NORTH AMERICAN ENSEMBLE FORECAST SYSTEM
SYSTÈME DE PRÉVISION D'ENSEMBLE NORD-AMÉRICAIN
SISTEMA CONJUNTO DE PRONÓSTICOS DE AMÉRICA DEL NORTE

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	***National Weather Service, USA***
MSC	***NWS***

PROJECT OVERSIGHT

Michel Beland, Director, ACSD	Louis Uccellini (Director, NCEP/NWS)
Pierre Dubreuil, Director, AEPD	Jack Hayes (Director, OST/NWS)
Jim Abraham, MRB	Steve Lord, EMC

PROJECT CO-LEADERS

Jean-Guy Desmarais (Implementation)	Zoltan Toth (Science)
Gilbert Brunet (Science)	David Michaud / Brent Gordon (Impl.)

JOINT TEAM MEMBERS

Meteorological Research Branch MRB	*Environmental Modeling Center EMC*
Peter Houtekamer, Herschel Mitchell,	Bo Cui, Richard Wobus, Yuejian Zhu
Lawrence Wilson	*NCEP Central Operations NCO*
	Hydrometeor. Prediction Center HPC
Canadian Meteorological Center CMC	Peter Manousos
Richard Hogue, Louis Lefaivre,	*Climate Prediction Center CPC*
Gerard Pellerin, Richard Verret	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

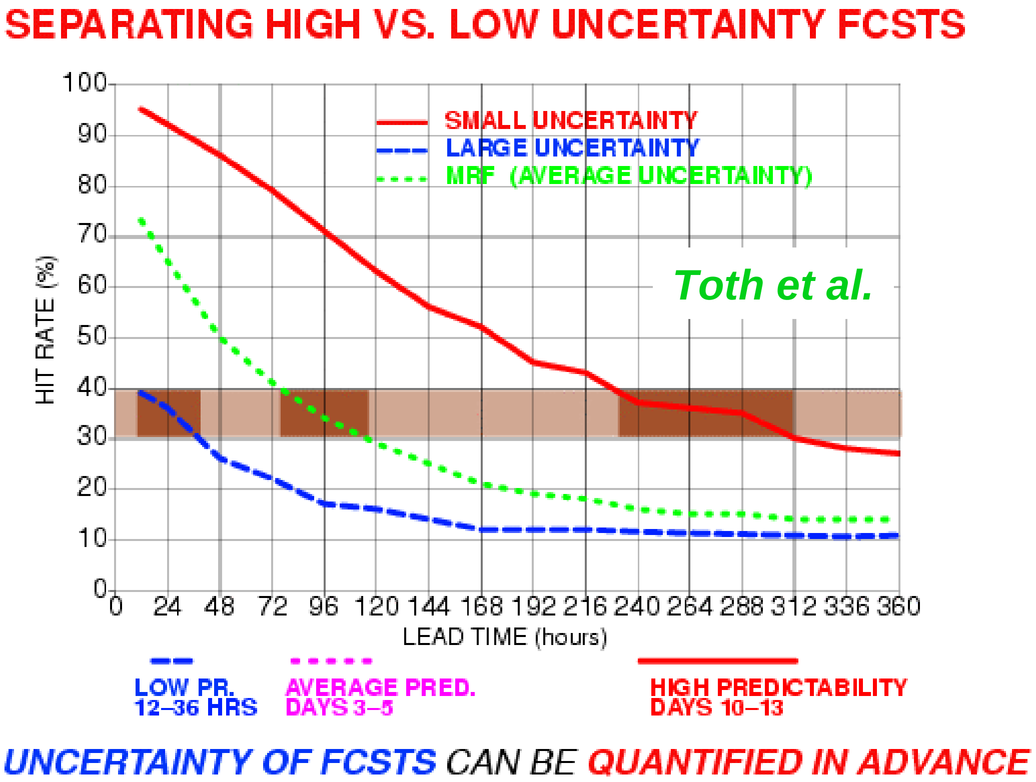
- February 2003, Long Beach, CA
  - NOAA / MSC high level agreement about joint ensemble research/development work (J. Hayes, L. Uccellini, D. Rogers, M. Beland, P. Dubreuil, J. Abraham)
- May 2003, Montreal (MSC)
  - 1^{st} NAEFS Workshop, planning started
- November 2003, MSC & NWS
  - 1^{st} draft 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 & 2^{nd} NAEFS Workshop
    - Leaders of NMS of Canada, Mexico, USA signed memorandum
    - 50 scientists from 5 countries & 8 agencies

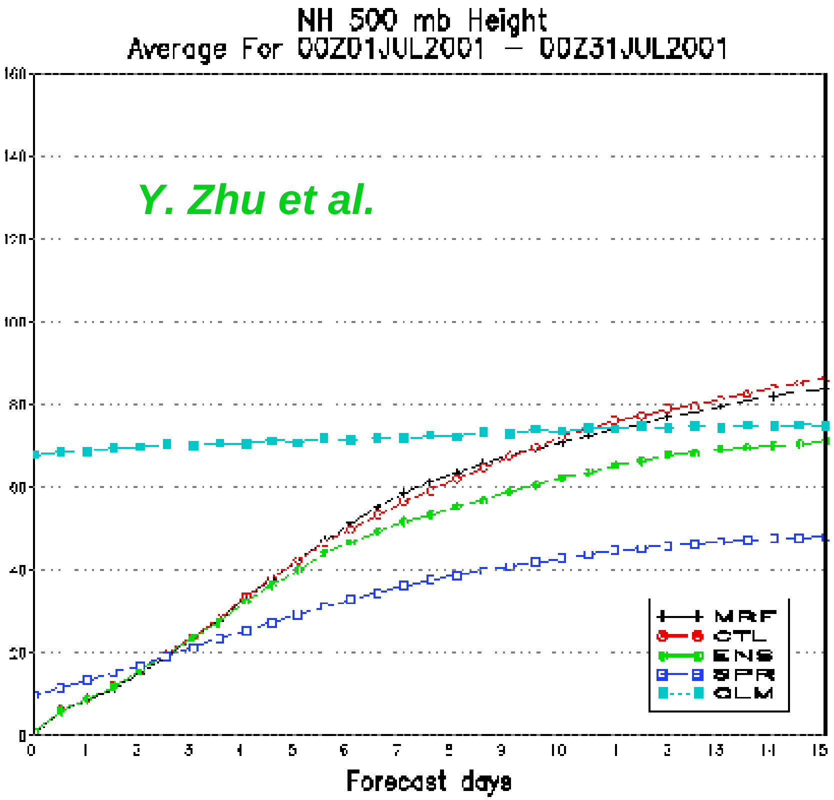
THORPEX & NAEFS

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

Ensemble can capture uncertainty associated with initial errors

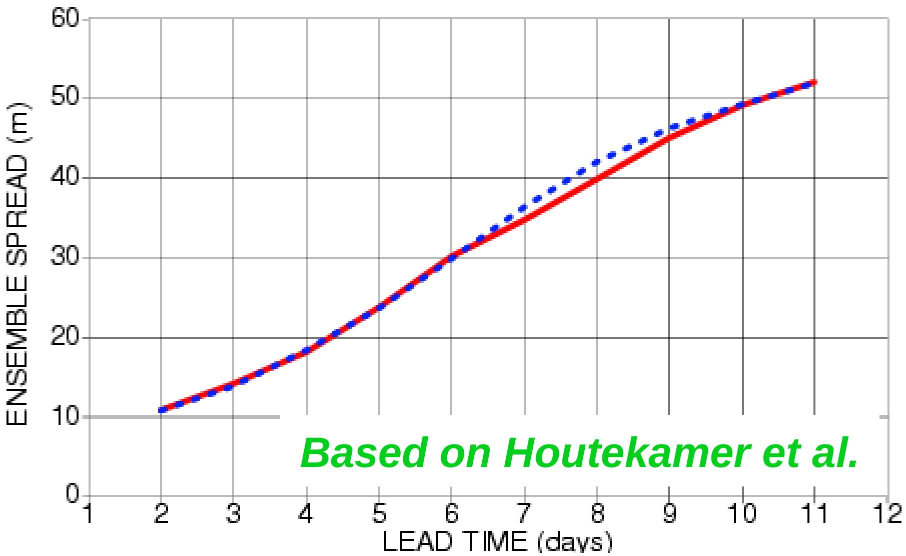
Problems with representing model-related forecast errors

