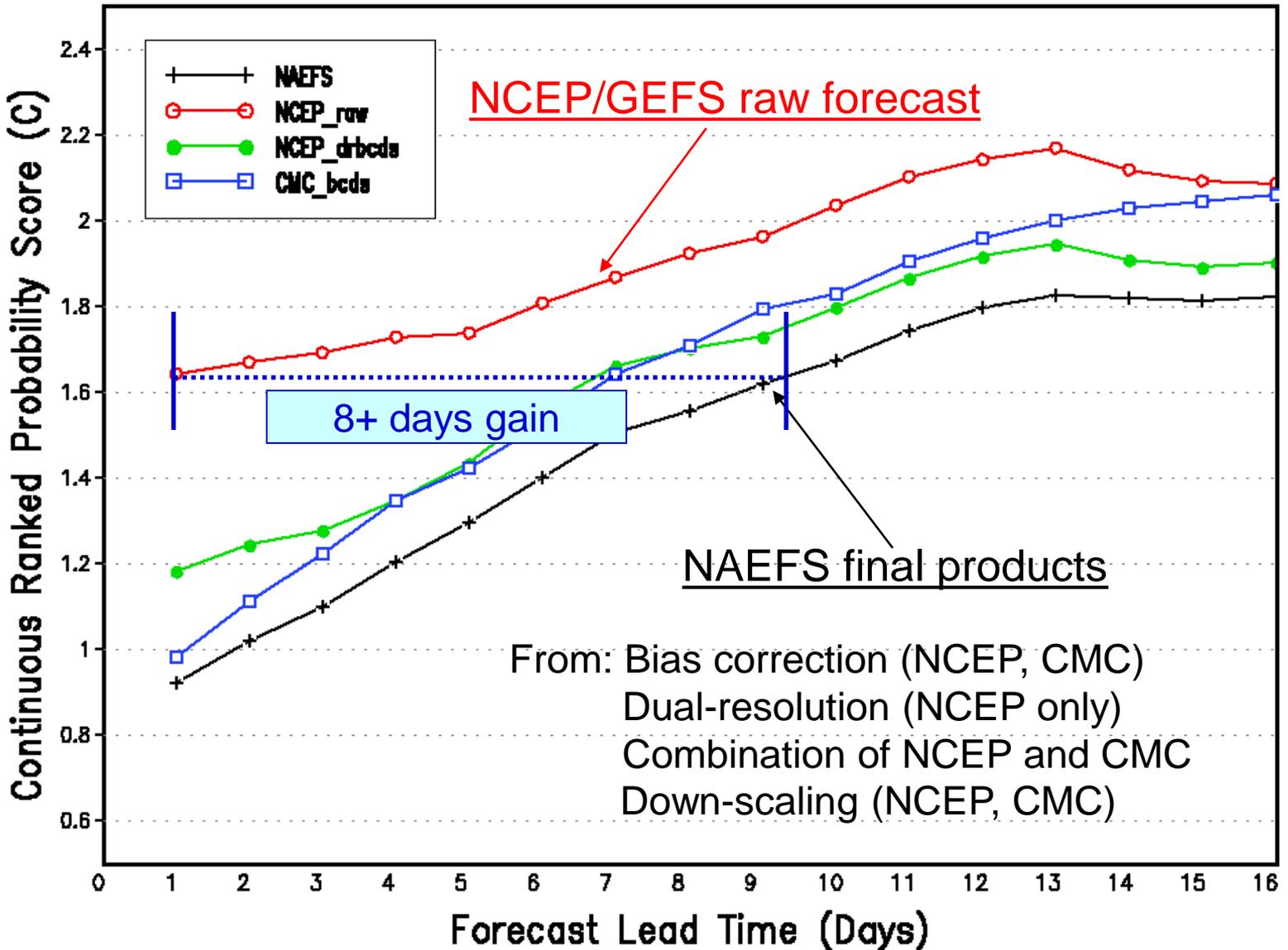


12hr 2m temperature forecast  
Mean Absolute Error (MAE)  
w.r.t RTMA for CONUS  
average for September 2007

# RTMA Region 2m Temperature Averaged From 2007090100 to 2007093000

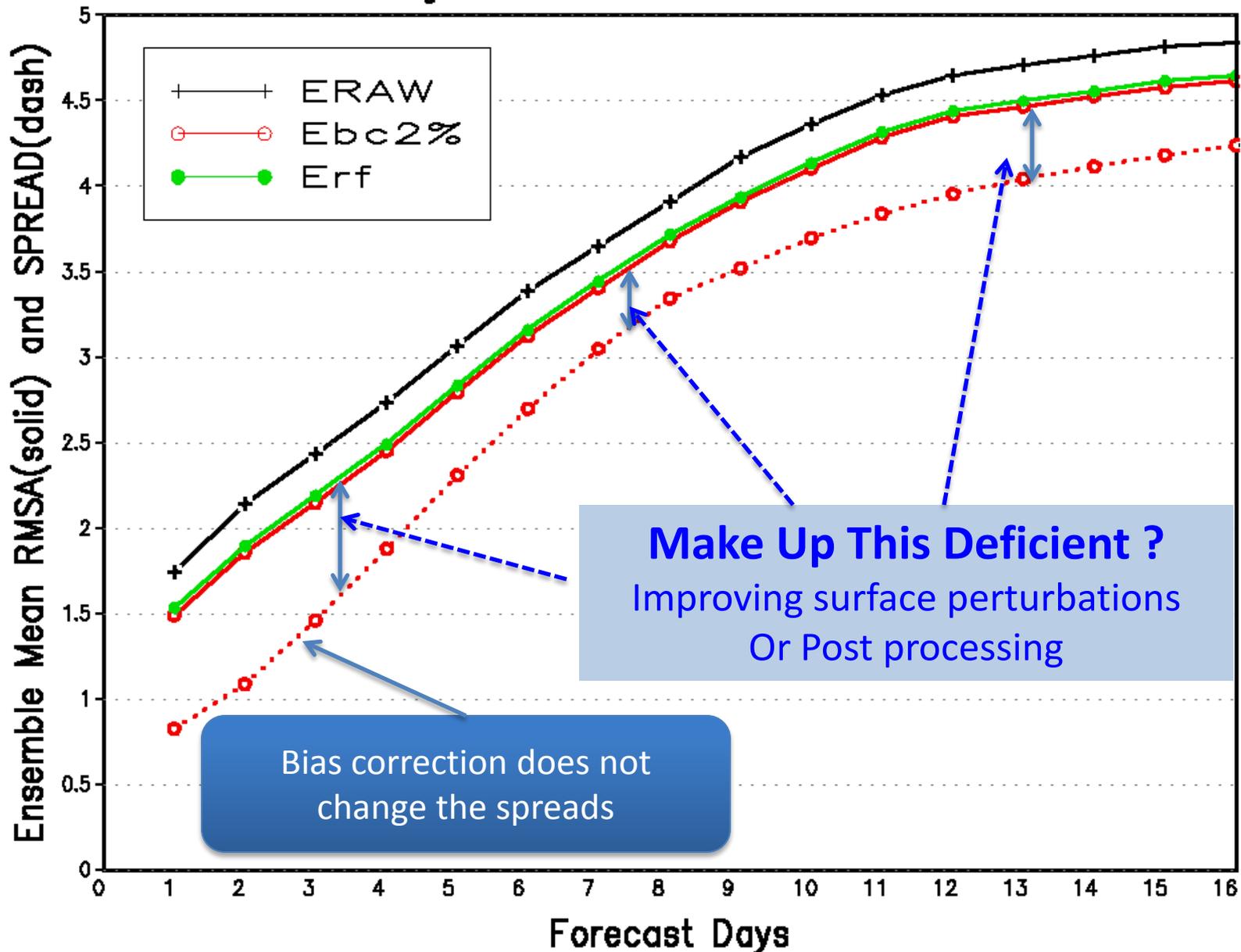


# NAEFS NDGD Probabilistic 2m Temperature Forecast Verification For 2007090100 – 2007093000



From: Bias correction (NCEP, CMC)  
 Dual-resolution (NCEP only)  
 Combination of NCEP and CMC  
 Down-scaling (NCEP, CMC)

Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 2010010100 – 2010022800



**Make Up This Deficient ?**  
Improving surface perturbations  
Or Post processing

Bias correction does not  
change the spreads

# 2<sup>nd</sup> moment adjustment

1<sup>st</sup> moment  
adjusted forecast

2<sup>nd</sup> moment adj.

$$F_{i,j}^m = F_{i,j}^{*m} + (1 - R_{i,j}) \cdot D^m$$

$$D^m = (f^m(t+1) - \bar{f}(t+1))$$

$$\bar{R} = \frac{\bar{S}}{\bar{E}} \quad \underline{R=1 \text{ if } E=0}$$

Ensemble skill

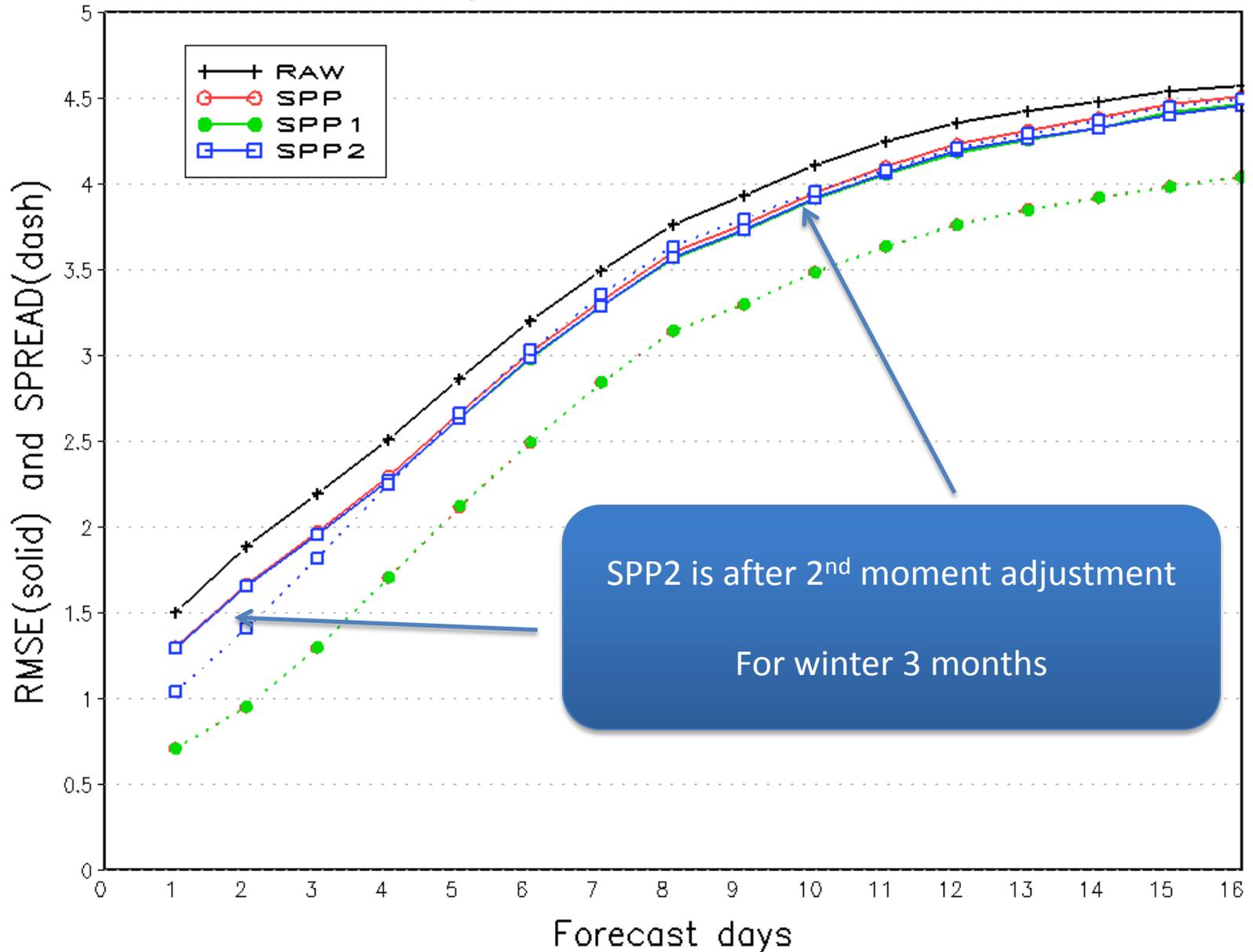
$$\bar{E} = \sqrt{\frac{1}{N} \sum_{t=1}^N (\bar{f}(t) - a(t))^2}$$

Estimated by  
decaying averaging

Ensemble spread

$$\bar{S} = \frac{1}{N} \sum_{t=1}^N \sqrt{\frac{1}{M-1} \sum_{m=1}^M (f^m(t) - \bar{f}(t))^2}$$

Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20091201 – 20100228



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  - **Concept**
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# Bayesian Model Average

Law of total probability

$$p(y) = \sum_{k=1}^K p(y | M_k) \cdot p(M_k | y^T)$$

$p(y | M_k)$  is forecast PDF based on model  $M_k$  (ensemble member)

$p(M_k | y^T)$  is a posterior probability of model  $M_k$  from training data

Sum of each posterior probability is equal to 1, therefore it can be viewed as weights

# Bayesian Model Average

Weights and standard deviations for each model ( $k$  - ensemble member) at step  $j$

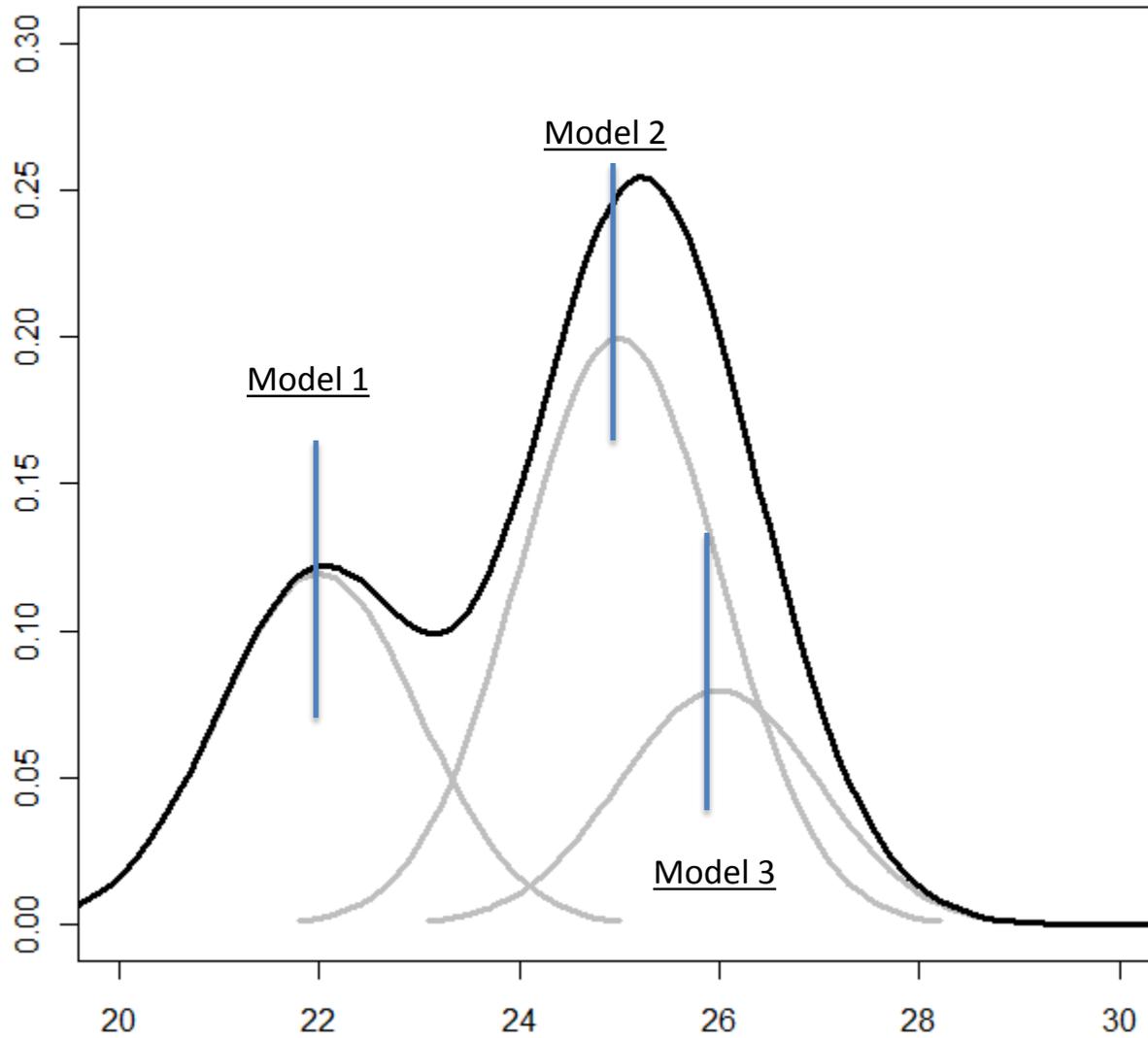
$$w_k^j = \frac{1}{n} \sum_{s,t} \hat{z}_{k,s,t}^j \quad \sigma_k^{2j} = \frac{\sum_{s,t} \hat{z}_{k,s,t}^j \cdot (y_{s,t} - \tilde{f}_{k,s,t})^2}{\sum_{s,t} \hat{z}_{k,s,t}^j}$$

