THORPEX program report

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Presentation for THORPEX program review
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Statistical Post-Processing of Ensembles

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Statistical Post-Processing Issues

- **GOAL**
  - 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

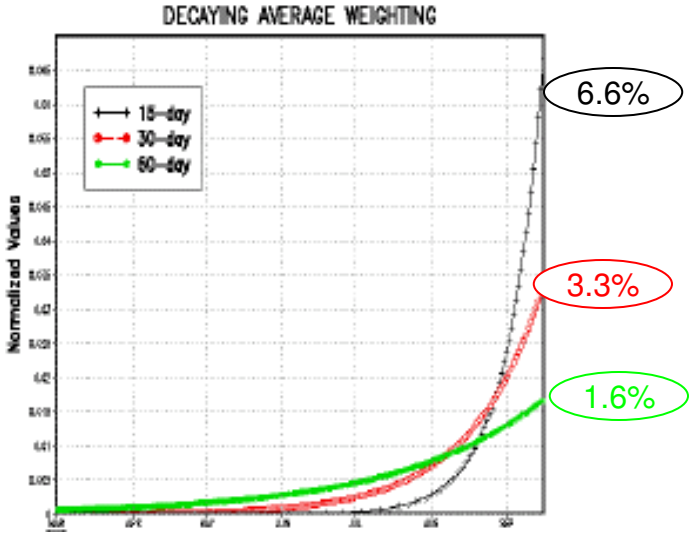
- **APPROACH** – Computational efficiency
  - Bias Correction : remove lead-time dependent bias on model grid
    - Working on coarser model grid allows use of more complex methods
    - Feedback on systematic errors to model development
  - Downscaling: downscale bias-corrected forecast to finer grid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

Bias Correction Method & Application

- **Bias Correction Techniques** – array of methods
  - Estimate/correct bias moment by moment (e.g., D. Unger et al.).
    - Simple approach, implemented partially
    - May be less applicable for extreme cases
  - Bayesian approach (e.g., Roman Krzysztofovicz)
    - Allows simultaneous adjustment of all modes considered, under development
- **Moment-based method at NCEP**: apply adaptive (Kalman Filter type) algorithm

decaying averaging mean error = (1-*w*) * prior t.m.e + *w* * (f – a)

For separated cycles, each lead time and individual grid point, t.m.e = time mean error



Toth, Z., and Y. Zhu, 2001

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

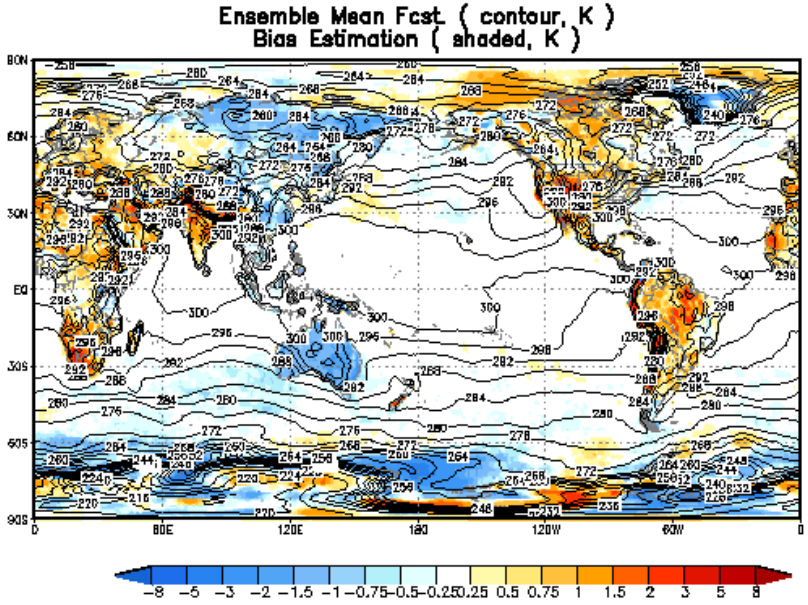
List of Variables for Bias Correction, Weights and Forecast Anomalies for CMC & NCEP Ensemble

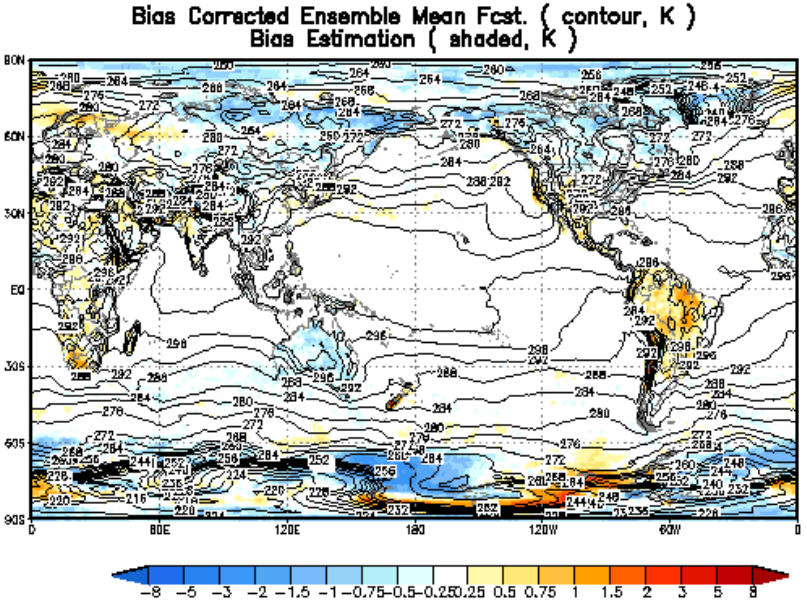
	CMC & NCEP
Ensemble	CMC (8 SEF, 8 GEM), NCEP (14 GFS)
GRID	1x1 deg (360x180 lat-lon)
DOMAIN	Global
FORMAT	WMO Grib Format
HOURS	6 hourly out of 384 hours (current 240 hours for CMC Ensemble)
GZ	200, 250, 500,700, 850 ,925,1000
TT	200, 250, 500,700, 850 ,925,1000
U,V	200, 250, 500,700, 850 ,925,1000
TT	2m
U, V	10m
MSLP	Sea Level Pressure
Sfc Pres	Surface Pressure
Tmax	2m
Tmin	2m

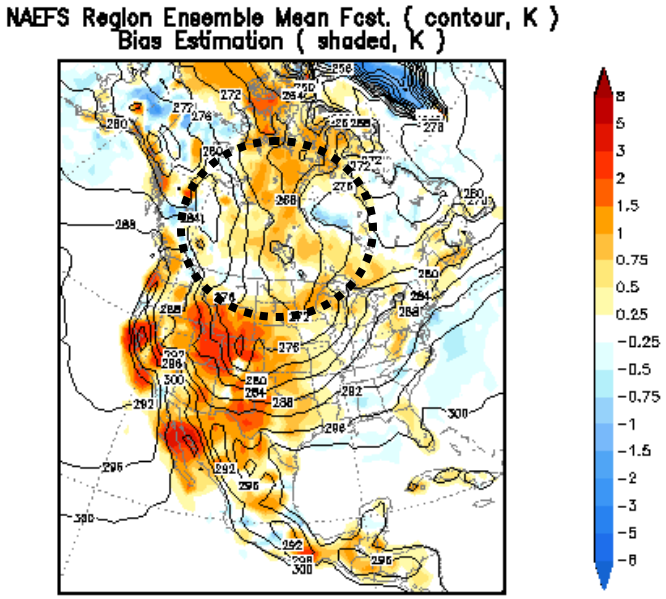
Note: 35 Variables in total, red variables are for climate anomalies only

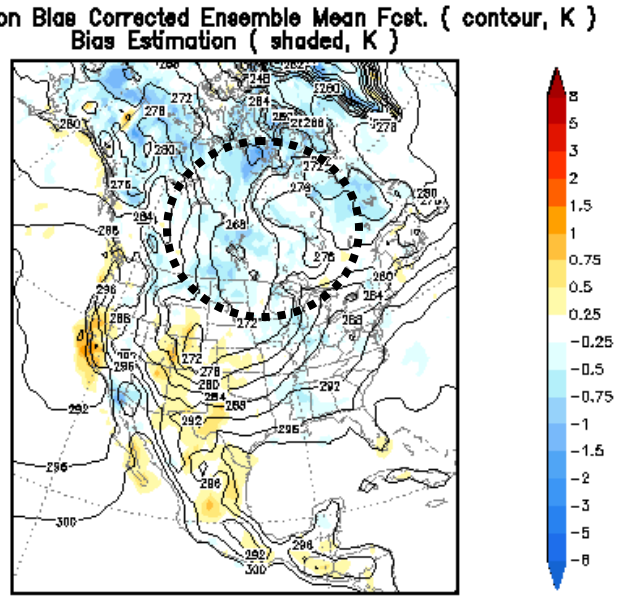
2 meter temperature: 120 hours forecast (ini: 2006100700)

Shaded: left – raw bias right – bias after correction

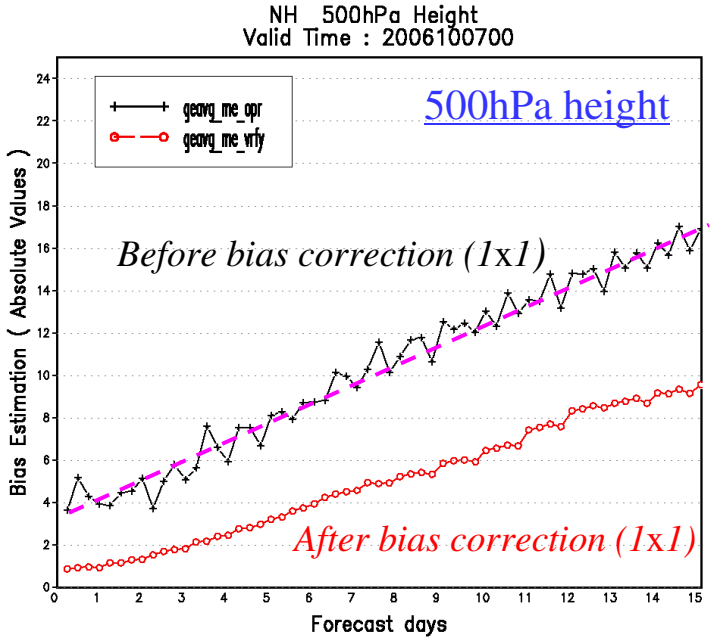


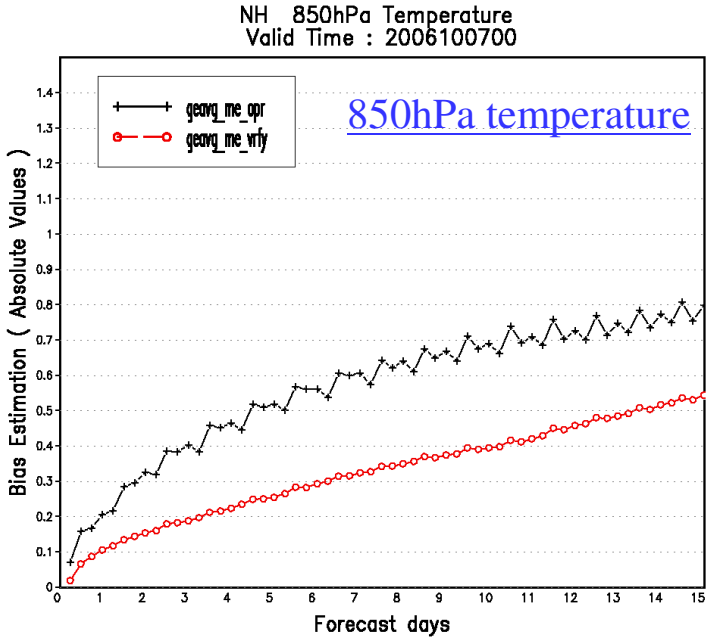


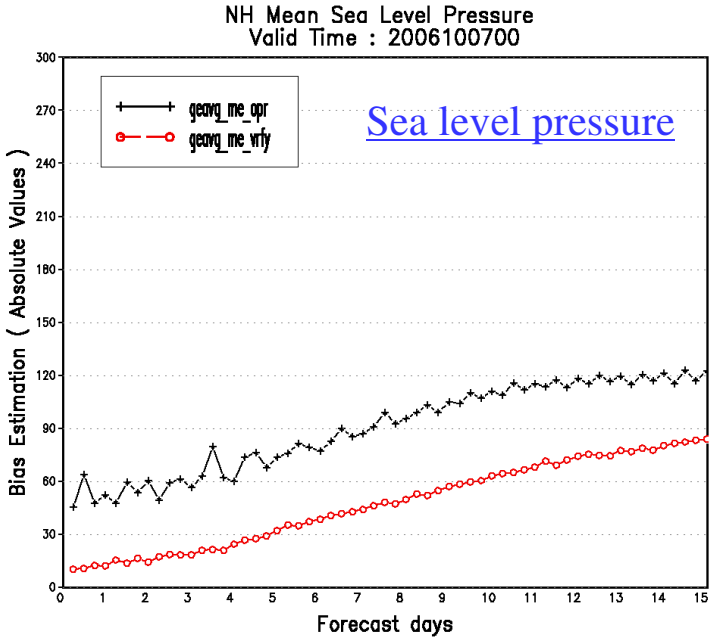


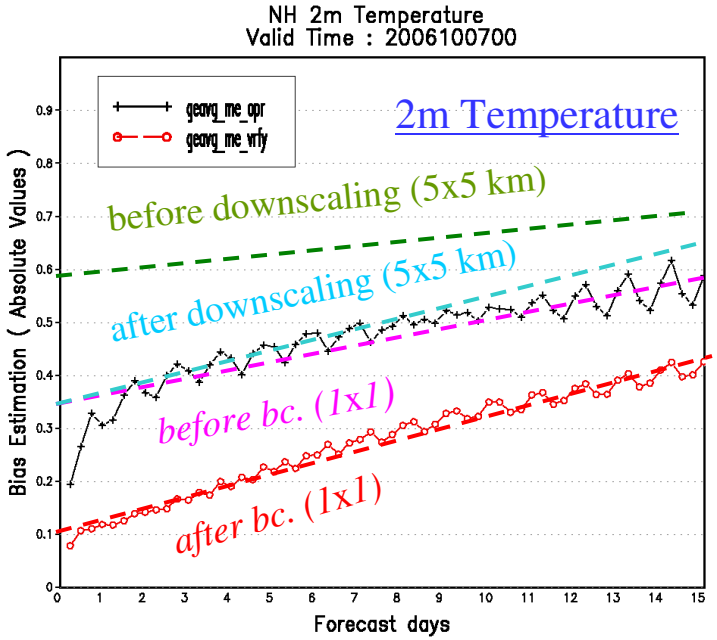


Bias Before/After Bias Correction (NCEP NH)

