Post Processing Methods

Contributors:
Bo Cui, Yan Lou and Hong Guan (Ensemble team)
Hui-Ya Chuang (GWCMB)
Environmental Modeling Center

Methodology

- Decaying average (or Kalman Filter method)
  - Ref: Cui and et al, 2012: *"Bias correction for global ensemble forecast"*, WAF
- Frequency Match Method for precipitation calibration
  - Ref: Zhu and Luo, 2015: *"Precipitation calibration based on FMM"*, WAF
- Recursive Bayesian Model Process for multi-model ensemble application.
  - Ref: Guan and et al, 2016: *"Multi-model ensemble application using RBMP"* (in preparing)

Description of NAEFS Bias Correction
(Decaying average method)

1). Bias Estimation:

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

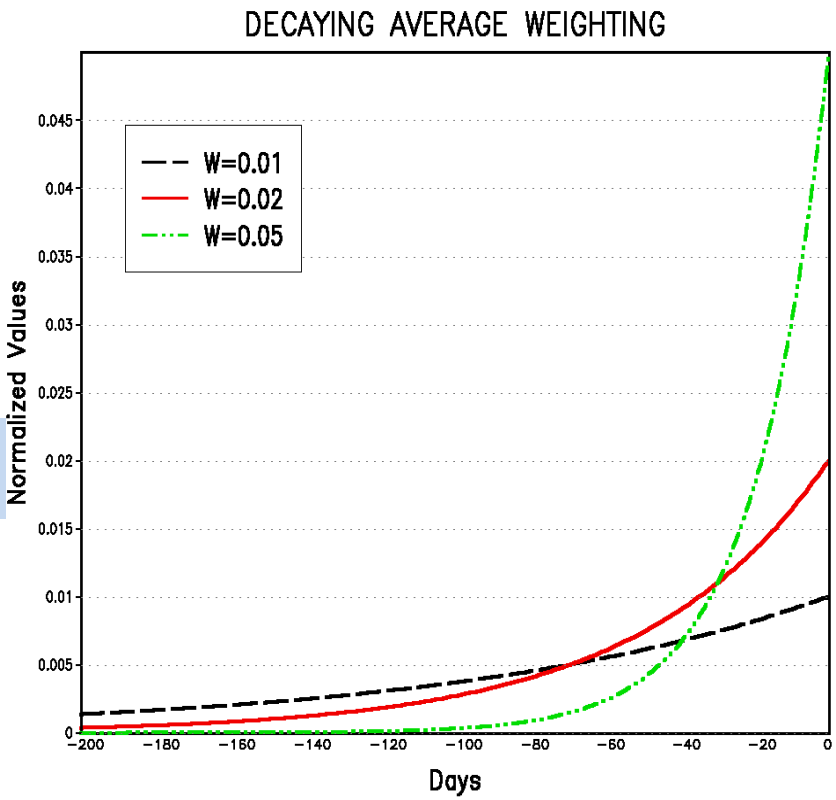
2). Decaying Average (Kalman Filter method)

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

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

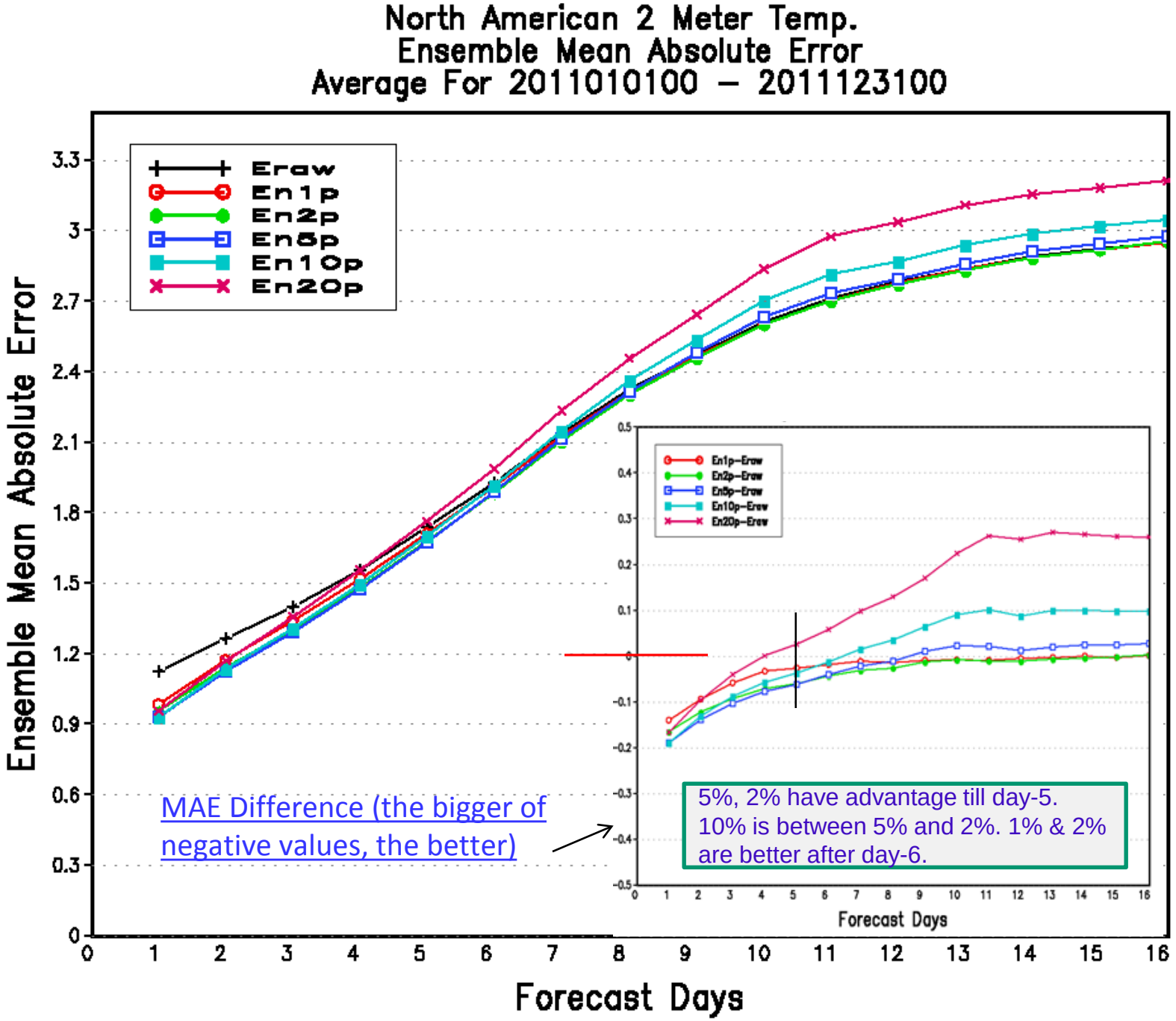
4). Bias corrected forecast:

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

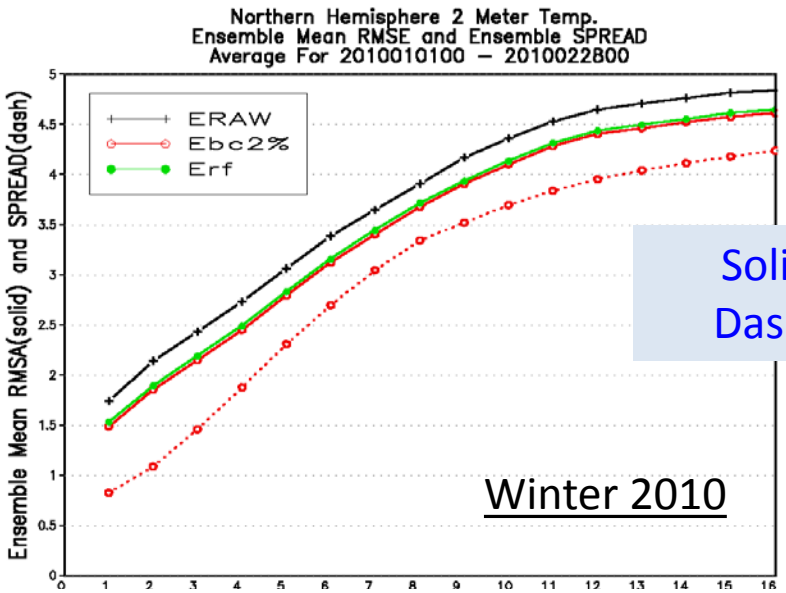


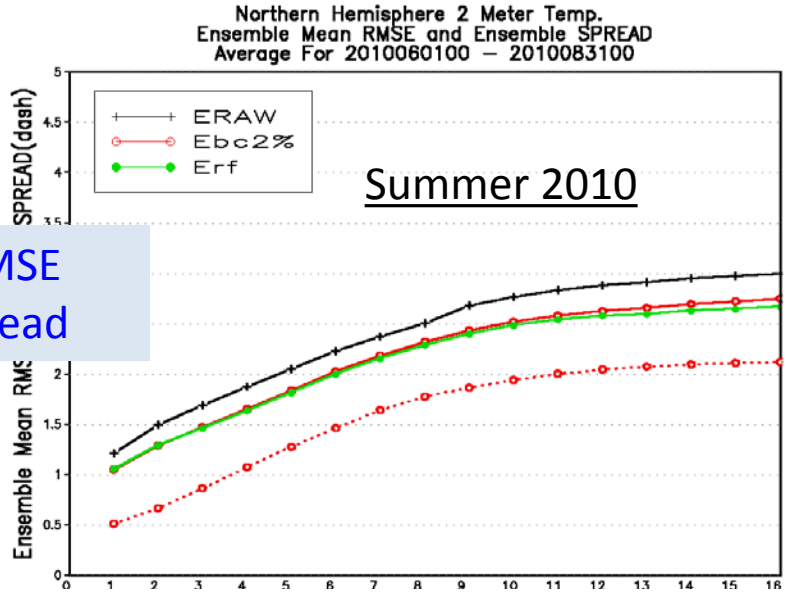
Simple Accumulated Bias

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

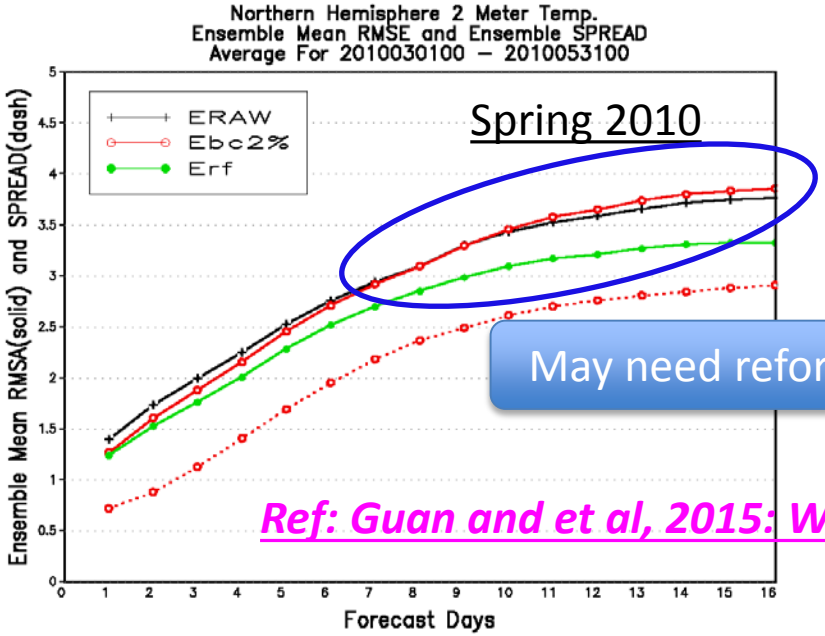

North American 2 Meter Temp.
Ensemble Mean Absolute Error
Average For 2011010100 – 2011123100
Eraw
En1p
En2p
En5p
En10p
En20p
Ensemble Mean Absolute Error
Forecast Days
MAE Difference (the bigger of negative values, the better)
5%, 2% have advantage till day-5.
10% is between 5% and 2%. 1% & 2% are better after day-6.
En1p–Eraw
En2p–Eraw
En5p–Eraw
En10p–Eraw
En20p–Eraw
Forecast Days

