ENSEMBLE FORECASTING AT NCEP: HISTORY, PRESENT STATUS, AND FUTURE DIRECTIONS

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Global
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Regional
Jeff McQueen, Jun Du\(^{(1)}\), Binbin Zhou\(^{(1)}\), Geoff Manikin, Brad Ferrier\(^{(1)}\)

Coupled ocean-atmosphere
Malaquias Pena

Adaptive observations

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    S. Tracton, E. Kalnay, I. Szunyogh, L. Holland
    C. Bishop, S. Majumdar

http://www.emc.ncep.noaa.gov/gmb/ens/index.html
OUTLINE

- GLOBAL ENSEMBLE FORECAST SYSTEM
- REGIONAL ENSEMBLE FORECAST SYSTEM
- ADVERTISEMENT FOR TWO POSTERS
  - Intercomparison of ECMWF, Canadian, & NCEP ensembles (Wei et al.)
  - Combining information from hires control & lowres ensemble (J. Du)
- REPRESENTING MODEL ERRORS:
  A NEW FRONTIER IN ENSEMBLE FORECASTING
GLOBAL ENSEMBLE FORECASTING AT NCEP

- **BACKGROUND**
  - Capturing case dependent fluctuations in forecast skill a long time desire
  - No tangible results regarding climatological regime classification
  - Lorenz, Leith, Epstein, etc investigations – ensemble is a theoretical possibility
  - Systematic errors in global models reduced by early 1990s
  - Cpu increase makes global ensemble work tangible by early 1990s
  - Ensemble is “in the air”

- **PERSONAL STORY**
  - Eugenia (then Development Division Director) asked me if interested
  - Started work in second half of 1991

- **HISTORY OF NCEP GLOBAL ENSEMBLE**
  - Breeding technique developed in 1991/92
  - Joe Irwin of NCO personally interested
  - Implemented in operational suite in December 1992 (days ahead of ECMWF)
  - Upgraded system implemented in March 1994
  - Today 40 members per day, heavily used by NCEP, NWS, public and private sector
  - Four people working on further development
  - **COMPARISON WITH ECMWF & CANADIAN ENSEMBLES** – Poster by Mozheng Wei

- **FUTURE DIRECTIONS**
  - Improved initial perturbations (THORPEX collaboration)
  - **REPRESENTING MODEL RELATED UNCERTAINTY**
  - New products/applications (NAEFS collaboration with Canadians)
NCEP GLOBAL ENSEMBLE FORECAST SYSTEM

RECENT UPGRADE (Apr. 2003)
10/50/60% reduction in initial perturbation size over NH/TR/SH

NEW CONFIGURATION
MARCH 2004

FORMER SYSTEM
REGIONAL ENSEMBLE FORECASTING AT NCEP

• BACKGROUND
  – Expectations raised by initial positive results from global ensemble systems
  – Short Range Ensemble Forecasting (SREF) workshop at NCEP, 1994
  – Steve Tracton spearheading effort

• HISTORY OF NCEP REGIONAL ENSEMBLE
  – 1995 Experimental system set up for ETA by Eric Rogers
    Based on global breds and 5 in-house analyses,
    Run about once a week on manually selected cases
  – 1996 Jun Du sets up regional breeding procedure, ETA & RSM models
  – 1997 SREF mini workshop
  – 1998 Quasi-real time ensemble during SAMEX
  – 2000 Modifications/upgrades (from 80km to 48km; further evaluation)
  – Apr 2001 5 ETA + 5 RSM members run operationally by NCO
  – 2002 5 KF members added
  – 2003-04 Physics diversity testing
  – 2004 INCREASED RESOLUTION & PHYSICS DIVERSITY TO BE IMPLEMENTED

• FUTURE DIRECTIONS
  – Transition into WRF era
  – New products
  – Improvements in configuration (initial/model perturbations, better coupling with hires fcst)
  – ADD LOW-RES PERTURBATIONS TO HIGHRES CONTROL?
## SREF Parallel Experiment

### Physics Members

Since March 3, 2004

<table>
<thead>
<tr>
<th>Model</th>
<th>Res (km)</th>
<th>Levels</th>
<th>Members</th>
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<th>Convection</th>
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<td>Op Ferrier</td>
<td>Betts-Miller-Janic</td>
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<td>Op Ferrier</td>
<td>Kain-Fritsch with enhanced</td>
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<td>detrainment</td>
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**Operational suite:** 3 model versions, 2 pairs plus one control each (15)  
**Parallel suite:** 6 model versions, one pair each plus 3 controls only (15)  
**Scaled breeding**  
**Expected Implementation:** Second half of 2004
PROBABILISTIC FORECASTING

• NWP is “bulldozer approach” to weather forecasting *P. Lynch*

• Probabilistic forecasts can be generated many different ways
  
  – *Ensemble is “bulldozer approach” to probabilistic forecasting*

• Does ensemble capture (some) case dependent uncertainty?
  
