Development of SPP and Best Products

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Presentation for NAEFS Workshop
May 1st 2012

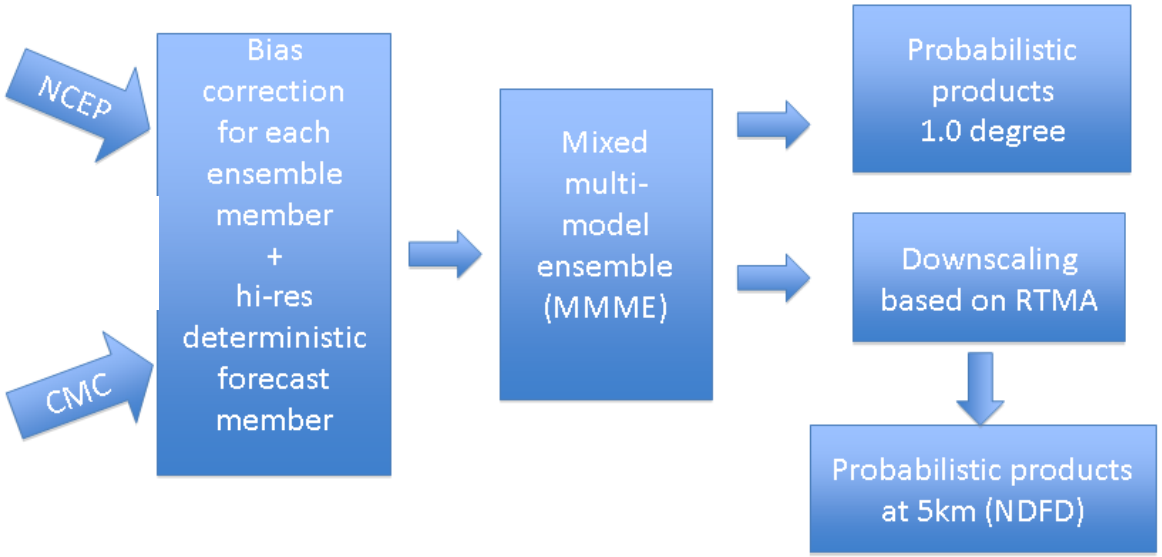
Review of Statistical Post-Process (SPP)

- 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

Current NCEP SPP System



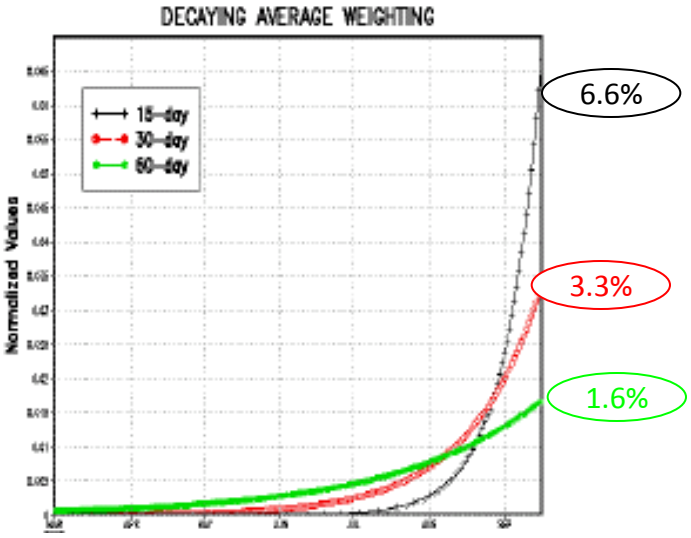
- Bias corrected NCEP/CMC GEFS and NCEP/GFS forecast (up to 180 hrs), same bias correction algorithm
  - Combine bias corrected NCEP/GFS and NCEP/GEFS ensemble forecasts
  - Dual resolution ensemble approach for short lead time
  - NCEP/GFS has higher weights at short lead time
- NAEFS products
  - Combine 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

Bias Correction Method & Application

- **Bias Correction Techniques** – array of methods
  - Estimate/correct bias moment by moment (*Cui and et al; 2012*)
    - Simple approach, implemented partially
    - May be less applicable for extreme cases
  - Mini-Bayesian approach (e.g., Roman Krzysztofovicz)
    - Consider joint sample correlations and others; under development
- **Moment-based method at NCEP**: apply adaptive (Kalman Filter type) algorithm

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

For separated cycles, each lead time and individual grid point, b=f-a (time mean error)



Toth, Z., and Y. Zhu, 2001

- *w* is decaying weight
- Test different decaying weights. 0.25%, 0.5%, 1%, 2%, 5% and 10%, respectively
- Decide to use 2% (~ 50 days) decaying accumulation bias estimation

NAEFS bias correction variables

(last update: March 1st 2010)

Variables	pgrba_bc file	Total 49
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
Notes		

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

NAEFS downscaling parameters and products

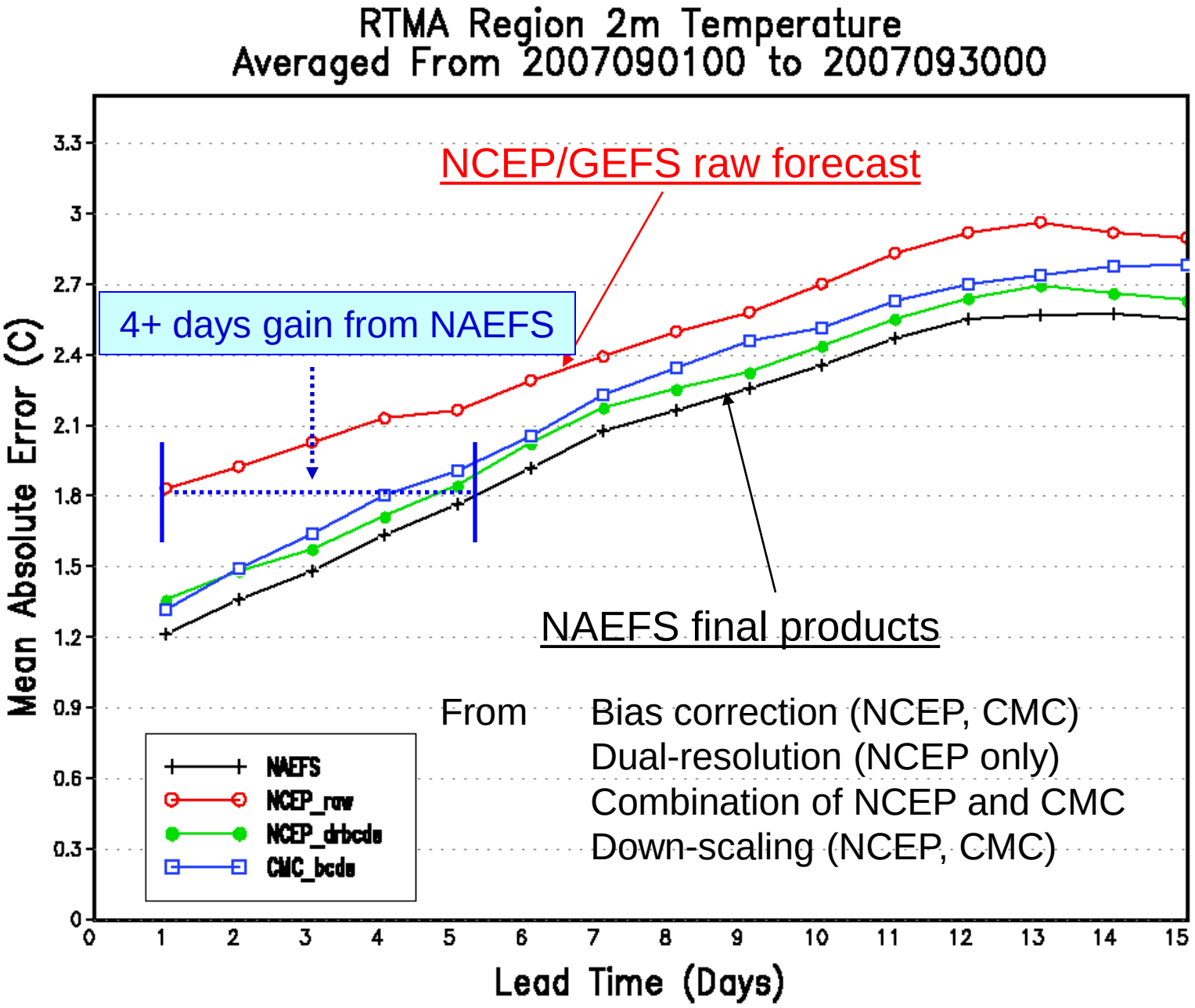
Plan: Q4FY2011

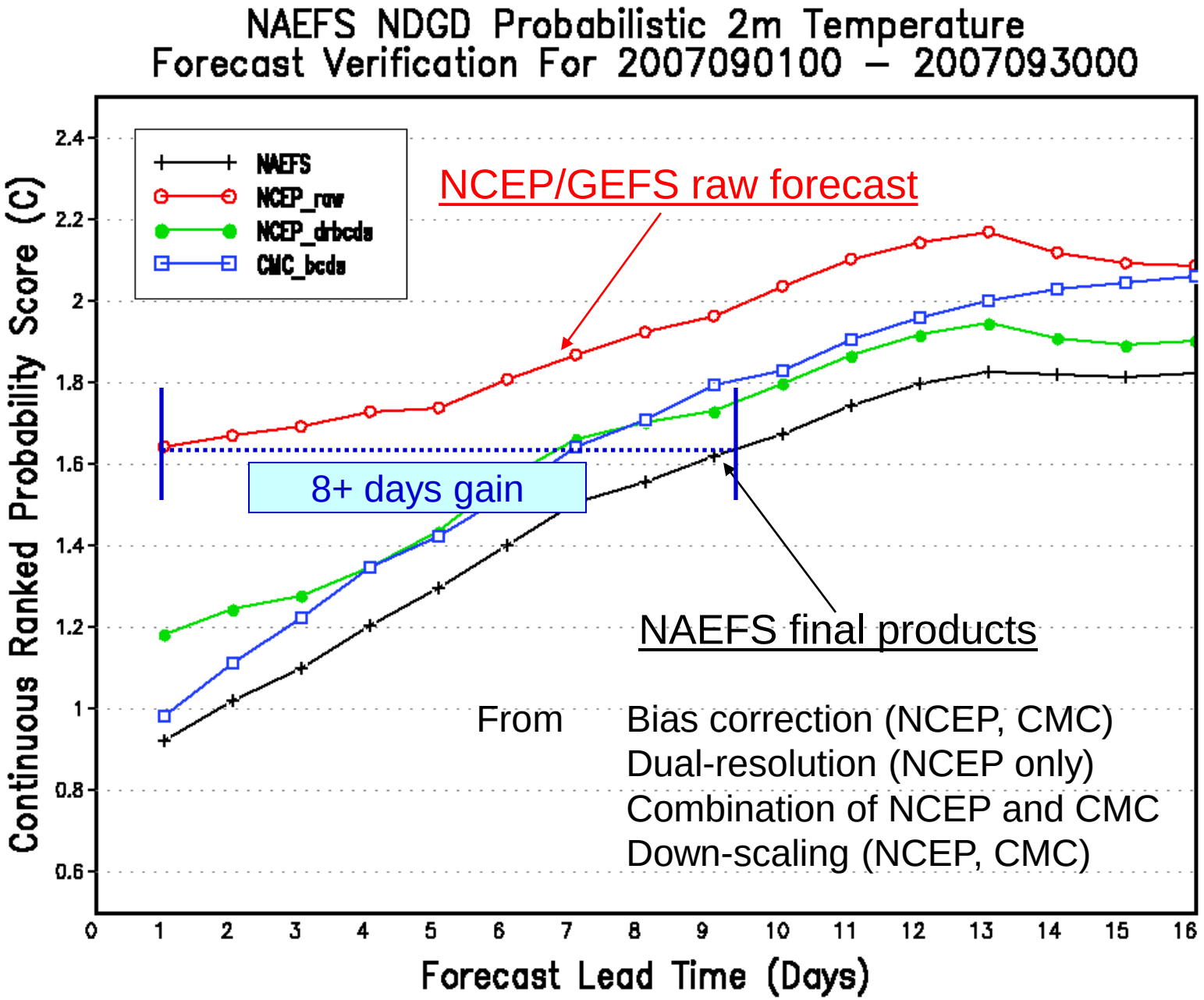
(NDGD resolutions)

