Multi-Model Ensemble Application Using Recursive Bayesian Model Process

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Highlights

- **Background**
  - **National Unified Operational Prediction Capability (NUOPC)**
  - **North American Ensemble Forecast System (NAEFS)**

- NAEFS Statistical Post Process (SPP)
  - Current status
  - Equal weights multi-model ensemble
  - Deficit of 2nd moment – under-dispersion

- Bayesian Model Average (BMA)
  - Recursive Bayesian Model Process (RBMP)
  - Concept
  - Modified BMA -2nd moment adjustment

- Future plan
  - Implement RBMP for NAEFS and NUOPC application

NUOPC

NATIONAL UNIFIED OPERATIONAL PREDICTION CAPABILITY

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 processes
Strong connection to NCEP stakeholders (WPC, CPC and et al.)

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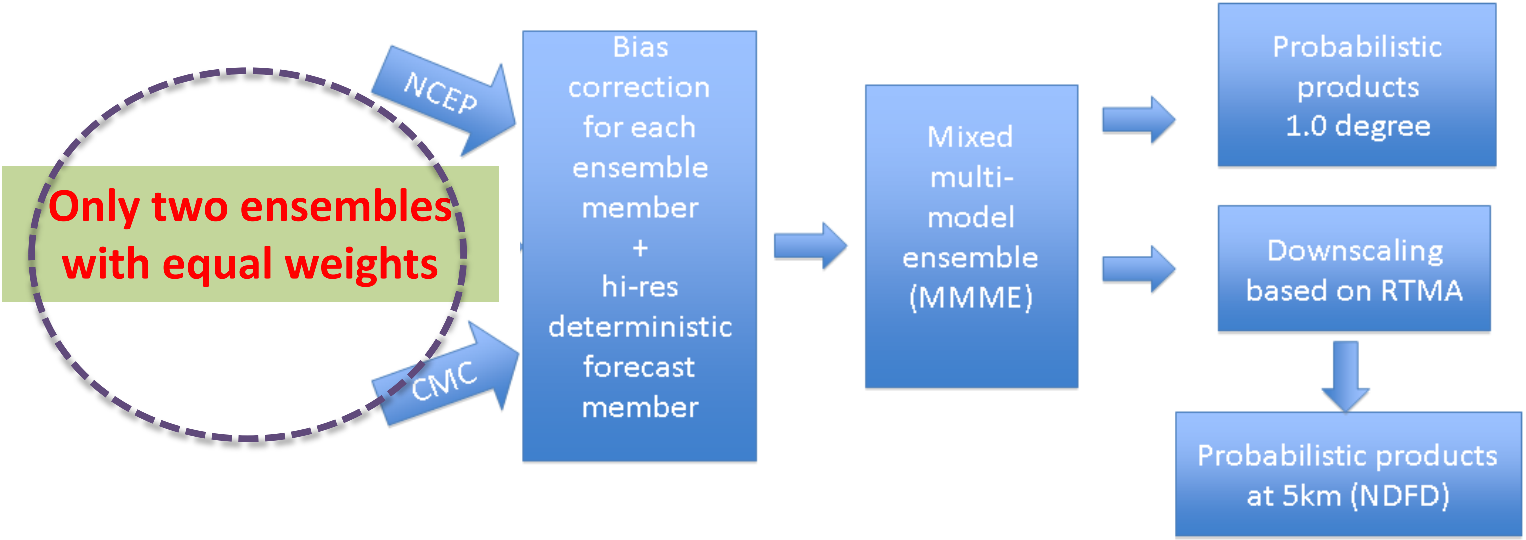
NAEFS Statistical Post-Processing System



- 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

Description of NAEFS Bias Correction
(Decaying average method)

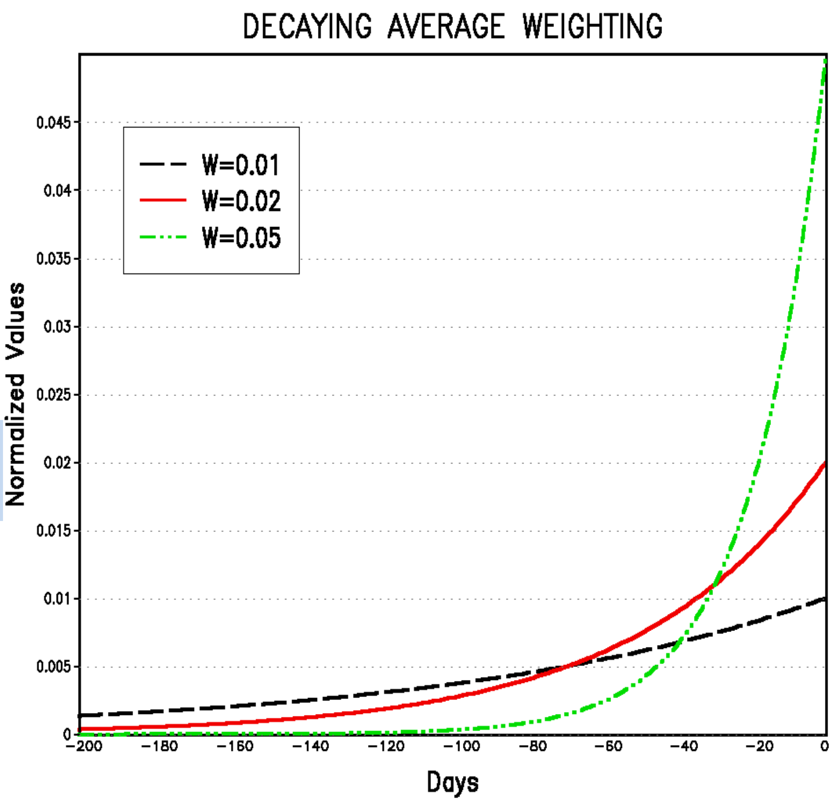
1). Bias Estimation:

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

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)

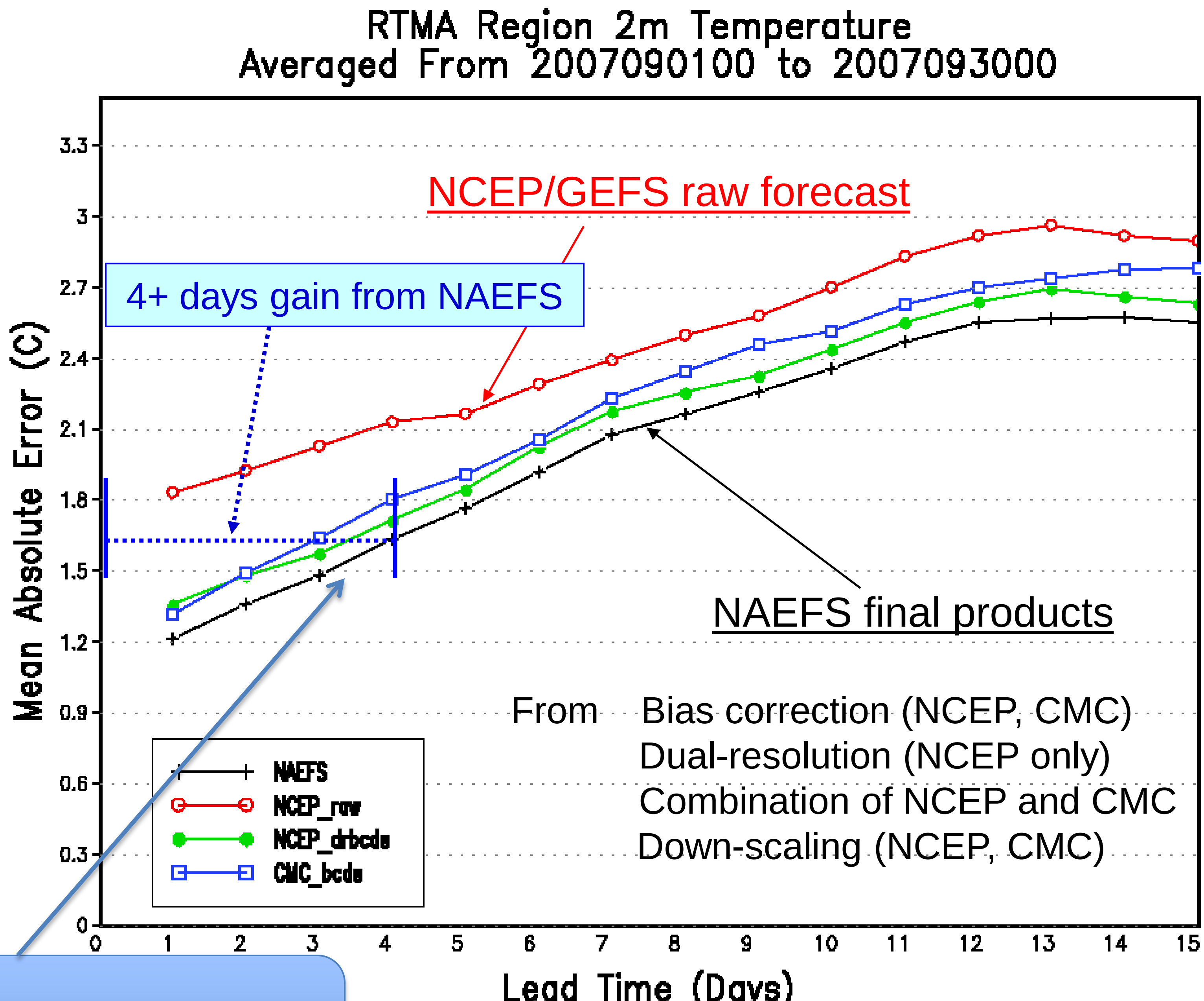


4). Bias corrected forecast:

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

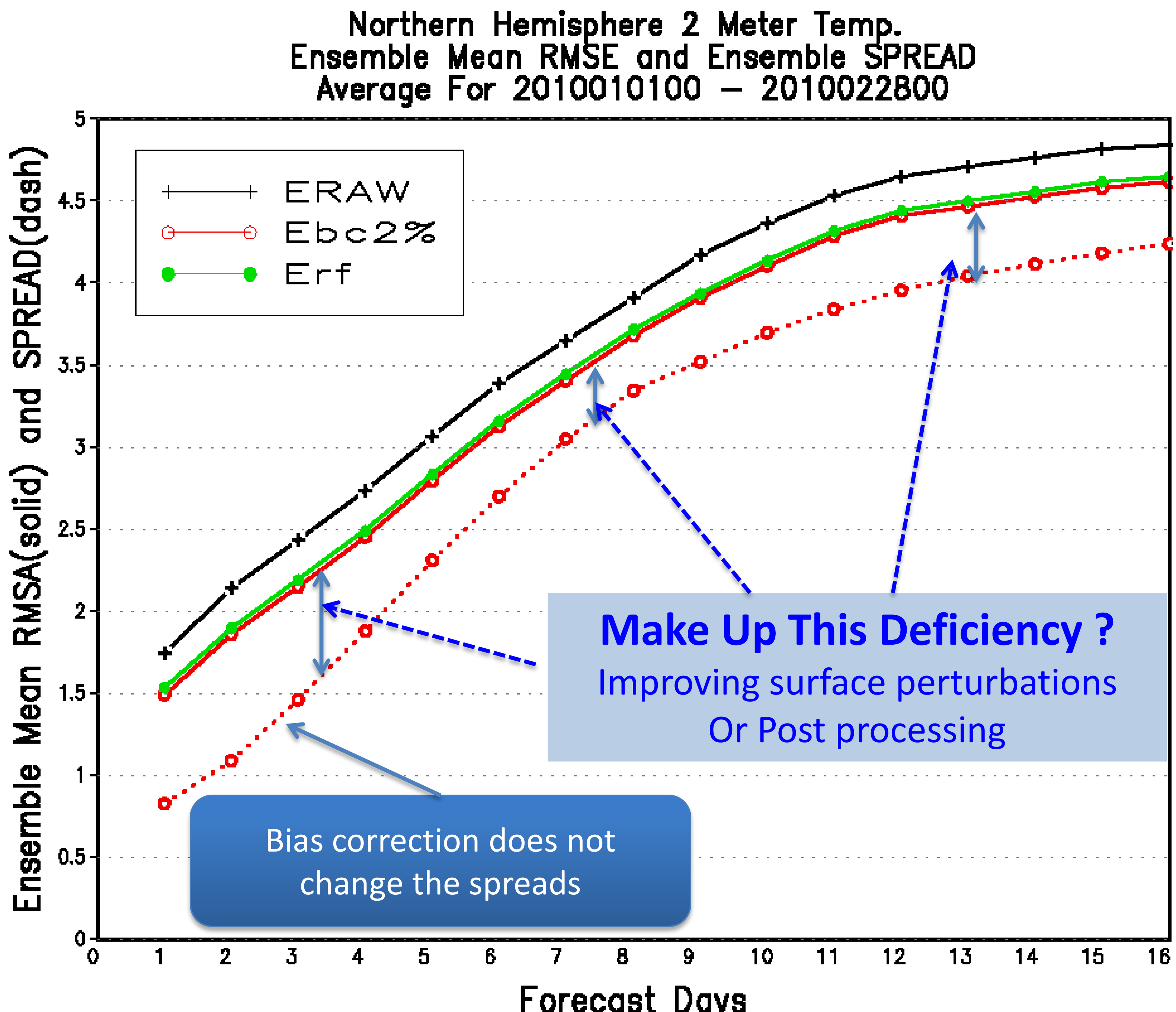
Simple Accumulated Bias

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



This is very good,
But, we use equal weights

BO CUI, GCWMB/EMC/NCEP/NOAA



Northern Hemisphere 2 Meter Temp.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 2010010100 – 2010022800
Ensemble Mean RMSA(solid) and SPREAD(dash)
Forecast Days
ERAW
Ebc2%
Erf
Make Up This Deficiency ?
Improving surface perturbations
Or Post processing
Bias correction does not change the spreads