*Sum of (s,t) represents the numbers of obs.*

Finally, the BMA predictive variance is

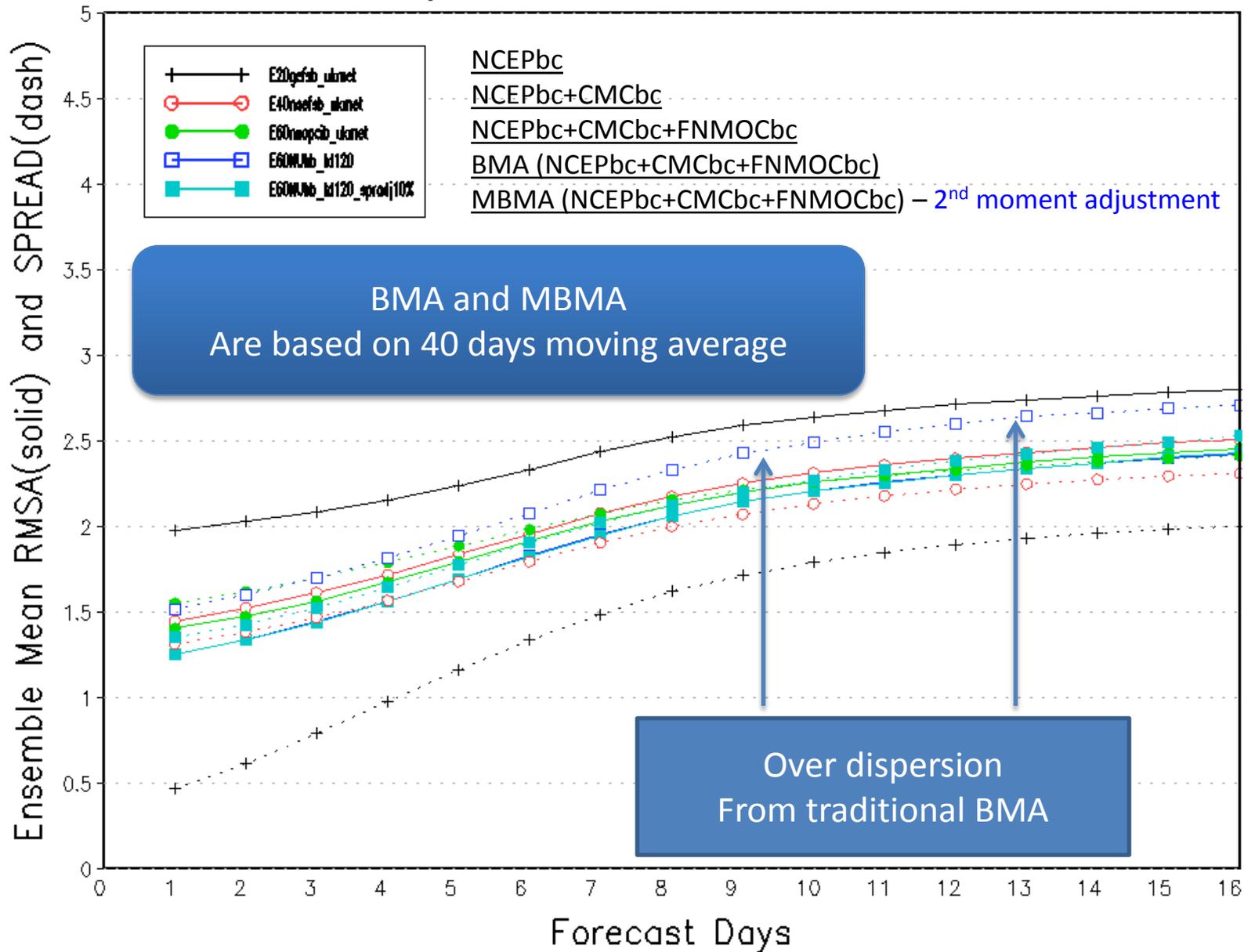
$$\text{Var}(y_{s,t} \mid \tilde{f}_{1,s,t}, \dots, \tilde{f}_{K,s,t}) = \underbrace{\sum_{k=1}^K w_k (\tilde{f}_{k,s,t} - \sum_{i=1}^K w_i \cdot \tilde{f}_{i,s,t})^2}_{\text{Between-forecast variance}} + \underbrace{\sum_{k=1}^K w_k \cdot \sigma_k^2}_{\text{Within-forecast variance}}$$

*It is good for perfect bias corrected forecast,  
Or bias-free ensemble forecast, but we do not*

