New Ensemble Probabilistic Forecasts Generation

(*North American Ensemble forecast System)*

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23th NWP, Chicago, July 2, 2015

Highlights

- **North American Ensemble Forecast System (NAEFS)**
  - Milestones
  - NAEFS Statistical Post-Processing System (SPP) review

- **Values of NAEFS products**
  - Objective evaluations/Comparison/User appreciations

- **Future Plans for new ensemble probabilistic forecasts generation**
  - High resolution downscaled probabilistic fcst. for CONUS (2.5km) and Alaska (3km) with additional variables
  - Blender – Recursive Bayesian Model Process
  - Variable decaying weights
  - Reforecast
  - 2nd moment adjustment

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;

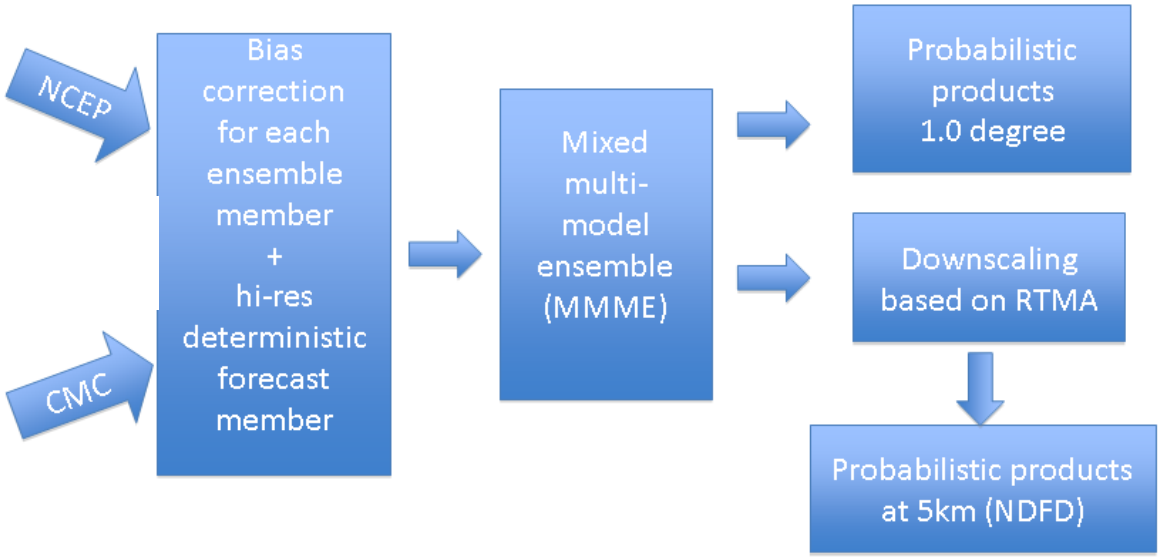
The signatories, hereby inaugurate the North American Ensemble Forecast System at Camp Springs, Maryland, USA, on this 16th Day of November 2004.

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
  - Implementation for CONUS/Alaska expansion
    - CONUS/Alaska expansion – Aril 8, 2014 Version 4
  - Implementation for high resolution CONUS/Alaska
    - 2.5km for CONUS/ 3km for Alaska – Q4FY15 Version 5

- Applications of NAEFS Statistical Post-Processing:
  - NCEP/GEFS and NAEFS – at NWS
  - CMC/GEFS and NAEFS – at MSC
  - FNMOC/GEFS – at NAVY
  - NCEP/SREF – at NWS

Current NCEP Statistical Post-Processing System



- Bias corrected NCEP/CMC GEFS and NCEP/GFS forecast (up to 180 hrs), same bias correction algorithm
  - 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
  - Combine NCEP/GEFS (20m) and CMC/GEFS (20m), FNMOC ens. will be in soon
  - Produce Ensemble mean, spread, mode, 10% 50%(median) and 90% probability forecast at 1*1 degree resolution
  - Climate anomaly (percentile) forecasts also generated for ens. mean
- 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 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
TCDC	Total Cloud Cover	1
Notes	CMC and FNMOC do not apply last upgrade yet	

NAEFS downscaling parameters and products

Last Upgrade: April 2014 (NDGD resolutions)

Variables	Domains	Resolutions	Total 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

NAEFS Bias Correction (Decaying average method)

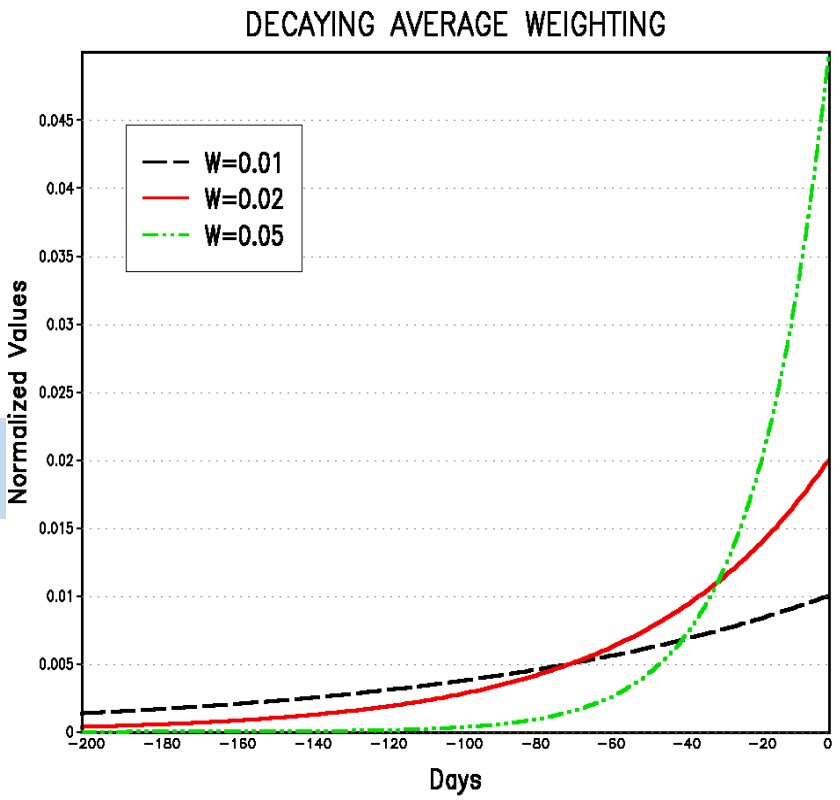
1). Bias Estimation:

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

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

Statistical downscaling for NAEFS forecast

- Proxy for truth
  - RTMA at 5km resolution
  - Variables (surface pressure, 2-m temperature, and 10-meter wind)
- Downscaling vector
  - Interpolate GDAS analysis to 5km resolution
  - Compare difference between interpolated GDAS and RTMA
  - Apply decaying weight to accumulate this difference – downscaling vector
- Downscaled forecast
  - Interpolate bias corrected 1*1 degree NAEFS to 5km resolution
  - Add the downscaling vector to interpolated NAEFS forecast
- Application
  - Ensemble mean, mode, 10%, 50%(median) and 90% forecasts

