NAEFS Statistical Post-Processing

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Highlights (1)

- NAEFS SPP review
  - Bias correction and downscaling
  - Milestones
  - Current status and performance
- Values of NAEFS products
  - Objective evaluations
  - Comparison
  - User appreciations
- Connection to Blender project
  - NAEFS SPP applies to ECMWF forecast
  - Blender method (another talk)
  - What will be if we don't have ECMWF forecast?

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 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 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 – Q2FY14 — Version 4
- 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
- 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

NAEFS bias correction variables

Plan: Q2FY14 - (bias correction)

Variables	pgrba_bc file	Total 52
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
Precip*	CONUS and NCEP only	1
	Last implementation: March 2010	
Notes		

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

NAEFS downscaling parameters and products

Plan: Q2FY2014 (NDGD resolutions)

Variables	Domains	Resolutions	Total 11/10
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
Precipitation	CONUS	5km	1/0

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

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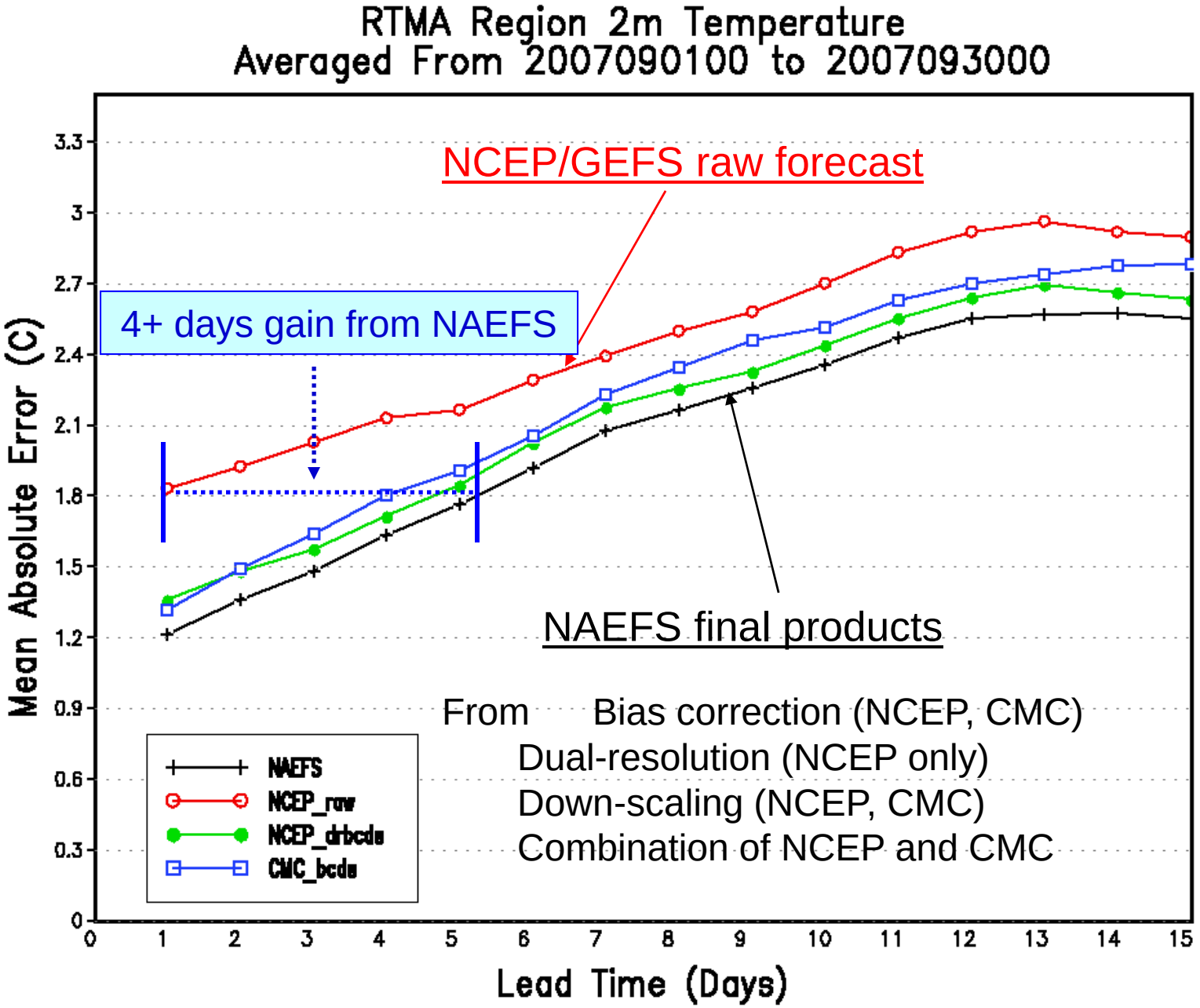
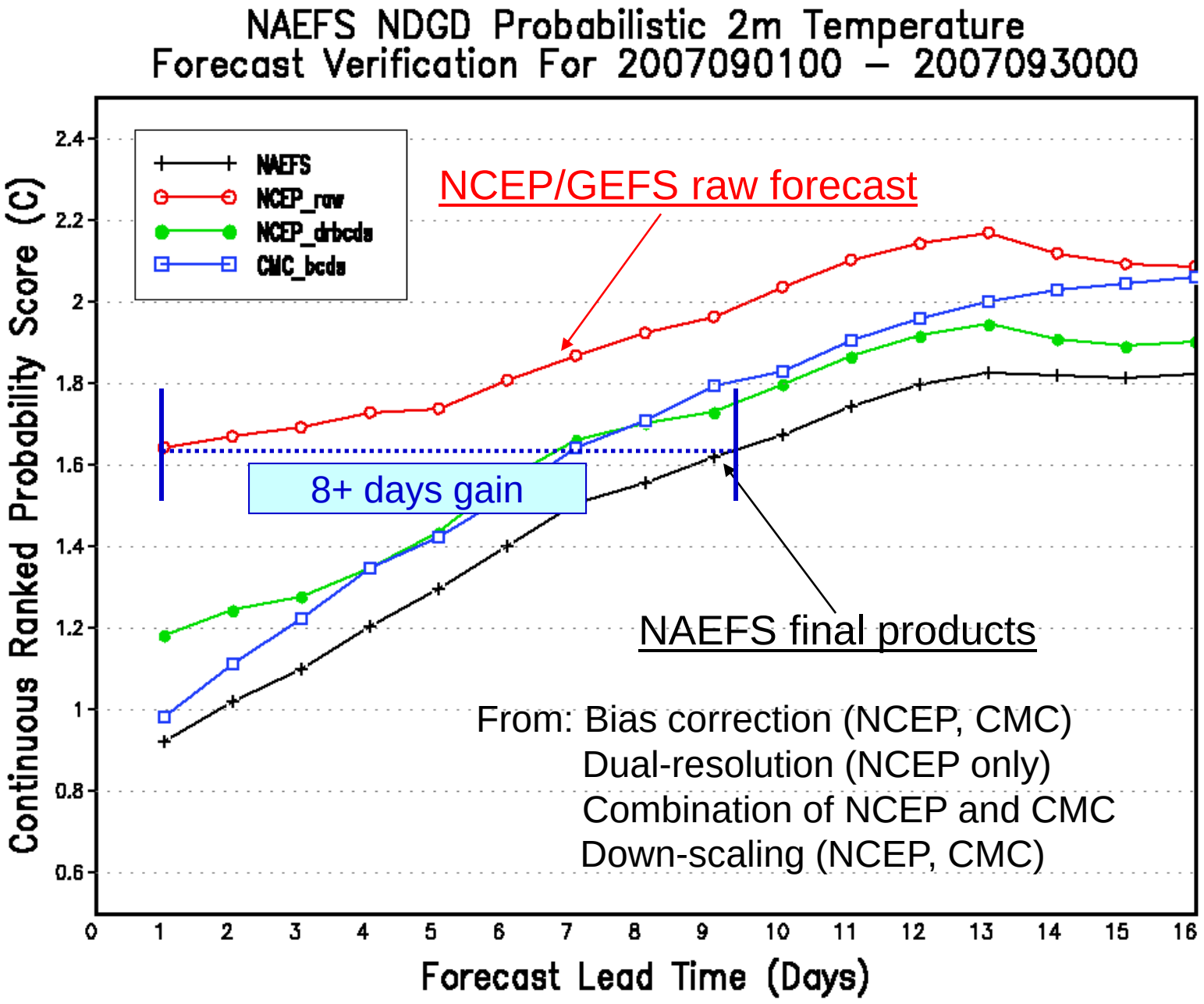


BO CUI, GCWMB/EMC/NCEP/NOAA



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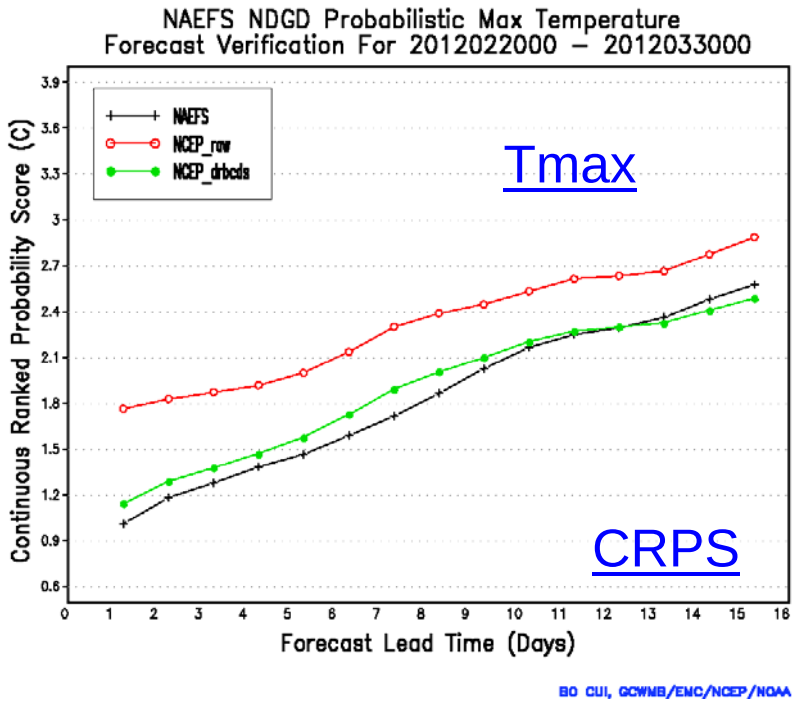
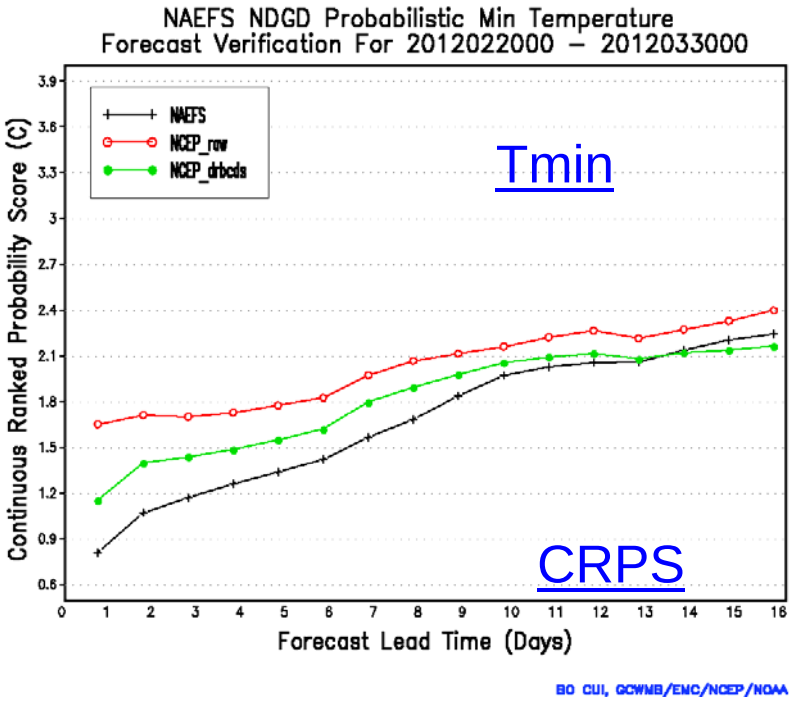
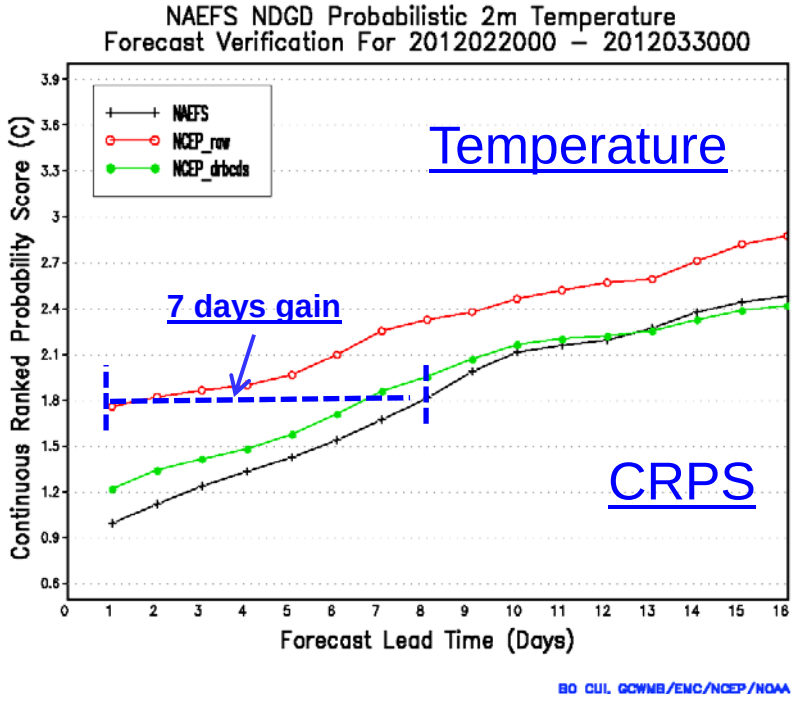