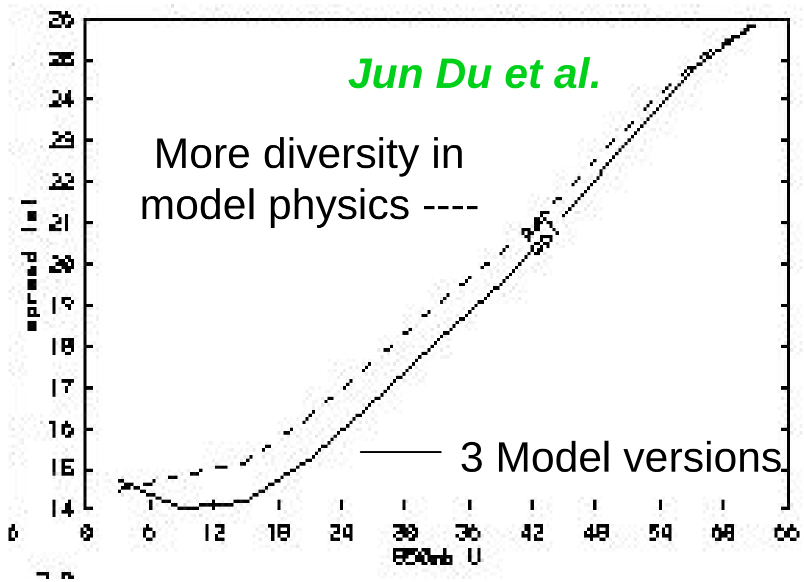




MULTI-MODEL ENSEMBLE APPROACH

- 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





- 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
  - Future enhancements in 3 phases: March 2006, 2007, 2008

LIST OF VARIABLES IDENTIFIED FOR ENSEMBLE EXCHANGE BETWEEN MSC - NCEP

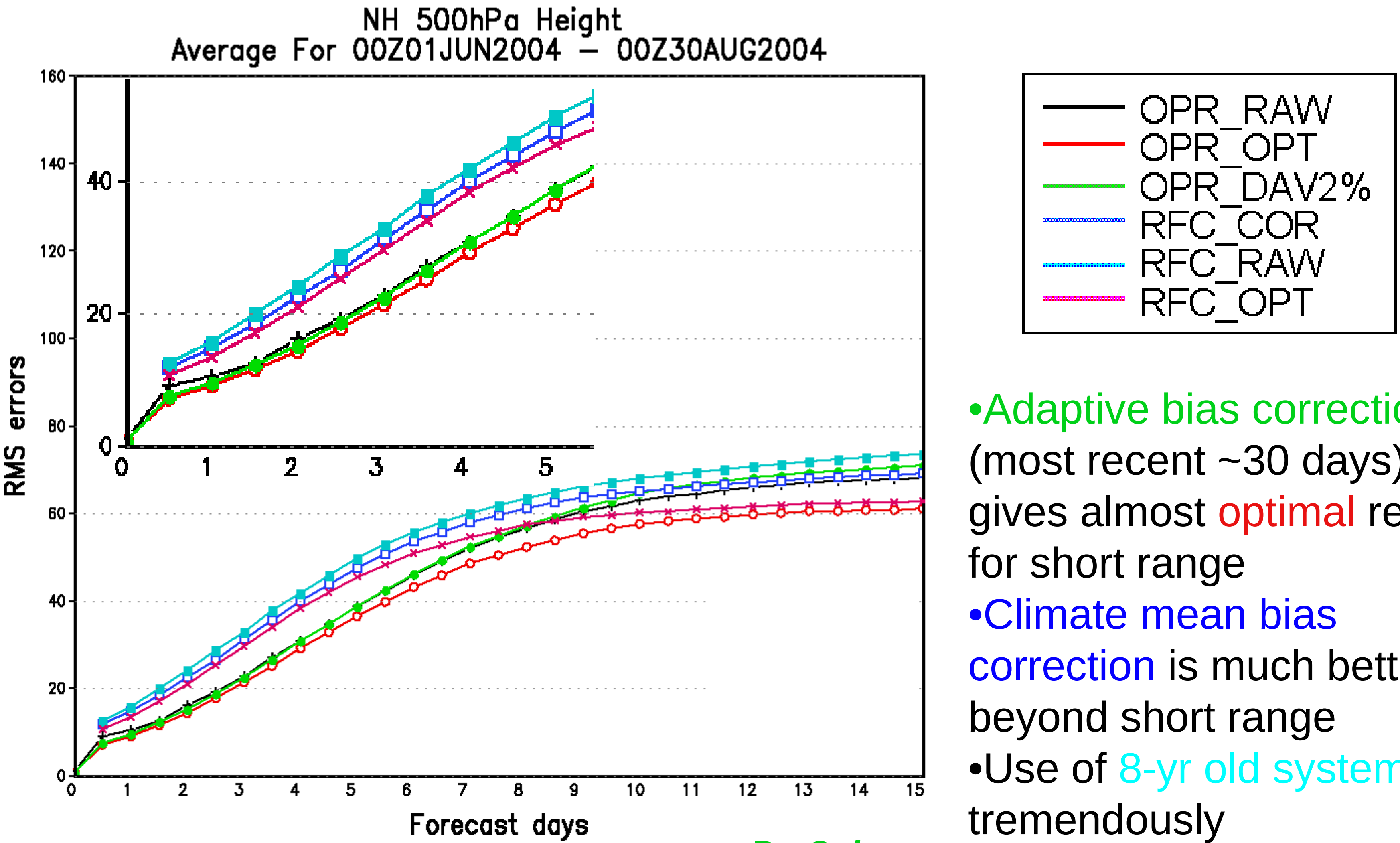
Parameter	CMC	NCEP
Ensemble	8 SEF, 8 GEM	10 paired
Grid	2.5x2.5 deg (144x73) & 1.2x1.2 deg (300x151)	2.5x2.5 deg (144x73) & 1.0x1.0 deg (360x181)
Domain	Global	Global
Format	WMO GRIB Format	WMO GRIB Format
Hours	0, 12, 24, 36, 48, . . . ,216, 228, 240	0, 6, 12, 18, 24, ……., 360, 366, 372, 378, 384
GZ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

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 VS. CLIMATE MEAN BIAS CORRECTION; CURRENT VS. 8-YR OLD DATA ASSIMILATION/MODEL