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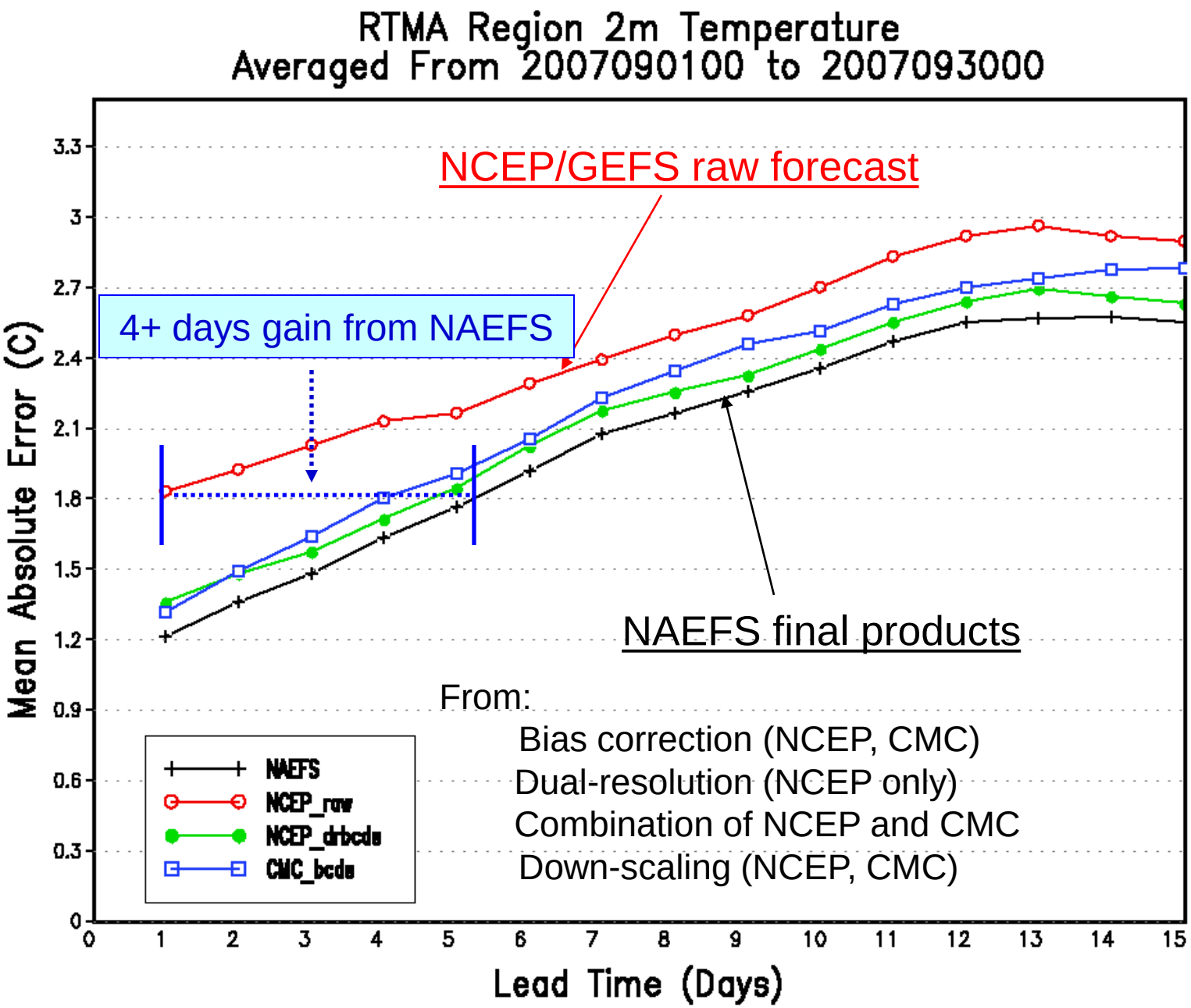
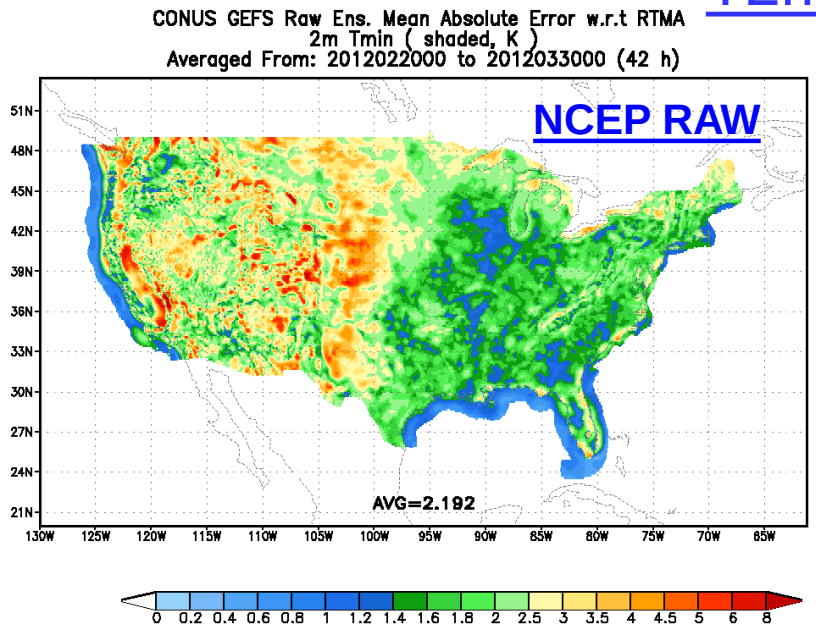
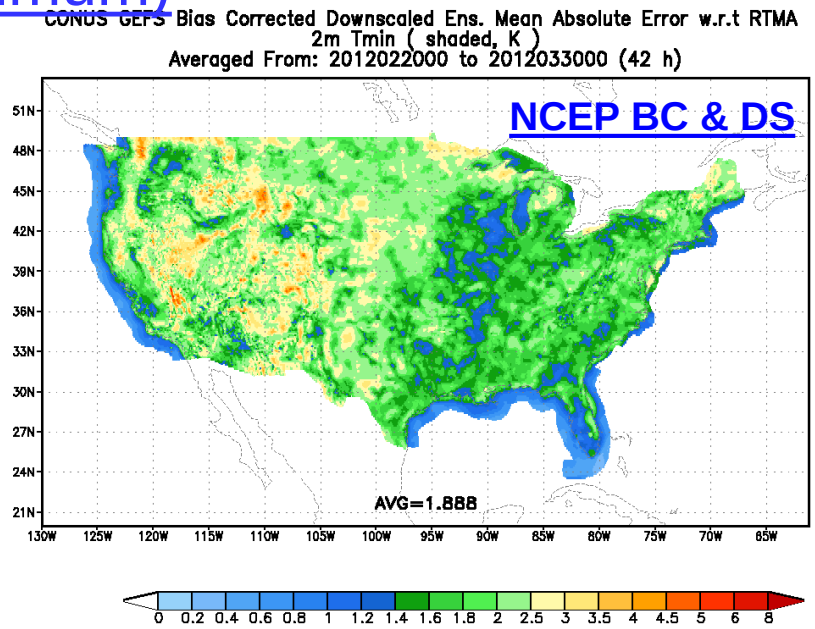
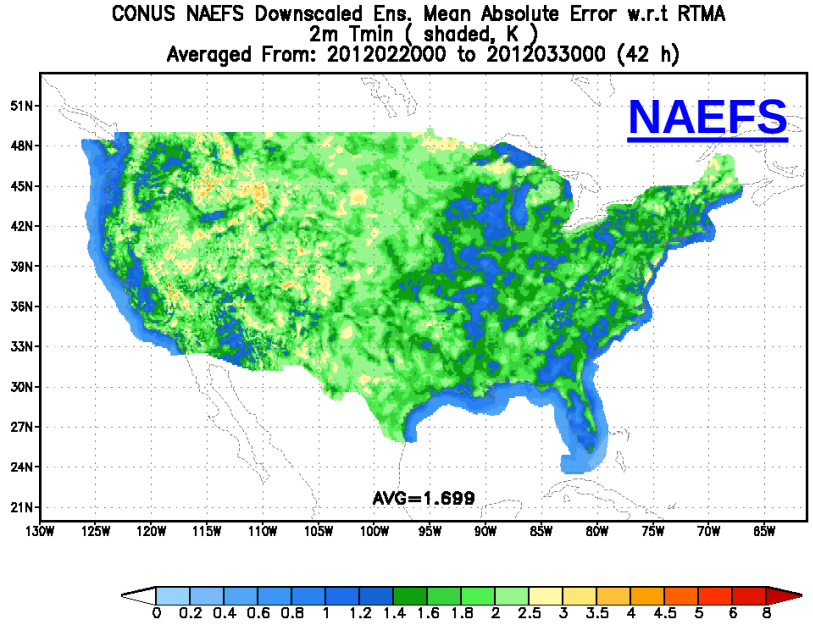
  - Reforecast
  - 2nd moment adjustment