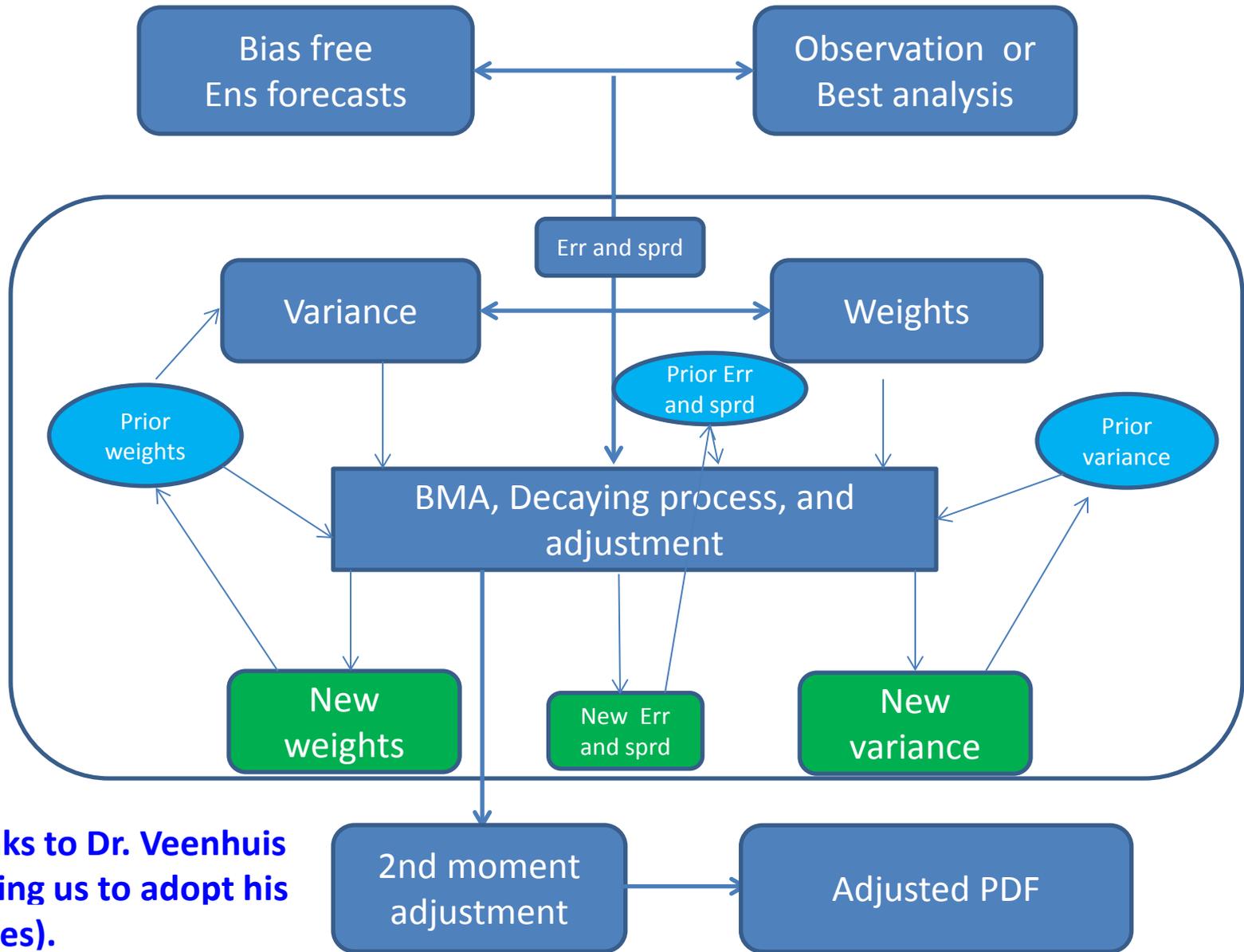


[Courtesy of Dr. Veenhuis](#)

Northern Hemisphere 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 2013060100 – 2013083100

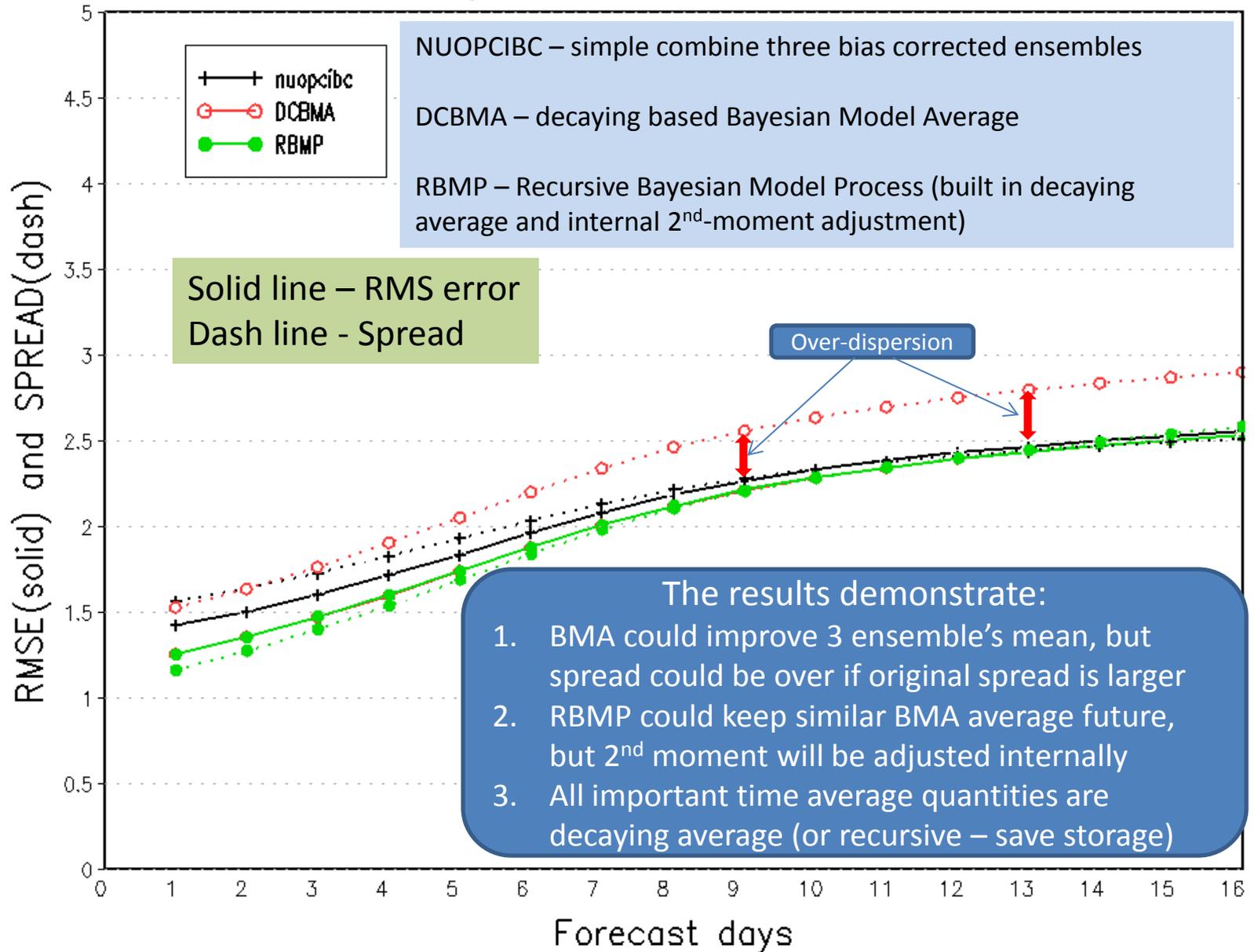


# Flow Chart of Recursive Bayesian Model Process (RBMP)

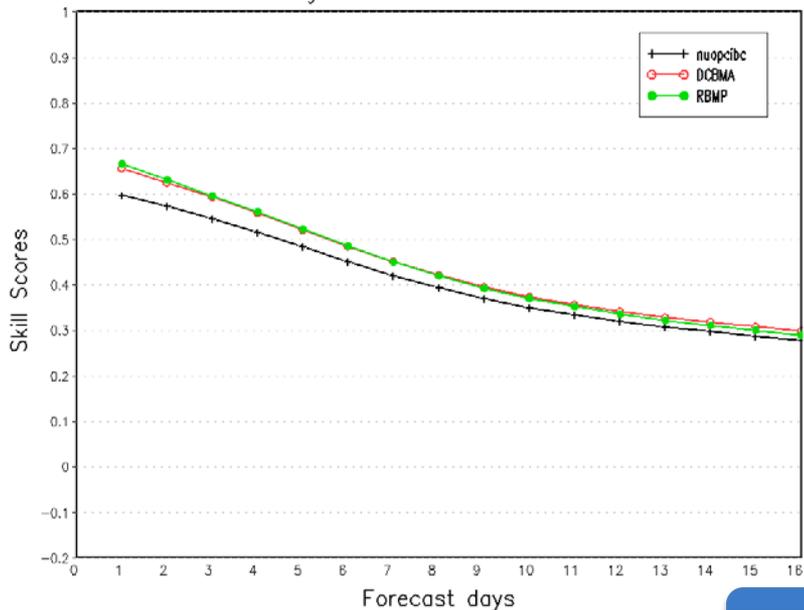


(We thanks to Dr. Veenhuis for allowing us to adopt his BMA codes).

