Report of Inclusion of FNMOC Ensemble into NAEFS

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October 20, 2009

Overview

- Background & Testing Procedure
- Results
- Conclusions
- Issues
- Recommendation and outlook

Background & Testing Procedure

- North American Ensemble Forecast System (NAEFS)
  - Collaboration between NCEP, Meteorological Service of Canada (MSC), FNMOC and Mexico Weather Service
  - Elements:
    - Demonstrate value of Multi-Model Ensemble (MME)
    - Engage in collaborative software development, focused on postprocessing products from an arbitrary number of forecast systems
    - Establish operational data transfer
    - Application to operational products with shared software
    - Continue to monitor value-added with MME strategy
- Global ensemble products
  - NCEP – operational
    - 20 members -16 days
  - CMC – operational
    - 20 members - 16 days
  - FNMOC – experimental
    - 16 members – 10 days

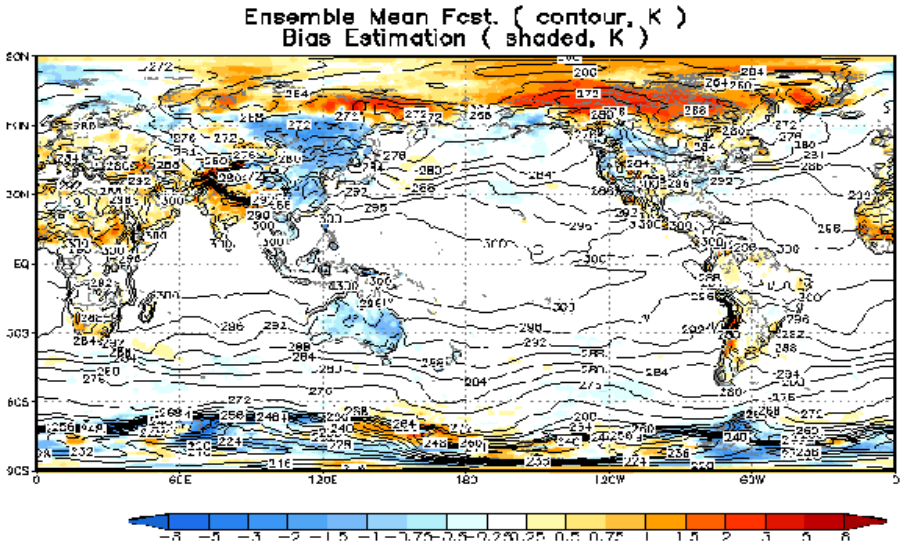
Background & Testing Procedure (cont)

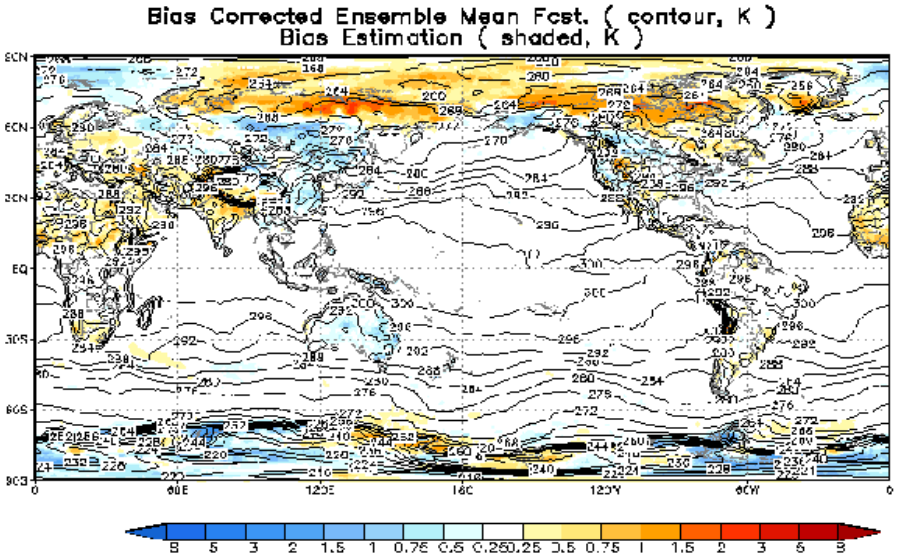
- **Forecast data**
  - 9 months of data collected (off line)
  - Communications pathway established with FNMOC
  - Raw forecasts
    - Fall 2008 (September 1st – November 30th 2008)
    - Winter 2008/2009 (December 1st 2008 – February 28th 2009)
    - Spring 2009 (March 1st – May 31st 2009)
  - Bias corrected forecasts – All ensembles bias corrected against NCEP analysis
    - Winter 2008/2009 (December 1st 2008 – February 28th 2009)
    - Spring 2009 (March 1st – May 31st 2009)

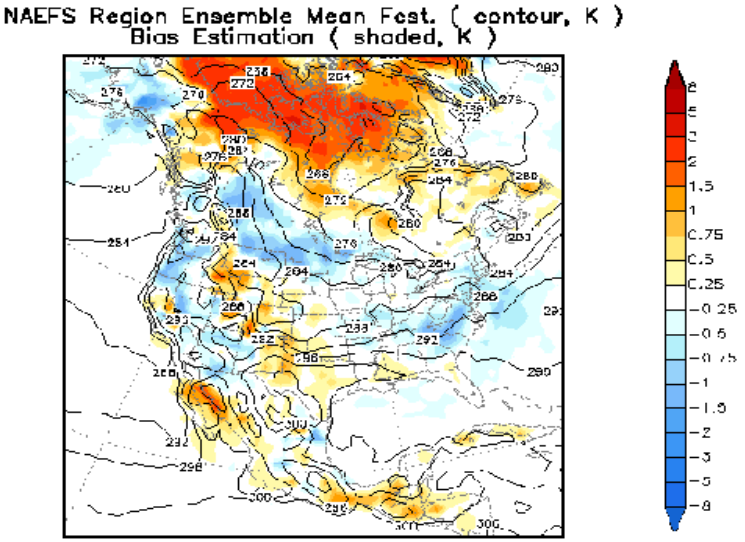
- **Verification methods**
  - Reference analysis
    - Individual ensembles – Each center's own
    - Combined ensembles – NCEP analysis
  - Scores
    - NCEP standard probabilistic verification package
      - AC and RMS for ensemble mean, spread, histogram
      - CRPS, RPSS, ROC, BSS (resolution and reliability)
  - Variables
    - 500 hPa and 1000 hPa height
    - 850 hPa and 2-meter temperature
    - 10-m U and V
    - Precipitation (limited scores, CONUS only)

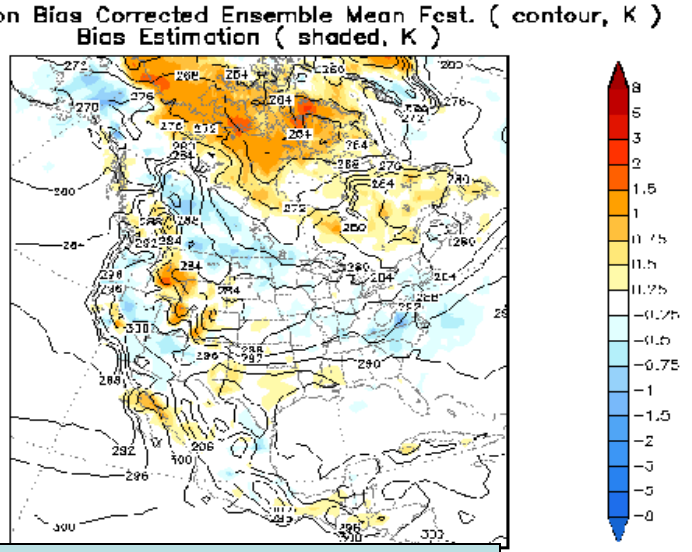
2 meter temperature: **120** hours forecast (ini: 2006043000)

