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

Zoltan Toth

Global

Yuejian Zhu, Richard Wobus[(1)], Mozheng Wei[(2)], Dingchen Hou[(1)]

Regional

Jeff McQueen, Jun Du[(1)], BinBin Zhou[(1)], Geoff Manikin, Brad Ferrier[(1)]

Coupled ocean-atmosphere

Malaquias Pena

Adaptive observations

Environmental Modeling Center
NOAA/NWS/NCEP

[(1)] : SAIC at NCEP/EMC, Washington, US (www.emc.ncep.noaa.gov)
[(2)] : UCAR Visiting Scientist, NCEP/EMC, Washington, US

Ackn.: L. Uccellini, S. Lord, H.-L. Pan, G. DiMego
D. Michaud, B. Gordon
S. Tracton, E. Kalnay, I. Szunyogh, L. Holland
C. Bishop, S. Majumdar

http://wwwt.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

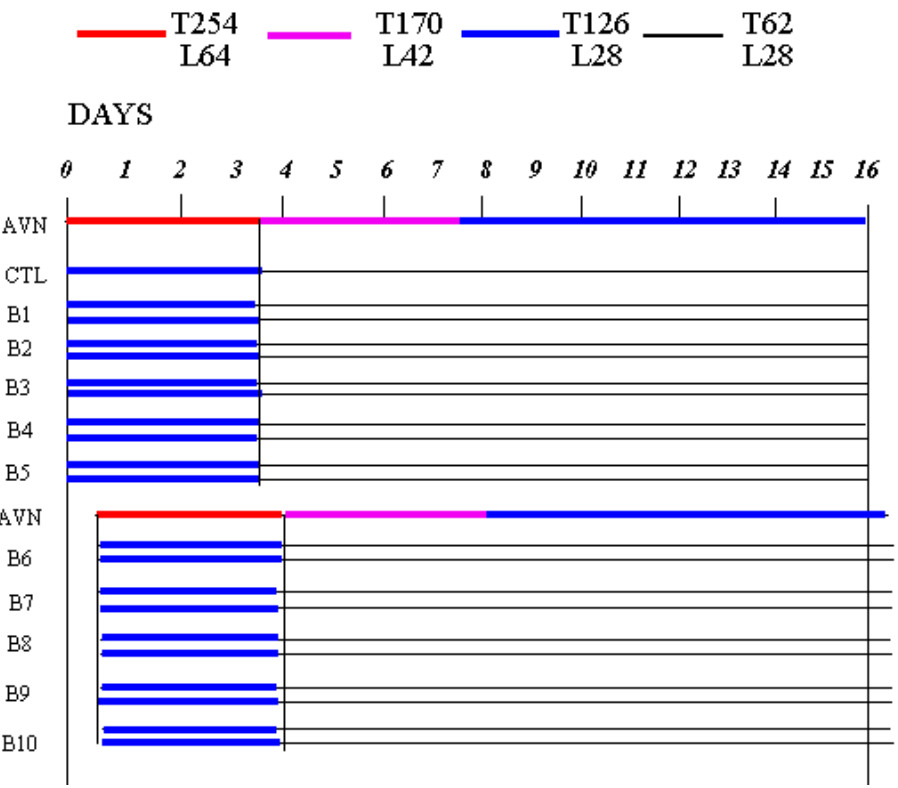
- **FUTURE DIRECTIONS**
  - Improved initial perturbations (THORPEX collaboration)
  - ***REPRESENTING MODEL RELATED UNCERTAINTY***
  - New products/applications (NAEFS collaboration with Canadians)

