Medium-range forecasting: latest operational HPC methodology

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Introduction

United States Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), Hydrometeorological Prediction Center (HPC) meteorologists manually produce a 3-7 day forecast product suite. Two forecasters work in tandem to complete this task and coordinate with users after the assessment of numerical, ensemble, and statistical guidance. Climatological data, observed data, and verification diagnostics are also available via N-AWIPS and AWIPS workstations and the Internet.

The HPC medium range product suite includes alphanumeric extended forecast discussions (AWIPS headers: PREEPD and PMDEPD) that address the evolution of the large scale hemispheric weather pattern, the envelope of ensemble and global model solutions, and forecast trends and differences. HPC forecaster preferences for higher weighting of particular forecast clusters within the envelop of solutions are discussed along with supporting physical reasoning, forecast confidence, and sensible weather highlights for the 3-7 day forecast period. Graphical products include: 1) 3-7 day deterministic MSLP, 500 mb, frontal, and high/low center positions for much of the Northern Hemisphere; including tropical systems as determined during a seasonal/daily conference call with the Tropical Prediction Center/National Hurricane Center (TPC/NHC), 2) 3-7 day deterministic temperature and 24 hour probability of precipitation (PoP) forecasts for the continental United States, and 3) 1-5 and 4-5 day cumulative quantitative precipitation forecasts for the continental United States. A 1-7 day alphanumeric model interpretation and precipitation forecast discussion is also produced for Hawaii (AWIPS header: PMDHI).

Seasonal products include the production of 3-7 day minimum, maximum and mean temperature heat index forecasts. Support is also provided for a Winter Storm Reconnaissance (WSR) targeted observation program (Holland et. al., 2004). This THORPEX (The Observing System Research and Predictability Experiment) regional project coordinates data gathering Pacific Ocean aircraft flights in an effort to reduce model and ensemble initialization errors in data sparse areas deemed critical for major downstream storm development with high societal impact.

HPC also produces a 4-7 day deterministic gridded forecast data set twice daily at 5 km horizontal grid spacing for the continental United States in support of the National Digital Forecast Database (NDFD). Forecast elements are daily minimum and maximum temperatures, 12 hour PoP and 6 hourly dewpoint temperature, wind speed and direction, sky cover, and weather type. Production of a corresponding probabilistic 5 km gridded product suite of manually and bias corrected North American Ensemble Forecast System (NAEFS) data is in development in conjuncture with NCEP's Environmental Modeling Center (EMC). NAEFS provides bias corrected and 5 km gridded downscaled forecasts from a combination of GEFS ensemble output from the United States and Canadian ensemble output.

HPC forecast procedure: hemispheric weather pattern diagnosis

Ensemble mean guidance, observational and analog data, five-day averaged atmospheric height analyses, and teleconnections are used to investigate trends and characteristics of the hemispheric long-wave pattern.

The first step performed in the production of a forecast is an analysis of observed surface, upper-air, and satellite data. This analysis allows a forecaster to determine the state of the atmosphere independent of model initialization errors.

Climatological cycles such as the North Atlantic Oscillation (NAO), La Nina and El Nino/Southern Oscillation (ENSO), and the Madden-Julian Oscillation (MJO) have been strongly linked to preferred storm tracks. Knowledge of these types of phenomena often enables forecasters to better determine areas prone to significant weather events. Analog analysis compares the evolution of model and ensemble forecast systems to similar observed systems that occurred within the current long-wave weather pattern or during past weather patterns with similar characteristics. An example analog analysis might indicate that intensifying storms tracked west of model or ensemble guidance or a specific geographic feature or location over the past month.

Hemispheric analyses may permit a forecaster to assess the applicability of numerical model biases and trends to the current weather regime. Teleconnections utilize historical data and refer to statistically derived distributions of atmospheric waves over a forecast domain with respect to a persistent large-scale feature as instituted by Walker (1923), O'Connor (1969), and Dunn (1983). Teleconnection on a dominant positive or negative height anomaly within a forecast domain might yield a similar or contrasting hemispheric long-wave flow pattern compared to global model or ensemble output. This information could be used to assess forecast uncertainty.

HPC forecast procedure: assess model, ensemble, and mos guidance

Current HPC forecast procedure success is largely reliant upon a proper comparison and assessment of ensemble and global model guidance. Ensemble guidance is a primary source for determining an envelope of solutions possible for a given forecast regime and provide a quantitative and qualitative assessment of forecast uncertainty. Run to run model output consistency and trends, vertical and spatial atmospheric consistency, physical reasoning, and model consistency with respect to the long-wave hemispheric weather pattern and the ensemble derived envelope of solutions are investigated. Ramifications of latest software changes and verification diagnostics are incorporated to update known characteristics and biases of the numerical models and Model Output Statistics (MOS) data.

HPC forecasters have workstation access to gridded data from the ECMWF, UKMET, Canadian (CMC), NOGAPS, and operational and experimental runs of the GFS global models. Regional models available include the NAM and DGEX. Medium range ensemble forecast guidance is available from the GEFS (Toth and Kalnay, 1993), (Tracton and Kalnay, 1993), and (Toth et. al., 1996), ECMWF, CMC, and NAEFS. Small error in numerical model initialized fields will lead to growing errors in the forecast and have shown to be a significant source of model forecast error. Ensemble forecasts provide a frequency distribution for an envelope of potential forecast solutions as derived from the application of different perturbations to the initialized atmospheric state in an effort to address forecast uncertainty. Slightly different initial conditions will produce a number of possible forecast solutions. Primary ensemble products include the ensemble mean, "spaghetti", "cluster", and spread diagrams. The ensemble mean provides on average the best single forecast by averaging out less predictable forecast components. "Spaghetti" diagrams display an array of solutions while "cluster" diagrams group forecasts that have similar hemispheric anomaly coefficients. Ensemble spread depicts the standard deviation of the ensemble forecast members as standardized by the climatological standard deviation and can be used to assess forecast uncertainty.

