New Ensemble Probabilistic Forecasts Generation

(North American Ensemble forecast System)

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Highlights

• North American Ensemble Forecast System (NAEFS)
  • Milestones
  • NAEFS Statistical Post-Processing System (SPP) review

• Values of NAEFS products
  • Objective evaluations/Comparison/User appreciations

• Future Plans for new ensemble probabilistic forecasts generation
  • High resolution downscaled probabilistic fcst. for CONUS (2.5km) and Alaska (3km) with additional variables
  • Blender – Recursive Bayesian Model Process
  • Variable decaying weights
  • Reforecast
  • 2nd moment adjustment
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
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
    • CONUS/Alaska expansion – Aril 8, 2014 Version 4
  – Implementation for high resolution CONUS/Alaska
    • 2.5km for CONUS/ 3km for Alaska – Q4FY15 Version 5

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

• NAEFS products
  • Combine NCEP/GEFS (20m) and CMC/GEFS (20m), FNMOC ens. will be in soon
  • Produce Ensemble mean, spread, mode, 10% 50%(median) and 90% probability forecast at 1*1 degree resolution
  • Climate anomaly (percentile) forecasts also generated for ens. mean

• Statistical downscaling
  • Use RTMA as reference - NDGD resolution (5km/6km), CONUS and Alaska
  • Generate mean, mode, 10%, 50%(median) and 90% probability forecasts
# NAEFS bias corrected variables

*Last upgrade: April 8th 2014 - (bias correction)*

<table>
<thead>
<tr>
<th>Variables</th>
<th>pgrba_bc file</th>
<th>Total 51</th>
</tr>
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<tbody>
<tr>
<td><strong>GHT</strong></td>
<td>10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa</td>
<td>10</td>
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<tr>
<td><strong>TMP</strong></td>
<td>2m, 2mMax, 2mMin, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa</td>
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<tr>
<td><strong>UGRD</strong></td>
<td>10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa</td>
<td>11</td>
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<tr>
<td><strong>VGRD</strong></td>
<td>10m, 10, 50, 100, 200, 250, 500, 700, 850, 925, 1000hPa</td>
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<tr>
<td><strong>VVEL</strong></td>
<td>850hPa</td>
<td>1</td>
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<tr>
<td><strong>PRES</strong></td>
<td>Surface, PRMSL</td>
<td>2</td>
</tr>
<tr>
<td><strong>FLUX (top)</strong></td>
<td>ULWRF (toa - OLR)</td>
<td>1</td>
</tr>
<tr>
<td><strong>Td and RH</strong></td>
<td>2m</td>
<td>2</td>
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<tr>
<td><strong>TCDC</strong></td>
<td>Total Cloud Cover</td>
<td>1</td>
</tr>
<tr>
<td><strong>Notes</strong></td>
<td>CMC and FNMOC do not apply last upgrade yet</td>
<td></td>
</tr>
</tbody>
</table>
### NAEFS downscaling parameters and products

**Last Upgrade: April 2014 (NDGD resolutions)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Domains</th>
<th>Resolutions</th>
<th>Total 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Pressure</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
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</tr>
<tr>
<td>2-m temperature</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>10-m U component</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>10-m V component</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>2-m maximum T</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>2-m minimum T</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>10-m wind speed</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>10-m wind direction</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>2-m dew-point T</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
<tr>
<td>2-m relative humidity</td>
<td>CONUS/Alaska</td>
<td>5km/6km</td>
<td>1/1</td>
</tr>
</tbody>
</table>

All downscaled products are generated from 1*1 degree bias corrected fcst. globally. Products include ensemble mean, spread, 10%, 50%, 90% and mode.
NAEFS Bias Correction (Decaying average method)

1). Bias Estimation:

\[ b_{i,j} (t) = f_{i,j} (t) - a_{i,j} (t_0) \]

2). Decaying Average (Kalman Filter method)

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

3). Decaying Weight: \( w = 0.02 \) in GEFS bias correction (~ past 50-60 days information)

4). Bias corrected forecast:

\[ F_{i,j} (t) = f_{i,j} (t) - B_{i,j} (t) \]

Simple Accumulated Bias
Assumption: Forecast and analysis (or observation) is fully correlated
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
Highlights

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  - Milestones
  - NAEFS Statistical Post-Processing System (SPP) review

• **Values of NAEFS products**
  • Objective evaluations/Comparison/User appreciations

- Future Plans for new ensemble probabilistic forecasts generation
  - High resolution downscaled probabilistic fcst. for CONUS (2.5km) and Alaska (3km) with additional variables
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  - Variable decaying weights
  - Reforecast
  - 2nd moment adjustment
RTMA Region 2m Temperature
Averaged From 2007090100 to 2007093000

NCEP/GEFS raw forecast

4+ days gain from NAEFS

NAEFS final products

From:
- Bias correction (NCEP, CMC)
- Dual-resolution (NCEP only)
- Combination of NCEP and CMC
- Down-scaling (NCEP, CMC)
Surface minimum temperature for 40 days (2/20/2012 – 3/30/2012) after GEFS upgrade.