NCEP GLOBAL ENSEMBLE FORECAST SYSTEM

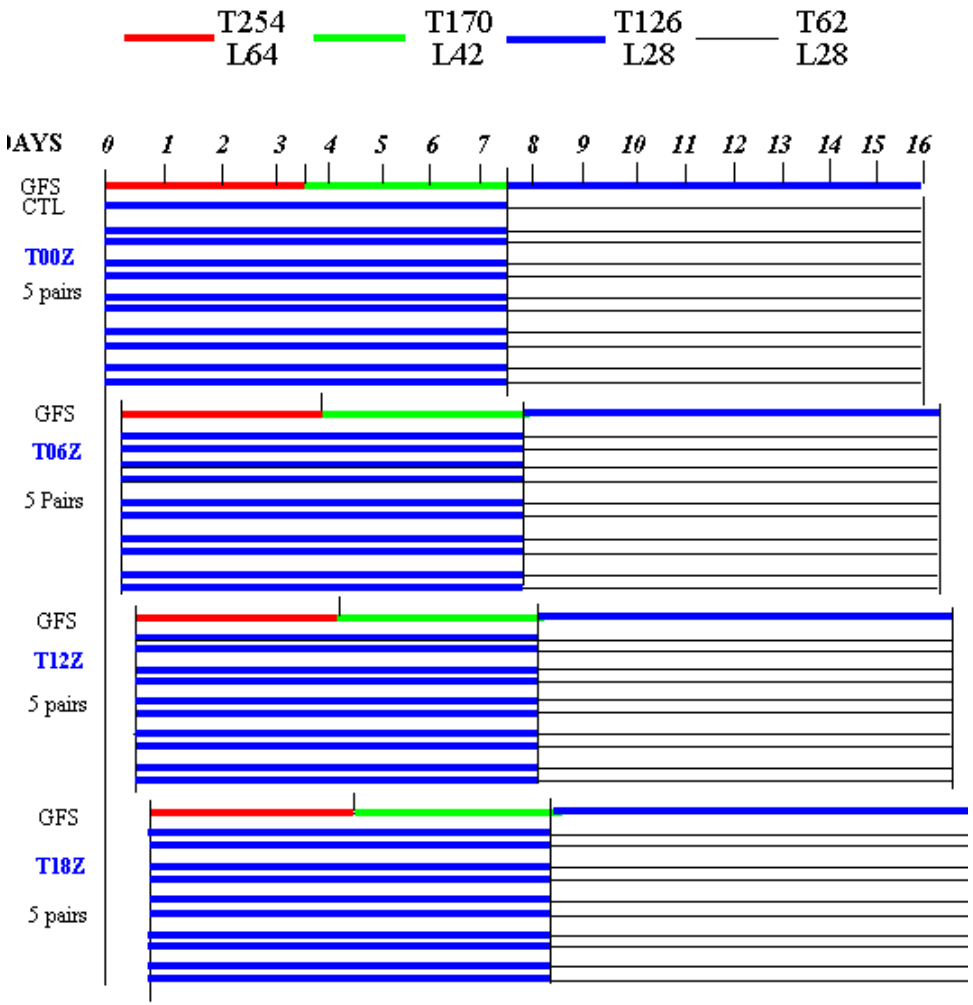
RECENT UPGRADE (Apr. 2003)

10/50/60% reduction
in initial perturbation size over
NH/TR/SH

FORMER SYSTEM



NEW CONFIGURATION MARCH 2004



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

Model	*Res (km)*	*Levels*	*Members*	*Cloud Physics*	*Convection*
RSM SAS	**32**	**28**	**Ctl,n1,p1**	**GFS physics**	**Simple Arakawa-Shubert**
RSM RAS	**32**	**28**	**n1,p1**	**GFS physics**	**Relaxed Arakawa-Shubert**
Eta-BMJ	**32**	**60**	**Ctl,n1,p1**	**Op Ferrier**	**Betts-Miller-Janic**
Eta-SAT	**32**	**60**	**n1,p1**	**Op Ferrier**	**BMJ-moist prof**
Eta-KF	**32**	**60**	**Ctl,n1,p1**	**Op Ferrier**	**Kain-Fritsch**
Eta-KFD	**32**	**60**	**n1,p1**	**Op Ferrier**	**Kain-Fritsch with enhanced detrainment**