Using 25-year reforecast bias (1985-2009) to calibrate 2010 forecast
Compare to 2% decaying average



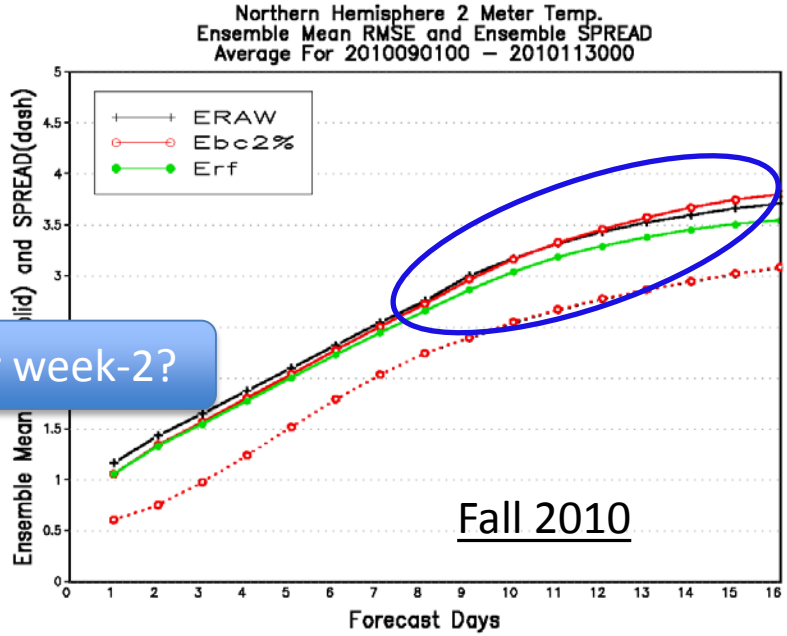


Solid line – RMSE
Dash line - Spread



May need reforecast for week-2?

Ref: Guan and et al, 2015: WAF

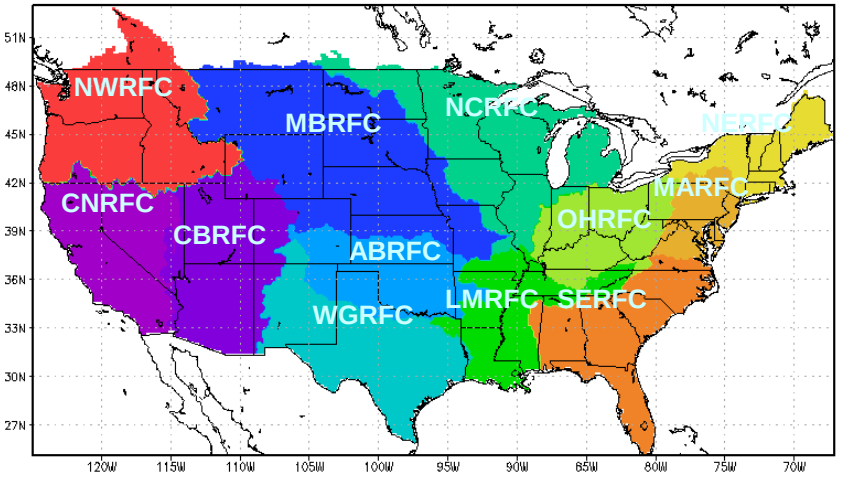


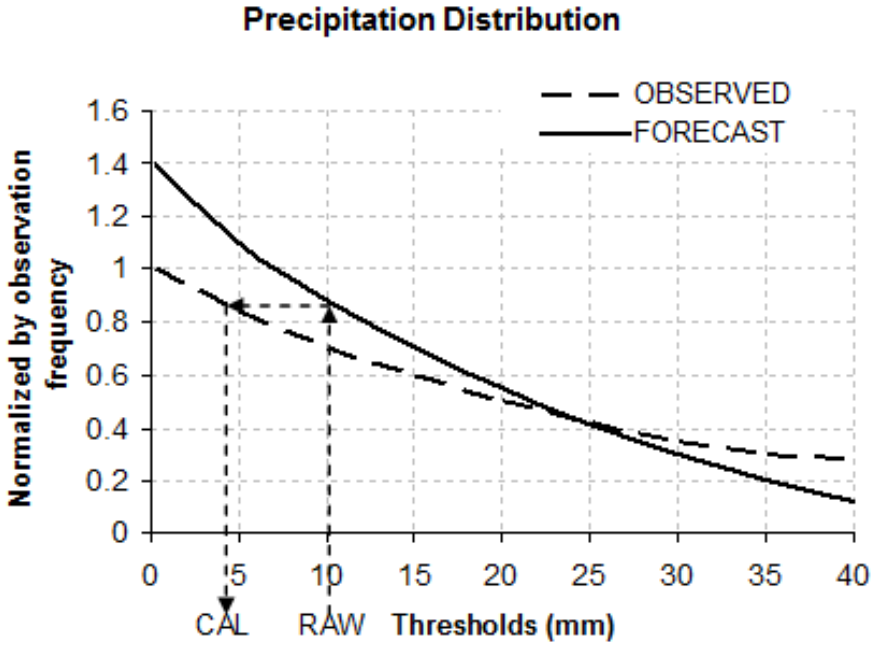
Frequency Matching Method (FMM) For Precipitation Calibration

