NORTH AMERICAN ENSEMBLE FORECAST SYSTEM (NAEFS)

Zoltan Toth, EMC/NCEP/NWS/NOAA, USA
Jean-Guy Desmarais, MSC/CMC, Canada
NAEFS ORGANIZATION

Meteorological Service of Canada
MSC

National Weather Service, USA
NWS

PROJECT OVERSIGHT

Michel Beland, Director, ACSD
Pierre Dubreuil, Director, AEPD
Jim Abraham, MRB

Louis Uccellini (Director, NCEP/NWS)
Jack Hayes (Director, OST/NWS)
Steve Lord, EMC

PROJECT CO-LEADERS

Jean-Guy Desmarais (Implementation)
Gilbert Brunet (Science)

Zoltan Toth (Science)
David Michaud / Brent Gordon (Impl.)

JOINT TEAM MEMBERS

Meteorological Research Branch
MRB

Environmental Modeling Center
EMC

Peter Houtekamer, Herschel Mitchell,
Lawrence Wilson

Bo Cui, Richard Wobus, Yuejian Zhu

NCEP Central Operations
NCO

Canadian Meteorological Center
CMC

Hydrometeor. Prediction Center
HPC

Richard Hogue, Louis Lefaivre,
Gerard Pellerin, Richard Verret

Peter Manousos

Climate Prediction Center
CPC

Ed O’Lenic, Mike Halpert, David Unger

National Meteorological Service of Mexico (NMSM) joined in Nov. 2004
OUTLINE

• ORGANIZATION

• PROJECT DESCRIPTION

• ANTICIPATED BENEFITS

• PROJECT MILESTONES

• MULTI-MODEL ENSEMBLE APPROACH

• MAJOR AREAS OF RESEARCH & DEV.

• THORPEX & NAEFS

• TIGGE & THORPEX
PROJECT DESCRIPTION

• Combines global ensemble forecasts from Canada & USA
  – 60+ members per day from MSC & NWS

• 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) and Mexico (NMSM)

• Requires moderate additional investment for
  – New telecommunication arrangements
  – Extra coordination in research/development & implementations
ANTICIPATED BENEFITS

- Improves probabilistic forecast performance
  - Earlier warnings for severe weather
    - Lower detection threshold due to more ensemble members
    - Uncertainty better captured via analysis/model/ensemble diversity
- Provides Seamless suite of forecasts across
  - International boundaries
    - Canada, Mexico, USA
  - Different time ranges (1-14 days)
- Saves development costs by
  - Sharing scientific algorithms, codes, scripts
    - Accelerated implementation schedule
    - Cost-free diversity via multi-center analysis/model/ensemble methods
  - Exchanging complementary application tools
    - MSC focus on end users (public)
    - NWS focus on intermediate user (forecaster)
- Saves production costs by
  - Leveraging computational resources
    - Each center needs to run only fraction of total ensemble members
  - Providing back-up for operations in case of emergencies
    - Use nearly identical operational procedures
    - Offers single center default ensemble to affected center
PROJECT MILESTONES

• February 2003, Long Beach, CA
  – NOAA / MSC high level agreement about joint ensemble research/development work (J. Hayes, L. Uccellini, D. Rogers, M. Beland, P. Dubreuil, J. Abraham)

• May 2003, Montreal (MSC)
  – 1st NAEFS Workshop, planning started

• November 2003, MSC & NWS
  – 1st draft of NAEFS Research, Development & Implementation Plan complete

• May 2004, Camp Springs, MD (NCEP)
  – Executive Review

• September 2004, MSC & NWS
  – Initial Operational Capability implemented at MSC & NWS

• November 2004, Camp Springs
  – Inauguration ceremony & 2nd NAEFS Workshop
    • Leaders of NMS of Canada, Mexico, USA signed memorandum
    • 50 scientists from 5 countries & 8 agencies
THORPEX & NAEFS

- THORPEX concerned about high impact weather
  - Cannot predict severe weather with certainty
- Need probabilistic forecasting

*Ensemble can capture uncertainty associated with initial errors*

Problems with representing model-related forecast errors

SEPARATING HIGH VS. LOW UNCERTAINTY FCSTS

*UNCERTAINTY OF FCSTS CAN BE QUANTIFIED IN ADVANCE*

Y. Zhu et al.
MULTI-MODEL ENSEMBLE APPROACH

- First suggested by Houtekamer et al.
- Improves certain verification statistics (RMS error, Talagrand, etc)
  - Little or no improvement after constituent ensembles bias corrected
- Does not increase growth of spread
  - Need other methods to account for uncertainty due to sub-grid scale processes

Based on Houtekamer et al.