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*

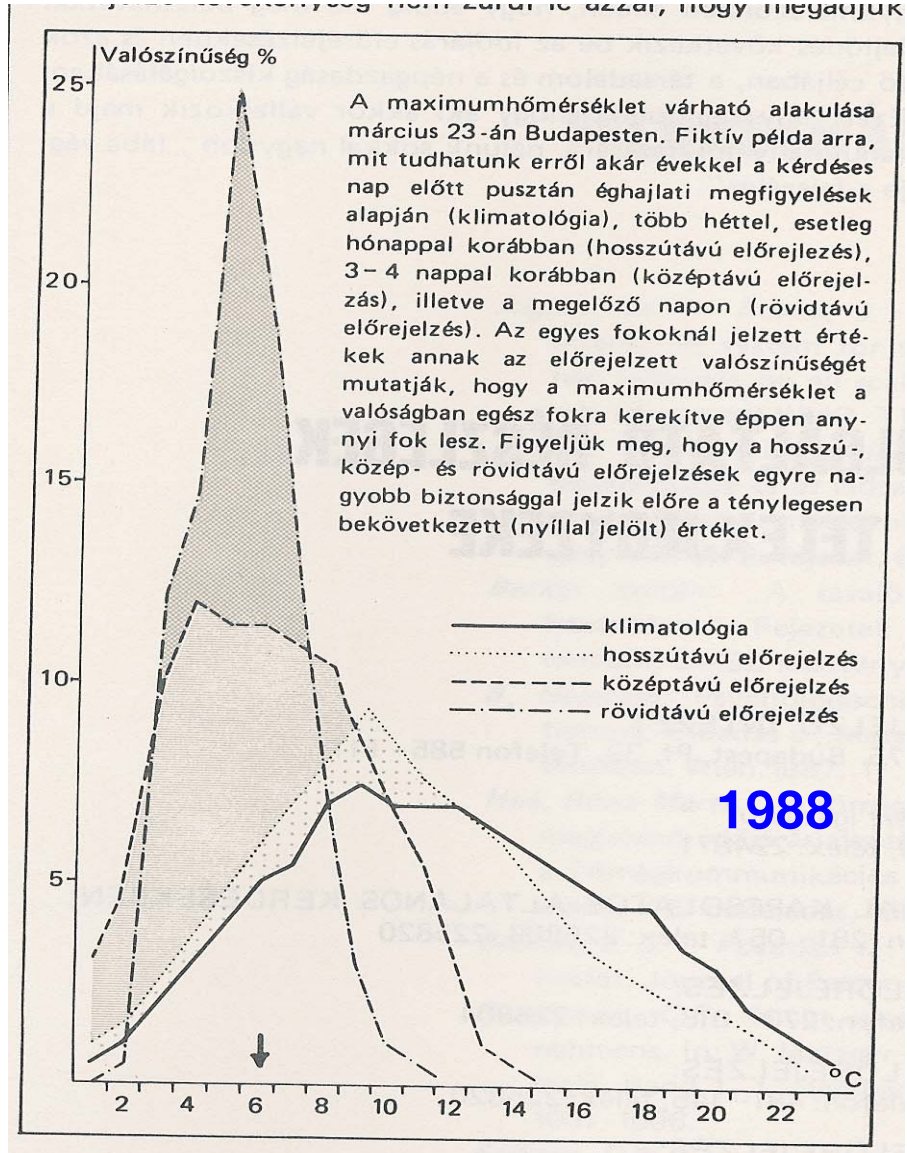
- Probabilistic forecasts can be generated many different ways