RTMA Region 2m Temperature
Averaged From 2007090100 to 2007093000
NCEP/GEFS raw forecast
4+ days gain from NAEFS
NAEFS final products
From:
Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Combination of NCEP and CMC
Down-scaling (NCEP, CMC)
NAEFS
NCEP_raw
NCEP_dribcda
CMC_bcda
Mean Absolute Error (C)
Lead Time (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

T2m (Minimum)







Surface minimum temperature for 40 days (2/20/2012 – 3/30/3012) after GEFS upgrade.

Average MAE improvements:

14% from NCEP GEFS post-process only

23% from NAEFS – final product

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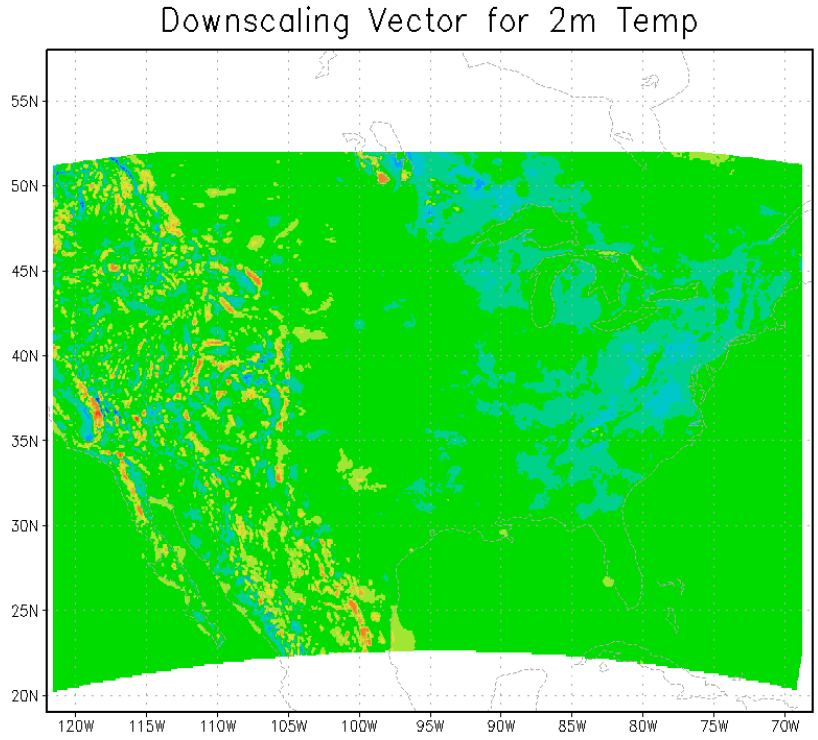
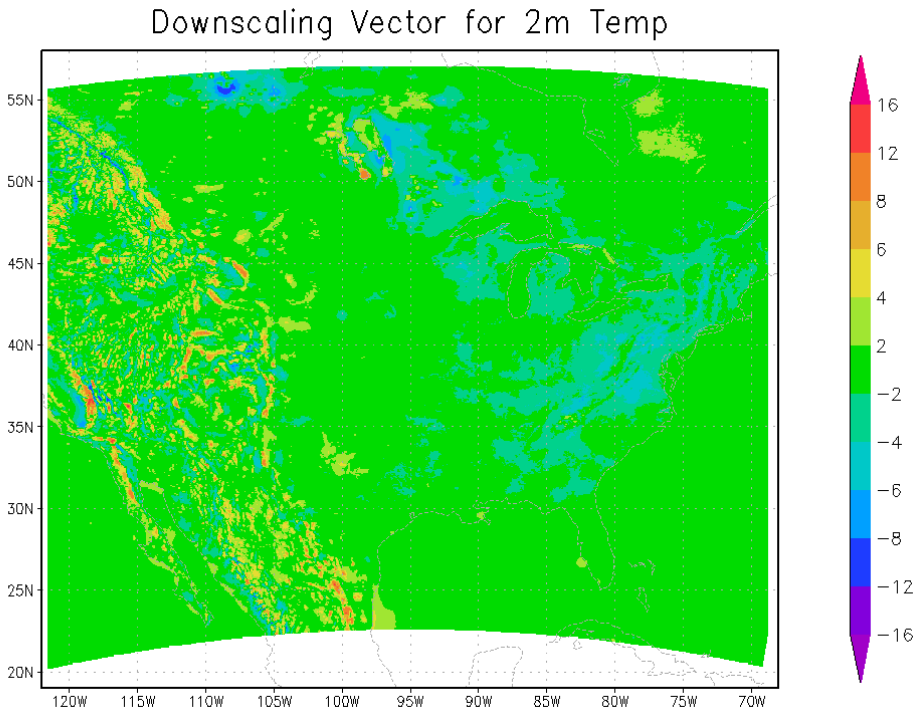
- Future Plans
  1. High resolution downscaled probabilistic forecast
     - 2.5km NDGD fields for CONUS extended area (new variable, TCDC)
     - 3km NDGD fields for Alaska (new)
  2. Variable decaying weights
  3. Blender – Recursive Bayesian Model Process
  4. Reforecast
  5. 2nd moment adjustment