MOS is a statistical weather forecast system based upon derived regression equations (Glahn and Lowry, 1972). MOS provides statistical data based on GFS and GEFS output and climatological data (Jensenius et. al., 1995, Erickson, 1996). Verification statistics indicate that MOS and gridded MOS provides a skillful product suite both at point locations and for gridded forecasts. However, verification statistics and case studies indicate that sufficiently numerous and large forecast errors exist in the medium range forecast period to justify adjustments of direct model and ensemble or MOS forecasts. HPC forecast adjustments are initiated on N-AWIPS workstations via graphical user interfaces that allow creation of numerically "blended" guidance calculated from user defined weighting of GFS and GEFS MOS values, the NDFD, previous HPC forecasts, and adjusted MOS output derived from NAEFS, ECMWF, ECMWF ensemble, CMC, and DGEX based upon their mass field differences with the GFS. Verification also shows that HPC forecaster adjustments add significant value and can be supplemented by local and terrain defined corrections. In this process, a strong emphasis is made to maintain as much day-to-day forecast continuity as possible within the constraints of weather pattern stability and forecast guidance variability and spread.

Future plans

A 2006 NRC (National Research Council) report, "Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions using Weather and Climate Forecasts", along with NFUSE (NOAA/NWS Forecast Uncertainty Steering Team) evaluations, and cooperative THORPEX initiatives including NAEFS, TIGGE (THORPEX Interactive Grand Global Ensemble) archive, T-PARC (THORPEX-Pacific Asian Regional Campaign) and the IPY (International Polar Year) lend to an emerging strategic goal for NOAA/NWS/NCEP to lead the way in the development, implementation, and evaluation of probabilistic products and data to users. Accordingly, development and testing is now underway in a cooperative venture between HPC and EMC to evaluate and develop a probabilistic forecast product suite that provides a frequency distribution forecast and quantitative assessment of uncertainty for all medium range variables in addition to the current single value deterministic forecast. Frequencies will be highlighted by the 10th and 90th percentile bounds. A frequency distribution for all forecast parameters is in development at EMC from NAEFS. This distribution will be subsequently adjusted based upon HPC forecaster input after consideration of alternate ensemble and global model output and physical reasoning. EMC and HPC will work jointly, incorporate field office forecaster feedback, and develop new products and missing tools for modification, transmission, testing, and storage of products.

Evaluation and development will initially be assessed via implementation and usage through a new HPC Alaskan Desk in support of the US National Weather Service Alaskan Region forecast offices. Accepted methodologies contingent upon verification and user feedback can then be adapted for usage for other spatial domains including the continental United States. It is strongly envisaged that forecasters will continue to add significant value to the resultant probabilistic forecast suite within this new forecast paradigm.

HPC forecasts, documentation, research, and verification scores are available on the internet at:
http://www.hpc.ncep.noaa.gov.

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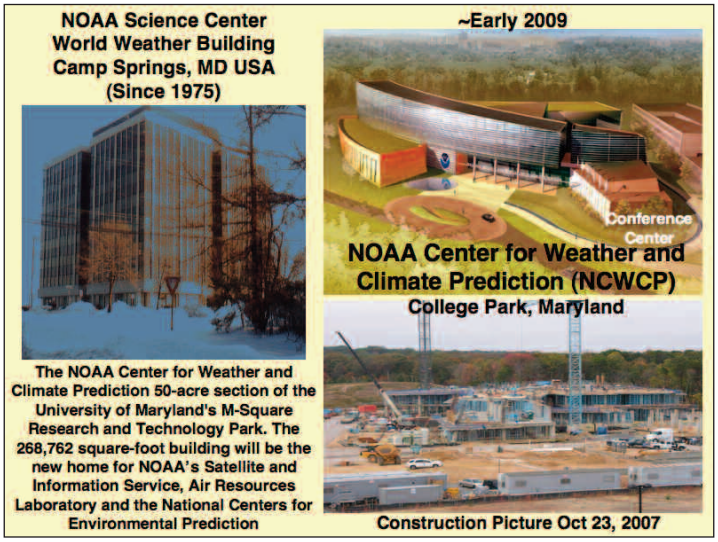
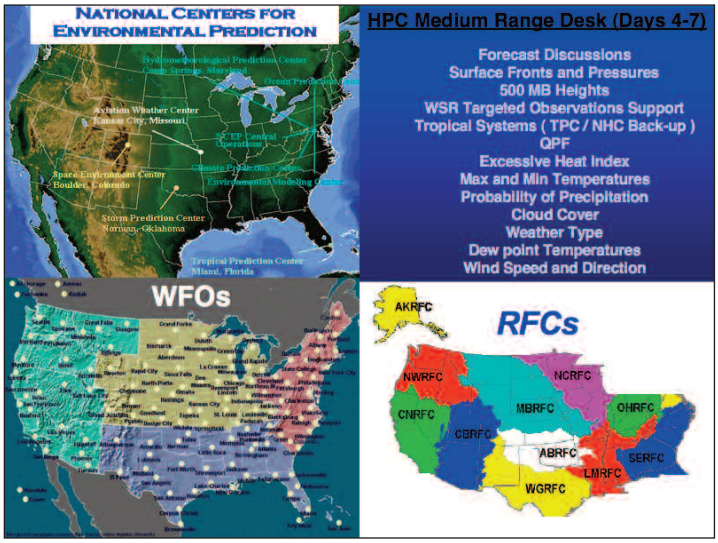
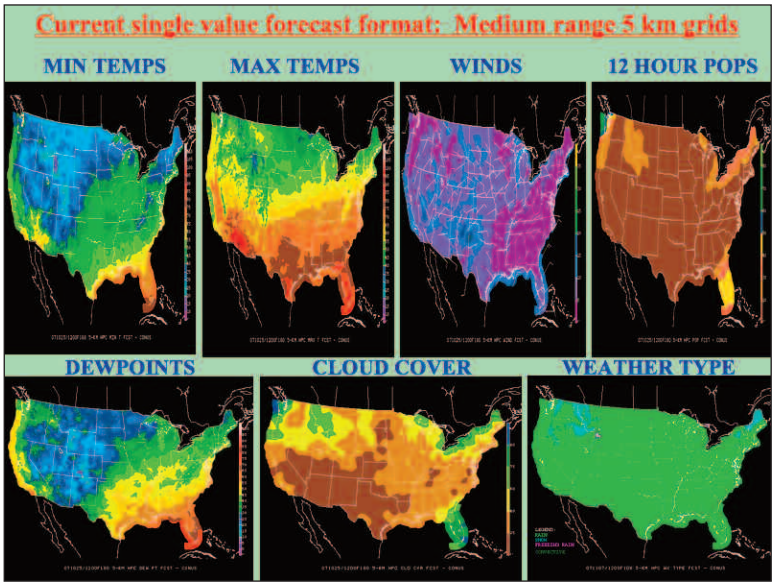
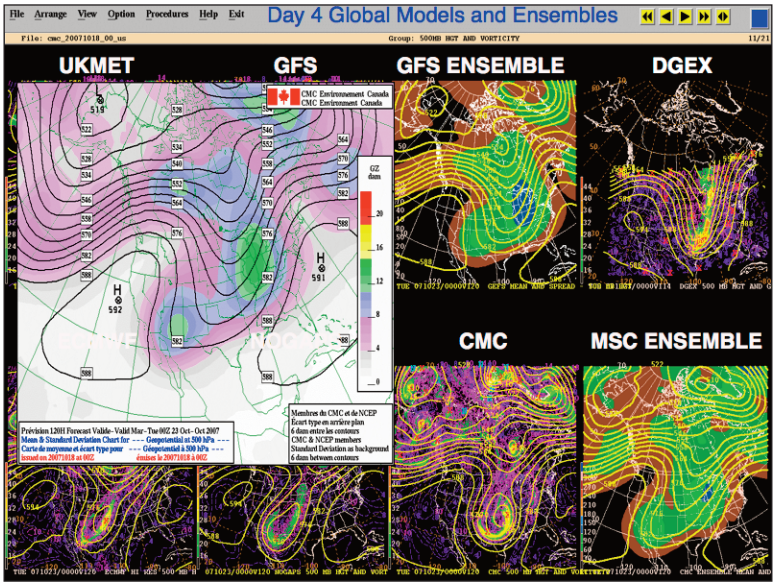