  - ***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

DREAM OF
"SEAMLESS SUITE OF PRODUCTS"
FROM HUNGARY, 16 YRS AGO

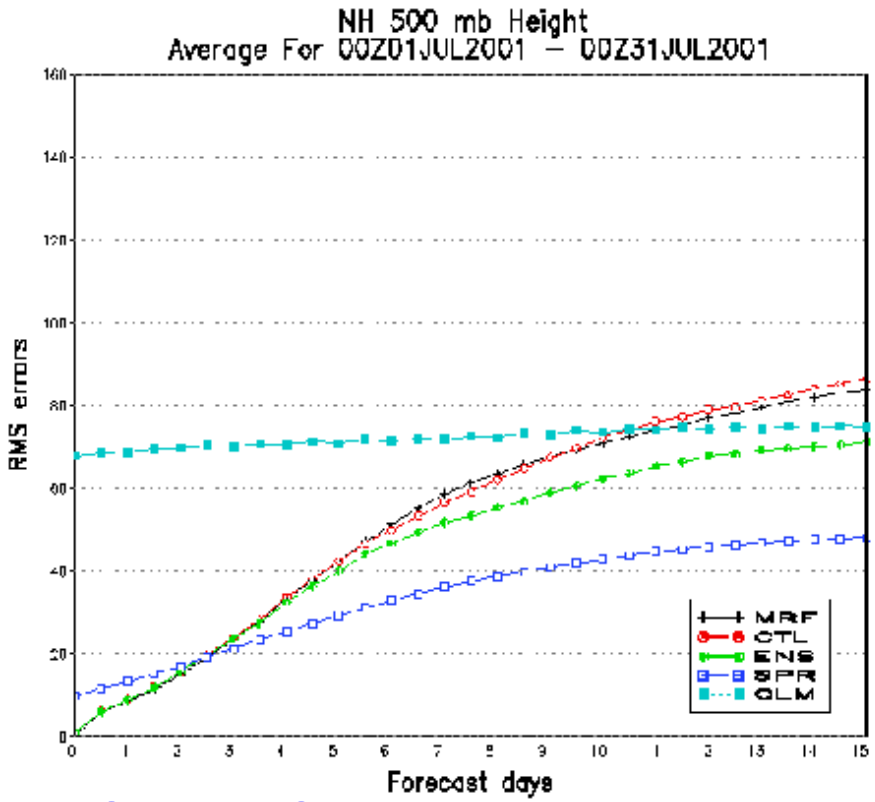


SOURCES OF FORECAST ERRORS

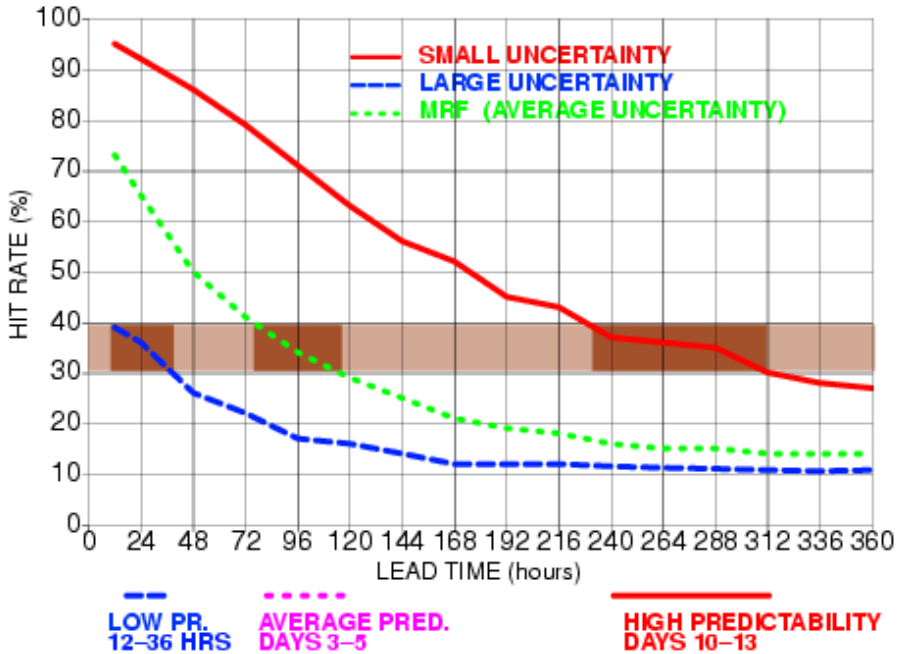
IMPERFECT KNOWLEDGE OF INITIAL CONDITIONS

RESULTS

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



SEPARATING HIGH VS. LOW UNCERTAINTY FCSTS



UNCERTAINTY OF FCSTS** CAN BE **QUANTIFIED IN ADVANCE

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

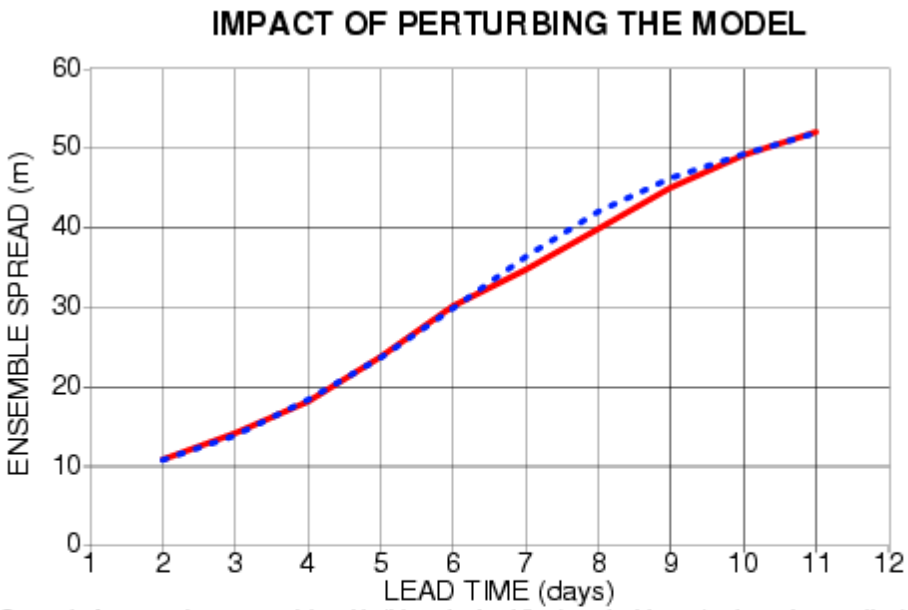
- ***MORE COMPREHENSIVE AND***
- ***THEORETICALLY APPEALING***