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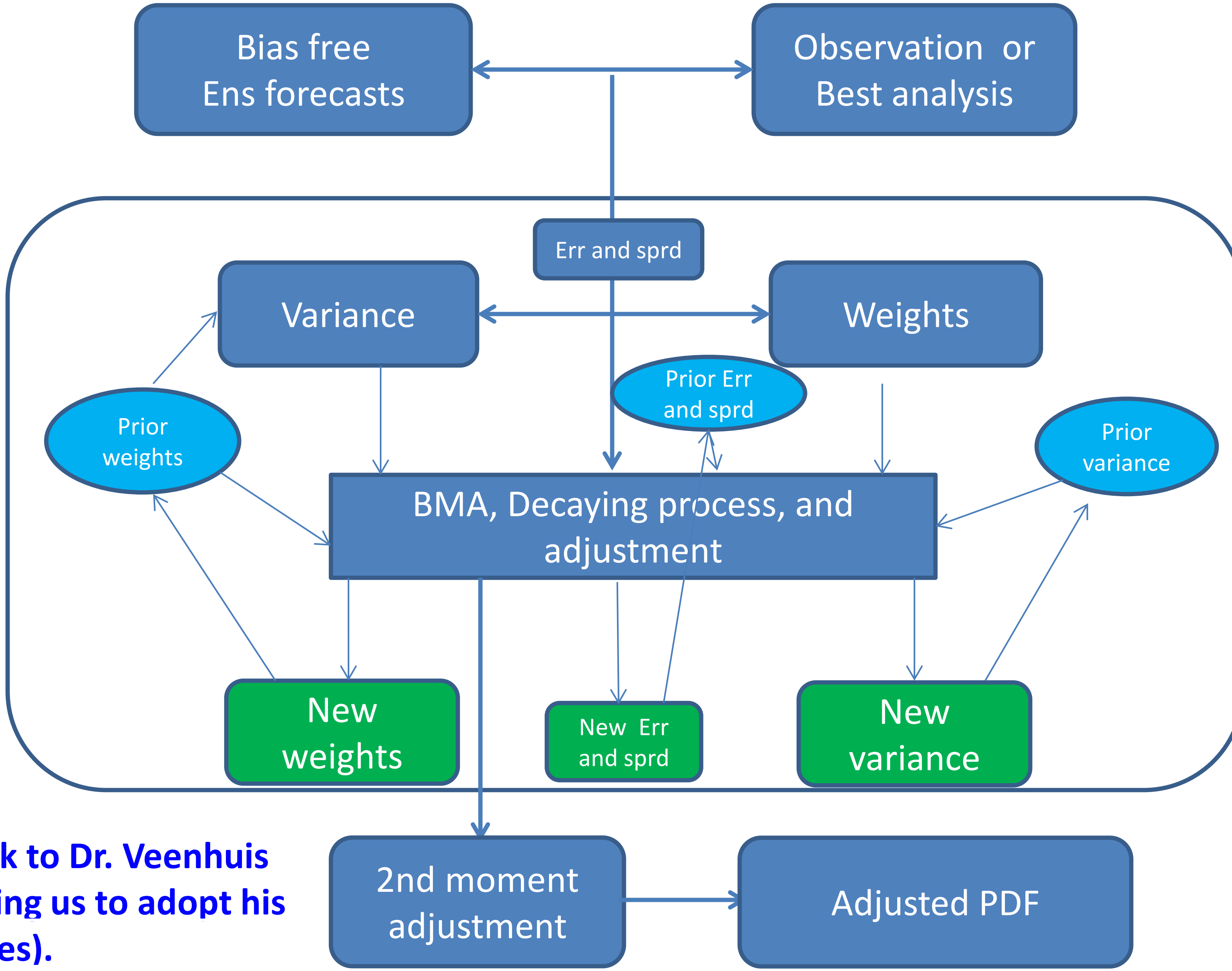
Flow Chart of Recursive Bayesian Model Process (RBMP)