COMUS Domain Change for NAEFS Upgrade

<u>CONUS at 5km</u>
<u>Production at 20150427 00z</u>

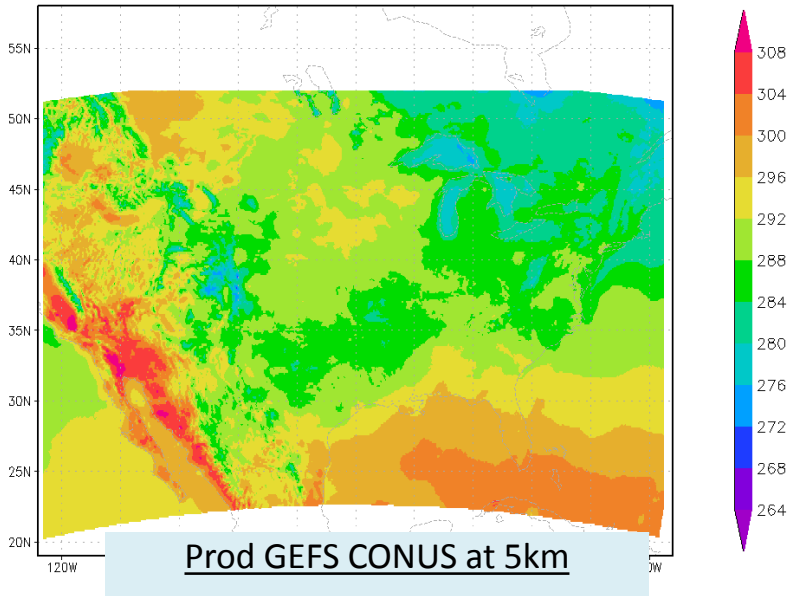


<u>CONUS with extended area at 2.5km</u>
<u>Parallel at 20150427 00z</u>



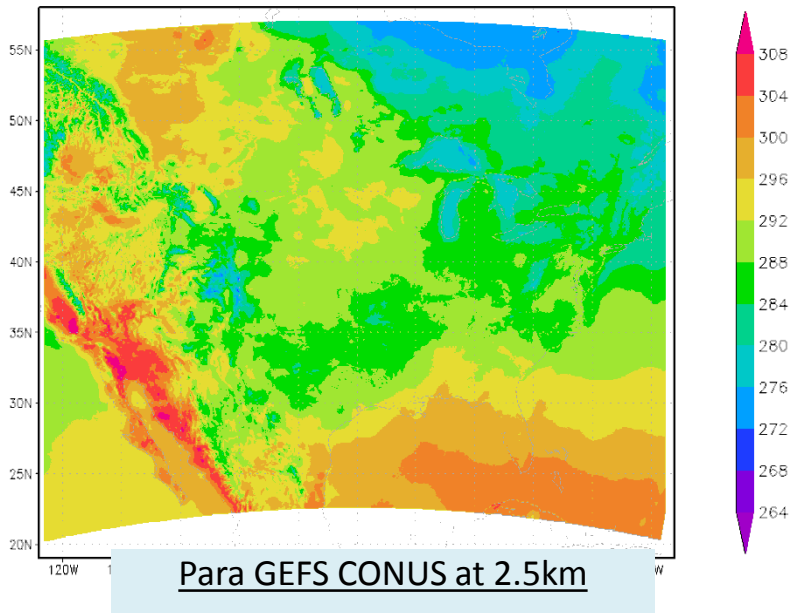
CONUS Downscaled Product Samples (T2m 48hr Fcst)