APPROACH

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

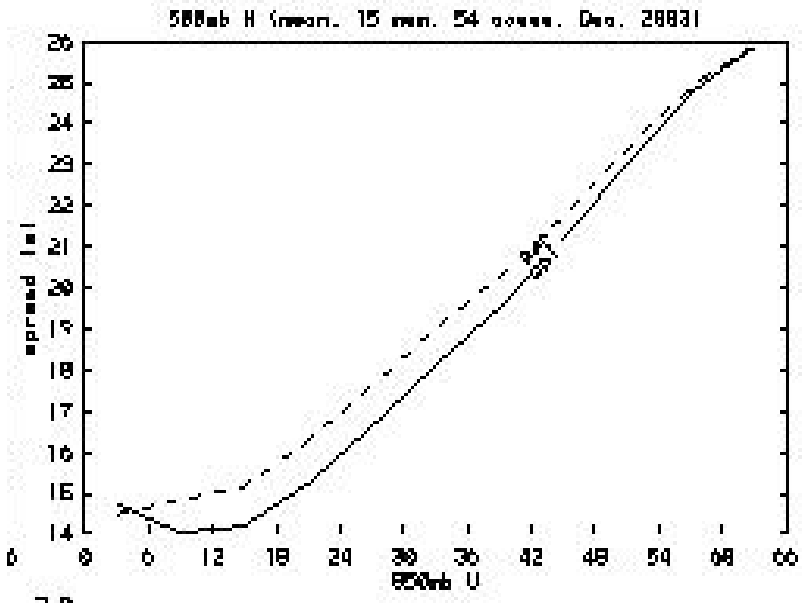
CURRENT METHODS

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 of 8–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 thechanging 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 chages in model configuration do not result in larger spread. Data are from Table 4 of Houtekamer et al., 1996.