Average MAE improvements:

14% from NCEP GEFS post-process only
23% from NAEFS – final product
Highlights

• NAEFS Statistical Post-Processing System (SPP) review
  – Milestones
  – Current status and performance
• Values of NAEFS products
  – Objective evaluations/Comparison/User appreciations
• Future Plans
  1. High resolution downscaled probabilistic forecast
     – 2.5km NDGD fields for CONUS extended area (new variable, TCDC)
     – 3km NDGD fields for Alaska (new)
  2. Variable decaying weights
  3. Blender – Recursive Bayesian Model Process
  4. Reforecast
  5. 2nd moment adjustment
COMUS Domain Change for NAEFS Upgrade

CONUS at 5km
Production at 20150427 00z

CONUS with extended area at 2.5km
Parallel at 20150427 00z
CONUS Downscaled Product Samples (T2m 48hr Fcst)

Before Upgrade

Prod GEFS CONUS at 5km

Para GEFS CONUS at 2.5km

Prod NAEFS CONUS at 5km

Para NAEFS CONUS at 2.5km
Statistical Verification from 20150311 to 20150427

prod_gefs_2p5: production GEFS downscaled product interpolated to 2.5km
prod_naeFs_2p5: production NAEFS downscaled product interpolated to 2.5km
para_gefs_2p5: parallel GEFS downscaled product at 2.5km
para_naeFs_2p5: parallel NAEFS downscaled product at 2.5km

CONUS at 2.5km (prod_gefs_2p5 & prod_naeFs_2p5 from interpolation of 5km forecasts)
Statistical Verification from 20150411 to 20150516
TCDC Bias Correction

**Egefs**: production GEFS raw forecast

**Egefs_testbc**: GEFS bias corrected forecast

**Enaefs_testbc**: GEFS bias corrected and CMC raw forecast combination
Highlights

• NAEFS Statistical Post-Processing System (SPP) review
  – Milestones
  – Current status and performance
• Values of NAEFS products
  – Objective evaluations/Comparison/User appreciations

• Future plans
  • High resolution (NDGD grid) downscaled probabilistic fcst.
  • Blender – Recursive Bayesian Model Process (RBMP)
  • 2nd moment adjustment
  • Reforecast
  • Variable decaying weights
Flow Chart of Recursive Bayesian Model Process (RBMP)

Bias free Ens forecasts

Observation or Best analysis

Variances

Weights

BMA, Decaying process, and adjustment

New weights

New variance

Prior weights

Prior variance

Err and sprd

Adjusted PDF

2nd moment adjustment

(We thanks to Dr. Veenhuis for allowing us to adopt his BMA codes).
Future NAEFS Statistical Post-Processing System

Bias correction for each ensemble member + High resolution deterministic forecast

Mixed Multi-Model Ensembles (MMME)

Reforecast

Probabilistic products at 1*1 (and/or) .5*.5 degree globally

Down-scaling (based on RTMA)

Probabilistic products at NSGD resolution (e.g. 2.5km – CONUS)

Varied decaying weights

Auto-adjustment of 2nd moment

RBMP For blender

CMC

NCEP

Others
Publications and References

- Zhu, Y., and B. Cui, 2006: “GFS bias correction” [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 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
Thanks !
Bayesian Model Average

Weights and standard deviations for each model (k - ensemble member) at step j

\[
W_k^j = \frac{1}{n} \sum_{s,t} \hat{z}_{k,s,t}^j
\]

\[
\sigma_k^2 = \frac{\sum_{s,t} \hat{z}_{k,s,t}^j \cdot (y_{s,t} - \tilde{f}_{k,s,t})^2}{\sum_{s,t} \hat{z}_{k,s,t}^j}
\]

*Sum of (s,t) represents the numbers of obs.*

Finally, the BMA predictive variance is

\[
Var(y_{s,t} | \tilde{f}_{1,s,t}, \ldots, \tilde{f}_{K,s,t}) = \sum_{k=1}^{K} w_k (\tilde{f}_{k,s,t} - \sum_{i=1}^{K} w_i \cdot \tilde{f}_{i,s,t})^2 + \sum_{k=1}^{K} w_k \cdot \sigma_k^2
\]

*Between-forecast variance*  
*Within-forecast variance*

*It is good for perfect bias corrected forecast,  
Or bias-free ensemble forecast, but we do not*
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 NDGD Probabilistic 2m Temperature Forecast Verification For 2007090100 – 2007093000

Continuous Ranked Probability Score (C)

Forecast Lead Time (Days)

From Bias correction (NCEP, CMC)
Dual-resolution (NCEP only)
Down-scaling (NCEP, CMC)
Combination of NCEP and CMC

NCEP/GEFS raw forecast

8+ days gain

NAEFS final products