Shaded: left – uncorrected right – after bias correction



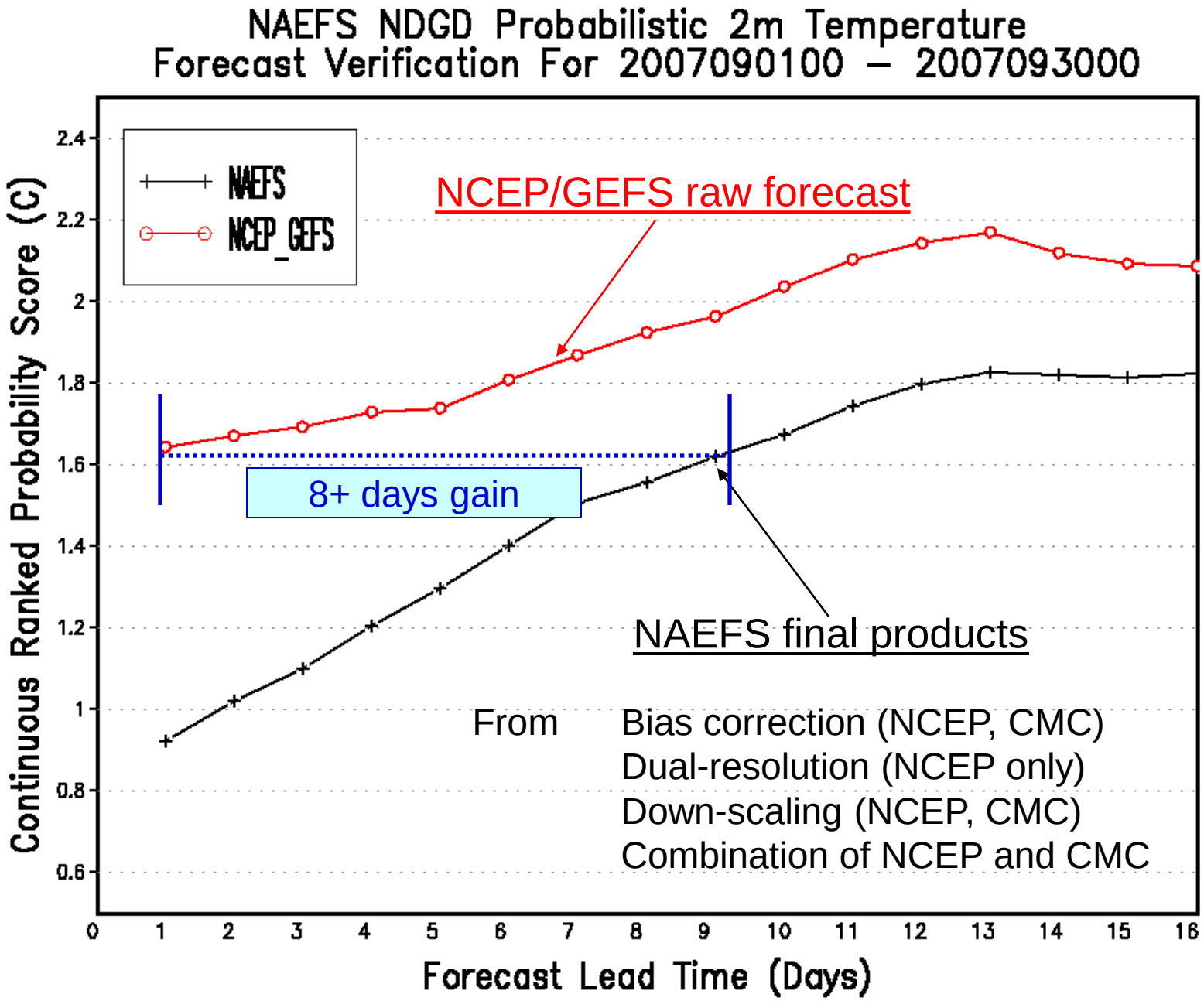




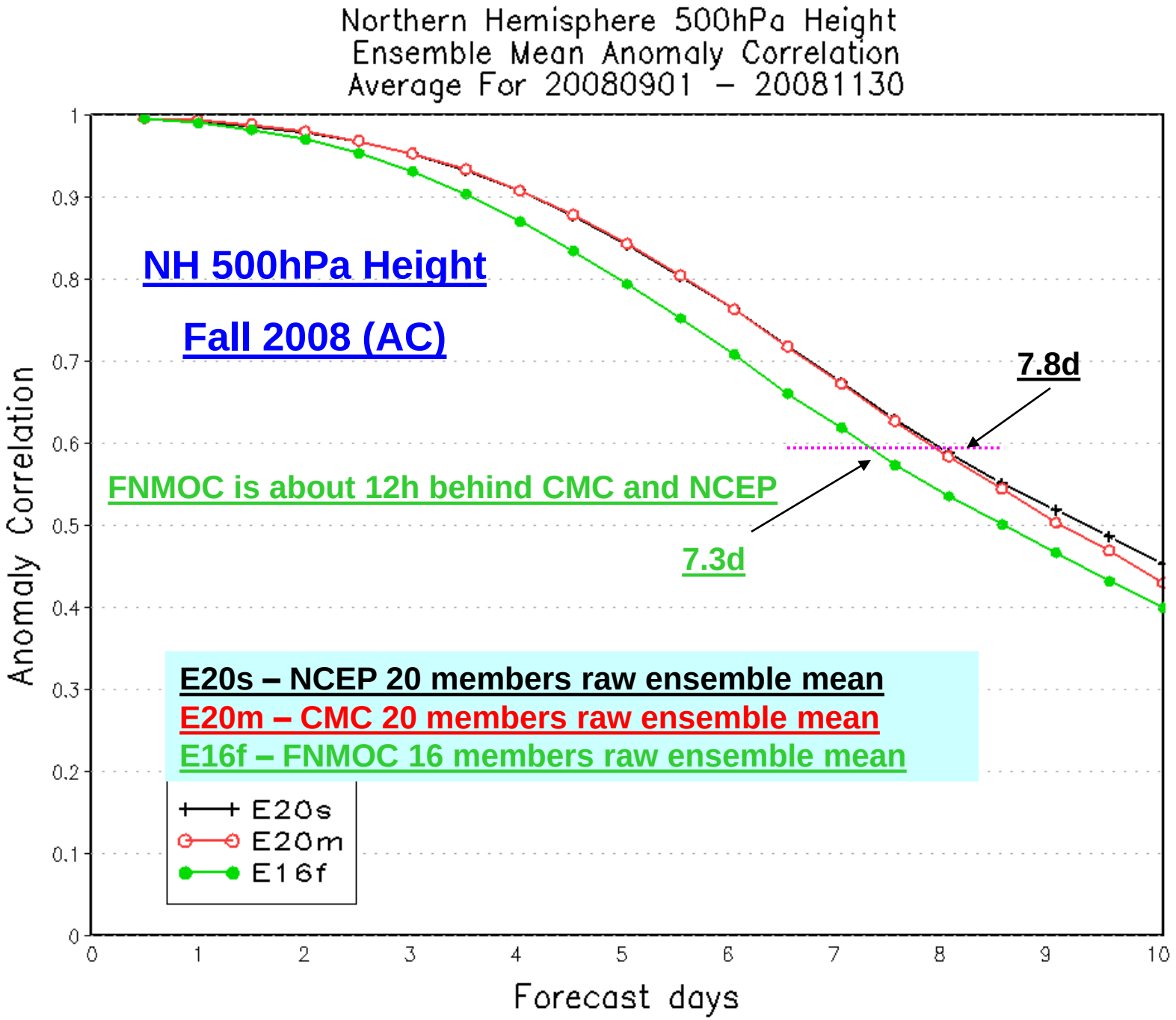


Bias reduced approximately 50% at early lead time

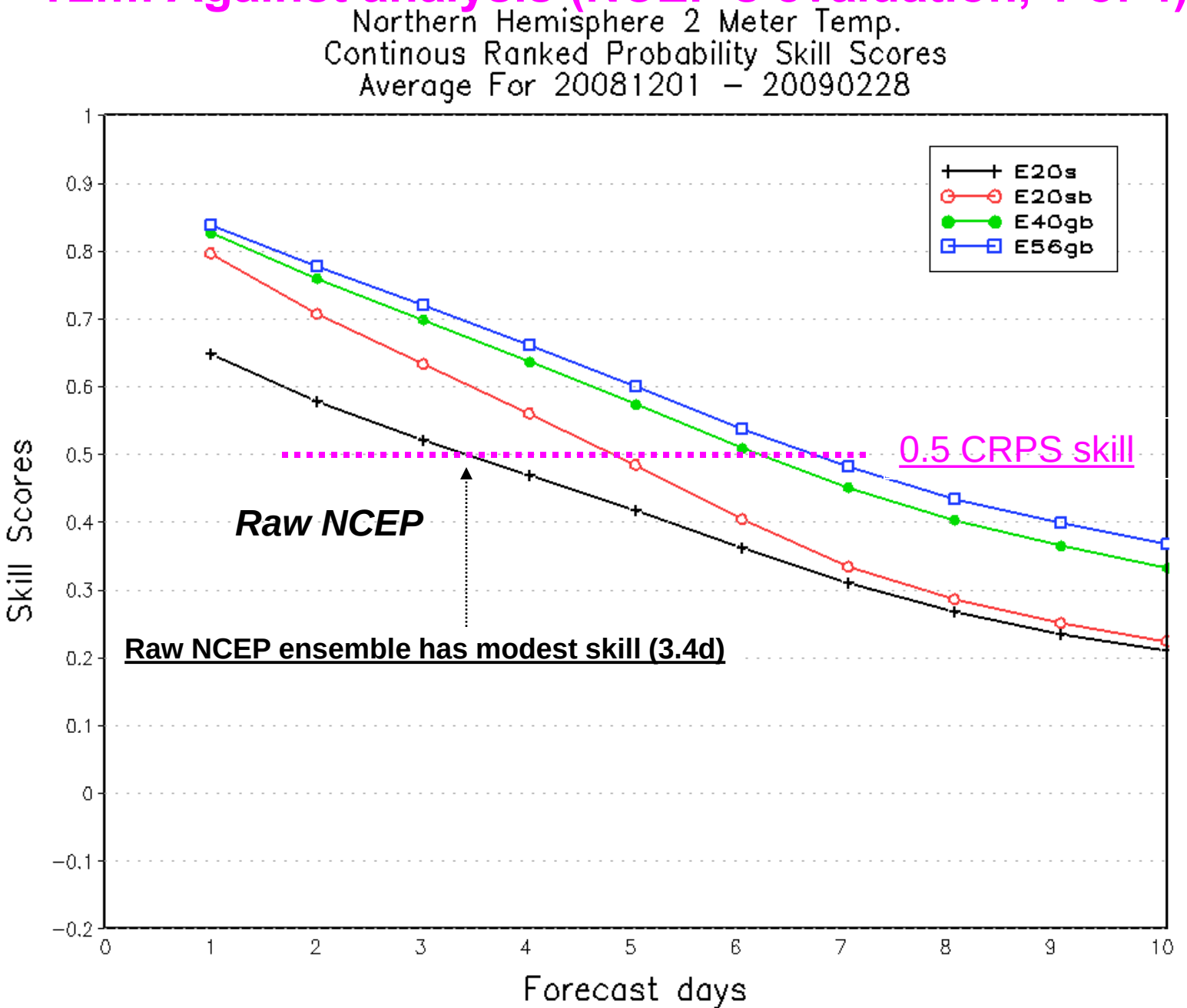
RMS errors improved by 9% for d0-d3



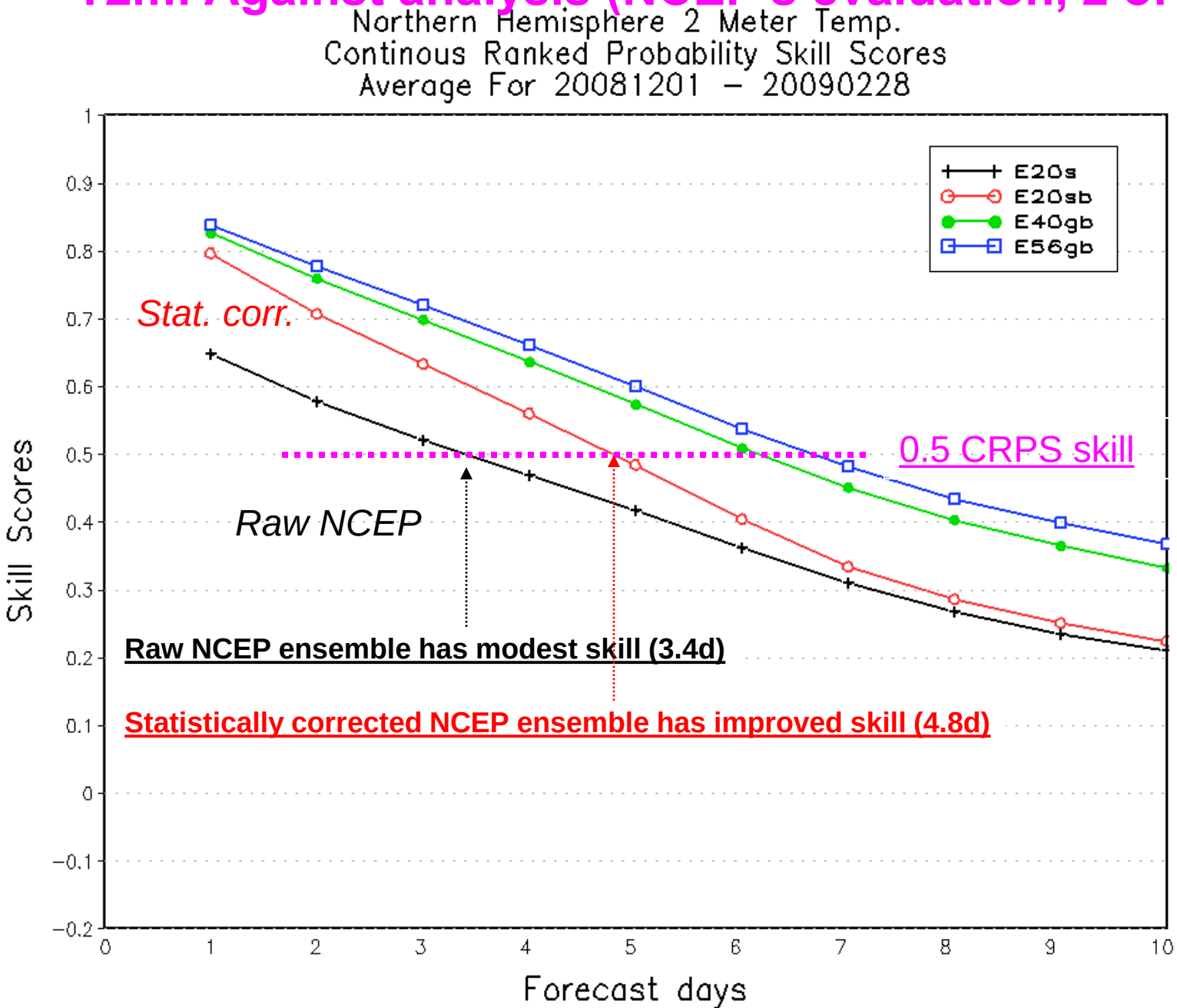
BO CUI, GCWMB/EMC/NCEP/NOAA


Northern Hemisphere 500hPa Height
Ensemble Mean Anomaly Correlation
Average For 20080901 – 20081130