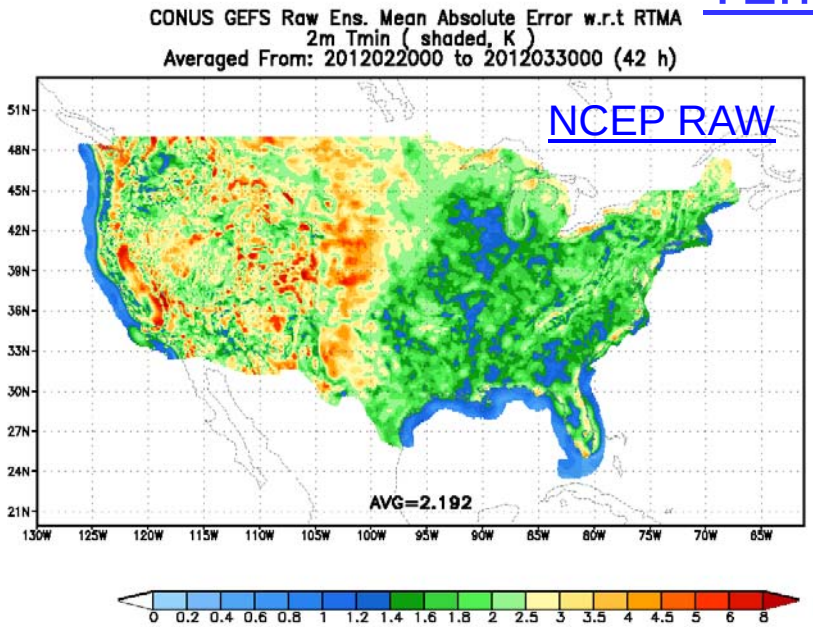


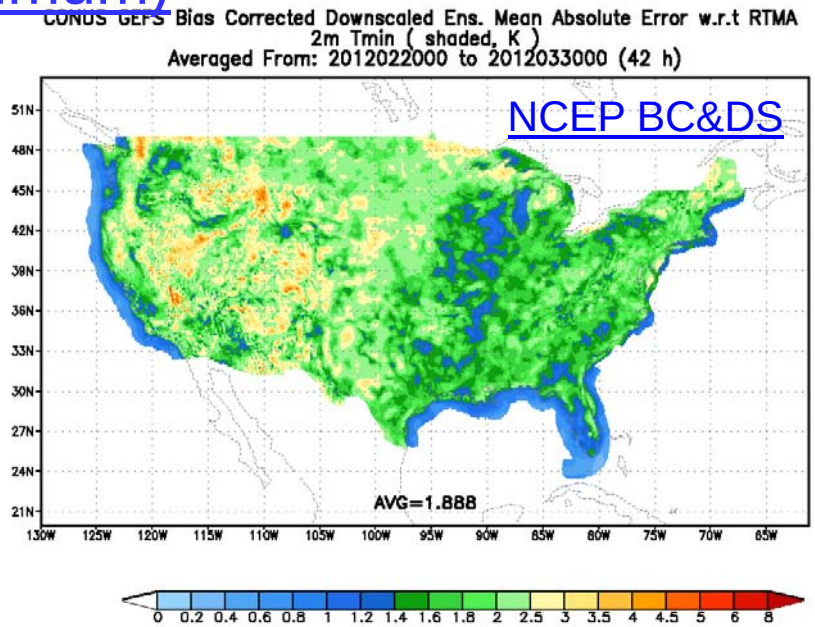


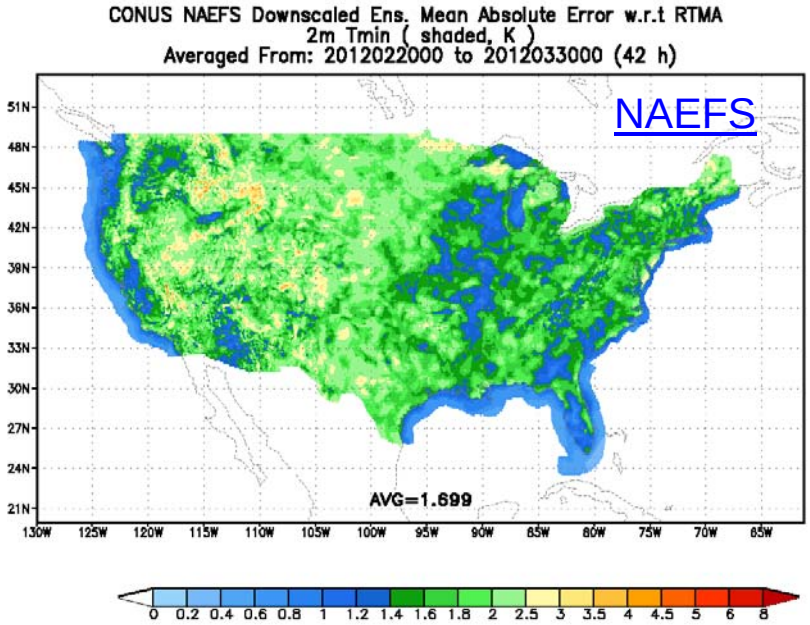
2012 Spring evaluation for CONUS temperature forecast by apply :

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

T2m (Minimum)





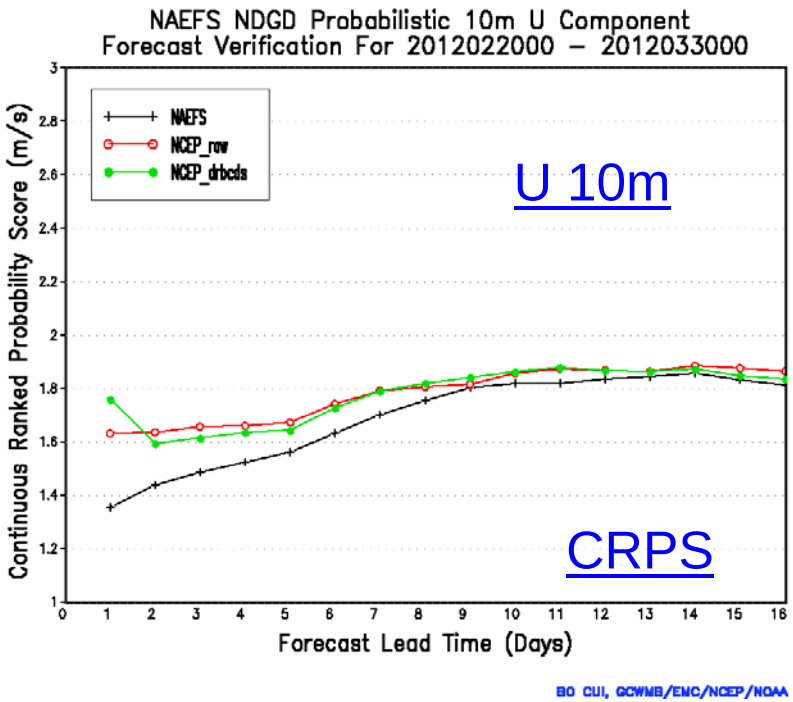


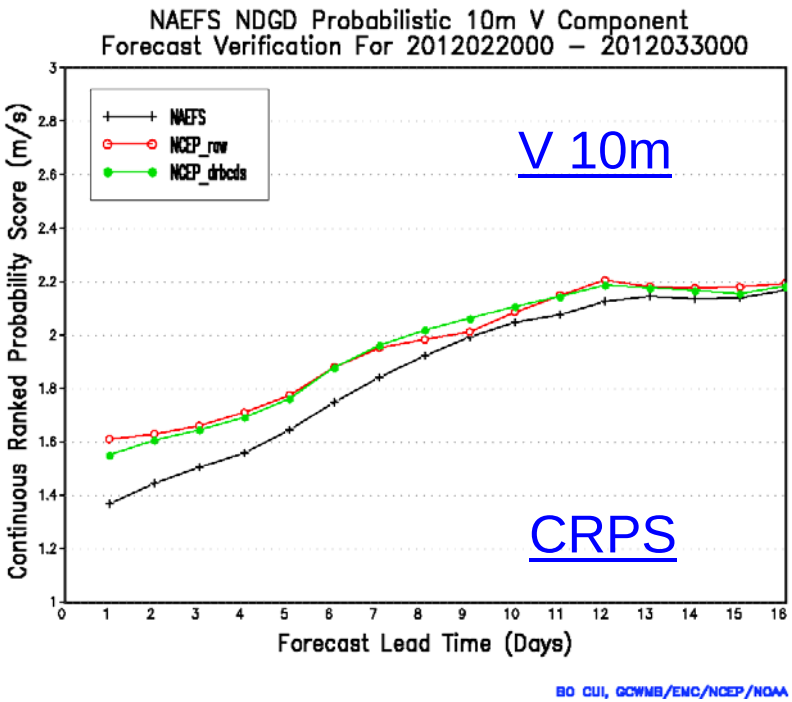
Surface minimum temperature for 40 days (2/20/2012 – 3/30/3012) after GEFS upgrade.