Before Upgrade

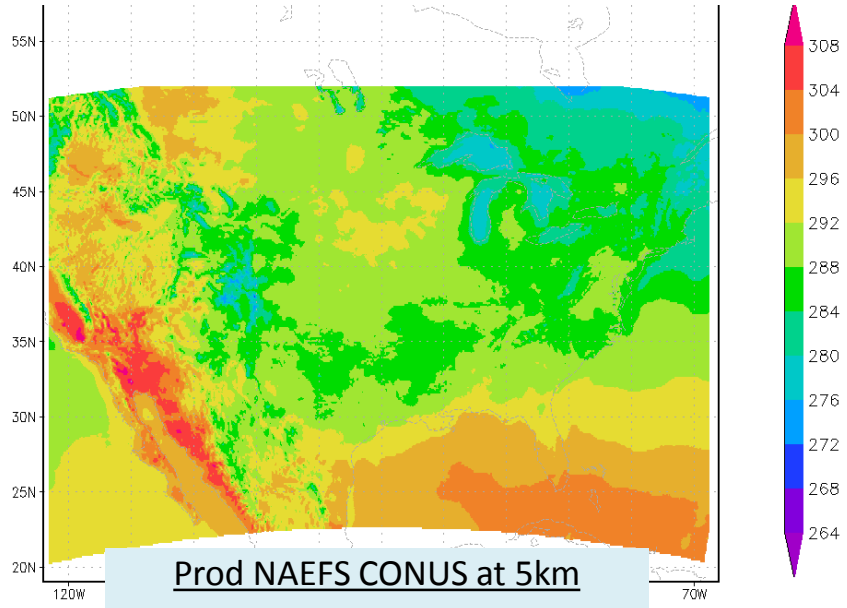


Prod GEFS CONUS at 5km

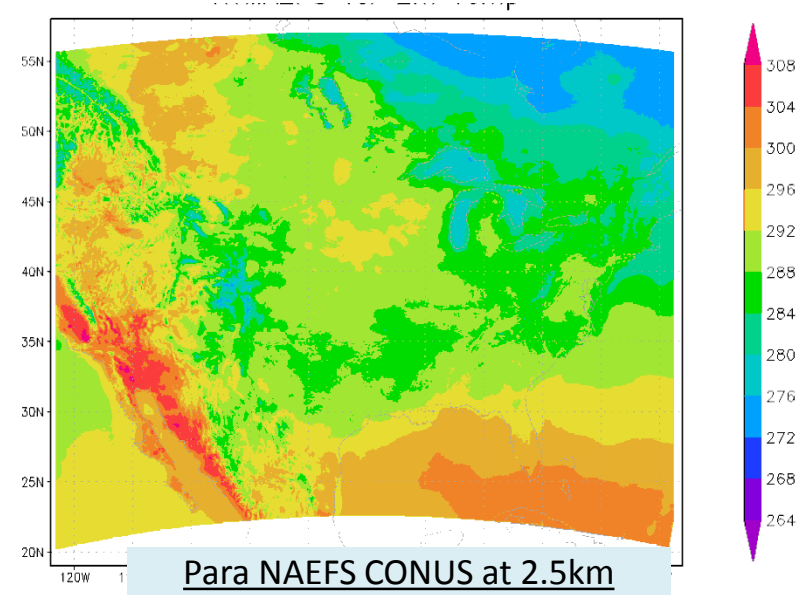
After Upgrade



Para GEFS CONUS at 2.5km

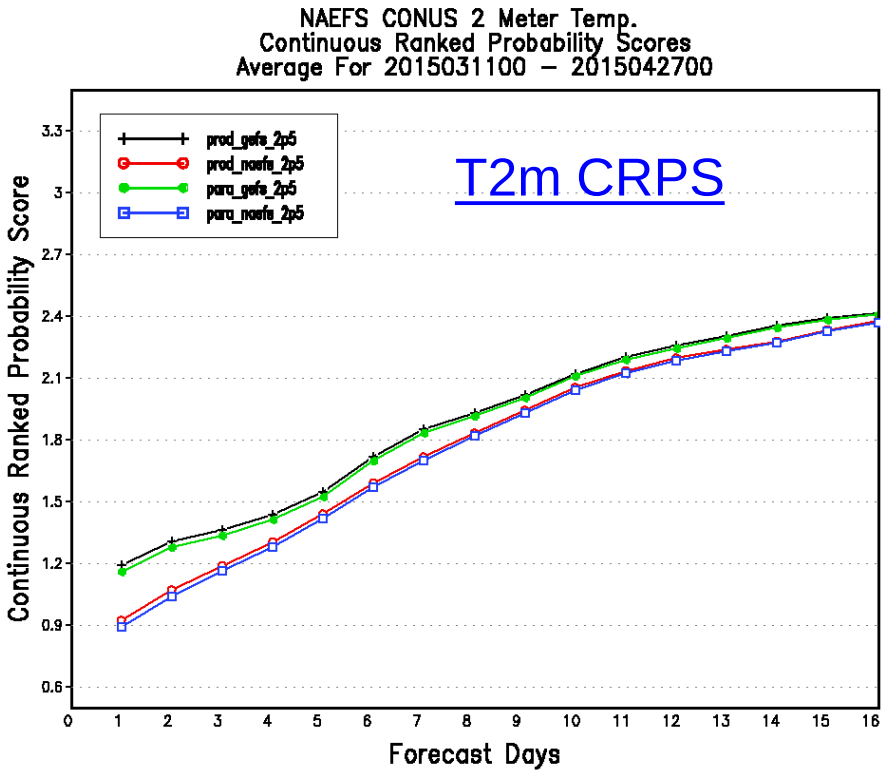


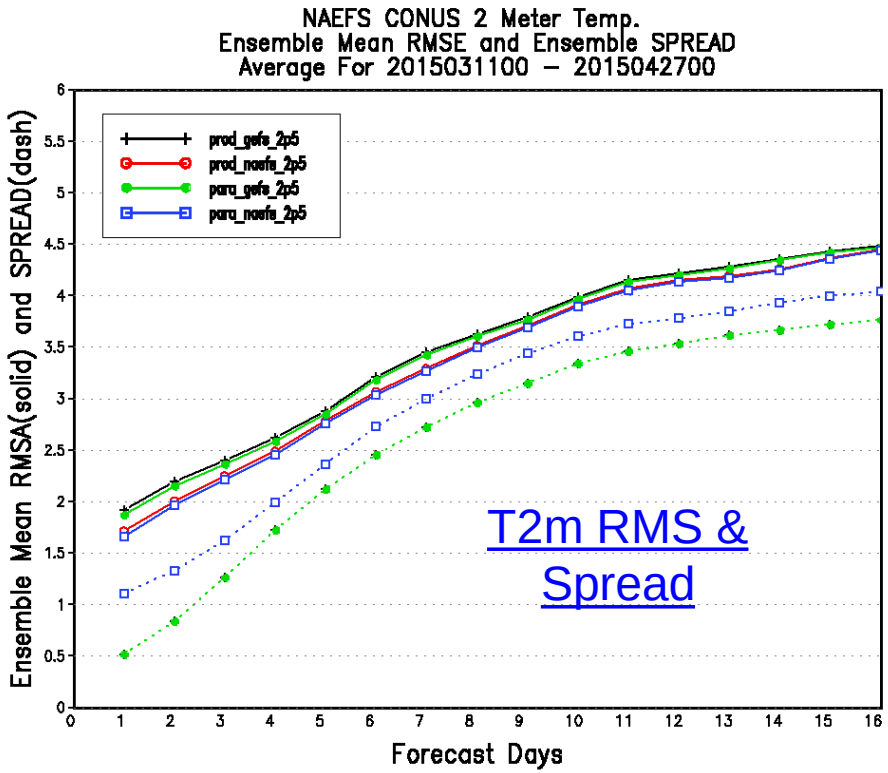
Prod NAEFS CONUS at 5km



Para NAEFS CONUS at 2.5km

Statistical Verification from 20150311 to 20150427





prod_gefs_2p5: production GEFS downscaled product interpolated to 2.5km

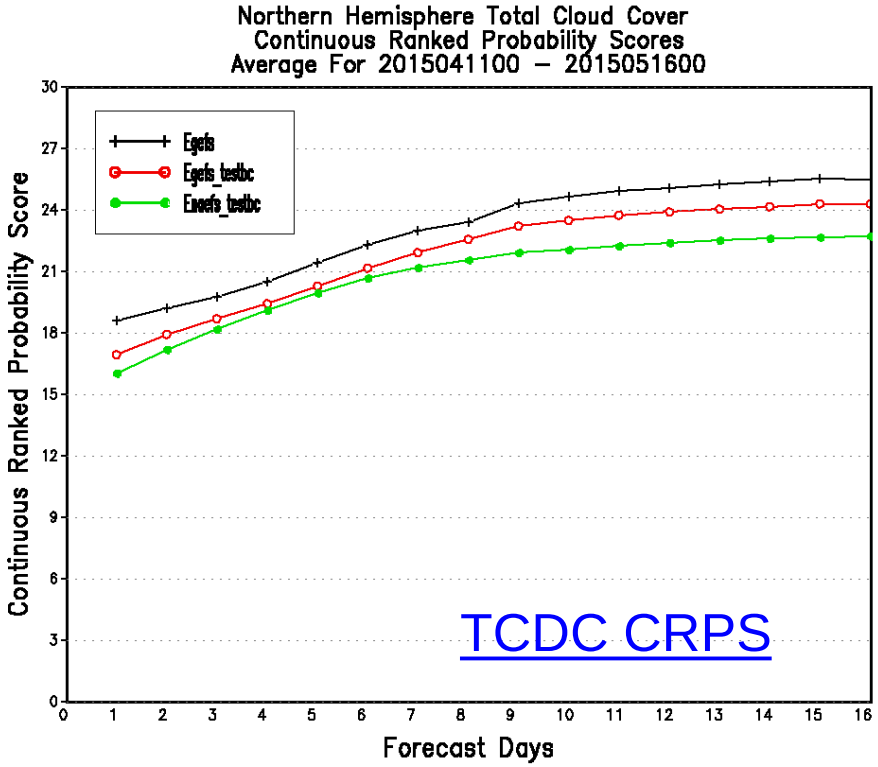
prod_naefs_2p5: production NAEFS downscaled product interpolated to 2.5km

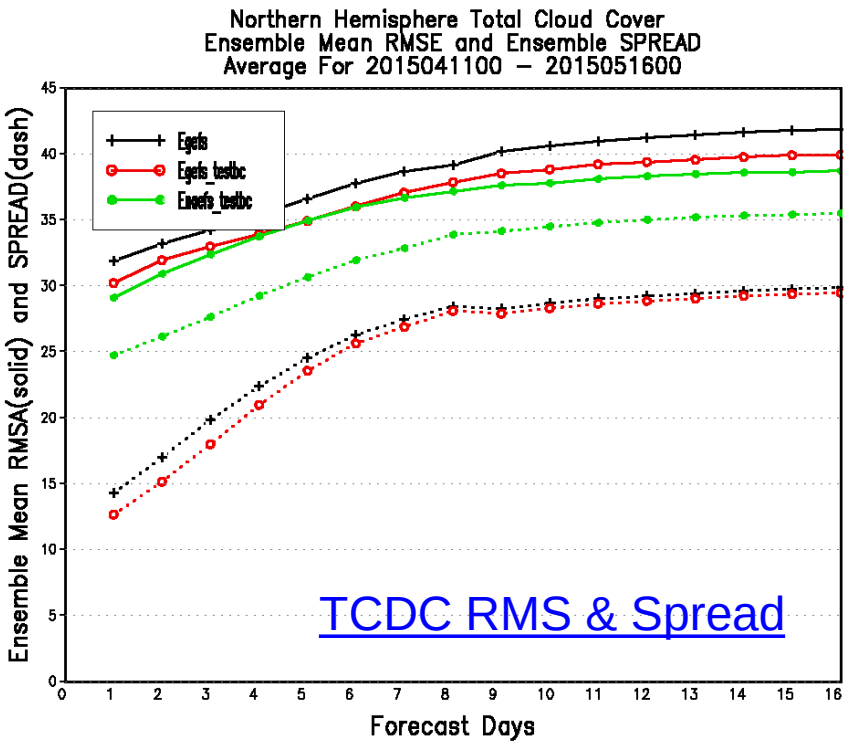
para_gefs_2p5: parallel GEFS downscaled product at 2.5km

para_naefs_2p5: parallel NAEFS downscaled product at 2.5km

CONUS at 2.5km (prod_gefs_2p5 & prod_naefs_2p5 from interpolation of 5km forecasts)