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

Bayesian Model Average

Law of total probability

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

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

$p(M_k \mid y^T)$ 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

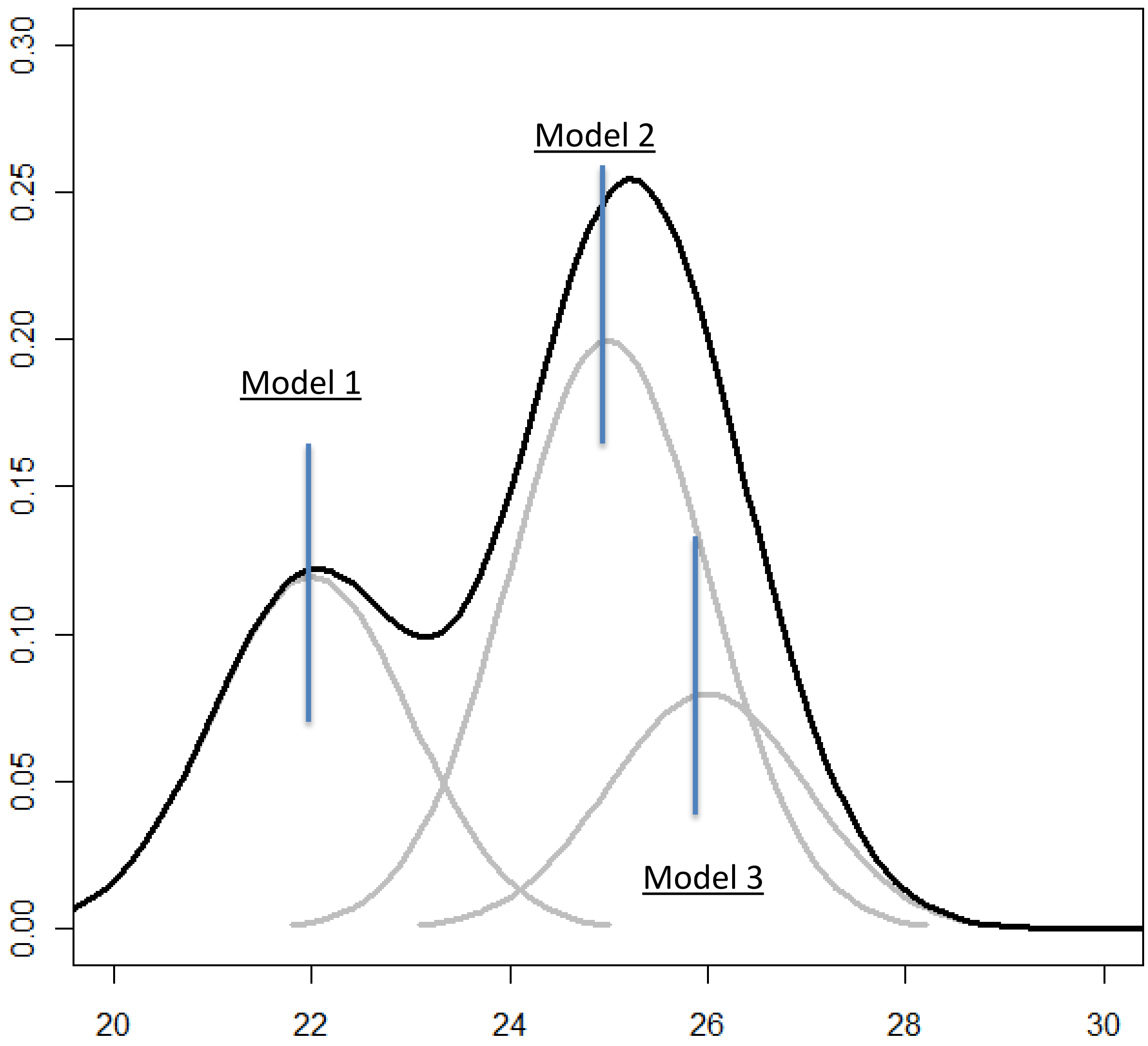
Weights and standard deviations for each model (k - ensemble member) at step *j*

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

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

Finally, the BMA predictive variance is

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



[Courtesy of Dr. Veenhuis](#)

2^{nd} moment adjustment

Under-dispersive/Over-dispersive

1st moment adjusted forecast

2nd moment adj.