  – For initial value related uncertainty *YES*
  
  – For model related uncertainty *NOT KNOWN YET*
SOURCES OF FORECAST ERRORS

IMPERFECT KNOWLEDGE OF INITIAL CONDITIONS

RESULTS

- Flow dependent variations in forecast uncertainty captured
- Forecast for first moment (ensemble mean) improved
- Difficult or impossible to reproduce with statistical methods

PROBLEMS

- Perturbation growth lags error growth – ensemble does not capture truth
- Case dependent model failures not indicated by ensemble
REPRESENTING MODEL RELATED UNCERTAINTY:
THE SECOND FRONTIER IN ENSEMBLE FORECASTING
SAMPLING FORECAST ERRORS = REPRESENTING ERRORS DUE TO USE OF IMPERFECT MODELS

CURRENT METHODS

1) Change structure of model (eg, use different convective schemes, etc, MSC)
   Model version fixed, whereas model error varies in time
   Random/stochastic errors not addressed
   Difficult to maintain

2) Add stochastic noise (eg, perturb diabatic forcing, ECMWF)
   Small scales perturbed
   If otherwise same model used, larger scale biases may not be addressed

Do they work? Advantages of various approaches need to be carefully assessed
   • Are flow dependent variations in uncertainty captured?
   • Can statistical post-processing replicate use of various methods?

NEED NEW
   • MORE COMPREHENSIVE AND
   • THEORETICALLY APPEALING

APPROACH
SAMPLING FORECAST ERRORS = REPRESENTING ERRORS DUE TO USE OF IMPERFECT MODELS - 1

CURRENT METHODS

1) Change structure of model (use different convective schemes, etc, MSC)
   • Perturbation growth not affected?
   • Biases of different model versions cancel out in ensemble mean?

Spread
Oper: 3 model versions
Para: More model diversity

 spreads of 2–member ensemble with (blue dashed line) and without (red continuous line) changing model parameters/physics packages from one ensemble member to the another. 500 hPa geopotential height, forecasts started at 0000 UTC on April 18, 1994. Note that initial perturbations are larger for the changing model ensemble and that the curve for the unchanging model ensemble has been shifted one day to the left, to illustrate that in this ensemble setup the changes in model configuration do not result in larger spread. Data are from Table 4 of Houtekamer et al., 1996.
USING DIFFERENT CONVECTIVE SCHEMES
CAN CHANGE PRECIP CHARACTERISTICS
BUT HAS LITTLE OR NO IMPACT ON CIRCULATION FORECASTS

[Graphs and maps showing precipitation and circulation patterns]
SAMPLING FORECAST ERRORS = REPRESENTING ERRORS DUE TO USE OF IMPERFECT MODELS – 2

CURRENT METHODS

1) Change structure of model (eg, use different convective schemes, etc, MSC)

2) Add stochastic noise (eg, perturb diabatic forcing, ECMWF)
   • Modest increase in perturbation growth for tropics
   • Some improvement in ROC skill for precip, for tropics

850 hPa Temp, NH

Oper vs. Stochastic perturbations
SAMPLING FORECAST ERRORS =
REPRESENTING ERRORS DUE TO USE OF
IMPERFECT MODELS

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APPROACH
NEW APPROACH TO NWP MODELING – REPRESENTING MODEL RELATED UNCERTAINTY

MODEL ERRORS ARE DUE TO:

- Truncation in spatial/temporal resolution –
  - Need to represent stochastic effect of unresolved scales
  - Add parameterized random noise
- Truncation in physical processes resolved
  - Need to represent uncertainty due to choice of parameterization schemes
  - Vary parameterization schemes / parameter values

MODEL ERRORS ARE PART OF LIFE, WILL NEVER GO AWAY

IN ENSEMBLE ERA,

NWP MODELING PARADIGM NEEDS TO CHANGE

<table>
<thead>
<tr>
<th>OLD</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOAL 1st Moment RMS error</td>
<td>Probability distribution Probabilistic scores</td>
</tr>
<tr>
<td>MEASURE Ignored / reduced</td>
<td>Emphasized</td>
</tr>
<tr>
<td>VARIANCE Search for best configuration</td>
<td>Represent uncertainty</td>
</tr>
</tbody>
</table>
NEW APPROACH TO NWP MODELING – REPRESENTING MODEL RELATED UNCERTAINTY

IT IS NOT ENOUGH TO PROVIDE SINGLE (BEST) MODEL FORECAST

JOINT EFFORT NEEDED BETWEEN MODELING & ENSEMBLE COMMUNITY

FOR OPTIMAL ENSEMBLE PERFORMANCE, MODELS NEED TO REALISTICALLY REPRESENT ALL MODEL-RELATED

Resolution (time and space truncation)

Parameterization-type (unresolved physics)

UNCERTAINTY AT THEIR SOURCE - Like in case of initial condition-related uncertainty

FOR MODEL IMPROVEMENTS, ENSEMBLE OFFERS TOOL TO SEPARATE INITIAL & MODEL ERRORS

Case dependent errors can potentially be captured and corrected

Only way to systematically evaluate model performance is through ensembles
WILL NEW APPROACH ADD VALUE?
WILL IT ENHANCE RESOLUTION OF PROBABILISTIC FCSTS?
WILL IT GIVE CASE-DEPENDENT ESTIMATES
(INSTEAD OF AVERAGE STATISTICAL MEASURE) OF
MODEL-RELATED UNCERTAINTY?