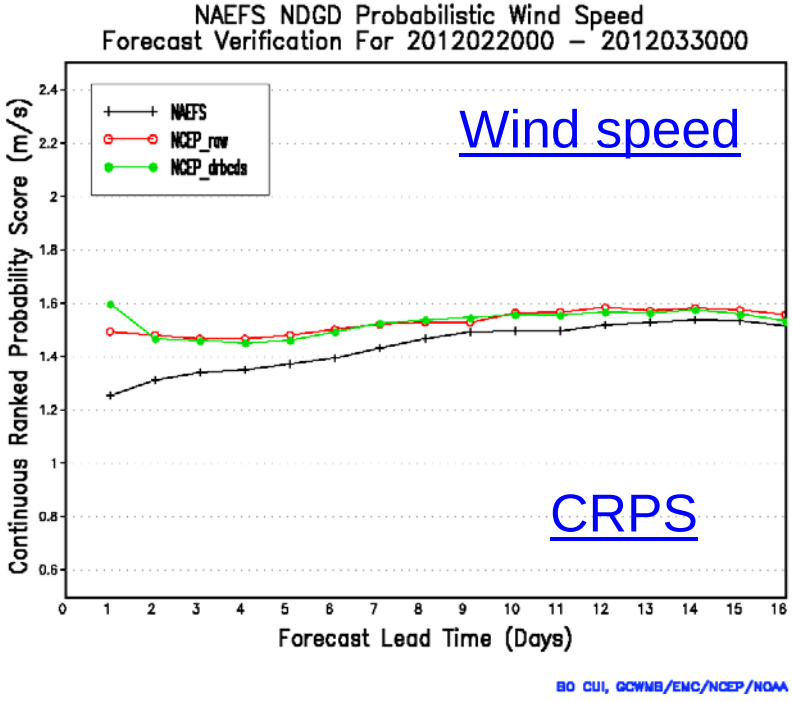
Average MAE improvements (against TMA):

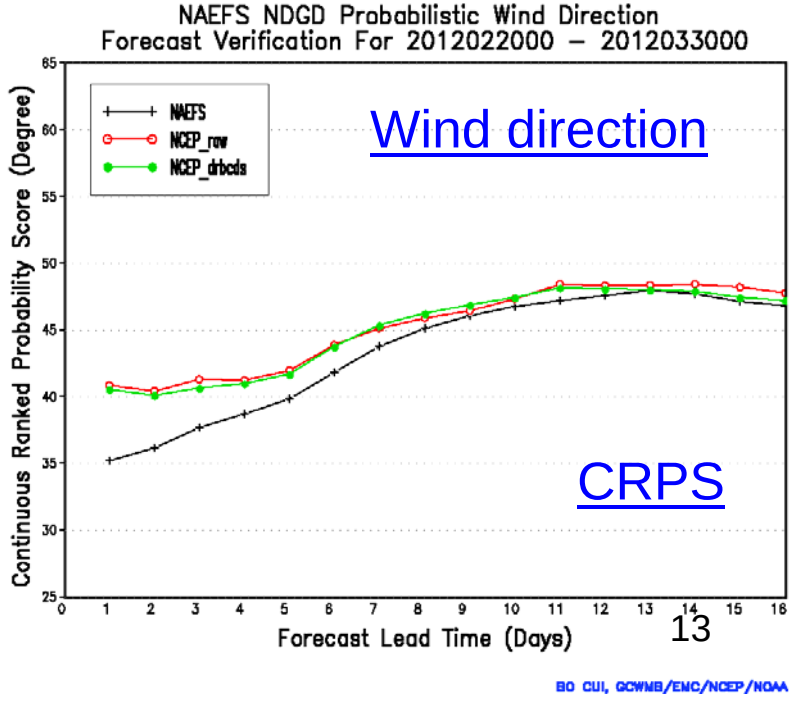
14% from NCEP model post-process only

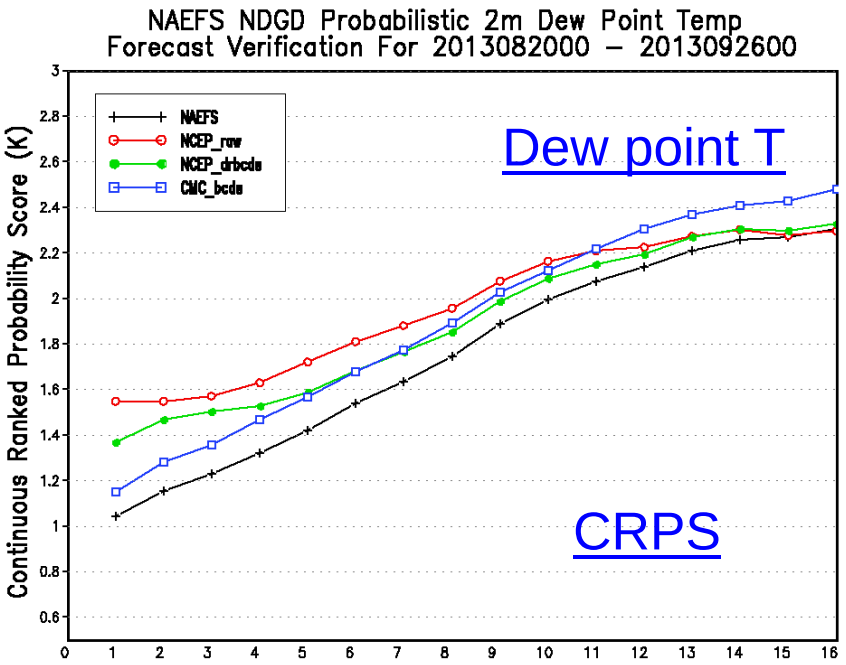
23% from NAEFS – final product

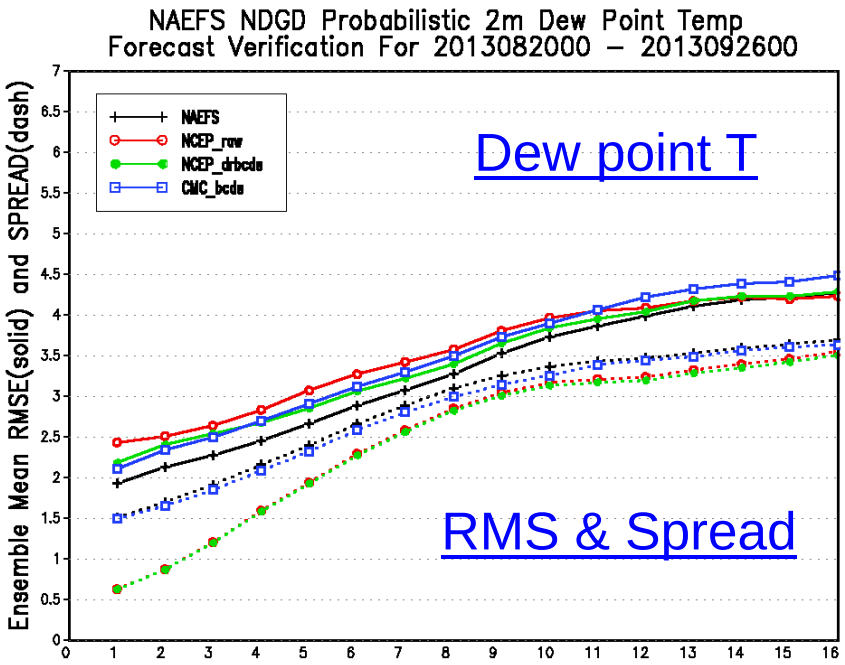

NAEFS NDGD Probabilistic 10m U Component
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
U 10m
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

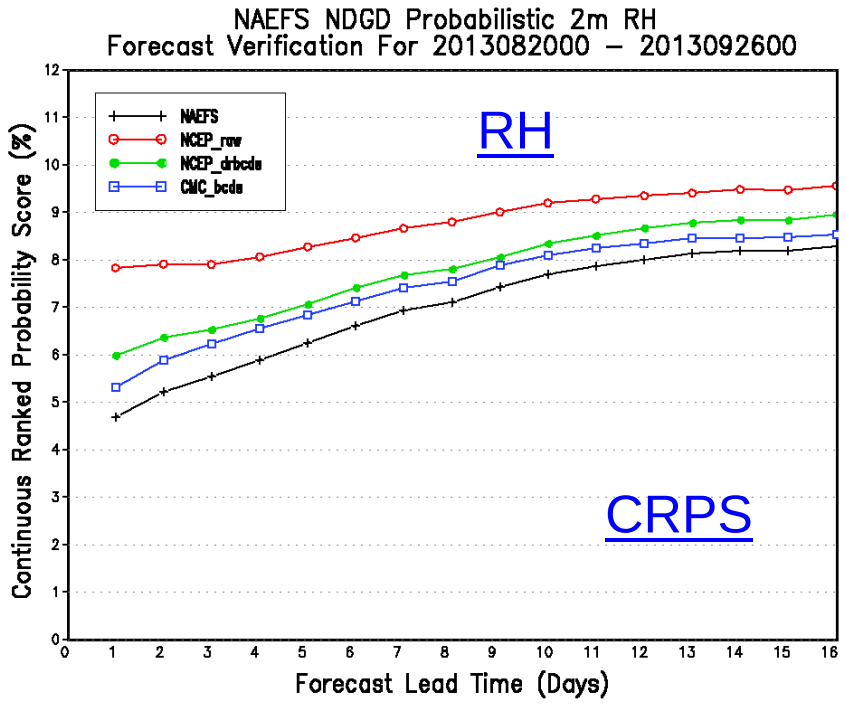

NAEFS NDGD Probabilistic 10m V Component
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
V 10m
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA

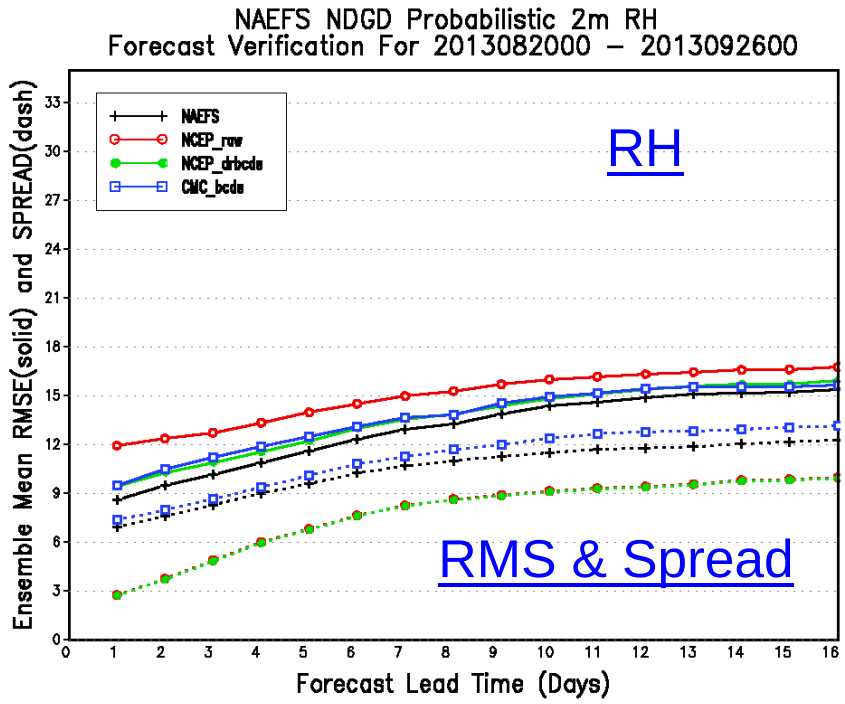

NAEFS NDGD Probabilistic Wind Speed
Forecast Verification For 2012022000 – 2012033000
NAEFS
NCEP_raw
NCEP_drbcds
Wind speed
CRPS
Continuous Ranked Probability Score (m/s)
Forecast Lead Time (Days)
BO CUI, GCWMB/EMC/NCEP/NOAA


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 2013082000 – 2013092600
Continuous Ranked Probability Score (K)
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
Dew point T
CRPS


NAEFS NDGD Probabilistic 2m Dew Point Temp
Forecast Verification For 2013082000 – 2013092600
Ensemble Mean RMSE(solid) and SPREAD(dash)
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
Dew point T
RMS & Spread


NAEFS NDGD Probabilistic 2m RH
Forecast Verification For 2013082000 – 2013092600
Continuous Ranked Probability Score (%)
Forecast Lead Time (Days)
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
RH
CRPS


NAEFS NDGD Probabilistic 2m RH
Forecast Verification For 2013082000 – 2013092600
Ensemble Mean RMSE(solid) and SPREAD(dash)
Forecast Lead Time (Days)
NAEFS
NCEP_raw
NCEP_drbcds
CMC_bcds
RH
RMS & Spread