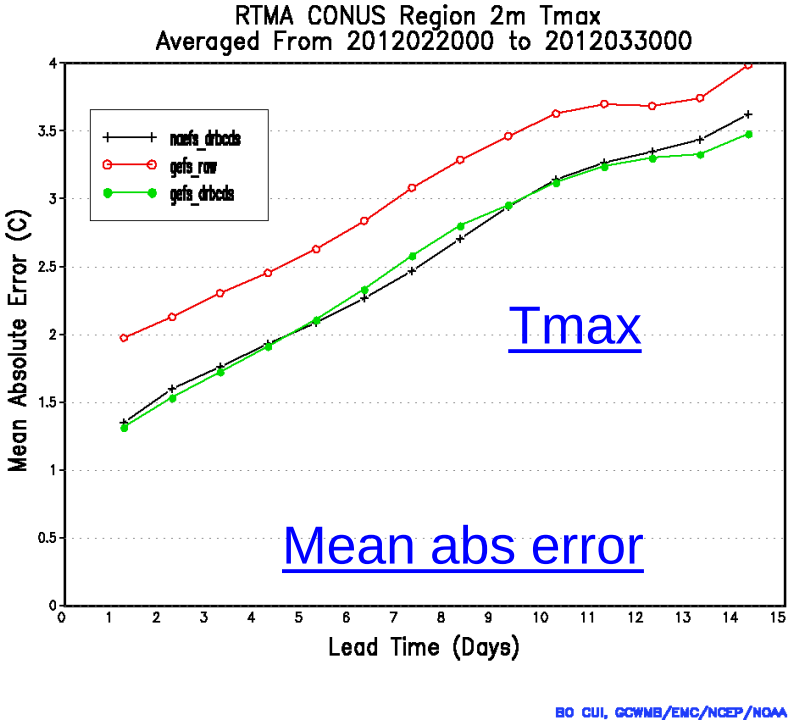
Variables	Domains	Resolutions	Total 10/8
Surface Pressure	CONUS/Alaska	5km/6km	1/1
2-m temperature	CONUS/Alaska	5km/6km	1/1
10-m U component	CONUS/Alaska	5km/6km	1/1
10-m V component	CONUS/Alaska	5km/6km	1/1
2-m maximum T	CONUS/Alaska	5km/6km	1/1
2-m minimum T	CONUS/Alaska	5km/6km	1/1
10-m wind speed	CONUS/Alaska	5km/6km	1/1
10-m wind direction	CONUS/Alaska	5km/6km	1/1
2-m dew-point T	CONUS	5km	1/0
2-m relative humidity	CONUS	5km	1/0
Total cloud cover?			

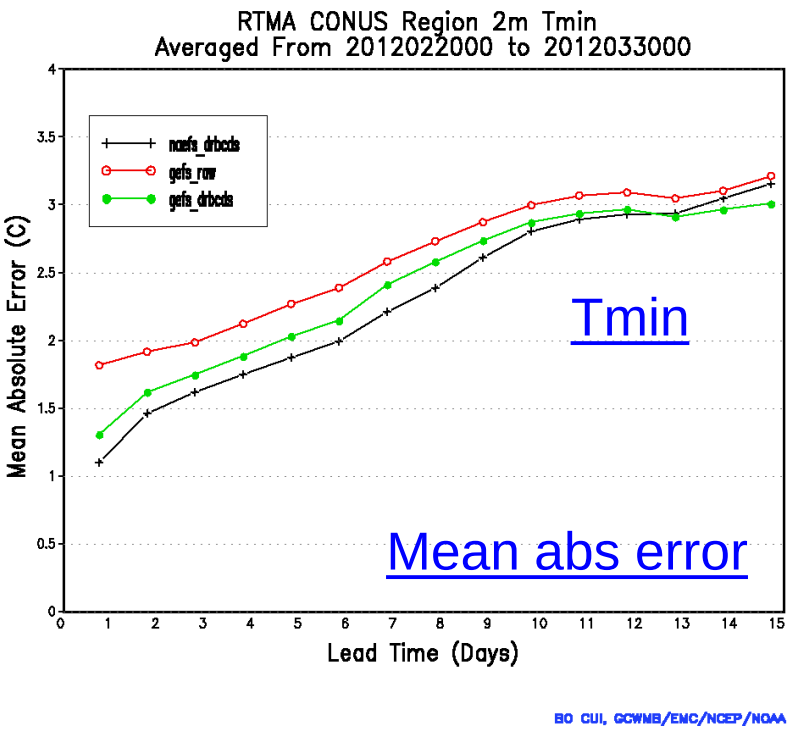
All downscaled products based on 1*1 (lat/lon) degree globally

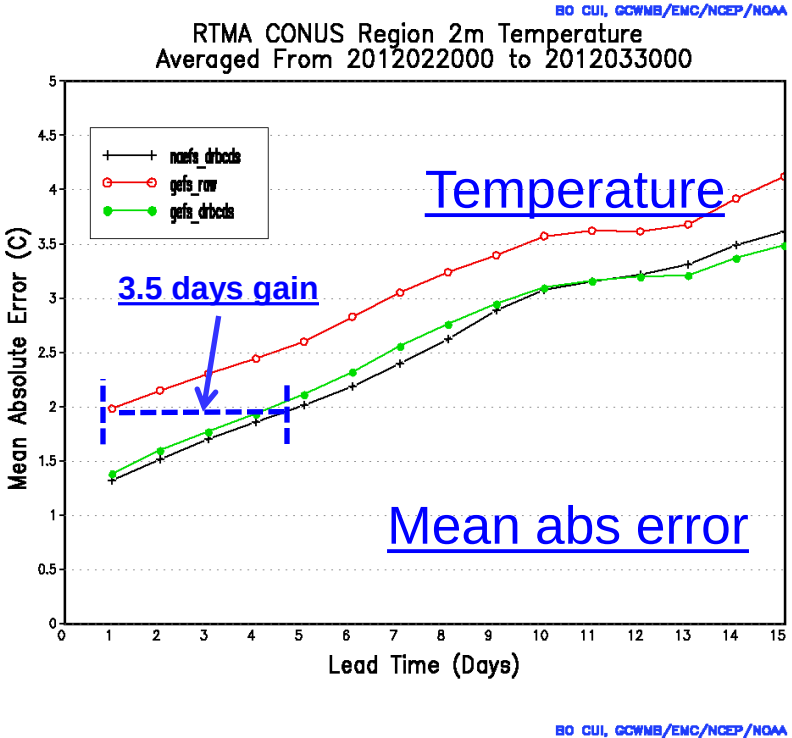
Products include ensemble mean, spread, 10%, 50%, 90% and mode


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_dribcds
CMC_bcds
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


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)
Combination of NCEP and CMC
Down-scaling (NCEP, 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

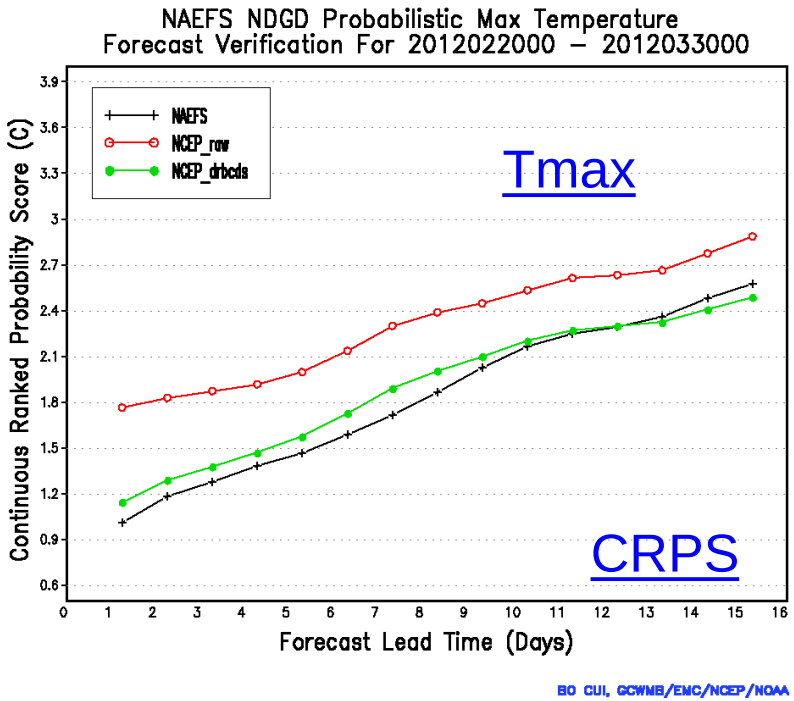


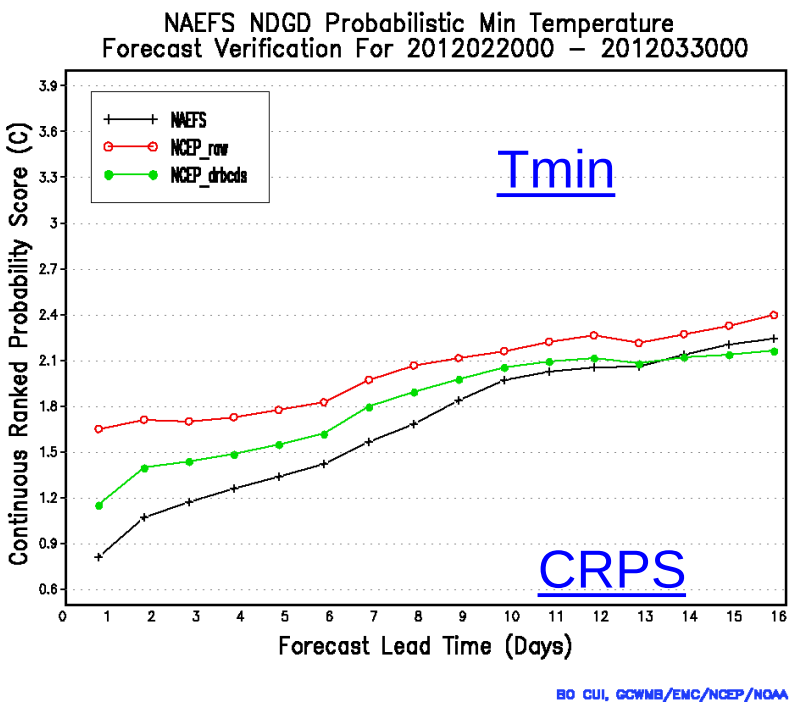


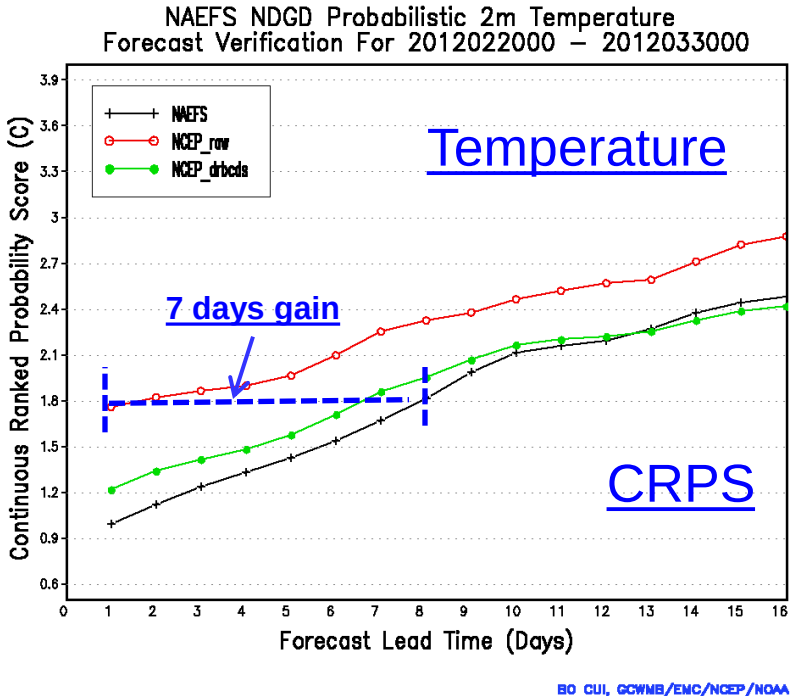


Latest evaluation for CONUS temperature forecast by apply :