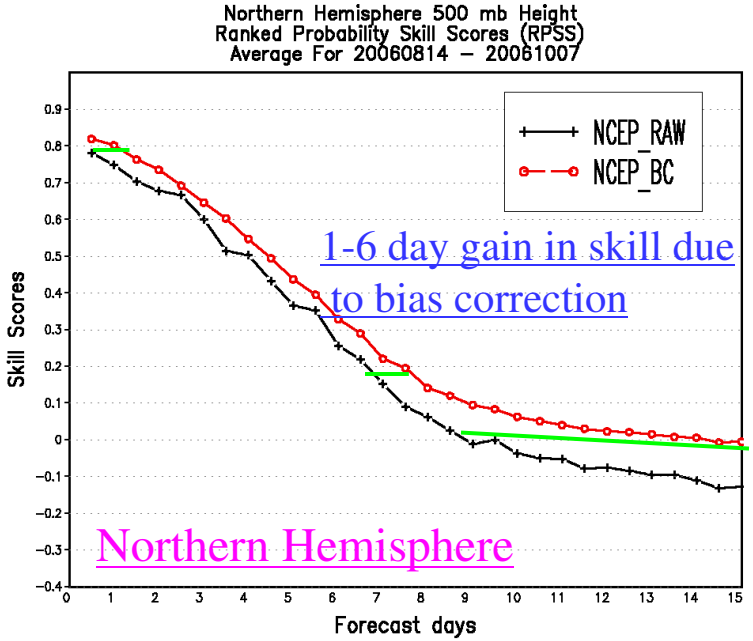


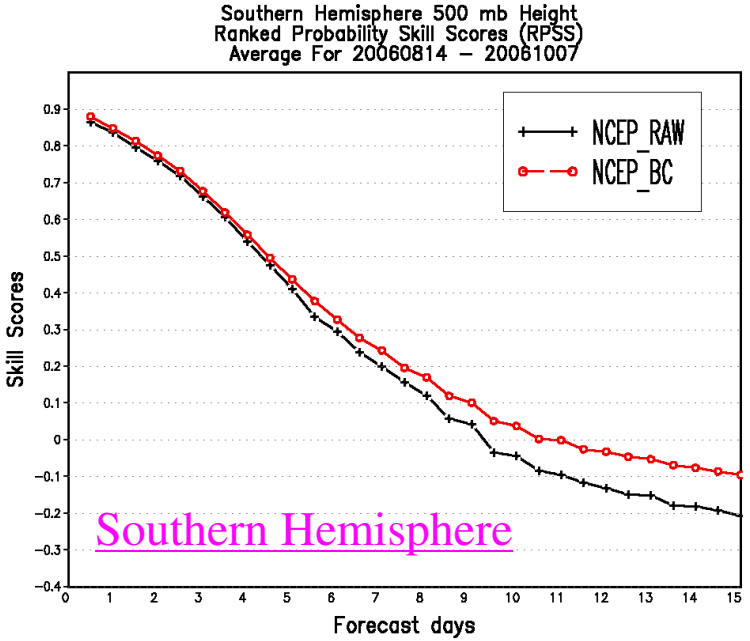


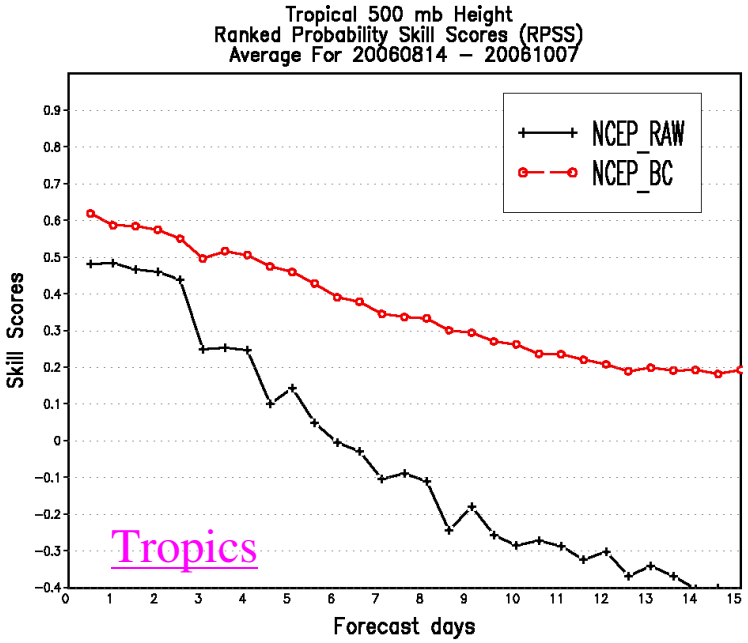


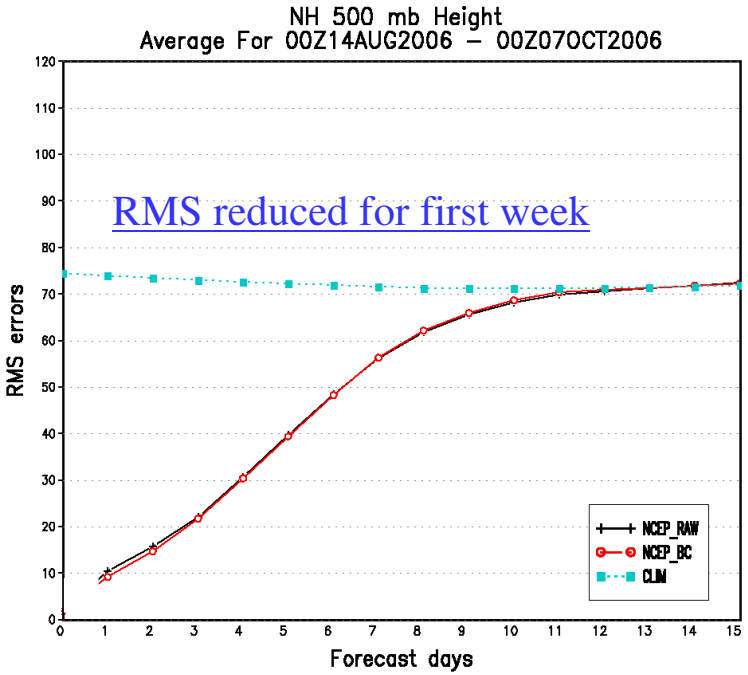


RPSS Before/After Bias Correction (NCEP 500 mb Height)

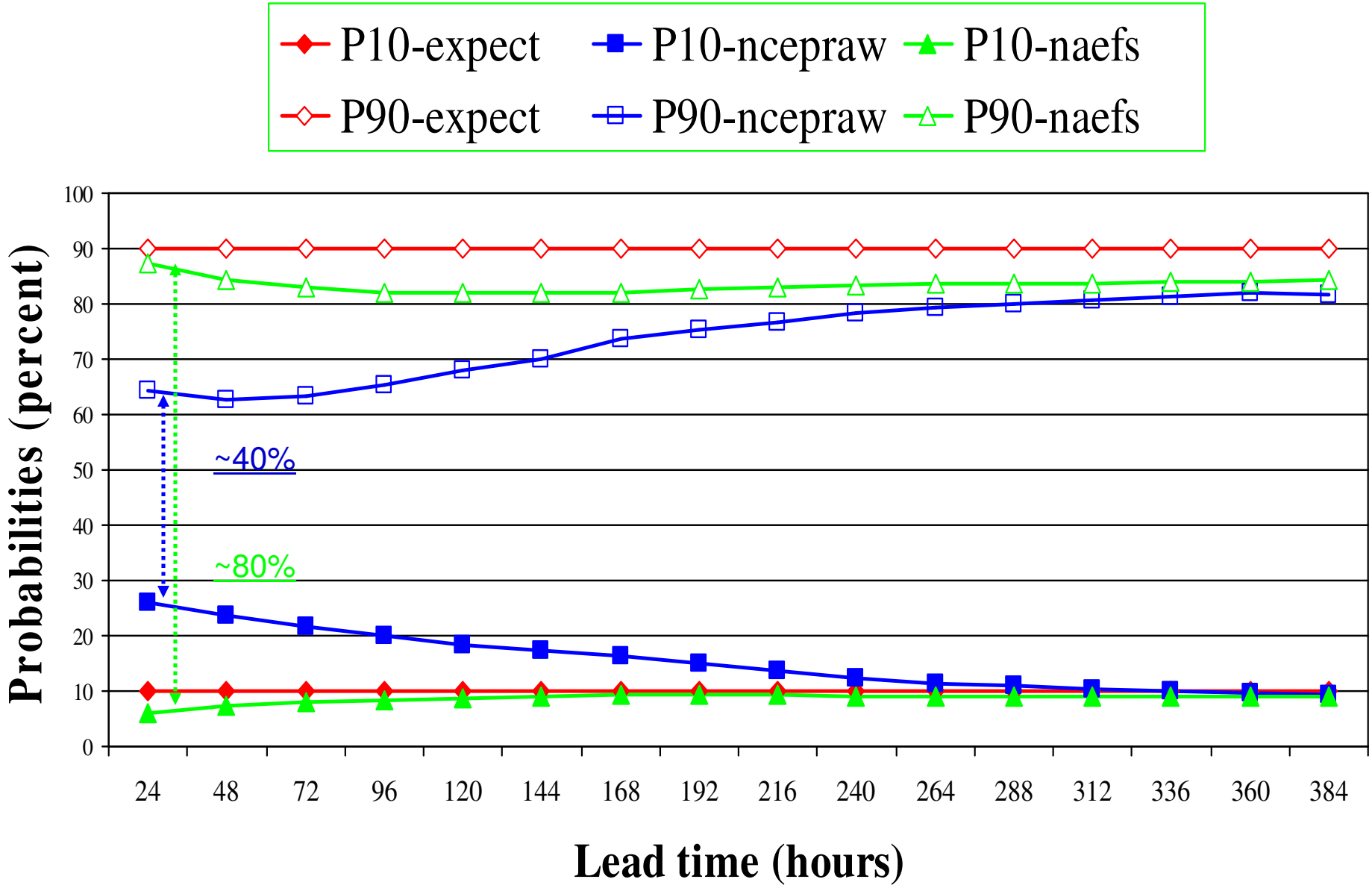




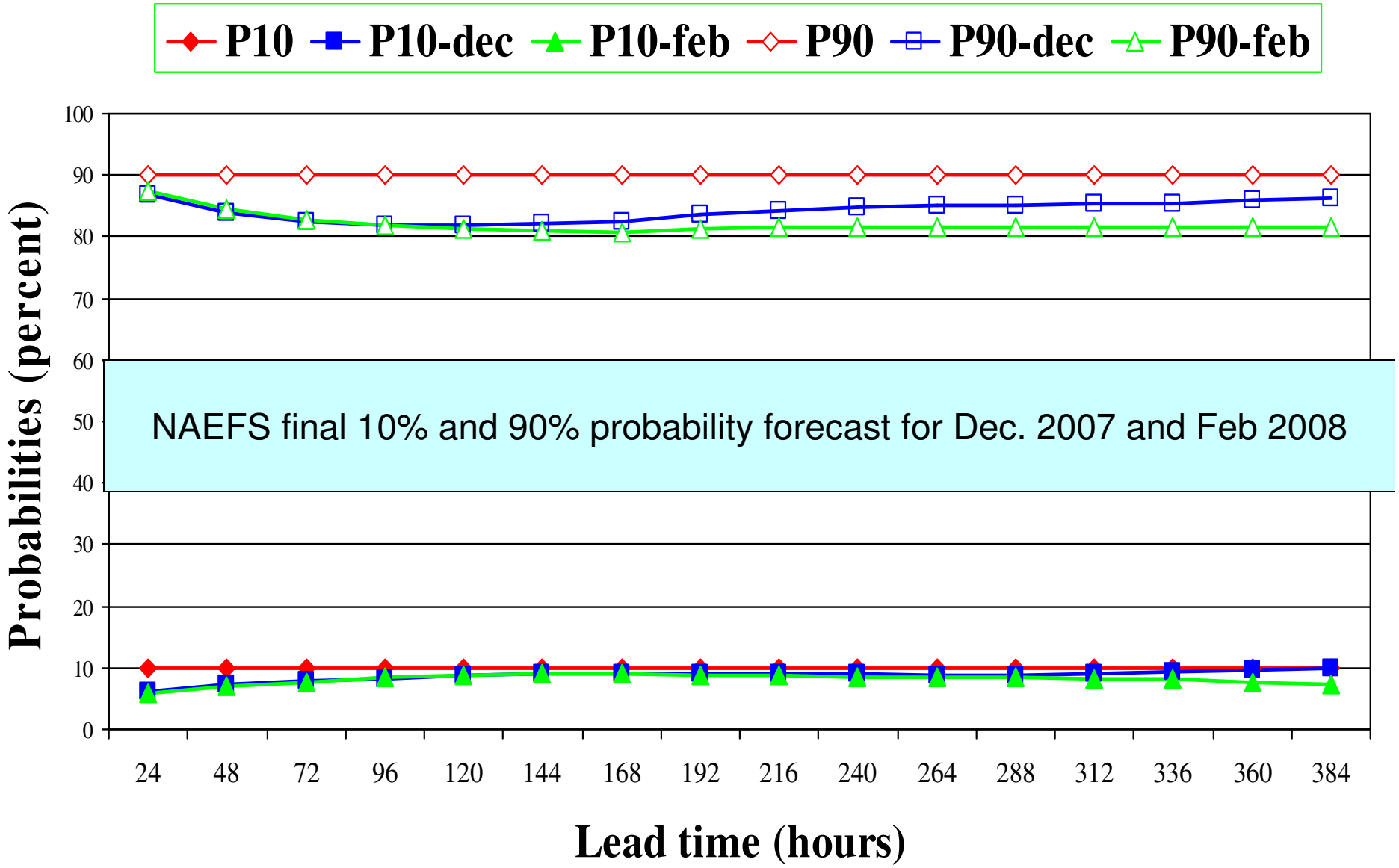




2-meter temperature 10/90 probability forecast verification
Northern Hemisphere, period of Dec. 2007 – Feb. 2008



2-meter temperature 10/90 probability forecast verification
Northern Hemisphere, seasonal variation for NAEFS



Downscaling Implementation

- Bias corrected GFS forecast
  - Use the same algorithm as ensemble bias correction
  - Up to 180 hours
- Combine bias corrected GFS and ensemble forecast
  - Dual resolution ensemble approach for short lead time
  - GFS has higher weights at short lead time
- NAEFS new products
  - 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 also generated for ens. mean
- Statistical downscaling
  - Use RTMA as reference - NDGD resolution (5km), CONUS only
  - Generate mean, mode, 10%, 50%(median) and 90% probability forecasts

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

Downscaling Method with Decaying Averaging Algorithm

- True = high resolution analysis
  - Operational North American Real-Time Mesoscale Analysis (RTMA)
    - 5x5 km National Digital Forecast Database (NDFD) grid (e.g. G. DiMego et al.)
    - 4 variables available: surface pressure, T2m, 10m U and V
  - Other data can also be used

- Downscaling method: apply decaying averaging algorithm

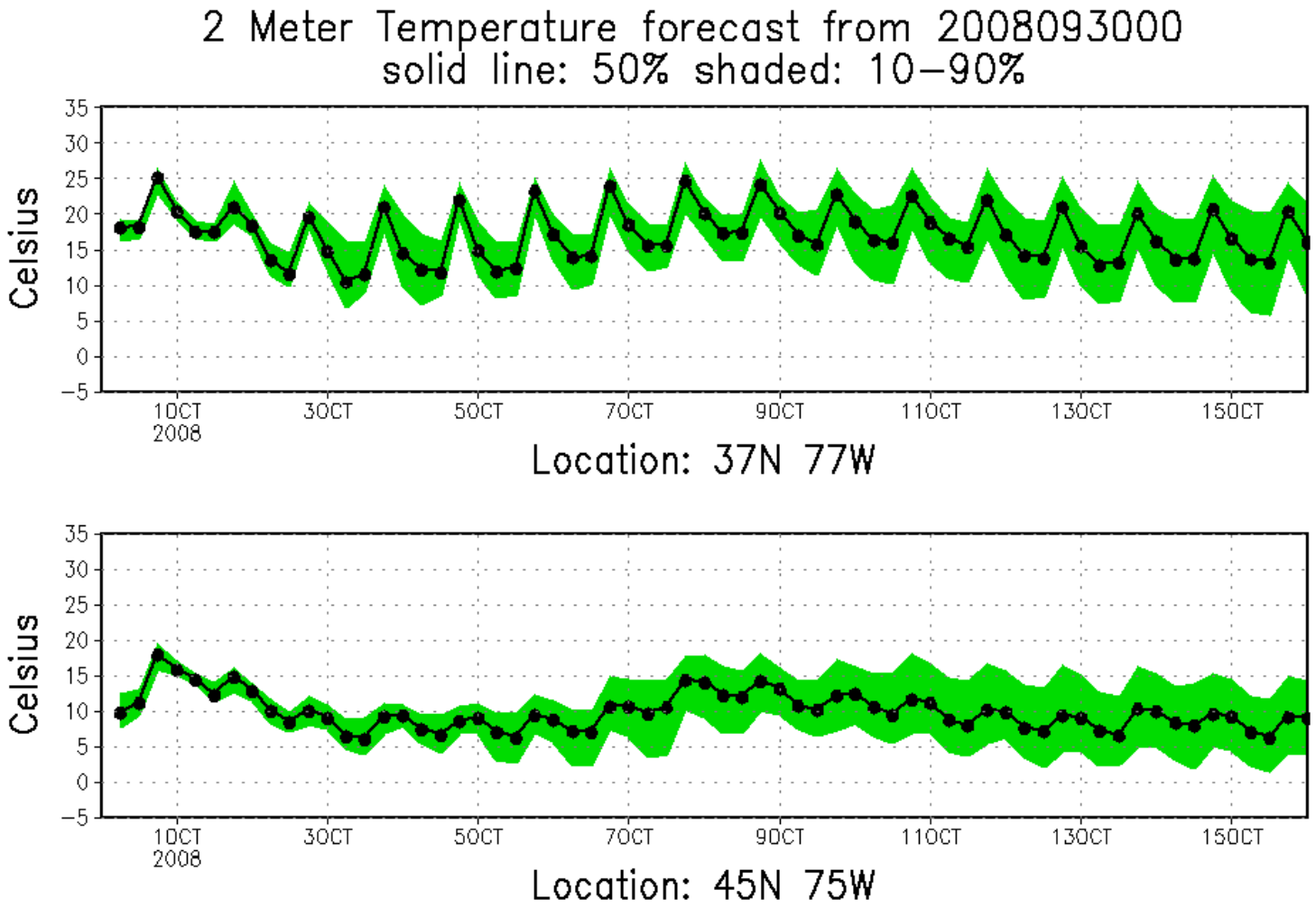
$$\text{Downscaling Vector}^{5km}(t_0) = (1-w) * \text{prior DV}^{5km}(t_{-1}) + w * (\text{GDAS}^{5km}(t_0) - \text{RTMA}^{5km}(t_0))$$