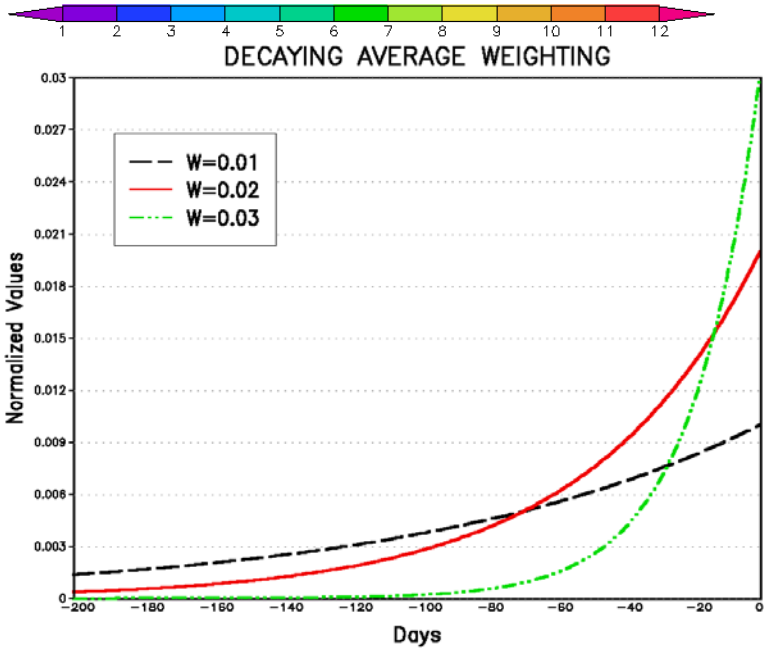
Calculate for Obs and Fcst respectively

$$\overline{PDF}_j = (1-W) * \overline{PDF}_{j-1} + W * PDF_j$$

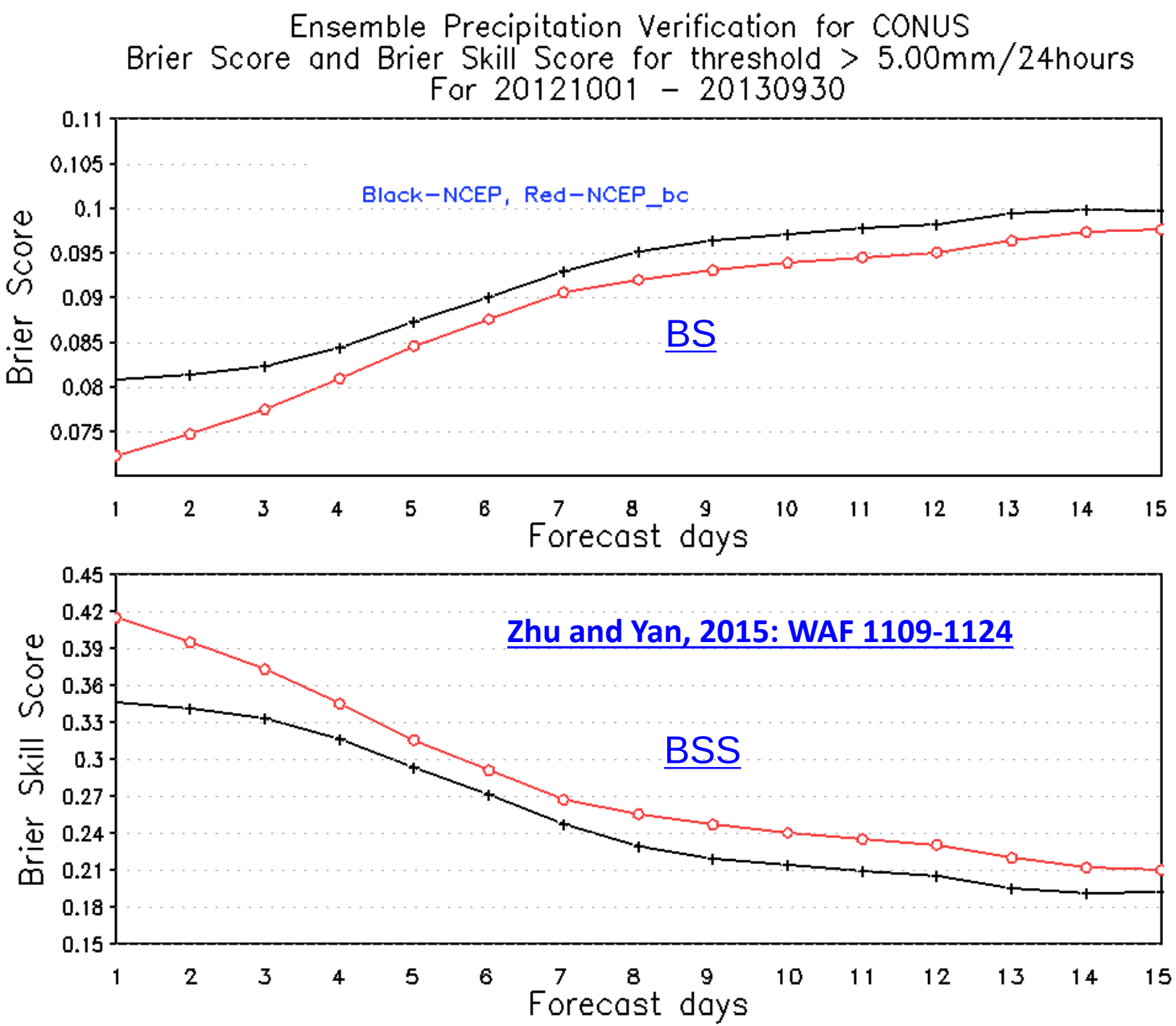
W is weight to accumulate PDF





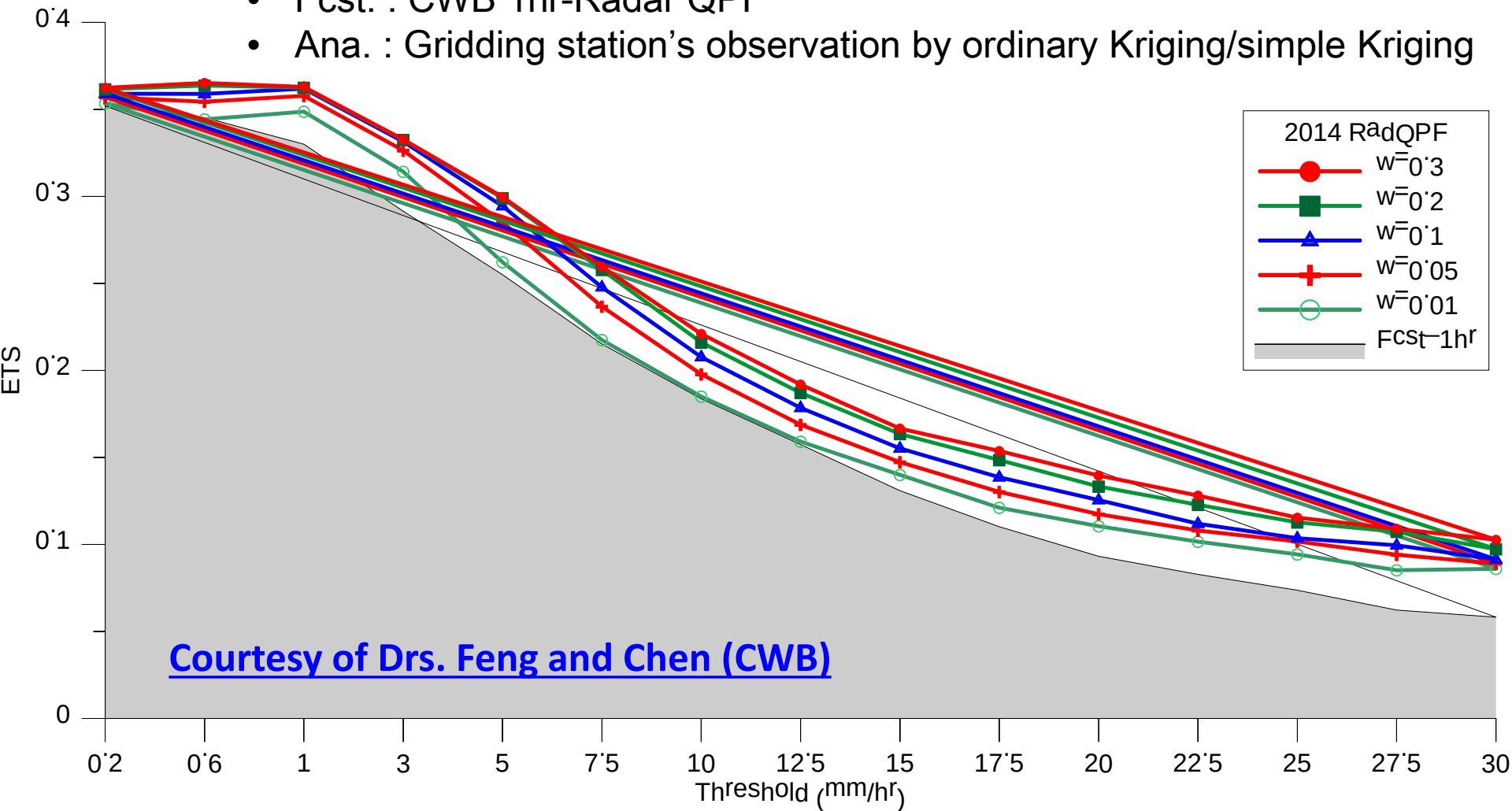


Zhu and Yan, 2015: WAF 1109-1124


Ensemble Precipitation Verification for CONUS
Brier Score and Brier Skill Score for threshold > 5.00mm/24hours
For 20121001 - 20130930
Black=NCEP, Red=NCEP_bc
Brier Score
0.11
0.105
0.1
0.095
0.09
0.085
0.08
0.075
BS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Forecast days
Brier Skill Score
0.45
0.42
0.39
0.36
0.33
0.3
0.27
0.24
0.21
0.18
0.15
Zhu and Yan, 2015: WAF 1109-1124
BSS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Forecast days