Bo Cui

- 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

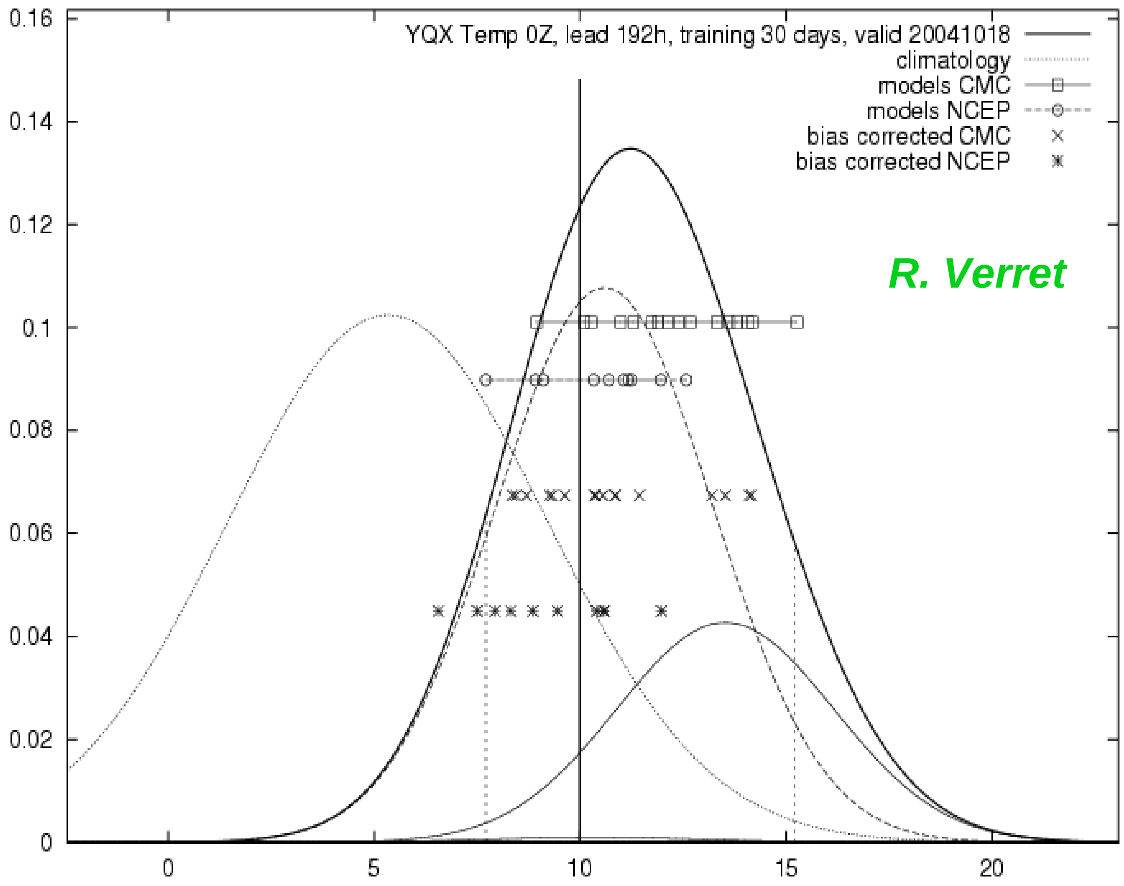
BIAS CORRECTION - TENTATIVE CONCLUSIONS

- 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

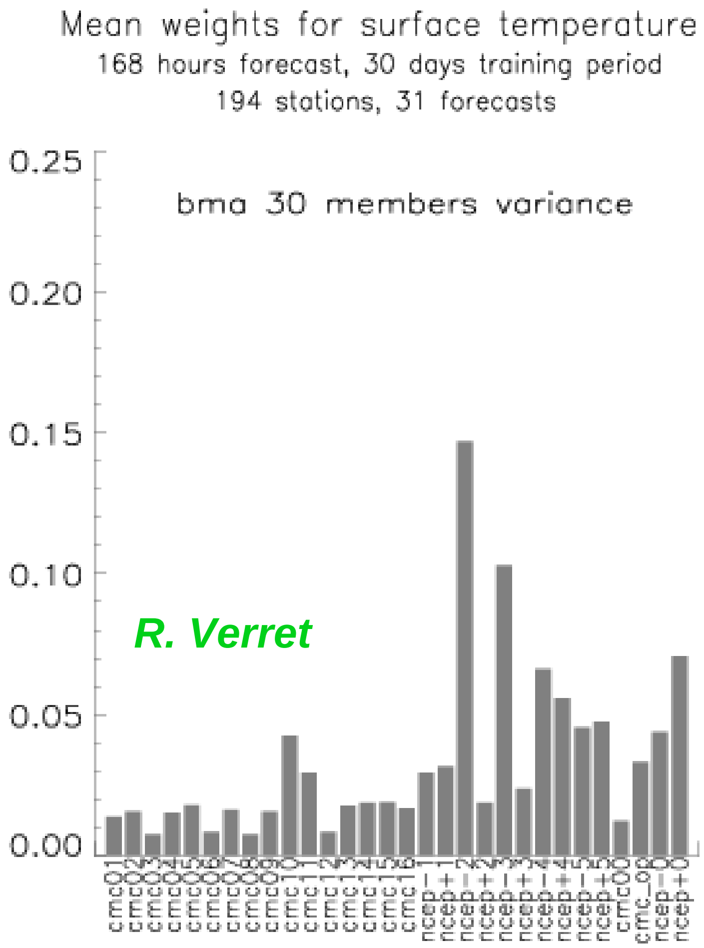
- Use of up-to-date data assimilation/NWP techniques imperative at all ranges

BAYESIAN MODEL AVERAGING (BMA)