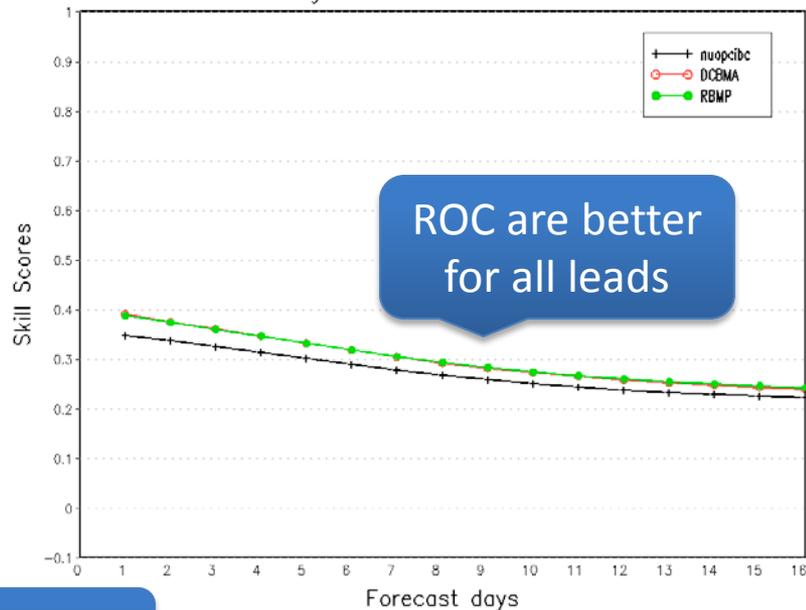
Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20130601 – 20130831



Northern Hemisphere 2 Meter Temp.  
 Continous Ranked Probability Skill Scores  
 Average For 20130601 - 20130831

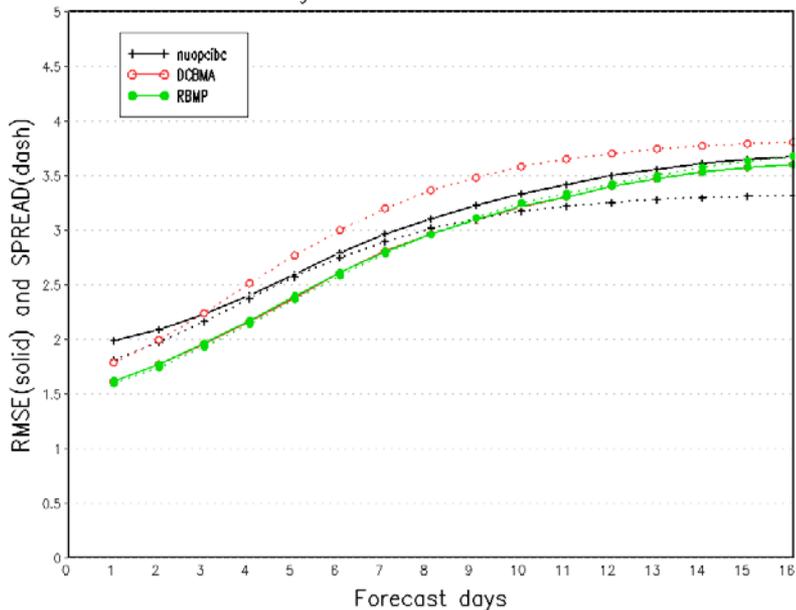


Northern Hemisphere 2 Meter Temp.  
 ROC area (0-1)  
 Average For 20130601 - 20130831

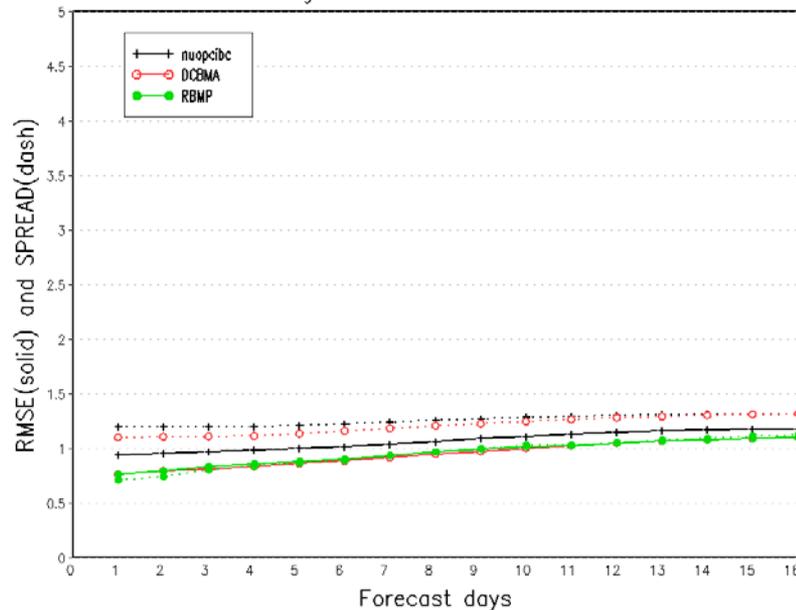


Summer 2013

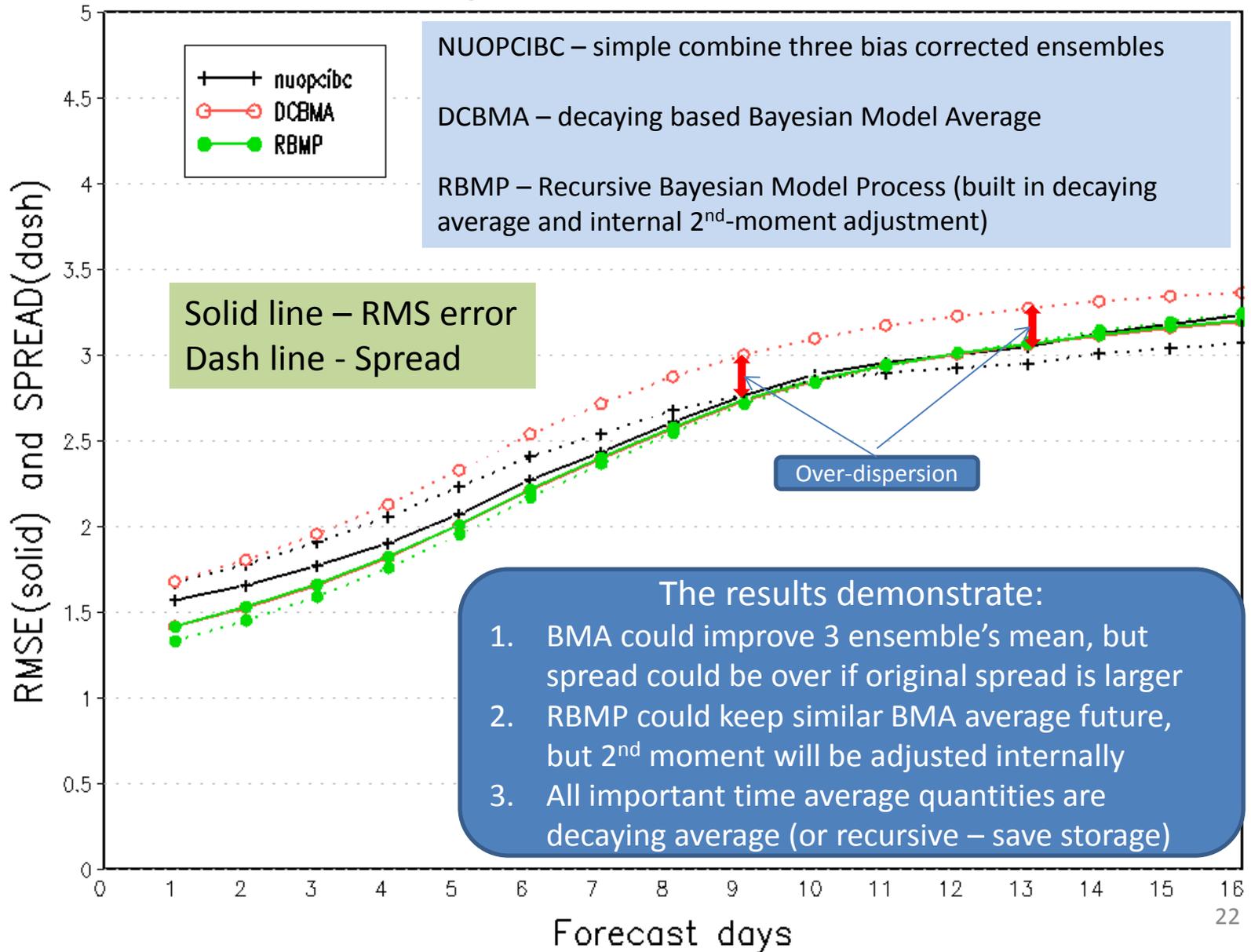
Southern Hemisphere 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 20130601 - 20130831