Jun Du et al.

More diversity in model physics ----

- Benefit is from cancellation of different systematic errors in various model versions?
- Systematic error can be removed via use of large climate sample of “hind-cast” data
  - Regime dependent bias can be reduced with multi-model approach?
- Very costly to maintain by a single NWP center
  - Update and development of multiple model versions is labor intensive
- Comes free if multiple NWP centers collaborate
MAJOR AREAS OF RESEARCH & DEVELOPMENT

• Exchange global ensemble data
  – 45 (~85) NCEP, 16 (~40) MSC current (planned) members
  – Telecommunication requirements

• Bias correct all forecasts
  – Reduce systematic errors to enhance reliability
  – Express forecasts as anomalies from climatology

• Merge two ensembles
  – Weighting to reflect skill level and cross-correlation

• Produce new products based on joint grand ensemble
  – Probabilistic warning for high impact weather

• Applications/Verification/Evaluation
  – Share procedures

• Operational implementation
  – Initial Operational Capability (IOC) – Sept. 2004
    • Data exchange, products based separately on each ensemble
# List of Variables Identified for Ensemble Exchange Between MSC - NCEP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CMC</th>
<th>NCEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensemble</td>
<td>8 SEF, 8 GEM</td>
<td>10 paired</td>
</tr>
<tr>
<td>Grid</td>
<td>2.5x2.5 deg (144x73) &amp; 1.2x1.2 deg (300x151)</td>
<td>2.5x2.5 deg (144x73) &amp; 1.0x1.0 deg (360x181)</td>
</tr>
<tr>
<td>Domain</td>
<td>Global</td>
<td>Global</td>
</tr>
<tr>
<td>Format</td>
<td>WMO GRIB Format</td>
<td>WMO GRIB Format</td>
</tr>
<tr>
<td>Hours</td>
<td>0, 12, 24, 36, 48, ... ,216, 228, 240</td>
<td>0, 6, 12, 18, 24, ........ , 360, 366, 372, 378, 384</td>
</tr>
<tr>
<td>GZ</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
</tr>
<tr>
<td>TT</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
</tr>
<tr>
<td>E</td>
<td>Tdd at 200, 250, 500, 700, 850, 925, 1000</td>
<td>RH at 200, 250, 500, 700, 850, 925, 1000</td>
</tr>
<tr>
<td>U, V</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
<td>200, 250, 500, 700, 850, 925, 1000</td>
</tr>
<tr>
<td>TT Sfc</td>
<td>12000, redefined in GRIB file as 2m AGL</td>
<td>2m</td>
</tr>
<tr>
<td>U, V Sfc</td>
<td>Redefined in GRIB file as 10m AGL</td>
<td>10m</td>
</tr>
<tr>
<td>ES</td>
<td>Tdd at 12000, redefined in GRIB file as 2m AGL</td>
<td>RH at 2M</td>
</tr>
<tr>
<td>MSLP</td>
<td>(SEF) (P0) level 0</td>
<td>PRMSL</td>
</tr>
<tr>
<td>PR (total precip)</td>
<td>Level 0, i.e at surface</td>
<td>Level 0, i.e at surface</td>
</tr>
<tr>
<td>NT (total cloud cover)</td>
<td>Level 0</td>
<td>Column</td>
</tr>
<tr>
<td>IH (total precipitable cover)</td>
<td>Level 0</td>
<td>Column</td>
</tr>
<tr>
<td>Sfc Pres</td>
<td>(SEF) (P0) level 0 at surface</td>
<td>Sfc Pressure</td>
</tr>
<tr>
<td>Model Topography</td>
<td>Model Topography</td>
<td>Model Topography at t=0 and t=192</td>
</tr>
<tr>
<td>CAPE</td>
<td>Most unstable layer</td>
<td>Most unstable layer</td>
</tr>
<tr>
<td>Precip Type</td>
<td>4 accumulations processed into 4 bitmaps</td>
<td>4 bitmap variables for 4 types</td>
</tr>
<tr>
<td>Tmax</td>
<td>2m derived from hourly</td>
<td>2m</td>
</tr>
<tr>
<td>Tmin</td>
<td>2m derived from hourly</td>
<td>2m</td>
</tr>
<tr>
<td>WAM</td>
<td>Later</td>
<td>Later</td>
</tr>
</tbody>
</table>

Black: data presently exchanged  
Blue: data exchanged & processed by NCEP June 2004  
Red: data added in September 2004  
Green: data to be exchanged later  

R. Wobus  
R. Hogue
Adaptive bias correction (most recent ~30 days) gives almost optimal results for short range.

- Climate mean bias correction is much better beyond short range.
- Use of 8-yr old system hurts tremendously.