1. Bias correction at 1*1 degree for NCEP GFS/GEFS, CMC/GEFS
2. Hybrid bias corrected NCEP GFS and GEFS
3. Apply statistical downscaling for all bias corrected forecast
4. Combined all forecasts at 5*5 km (NDGD) grid with adjustment - NAEFS







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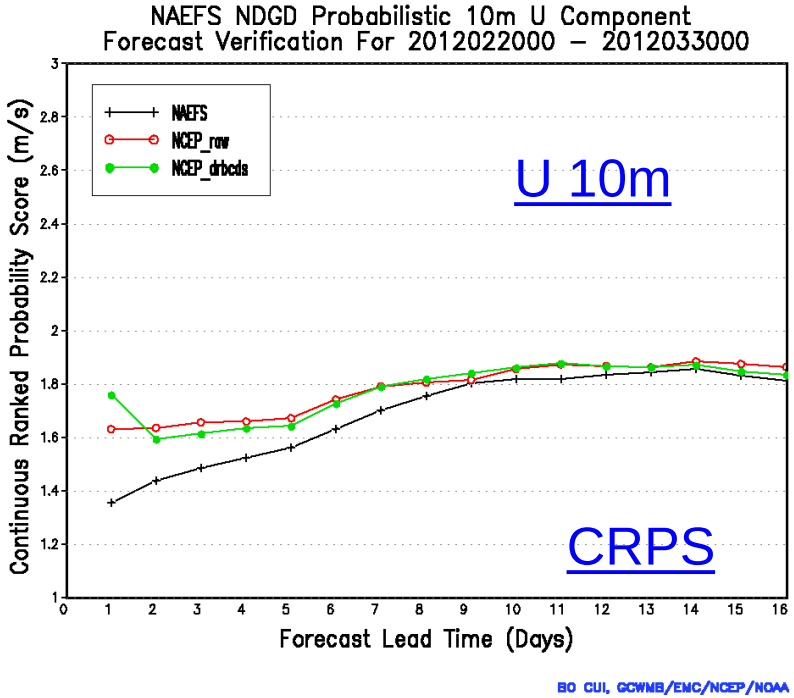
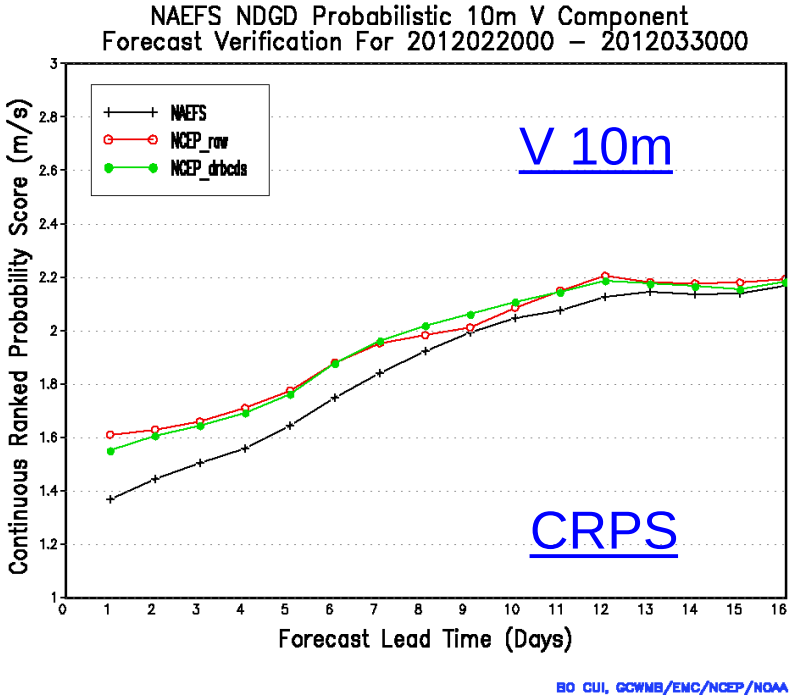
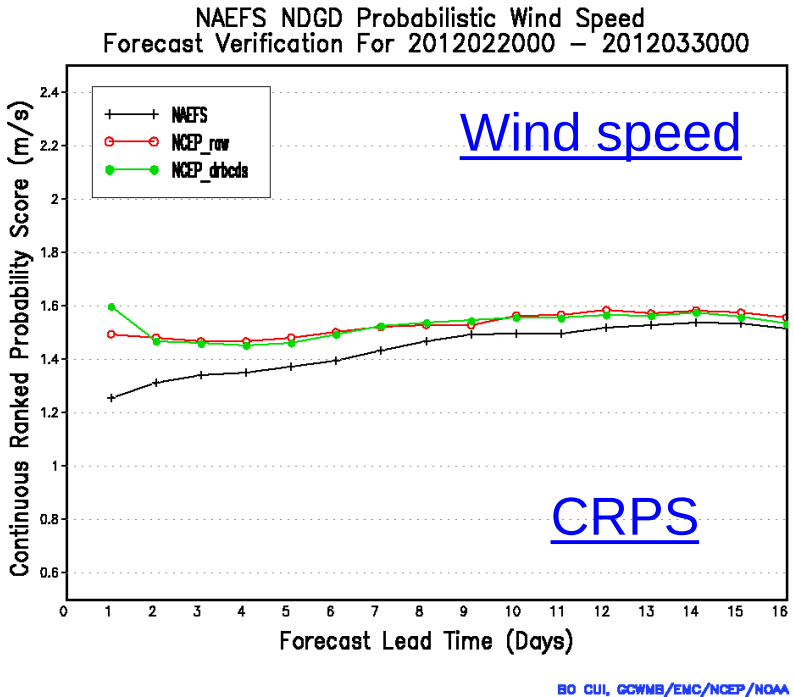
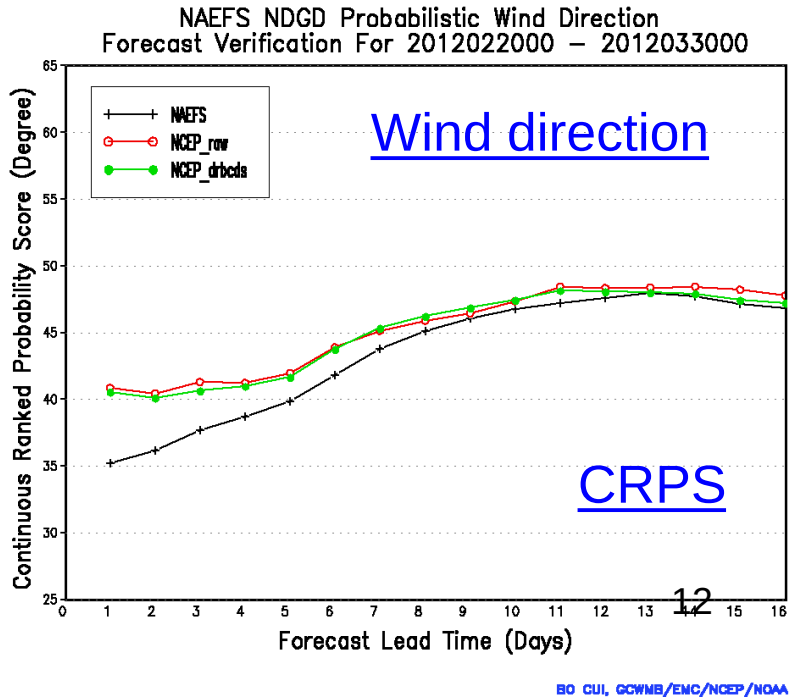
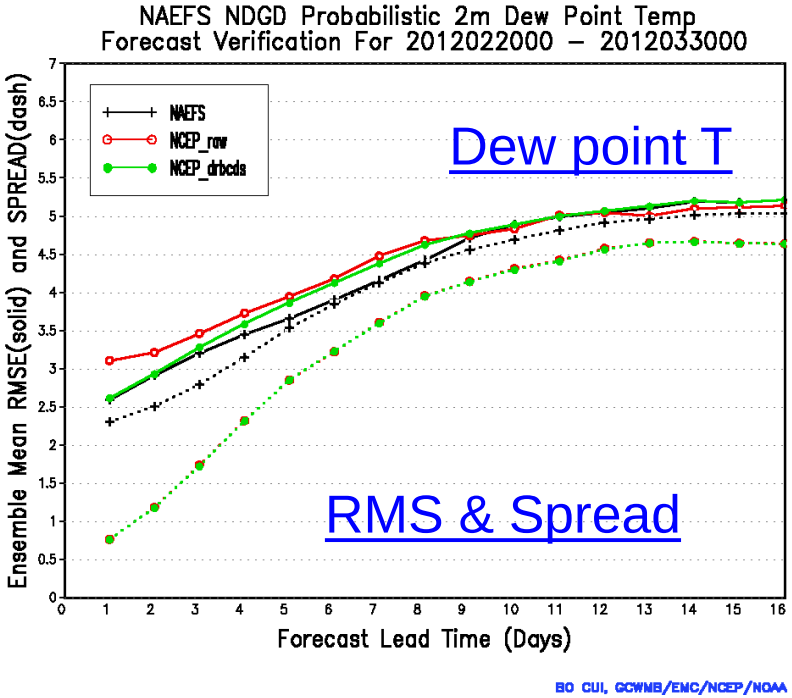
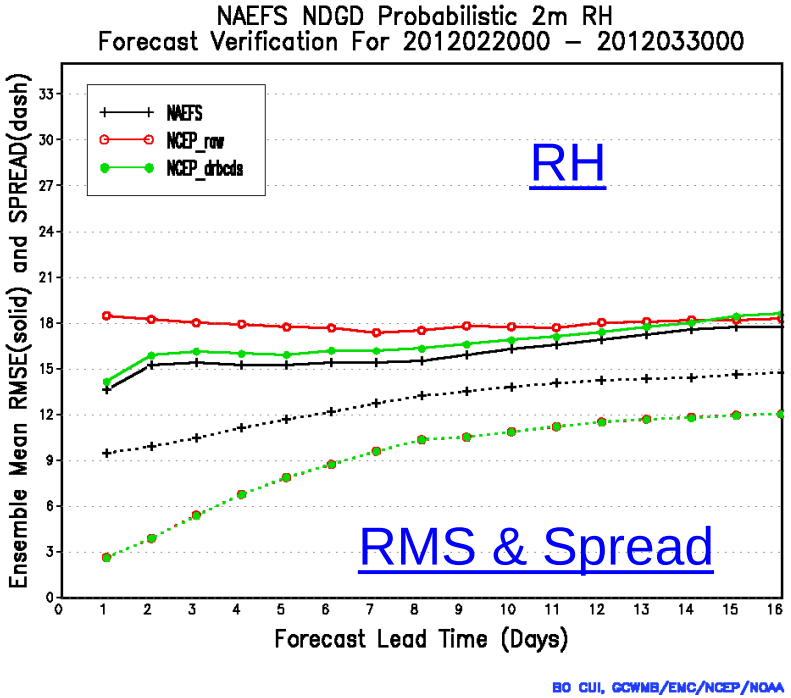