NH 500hPa Height
Fall 2008 (AC)
7.8d
FNMOC is about 12h behind CMC and NCEP
7.3d
E20s – NCEP 20 members raw ensemble mean
E20m – CMC 20 members raw ensemble mean
E16f – FNMOC 16 members raw ensemble mean
E20s
E20m
E16f
Anomaly Correlation
Forecast days
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7
8
9
10

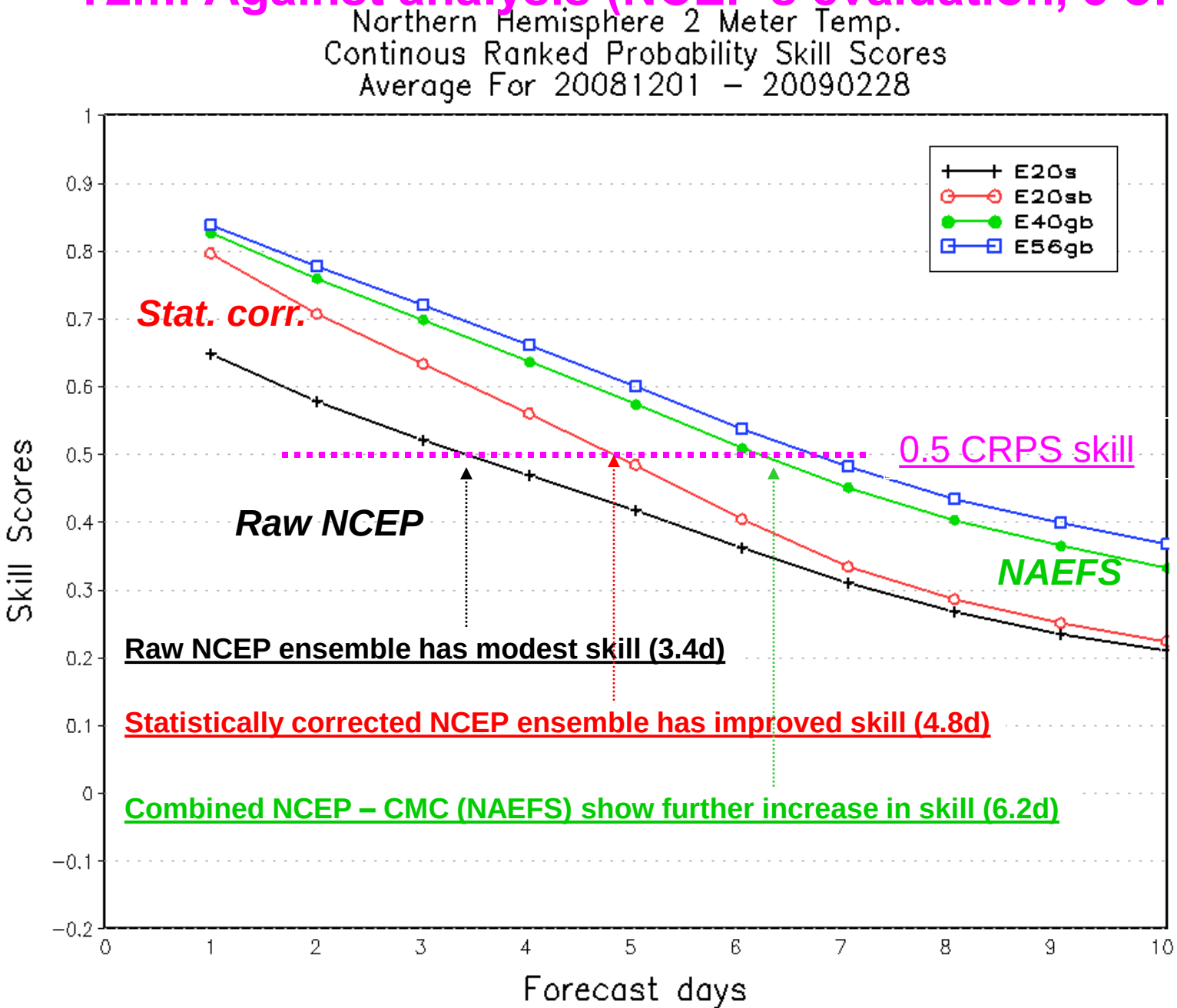
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 1 of 4)