Spread

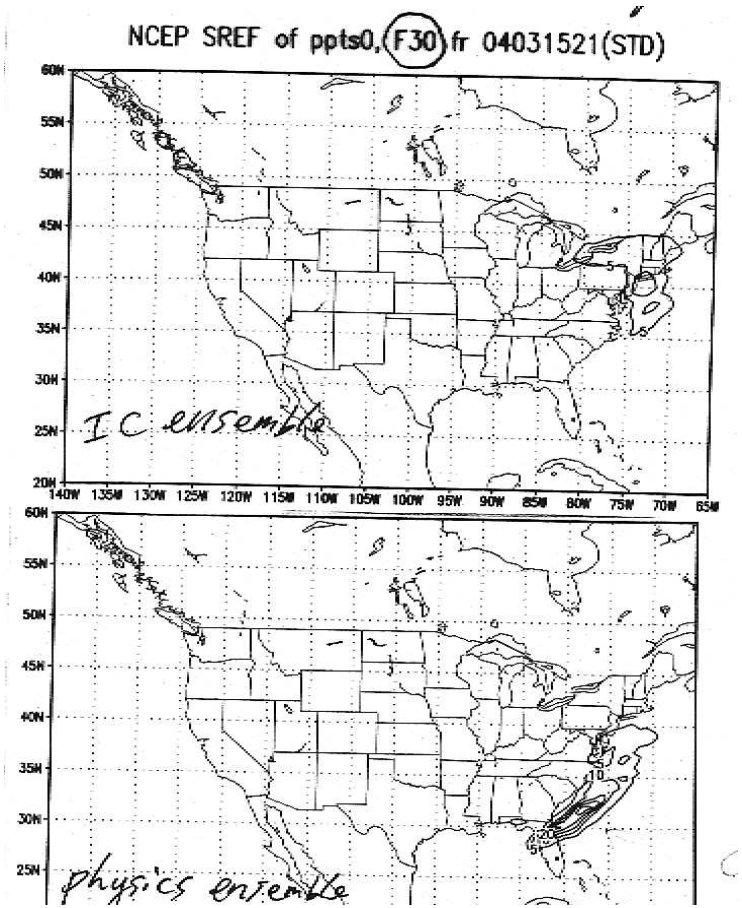


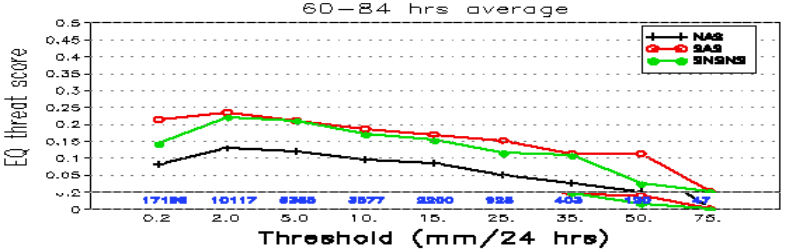
Oper: 3 model versions

Para: More model diversity

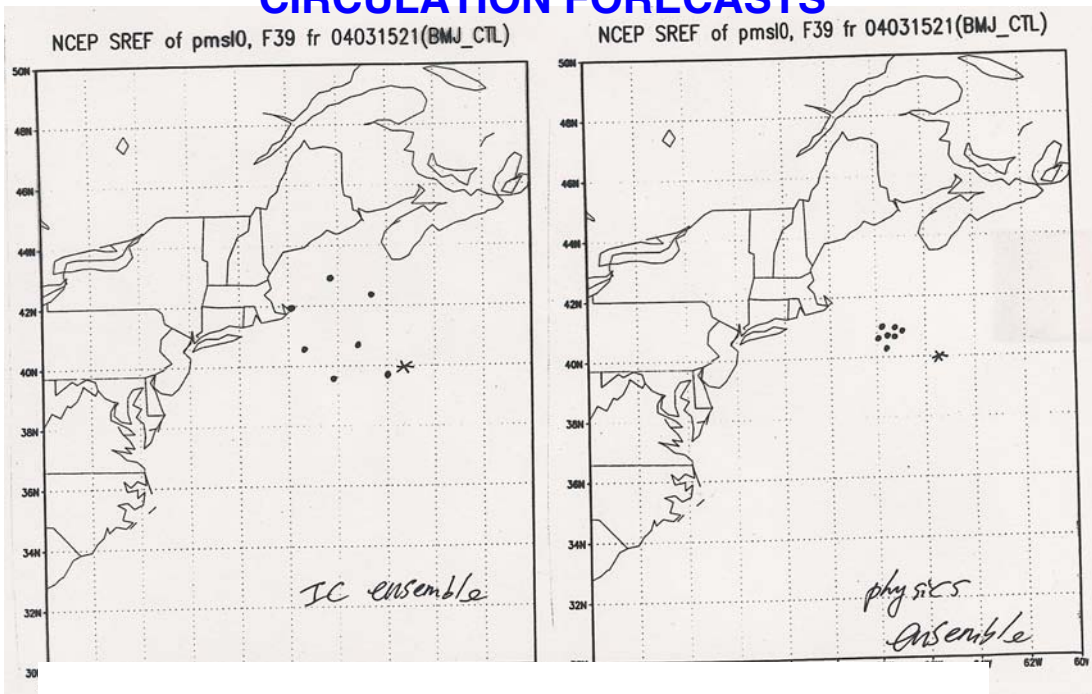
USING DIFFERENT CONVECTIVE SCHEMES

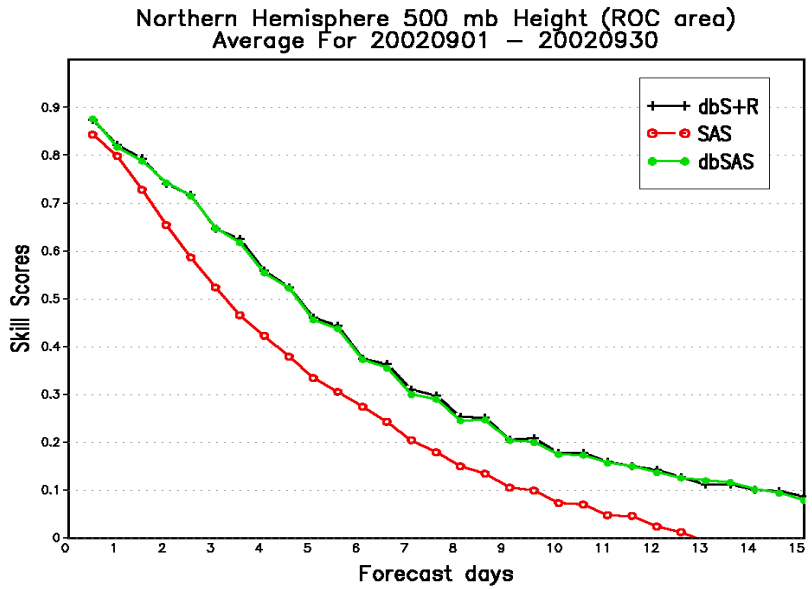
CAN CHANGE PRECIP CHARACTERISTICS





BUT HAS LITTLE OR NO IMPACT ON CIRCULATION FORECASTS





SAMPLING FORECAST ERRORS =
REPRESENTING ERRORS DUE TO USE OF
IMPERFECT MODELS – 2

CURRENT METHODS

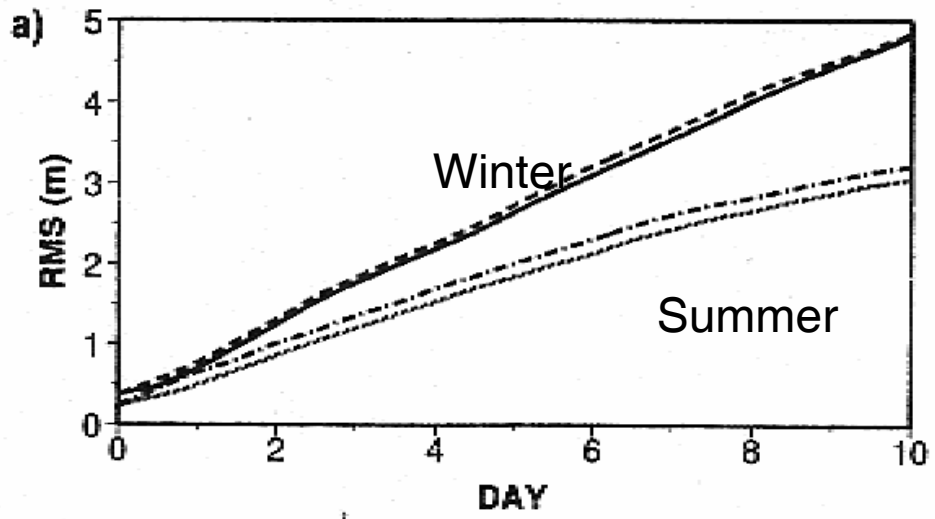
1) Change structure of model (eg, use different convective schemes, etc, MSC)