NAEFS NDGD Probabilistic 10m U Component
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
U 10m
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

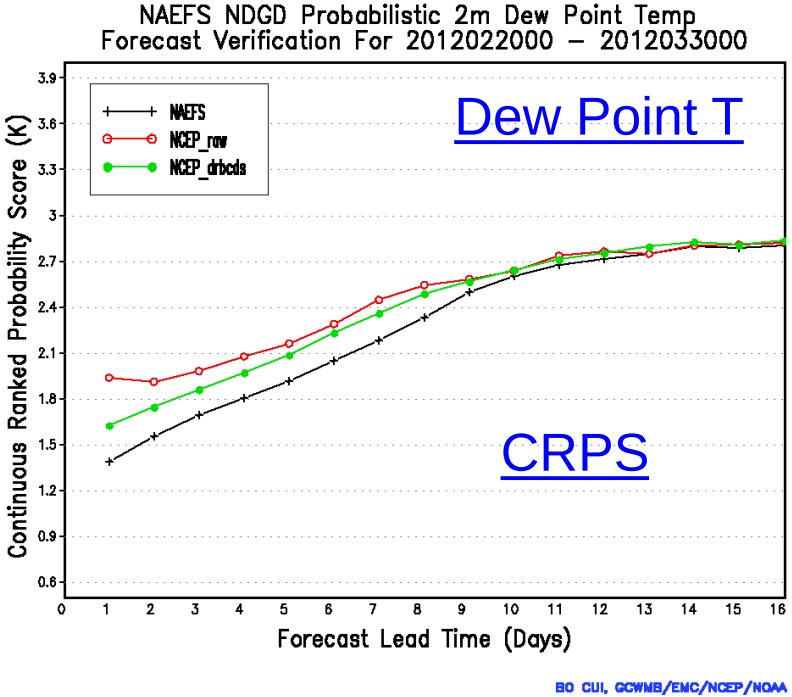

NAEFS NDGD Probabilistic 10m V Component
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
V 10m
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

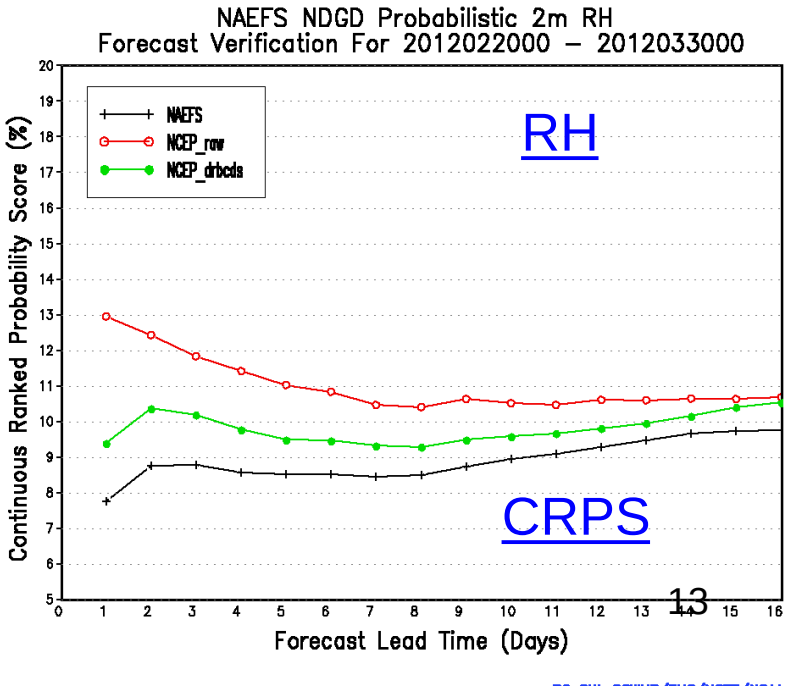

NAEFS NDGD Probabilistic Wind Speed
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
Wind speed
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA


NAEFS NDGD Probabilistic Wind Direction
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
Wind direction
CRPS
Continuous Ranked Probability Score (Degree)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

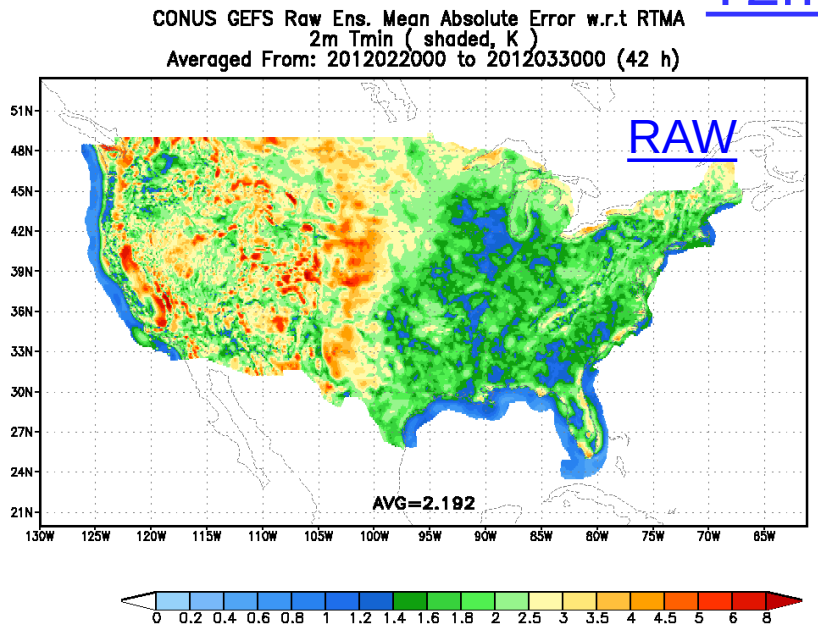

NAEFS NDGD Probabilistic 2m Dew Point Temp
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcls
Dew point T
RMS & Spread
Ensemble Mean RMSE(solid) and SPREAD(dash)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

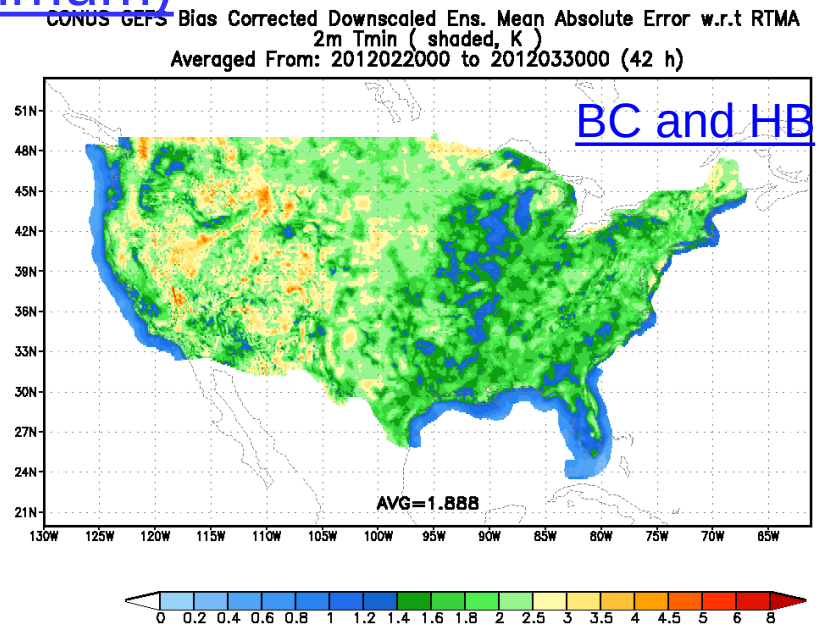

NAEFS NDGD Probabilistic 2m RH
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcls
RH
RMS & Spread
Ensemble Mean RMSE(solid) and SPREAD(dash)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

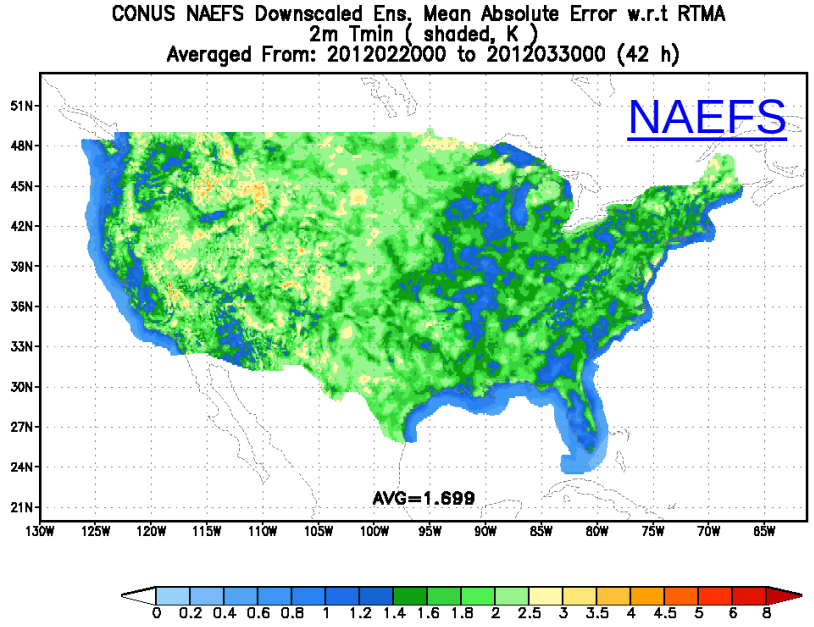

NAEFS NDGD Probabilistic 2m Dew Point Temp
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcls
Dew Point T
CRPS
Continuous Ranked Probability Score (K)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA


NAEFS NDGD Probabilistic 2m RH
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcls
RH
CRPS
Continuous Ranked Probability Score (%)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

T2m (Minimum)







