P 2-19

Synthesis of Climate Modeling and Prediction Issues from FY09 CTB Joint Seminar Series

" Research to Operations and Operations to Research "

Jiayu Zhou, S&TI Climate Mission, Office of Science and Technology
Wayne Higgins and Fiona Horsfall, Climate Prediction Center
NOAA's National Weather Service

Introduction

The FY09 NOAA Climate Test Bed (CTB) Joint Seminar Series focused on the CTB strategic priorities to accelerate improvements to: (1) NCEP Climate Forecast System (CFS); (2) Multi-model ensemble prediction systems; (3) Climate forecast products. This presentation synthesizes outstanding issues and R&D needs in climate modeling and prediction, contributing to NWS S&T roadmap and strategic plan with key goals to influence research priorities, improve the transition of research to operations and guide programming priorities to achieve performance goals.

1. Prediction

1.1 Data and Tools

1.1.1 Internal Development

Forecast Evaluation Tool (O'Lenic, CPC/NCEP)

- Trust is at the core of successful product suite. Transparent verification is one way to secure trust. FET can be a laboratory for growing services to users.

3CVRE for MME (van den Dool, CPC/NCEP)

- For better handling degeneracy problem in regression to obtain more reliable skill estimates on future (independent) data.

Transition from CDAS to CFSR for Monitoring (Silva, CPC/NCEP)

- Validate the current generation of reanalysis products to provide a benchmark from which an objective evaluation of improvements in the new generation of reanalysis products can be made.

1.1.2 External Research

Ensemble Empirical Mode Decomposition (EEMD) (Z. Wu, COLA/FSU)

- Climate system is neither stationary nor linear. Variability on different timescales is driven by different physical mechanisms and the variability associated with one physical mechanism could be more predictable than the total variability.

Prospects in Ocean Reanalyses (Carton, AOSC/UM)

- Ocean reanalyses do contain 'real' climate signals. Some coupled problems, such as surface heat flux estimates, are based on the ocean reanalyses, and are likely more accurate than their meteorological counterparts.
- Prosperous developments would be: (1) new methodology, e.g. ensemble methods; (2) extending the record back into the 1st half of the 20th century; (3) new applications, e.g. reanalysis of ocean ecosystems based on an understanding of changing ocean physical properties.

1.2 Predictability

1.2.1 Potential Sources

MJO & Hurricane Outlook (Pegion, COLA)

The ability of the MJO to change the large-scale environment, making it more or less favorable for tropical cyclone development. Quantification of the relationship between the hurricane indices and MJO revealed a statistically significant relationship in the eastern Pacific. CFS is able to simulate the observed relationship between the hurricane indices and the MJO index and can be used to make actual forecasts.

IO SST & La Niña Onset (Yoo, CPC/NCEP)

Indian Ocean (IO) SST plays an important role in the phase transition from El-Nino to La-Niña through the Kelvin wave response. The relationship between Southern IO SST and ENSO onset is particularly strong for La Niña onsets following a relatively strong El Niño.

1.2.2 Limitations

Limited Land Impact in CFS (Wei, COLA)

Large uncertainties in inter-comparison of modeling the land-atmosphere coupling strength. Weaker coupling strength of Noah land model with GFS indicates less predictability contributed by the land condition in CFS.

Soil Moisture (Fan, CPC/NCEP)

Forecast skill hardly beats its persistence over CONUS.

2. Modeling and Assimilation

2.1 System Development

2.1.1 Internal Development

Neural Network Emulation of Model Radiation (Krasnopolsky, EMC/NCEP)

Improving the computational performance of climate simulations and seasonal forecast.

CFS Development Plan (Lord and Pan, EMC/NCEP)

- Implementing CFS-v2 for CFSRR and beginning scientific development for CFS-v3 for Integrated Earth System Analysis (IESA).
- Building a MME system with international and US contributions and moving toward weather-climate forecasting from 1 day to 3 years.