  - *GDAS^{5km}: GDAS 1x1 analysis interpolated to RTMA^{5km} grids by bilinear interpolation*
  - *4 cycles, individual grid point, DV^{5km} = Downscaling Vector on 5km grids*
  - *choose different weight: 0.5%, 1%, 2%, 5%, 10%*

- Downscaling Process

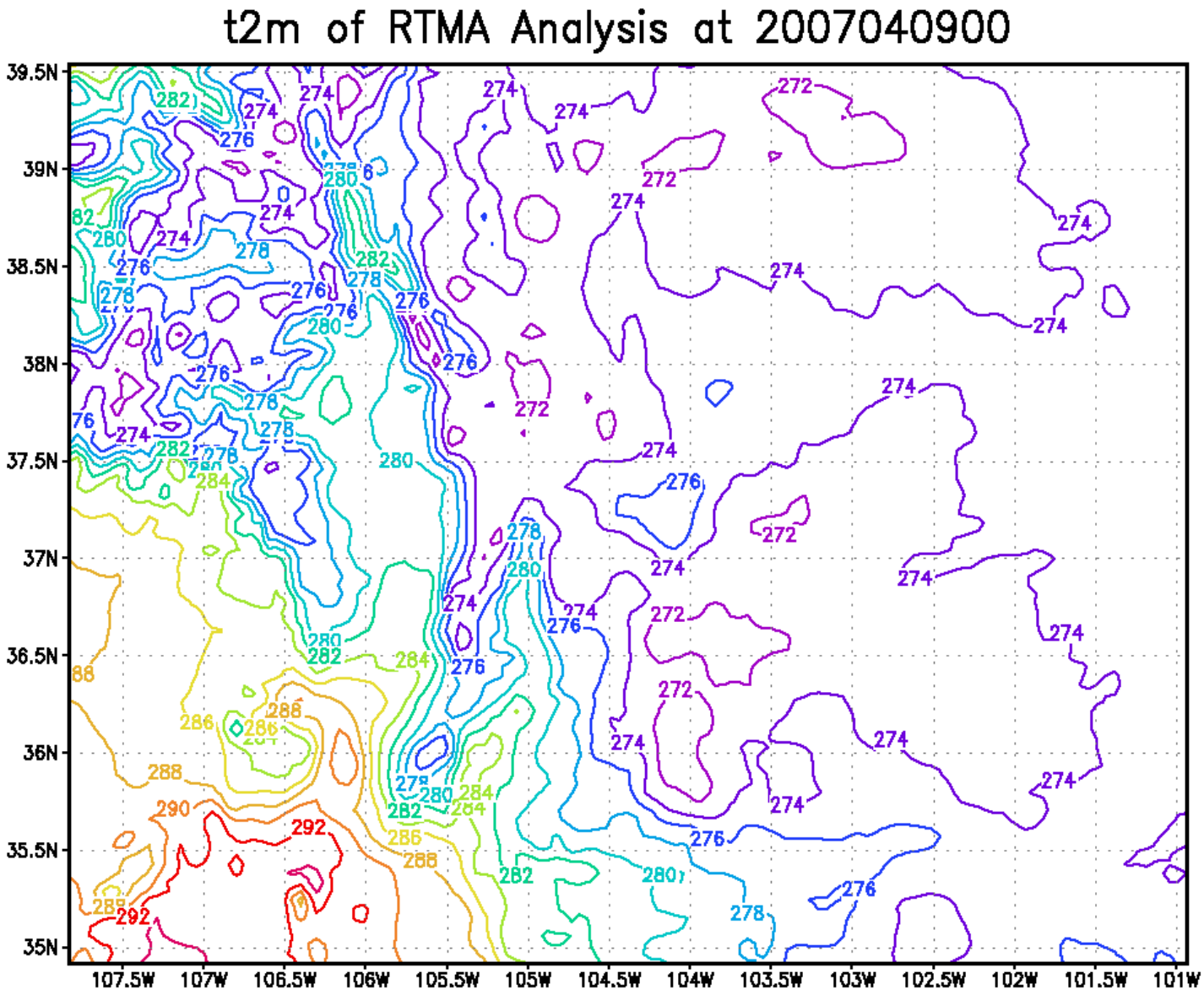
$$\text{Downscaled Forecast}^{5km}(t) = \text{Bias-corrected Forecast}^{5km}(t) - \text{DV}^{5km}(t_0)$$

  - *Bias-corrected Forecast$^{5km:}$ interpolated to RTMA^{5km} grids by bilinear interpolation*
  - *subtract DV^{5km} from bias-corrected forecast^{5km} valid at analysis time*



NAEFS Downscaled Probability Forecast (6 hour interval)
Washington DC (37N 77W) & Montreal (45N 75W)

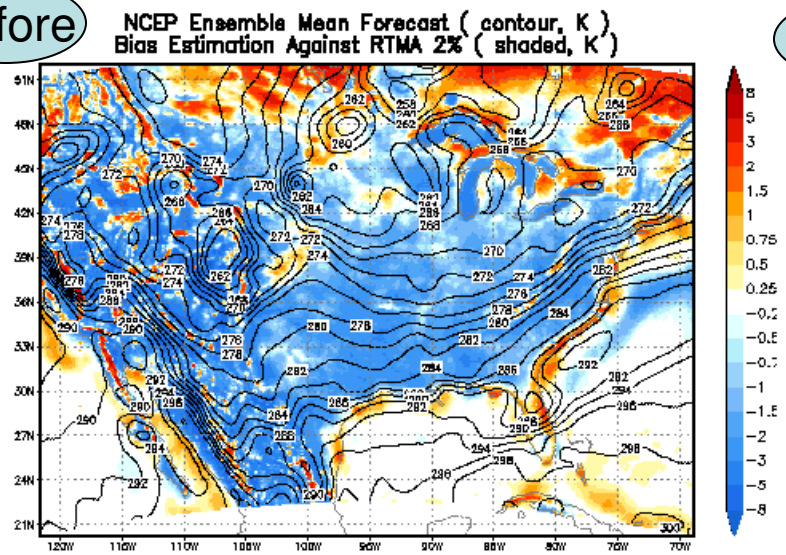
2m Temperature: RTMA Analysis



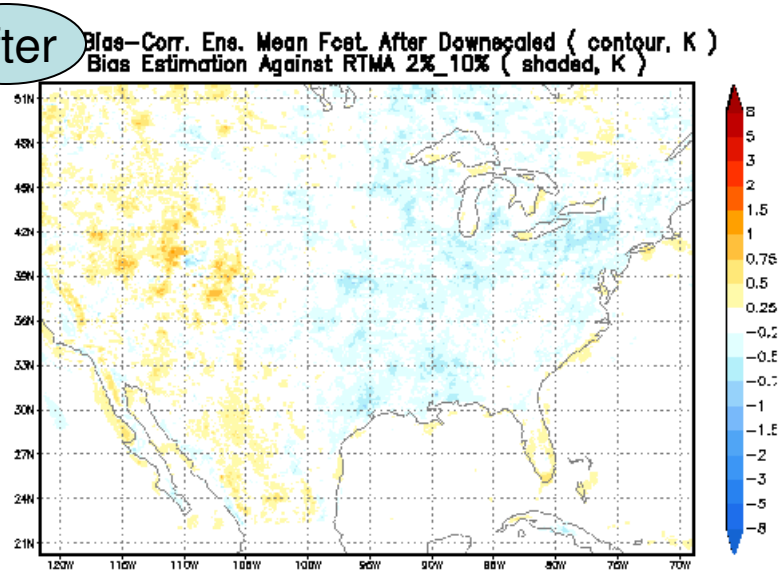
00hr GEFS Ensemble Mean & Bias Before/After Downscaling 10%

2m Temperature

Before

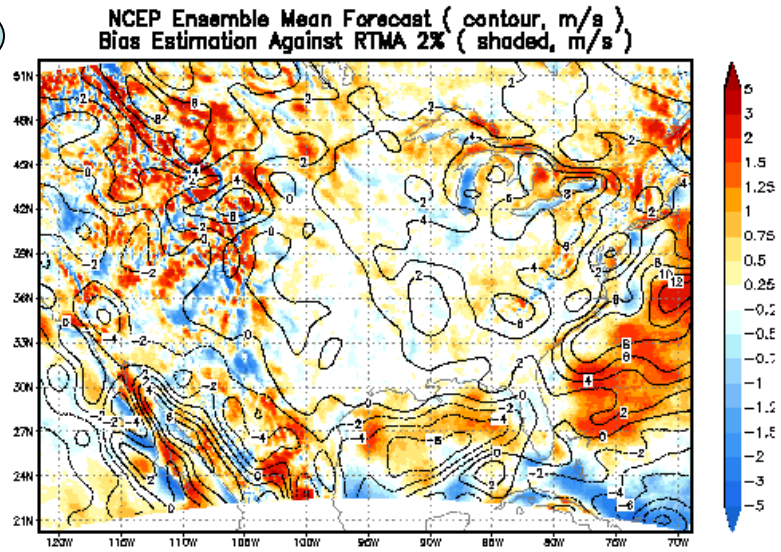


After

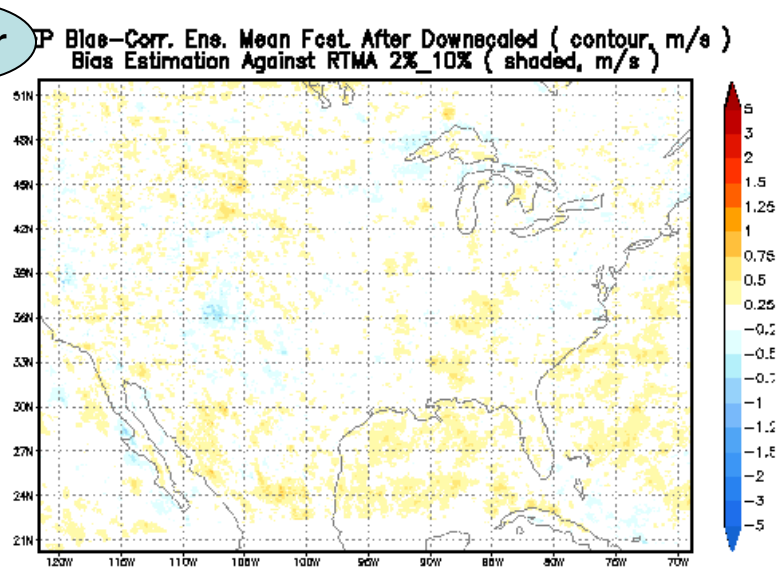


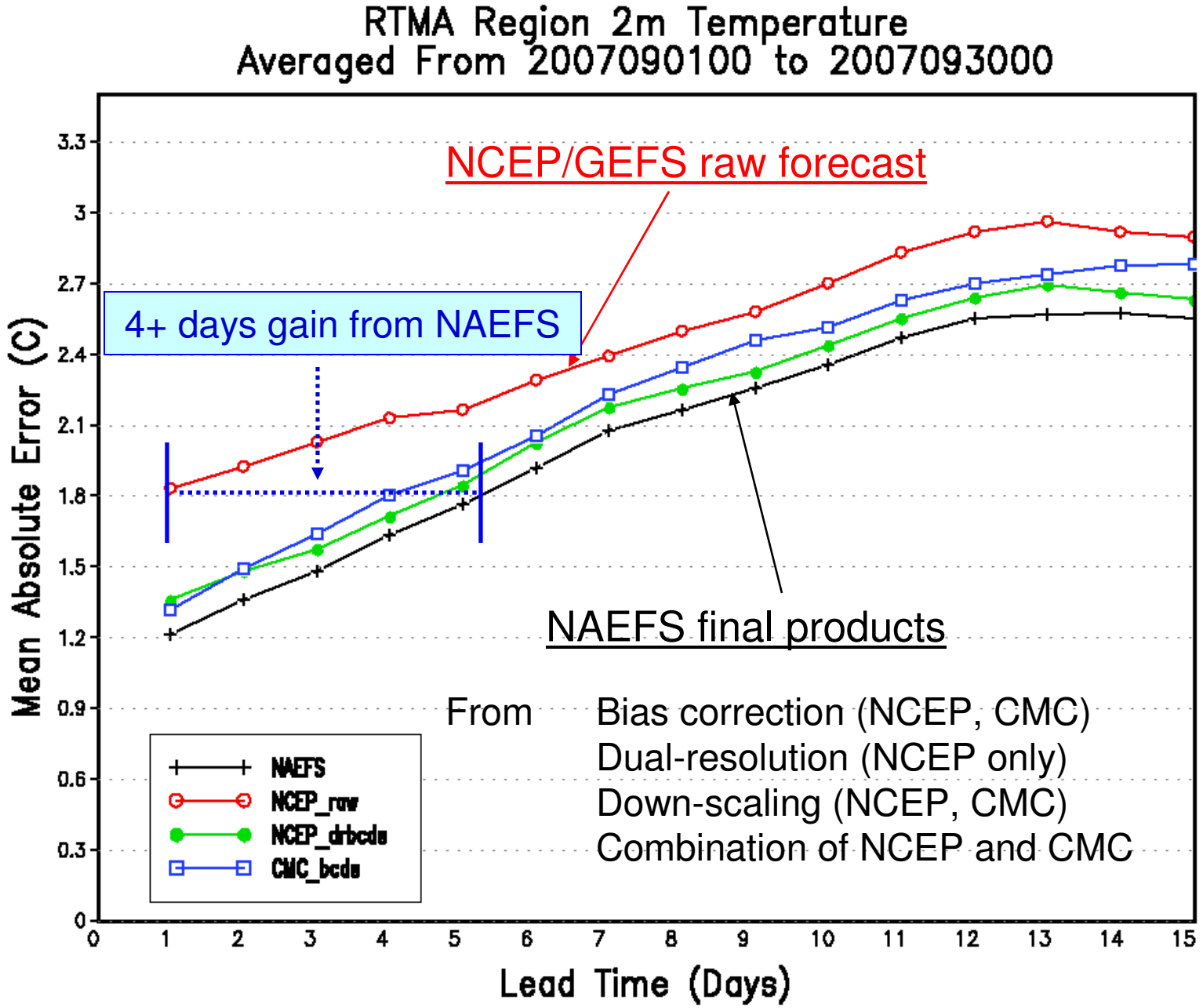
10m U Wind

Before



After





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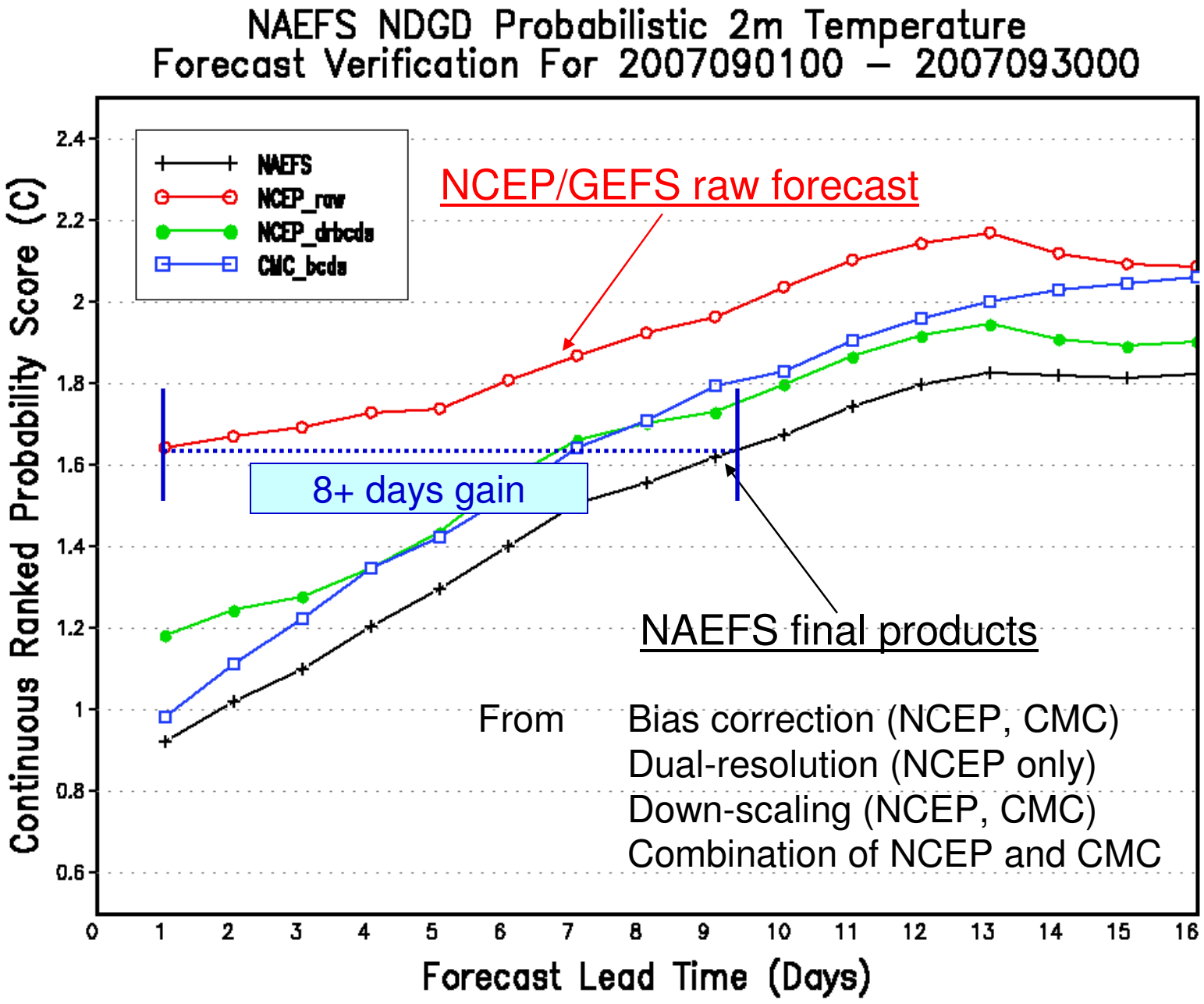