Surface Temperature MAE

CONUS, Sept. 2007

00Z GMOS vs. 00Z NAEFS

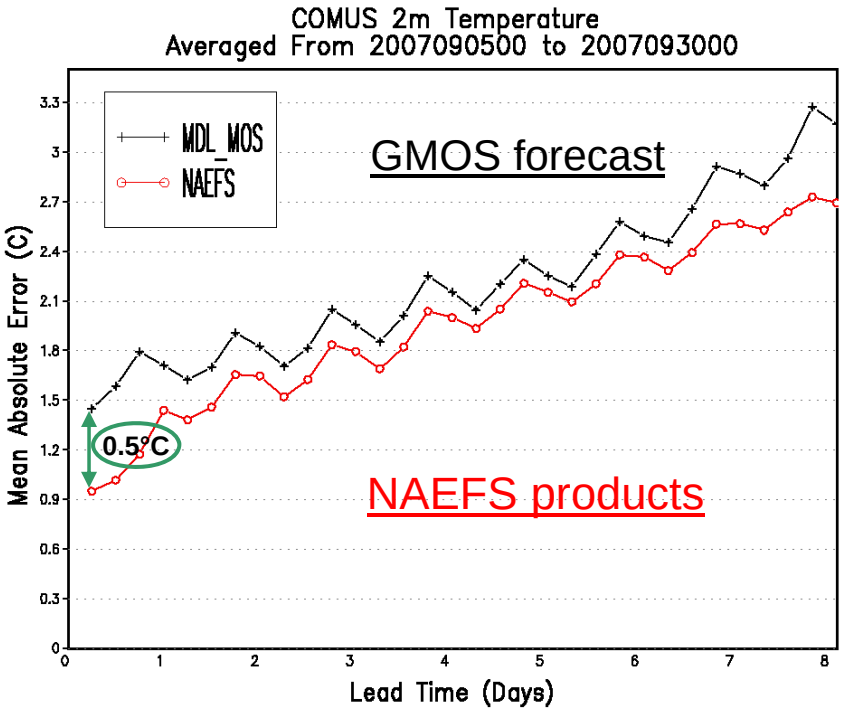
RTMA Analysis

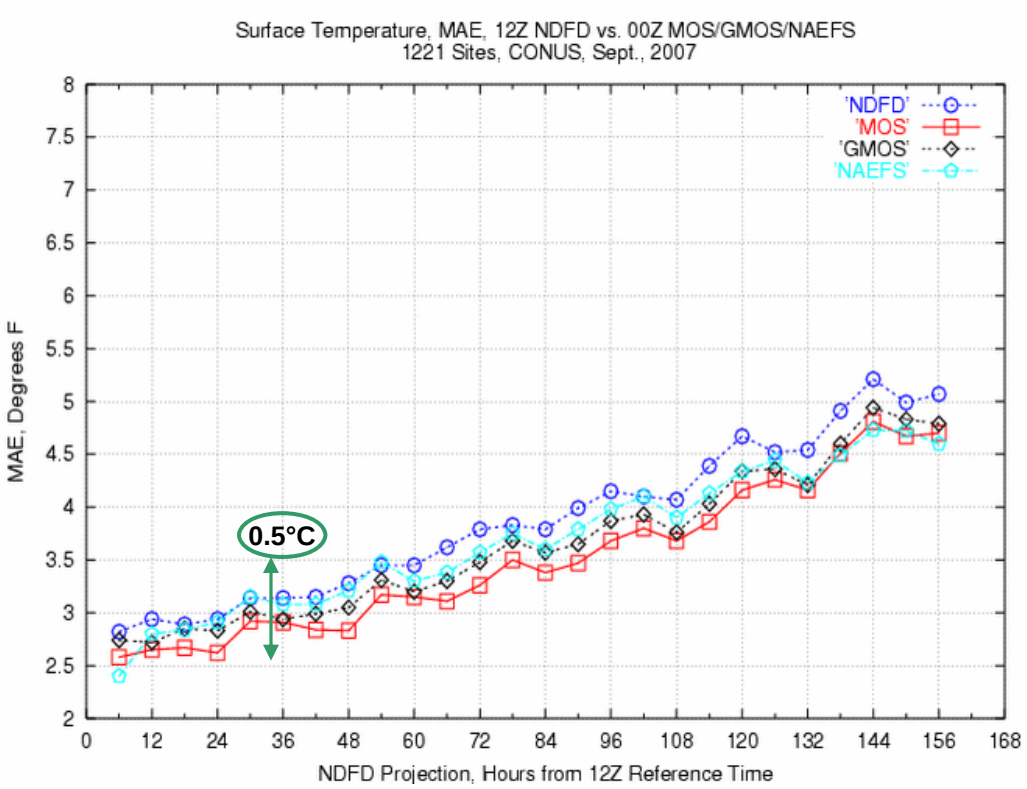
Surface Temperature MAE

CONUS, Sept. 2007

12Z NDFD vs. 00Z MOS/GMOS/NAEFS

METAR obs. 1221 sites





Surface Temperature Pointwise Bias

CONUS, Sept. 2007

00Z GMOS vs. 00Z NAEFS

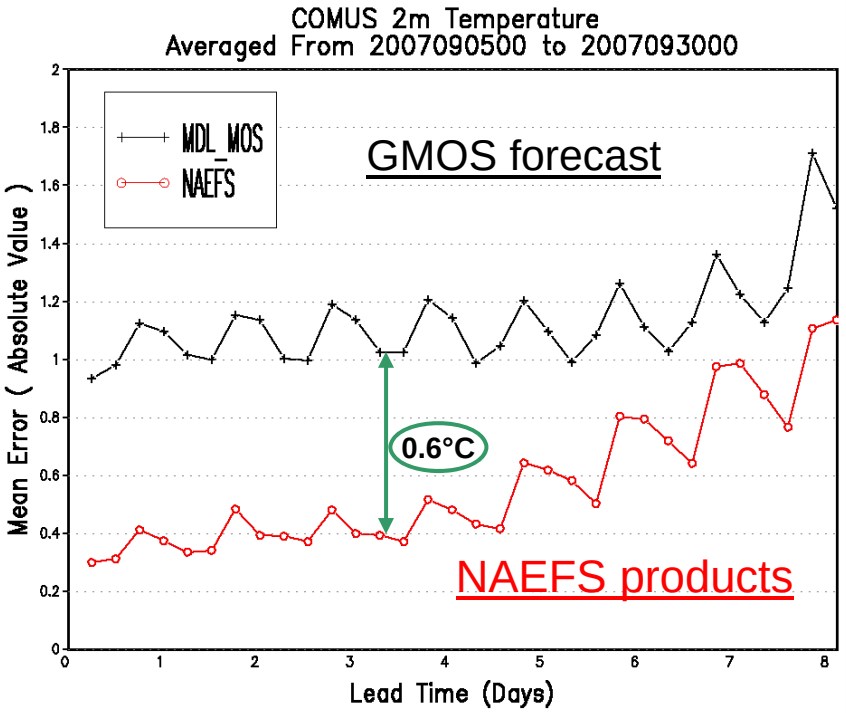
RTMA Analysis

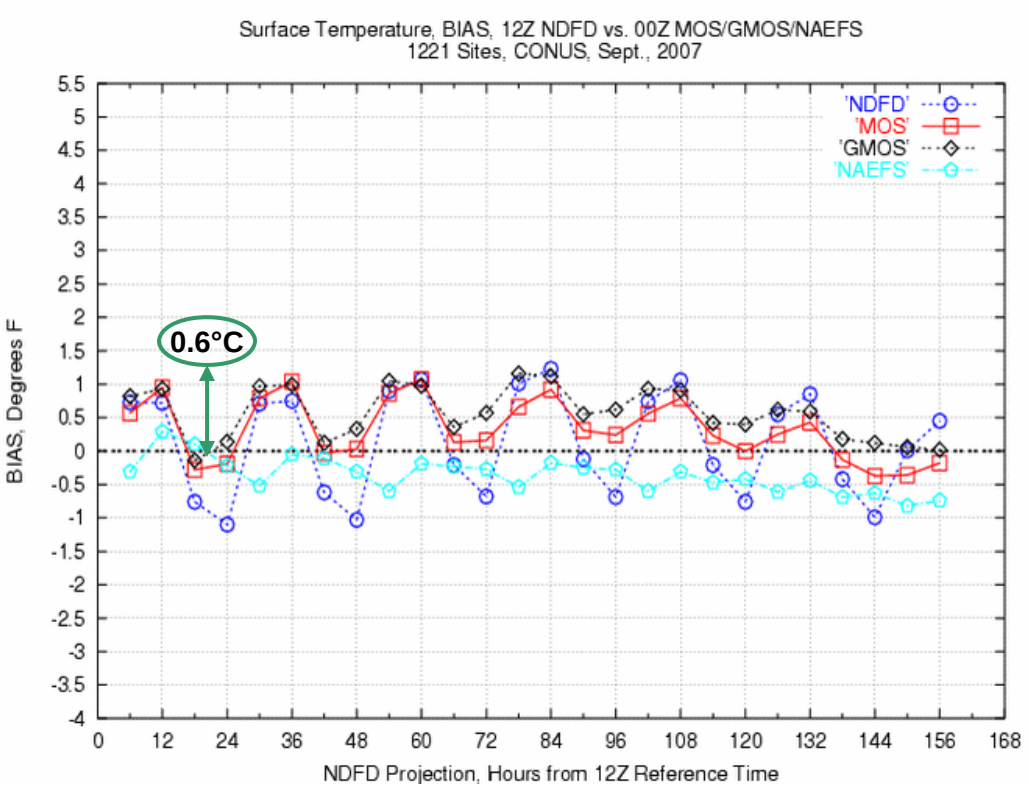
Surface Temperature Area Mean Bias

CONUS, Sept. 2007

12Z NDFD vs. 00Z MOS/GMOS/NAEFS

METAR obs. 1221 sites





User appreciations

The evaluations from WFO (State College) forecaster for NAEFS mean minimum temperature

Minimum temperature forecast: Average over past 30 days: (20080929-20081028)

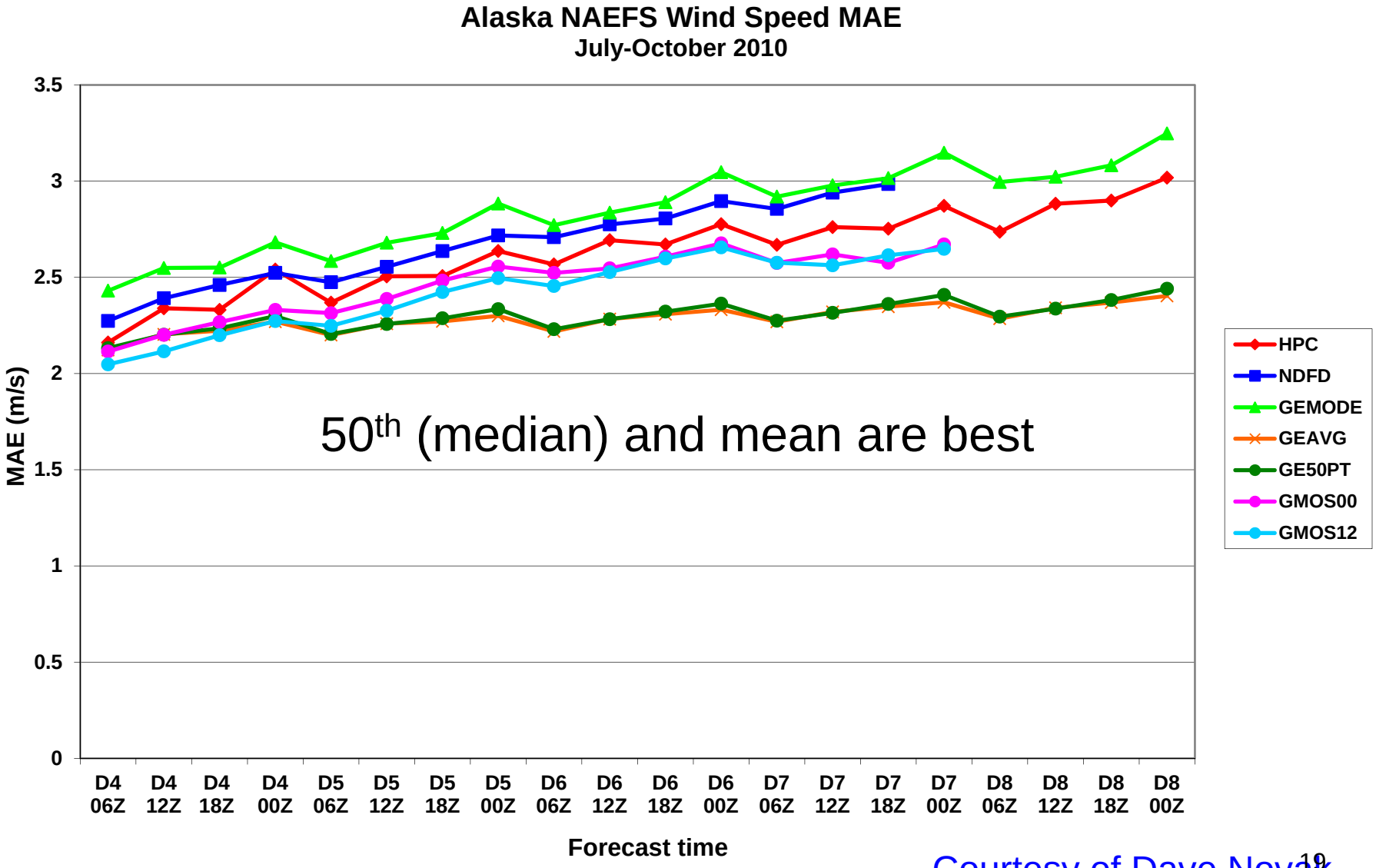
		MAE	Bias	>10 err	<3 err	off. rank	Best G.		2nd G.		Worst G.	
1	12-hr	3.17	-1.2	1.0%	53.4%	3 out of 7	NAEFS	59.7%	SREF	57.1%	NGM80	21.8%
2	24-hr	3.03	-0.9	0.6%	55.5%	2 out of 7	SREF	57.2%	NAEFS	54.2%	NGM80	24.9%
3	36-hr	3.25	-0.8	0.9%	51.6%	3 out of 7	NAEFS	54.2%	SREF	53.9%	NGM80	23.2%
4	48-hr	3.94	-1.1	2.9%	43.2%	3 out of 7	NAEFS	51.9%	SREF	45.8%	NGM80	6.2%
5	60-hr	4.30	-0.4	4.4%	39.1%	4 out of 6	NAEFS	49.2%	SREF	43.0%	NAM40	8.9%
6	72-hr	4.76	0.1	6.4%	33.7%	5 out of 5	NAEFS	42.9%	SREF	40.1%	NAM12	35.2%
7	84-hr	4.85	0.3	7.5%	34.7%	2 out of 6	NAEFS	40.0%	MOSGd	33.4%	NAM12	8.9%
8	96-hr	5.24	0.4	13.0%	33.1%	1 out of 3	NAEFS	32.7%	MOSGd	29.9%	MOSGd	29.9%
9	108-hr	5.11	0.8	12.8%	35.4%	1 out of 4	HPCGd	34.5%	NAEFS	32.1%	MOSGd	30.5%
10	120-hr	5.31	0.7	12.0%	31.9%	1 out of 3	MOSGd	31.6%	NAEFS	24.8%	NAEFS	24.8%
11	132-hr	4.97	0.7	9.9%	35.1%	2 out of 4	HPCGd	38.0%	MOSGd	30.9%	NAEFS	27.2%
12	144-hr	5.42	0.6	15.0%	35.0%	1 out of 3	MOSGd	31.3%	NAEFS	29.0%	NAEFS	29.0%
13	156-hr	5.40	0.5	14.9%	35.7%	1 out of 4	HPCGd	32.9%	MOSGd	32.7%	NAEFS	23.4%
14	168-hr	5.46	1.1	17.7%	38.1%	1 out of 3	MOSGd	35.6%	NAEFS	28.4%	NAEFS	28.4%