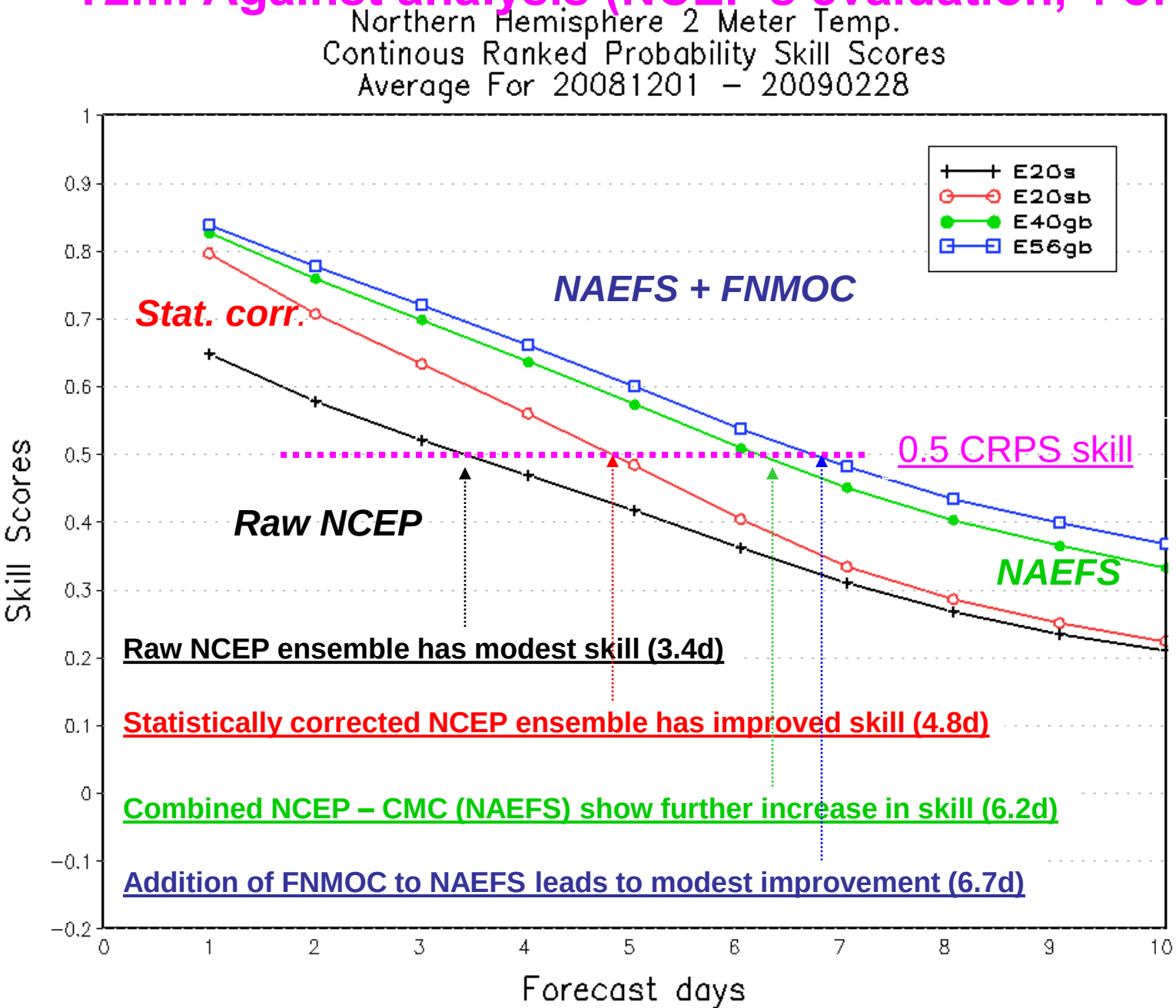
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 2 of 4)



Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 3 of 4)

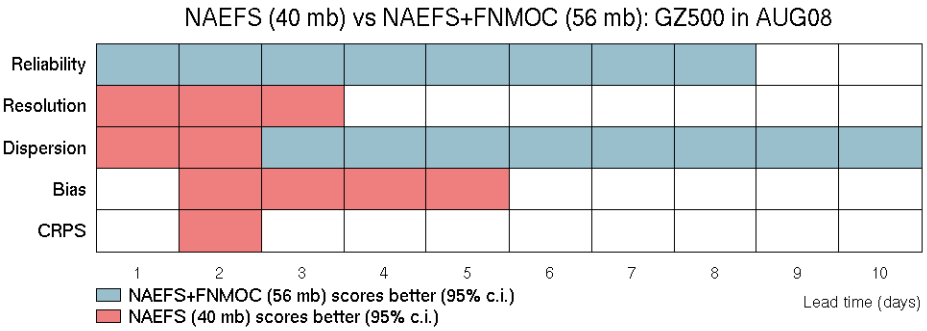


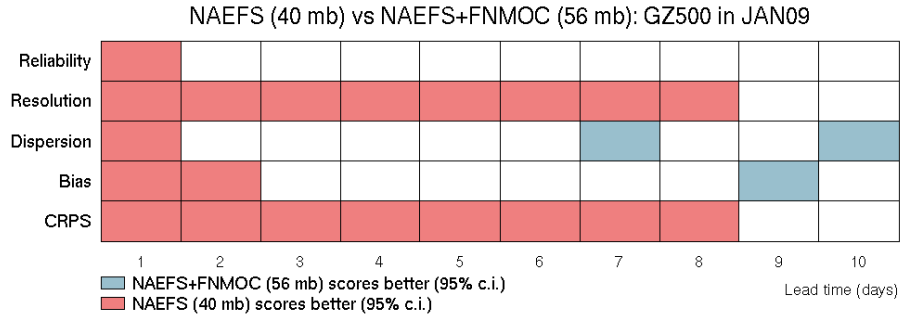
Value-added by including FNMOC ensemble into NAEFS
T2m: Against analysis (NCEP's evaluation, 4 of 4)

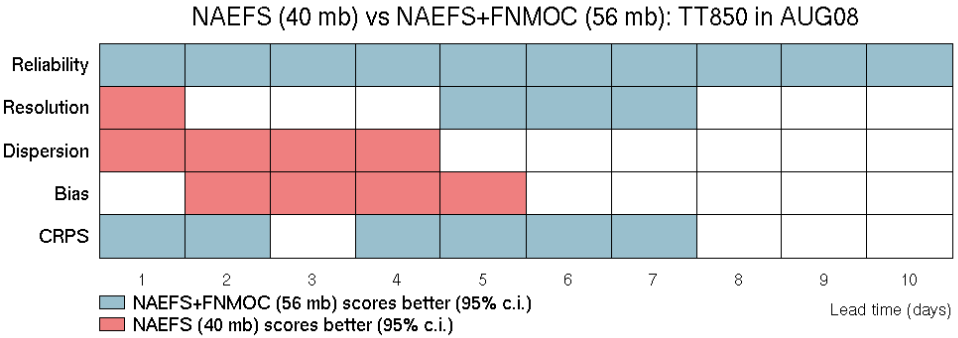


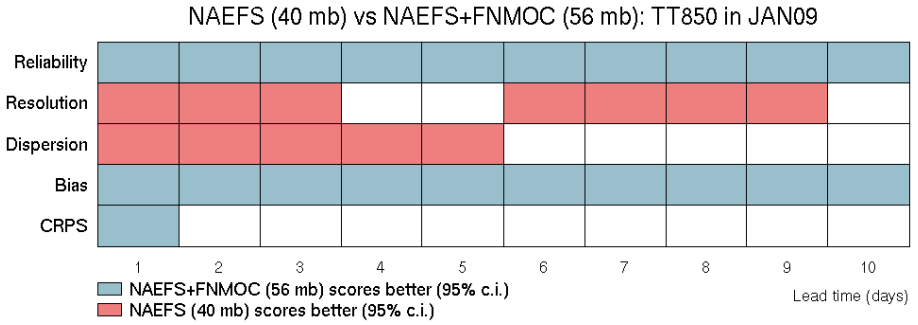
Preliminary Results from CMC (raw forecast)

Verification Against Observations



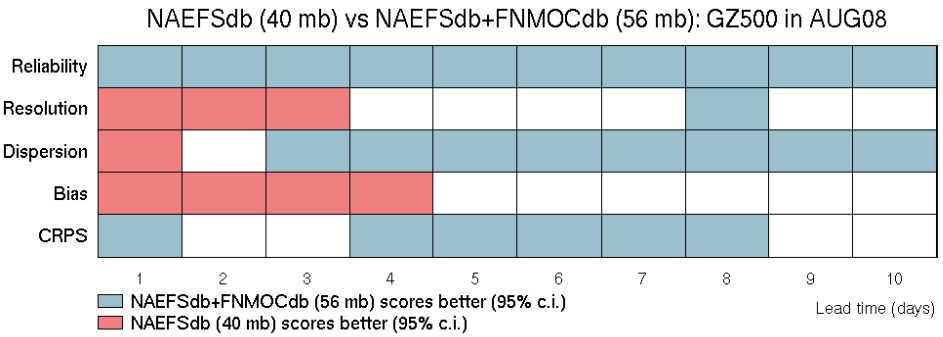


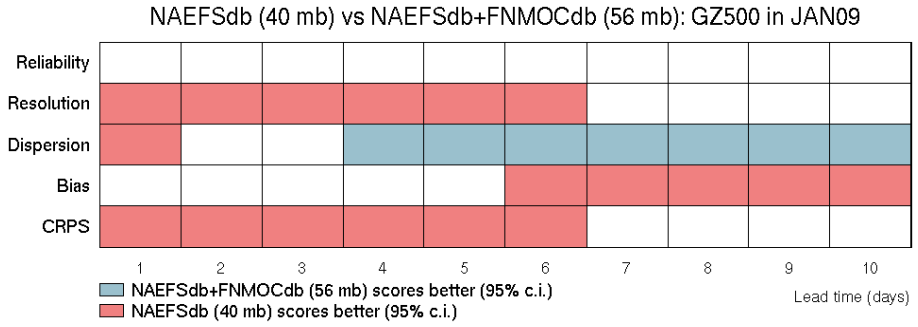


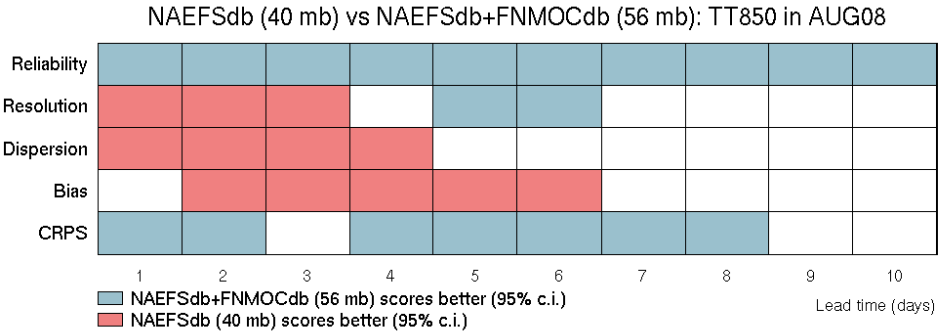


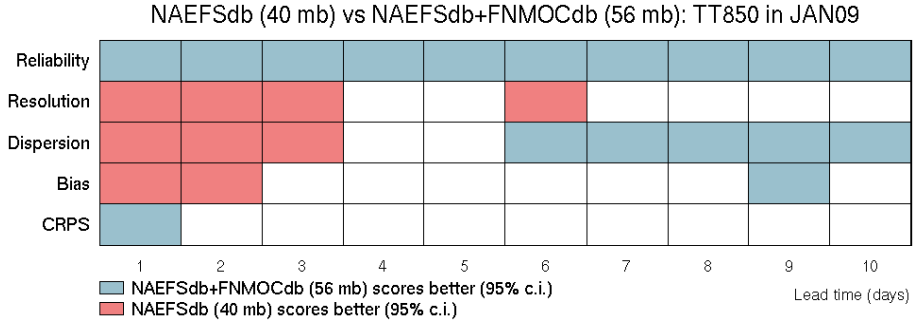
Preliminary Results from CMC (bias corrected forecast)