BO CUI, GCWMB/EMC/NCEP/NOAA

Summary

- Bias corrected NAEFS products has been implemented in both CMC and NCEP
  - Apply to 34 variables at 1*1 degree resolution (globally)
  - Generate probabilistic forecasts
    - 10%, 50%, 90%, mode, mean and spread
  - Generate anomaly forecasts
  - Improving probabilistic forecast skills
  - Absolute errors are reduced significantly
- Downscaling NAEFS products has been implemented in NCEP only
  - To NDFD grids (~5km resolution)
  - Apply to 4 variables
    - Surface pressure, 2m temperature and 10m u and v
  - CONUS only
  - Generate probabilistic forecasts
    - 10%, 50%, 90%, mode, mean and spread
  - Reduced mean absolute errors (by 4+ days)
  - Improved probabilistic skills (by 8+ days)
- Users feedback from WFO (State College, PA)
  - Ranked #1 for minimum temperature forecast from 7 official guidences
  - Official Guidance: NGM80, NAM40, SREF, NAM12, MOSGd, HPCGd, NAEFS
- This method could apply to SREF, too.
- Enhance products by
  - Improvements to RTMA
    - Bias correction of forecast first guess using recursive algorithm

Plan

- Bias correction
  - Improving current method
    - Testing mini-Bayesian method
  - Bias correct all model variables
    - Working on model native variables (with Mozheng Wei)
    - Using hind-cast information for longer lead-time forecast
- Downscaling products
  - Apply statistical downscaling method to other regions, Alaska, Hawaii, Puerto Rico and Guam, when RTMA is available
    - Needed in support of Alaska Desk, etc
    - Following after RTMA implementation
  - Add new variables to NDFD grids, such as wind speed/direction, maximum/minimum temperature, 2-meter dew point temperature etc…
  - Enhance products by Improvements to RTMA
    - Bias correction of forecast first guess using recursive algorithm
  - Testing or combining “Smartinit” (Geoff Manikin)
- Precipitation (separated consideration from others)
  - Bias correction and downscaling
    - Downscaling analysis – 5km and every 6-hr (Mike Charles)
    - Pseudo precipitation (Paul Schultz and Huiling Yuan)
    - Full Bayesian method
- Evaluations
  - For current bias correction and downscaling forecast products
  - Objective evaluation for FNMOC ensemble system
- Other NAEFS related issues
  - Data exchange with CMC (adding new variables)
  - Exchange bias correction forecast (in the future plan)
  - New data format (GRIB2)

Background

Overall temperature forecasts: Average over past 30 days: (20080929-20081028)

		MAE	Bias	>10 err	<3 err	off. rank	Best G.		2nd G.		Worst G.	
1	12-hr	2.44	0.7	0.1%	67.3%	1 out of 7	NAM40	65.4%	NAM12	60.1%	NGM80	44.4%
2	24-hr	2.84	1.0	0.3%	59.1%	2 out of 7	NAM40	60.3%	NAM12	56.9%	SREF	47.0%
3	36-hr	2.94	0.8	0.3%	57.8%	1 out of 7	NAM40	55.9%	NAM12	52.6%	NGM80	44.0%
4	48-hr	3.36	1.6	2.1%	52.8%	1 out of 7	MOSGd	48.9%	NAM40	48.3%	NGM80	12.9%
5	60-hr	3.26	1.0	1.7%	54.8%	1 out of 6	MOSGd	50.1%	NAM12	48.8%	NAM40	6.2%
6	72-hr	3.35	1.3	2.1%	53.1%	1 out of 5	MOSGd	49.9%	NAM12	49.5%	SREF	44.0%
7	84-hr	3.80	0.6	4.7%	49.0%	1 out of 5	NAEFS	48.6%	SREF	44.5%	NAM12	2.6%
8	96-hr	3.96	0.7	4.0%	44.4%	2 out of 4	NAEFS	46.2%	HPCGd	42.6%	MOSGd	40.6%
9	108-hr	4.43	0.9	5.5%	38.5%	2 out of 3	NAEFS	41.7%	MOSGd	37.7%	MOSGd	37.7%
10	120-hr	4.57	1.0	5.9%	36.6%	2 out of 4	NAEFS	40.9%	HPCGd	36.5%	MOSGd	36.3%
11	132-hr	4.83	0.7	7.8%	34.7%	1 out of 3	NAEFS	34.5%	MOSGd	34.4%	MOSGd	34.4%
12	144-hr	4.83	0.5	7.4%	34.7%	3 out of 4	HPCGd	36.4%	NAEFS	35.5%	MOSGd	33.3%
13	156-hr	5.43	0.1	11.9%	30.3%	3 out of 3	NAEFS	32.1%	MOSGd	30.8%	MOSGd	30.8%
14	168-hr	5.74	0.3	14.4%	27.7%	2 out of 4	HPCGd	27.7%	MOSGd	26.9%	NAEFS	26.1

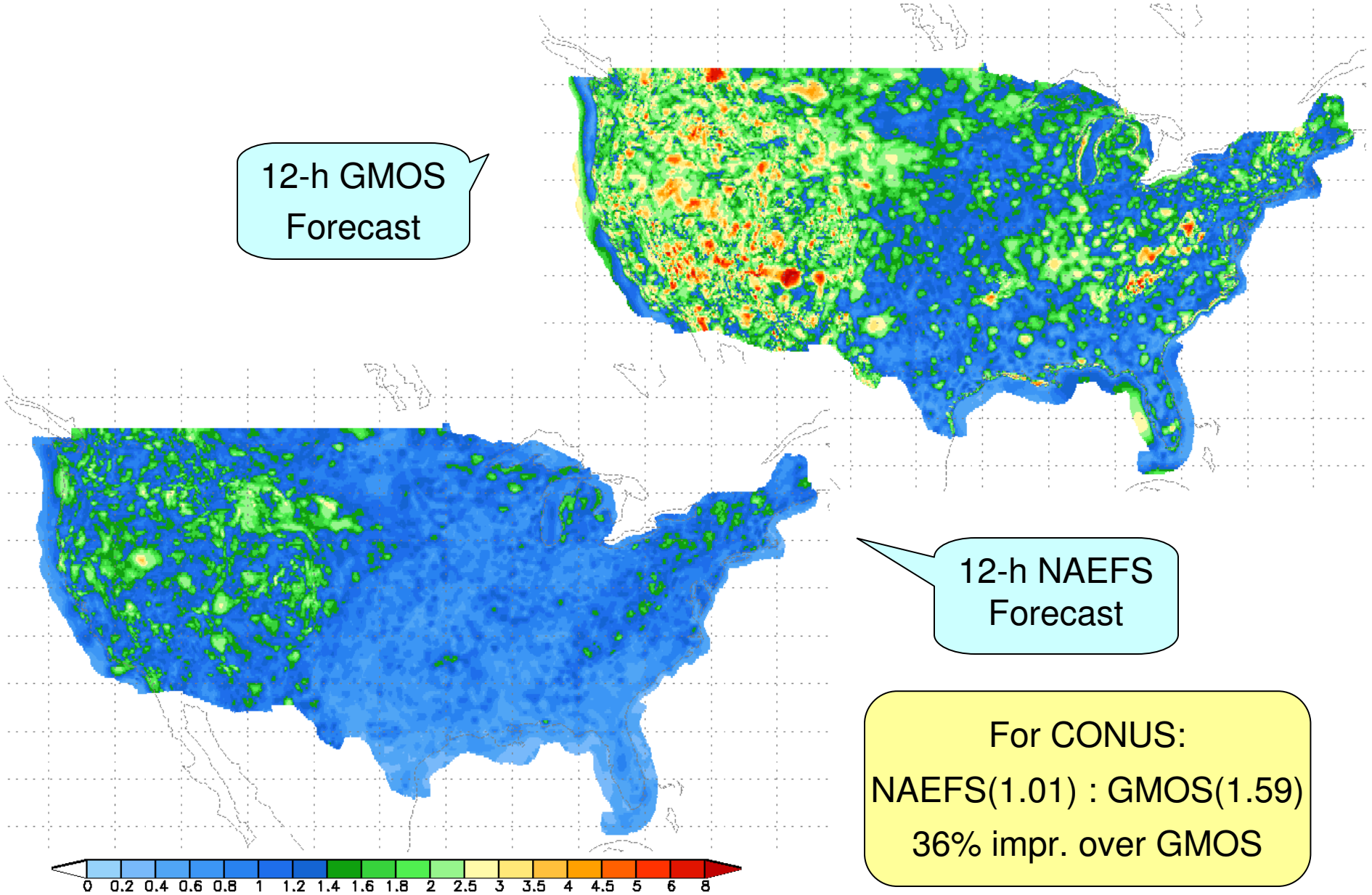
Minimum temperature forecast: Average over past 30 days: (20080929-20081028)

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

Contributed by Richard Grumm (WFO)

MDL GMOS & NAEFS Downscaled Forecast
Mean Absolute Error w.r.t. RTMA Average For Sept. 2007

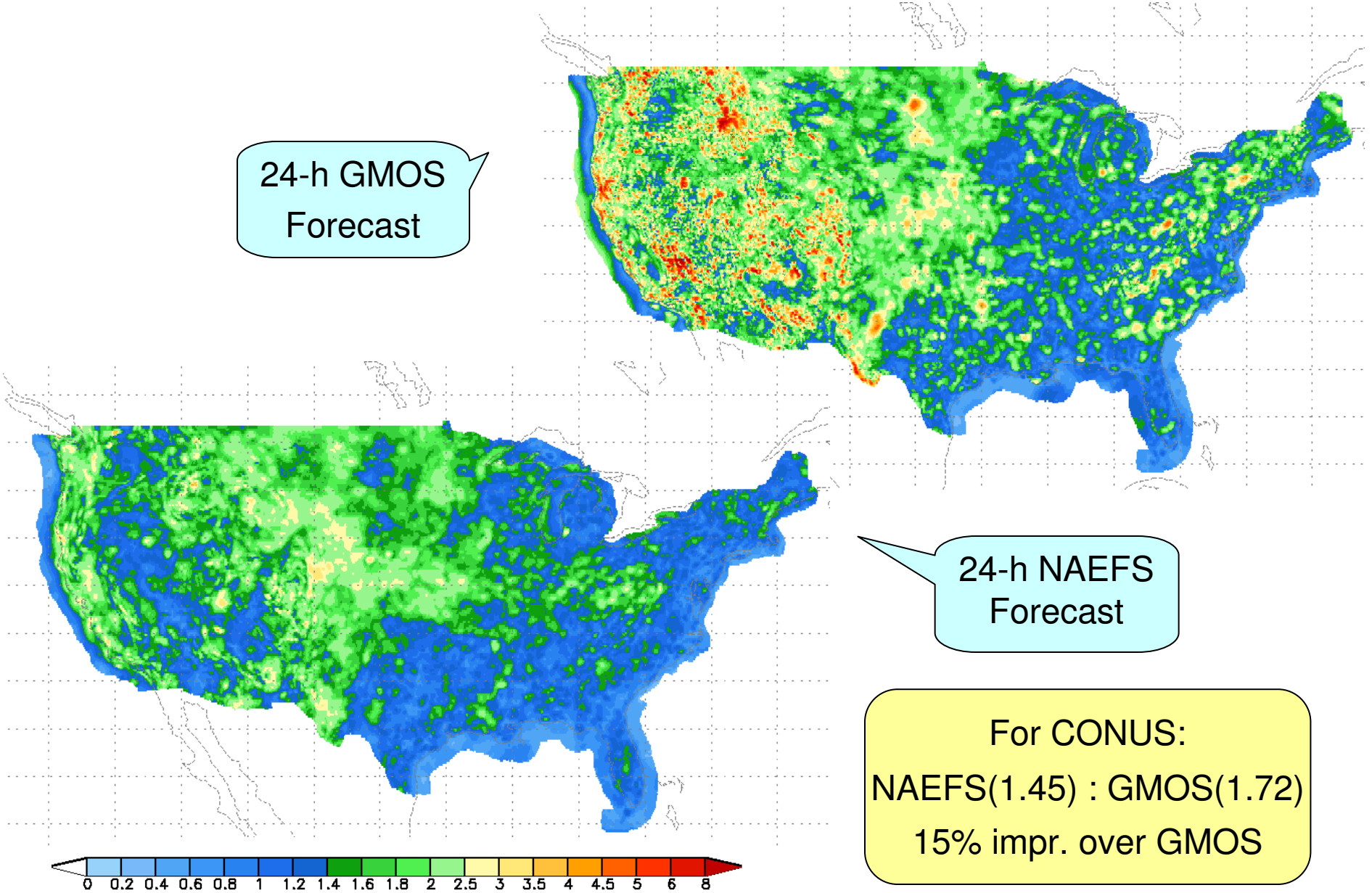


For CONUS:

NAEFS(1.01) : GMOS(1.59)

36% impr. over GMOS

MDL GMOS & NAEFS Downscaled Forecast
Mean Absolute Error w.r.t. RTMA Average For Sept. 2007



For CONUS:

NAEFS(1.45) : GMOS(1.72)