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

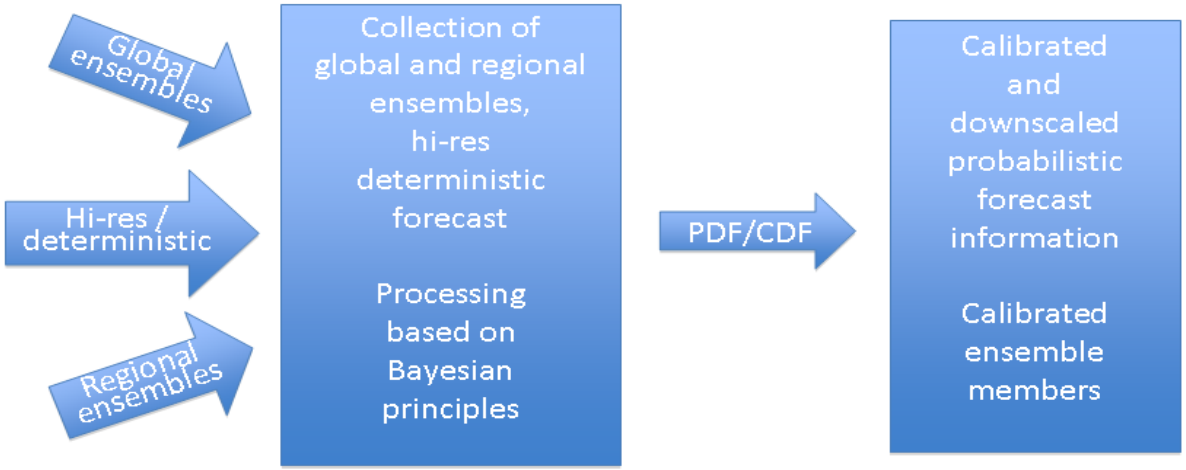
Average MAE improvements:

14% from NCEP model post-process only

23% from NAEFS – final product

Future Development Plan

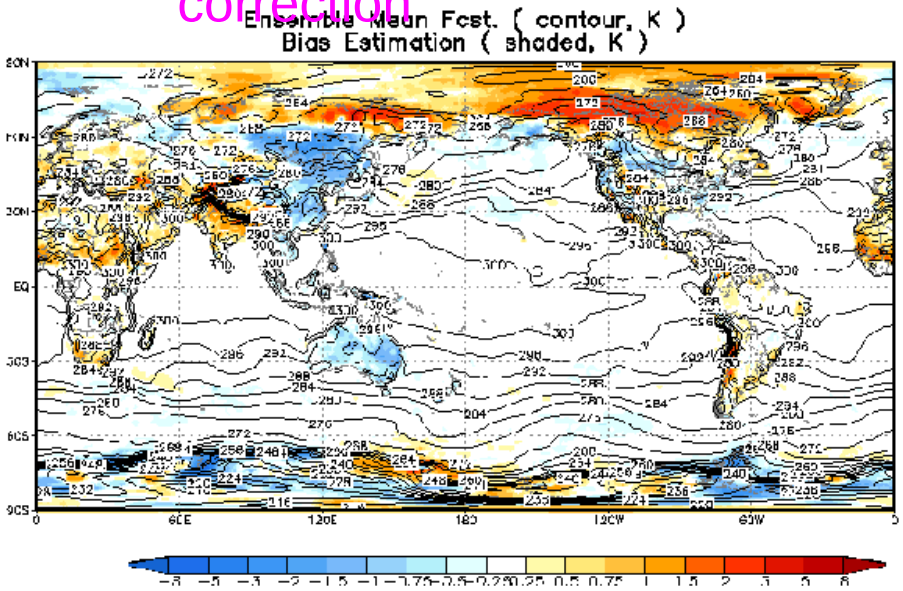
Development Plan of Best Products

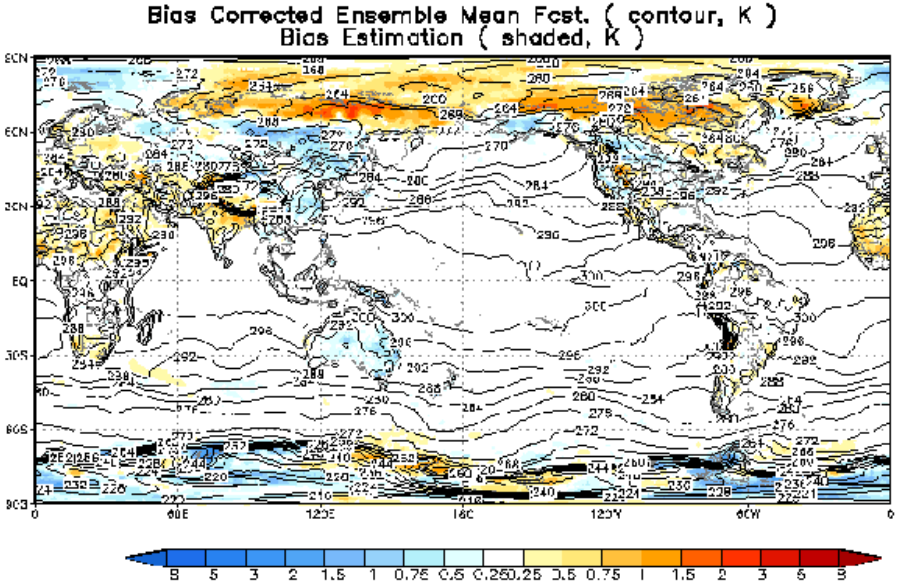


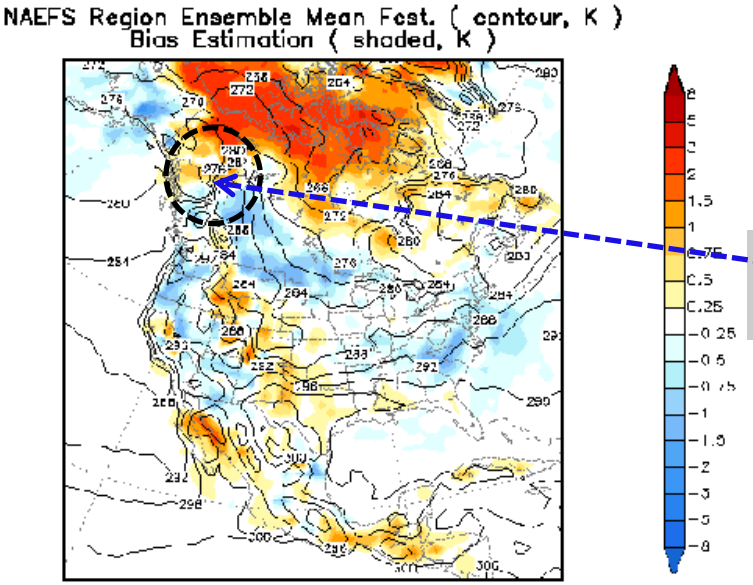
- Utilization of all valuable information, such as:
  - High resolution deterministic forecasts
  - Global and regional ensemble forecasts
  - Global ensemble re-forecast
  - Daily climatology
- Apply SPP – Statistical Post Process for calibration and downscaling
  - Find best deterministic solution (after bias correction)
  - Find best 2nd moment from all ensemble (multi-model: under development)
  - Hybrid of calibrated spread and best deterministic solution – best product
- Future improvement
  - Improving analysis fields (such as RTMA and et al)
  - Improving calibration technique - adaptive of Bayesian concept
  - Optimum decaying weights for bias correction and downscaling
  - Calibration for non-gaussian distribution variables, such as precipitation
  - Correct all model output variables (>200 which include precipitation)

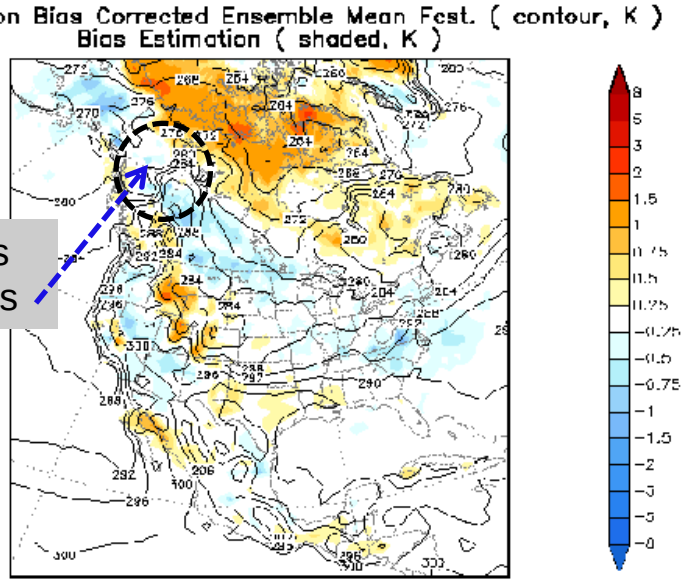
2 meter temperature: 120 hours forecast (ini: 2006043000)