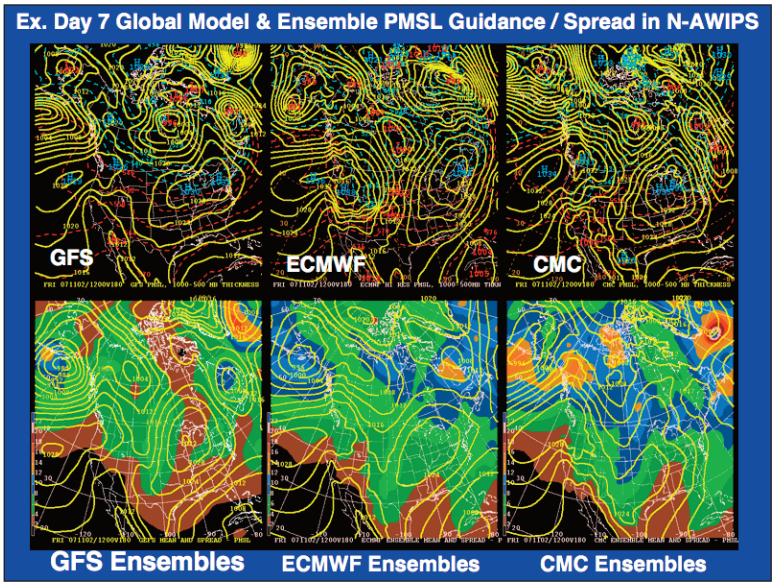


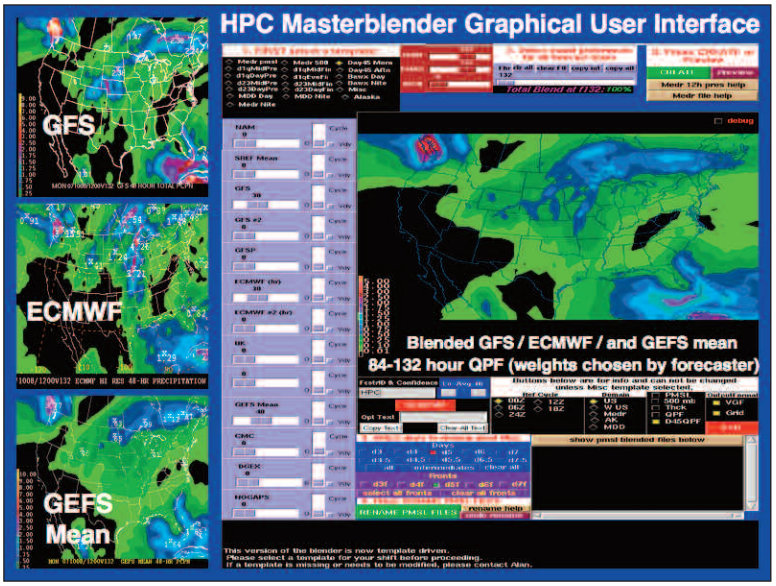


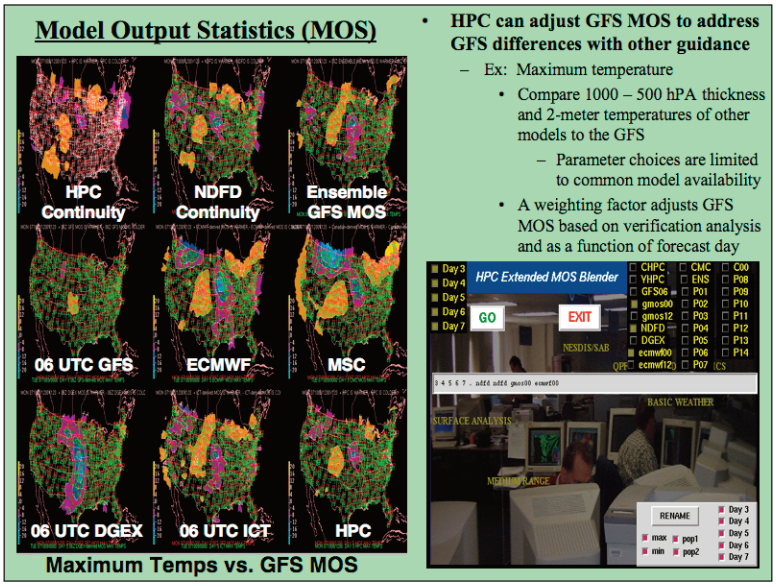
Primary Medium Range Models/Ensembles used at HPC

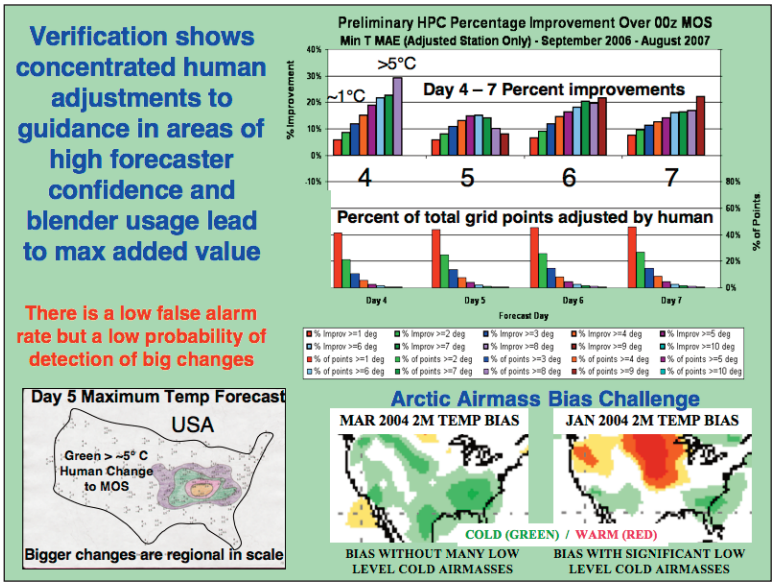
Model	Cycle (UTC)	Run Duration (Days)	Approx Min Horizontal Grid Spacing (km)	Members per Day
DGEX	06, 18	8	15	2
ECMWF	00, 12	10	20	2
ECMWF Ens.	00, 12	10	40	102
GFS	00, 06, 12, 18	16	40	4
GEM Global	00, 12	10/6	40	2
UKMET	00, 12	6	40	2
FNMOC	00, 06, 12, 18	8	55	4
NAEFS	00, 12	16	80	40
FNMOC Ens.	00	10	80	10
GFS Ens.	00, 06, 12, 18	16	80	80
GEM Ens.	00, 12	16	80	40

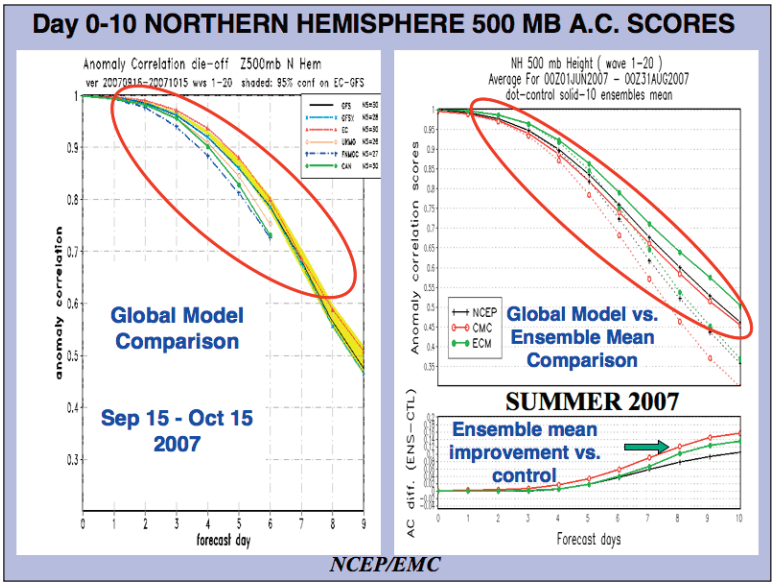



Ex. Day 7 Global Model & Ensemble PMSL Guidance / Spread in N-AWIPS
GFS
ECMWF
CMC
GFS Ensembles
ECMWF Ensembles
CMC Ensembles


HPC Masterblender Graphical User Interface
GFS
ECMWF
GEFS Mean
Blended GFS / ECMWF / and GEFS mean
84-132 hour QPF (weights chosen by forecaster)


Model Output Statistics (MOS)
HPC Continuity
NDFD Continuity
Ensemble GFS MOS
06 UTC GFS
ECMWF
MSC
06 UTC DGEX
06 UTC ICT
HPC
Maximum Temps vs. GFS MOS
HPC can adjust GFS MOS to address GFS differences with other guidance
Ex: Maximum temperature
Compare 1000 – 500 hPA thickness and 2-meter temperatures of other models to the GFS
Parameter choices are limited to common model availability
A weighting factor adjusts GFS MOS based on verification analysis and as a function of forecast day
HPC Extended MOS Blender
GO
EXIT





Changing Atmosphere

Responses to: "Look at the ensembles."