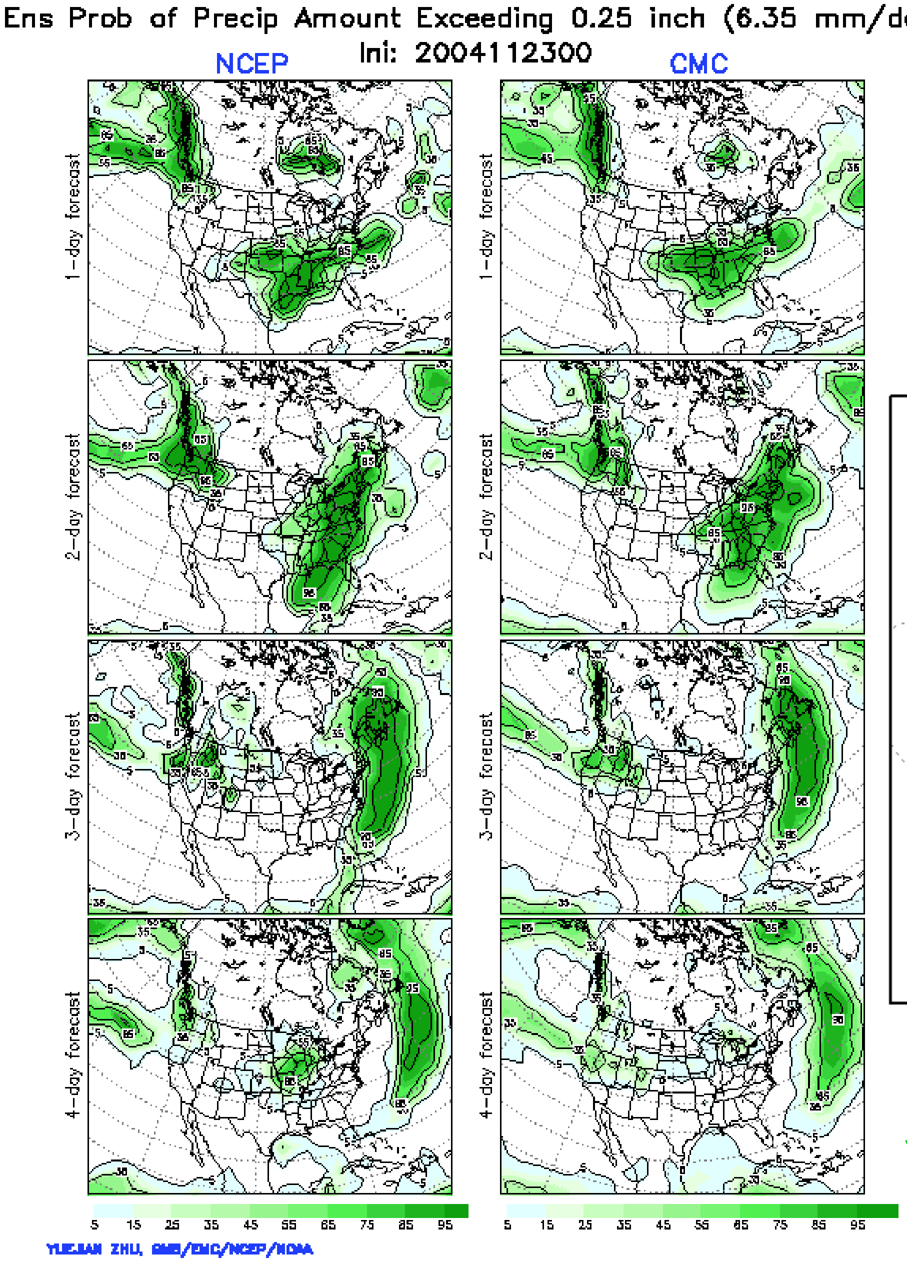
MERGING 2 ENSEMBLES

WEIGHTS FOR 30 MEMBERS



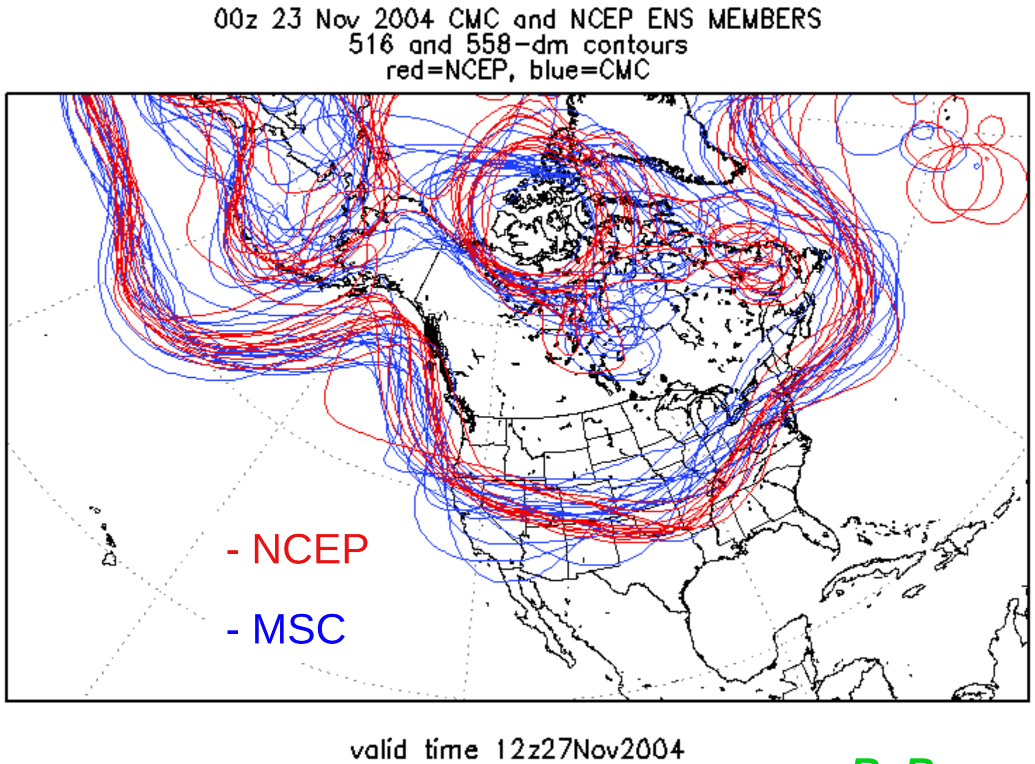
PRODUCTS

PQPF



Y. Zhu

SPAGHETTI



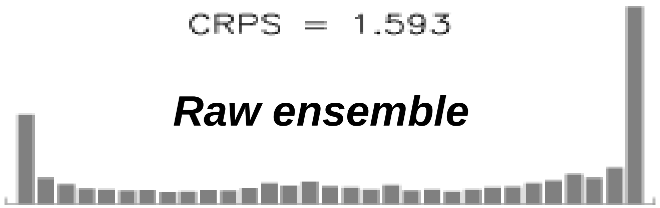
B. Bua

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

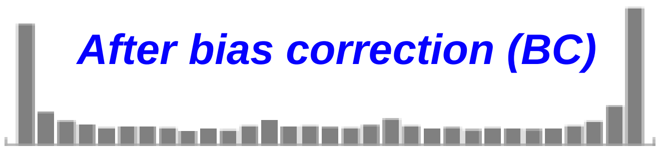


standard 30 members

Bias correction

RMSE = 2.077
CRPS = 1.170

After bias correction (BC)

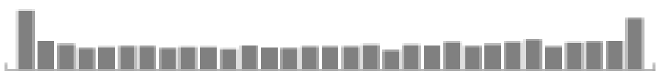


regression 30 members

BMA weighting

RMSE = 1.989
CRPS = 1.068

After BC & BMA



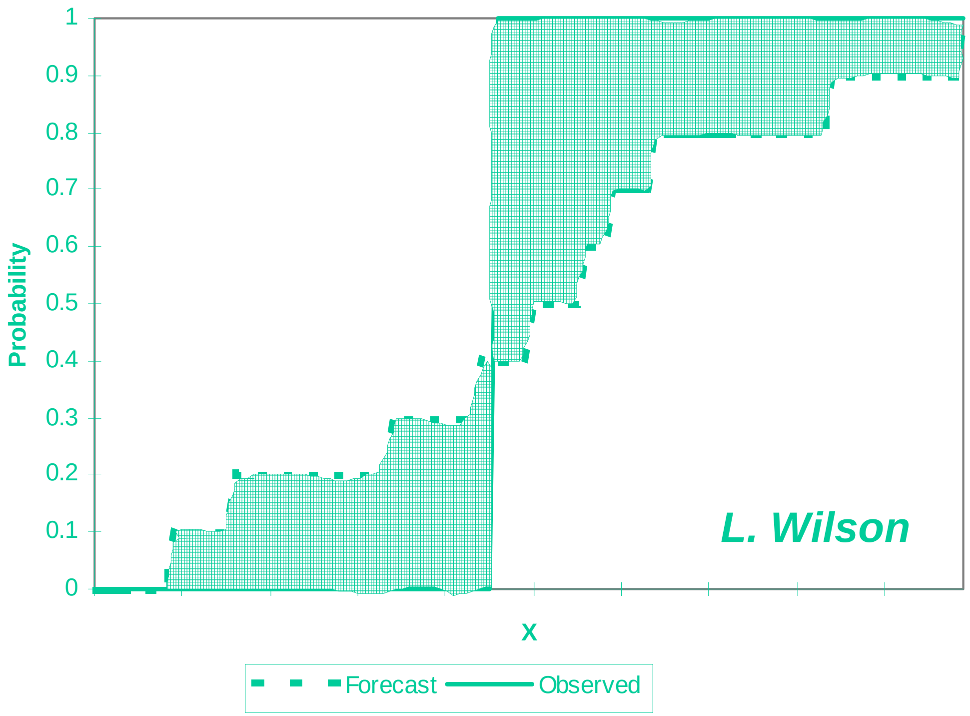
bma 30 members

R. Verret

CONTINUOUS RANKED PROBABILITY SCORE

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

CDF - Forecast-observed



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 one to fourteen day probabilistic forecasts;