Official Guidance: NGM80, NAM40, SREF, NAM12, MOSGd, HPCGd, NAEFS

NAEFS downscaled 5km (NDGD) minimum temperature (mean) is the best guidance for first 96hr forecasts from 7 different guidance

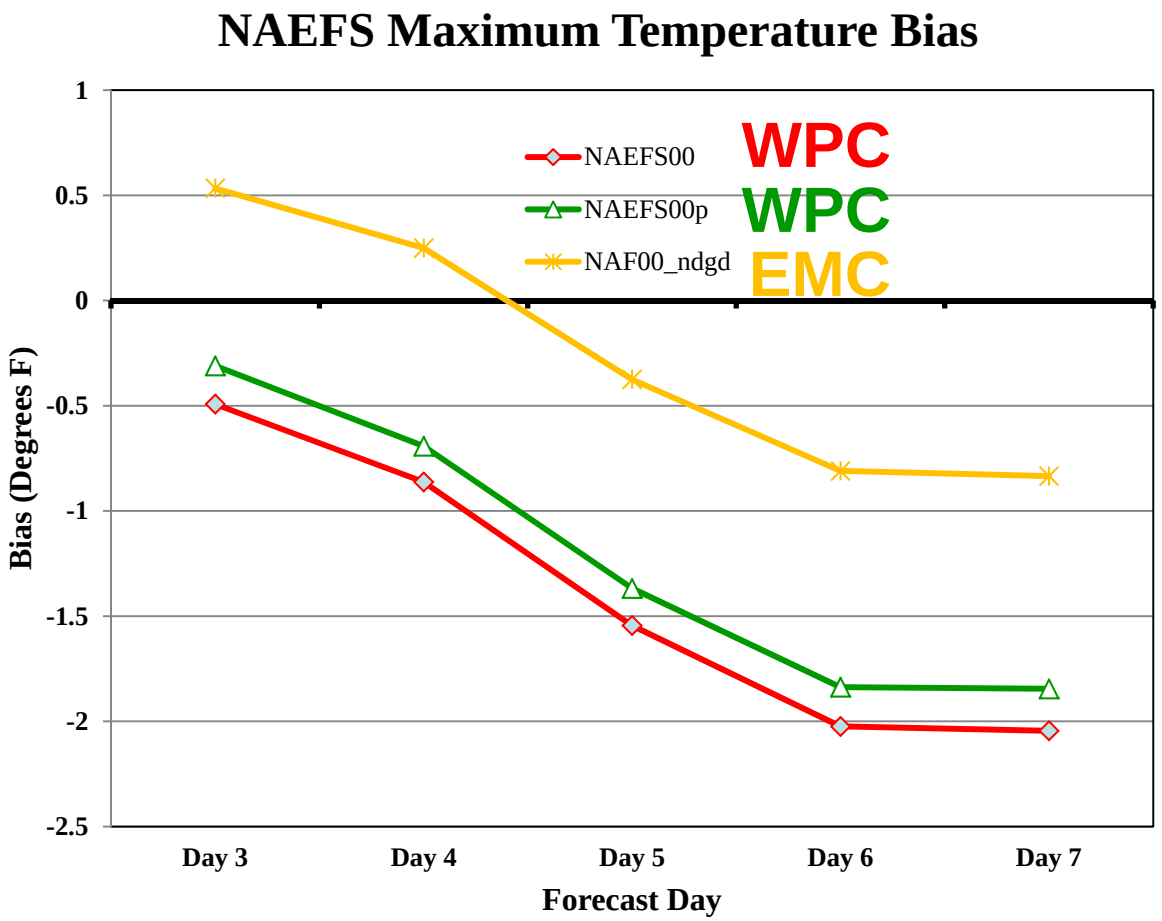
Courtesy of Mr. Richard Grumm (WFO)

WPC (HPC) real time evaluation of NAEFS implementation (Alaska)



Courtesy of Dave Novak

2014 NAEFS implementation
NAEFS Tmax Bias



WPC Evaluation

- EMC approach shows better bias characteristics than WPC approach
- Results suggest that WPC will be able to transition to EMC method when 2.5km resolution available

Courtesy of Wallace Hogsett & Chris Bailey

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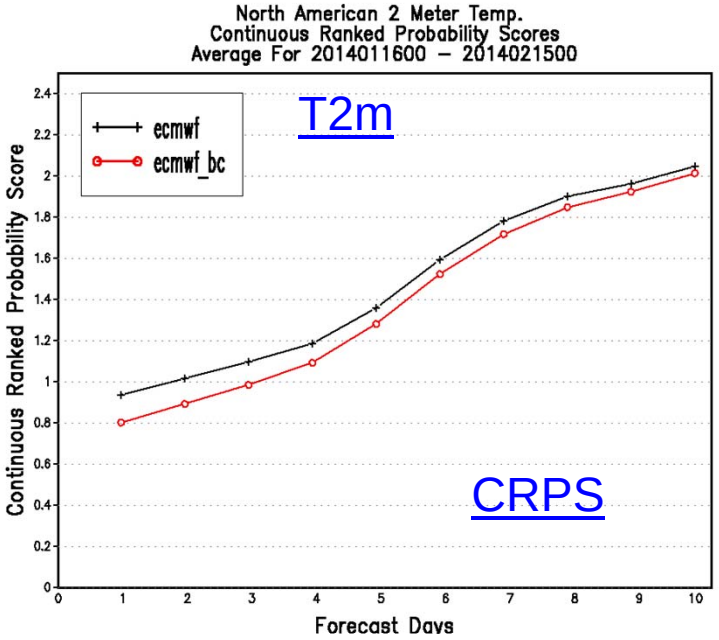
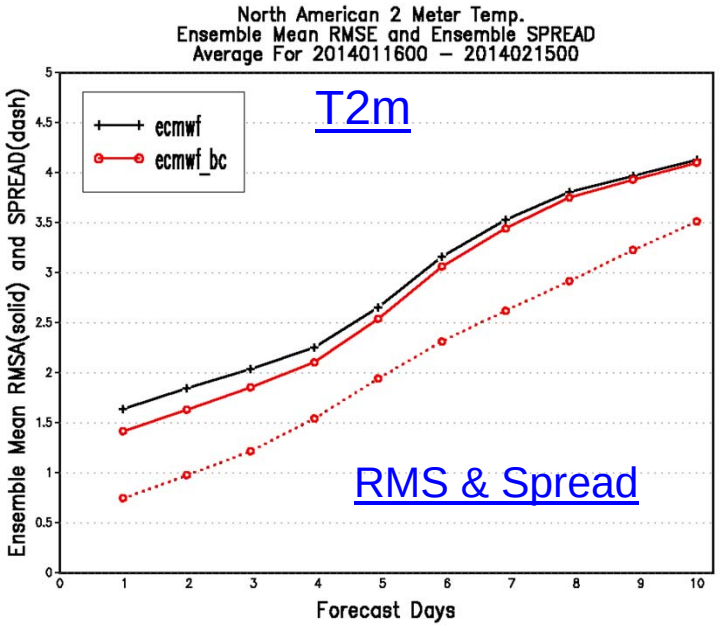
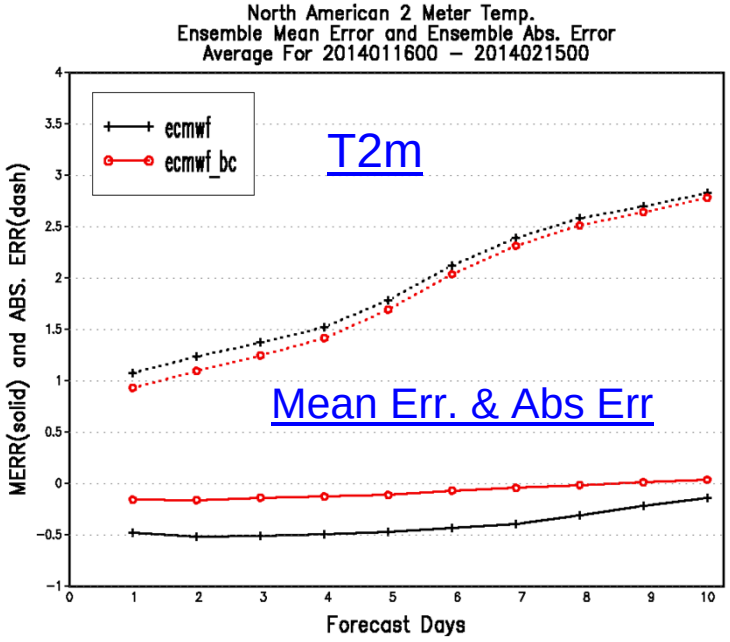
Bias Correction Application on ECMWF

- Based on ECMWF operational ensemble systems
- For raw and bias corrected ECMWF ensembles
- Bias estimation: against ECMWF analysis
- Period: Winter – Jan.16th 2014 – Feb. 15th 2014
- Variables (6): 1000hPa, 500hPa height, 850hPa, 2-meter temperature, and 10-meter U & V
- 1*1 degree resolution globally
- Verify against ECMWF analysis
- Two ensembles
  - ecmwf: ECMWF 50 raw ensemble
  - ecmwf_bc: ECMWF bias corrected ensemble
- More results:
  - http://www.emc.ncep.noaa.gov/gmb/wx20cb/ECMWF/score_crps_ecmwf_2014011600.2014021500_wrt_ecmwf_gfs/NAEFS_Win2014.html