August 2003:

Why? It just tells us that there is uncertainty in the forecasts. We already knew that. (Erich Wolf prior to retirement from HPC)

October 2007:

"Show me!" (Frank Rosenstein / HPC)

"It's like Christmas! (more ensembles in N-AWIPS) (Jim Cisco / HPC)

"Who cares?" (Anonymous / HPC…not everyone agrees yet)

RNK_3: rah…basically blending the previous forecast with hpc's which looks like it is going with the average of the ensembles. Tuesday looks like a bust day for the forecast. showing a spread of the ensembles for Roanoke from high of 80 to a high of 59.
(WFO Blacksburg, VA 12Planet coordination chat to Raleigh, NC)

It would be important to hear a range of temperatures instead of just one number. I could make more informed decisions. But…what do you think will be the real temperature? The TV guy said 75. (my wife)

NOAA/National Weather Service Strategic Goals

NATIONAL RESEARCH COUNCIL (NRC) REPORT
COMPLETING THE FORECAST: CHARACTERIZING AND COMMUNICATING
UNCERTAINTY FOR BETTER DECISIONS USING WEATHER AND CLIMATE FORECASTS

- "NWS should take a lead role…"
- Provide ensembles at various scales and applications
- Engage and educate users, partners, social science in product development and use
  - THORPEX
  - North American Ensemble Forecast System (NAEFS)
  - Test-beds (example: NCEP / HPC Alaskan Desk)
  - T-PARC (THORPEX-Pacific Asian Regional Campaign) / IPY (International Polar Year)
    - Tropical Cyclogenesis (Western Pacific, Aug-Sep 2008)
    - Extratropical Transition (Western Pacific, Aug-Sep 2008)
    - Winter Phase (North Pacific, Jan-Feb 2009)

    Strong participation from Asia:
    - Dr. L. Uccellini visited CMA in October 2007
      - » CMA interested in possibly joining NAEFS (other centers? / logistical issues?)
      - » TIGGE collaboration
      - » Beijing Olympics demo project
  - Provide access to all forecast data / verification information
- "…no forecast is complete without a description of its uncertainty"

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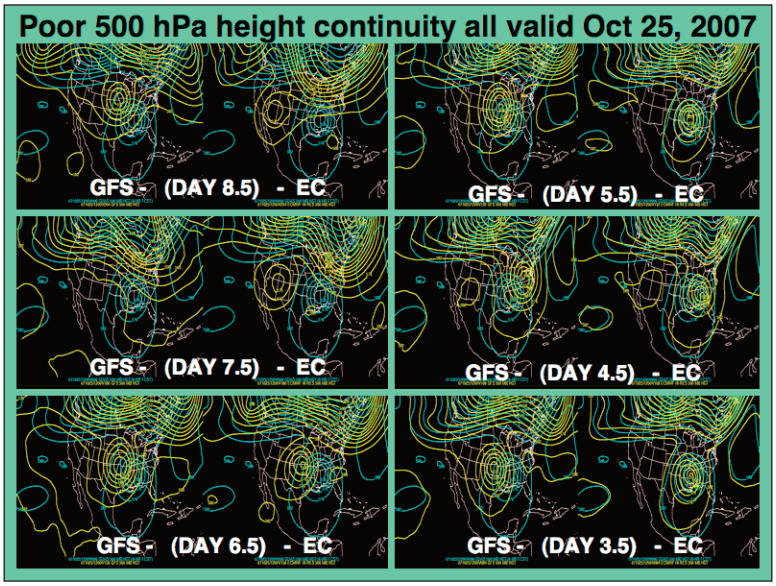
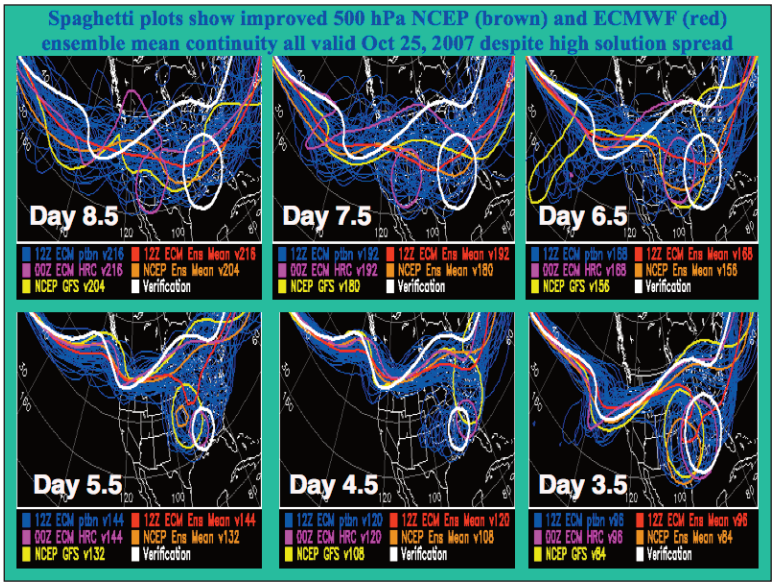
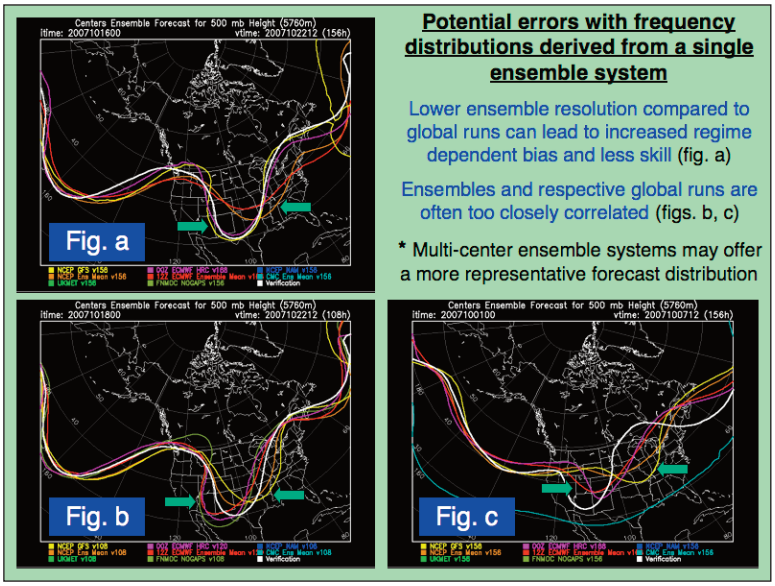
Challenges