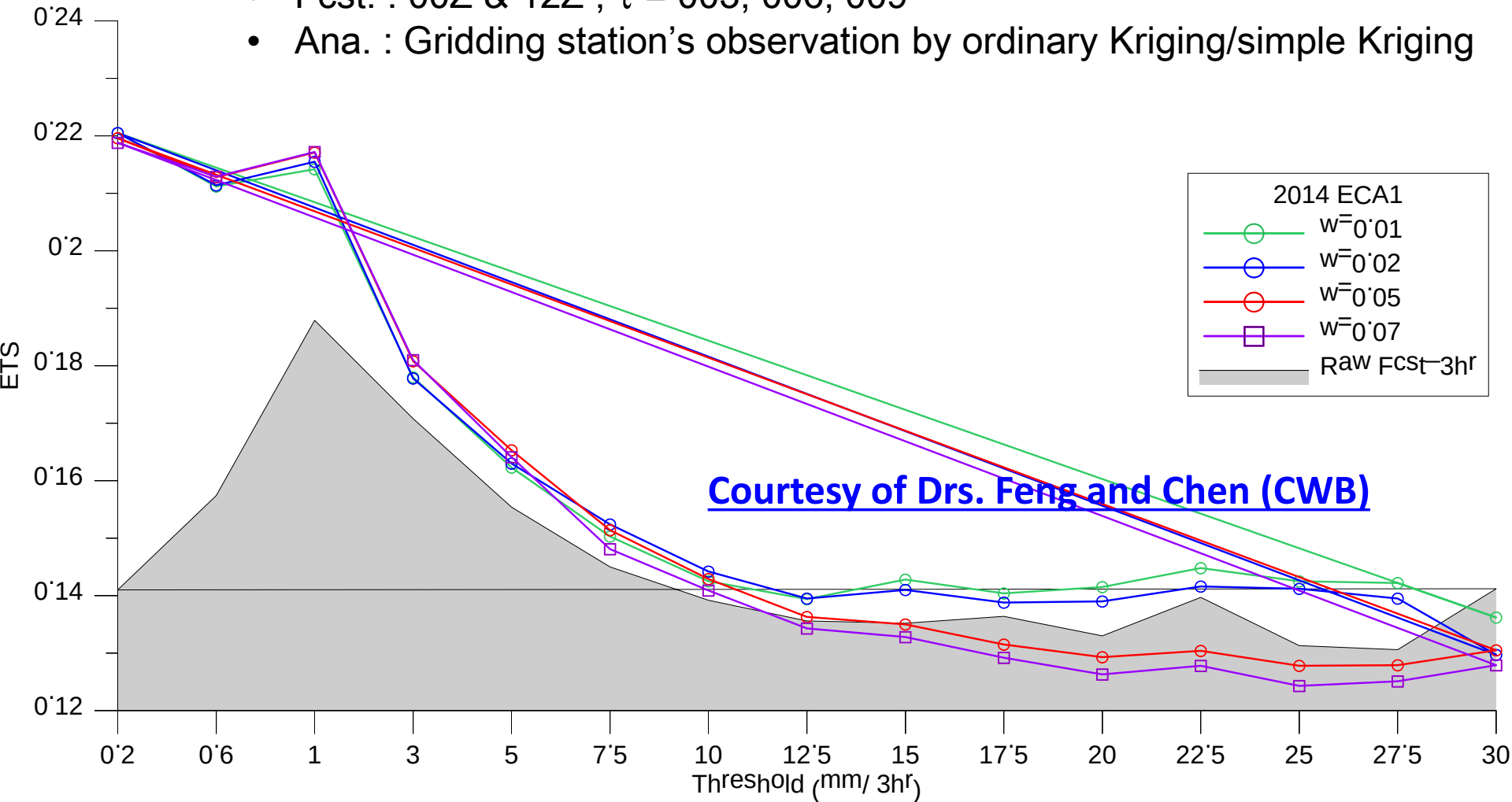
Calibrate Radar QPF with FMM

- Region : 21.8~25.4°N & 120.0~122.0°E (resolution=0.0125°)
- Fcst. : CWB 1hr-Radar QPF
- Ana. : Gridding station's observation by ordinary Kriging/simple Kriging



Calibrate ECMWF 3hr-Precip. with FMM

- Region : 21.8~25.4°N & 120.0~122.0°E (resolution=0.125°)
- Fcst. : 00Z & 12Z , τ = 003, 006, 009
- Ana. : Gridding station's observation by ordinary Kriging/simple Kriging



Concept of Bayesian Model Average

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

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

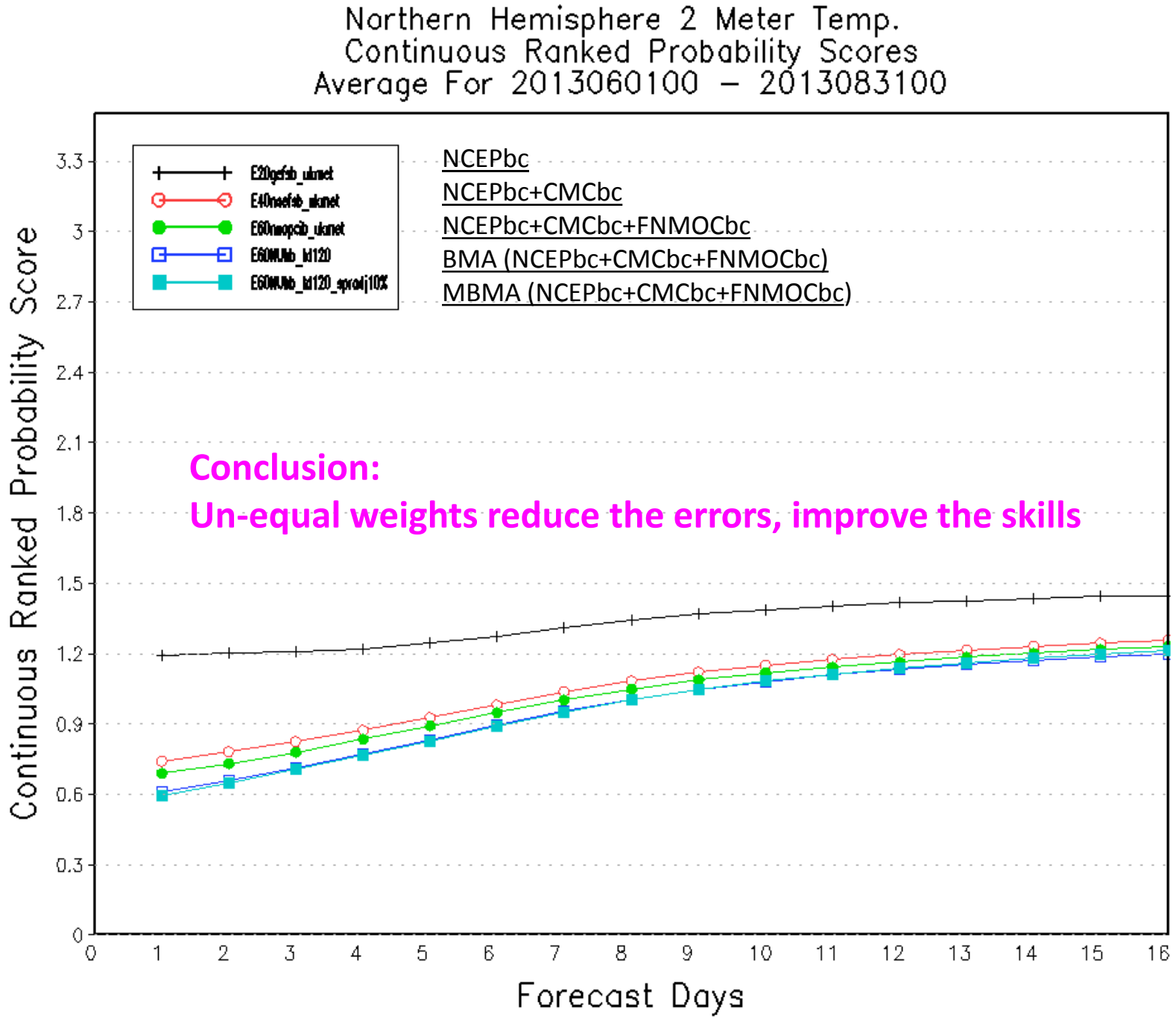
Sum of (s,t) represents the numbers of obs.