Verification Against Observations









Preliminary Conclusions

- **Individual ensemble systems (individual Centers' forecasts)**
  - NCEP and CMC have similar performance
  - FNMOC performance similar to NCEP & FNMOC for near surface variables, including precipitation
  - FNMOC is less skillful than NCEP and CMC for upper atmosphere variable (500hPa)

- **Combined ensemble system (without bias correction)**
  - Multi-model ensembles have higher skill than single system
  - Adding FNMOC ensemble to current NAEFS (NCEP+CMC) adds value for most forecast variables
    - Noticable improvement for surface variables
    - Minimal improvement for upper atmosphere

- **Combined ensemble system (with operational NAEFS bias correction)**
  - Improved near surface variables with FNMOC ensemble
    - NCEPbc + CMCbc + FNMOCbc
  - Less improvement for upper atmosphere (e.g. 500hPa height))
    - Some degradation for short lead times (related to large spread in FNMOC ensemble)

- **CMC evaluation against observations**
  - Preliminary results combining raw ensembles are mixed
  - Results with bias corrected data still mixed

Issues

1. **Data flow**
   - FNMOC processing at NCEP must be completed by the time NAEFS processing begins
   - Currently
     - NAEFS processing begins at 0730 and 1930 Z
     - Processing of FNMOC data takes 30 minutes
     - FNMOC delivery to NCO is 0730 and 1930 Z
   - Require 30 minute overall gain for timely availability of FNMOC ensemble for NAEFS (0730 and 1930) processing
     - Processing time at NCEP can be reduced by ~10 minutes
     - Arrival at NCEP by 0710, 1910 required (if NCEP speedup is 10 minutes)
   - Data delivery needs to be accelerated by 20 minutes
2. **FNMOC ensemble upgrades**
   - Extend forecast from 10 days to 16, and add 4 members
   - Expand variables from 52 to 80
   - Reduce initial spread in ensemble generation
   - Receive in GRIB2 format
3. **FNMOC use of MSC ensemble**
   - Optional
   - May be security issues

Recommendation and Outlook

- **NCEP plans to include FNMOC ensemble in NAEFS based on**
  - Preliminary evaluations (shown here)
  - Future improvements
    - NOGAPS 4-D Var (recently implemented)
    - Ensemble system upgrade
      - Reduced initial ensemble spread for variables related to 500hPa height
    - Extended forecast from current 10d to 16d
    - 4 additional members (16 → 20)
    - Increase variables from 52 to 80
    - Upgrade exchange data format to GRIB2 for reduced data flow
  - Earlier data delivery from FNMOC
  - Final Real Time parallel evaluation (Q3FY10) with all partners (NCEP, FNMOC, MSC) for 3-months including above improvements
    - MSC reserves right to not include FNMOC data but no decision yet

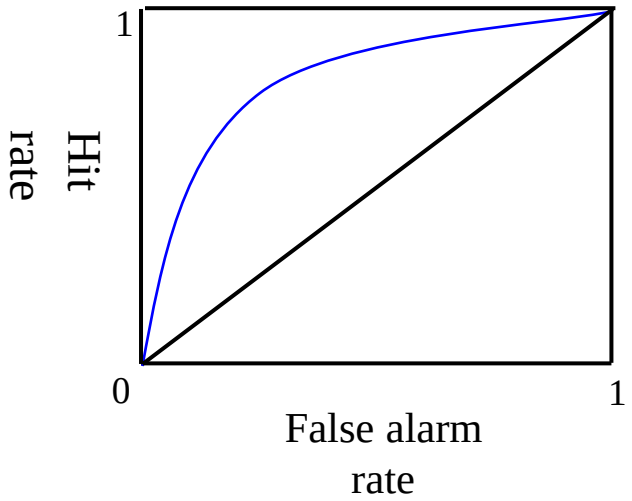
- **Proposed data flow**
  - NCEP data: NCEP to FNMOC and CMC directly
  - FNMOC data: FNMOC to NCEP, then NCEP to CMC
  - CMC data: CMC to NCEP, then NCEP to FNMOC (?)

- **Anticipated implementation: Q4FY10**
  - Address new issues as they arise

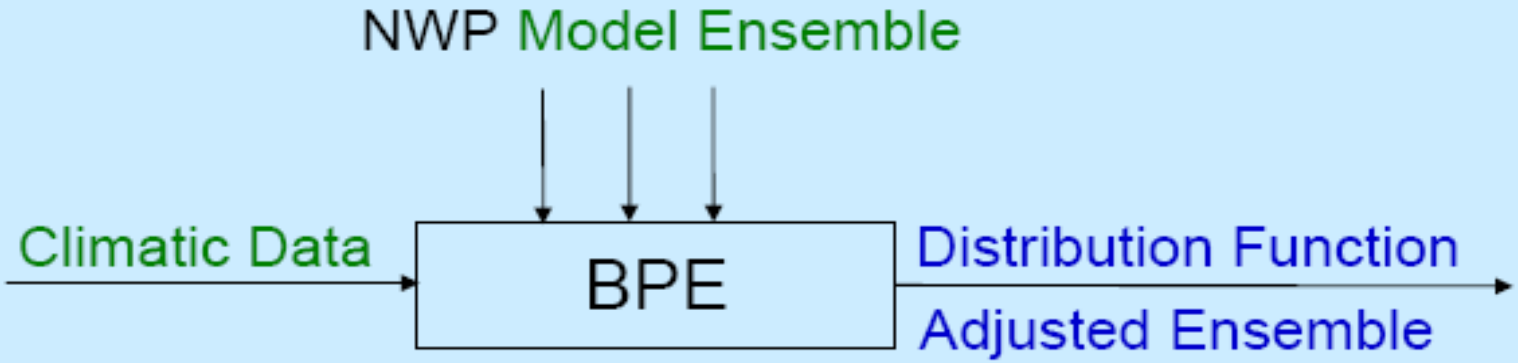
Backup

Standard Probabilistic Scores

- Continuous Ranked Probabilistic Skill Score (CRPSS)
  - Ability of ensemble to forecast the observed (climatological) distribution of values
  - Maximum value is 1.0, >0 more skillful than climatology
- Brier Skill Score (BSS)
  - Ability of ensemble to predict spatial and temporal variability of observed events (e.g. T2>10 K) skillfully (relative to climatological probability)
  - BSS=1 for perfect, BSS=0 for no skill
- Relative Operating Characteristic
  - Ability of an ensemble membership to distinguish “hits” and “false alarms”



Bayesian Processor of Ensemble (BPE)



- extracts and fuses information
- quantifies total uncertainty
- calibrates (de-biases) ensemble