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

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

$$\overline{R} = \frac{\overline{S}}{\overline{E}}$$

R=1 if E=0

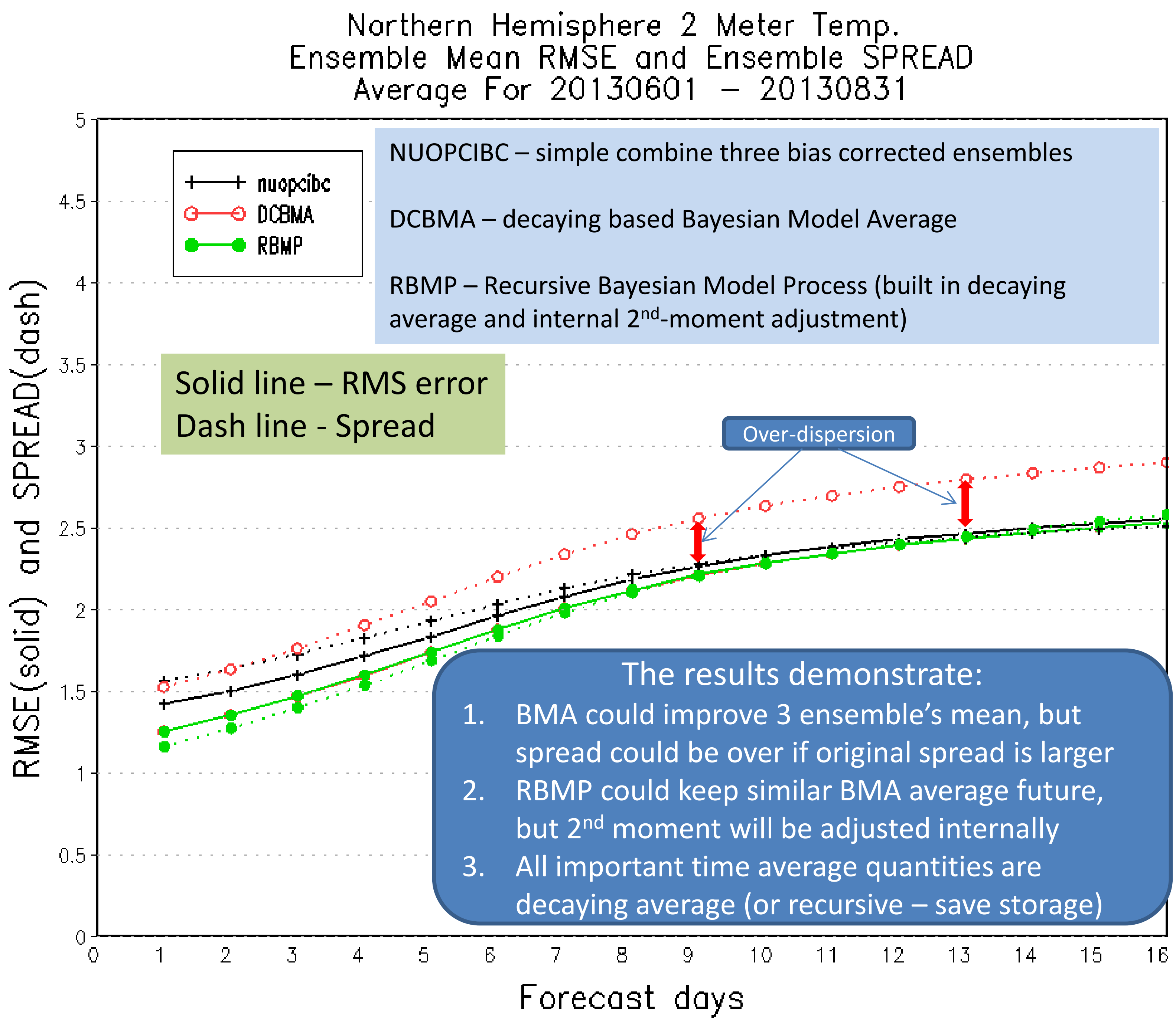
Estimated by decaying averaging

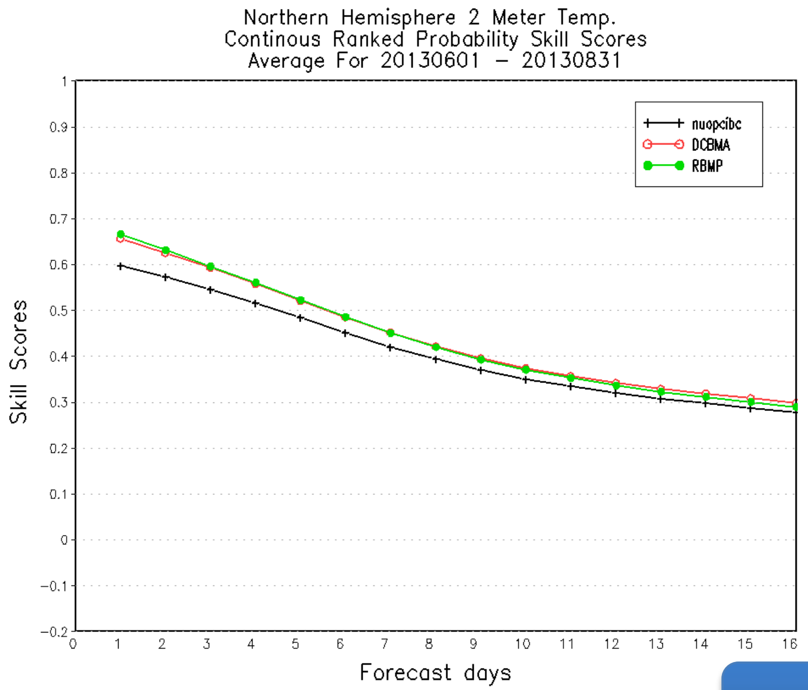
Ensemble skill

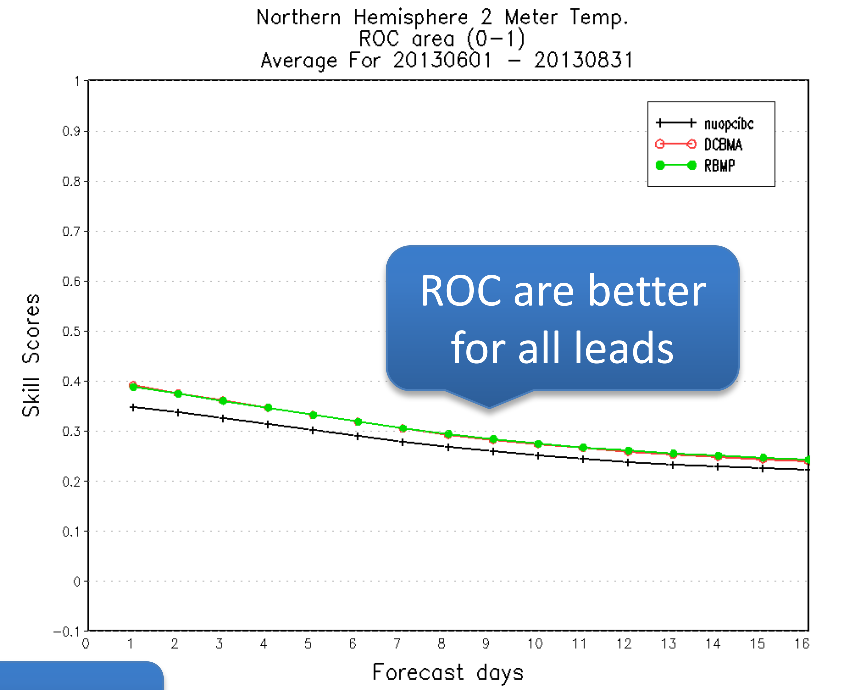
$$\overline{E} = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(\overline{f}(t) - a(t))^2}$$

Ensemble spread