Finally, the BMA predictive variance is

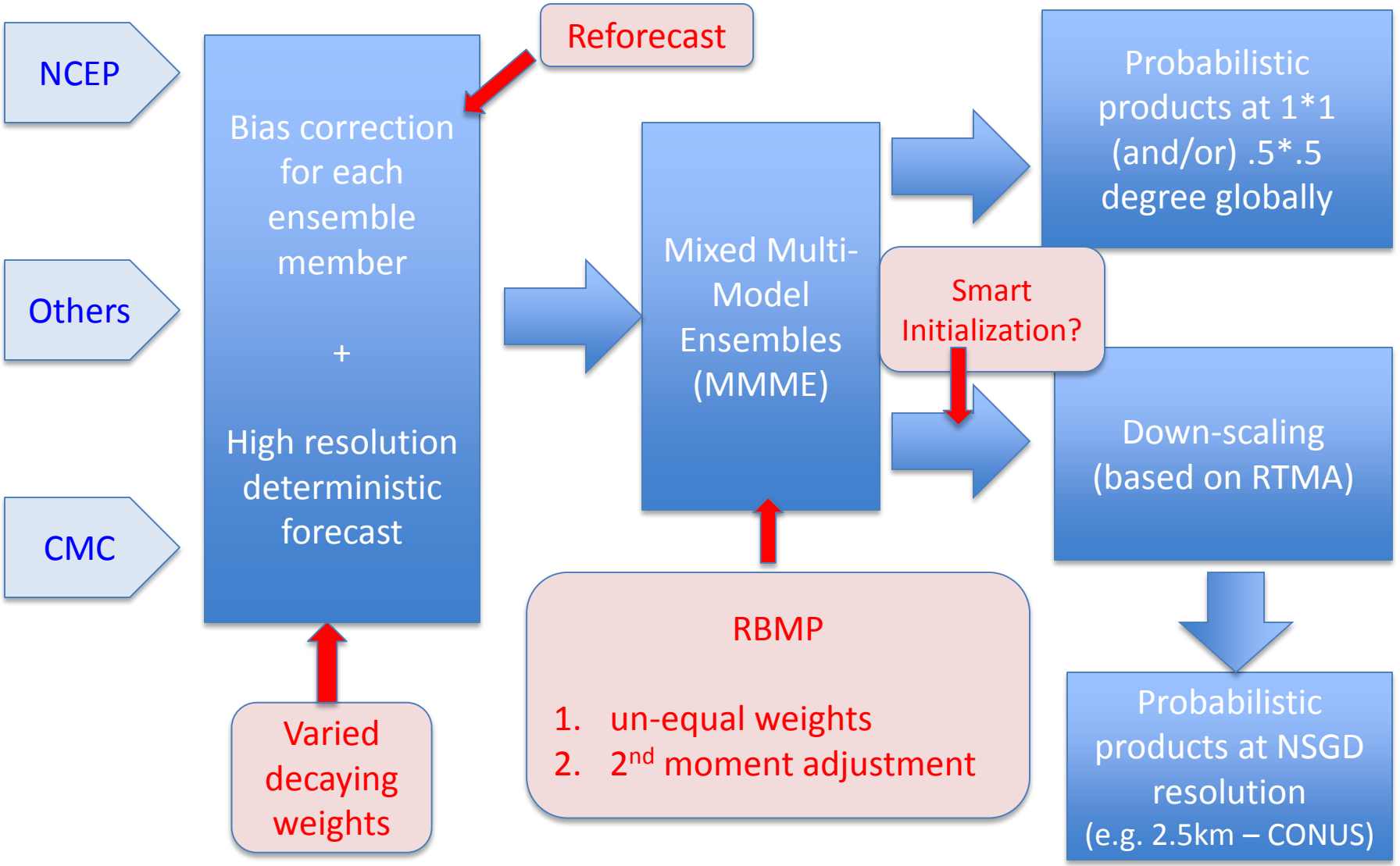
Between-forecast variance *Within-forecast variance*

$$Var(y_{s,t} \mid \tilde{f}_{1,s,t},\ldots,\tilde{f}_{K,s,t}) = \sum_{k=1}^{K} w_k (\tilde{f}_{k,s,t} - \sum_{i=1}^{K} w_i \cdot \tilde{f}_{i,s,t})^2 + \sum_{k=1}^{K} w_k \cdot \sigma_k^2$$

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


Northern Hemisphere 2 Meter Temp.
Continuous Ranked Probability Scores
Average For 2013060100 - 2013083100
Continuous Ranked Probability Score
Forecast Days
0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3
3.3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
NCEPbc
NCEPbc+CMCbc
NCEPbc+CMCbc+FNMOCbc
BMA (NCEPbc+CMCbc+FNMOCbc)
MBMA (NCEPbc+CMCbc+FNMOCbc)
Conclusion:
Un-equal weights reduce the errors, improve the skills

Improving NAEFS Statistical Post-Processing



Brief Introduction to UPP

Hui-Ya Chuang

- EMC developed Unified Post Processor to be used as the common post processor for all NOAA's operational models, including GFS, NAM, GEFS, SREF, HWRF, RAP, HRRR, and WRF ARW.
- UPP has been widely used as a community post, through EMC's collaboration with NCAR DTC.
- Main functions include performing vertical interpolations and computing diagnostic variables.
- Use MPI and threading to ensure fast product delivery.

Perform Calibration in Unified Post Processor

Hui-Ya Chuang and Yuejian Zhu

- Calibration for model native grid
  - High resolution and all variables
  - Models: NAM, GFS, SREF, GEFS and RAP
  - Bias correction (and 2nd moment adjustment for ensemble)
- Proxy truth
  - Best analysis (and/or observation)
- Methodology
  - Decaying average (and FMM) of NAEFS SPP
  - Reforecast could help for longer lead-time forecast, and/or heavy precipitation forecast (if it is available)
- Advantage/beneficent
  - Reduce IO motion and memory requirement
  - Provide calibrated (or bias free) model output
    - Include derived variables, **such as CAPE**
  - Avoid many duplications
  - Good for downstream applications

Extra slides or background!!!

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

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 16th Day of November 2004.