2.1.2 External Research

GFDL Earth System Model (ESM) (Ramaswamy, GFDL)

Including interactive atmospheric chemistry and biogeochemistry with a focus on decadal variability and climate change.

ESRL Nonhydrostatic Icosahedral Model (NIM) (MacDonald, ESRL)

Using advanced dynamical core (*in terms of operational counts in high-resolution models and global communication overheads in massively parallel processors*) and cloud resolving globally, aiming at 100 day prediction for operation in 2013.

UM/AOSC 4D-Local Ensemble Transform Kalman Filter (LETKF) (Kalnay, AOSC/UM)

Providing an estimate of forecast and analysis error covariances that is much simpler to implement than 4D-Var, and giving similar results with simple strategies that can capture current advantages developed within 4D-Var.

UM/ESSIC Fresh Water Flux (FWF) (Zhang and Busalacchi, ESSIC/UM)

Playing an important role (in addition to that of heat, buoyancy and momentum fluxes) in determining SST anomaly in the coupled system, which is underrepresented in the current model.

2.2 Systematic Bias

2.2.1 Atmosphere

Annual Mean and Annual Cycle (Fan and van den Dool, CPC/NCEP)

GFS precipitation forecast has prominent large-scale & low-frequency errors, which are time and location dependent and to some extent can be corrected through bias correction (e.g. by removing last 30-day bias), especially in northern winter. There is too much rainfall in most regions in annual mean.

	Week 1 Bias Correction	Week 1 No Bias Correction	Week 2 Bias Correction	Week 2 No Bias Correction
North America	0.49	0.48	0.24	0.26
South America	0.45	0.25	0.31	0.18
Asia Australia	0.47	0.40	0.29	0.26
Africa	0.40	0.24	0.25	0.13

Increased by 67% — Increased by 80%

The effectiveness of bias correction is mainly space dependent. Bias correction can correct spatial distribution of P_f & reduce its error.

Similarity of P_f & P_o

	Week 1 Bias Correction	Week 1 No Bias Correction	Week 2 Bias Correction	Week 2 No Bias Correction
North America	19.18	22.82	21.61	23.58
South America	29.55	41.06	32.27	41.72
Asia Australia	22.65	27.62	25.24	29.15
Africa	17.06	19.47	17.66	19.33

Reduced by 28% — Reduced by 23%

Distance of P_f & P_o

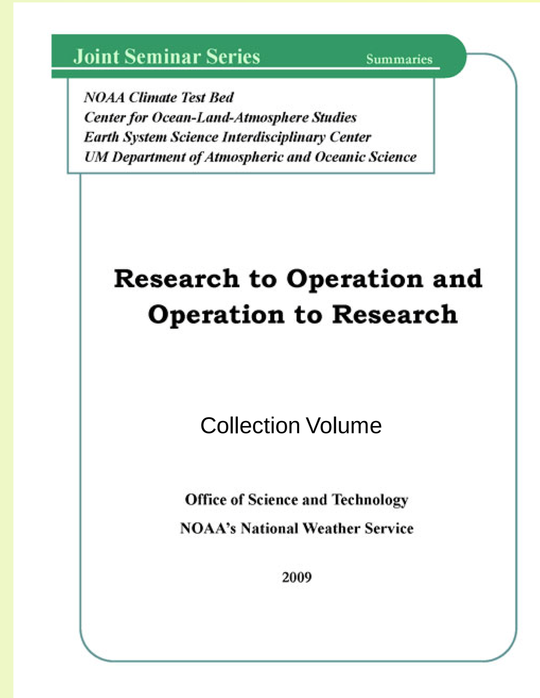
Table 1 Averaged (5/1/08-6/7/09) spatial correlations (top) and RMSE (bottom, mm/wk) of GSF forecasted precipitation anomalies over monsoon regions. (Fan and van den Dool)