Statistical Verification from 20150411 to 20150516
TCDC Bias Correction





Egefs: production GEFS raw forecast

Egefs_testbc: GEFS bias corrected forecast

Enaefs_testbc : GEFS bais corrected and CMC raw forecast combination

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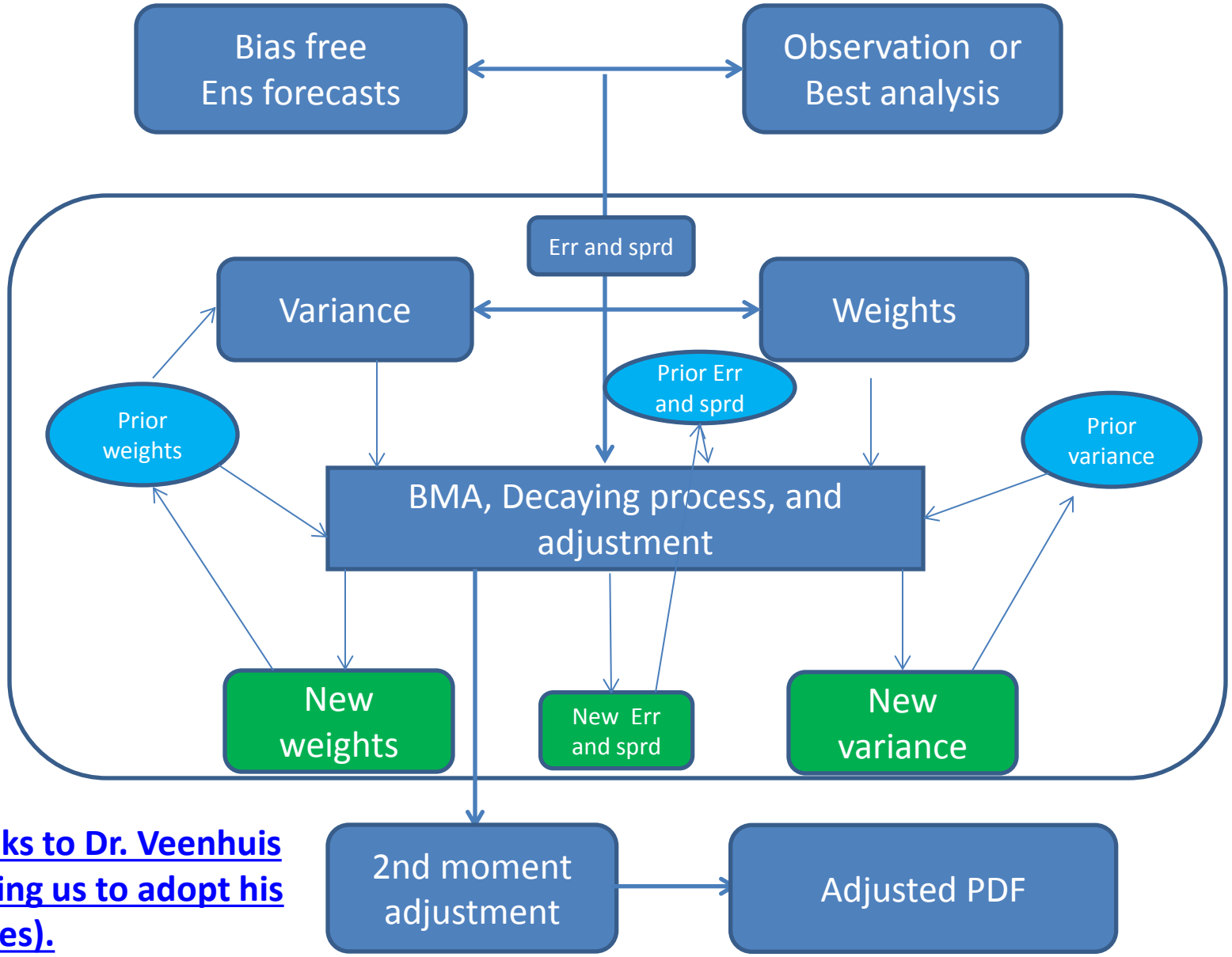
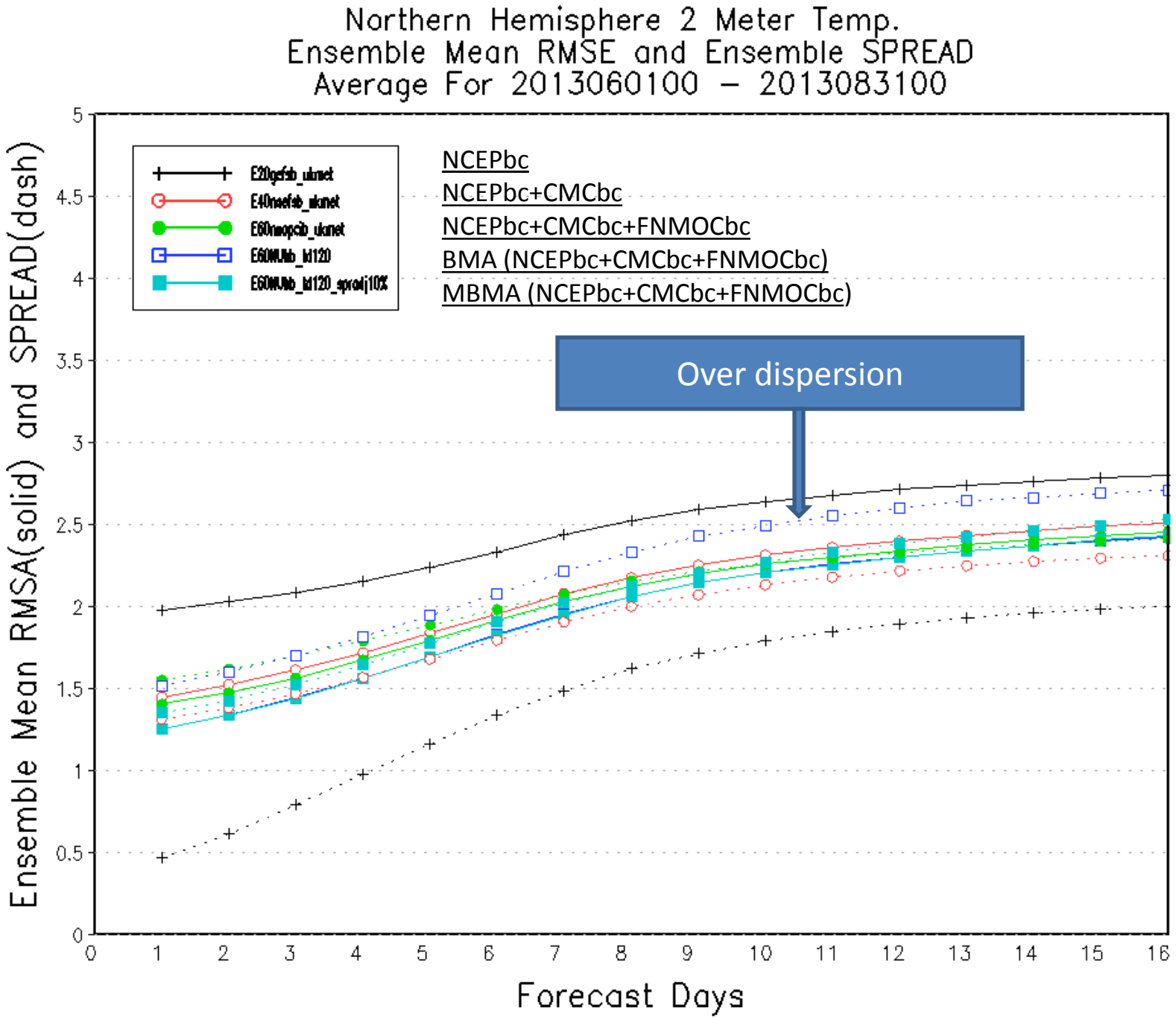
  - High resolution (NDGD grid) downscaled probabilistic fcst.
  - Blender – Recursive Bayesian Model Process (RBMP)
  - 2nd moment adjustment
  - Reforecast
  - Variable decaying weights