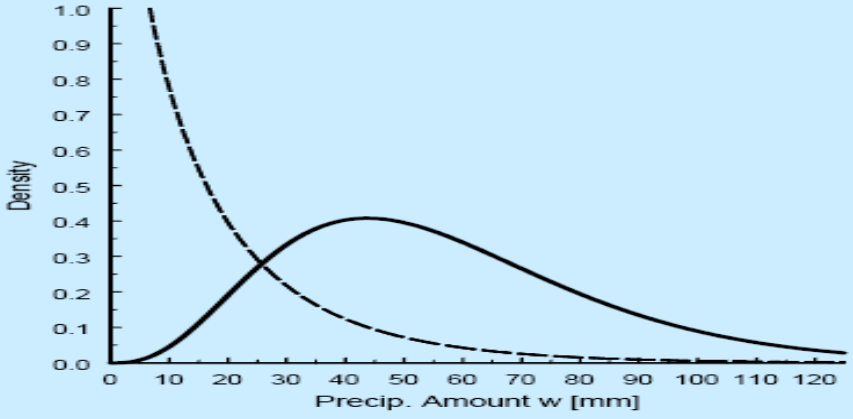
Prior d.f. $g(w)$

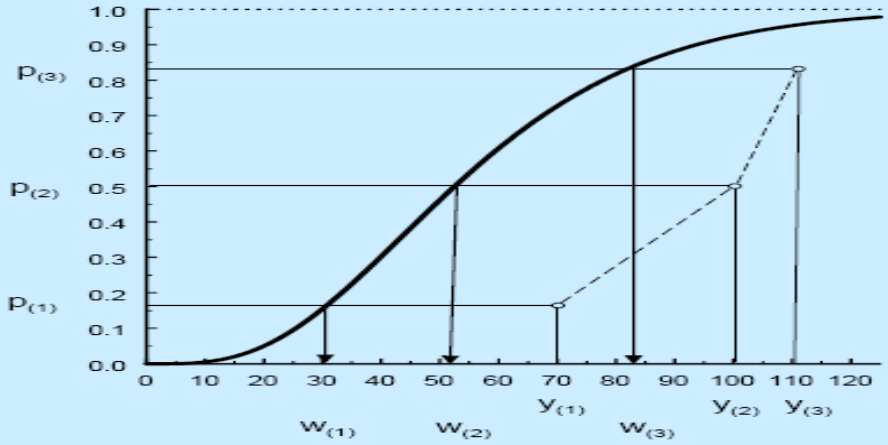
Posterior d.f. $\phi(w|\mathbf{x})$

Posterior D.F. $\Phi(w|\mathbf{x})$

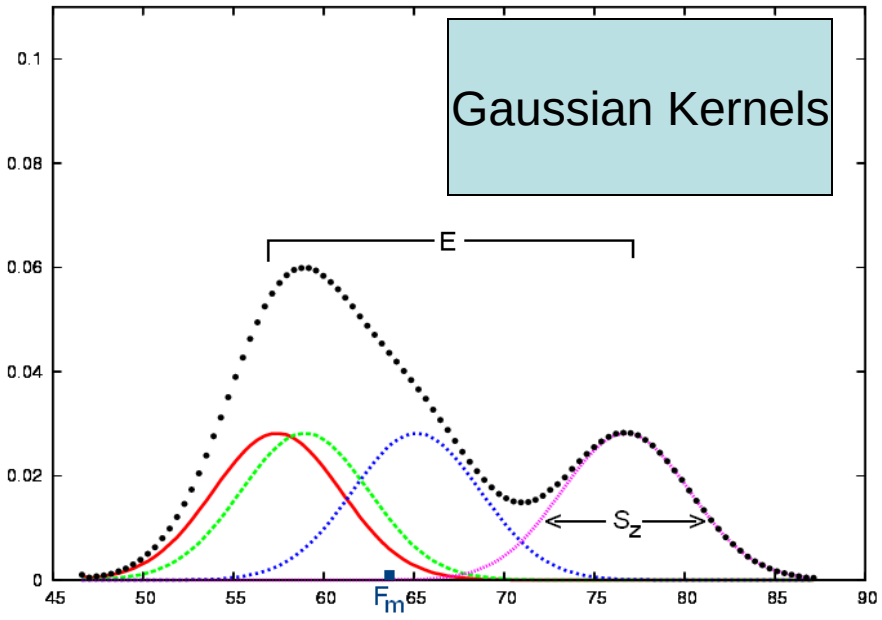
Model ensemble

Posterior ensemble





Construction of Optimum Forecast Guidance from Multi-Model Ensembles



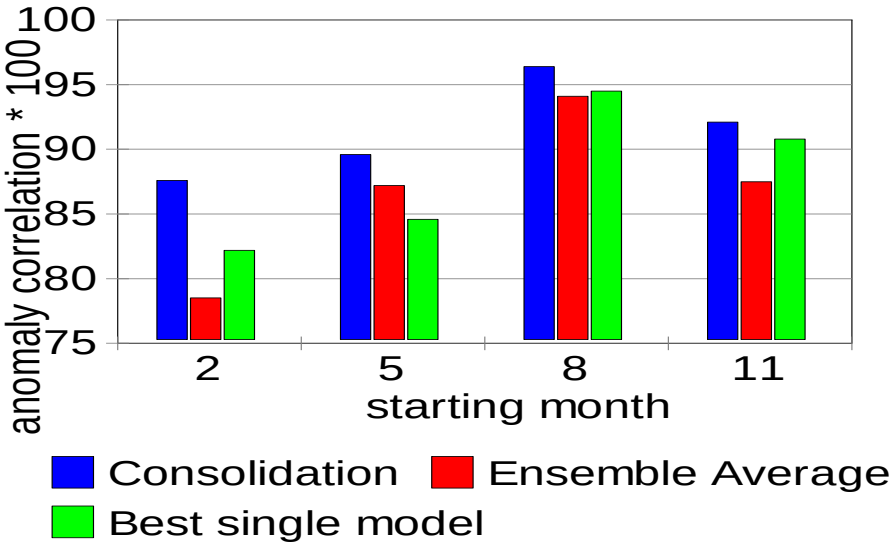
1. Multiple independent realizations
2. Historical "reforecast" data set
3. Optimal post-processing to produce "the best" forecast
4. Compact information dissemination