15% impr. over GMOS

Surface Temperature MAE

CONUS, Sept. 2007

00Z GMOS vs. 00Z NAEFS

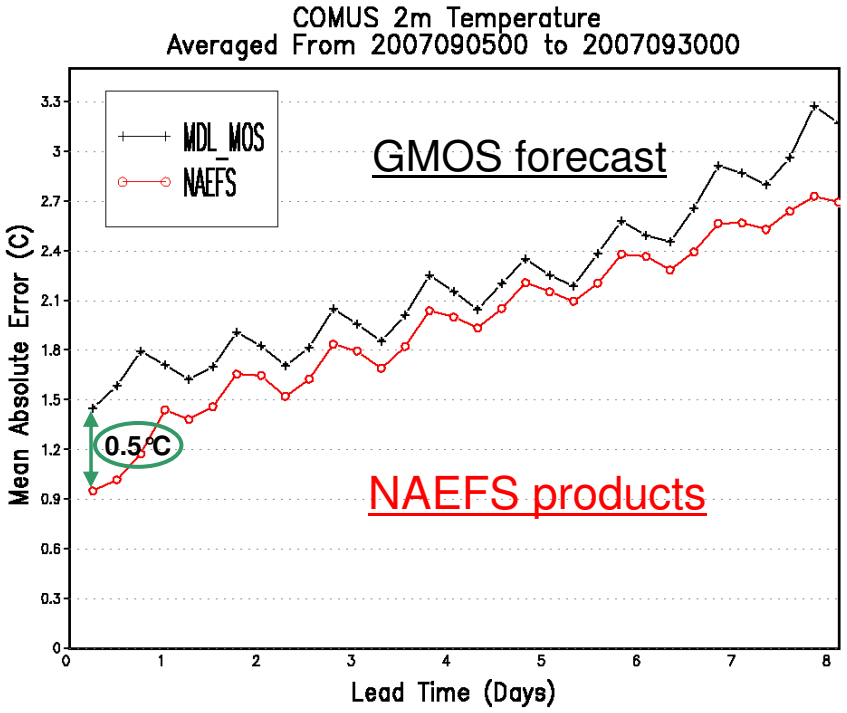
RTMA Analysis

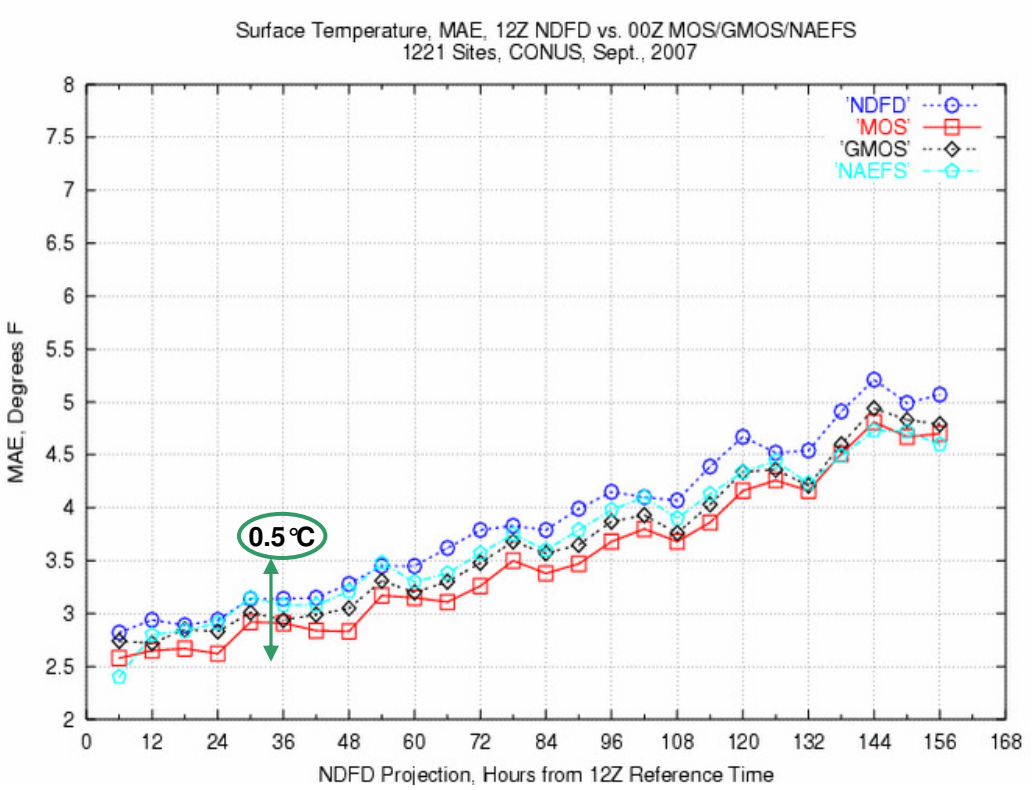
Surface Temperature MAE

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

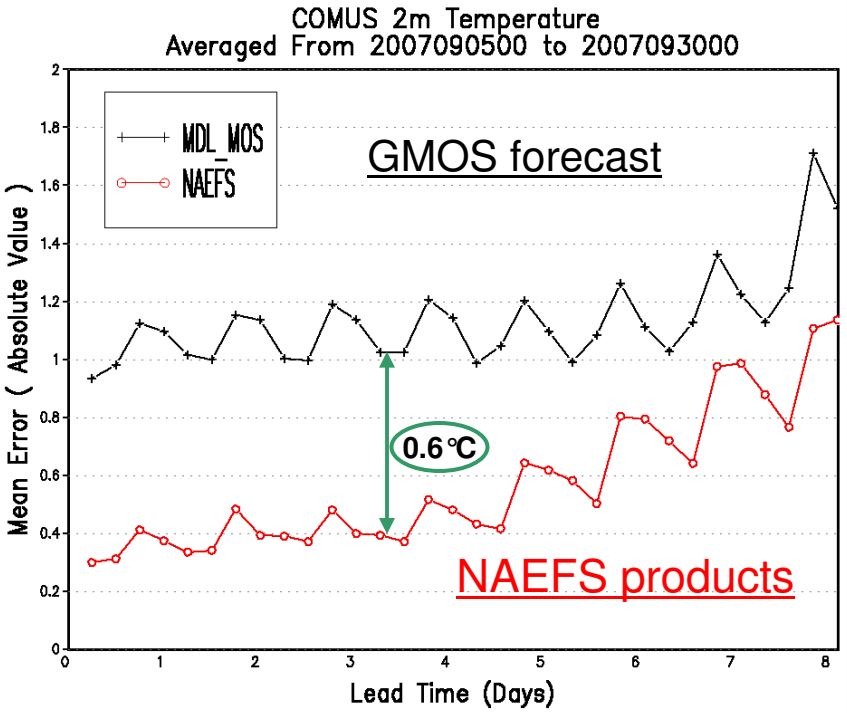
RTMA Analysis

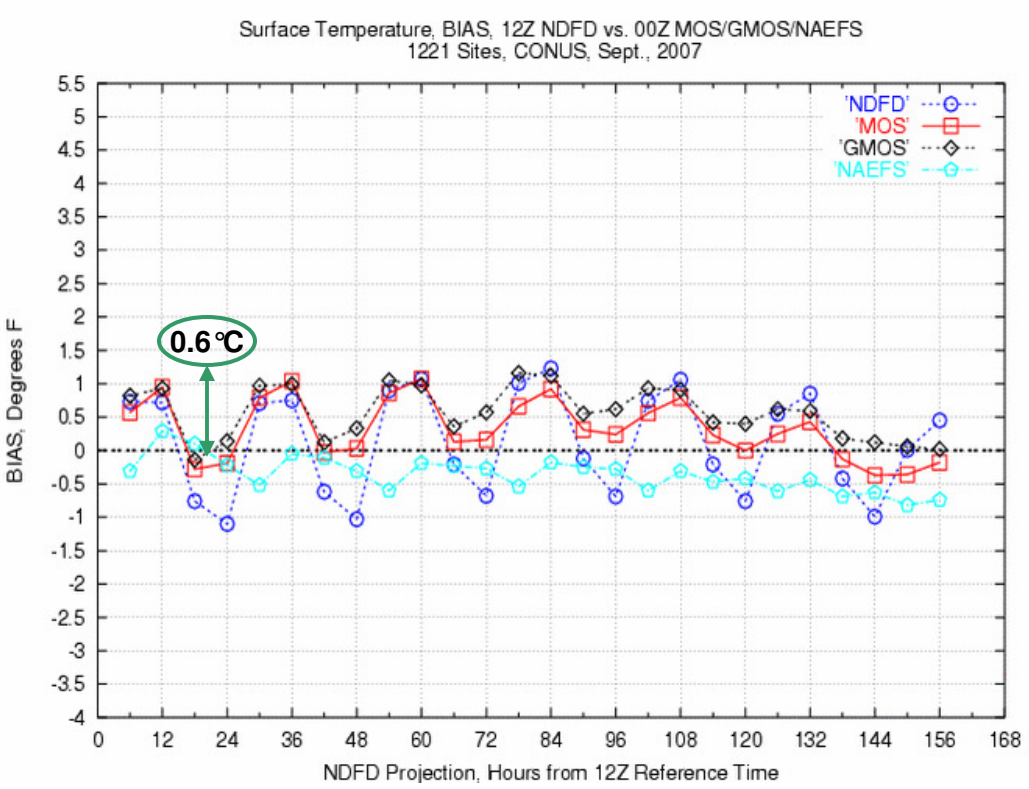
Surface Temperature Area Mean Bias

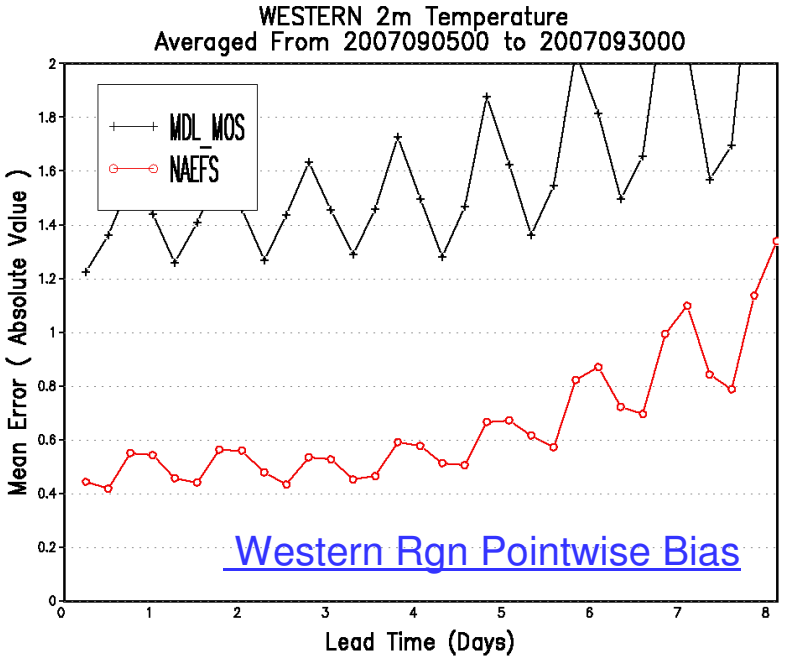
CONUS, Sept. 2007

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

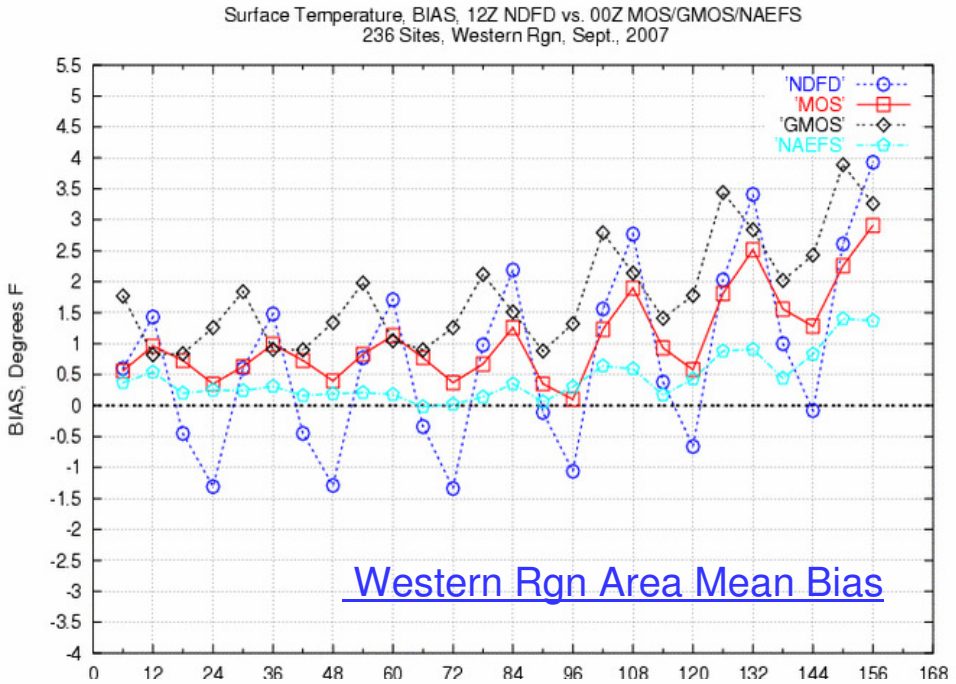
METAR obs. 1221 sites



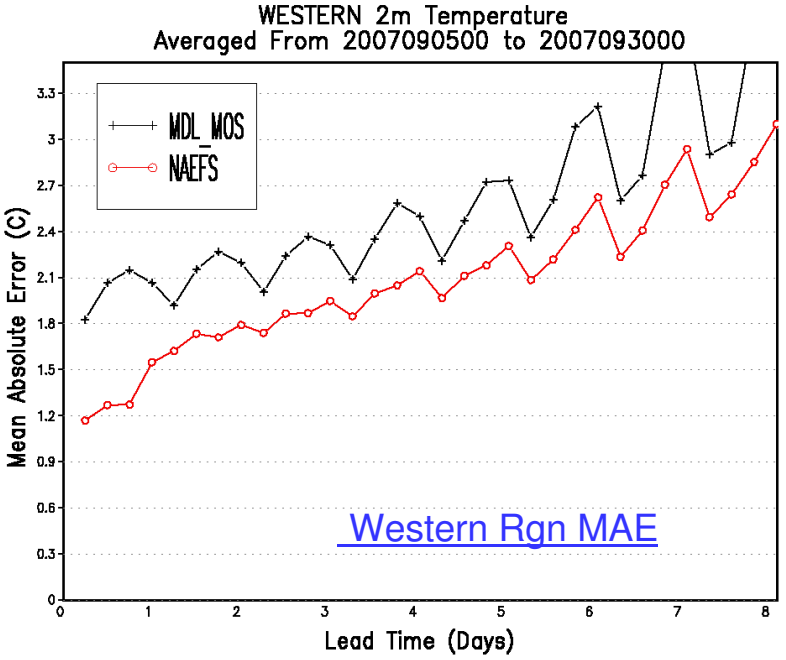




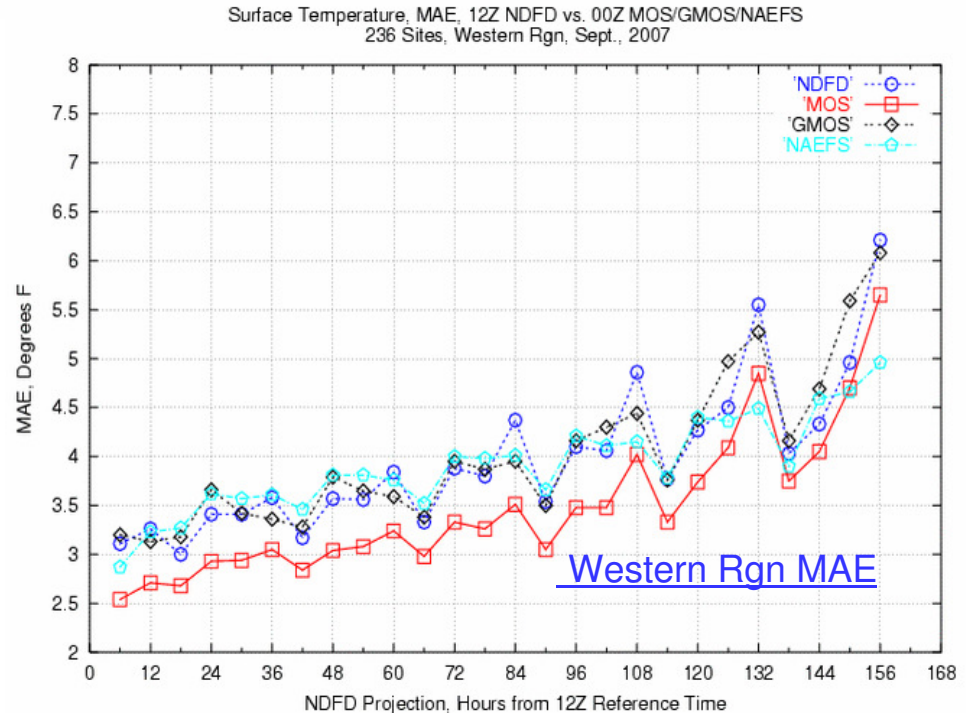
Western Rgn Pointwise Bias