ECMWF Forecast Comparison After Bias Correction







2 meter Temperature

- North American again ECMWF analysis
- Period: Jan.16th 2014 – Feb. 15th 2014

ecmwf: raw ensembles

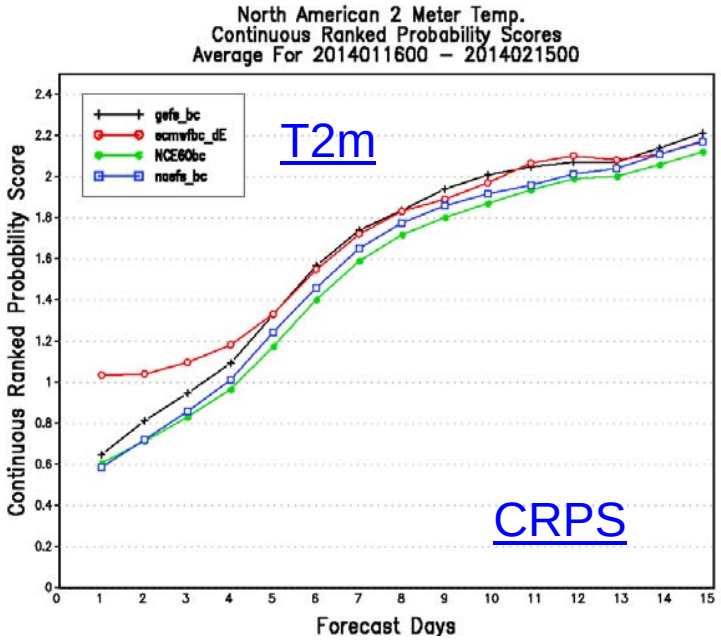
ecmwf_bc: bas corrected ensembles

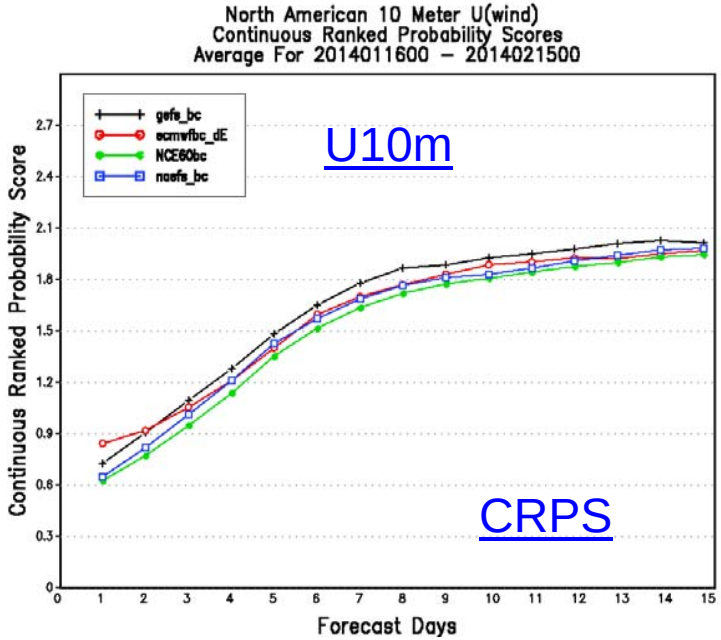
Top left – CRPS

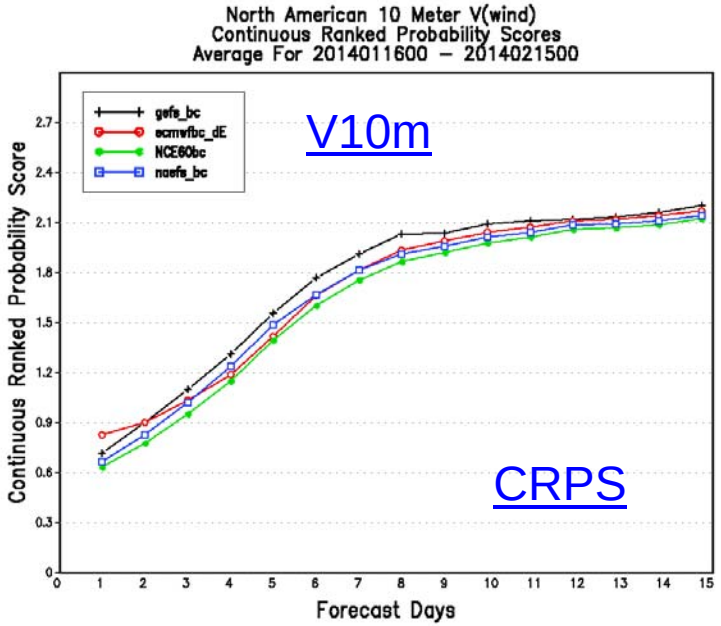
Top right – RMS & ensemble spread

Bottom left – mean error & absolute error

NCEP, CMC & ECMWF Bias Corrected Ensembles







2 meter Temperature, U10m and V10m

- North American again NCEP analysis
- Period: Jan.16th 2014 – Feb. 15th 2014

gefs_bc: NCEP bias corrected ensemble
ecmwfbc_dE: ECMWF bas corrected ensemble with anaylsys adjustment
naefs_bc: NAEFS ensemble
NCE60bc: NCEP, CMC & ECMWF bias corrected ensemble combination

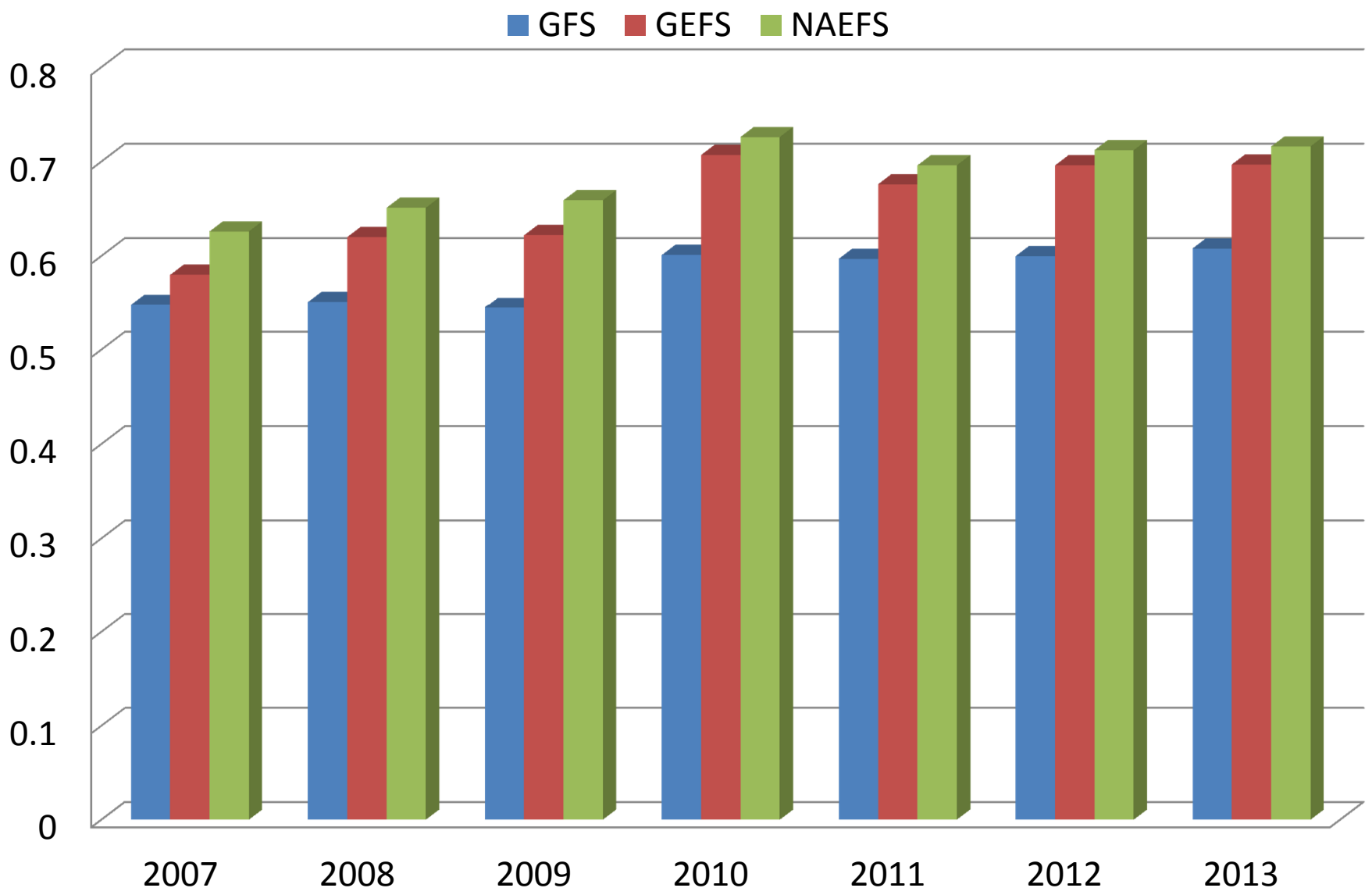
Summary

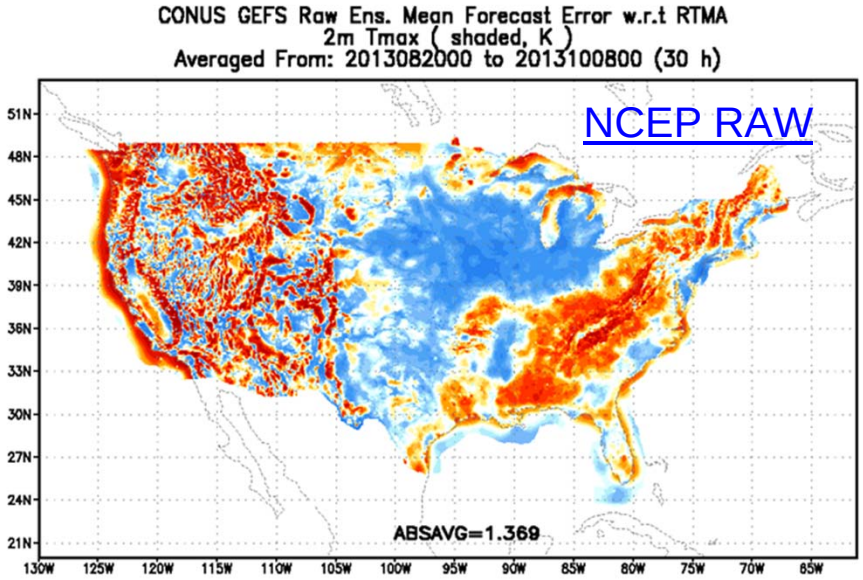
- NCEP/NAEFS bias correction method could apply to any ensemble system calibration. At least it works very well for NCEP, CMC, FNMOC and ECMWF ensemble right now.
- The improvement will depend on model systematic error level.
  - 2-meter temperature has largest improvement through bias correction
  - NCE60 (3 ensemble combination with CMC adjustment & ECMWF adjustment) has overall better skills than ECMWF single ensemble for both probabilistic and deterministic evaluations
- NCEP/NAEFS bias correction method is easiest way to carry on, and for operation application
  - It is not necessary to have training data – cold start
  - No additional disk space is needed (only one carry on bias accumulation files)
  - Less computation cost, one step for accumulation, one step for de-bias
  - Easy for forecast model upgrade – copy over one bias accumulation file or cold start.
- Suggestion: any new calibration method for future operational application needs to be compare to the results from NCEP/NAEFS bias correction method.