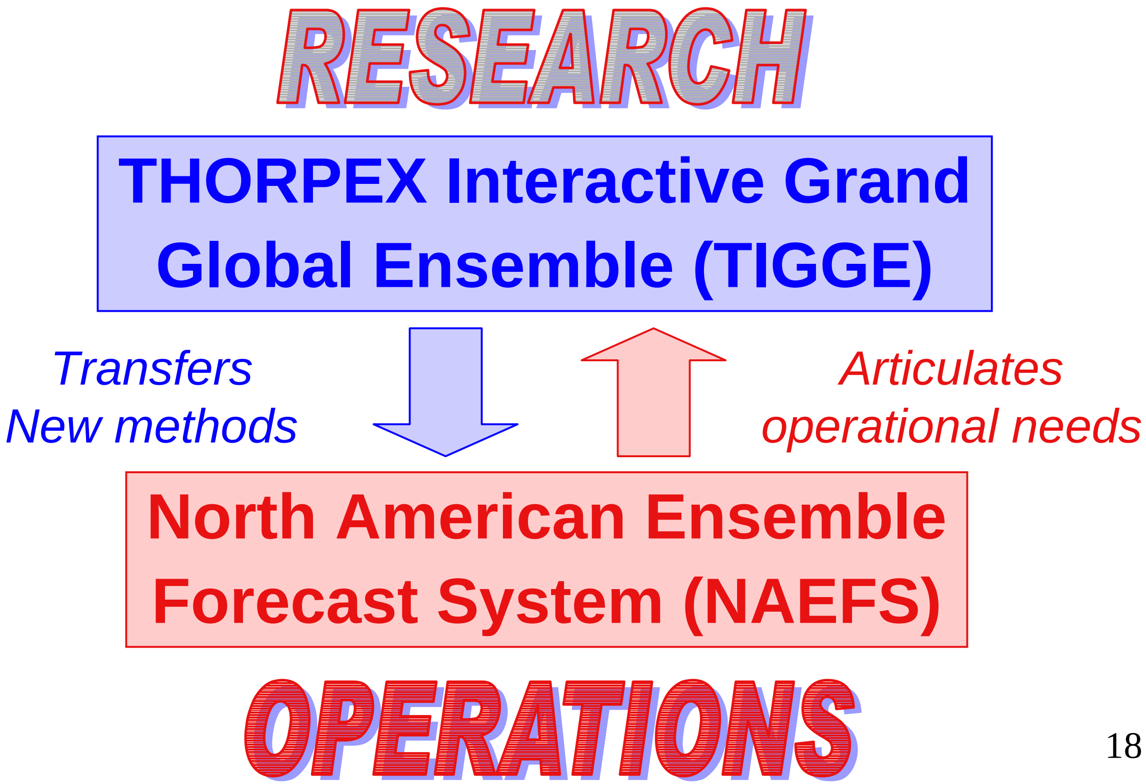
Noting the significant international cooperation undertaken to develop and implement an operational ensemble forecast system for the benefit of North America and surrounding territories;

The signatories, hereby inaugurate the North American Ensemble Forecast System at Camp Springs, Maryland, USA, on this 16th Day of November 2004.

Brig. Gen. David L. Johnson, USAF (Ret.) National Oceanic and Atmospheric Administration Assistant Administrator for Weather Services	Dr. Marc Denis Everell Assistant Deputy Minister Meteorological Service of Canada	Dr. Michel Rosengaus Head of Unit National Meteorological Service of Mexico

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 forecst system: ***Global Interactive Forecast System (GIFS)***



ENSEMBLE RESEARCH WITHIN THORPEX

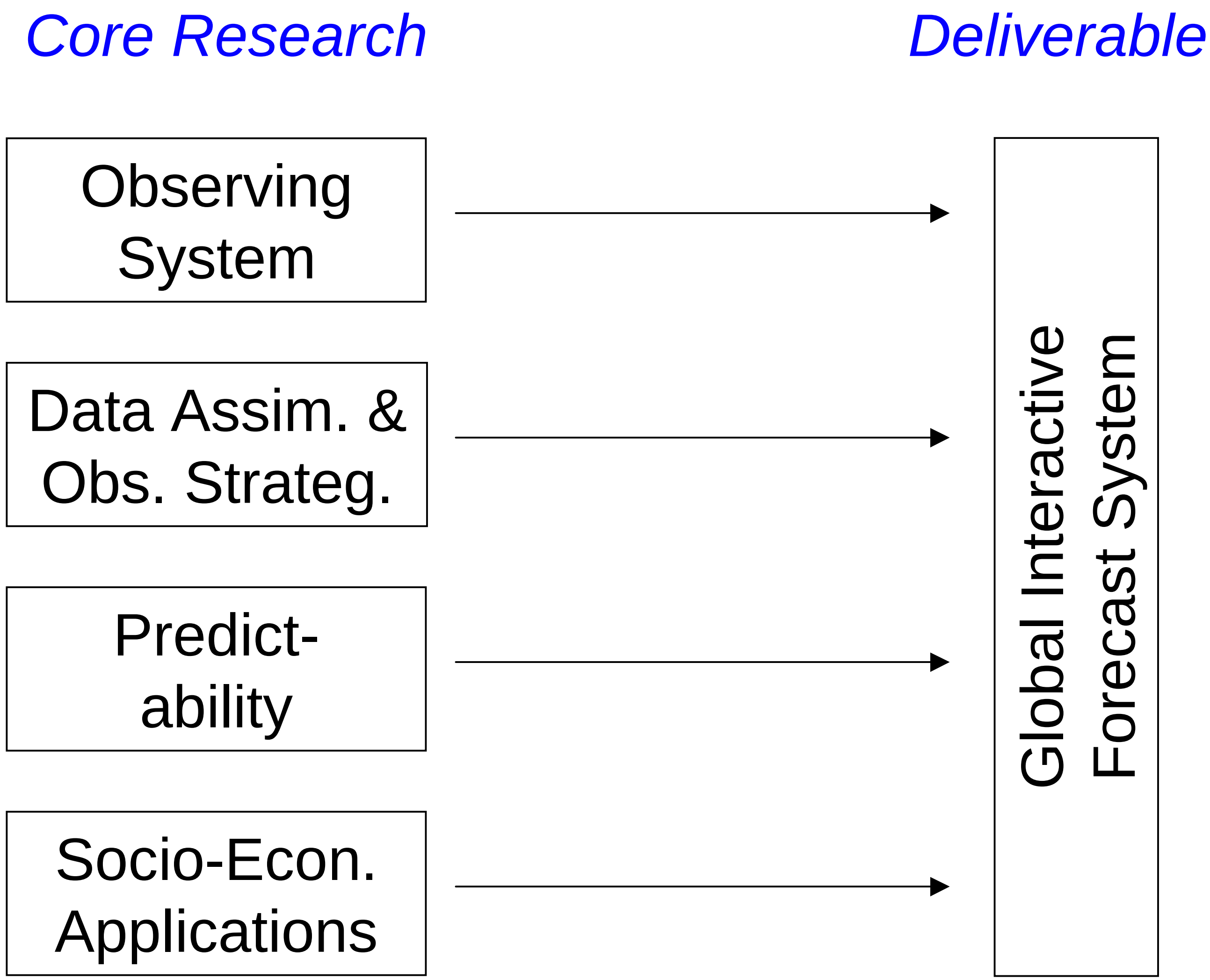
- Goal of THORPEX: Accelerate improvements in utility of fcsts
- THORPEX research organized under 4 major areas- core WGs:
  - Observing System
  - Data Assimilation / Observing Strategies
  - Predictability
  - Socio-Economic Applications
- Which area offers greatest benefit?
  - Resource allocation / 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