- **Communication / Interaction / Cooperation:**
  - Research community, forecasters, management, public sector
  - Workshops and conferences
  - Data and guidance exchange
- **Science:**
  - New and varied model and ensemble methodologies
  - Verification (skill and continuity)
- **Resource priority:**
  - Computational costs
  - Transmission limitations
  - Data and guidance storage limitations
  - User deadlines
- **Availability:**
  - User friendly format
  - General and sophisticated user training and feedback







NORTH AMERICAN ENSEMBLE FORECAST SYSTEM

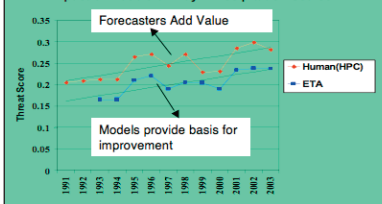
- Operational multi-center ensemble products coordinated among National Weather Services of Canada, Mexico, US
- Combines global ensemble forecasts from Canada & USA
  - 40 members per cycle, 2 cycles per day from MSC & NWS
    - 6-hourly output frequency out to 16 days
    - 1x1 lat / lon resolution
- Generates products for
  - Intermediate users
    - E.g., weather forecasters at NCEP Service Centers (US NWS)
  - Specialized users
    - E.g., hydrologic applications in all three countries
  - End users
    - E.g., forecasts for public distribution in Canada (MSC), Mexico (NMSM), Caribbean, South America, Africa (AMMA)
- Prototype ensemble component of THORPEX Global Interactive Forecast System (GIFS)
  - Operational outlet for THORPEX research using THORPEX Interactive Grand Global Ensemble (TIGGE) archive
    - Distribution
      - Ftp – *http://nomad5.ncep.noaa.gov/ncep_data/*

NOMADS
The NOAA Operational Model Archive and Distribution System

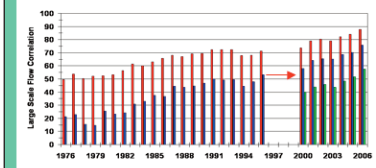
THORPEX GOAL

- Accelerate improvements in skill & utility of high impact forecasts
  - Forecaster improvements are strongly related to advances in NWP skill and access to information

Impact of Models on Day 1 Precipitation Scores

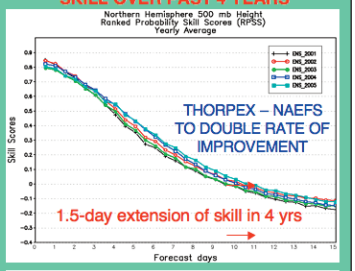


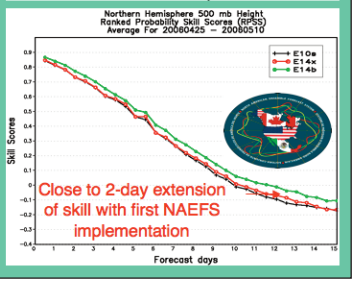
HPC Medium Range Verification
No. American MSLP Forecast Skill



NCEP / HPC Day 7 forecast skill in 2006 equals day 5 skill in 2000 (2 day increase in 6 years)

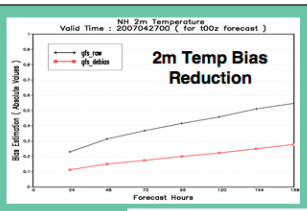
IMPROVEMENT IN PROBABILISTIC SKILL OVER PAST 4 YEARS

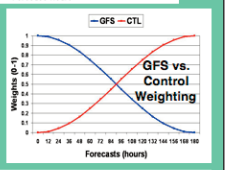


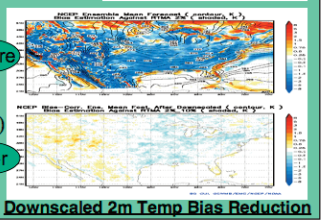


NAEFS Planned Upgrade December 4, 2007

- ❑ Bias corrected GFS forecast
  - Use the same algorithm as ensemble bias correction up to 180 hours
- ❑ Combine bias corrected GFS and ensemble forecast
  - GFS has higher weights at short lead times
- ❑ NAEFS new products
  - Combine NCEP/GEFS (20m) and CMC/GEFS (20m)
  - Produce Ensemble mean, spread, mode, 10% 50% and 90% probability forecast at 1*1 degree resolution
  - Anomaly forecast from ensemble mean
- ❑ Statistical downscaling by using RTMA as reference
  - At NDGD resolution (5km), CONUS only
  - Generate mean, mode, 10%, 50% (median) and 90% probability forecasts
  - Variables (surface pressure, 2-m temperature, and 10-meter wind)