Bo Cui
BIAS CORRECTION - TENTATIVE CONCLUSIONS

• Adaptive, regime dependent bias correction works well for first few days (almost as good as “optimal”)
  – Frequent updates of DA/NWP modeling system possible

• Climate mean bias correction can add value, especially for wk2 prob. fcsts
  – Generation of large hind-cast ensemble is expensive but can be helpful

• Use of up-to-date data assimilation/NWP techniques imperative at all ranges
BAYESIAN MODEL AVERAGING (BMA)

MERGING 2 ENSEMBLES

WEIGHTS FOR 30 MEMBERS

Mean weights for surface temperature
168 hours forecast, 30 days training period
194 stations, 31 forecasts
PRODUCTS

PQPF
Ens Prob of Precip Amount Exceeding 0.25 inch (6.35 mm/day)
Inl: 2004112300

SPAGHETTI
00z 23 Nov 2004 CMC and NCEP ENS MEMBERS
516 and 558-dm contours
red=NCEP, blue=CMC

valid time 12z27Nov2004

B. Bua
Y. Zhu
VERIFICATION OF JOINT ENSEMBLE

Talagrand diagrams for surface temperature
24 hours forecast, 30 days training period
194 stations, 31 forecasts

RMSE = 2.801
CRPS = 1.593

Raw ensemble

RMSE = 2.077
CRPS = 1.170

After bias correction (BC)

RMSE = 1.989
CRPS = 1.068

After BC & BMA

CONTINUOUS RANKED PROBABILITY SCORE

\[
CRPS\ ( P, \ x_a ) = \int_{-\infty}^{\infty} \left[ P( x ) - P_a( x ) \right]^2 dx
\]

CDF - Forecast-observed

L. Wilson

R. Verret
INAUGURATION CEREMONY

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
cone-to-farther day and basin forecasts;
Noting the significant international cooperation undertaken to develop and
implement an operational experimental forecast system to the benefit of
North America and surrounding territories;

The representatives hereby inaugurate the
North American Essential Forecast System
at Camp Springs, Maryland, USA, on this
11th Day of November 2014.

The signatures:

[Signatures of representatives]
NAEFS & THORPEX

- Expands international collaboration
  - Mexico joined in November 2004
  - UK Met Office to join in 2006
- Provides framework for transitioning research into operations
  - Prototype for ensemble component of THORPEX legacy forecast system: *Global Interactive Forecast System (GIFS)*
ENSEMBLE RESEARCH WITHIN THORPEX

- Goal of THORPEX: Accelerate improvements in utility of fcsts
- THORPEX research organized under 4 major areas- core WGs:
  - Observing System
  - Data Assimilation / Observing Strategies
  - Predictability
  - Socio-Economic Applications
- Which area offers greatest benefit?
  - Resource allocation / priorities question
    - Initially, balanced funding of work in 4 WGs & areas underneath
    - Later, more selective funding to emphasize areas of greatest promise
- Ensemble-related research falls under:
  - Data Assimilation - Initial perturbations
  - Predictability - Model-related uncertainty
  - Socio-Economic Applications - Post-processing, applications
- Ensemble research should be integrated within 3 core WGs
  - Puts ensemble work into context of overall THORPEX research
    - Interaction with related research
    - Balanced approach / right priorities
ROLE OF TIGGE WITHIN THORPEX

Data base of multi-center ensemble forecasts for
- Forecast demonstration projects - Real time
- Some ensemble-related research - Archived

TIGGE database will
- Focus research on multi-center ensemble approach
  • Identify strengths/weaknesses as compared to single center approach
- Foster international collaboration
- Facilitate transfer of research into operations

What it should not be
- Should not pre-empt systematic ensemble research under core WGs
- Should not replace oversight by core WGs over THORPEX research =>

TIGGE must coordinate (with yet not formed) WGs
- Funnel research into Core WGs; Ask assistance of Data Mngmnt WG
- Under direction of (yet not formed) Executive Board =>

Tread softly (yet decisively)
THORPEX ORGANIZATIONAL FLOWCHART

Core Research

- Observing System
- Data Assim. & Obs. Strateg.
- Predictability
- Socio-Econ. Applications

Deliverable

- Global Interactive Forecast System
THORPEX ORGANIZATIONAL FLOWCHART

Support  Core Research  Deliverable

Data Management and Policy  

Observing System  

Data Assim. & Obs. Strateg.  