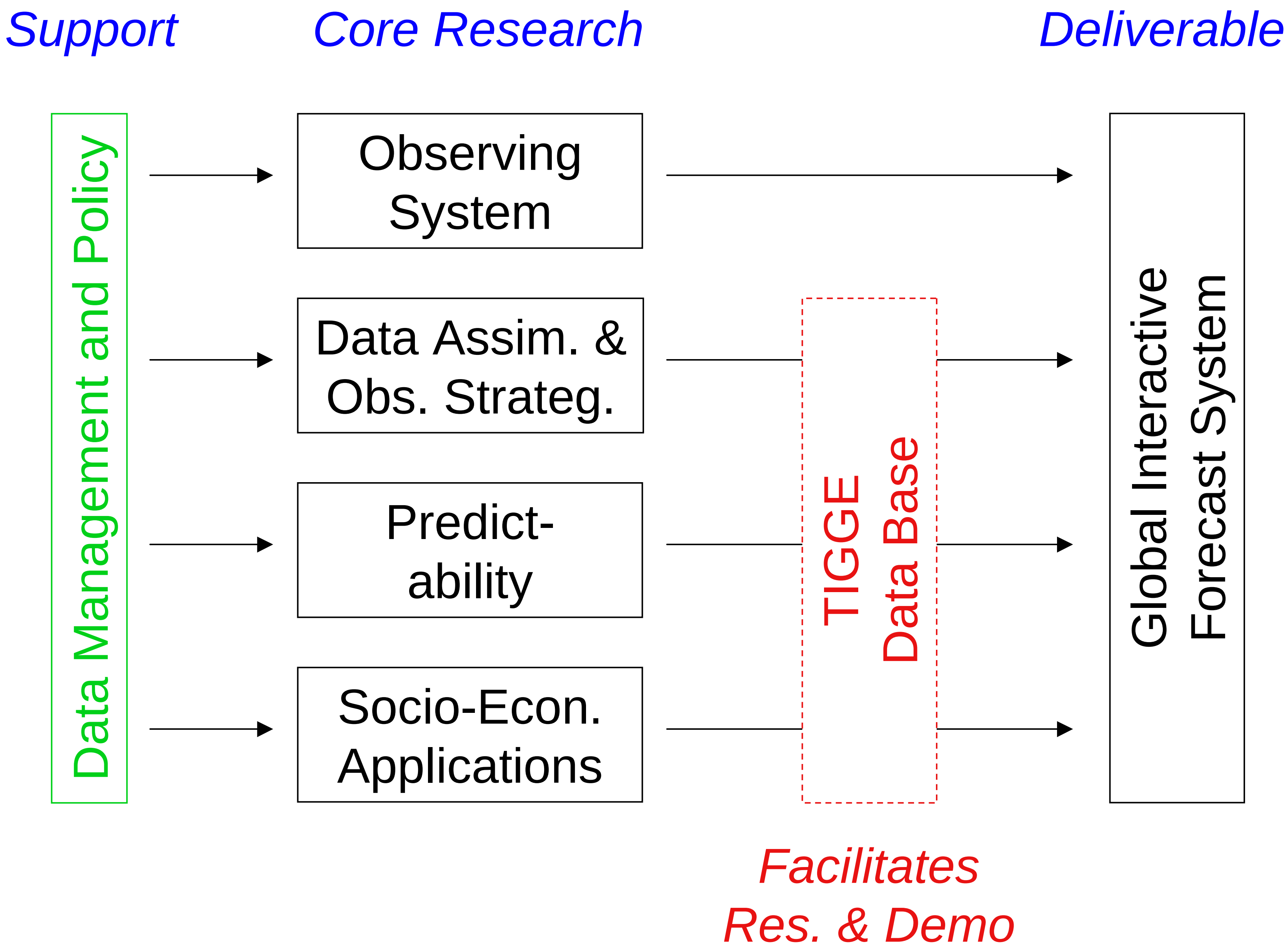
- **Data base of multi-center ensemble forecasts for**
  - Forecast demonstration projects - Real time
  - Some ensemble-related research - Archived
- **TIGGE database will**
  - **Focus research on multi-center ensemble approach**
    - Identify strengths/weaknesses as compared to single center approach
  - **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 assistence of Data Mngmnt WG
  - Under direction of (yet not formed) Executive Board =>

Tread softly (yet decisively)