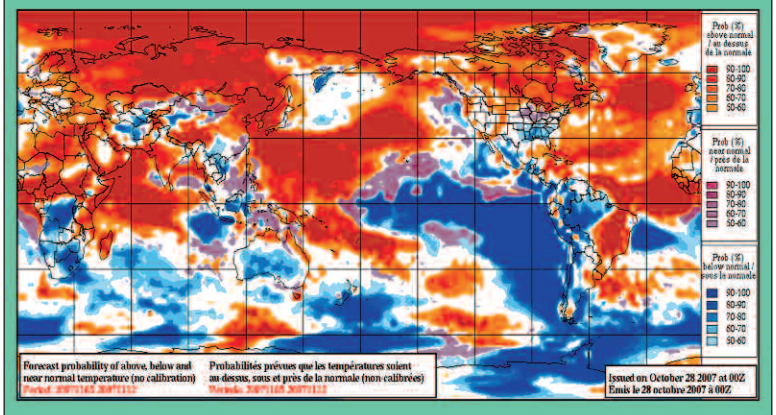




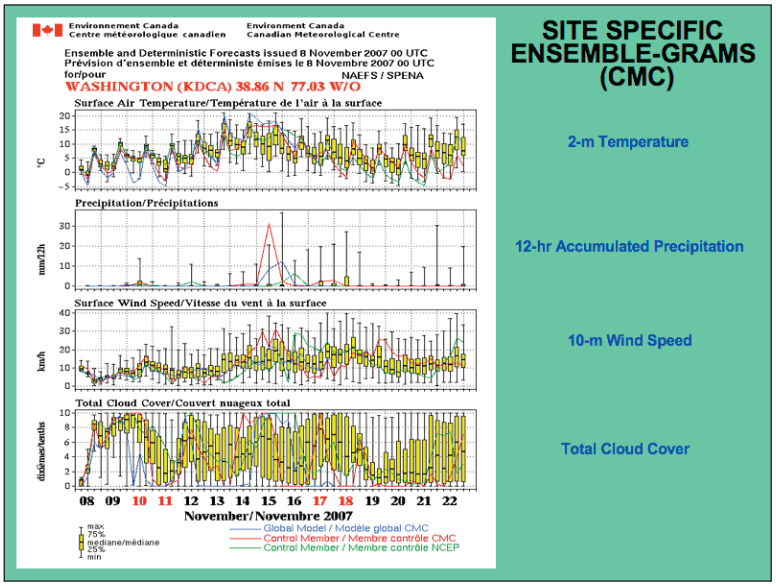


Downscaled 2m Temp Bias Reduction

NAEFS product example: Week-2 Mean Temperature



http://meteo.ec.gc.ca/ensemble/index_naefs_e.html



SITE SPECIFIC ENSEMBLE-GRAMS (CMC)

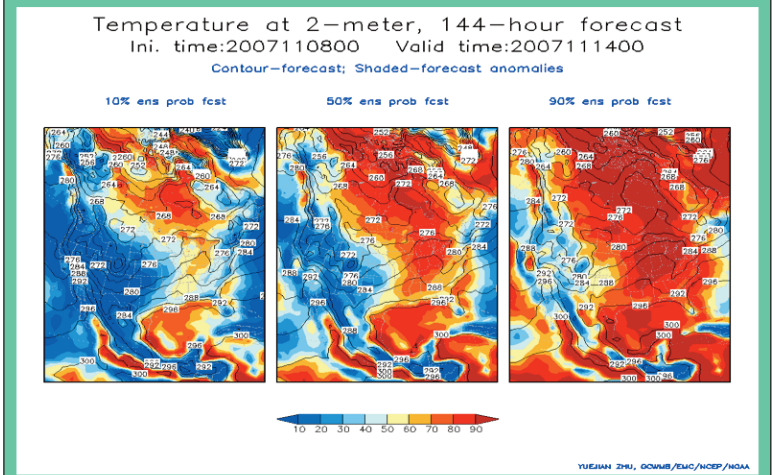
2-m Temperature

12-hr Accumulated Precipitation

10-m Wind Speed

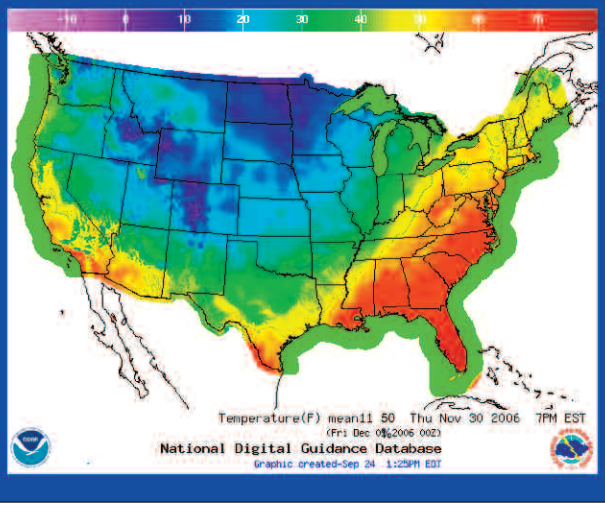
Total Cloud Cover

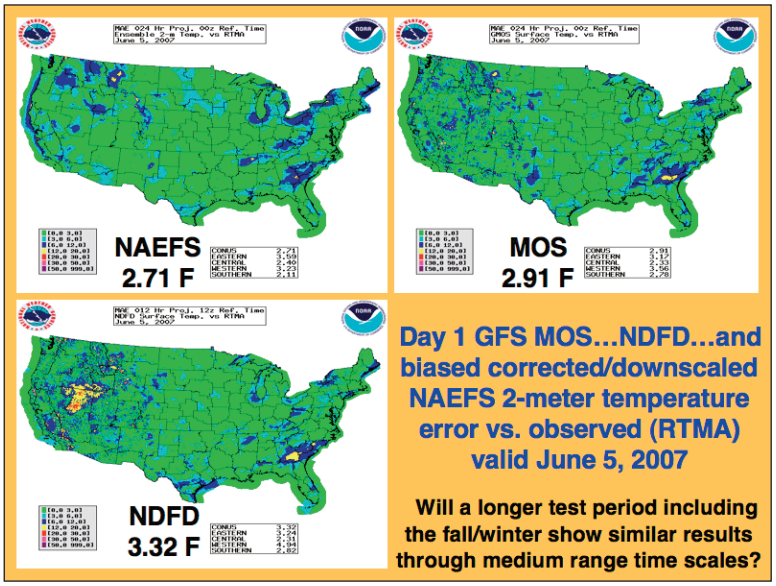
ENSEMBLE 10-, 50- (MEDIAN) & 90-PERCENTILE FORECAST VALUES (BLACK CONTOURS) AND CORRESPONDING CLIMATE PERCENTILES (SHADES OF COLOR