"Frequentist" methods

"Bayesian" methods

Potential Benefits of Using 9 I

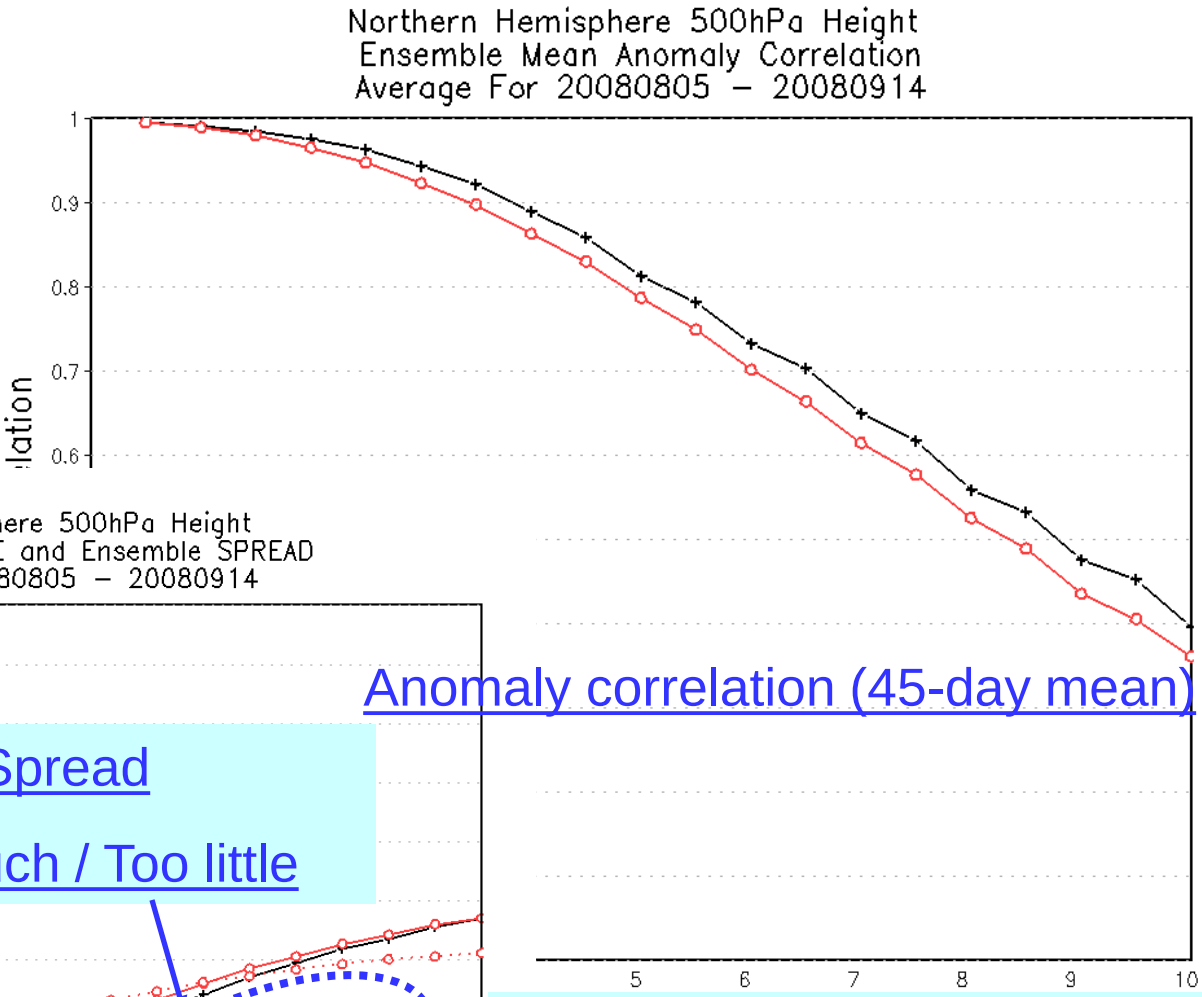
Lead 5 Nino34 forecast 1981-



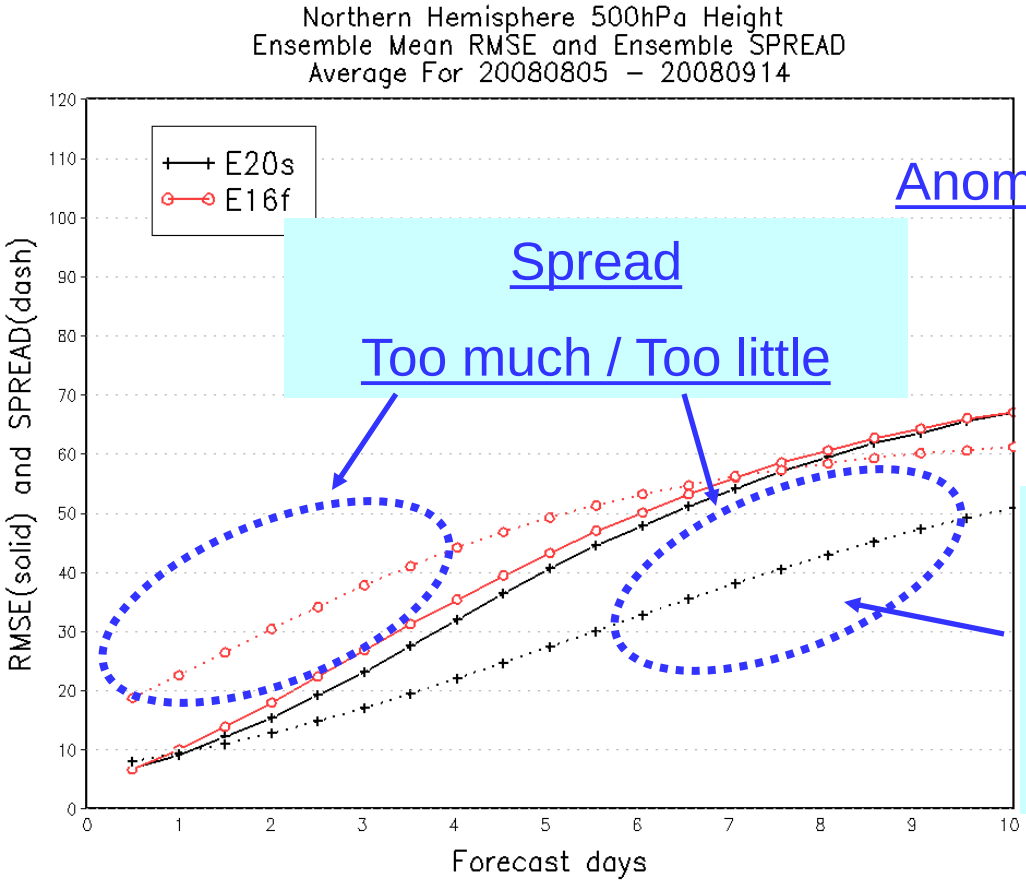
Ensemble Spread

500hPa height

(example)



Anomaly correlation (45-day mean)

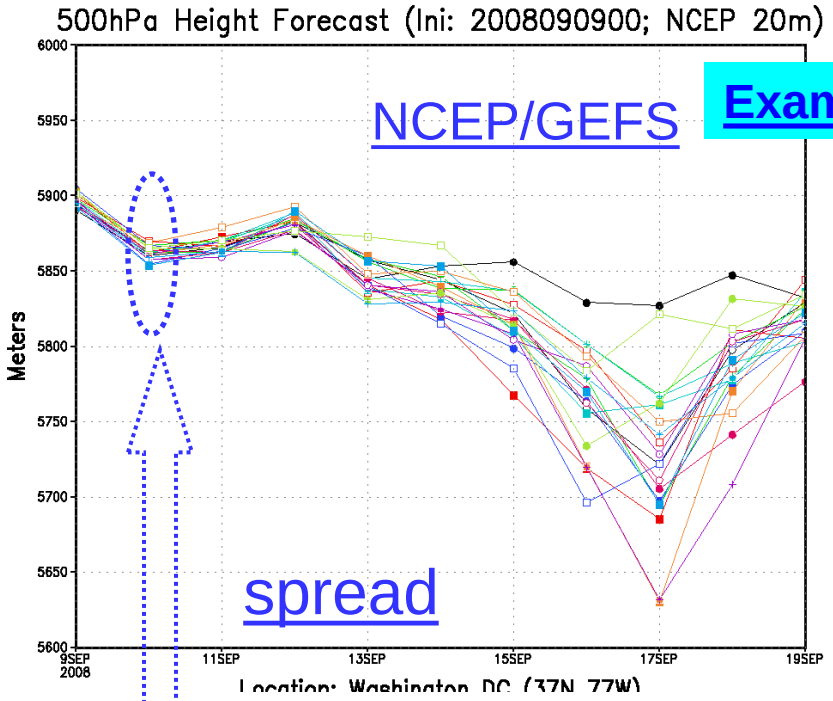


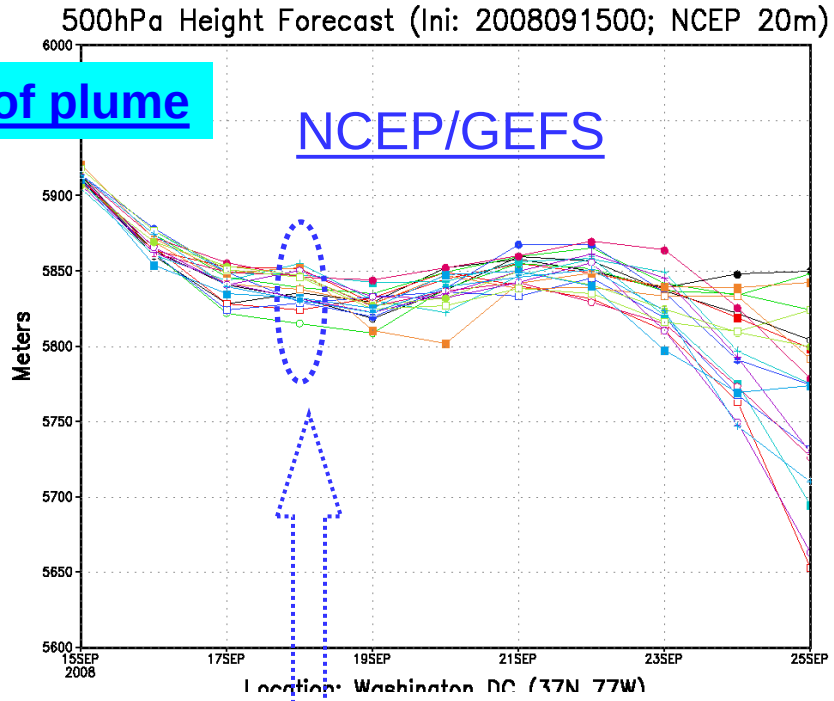
Spread

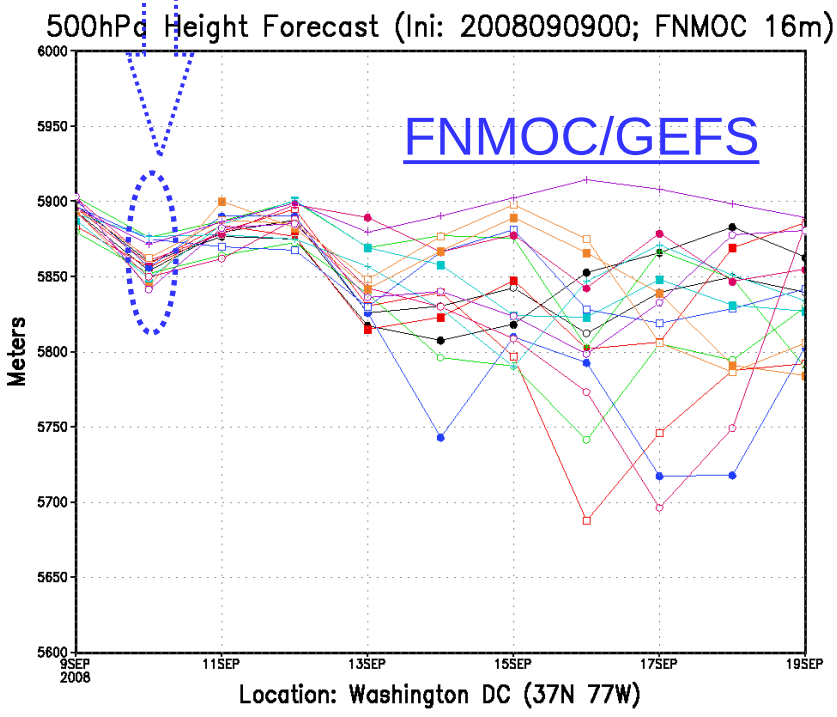
Too much / Too little

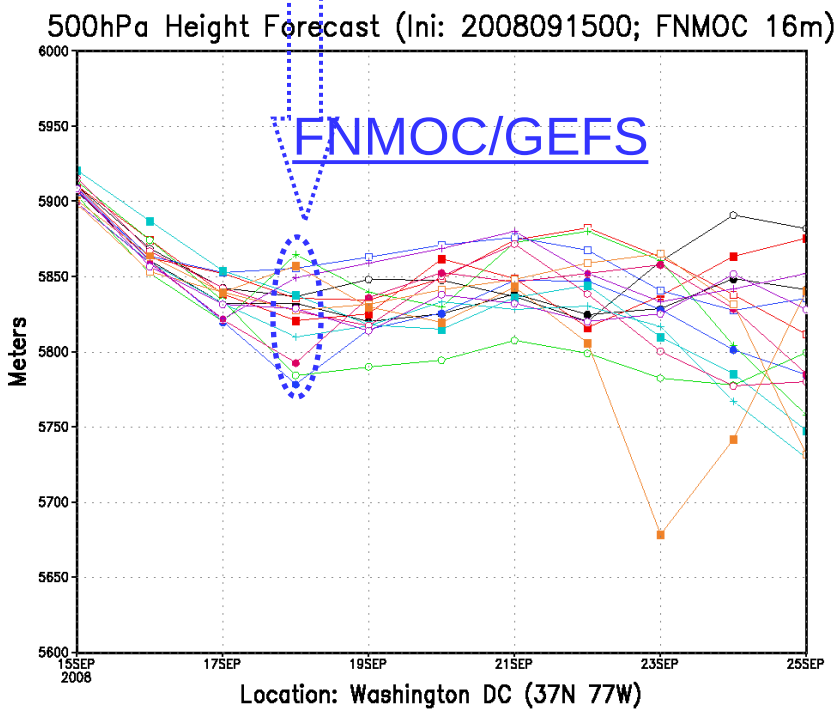
NCEP spread will be much increased after 2009 NCEP/GEFS implementation (due to introduction of stochastic scheme, higher resolution model & higher order horizontal diffusion)