THORPEX ORGANIZATIONAL FLOWCHART



THORPEX ORGANIZATIONAL FLOWCHART

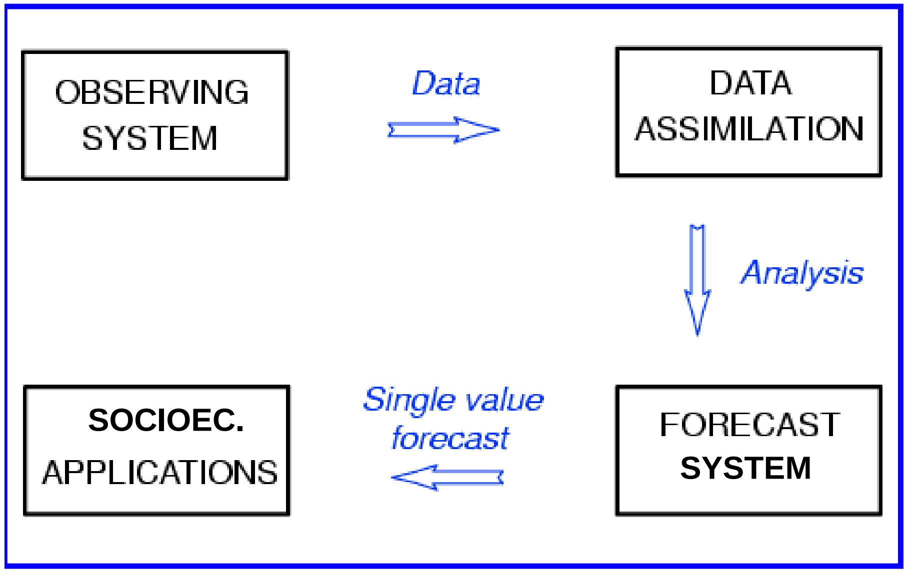


NOAA SERVICE GOAL: ACCELERATE IMPROVEMENTS IN 3-14 DAY FORECASTS

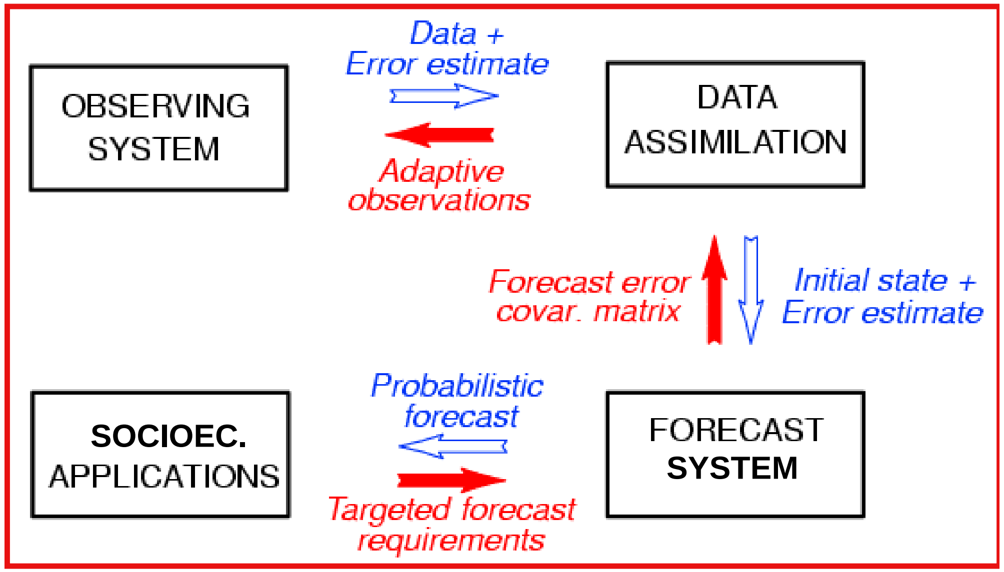
NOAA SCIENCE OBJECTIVE: REVOLUTIONIZE NWP PROCESS

TRADITIONAL NWP	NEW NWP
Each discipline developed on its own	Sub-systems developed in coordination
Disjoint steps in forecast process	End-to-end forecast process
Little or no feedback	Strong feedback among components
One-way flow of information	Two-way interaction
Uncertainty in process ignored	Error/uncertainty accounted for

TRADITIONAL NWP PROCESS

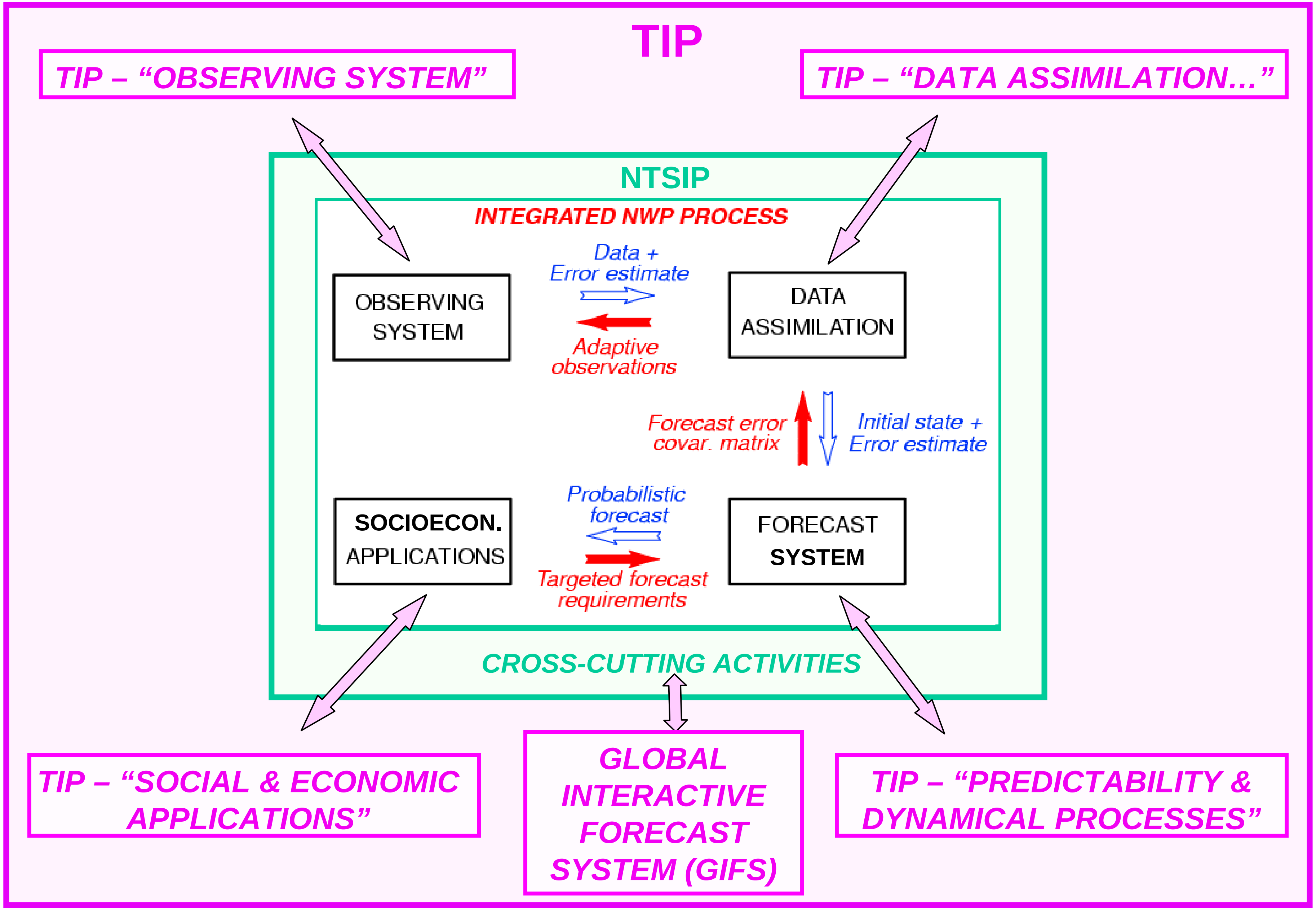


INTEGRATED NWP PROCESS



INTEGRATED, ADAPTIVE, USER CONTROLLABLE

DIRECT LINK BETWEEN
NOAA THORPEX SCIENCE AND IMPLEMENTATION PLAN *(NTSIP-2002)* AND
THORPEX INTERNATIONAL SCIENCE PLAN & THORPEX IMPLEMENTATION PLAN *(TIP)*