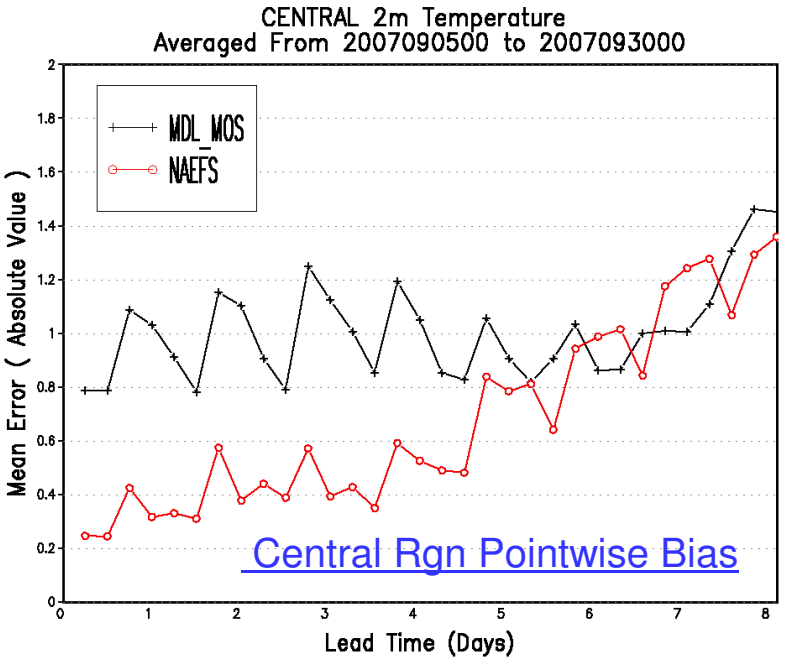
Western Rgn Area Mean Bias



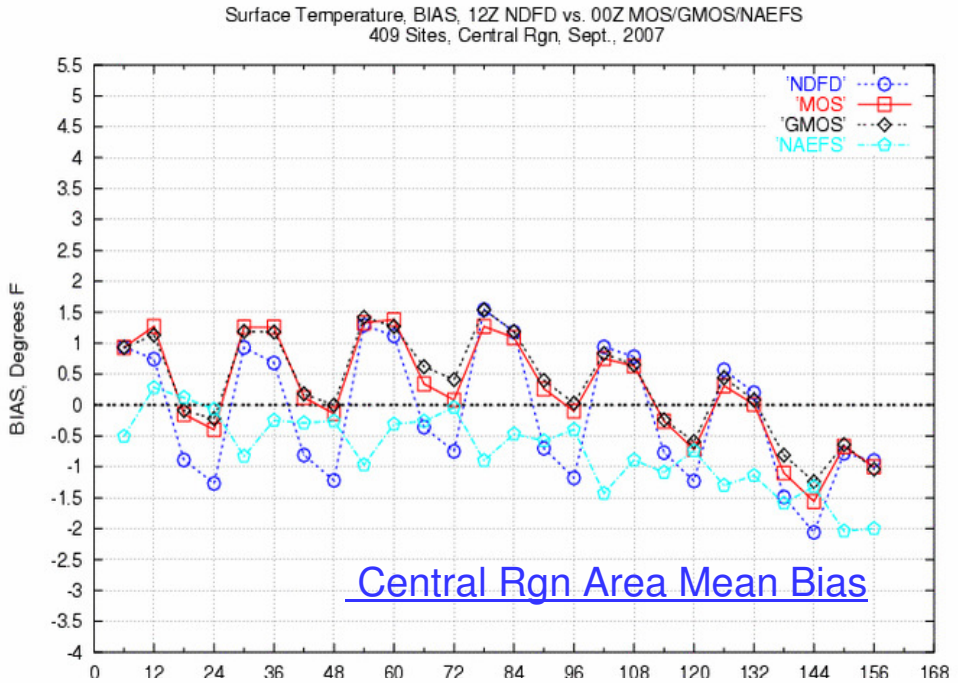
Western Rgn MAE



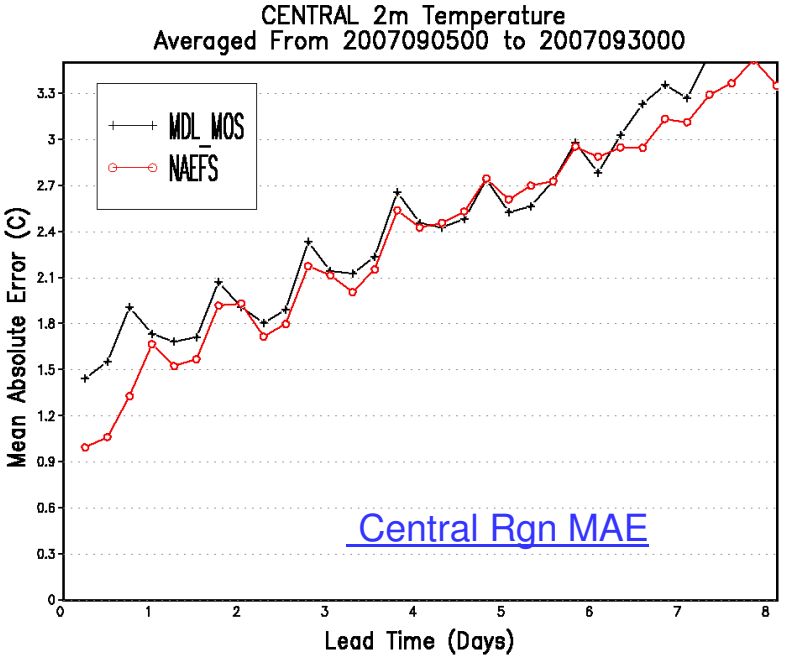
Western Rgn MAE



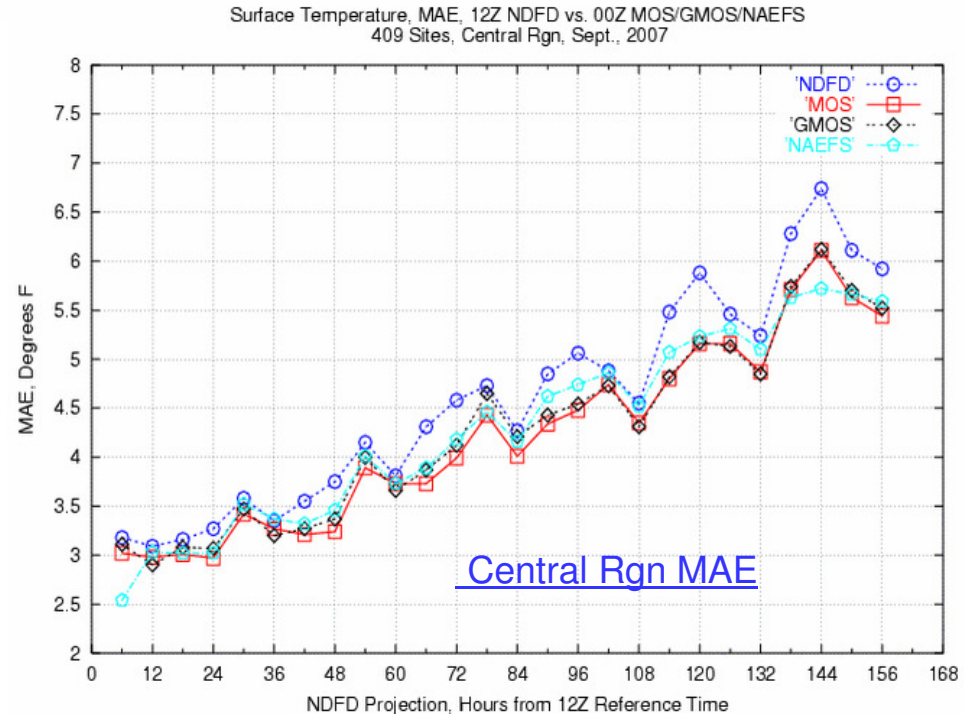
Central Rgn Pointwise Bias



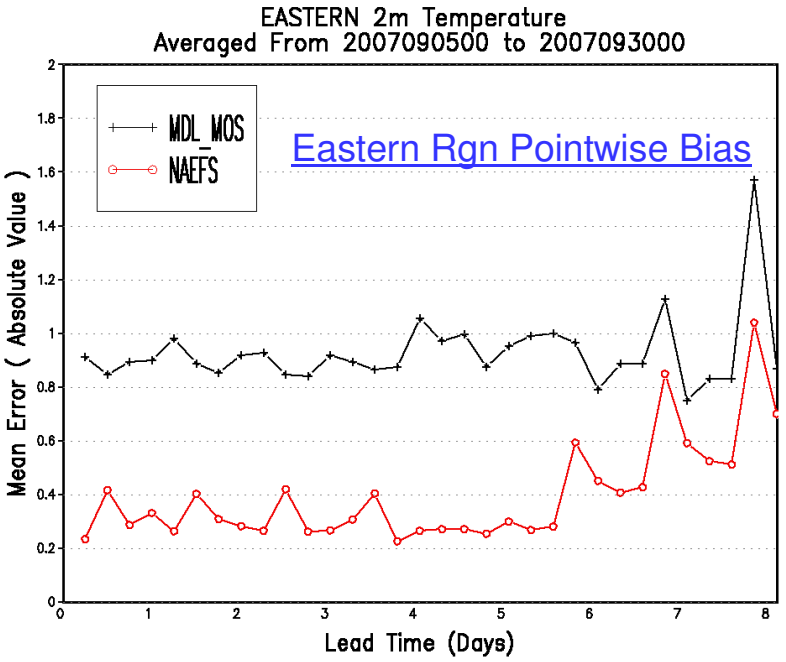
Central Rgn Area Mean Bias

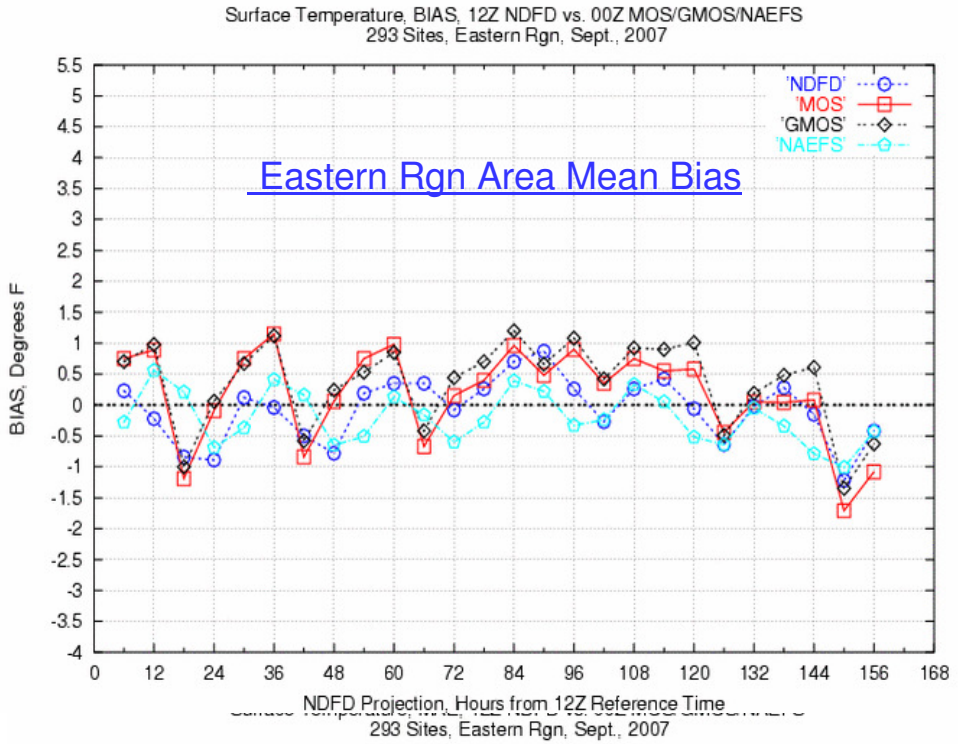


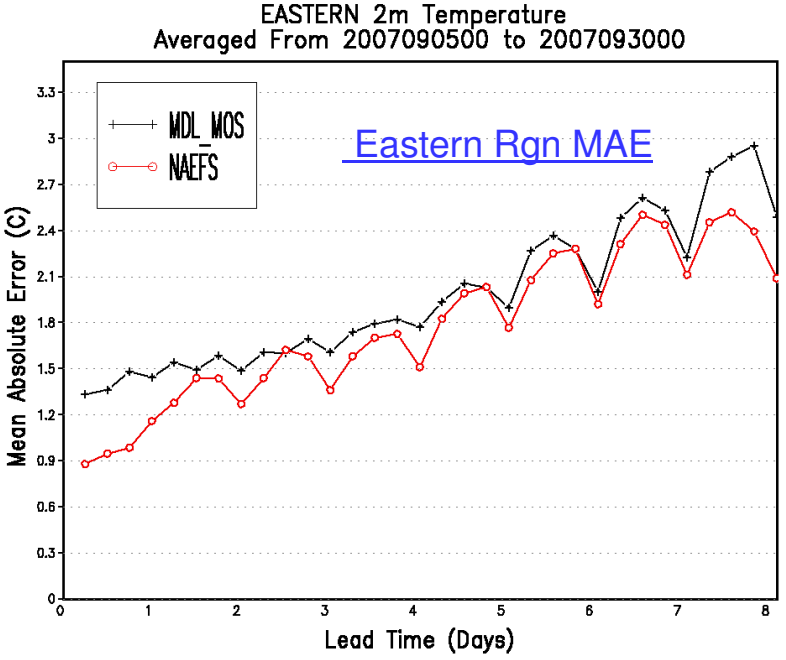
Central Rgn MAE

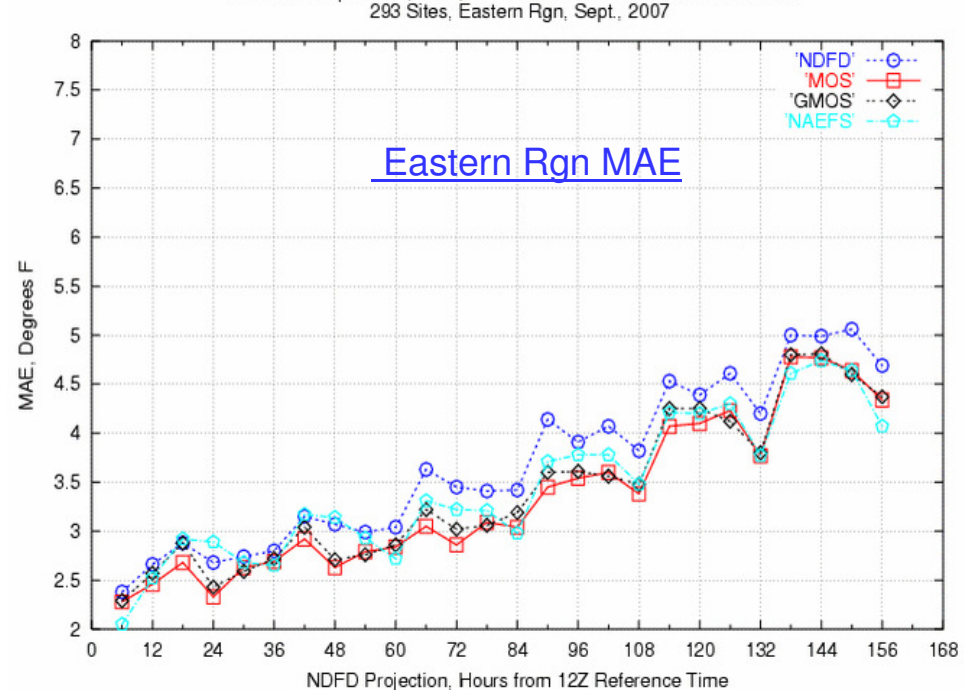


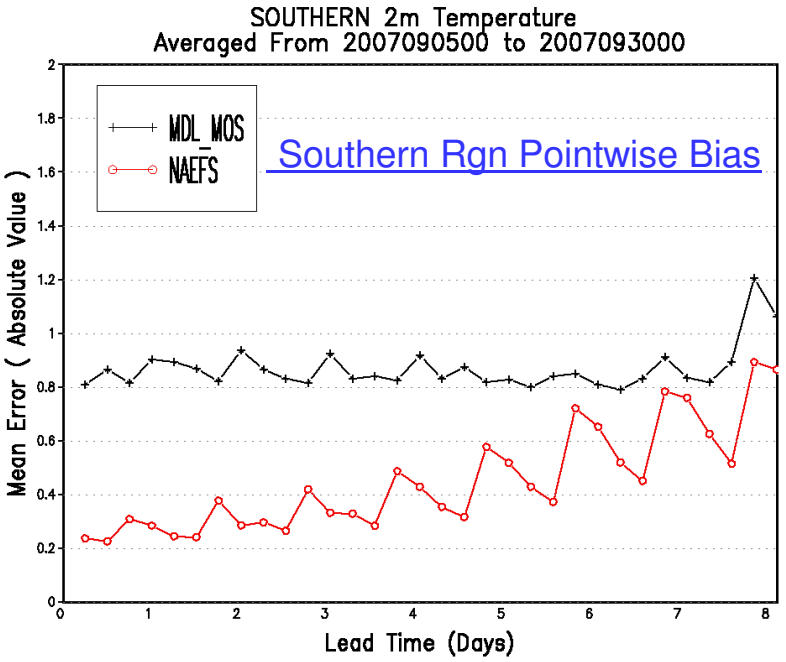
Central Rgn MAE


EASTERN 2m Temperature
Averaged From 2007090500 to 2007093000
MDL_MOS
NAEFS
Eastern Rgn Pointwise Bias
Mean Error (Absolute Value)
Lead Time (Days)