Examples of plume



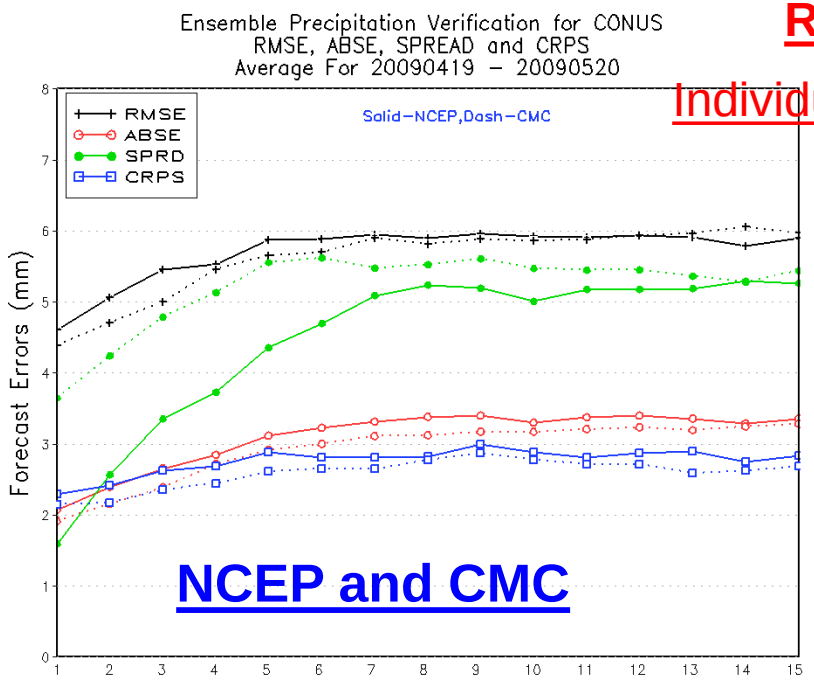




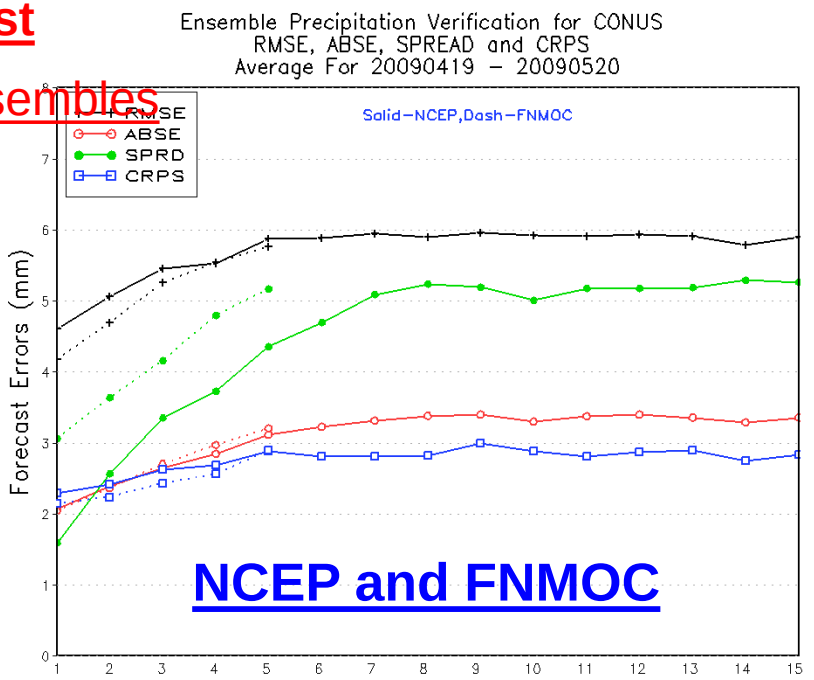


Raw Fcst

Individual ensembles

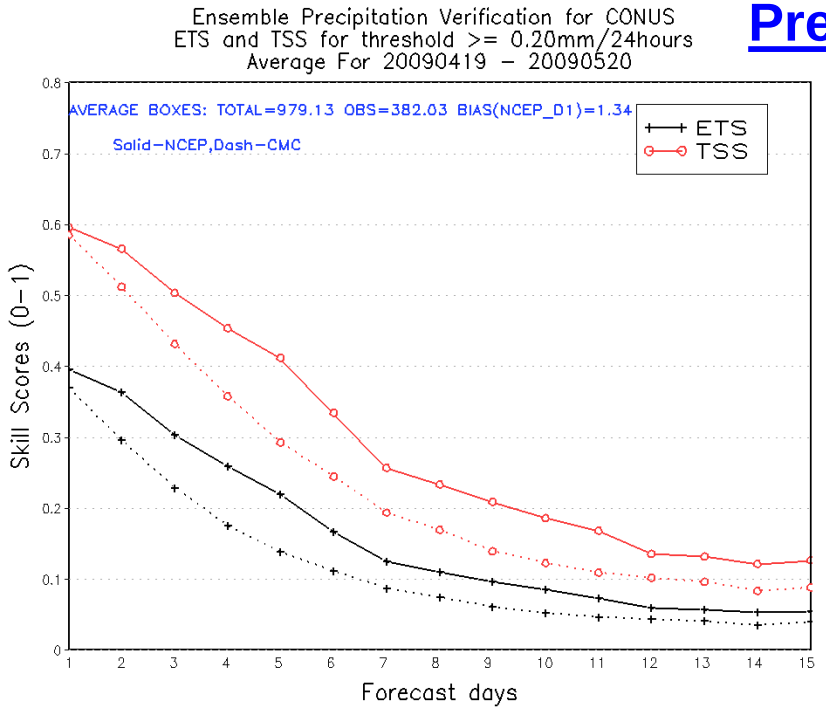


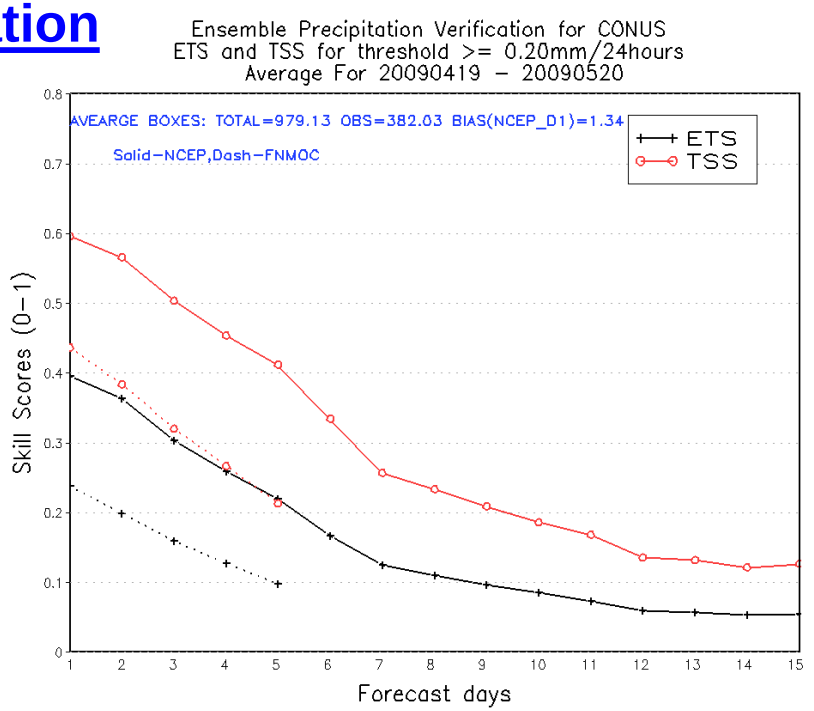
NCEP and CMC



NCEP and FNMOC

Precipitation





NEXT NAEFS exchange pgrba files

Variables	pgrba file	Total 80 (28)
GHT	Surface, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
TMP	2m, 2mMax, 2mMin, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	13 (3)
RH	2m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
UGRD	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
VGRD	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
VVEL	850hPa	1 (1)
PRES	Surface, PRMSL	2 (0)
PRCP (types)	APCP, CRAIN, CSNOW, CFRZR, CICEP	5 (0)
FLUX (surface)	LHTFL, SHTFL, DSWRF, DLWRF, USWRF, ULWRF	6 (6)
FLUX (top)	ULWRF (OLR)	1 (1)
PWAT	Total precipitable water at atmospheric column	1 (0)
TCDC	Total cloud cover at atmospheric column	1 (0)
CAPE and CIN	Convective available potential energy, Convective Inhibition	2 (1)
SOIL	SOILW(0-10cm), WEASD(water equiv. of accum. snow depth), SNOD(surface), TMP(0-10cm down)	4 (4)
Notes	Surface GHT is only in analysis file and first pgrb file when the resolution changed. 25 of 28 new variables are from pgrbb files, 10, 50hPa RH and SNOD are new variables	28 new vars

NEXT NAEFS pgrba_bc files

(bias correction)

Variables	pgrba_bc file	Total 49 (14)
GHT	10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	10 (3)
TMP	2m, 2mMax, 2mMin, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	13 (3)
UGRD	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
VGRD	10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa	11 (3)
VVEL	850hPa	1(1)
PRES	Surface, PRMSL	2(0)
FLUX (top)	ULWRF (toa - OLR)	1 (1)
		14 new vars
Notes		

Data Flow

- NCEP receives 00 and 12Z cycle data
- Data path from FNMOC to the NWS/TOC then to the NCEP/CCS
- April 2009 requirements study
  - NCO, TOC, FNMOC examined data delivery
  - Offline delivery time (for evaluation) is 11Z and 23Z
  - For operations, NCO requires data here and packaged appropriately by 730Z (1930 for the 12Z cycle) to meet the current start time of the NAEFS processing
- NCO currently receives FNMOC ensemble data 720 to 740Z for the 00Z (1930 to 2000Z for the 12Z)
- Processing takes 30 minutes
- Delivery by 0710, 1910 required (if NCEP speedup is 10 minutes)