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

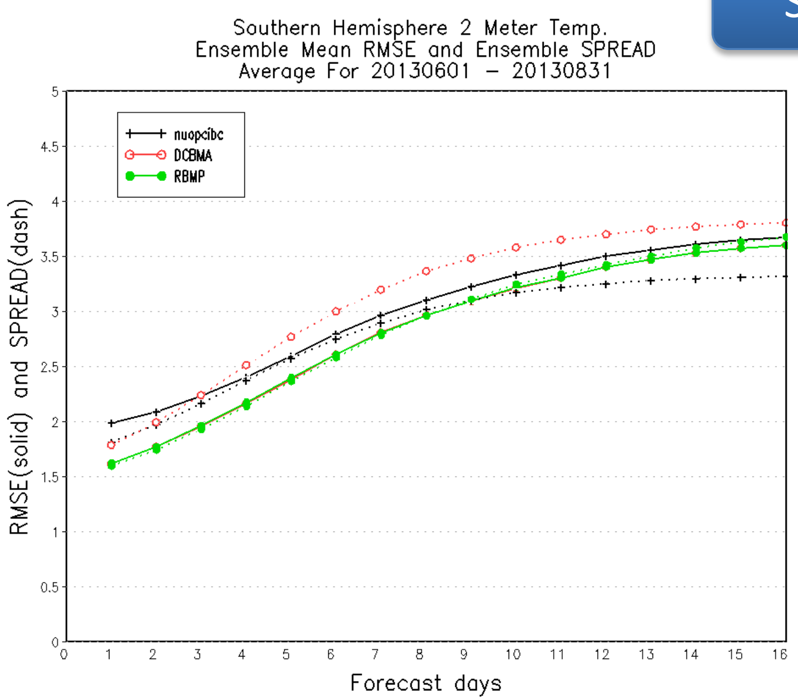

Northern Hemisphere 2 Meter Temp.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20130601 – 20130831
nuopcibc
DCBMA
RBMP
NUOPCIBC – simple combine three bias corrected ensembles
DCBMA – decaying based Bayesian Model Average
RBMP – Recursive Bayesian Model Process (built in decaying average and internal 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