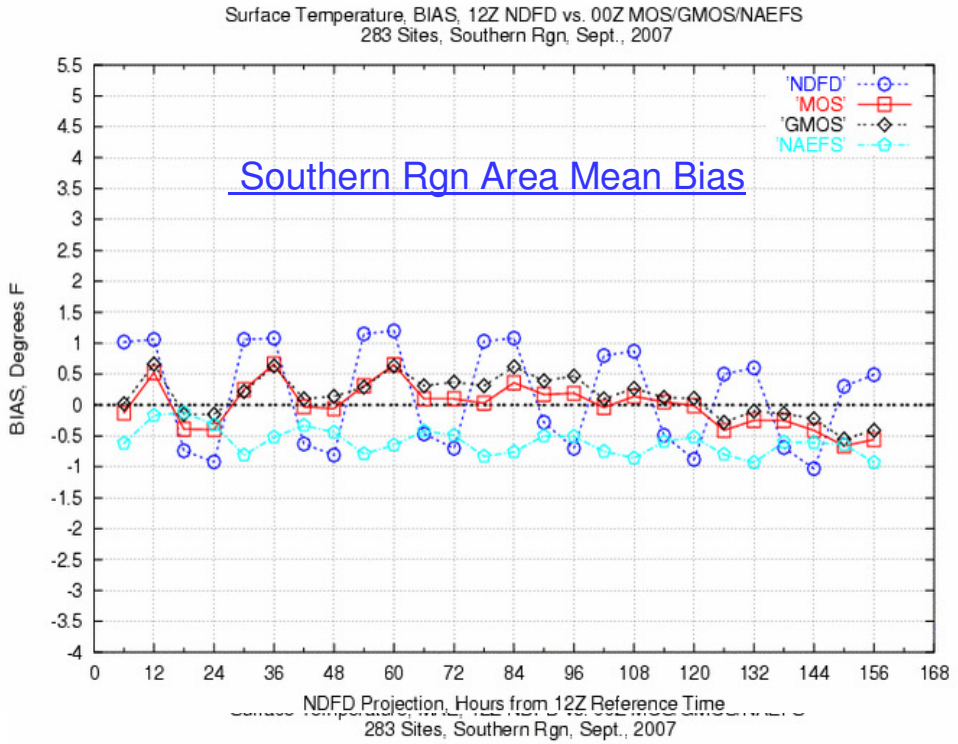

Surface Temperature, BIAS, 12Z NDFD vs. 00Z MOS/GMOS/NAEFS
293 Sites, Eastern Rgn, Sept., 2007
'NDFD'
'MOS'
'GMOS'
'NAEFS'
Eastern Rgn Area Mean Bias
BIAS, Degrees F
NDFD Projection, Hours from 12Z Reference Time


EASTERN 2m Temperature
Averaged From 2007090500 to 2007093000
MDL_MOS
NAEFS
Eastern Rgn MAE
Mean Absolute Error (C)
Lead Time (Days)

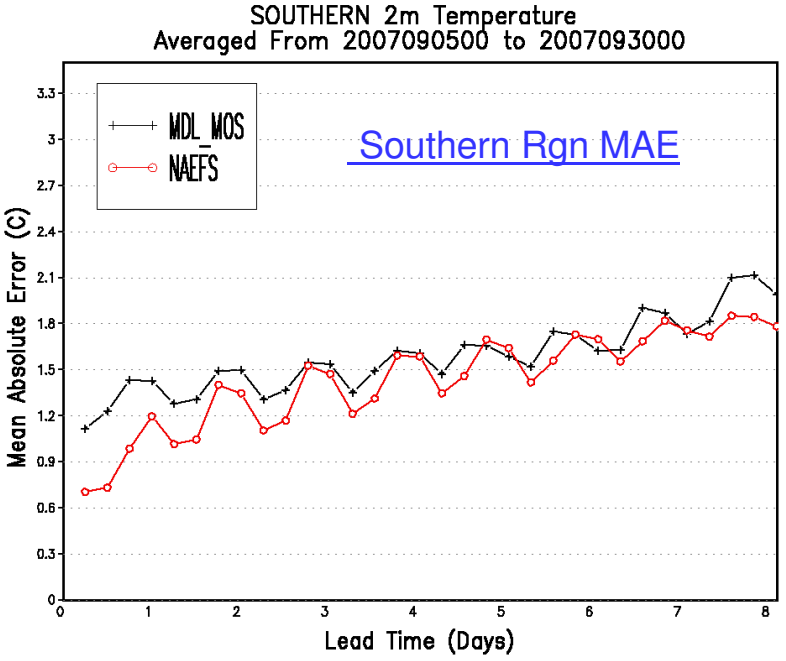

293 Sites, Eastern Rgn, Sept., 2007
'NDFD'
'MOS'
'GMOS'
'NAEFS'
Eastern Rgn MAE
MAE, Degrees F
NDFD Projection, Hours from 12Z Reference Time



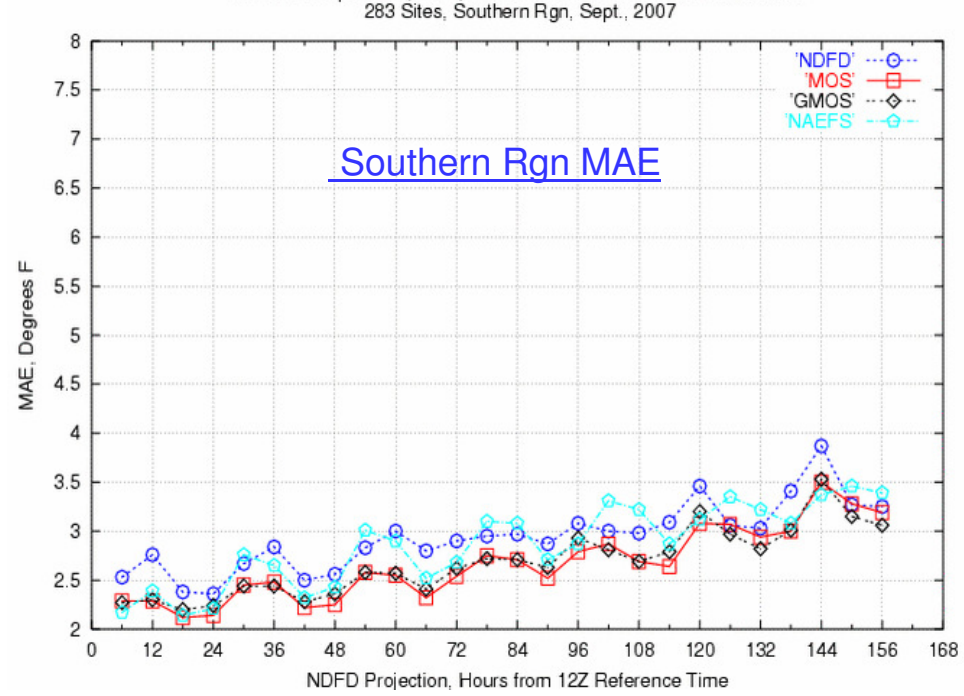
Southern Rgn Pointwise Bias



Southern Rgn Area Mean Bias



Southern Rgn MAE

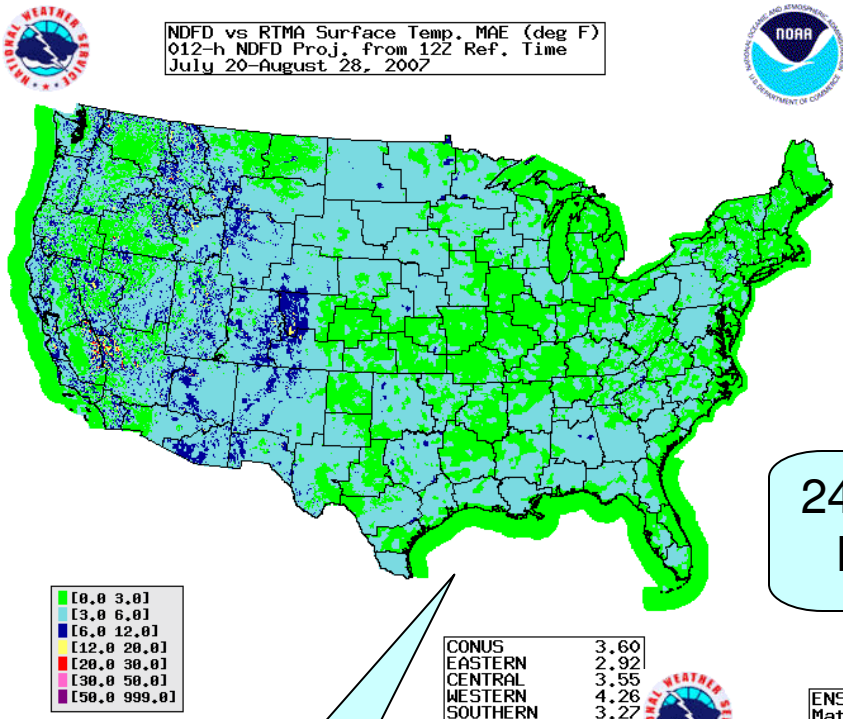


Southern Rgn MAE

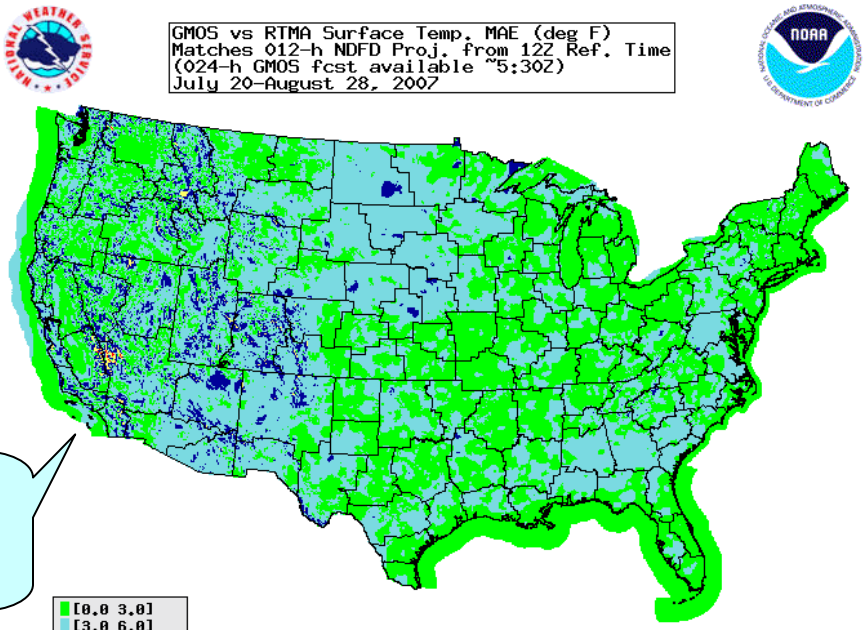
Statistical Downscaling Verification

-Contribute by MDL

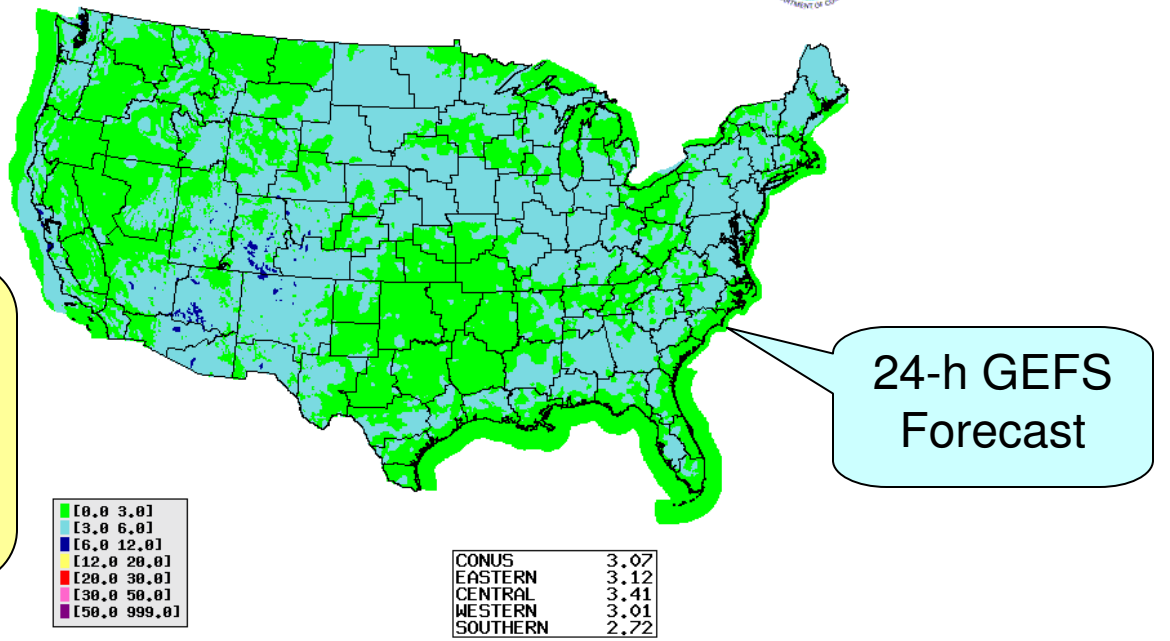
- 2-meter temperature only
- Period: July 20 – August 28 2007 (40 days)
- All verifications against RTMA
- NDFD: Official forecasts from previous day 12UTC
- GMOS: Gridded MOS forecasts from 00UTC
- GEFS: Bias corrected & downscaled 00UTC GEFS forecasts
  - Bias corrected NCEP GEFS ensemble mean only
    - Significant improvements not assess yet from
      - Dual resolution GEFS
      - NAEFS combination (GEFS + CMC)
      - Tuned downscaling method (0.3 coefficient instead of 0.1)