Predict-ability  

Socio-Econ. Applications  

Global Interactive Forecast System  

TIGGE Data Base  

Facilitates Res. & Demo
NOAA SERVICE GOAL: ACCELERATE IMPROVEMENTS IN 3-14 DAY FORECASTS

NOAA SCIENCE OBJECTIVE: REVOLUTIONIZE NWP PROCESS

TRADITIONAL NWP
Each discipline developed on its own
Disjoint steps in forecast process
Little or no feedback
One-way flow of information
Uncertainty in process ignored

NEW NWP
Sub-systems developed in coordination
End-to-end forecast process
Strong feedback among components
Two-way interaction
Error/uncertainty accounted for

INTEGRATED, ADAPTIVE, USER CONTROLLABLE
DIRECT LINK BETWEEN
NOAA THORPEX SCIENCE AND IMPLEMENTATION PLAN (NTSIP-2002) AND
THORPEX INTERNATIONAL SCIENCE PLAN & THORPEX IMPLEMENTATION PLAN (TIP)

TIP – “OBSERVING SYSTEM”

TIP – “DATA ASSIMILATION…”

TIP – “SOCIAL & ECONOMIC APPLICATIONS”

GLOBAL INTERACTIVE FORECAST SYSTEM (GIFS)

TIP – “PREDICTABILITY & DYNAMICAL PROCESSES”
BACKGROUND
CROSS-CUTTING ACTIVITIES

Integrating NWP procedures from four sub-systems
Observing System Simulation Experiments (OSSEs)

• Data needs of NWP
  – What variables/resolution/accuracy required
  – Instrument/platform neutral assessment

• What instruments/platforms can provide data needs
  – Existing and new in-situ & remote platforms
  – Adaptive component to complement fixed network
  – Most cost effective solution

• Relative value of improvements in four sub-systems
  – Improvements in which sub-system offer best return?
  – Reallocation of resources

• Test of proposed operational configurations
  – Major field program if needed
  – Cost/benefit analysis - Select most cost effective version
BIAS CORRECTION

Northern Hemisphere 500hPa Height
Economic Values for 10:1 Ratio
Average For 20040301 – 20040531

- Raw operational forecast
- 30-day running mean error removed
  (dependent sample bias correction, “optimal”)
- Preceding 30-day mean error removed
  (same model, short & flow-dependent sample)
- Past 4 yrs seasonal mean error removed
  (Various model versions, larger climate sample)

Economic Value, 1:10 Cost/Loss

Forecast days

Bo Cui
**BMA**

\[
p(y|\tilde{f}_1,...,\tilde{f}_K) = \sum_{k=1}^{K} w_k p(y|\tilde{f}_k)
\]

\[
\tilde{f}_k = \text{bias-corrected forecast } f_k
\]

\[
w_k = \text{weight associated with member } k
\]

\[
= \text{posterior probability of } \tilde{f}_k \text{ being correct}
\]

**For temperature:**

\[
\tilde{f}_k = a_k + b_k f_k
\]

\[
p(y|\tilde{f}_k) = N(\tilde{f}_k, \sigma_k)
\]

\[
E(y|\tilde{f}_1,...,\tilde{f}_K) = \sum_{k=1}^{K} w_k \tilde{f}_k
\]

Forecast error PDF centered on each individual bias-corrected forecast
BMA

\[ p(y|\tilde{f}_1, \ldots, \tilde{f}_K) = \sum_{k=1}^{K} w_k p(y|\tilde{f}_k) \]

\[ \tilde{f}_k = \text{bias-corrected forecast } f_k \]

\[ w_k = \text{posterior probability of } \tilde{f}_k \text{ being correct} \]

\[ \sum_{k=1}^{K} w_k = 1 \]

For temperature:

\[ \tilde{f}_k = a_k + b_k f_k \]

\[ p(y|\tilde{f}_k) = N(\tilde{f}_k, \sigma_k) \]

\[ b_k \equiv 1 \]
MOTIVATION FOR NAEFS

• **Share resources**
  – Development (research)
    • Joint/shared development of algorithms, codes, scripts, etc
      – Accelerated pace of improvement
  – Production (operations)
    • Share real-time forecasts & all supporting data (reanalysis climatology, etc)
    • Provide back-up operations in case of emergencies
      – All operational procedures nearly identical
      – Offer single center default ensemble to affected center

• **Exchange complementary application tools**
  – MSC focus on end users (public)
  – NWS focus on intermediate user (forecaster)

• **Improve performance**
  – Double ensemble membership
    • Lower detection threshold for high impact weather
  – Multi-center ensemble approach
    • Anticipated enhancement due to analysis/model/ensemble-related diversity