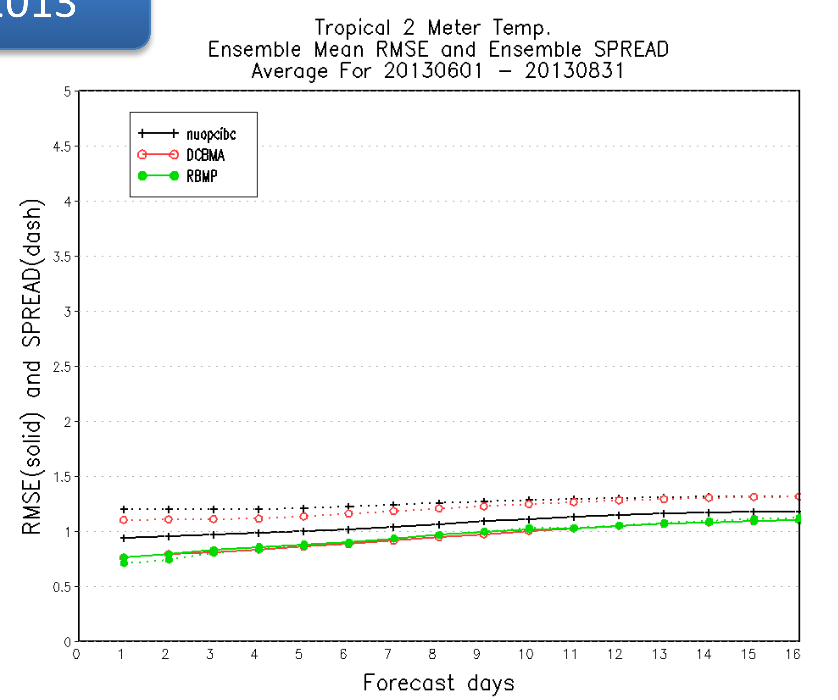


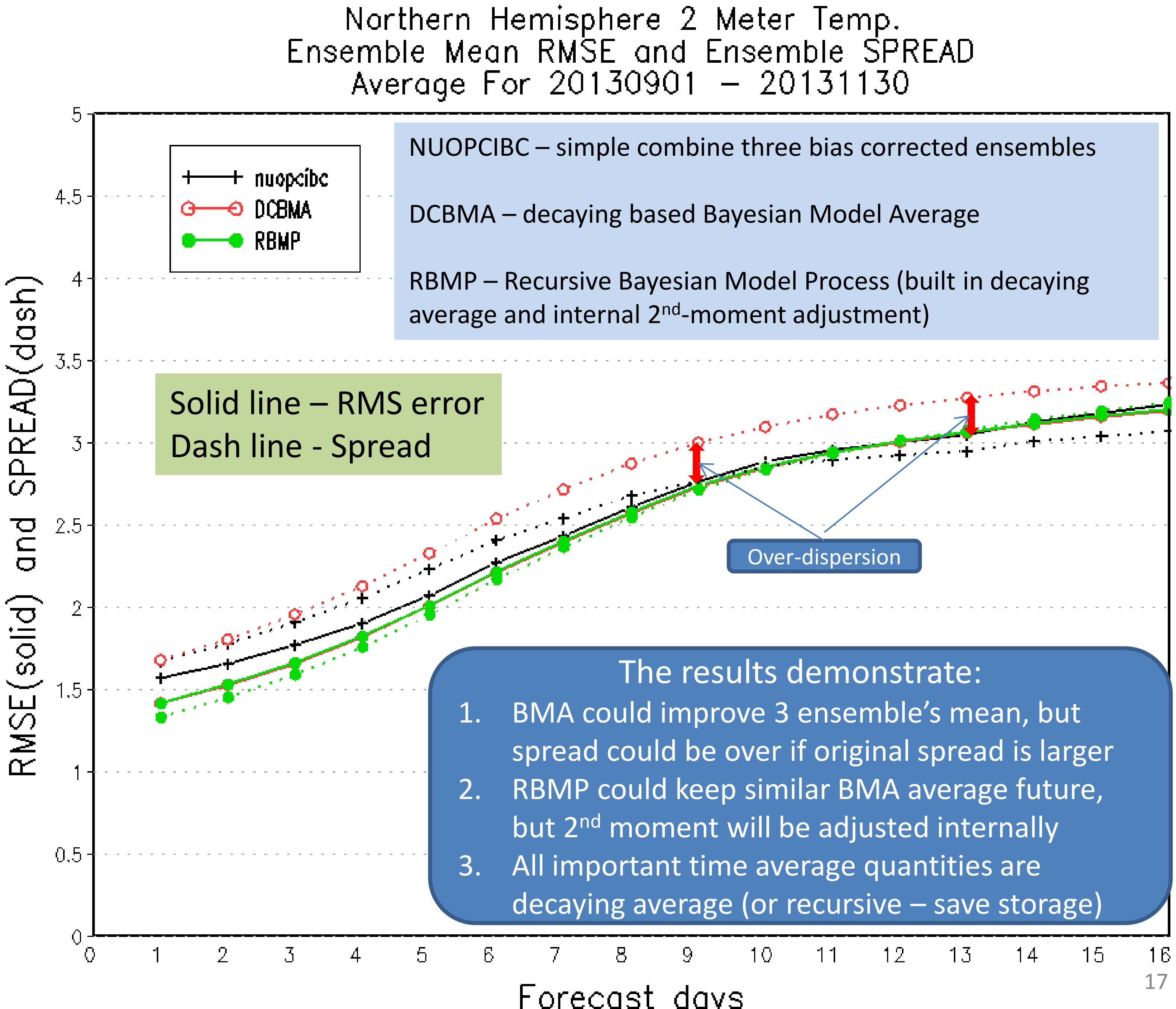


ROC are better for all leads

Summer 2013






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

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- **Summary and Future plan**
  - **Implement RBMP for NAEFS and NUOPC application**

Summary and Future Plan

We have developed RBMP and applied it to NUOPC forecast of T2M for summer and fall of 2013. The results demonstrate that:

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 feature, but 2nd moment can be adjusted internally.
3. The method is efficient which improves ensemble forecast skill for all lead time with a maximum improvement for short lead-time forecasts.
4. In the future, we will do the tests for winter and spring seasons.

   We also plan to Implement RBMP for NAEFS and NUOPC application