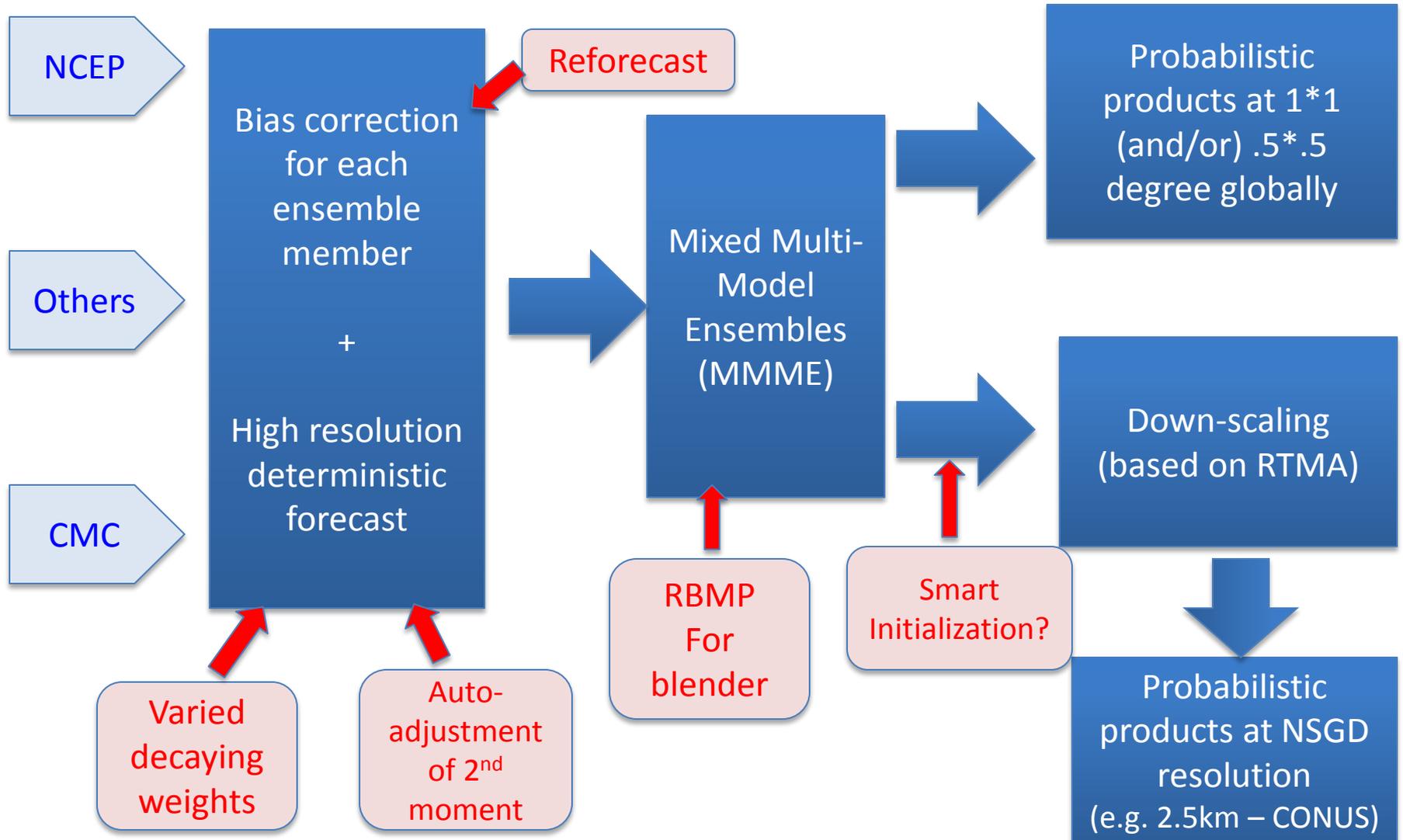
Tropical 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 20130601 - 20130831



Northern Hemisphere 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 20130901 – 20131130



# Future NAEFS Statistical Post-Processing System



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**Thanks and questions?**

# NAEFS bias corrected variables

Last upgrade: April 8<sup>th</sup> 2014 - (bias correction)

Variables	pgrba_bc file	Total 51
<b>GHT</b>	10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	10
<b>TMP</b>	2m, 2mMax, 2mMin, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	13
<b>UGRD</b>	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11
<b>VGRD</b>	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11
<b>VVEL</b>	850hPa	1
<b>PRES</b>	Surface, PRMSL	2
<b>FLUX (top)</b>	ULWRF (toa - OLR)	1
<b>Td and RH</b>	2m	2
<b>Notes</b>	CMC and FNMOC do not apply last upgrade yet	

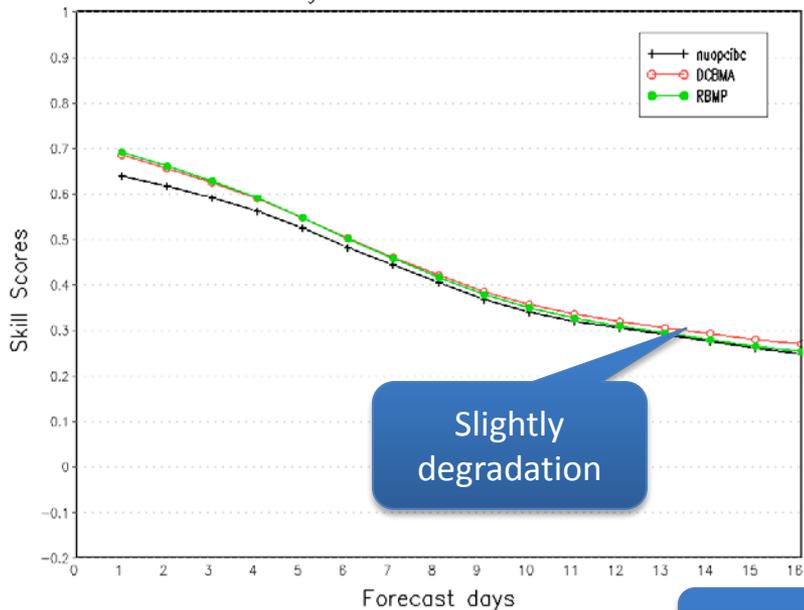
# NAEFS downscaling parameters and products

Last Upgrade: April 8 2014 (NDGD resolution)