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BACKGROUND

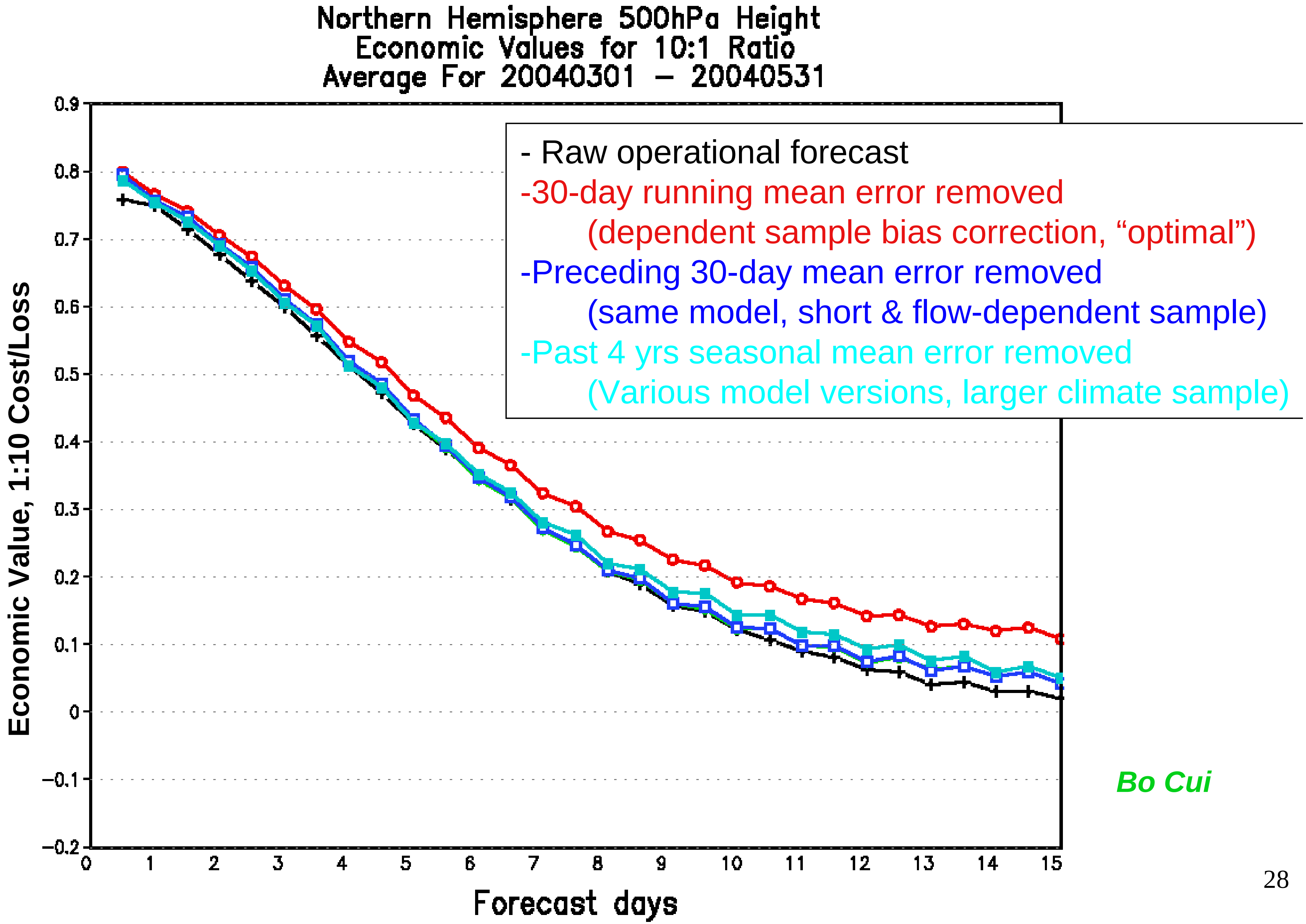
CROSS-CUTTING ACTIVITIES

Integrating NWP procedures from four sub-systems

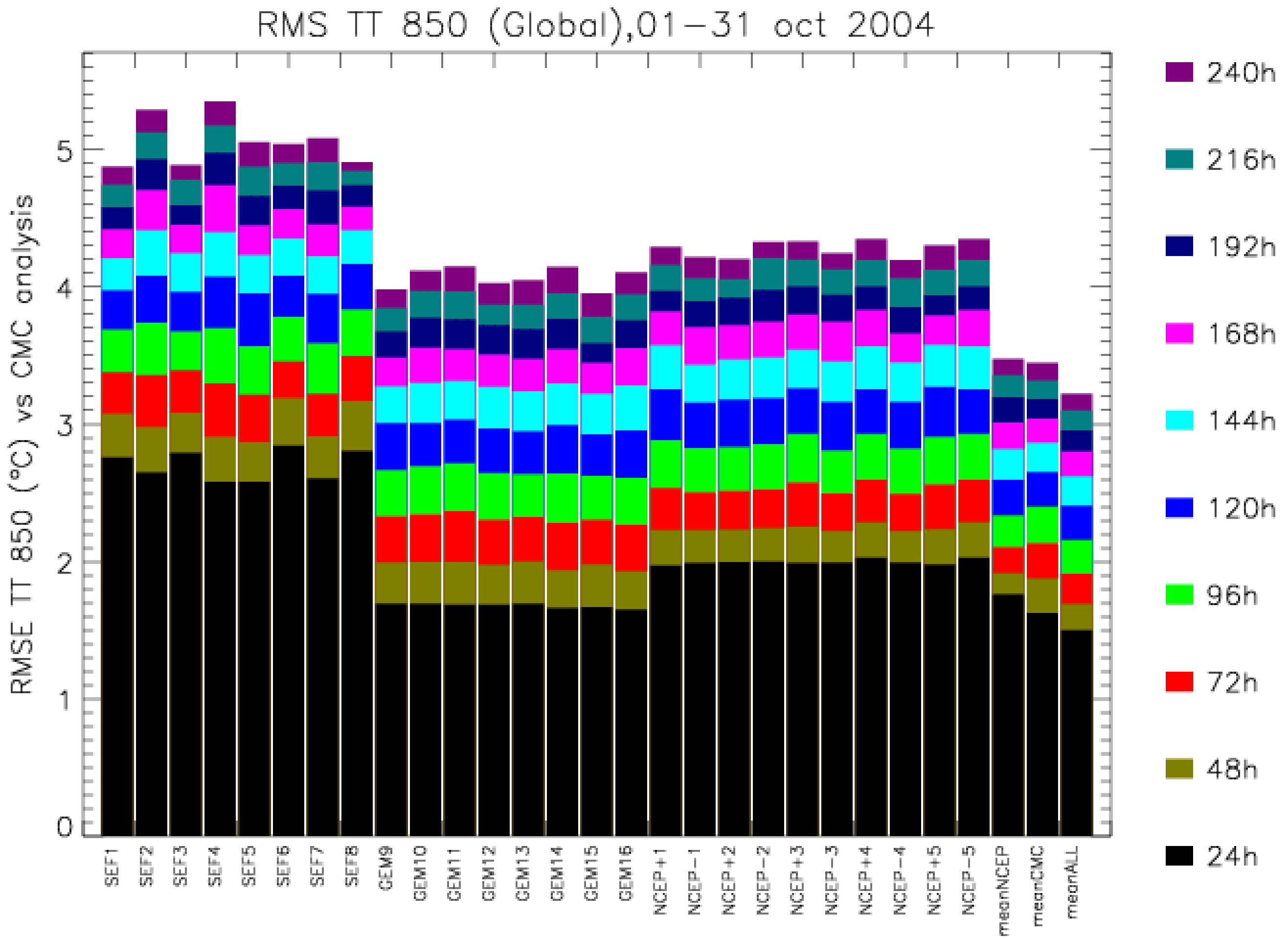
Observing System Simulation Experiments (OSSEs)

- 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



Bo Cui


RMS TT 850 (Global),01-31 oct 2004
RMSE TT 850 (°C) vs CMC analysis
0
1
2
3
4
5
SEF1
SEF2
SEF3
SEF4
SEF5
SEF6
SEF7
SEF8
GEM9
GEM10
GEM11
GEM12
GEM13
GEM14
GEM15
GEM16
NCEP+1
NCEP-1
NCEP+2
NCEP-2
NCEP+3
NCEP-3
NCEP+4
NCEP-4
NCEP+5
NCEP-5
meanNCEP
meanCMC
meanALL
240h
216h
192h
168h
144h
120h
96h
72h
48h
24h

BMA

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

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

$$w_k = \text{weight associated with member } k$$

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

$$\sum_{k=1}^{K} w_k = 1$$

For temperature:

$$\tilde{f}_k = a_k + b_k f_k \qquad p(y|\tilde{f}_k) = N(\tilde{f}_k, \sigma_k) \qquad E(y|\tilde{f}_1,\ldots,\tilde{f}_K) = \sum_{k=1}^{K} w_k \tilde{f}_k$$

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 = posterior probability of $\tilde{f}_k$ being correct $\qquad \sum_{k=1}^{K} w_k = 1$

For temperature:

$$\tilde{f}_k = a_k + b_k f_k \qquad p(y|\tilde{f}_k) = N(\tilde{f}_k, \sigma_k)$$

$$\Rightarrow b_k \equiv 1$$

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