12-h NDFD Forecast

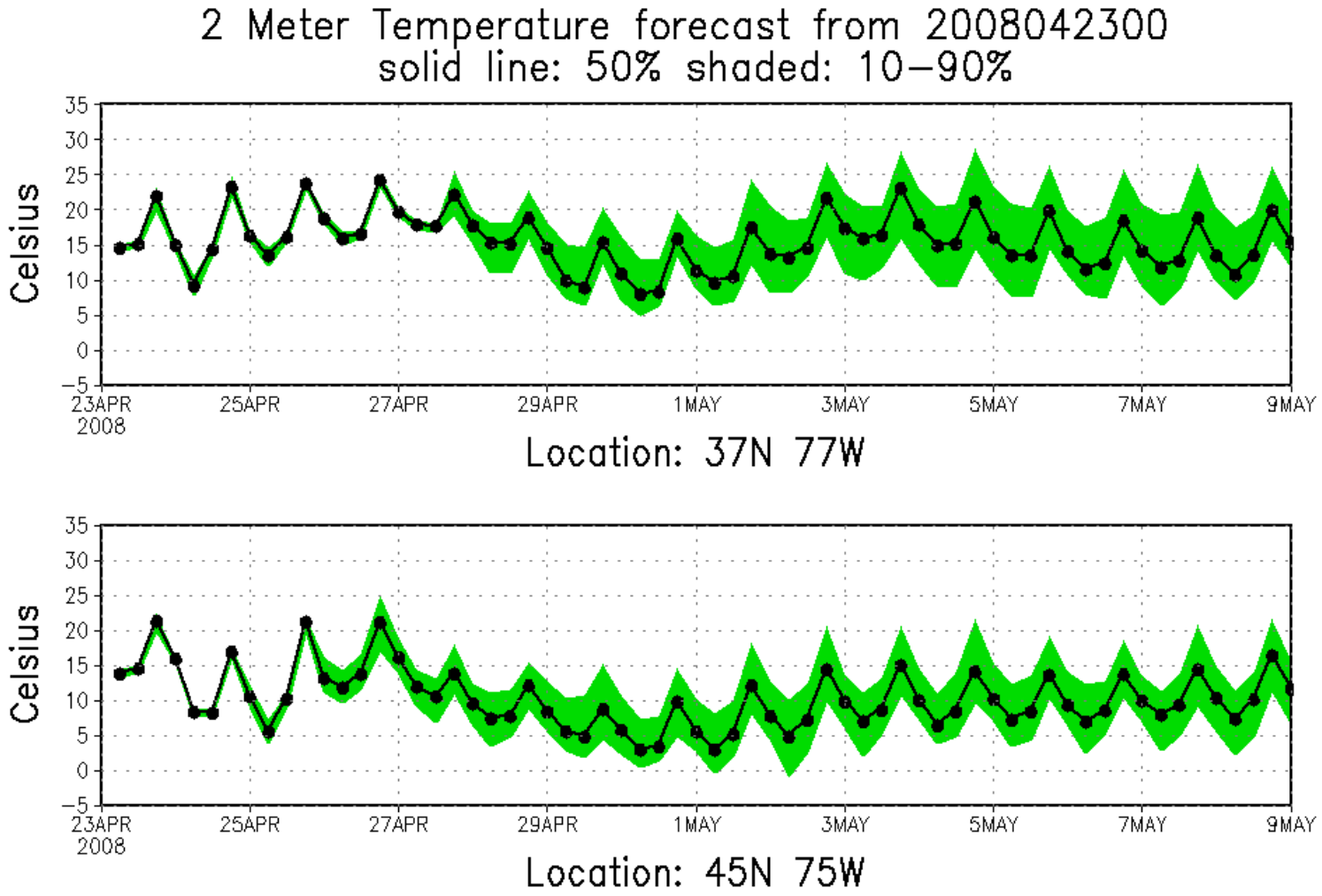


24-h GMOS Forecast

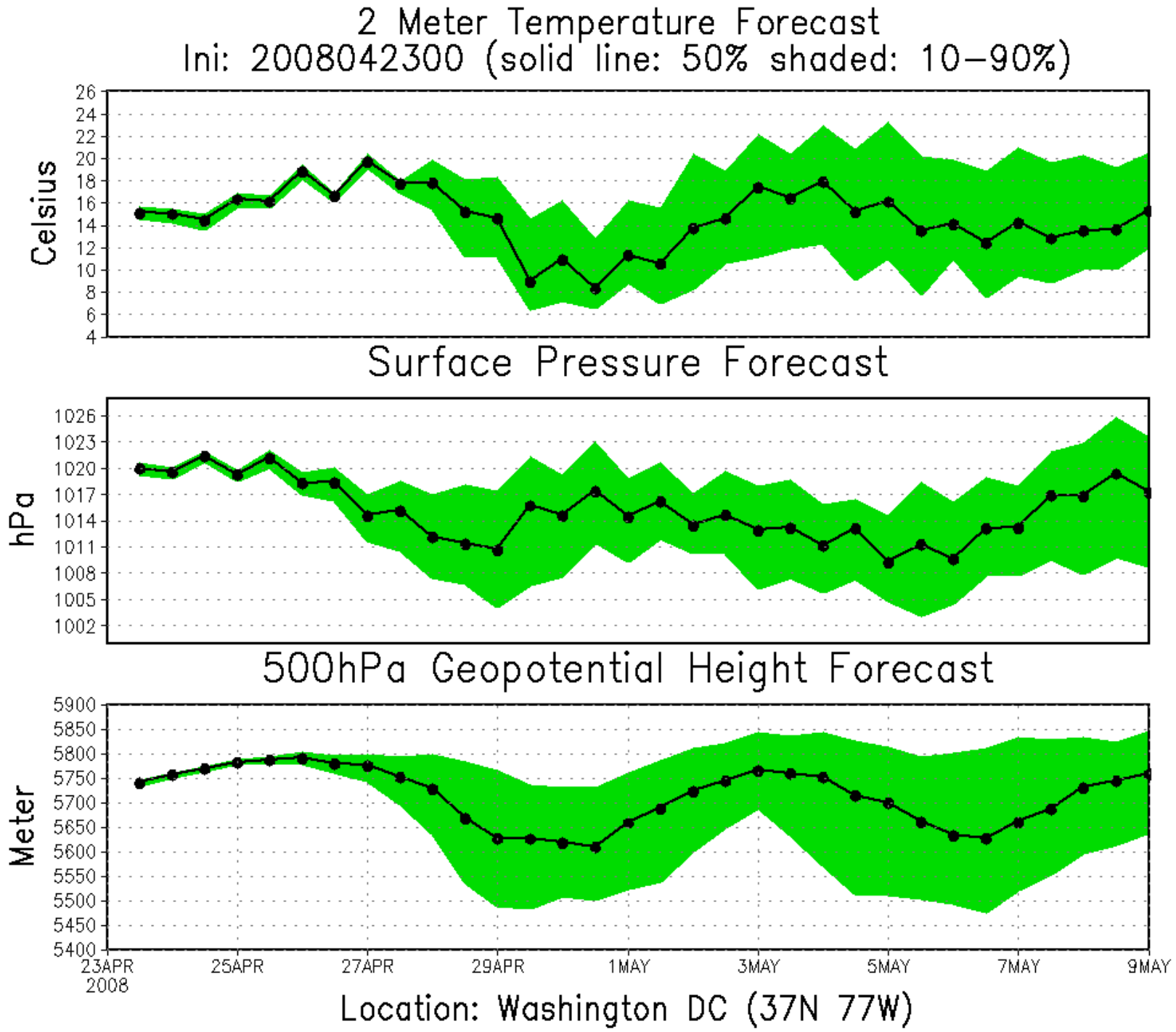


24-h GEFS Forecast

For CONUS:
GEFS(3.07) : NDFD(3.60)
17% impr. over NDFD
GEFS(3.07) : GMOS(3.37)
10% impr. over GMOS



GEFS Ensemble Probability Forecast (6 hour interval)
Washington DC (37N 77W) & Montreal (45N 75W)


2 Meter Temperature Forecast
Ini: 2008042300 (solid line: 50% shaded: 10-90%)
Celsius
26
24
22
20
18
16
14
12
10
8
6
4
Surface Pressure Forecast
hPa
1026
1023
1020
1017
1014
1011
1008
1005
1002
500hPa Geopotential Height Forecast
Meter
5900
5850
5800
5750
5700
5650
5600
5550
5500
5450
5400
23APR
2008
25APR
27APR
29APR
1MAY
3MAY
5MAY
7MAY
9MAY
Location: Washington DC (37N 77W)

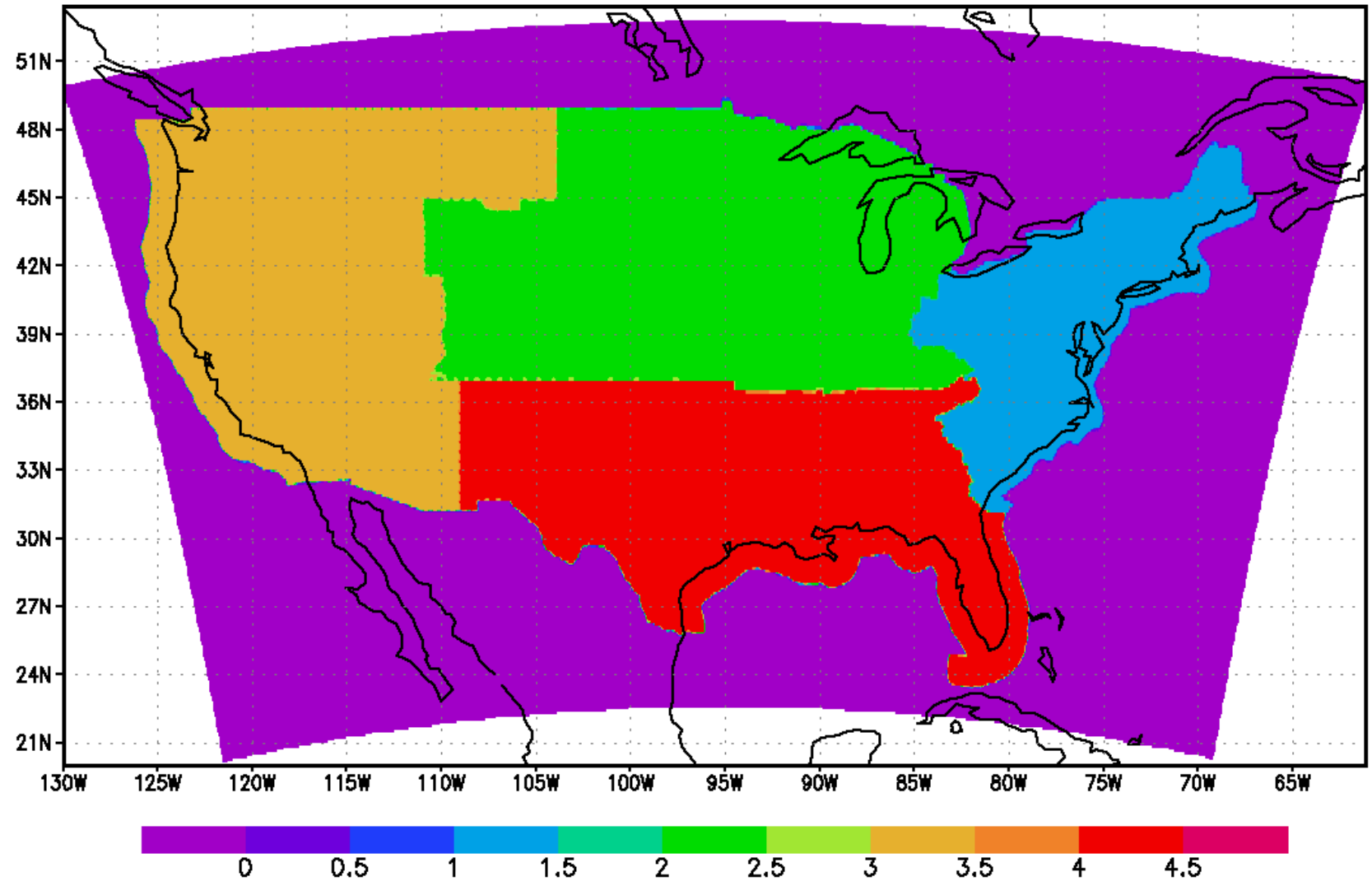
Real-Time Mesoscale Analysis (RTMA)

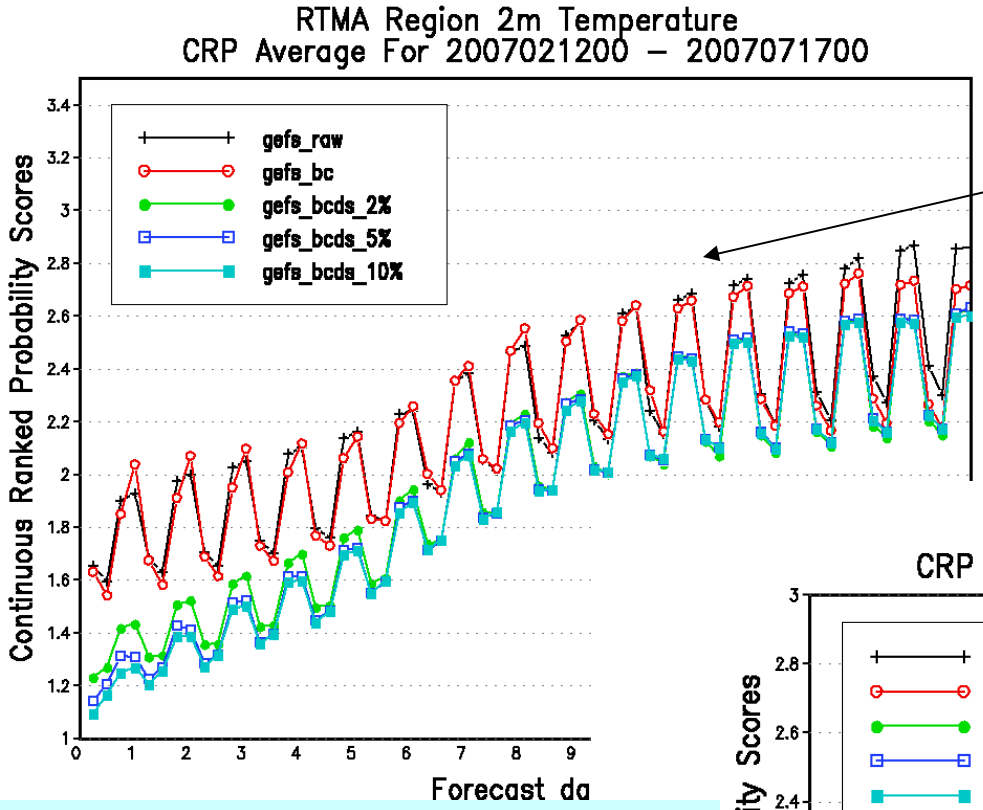
- from Manuel Pondeca

- Fast-track, proof-of-concept of the AOR (analysis of record) program. Intended to:
  - Enhance existing analysis capabilities at the NWS and generate near real-time hourly analyses of surface observations on domains matching the NDFD grids.
  - Provide estimates of analysis uncertainty
  - Establish a benchmark for future AOR efforts

- Developed at NCEP, ESRL, and NESDIS
  - Implemented in August 2006 for the CONUS NDFD grid
  - Analyzed parameters: 2-m T, 2-m q, 2-m Td, psfc, 10-m winds, precipitation, and effective cloud amount

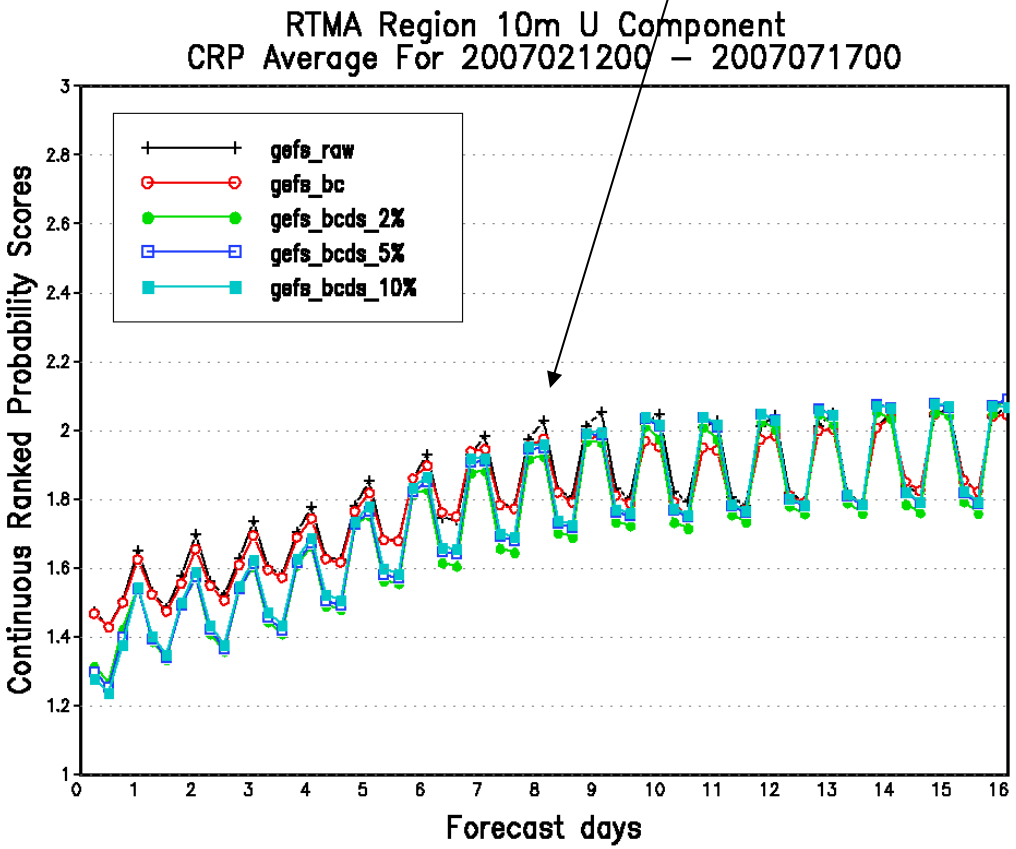
Example for using regional mask





T2M for CONUS

U10m for CONUS



Continuous Ranked Probability Scores (CRPS) is to measure the distance of truth from ensemble's distribution. These two stats show which decaying weight is best to CONUS region statistical down-scaling