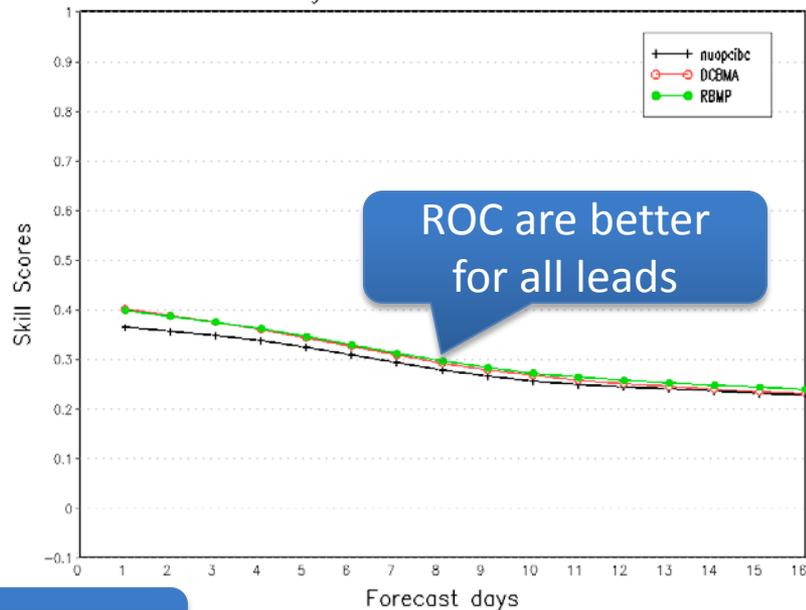
Variables	Domains	Resolutions	Total 10/10
Surface Pressure	CONUS/Alaska	5km/6km	1/1
2-m temperature	CONUS/Alaska	5km/6km	1/1
10-m U component	CONUS/Alaska	5km/6km	1/1
10-m V component	CONUS/Alaska	5km/6km	1/1
2-m maximum T	CONUS/Alaska	5km/6km	1/1
2-m minimum T	CONUS/Alaska	5km/6km	1/1
10-m wind speed	CONUS/Alaska	5km/6km	1/1
10-m wind direction	CONUS/Alaska	5km/6km	1/1
2-m dew-point T	CONUS/Alaska	5km/6km	1/1
2-m relative humidity	CONUS/Alaska	5km/6km	1/1

All downscaled products are generated from 1\*1 degree bias corrected fcst. globally  
Products include ensemble mean, spread, 10%, 50%, 90% and mode

Northern Hemisphere 2 Meter Temp.  
 Continous Ranked Probability Skill Scores  
 Average For 20130901 - 20131130

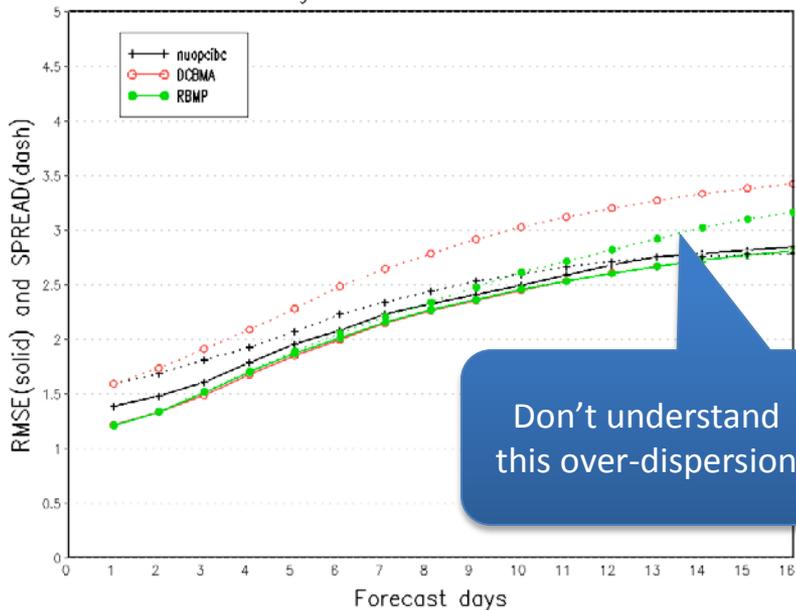


Northern Hemisphere 2 Meter Temp.  
 ROC area (0-1)  
 Average For 20130901 - 20131130

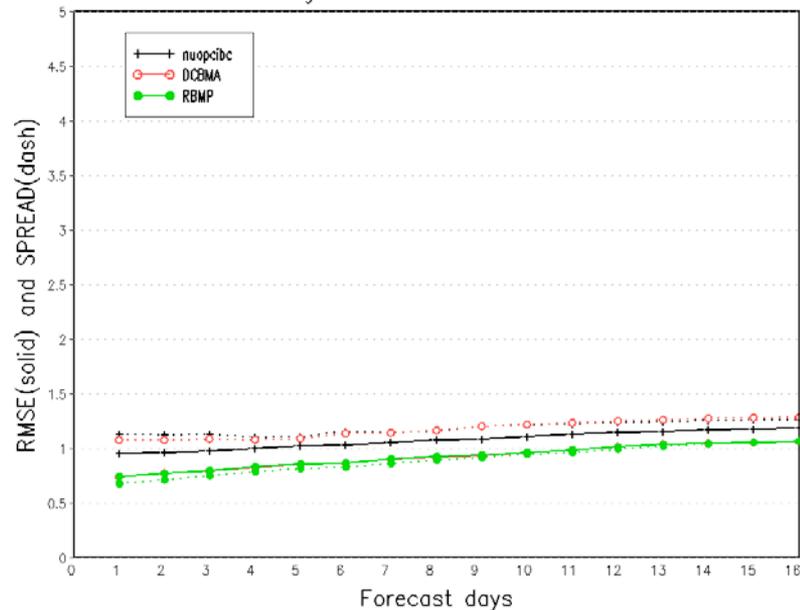


Fall 2013

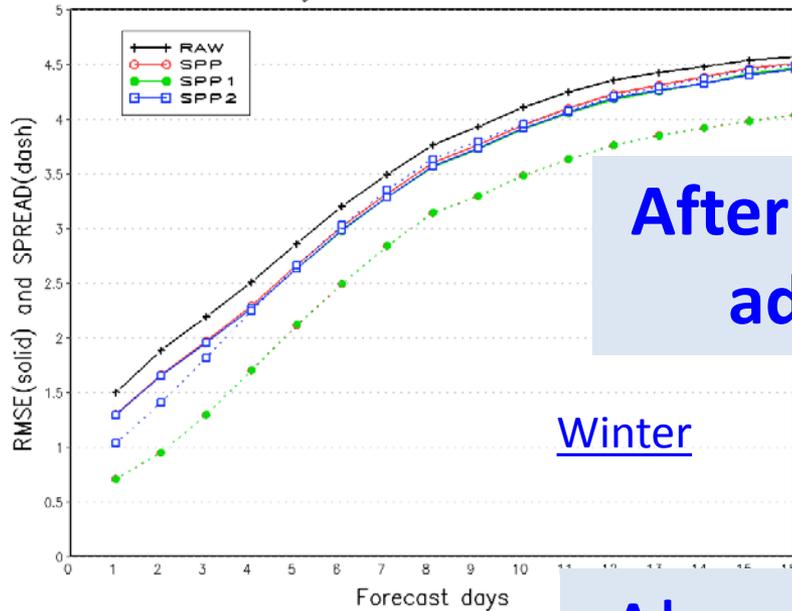
Southern Hemisphere 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 20130901 - 20131130



Tropical 2 Meter Temp.  
 Ensemble Mean RMSE and Ensemble SPREAD  
 Average For 20130901 - 20131130