Shaded: left – raw bias right – bias after correction



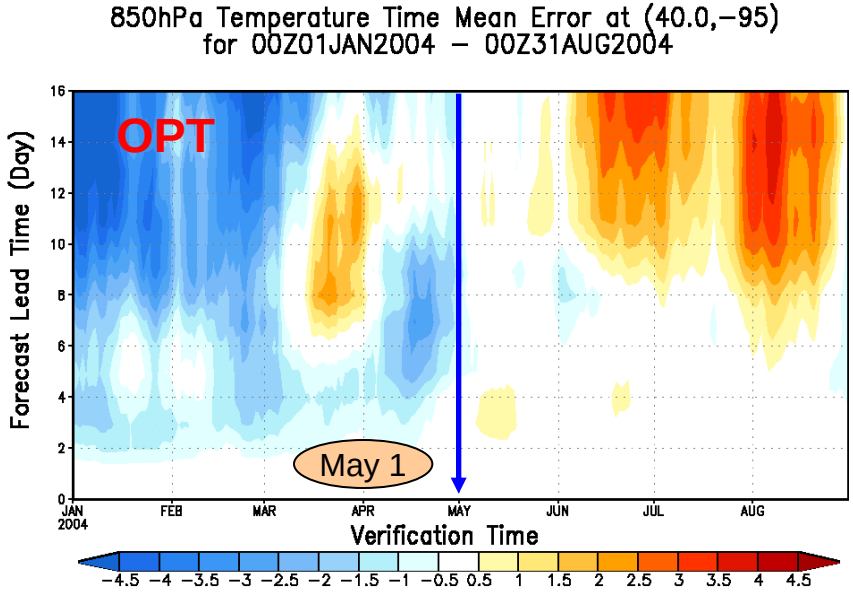


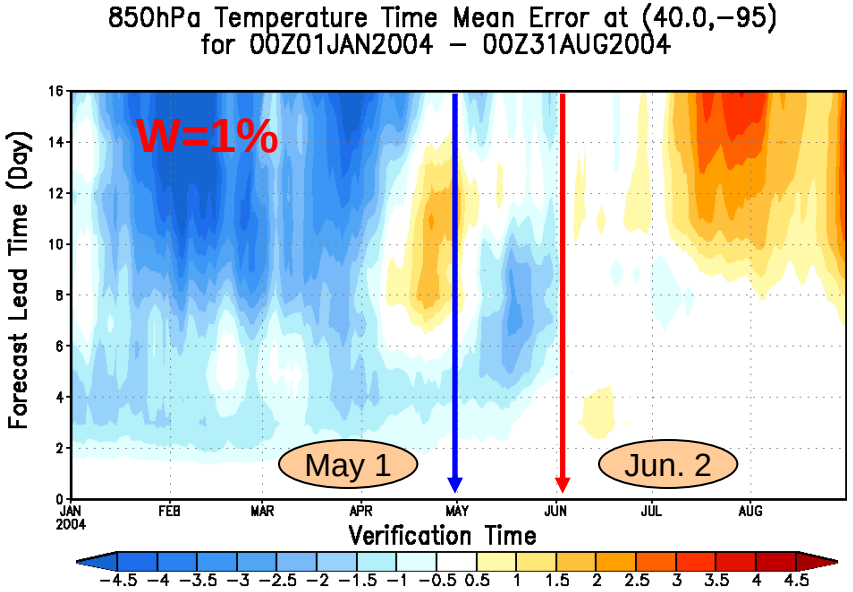


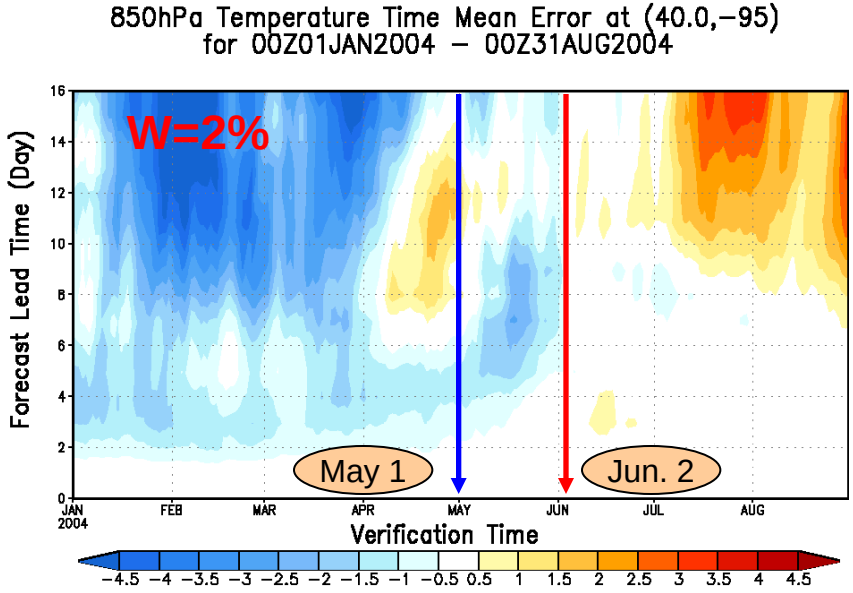


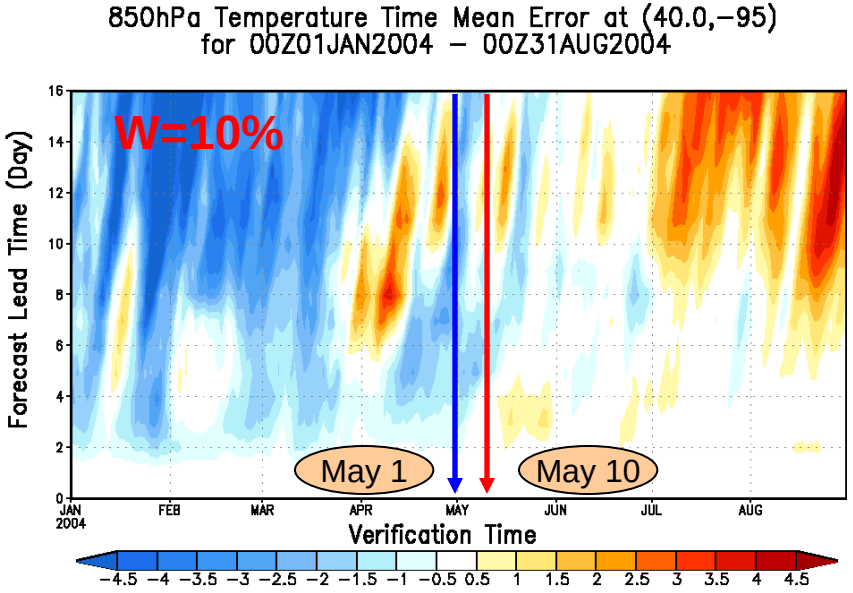
Positive bias
Negative bias

Temporal Cross Section: 850 mb Temp. Time Mean Error (40° N, 95° W, Jan. to Aug. 2004)









Concept for Mini-Bayesian Correction

1. testing for using climatology

Bias corrected forecast: The new (or bias corrected) forecast (***F)*** will be generated by applying decaying average bias (***B***) if ***A*** equals to one to current raw forecast (***f***) and climatological mean (***c***) for each lead time, at each grid point, and each parameter.

$$F_{i,j}(t) = f_{i,j}(t) + (1 - A_{i,j}(t)) \cdot c_{i,j} - B_{i,j}(t)$$

Additional term is added if A is not equal one. This adjustment is expected to benefit for longer lead time forecast

A and ***B*** could be estimated by linear regression from joint samples, the joint sample mean could be generated from decaying average (*Kalman Filter* average) for easy forward.

Concept for Mini-Bayesian Correction

Linear regression for prior joint samples

Slope

$$\hat{A} = \frac{\overline{a.f} - \overline{a} \cdot \overline{f}}{\overline{a \cdot a} - \overline{a}^2} = \frac{\overline{S}_{af}}{\overline{S}_{aa}} = r_{af} \cdot \frac{\overline{S}_{ff}}{\overline{S}_{aa}}$$

Intercept

$$\hat{B} = \overline{f} - \hat{A} \cdot \overline{a}$$

B is bias if A is one

Residuals

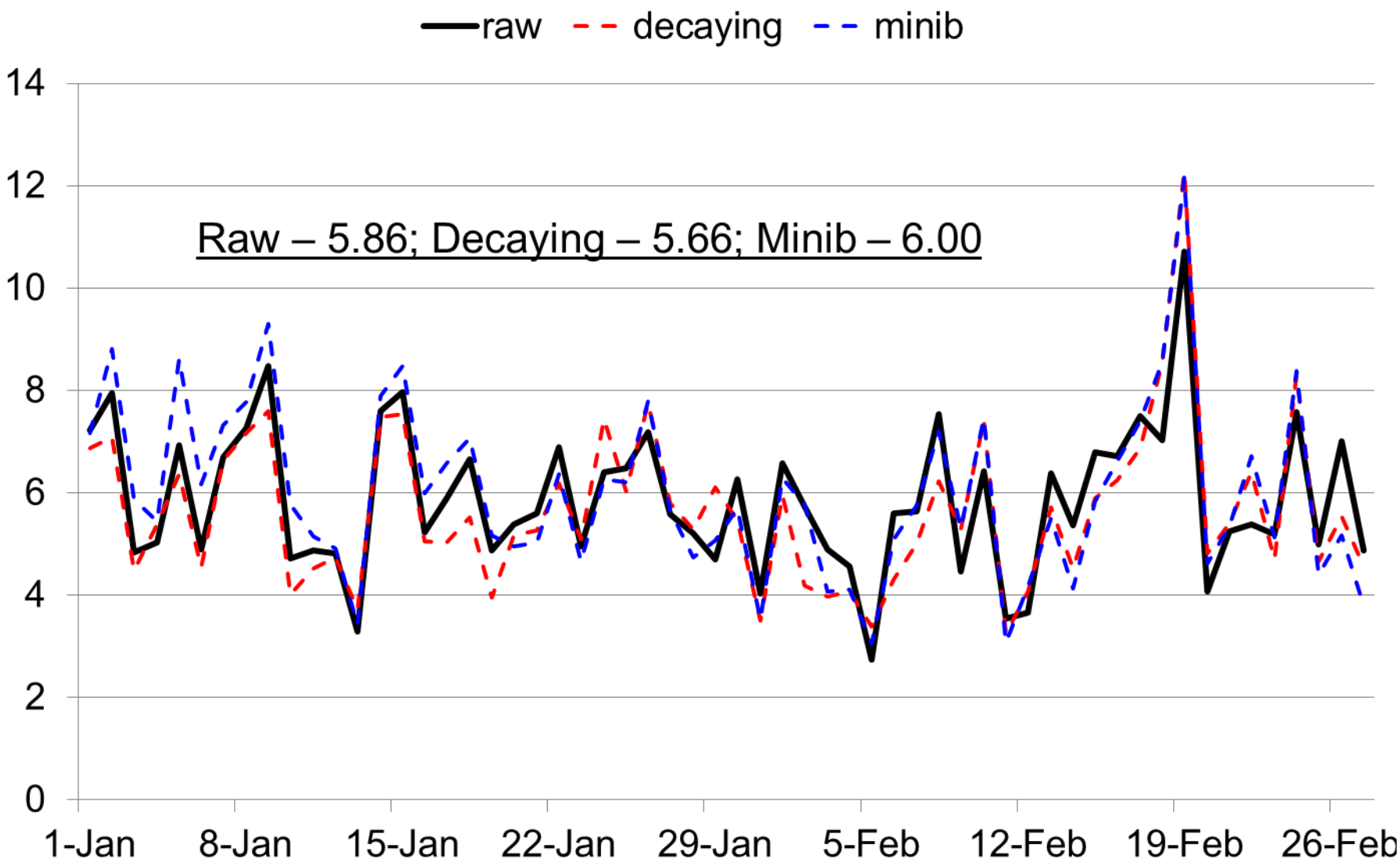
$$\hat{\sigma}^2 = \frac{1}{N} \sum_{n-1}^{N} \left[f(n) - \hat{A}a(n) - \hat{B} \right]^2$$

Correlation Coefficient

$$r_{af} = \frac{\overline{S}_{af}}{\sqrt{\overline{S}_{aa} \cdot \overline{S}_{ff}}}$$

|R| <= 1.0

850hPa temp. bias correction for 384 hours forecast



Concept for Mini-Bayesian Correction

2. testing for using reforecast

Bias corrected forecast: The new (or bias corrected) forecast (***F)*** will be generated by applying decaying average bias (***B***) and reforecast bias (***b***) to current raw forecast (***f***) for each lead time, at each grid point, and each parameter.

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

Additional term (bias from reforecast) is added if ***r*** (correlation coefficient) is not equal one. This adjustment is expected to benefit for longer lead time forecast

r could be estimated by linear regression from joint samples, the joint sample mean could be generated from decaying average (*Kalman Filter* average) for easy forward.

Concept for Mini-Bayesian Correction

With 2nd moment correction (spread)

Ensemble skill

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

Ensemble spread

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

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

R=1 if E=0

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

$$F_{i,j}^m = f_{i,j}^m + (r_{i,j} - 1)\cdot b_{i,j} - r_{i,j}B_{i,j} + (1 - R_{i,j})\cdot D^m$$

Background

Process to Downscale Tmax & Tmin for CONUS

- Based on 1*1 degree 6-hr bias corrected Tmax, Tmin and down-scaling vectors (DV) for T2m at each 6-hr cycle
  - Definition of Tmax and Tmin for Conus region
    - ➢ Tmax period: 11/12UTC(7am-local) – 23/00UTC(7pm-local) – EAST
    - ➢ Tmin period: 23/00UTC(7pm-local) – 12/13UTC(8am-local) – EAST
  - Definition of approximated period for Tmax and Tmin for giving initial cycle
  - Mean DV of T2m for 6-hr period: weighted average of two instantaneous DVs
  - Interpolating bias corr. 6-hr Tmax & Tmin (1X1) to 6km NDGD grid for Conus
  - Detailed Process
    - Apply mean DV to each grid point, each ens. member, and each 6-hr lead-time period, to produce down-scaled Tmax and Tmin for each 6-hr lead-time period
    - Find out highest Tmax and lowest Tmin for approximated period
    - For different grid points, different ens. members, highest Tmax could be in different 6-hr period, the same for lowest Tmin
    - Only one down-scaled Tmax and Tmin for every 24-hr. fcst, up to 384 hours
  - Calculate the mean, spread, mode, 10%, 50% and 90% based on above step

Process to Downscale Dew Point Temperature

- Output products: DPT, RH2m
  - NCEP & CMC bias corrected DPT, RH2m on 1 degree
  - NAEFS probabilistic forecasts on 1 degree: mean, spread, mode, 10%, 50% and 90% fcst
  - Downscaled probabilistic forecasts on NDGD 5km