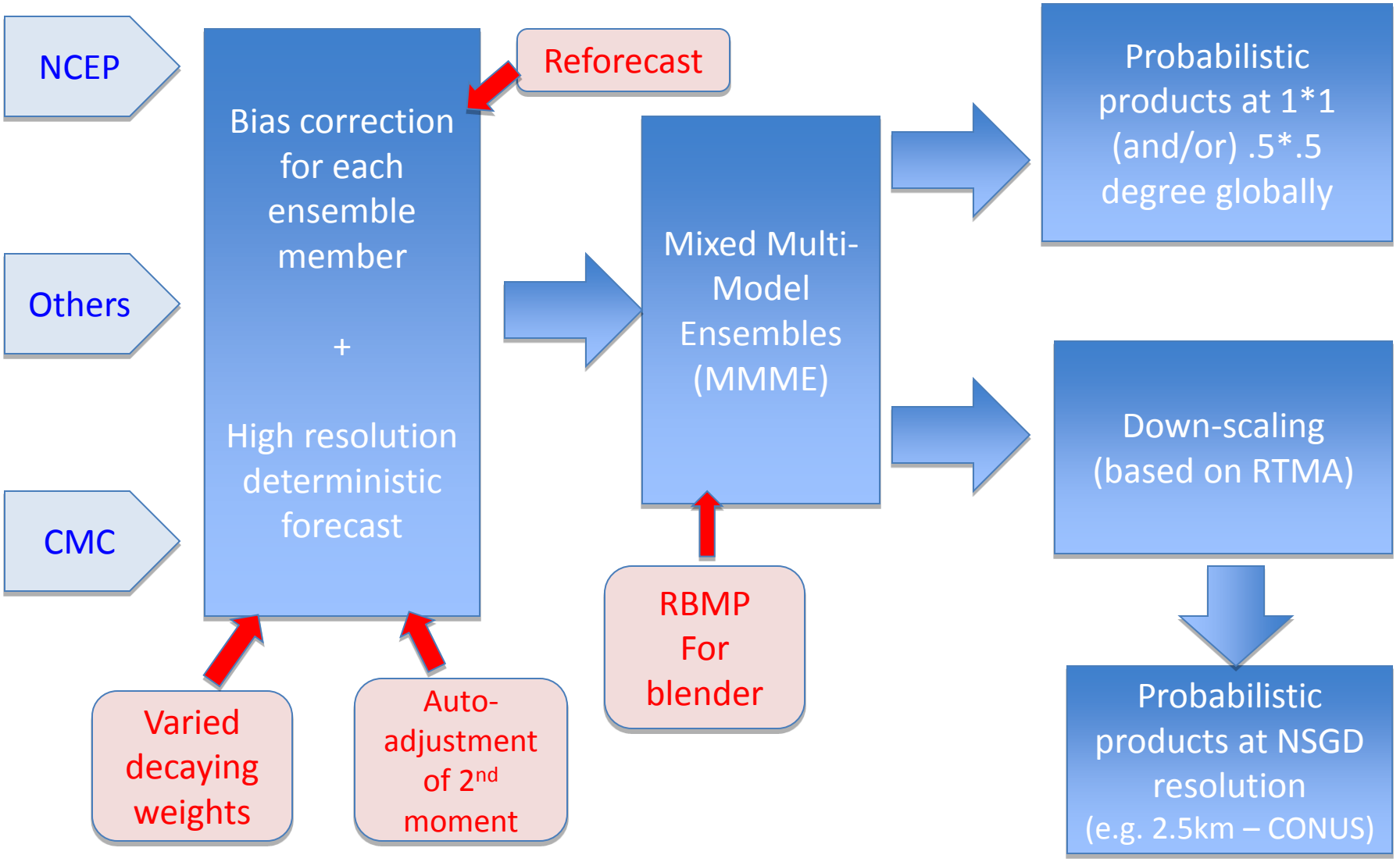
Flow Chart of Recursive Bayesian Model Process (RBMP)



(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 2013060100 - 2013083100
Ensemble Mean RMSA(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
E20gefsb_ukmet
E40naefsb_ukmet
E60naopcsb_ukmet
E60MMb_td120
E60MMb_td120_sprcalj10%
NCEPbc
NCEPbc+CMCbc
NCEPbc+CMCbc+FNMOCbc
BMA (NCEPbc+CMCbc+FNMOCbc)
MBMA (NCEPbc+CMCbc+FNMOCbc)
Over dispersion