Example of probabilistic forecast in terms of climatology

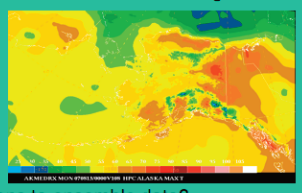
Gridded GFS MOS 5–95% Temperature Probability Forecast





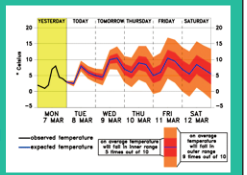
NCEP HPC / EMC COLLABORATION FOR A NEW ALASKAN DESK IN DEVELOPMENT

- Context
  - Alaska Desk considered experimental ground for new uncertainty products
  - After testing…consider introduction of products / procedures to other regions
- Activities
  - Jointly identify format of new products (HPC / EMC)
  - Develop ensemble-based numerical guidance for new products (EMC)
  - Operationally implement numerical guidance (EMC / NCO)
  - Develop missing tools for modification / transmission / storage of new products (HPC / EMC / NCO)
  - Experimental forecast activities (testing, feedback: HPC / Alaska Region / EMC)
- Envisaged flow of steps in operations
  - Numerical guidance generated by NCO
  - HPC modifies numerical guidance
  - HPC guidance sent to AR WFOs
  - AR modifies guidance if needed
  - Final NDFD (or NDGD) product
  - Back-propagate HPC forecaster modifications to ensemble data?

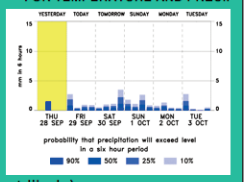


PROPOSED FORECAST FORMAT

- In addition to most likely value that is in NDFD now
  - Add two bounds corresponding to two percentile values in forecast distribution
- Specific format
  - Mid-point value
    - Use mode (not mean or median)
      - Most intuitive
      - Allows for generalization when multiple modes considered
  - Extreme bounds
    - Use 10 & 90 percentile
      - Encompasses 80% of distribution
      - More extreme values may not be statistically that reliable
- Necessary tools
  - Derive parameters from NAEFS ensemble
    - For numerical guidance
      - Bounds
      - Mode
  - Field modification – available in N-AWIPS (just like most likely)
    - Move entire distribution (i.e., bounds) if only mode modified
    - Convert three values to full pdf distribution
    - Derive additional products

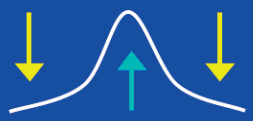


EXAMPLES FROM UKMET OFFICE FOR TEMPERATURE AND PRECIP



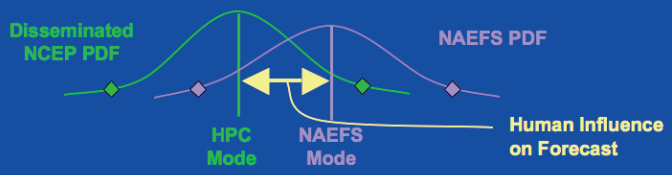
Alaska Medium Range Desk (developments so far)

- A probability density frequency (PDF) curve will be developed from the NAEFS and bias-corrected
- From the PDF, magnitudes of the 10th and 90th percentiles will initially be calculated for:
  - Maximum Temperature
  - Minimum Temperature
  - Wind Speed and direction



- Employing a downscaling vector, the 10th and 90th percentile values will be converted from a 1° by 1° grid to a 5 km grid.

- Developments thus far (cont):
  - The HPC forecast will then be compared to the mode of the PDF, and the grids will be adjusted towards the HPC forecast if there is a difference.



  - Alaska will be the first Region to receive medium range grids from HPC that include probabilistic bounds for meteorological variables
  - HPC hopes to use a similar method for introducing a sense of "what's meteorologically possible" into the NDFD over the lower 48 states

- Developments thus far (cont):
  - Additional variables are under consideration for inclusion into the HPC Alaska Medium Range grids:
    - QPF: The idea of negative precipitation would be introduced to indicate how close the model is to producing qpf, rather than the typical QPF yes or no. This will require hires gridded observationally-based analysis of precipitation.
    - Cloud Cover
    - Dewpoint
    - More?

Links with NOAA/NWS Forecast Uncertainty Service Evolution Steering Team (NFUSE) PLANS

- Current system
  - **Single value format**
- Short-term (2-3 yrs) plan – **3 values format** (pdf)
  - Provide best (bias corrected) numerical guidance in agreed upon format
  - Human forecasters modify numerical guidance using agreed upon format
  - External users provided with products in format of their choice
- Long-term (5-10 yrs) plan – **ensemble format**
  - Provide best numerical guidance in agreed upon format
  - Human forecasters modify numerical guidance using agreed upon format
    - Propagate information to modify bias corrected ensemble data
      - Modified bias corrected ensemble data is complete and final forecast dataset includes uncertainty information regarding spatial, temporal, cross-variable co-variances
      - Forecasters need ensemble access for:
        - » Manipulation (added value)
        - » Interpretation (user outreach)
  - External users provided with products in format of their choice