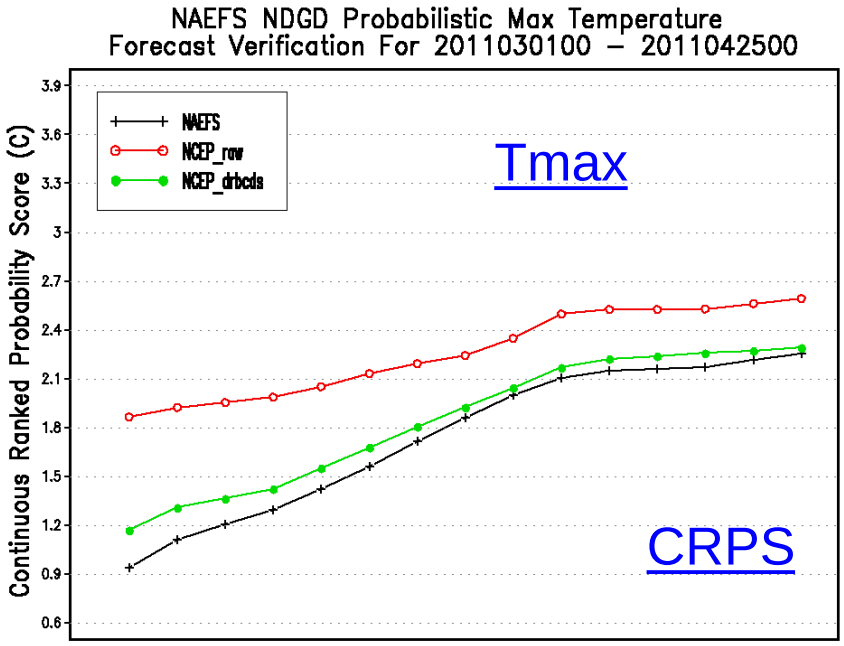
- NCEP/CMC Bias correction process on 1 degree
  - Calculate DPT fcst. & analysis from T2m and RH2m, accumulate bias by applying decaying weight
  - Calculated DPT from T2m and RH2m forecast, bias correct DPT
    - Adjust bias corrected DPT, comparing with bias corrected T2m, smaller value as the DPT
  - Bias correct RH2m by removing RH2m bias accumulation

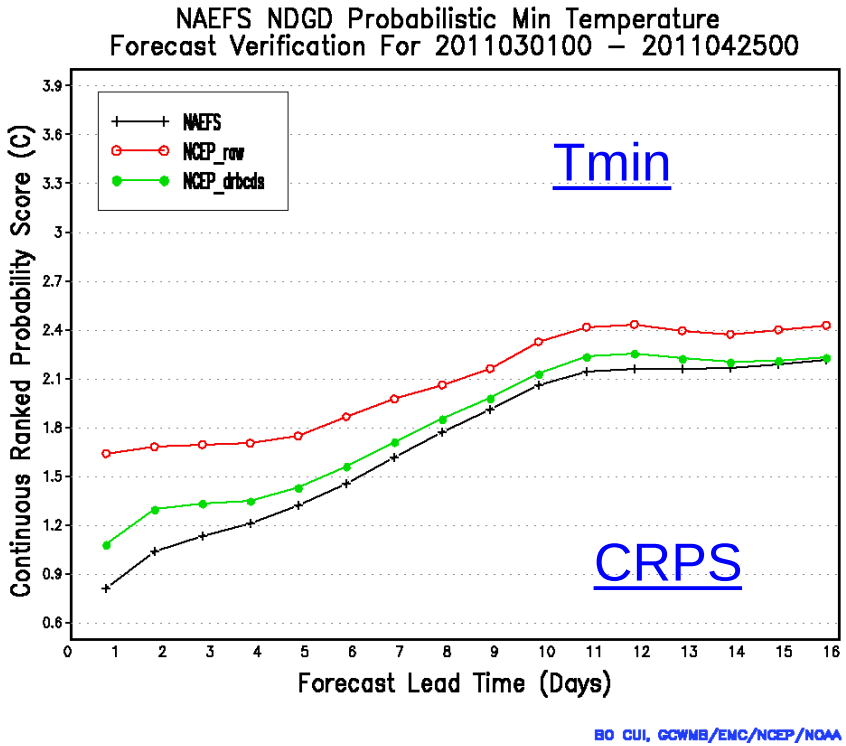
- NCEP/CMC combination process on 1 degree
  - Combine bias corrected NCEP/CMC DPT to generate probabilistic forecasts
    - Compare DPT and T2m probabilistic forecasts, DPT are smaller than T2m
  - Combine NCEP/CMC RH2m to generate probabilistic forecasts
    - Adjust RH2m probabilistic forecasts, values not larger than 100% or smaller than 0%

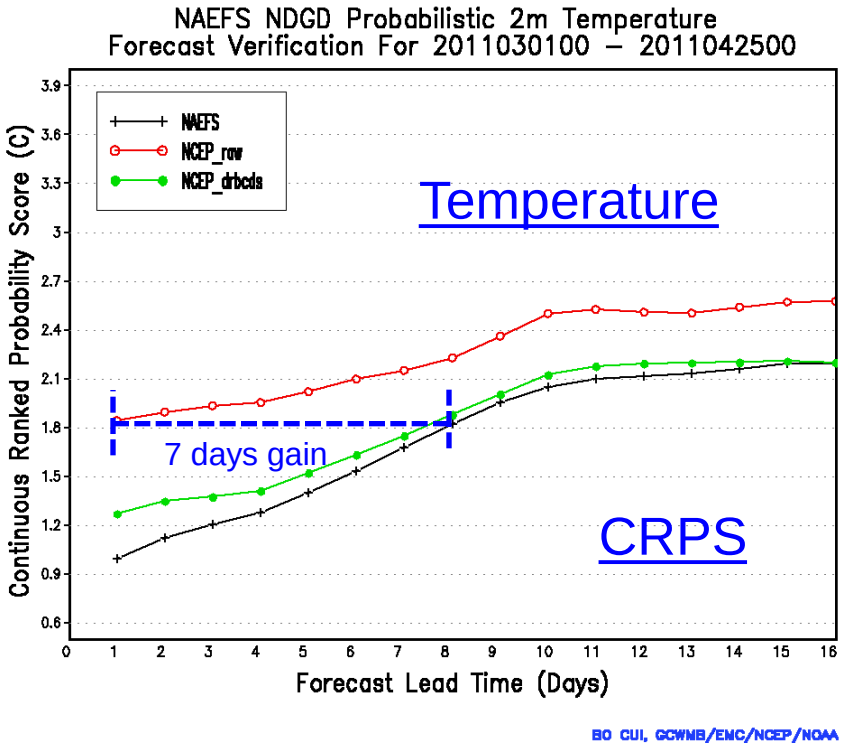
- Downscaling process
  - Get downscaling vectors (DV) for DPT, T2m and RH2m at each 6-hr cycle
  - Apply DV to produce down-scaled DPT,T2m and RH2m for each 6-hr lead-time period
  - Generate the mean, spread, mode, 10%, 50% and 90% based on above step

Schemes to develop T2m, Td2m, RH probabilistic products

Products	1x1 degree resolution			NDGD (5km) resolution		
	T2m	Td2m	RH	T2m	Td2m	RH
Raw ensemble members	Yes	Yes Derived from t2m and RH	Yes	N/A	N/A	N/A
Bias corrected ensemble members	Yes	Yes One end is bounded (T2m)	Yes Two ends are bounded (0,100)	N/A	N/A	N/A
Ensemble mean, mode, 10%, 50% and 90%	Yes	Yes One end is bounded (T2m)	Yes Two ends are bounded (0,100)	Yes Apply DV RTMA - Yes	Yes Apply DV RTMA - Yes One end is bounded	Yes Apply DV RTMA (T2m &Td2m) Two ends are bounded
Ensemble spread	Yes	Yes	Yes	Yes Interpolated	Yes Interpolated	Yes Interpolated bounded
	Probabilistic products and spread of T2m and Td2m are not compatible to RH					