2) Add stochastic noise (eg, perturb diabatic forcing, ECMWF)

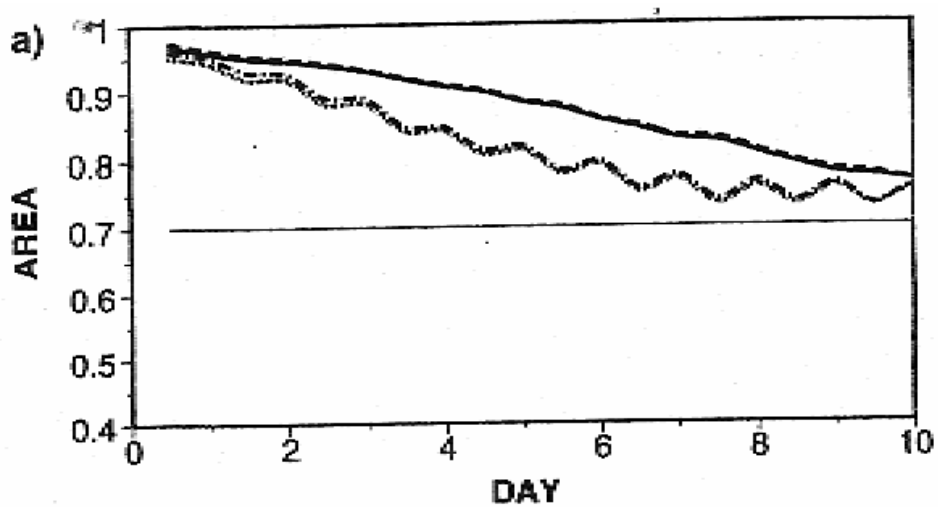
- Modest increase in perturbation growth for tropics
- Some improvement in ROC skill for precip, for tropics

850 hPa Temp, NH

Spread



ROC Area



Oper vs. Stochastic perturbations

SAMPLING FORECAST ERRORS =
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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

	OLD	NEW
GOAL	1st Moment	Probability distribution
MEASURE	RMS error	Probabilistic scores
VARIANCE	Ignored / reduced	Emphasized
NWP MODEL	Search for best configuration	Represent uncertainty