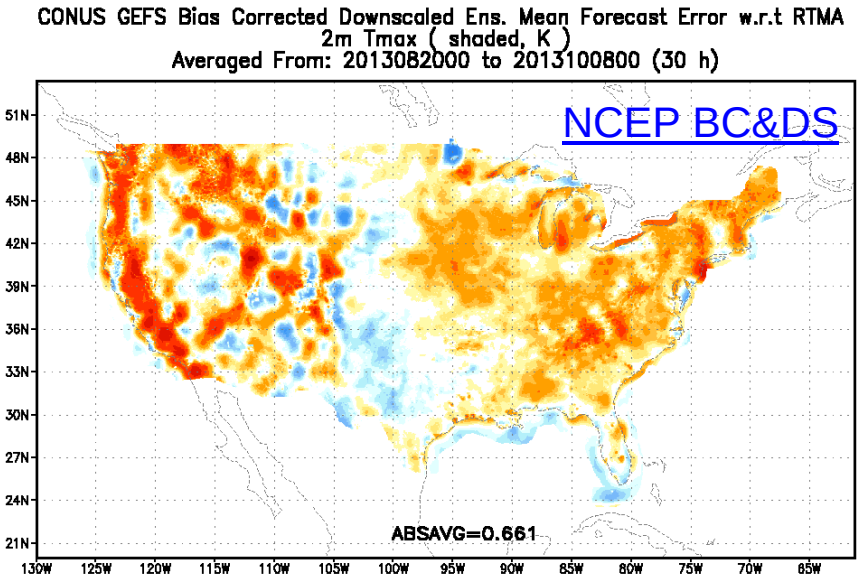
Blender project

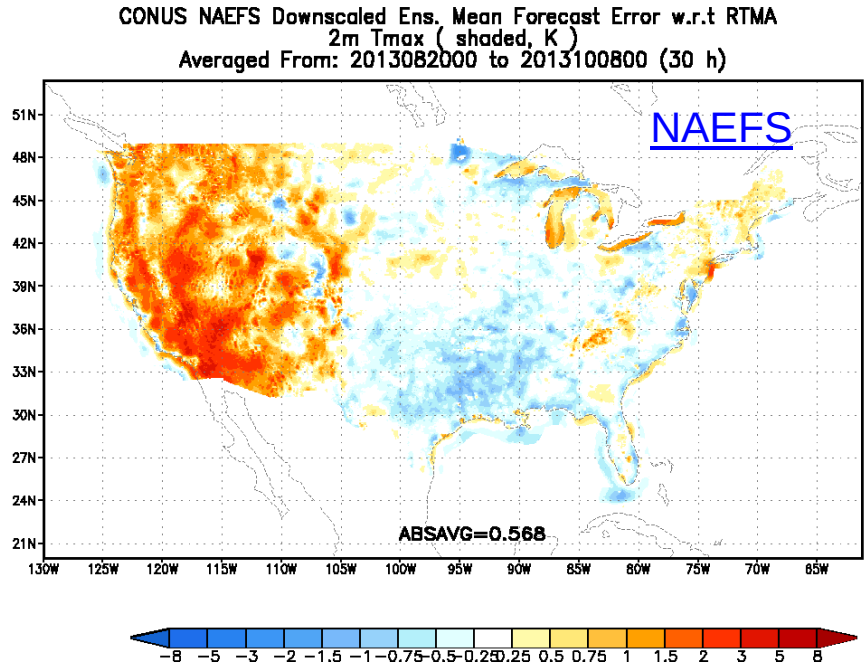
- Bring in all possible model forecasts:
  - NCEP deterministic forecast
  - NCEP ensemble forecast
  - CMC deterministic forecast
  - CMC ensemble forecast
  - ECMWF deterministic forecast
  - ECMWF ensemble forecast
- Bias correction and downscaling
- Blender techniques (different weights)
- Reforecast data???

Background !!!


NH 500hPa height AC for day-8 of calendar year mean
GFS
GEFS
NAEFS
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2007
2008
2009
2010
2011
2012
2013







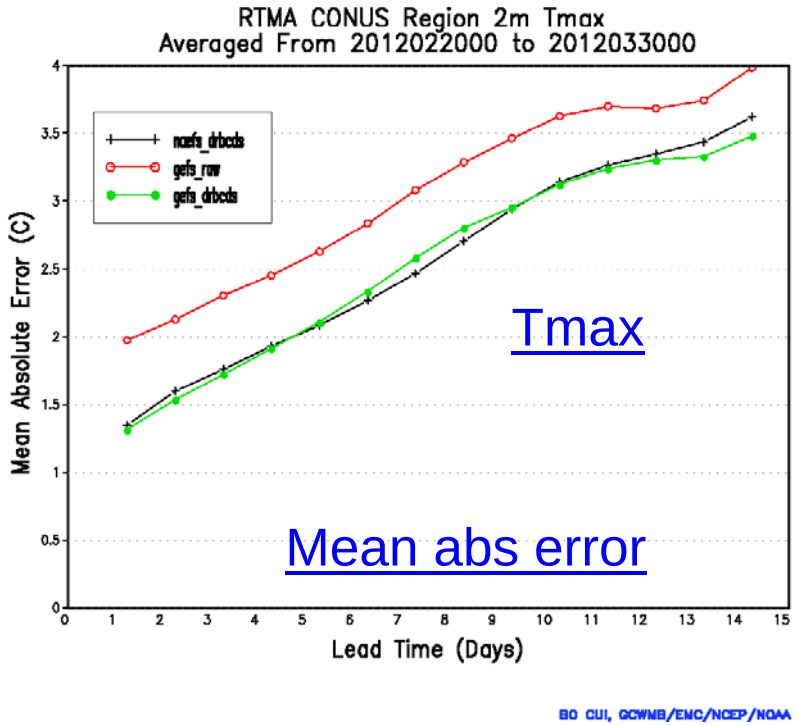
T2m (Maximum)

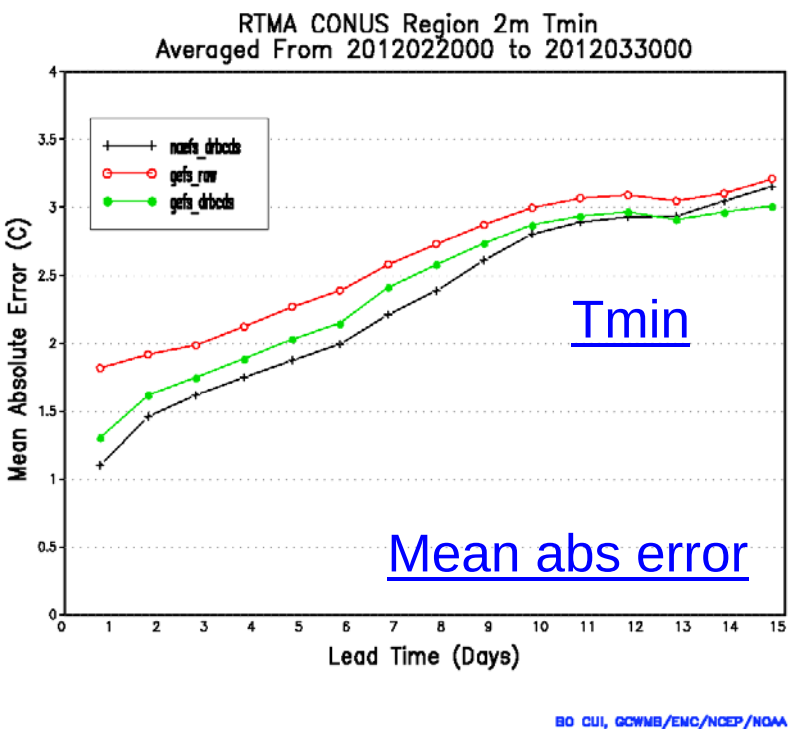
Period: 02/20-03/30/2012

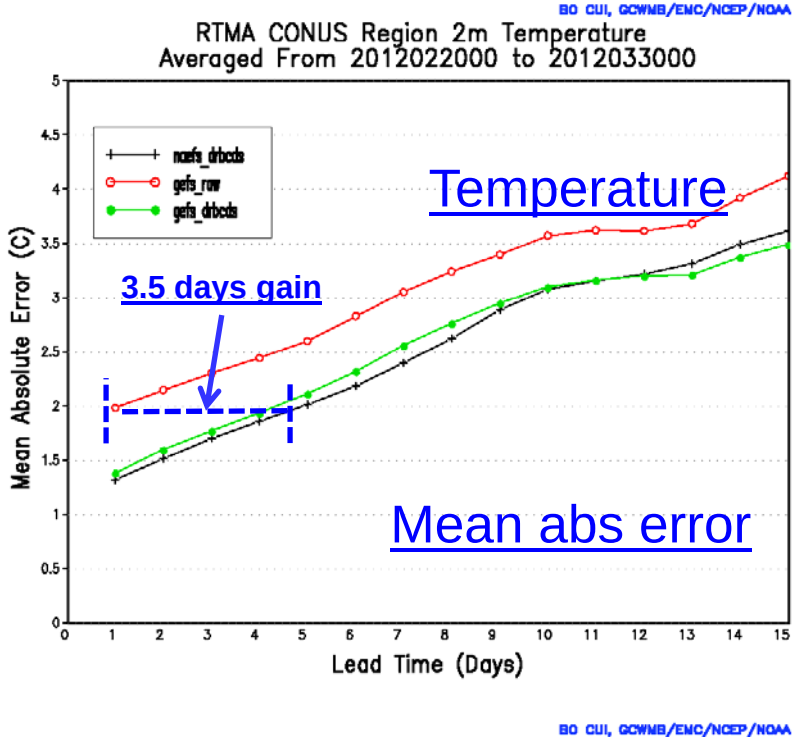
Lead time: 30hr

Mean Forecast Error (against RTMA)

More than 50% error reduction





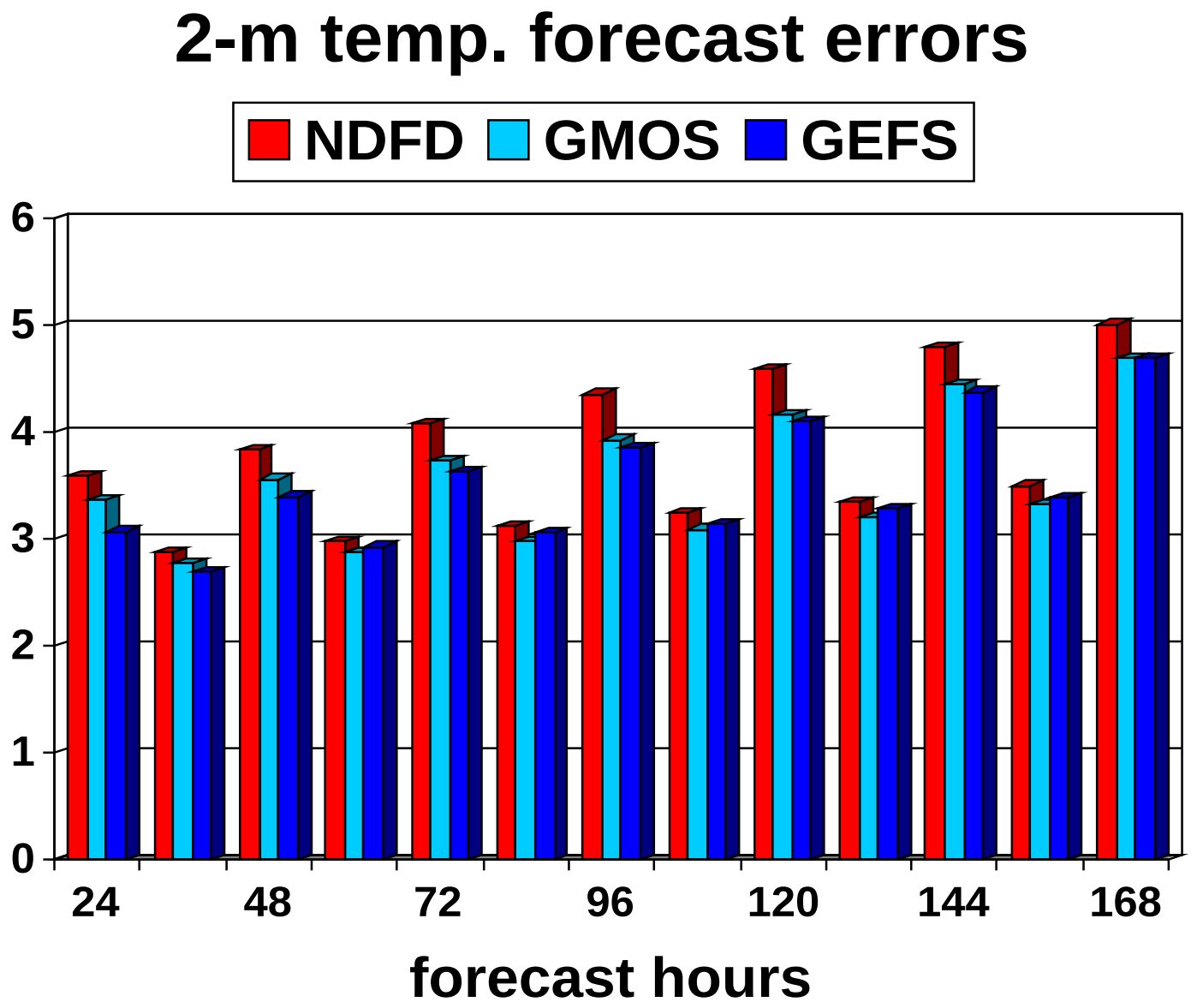


2012 Spring evaluation for CONUS temperature forecast by apply :

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

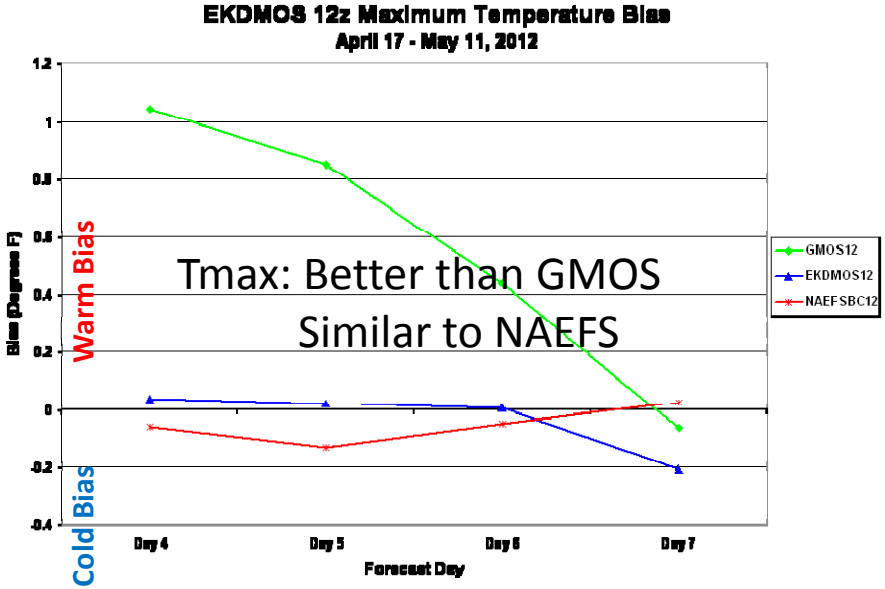
40 day average absolute errors of 2-meter temperature (NDFD has 12hr advantage)