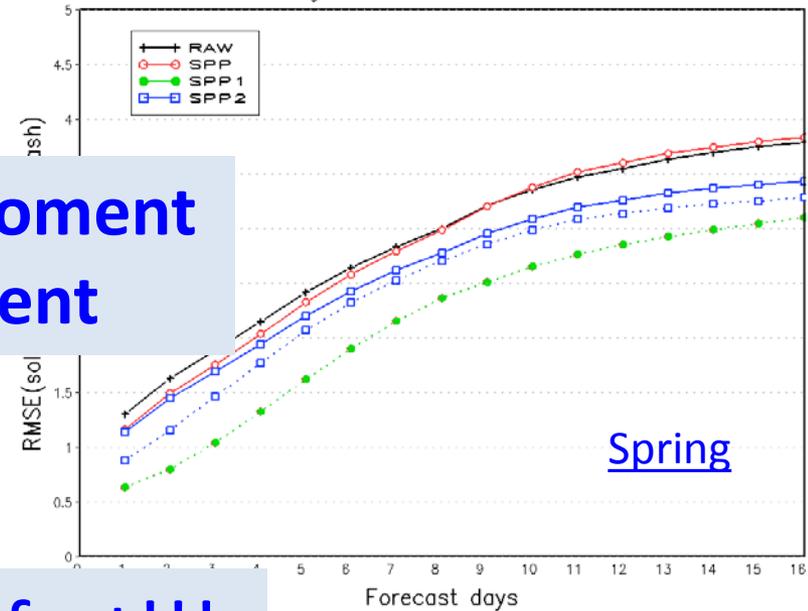


Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20091201 - 20100228



Winter

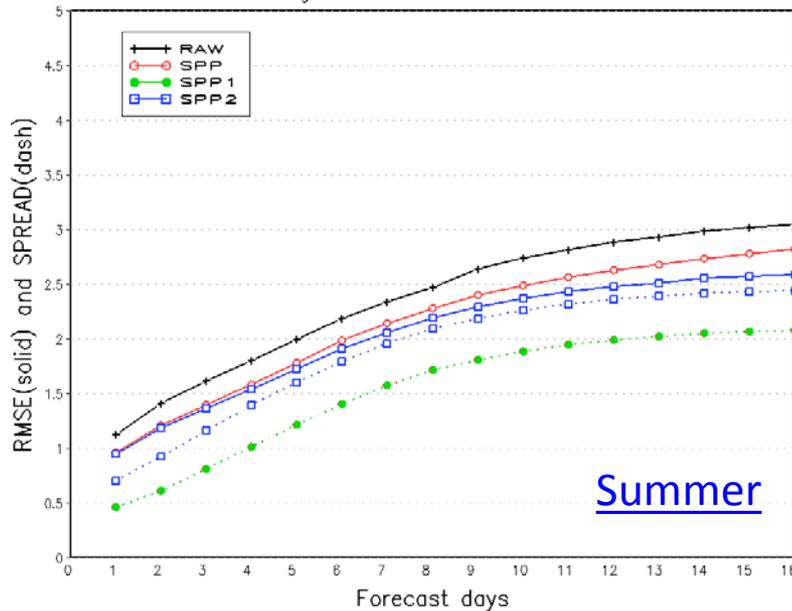
Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20100301 - 20100531



Spring

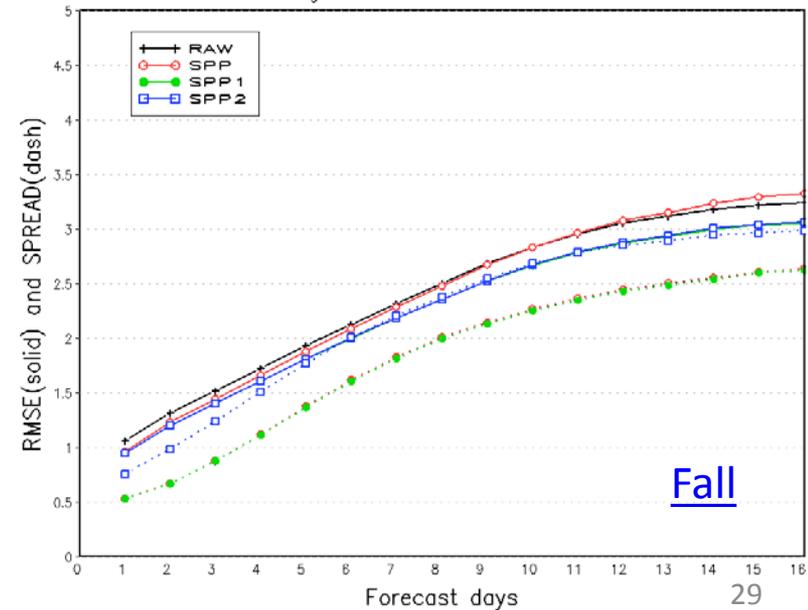
**Almost Perfect!!!**

Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20100601 - 20100831



Summer

Northern Hemisphere 2 Meter Temp.  
Ensemble Mean RMSE and Ensemble SPREAD  
Average For 20100901 - 20101130

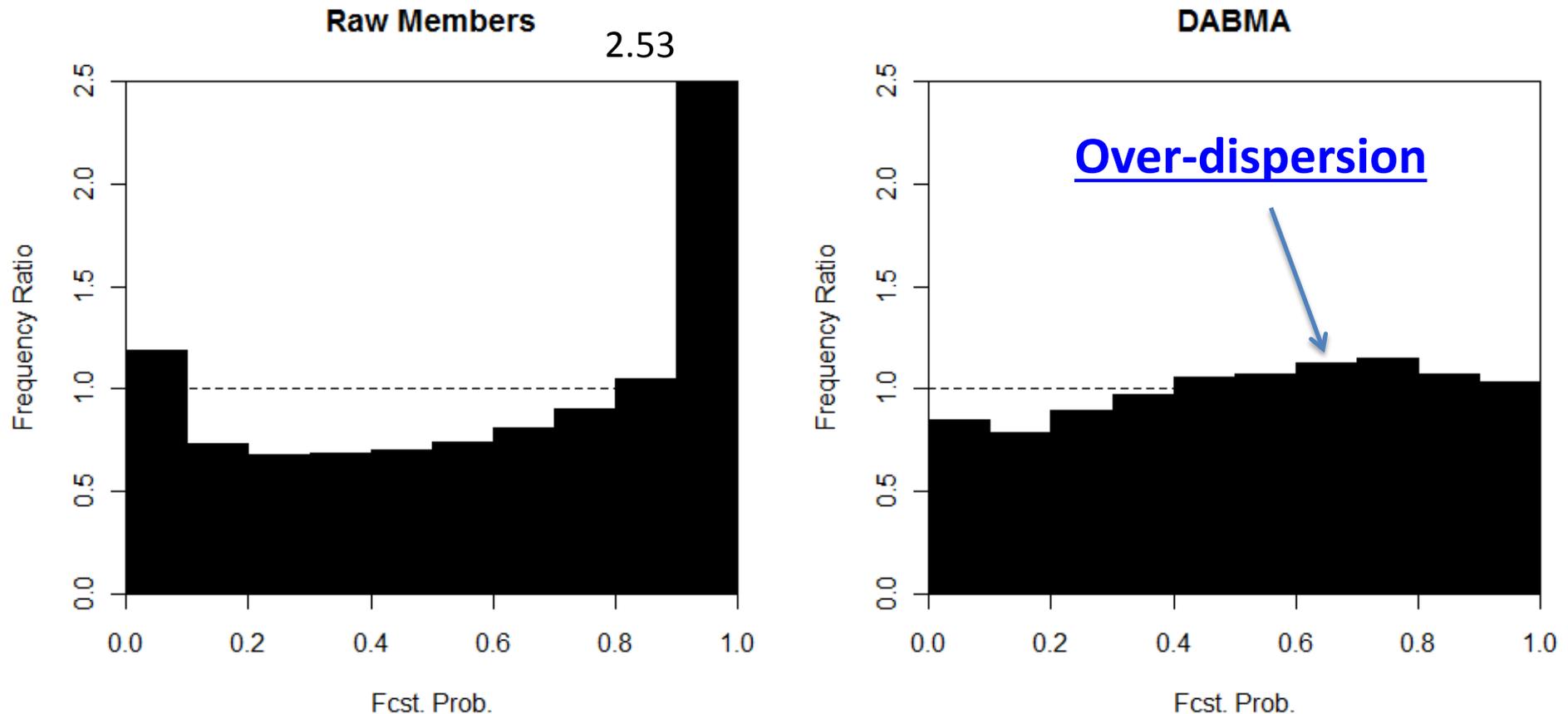


Fall

# DABMA Applied SREF 850hPa temperature

15 Dec. 2012 – 10 Feb. 2013

## 48-hr Projection



Courtesy of Dr. Veenhuis