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

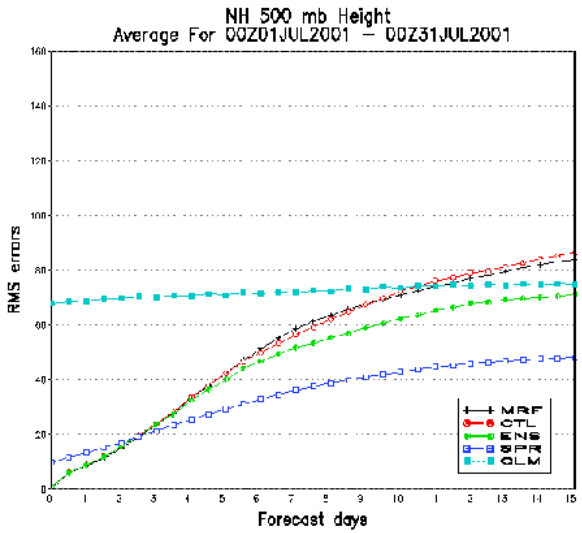
Case dependent errors can potentially be captured and corrected

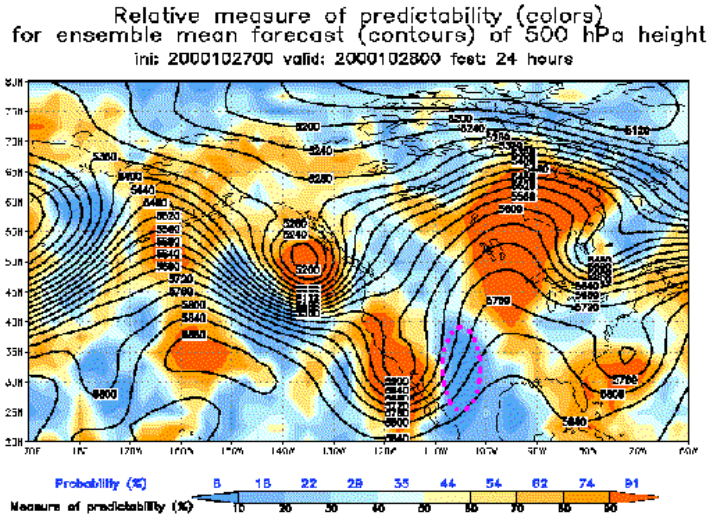
Only way to systematically evaluate model performance is through ensembles

WILL NEW APPROACH ADD VALUE?

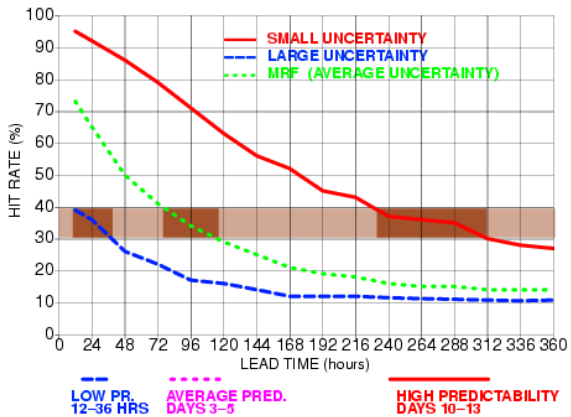
WILL IT ENHANCE RESOLUTION OF PROBABILISTIC FCSTS?

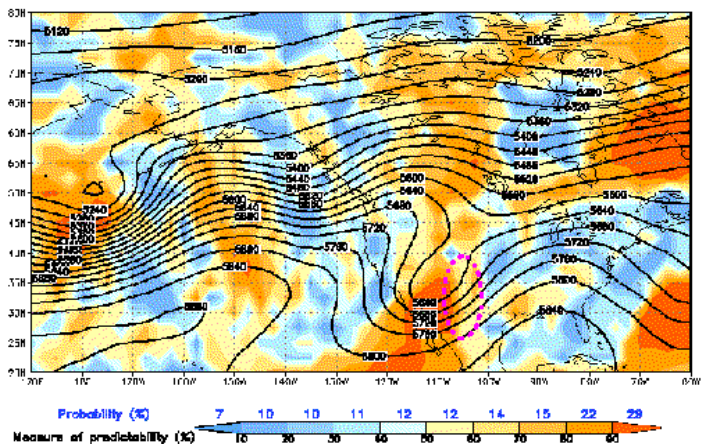
WILL IT GIVE CASE-DEPENDENT ESTIMATES (INSTEAD OF AVERAGE STATISTICAL MEASURE) OF MODEL-RELATED UNCERTAINTY?





SEPARATING HIGH VS. LOW UNCERTAINTY FCSTS





UNCERTAINTY OF FCSTS** CAN BE **QUANTIFIED IN ADVANCE