Future NAEFS Statistical Post-Processing System

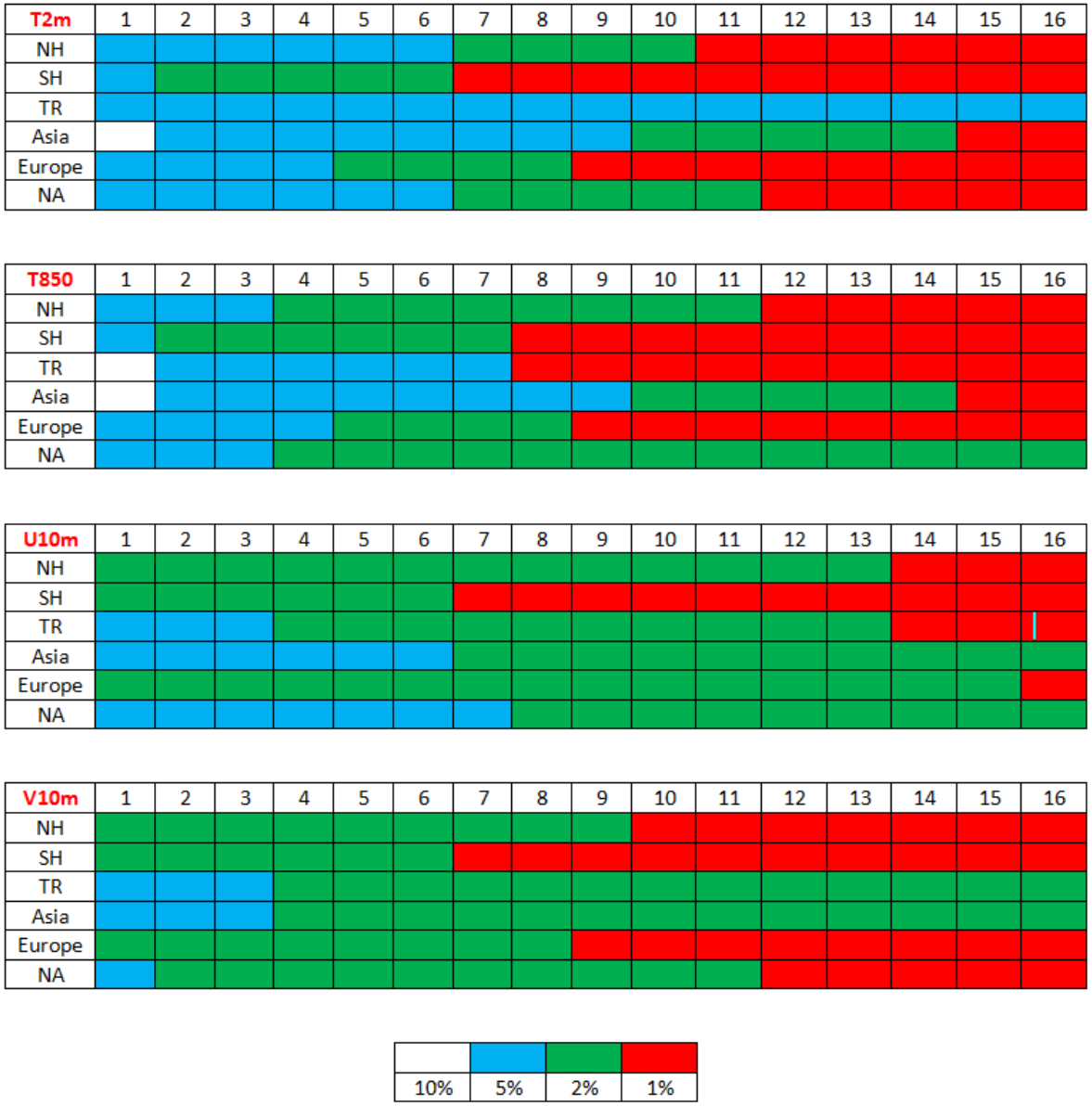


Publications and References

- 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, 2013: *"Precipitation Calibration Based on Frequency Matching Method (FMM)"*. Weather and Forecasting (in process)
  - Glahn, B., 2013: *"A Comparison of Two Methods of Bias Correcting MOS Temperature and Dewpoint Forecasts"* MDL office note, 13-1

Thanks !

Ensemble MAE for Decaying Weighting Tests 2011



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*

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

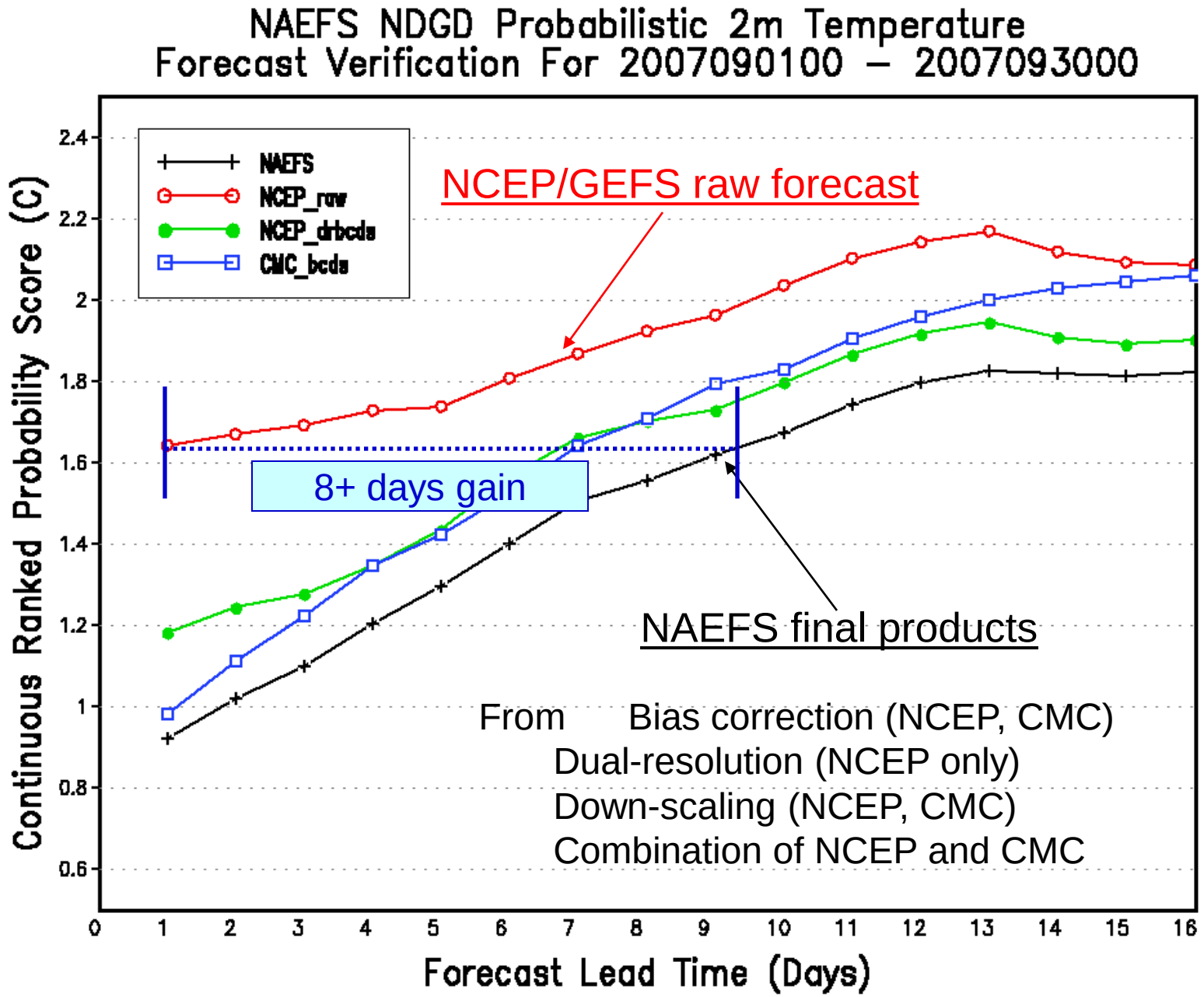
It is good for perfect bias corrected forecast,
Or bias-free ensemble forecast, but we do not

NAEFS Statistical Post-Process (SPP)

- Purpose
  - Improve reliability while maintaining resolution in NWP forecasts
    - Reduce systematic errors (improve reliability) while
    - Not increasing random errors (maintaining resolution)
      - Retain all useful information in NWP forecast

- Methodology
  - Use bias-free estimators of systematic error
  - Need methods with fast convergence using small sample
  - Easy implementation for frequency upgraded forecast system

- Approaches – Computational efficiency
  - Bias Correction : remove lead-time dependent bias on model grid
    - Working on coarser model grid allows use of more complex methods
    - Feedback on systematic errors to model development
  - Downscaling: downscale bias-corrected forecast to finer grid
    - Further refinement/complexity added
      - No dependence on lead time


NAEFS NDGD Probabilistic 2m Temperature
Forecast Verification For 2007090100 – 2007093000
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
NCEP/GEFS raw forecast
8+ days gain
NAEFS final products
From Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Down-scaling (NCEP, CMC)
Combination of NCEP and CMC
Continuous Ranked Probability Score (C)
Forecast Lead Time (Days)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16