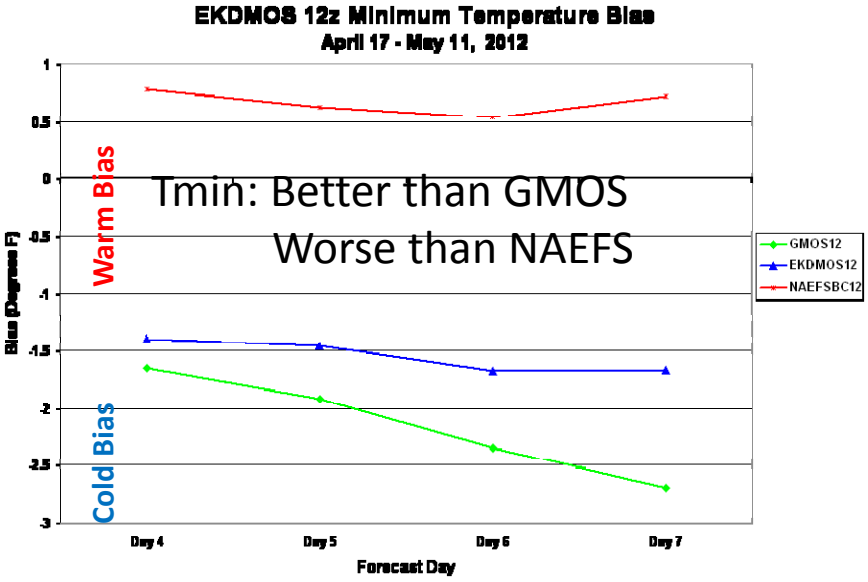
COUNS only – verified against RTMA

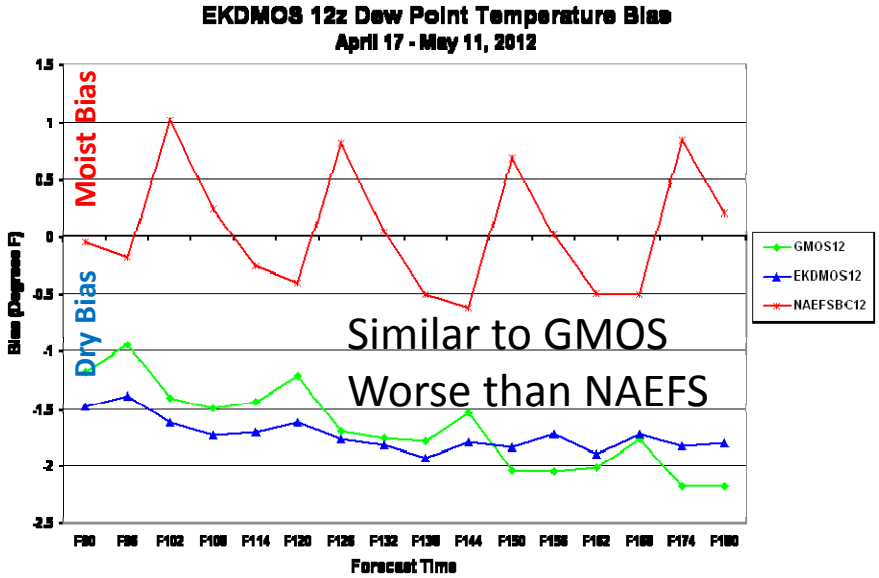


2012 EKDMOS Implementation – HPC's real time evaluation

Objective Verification (Bias)







Results sensitive to choice of analysis used in verification

(RTMA used in this verification)

Courtesy of Dr. Novak

Blender project

Assume: we don't have ECMWF forecasts

- Bring in all possible model forecasts:
  - NCEP deterministic forecast
  - NCEP ensemble forecast
  - CMC deterministic forecast
  - CMC ensemble forecast
  - ECMWF deterministic forecast
  - ECMWF ensemble forecast

This is NAEFS

- Bias correction and downscaling
- Blender techniques (different weights)
- Reforecast data???

Weather elements

Initial elements:

- Temperature (instantaneous, daytime max, nighttime min)
- Dewpoint temperature
- Sky Cover
- Wind Speed
- Wind Direction
- Precipitation Type (needed for Predominant Weather):
- Quantitative precipitation amount
  - deterministic amount
  - Probabilistic QPF, including probability of precipitation (PoP)
- Blending algorithms

MDL's to lead

ESRL's to lead

Second Phase of Development:

- Snowfall Amount (not required at this time for the medium-range, needed through 72 hours for WPC, 48 or 72 hours for WFOs)
- Wind Gusts (not required at this time for the medium-range, needed through 72 hours)

Question: what is NCEP/EMC's contribution? Can you help with data set preparation?

Weather elements (EMC's contributions)

Initial elements:

- Temperature (instantaneous, daytime max, nighttime min)
- Dewpoint temperature
- Sky Cover
- Wind Speed
- Wind Direction
- Precipitation Type (needed for Predominant Weather):
- Quantitative precipitation amount
  - deterministic amount
  - Probabilistic QPF, including probability of precipitation (PoP)
- Blending algorithms

NAEFS has produced daily

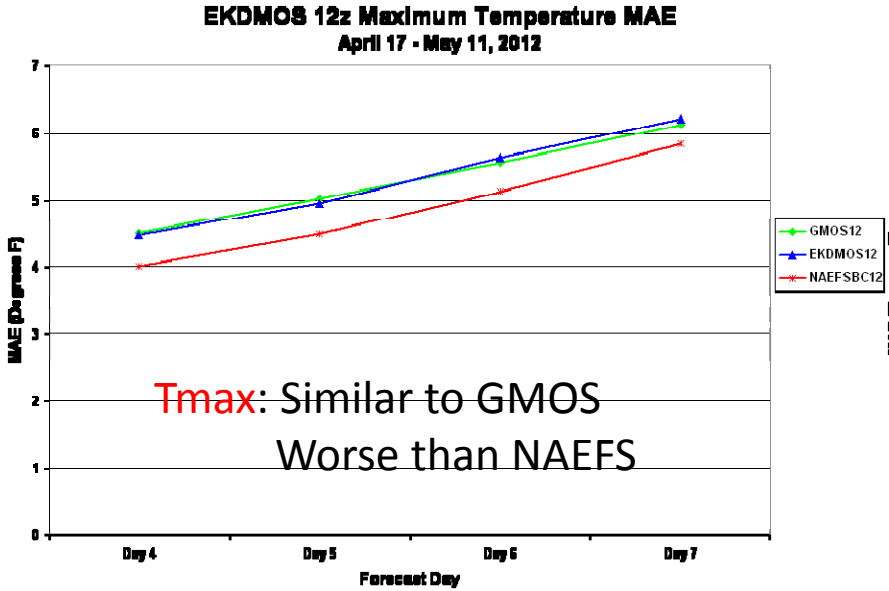
Second Phase of Development:

- Snowfall Amount (not required at this time for the medium-range, needed through 72 hours for WPC, 48 or 72 hours for WFOs)
- Wind Gusts (not required at this time for the medium-range, needed through 72 hours)

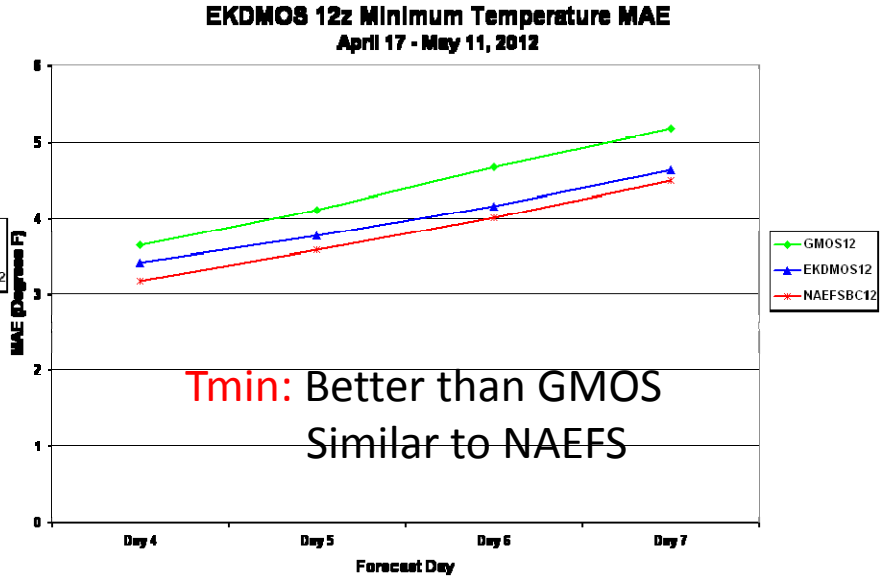
Question: what is NCEP/EMC's contribution? Can you help with data set preparation?

2012 EKDMOS Implementation – HPC's real time evaluation

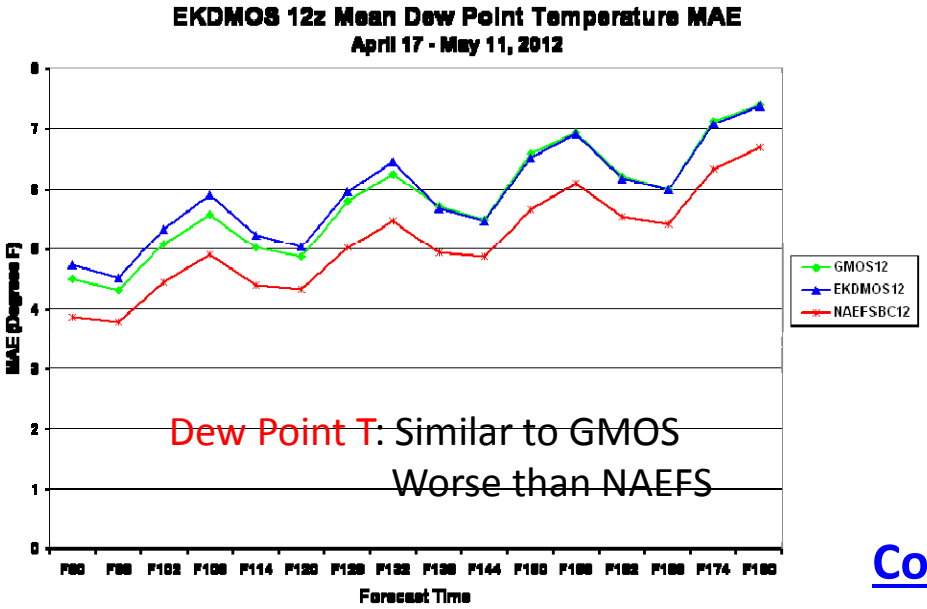
Objective Verification (MAE)



Tmax: Similar to GMOS
Worse than NAEFS



Tmin: Better than GMOS
Similar to NAEFS



Dew Point T: Similar to GMOS
Worse than NAEFS

Results sensitive to choice of analysis used in verification

(RTMA used in this verification)

Courtesy of Dr. Novak