Generates products for:
Weather forecasters
Specialized users and end users

It is part of NGGPS-ensemble post process
Strong connection to stakeholder
(WPC, CPC and et al)

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 – Q3FY16 — 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. Beauregard, 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

NAEFS bias corrected variables

Last upgrade: April 8th 2014 - (bias correction)

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

18

NAEFS downscaling parameters and products

Plan: Q2FY2016 (NDGD resolutions)

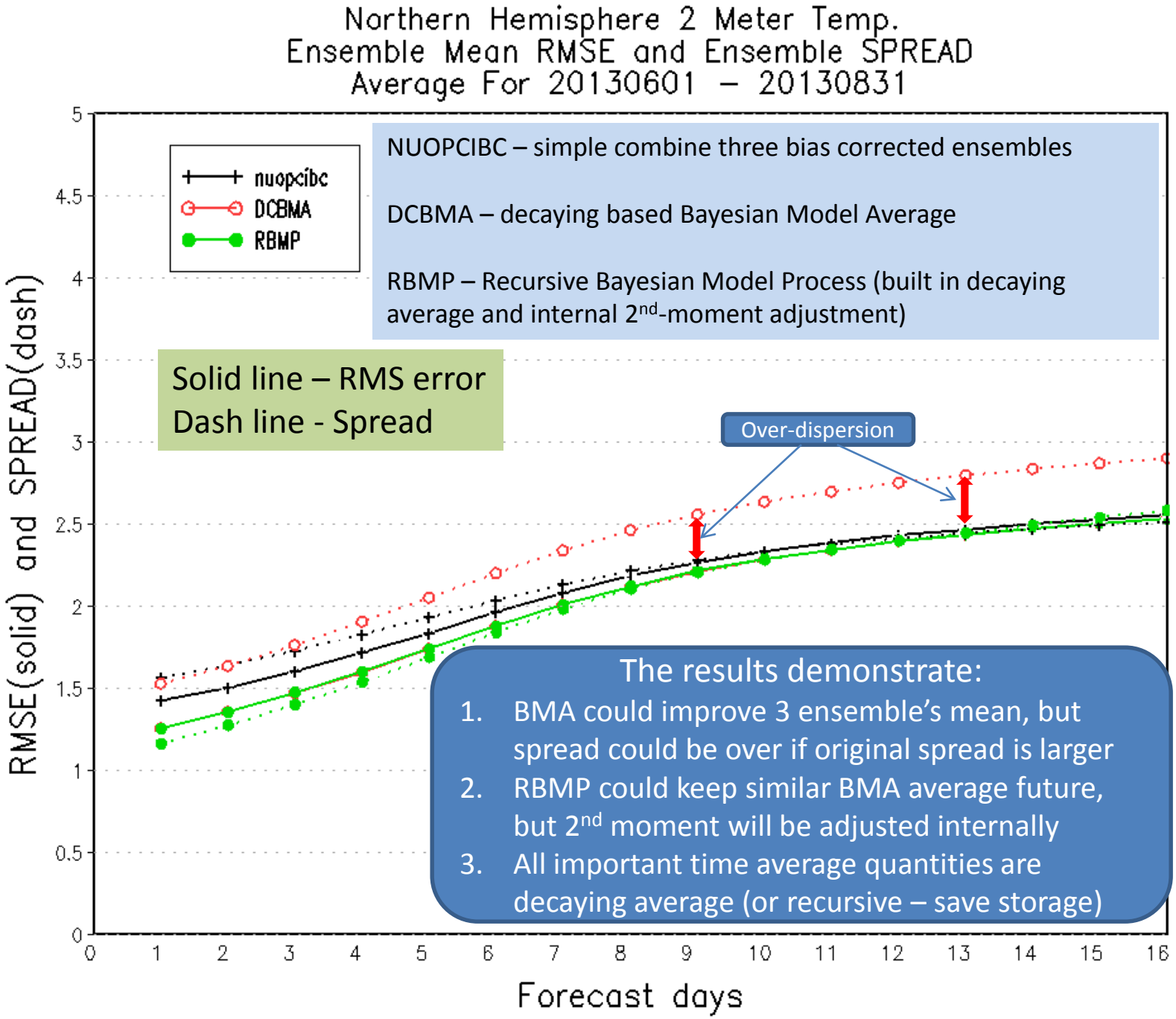
Variables	Domains	Resolutions	Total 10/10
Surface Pressure	CONUS/Alaska	2.5km/3km	1/1
2-m temperature	CONUS/Alaska	2.5km/3km	1/1
10-m U component	CONUS/Alaska	2.5km/3km	1/1
10-m V component	CONUS/Alaska	2.5km/3km	1/1
2-m maximum T	CONUS/Alaska	2.5km/3km	1/1
2-m minimum T	CONUS/Alaska	2.5km/3km	1/1
10-m wind speed	CONUS/Alaska	2.5km/3km	1/1
10-m wind direction	CONUS/Alaska	2.5km/3km	1/1
2-m dew-point T	CONUS/Alaska	2.5km/3km	1/1
2-m relative humidity	CONUS/Alaska	2.5km/3km	1/1
Total cloud cover?			
Wind Gust?			
Significant wave height			

Downscaled products are generated from 1*1 degree probabilistic fcst globally
Products include ensemble mean, spread, 10%, 50%, 90% and mode

The NUOPC Tri-Agency (NOAA, Navy, Air Force) agreed to work on a collaborative vision through coordinated research, transition and operations in order to develop and implement the next-generation National Operational Global Ensemble modeling system. This NUOPC plan consists of the following elements:

- A National operational numerical weather prediction system with a commitment to address common requirements
- A multi-component system with interoperable components built upon common standards and a common framework
- **Managed ensemble diversity to quantify and bound forecast uncertainty**
- Ensemble products used to drive high-resolution regional/local prediction and other downstream models
- A National research agenda for global numerical weather prediction to accelerate development and transition to operations
- Increased leverage of partner agencies to avoid independent/duplicative operating costs

Multi-model ensemble application is one of NGGPS-ensemble post process
Strong connection to NCEP stakeholders (WPC, CPC and et al)


Northern Hemisphere 2 Meter Temp.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20130601 - 20130831
nuopcibc
DCBMA
RBMP
NUOPCIBC – simple combine three bias corrected ensembles
DCBMA – decaying based Bayesian Model Average
RBMP – Recursive Bayesian Model Process (built in decaying average and internal 2nd-moment adjustment)
Solid line – RMS error
Dash line - Spread
Over-dispersion
The results demonstrate:
1. BMA could improve 3 ensemble's mean, but spread could be over if original spread is larger
2. RBMP could keep similar BMA average future, but 2nd moment will be adjusted internally
3. All important time average quantities are decaying average (or recursive – save storage)
RMSE(solid) and SPREAD(dash)
Forecast days
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16