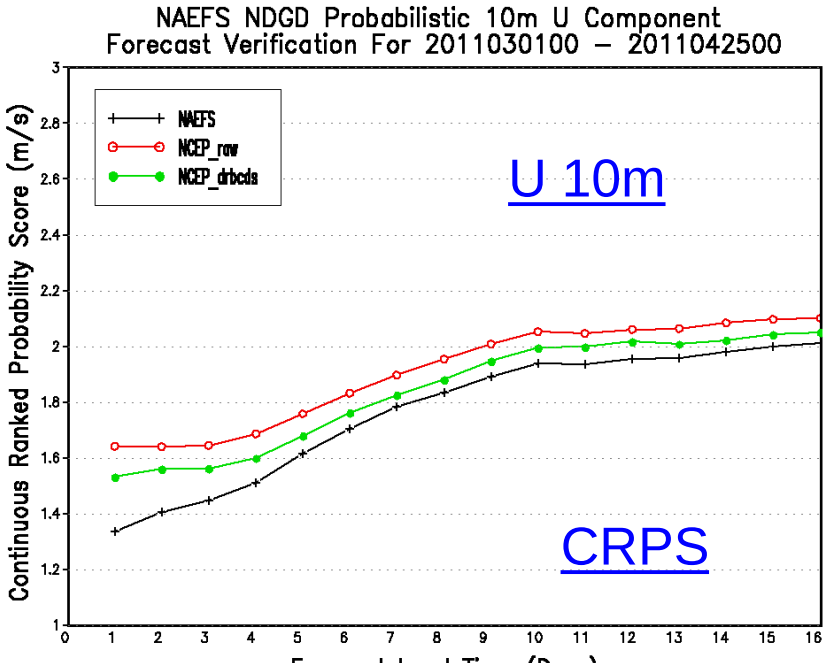


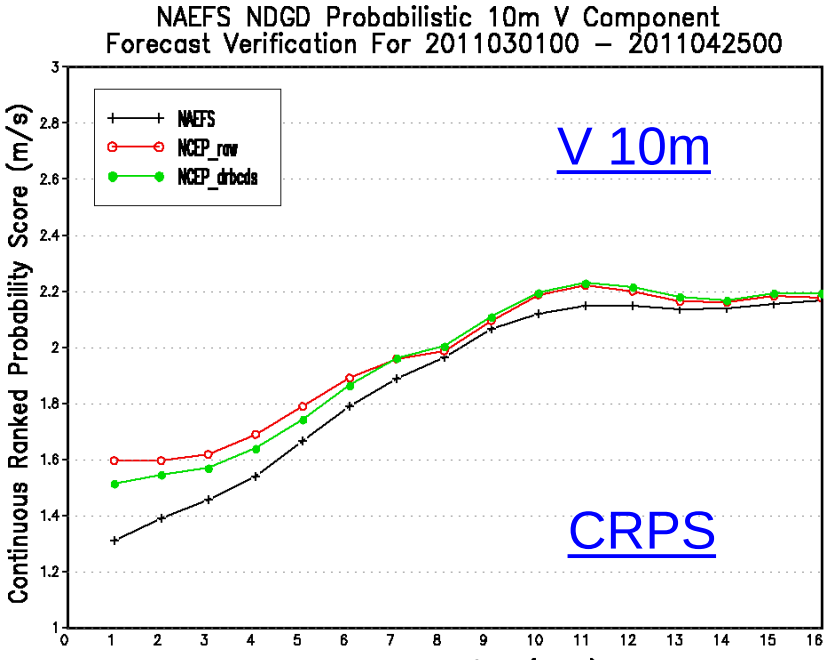


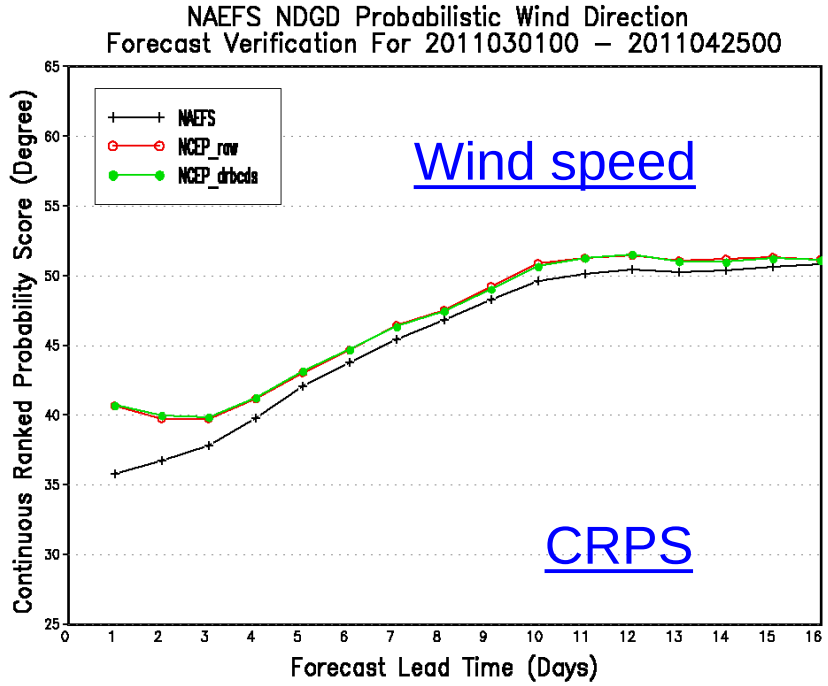


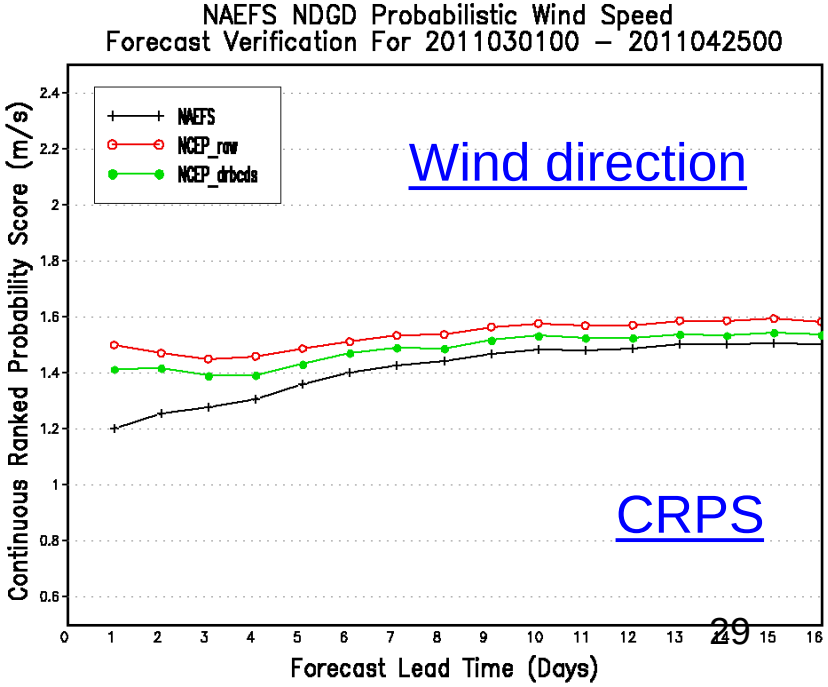
Latest evaluation for CONUS temperature forecast by apply :

1. Bias correction at 1*1 degree for NCEP GFS/GEFS, CMC/GEFS
2. Hybrid bias corrected NCEP GFS and GEFS
3. Apply statistical downscaling for all bias corrected forecast
4. Combined all forecasts at 5*5 km (NDGD) grid with adjustment - NAEFS

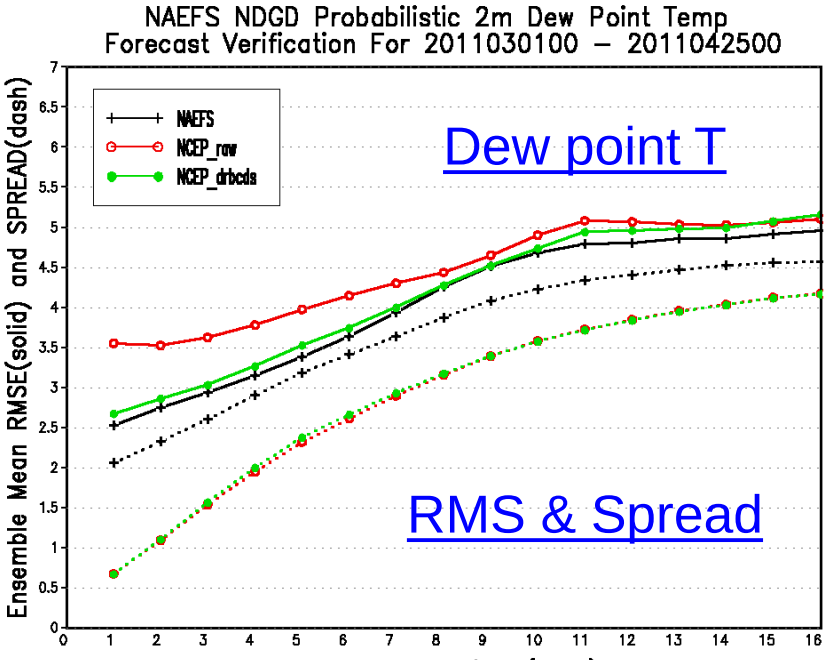


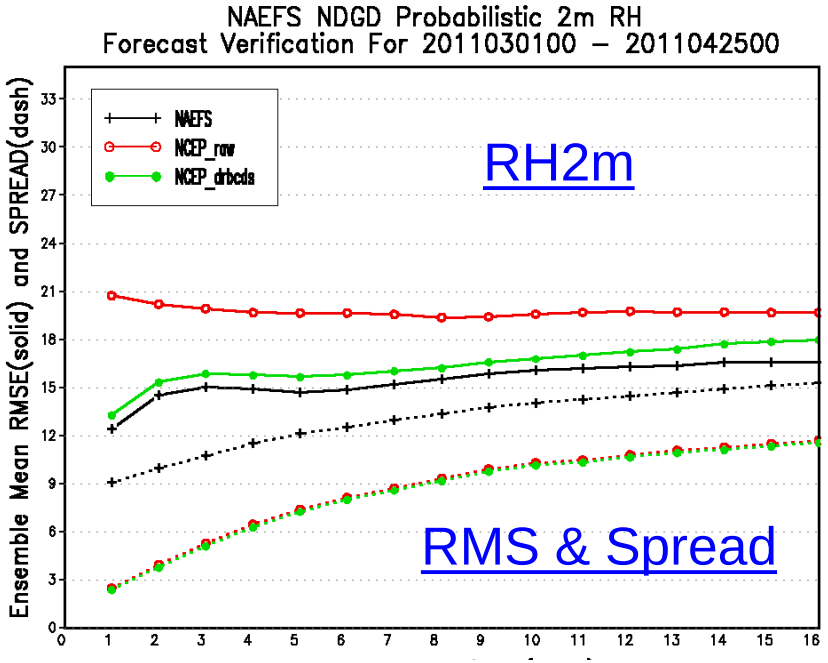


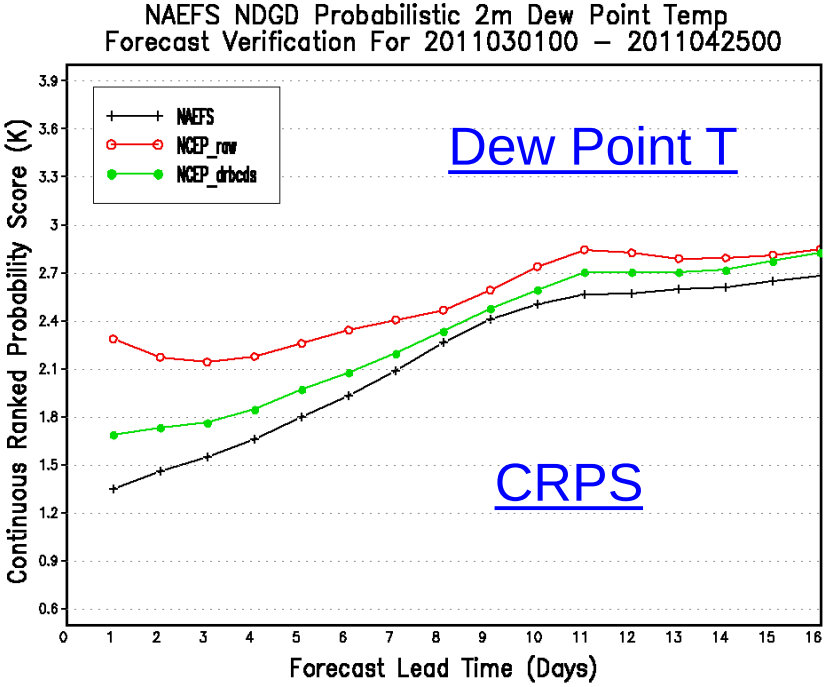


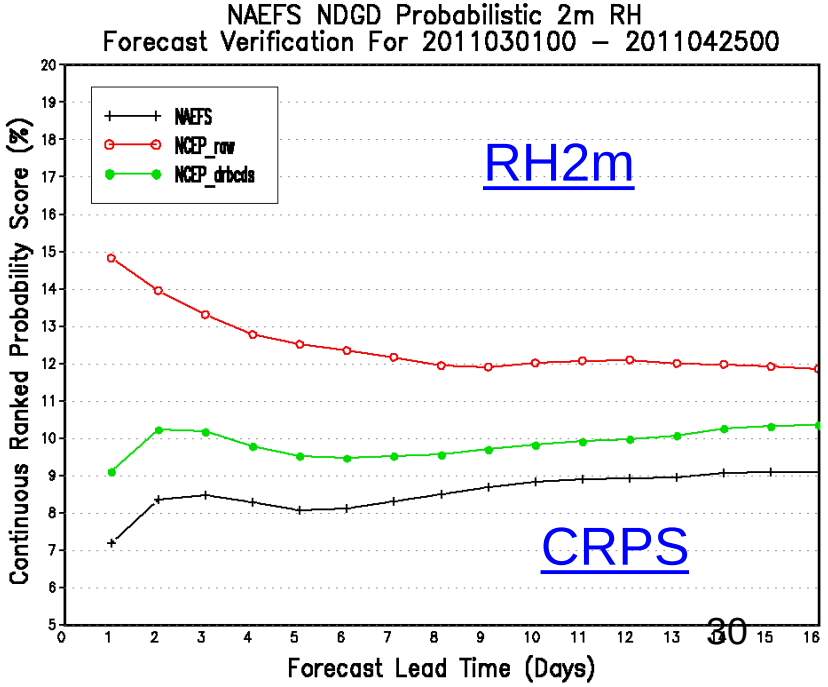


BO CUI, GCWMB/EMC/NCEP/NOAA









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