At a Glance

- Focus: Research to Operations and Operations to Research
- Period: Oct 08 – Jun 09
- Locations: NCEP, COLA and ESSIC
- 24 Speakers: NCEP (11), COLA (8), ESSIC (3), GFDL (1) and ESRL (1)
- Extended summaries: 17
- Collection volume: Available online
- S&TI synthesis report: What has been learned? – Issues and R&D needs
- Seminar web site: Complete information & timely posted

http://www.weather.gov/ost/climate/STIP/fy09jsctb.htm

~~~~~~~~~~~~~~~~ ~~~~~~~~~~~~~~~~



Joint Seminar Series Summaries

NOAA Climate Test Bed
Center for Ocean-Land-Atmosphere Studies
Earth System Science Interdisciplinary Center
UM Department of Atmospheric and Oceanic Science

Research to Operation and Operation to Research

Collection Volume

Office of Science and Technology
NOAA's National Weather Service

2009

(Cont. from Left)

Besides, the first mode of the error is characterized by the annual cycle, which is particularly strong over South America (S.A.), implying the problems in model simulating S.A. monsoon climate. Though the bias correction shows little help to the forecast over CONUS, the improvement of tropical precipitation forecast will influence global teleconnection patterns, hence impact on climate systems over CONUS.

MJO (Maritime Continent Prediction/Predictability Barrier) (Vintzlieos, EMC/NCEP)

The CFS has better skill than persistence during the propagation of the dry phase of the MJO through the Maritime Continent. However, during the transition of the wet phase of the MJO through the Maritime Continent the CFS is not better than persistence. The Maritime Continent is sometimes a barrier even for the observed MJO. Neither Atmosphere nor Ocean IC was capable to break through the Maritime Continent prediction barrier. The ocean model seems to be the reason for a decrease of the amplitude of intraseasonal modes in the coupled model. To improve the model skill, improving the ability of the ocean model to simulate intraseasonal modes is very important.

Atlantic Hurricane (Schemm and Long, CPC/NCEP)

Weaker wind shear bias over MDR and stronger bias over the Gulf of Mexico and the Atlantic north of 20ºN lead to less number of TCs formed over the Gulf of Mexico and along the east coast of U.S.

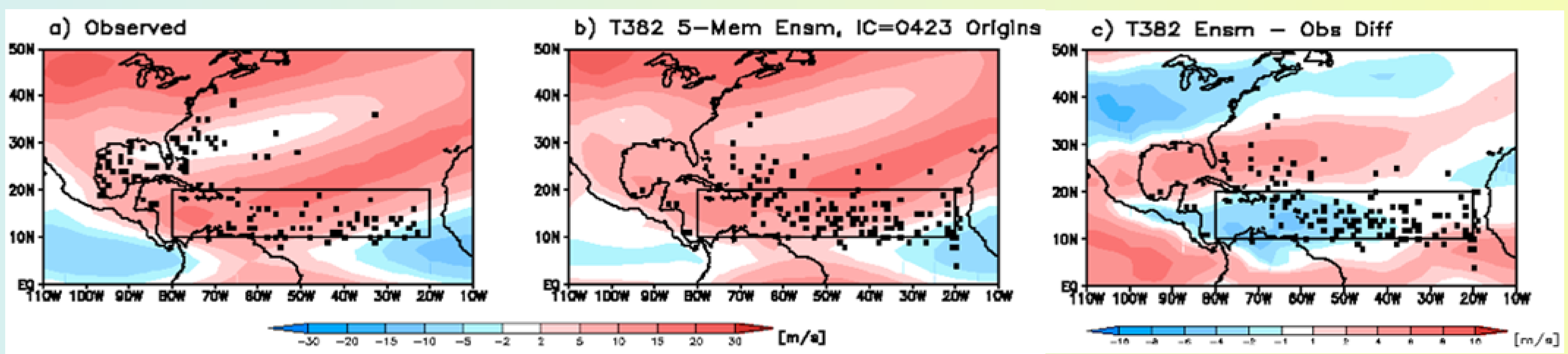


Figure 1 JJA tropical storm origins (black square) and climatological vertical wind shear (shaded) from observations (a) and CFS hindcast runs (b). Right panel shows wind shear bias and the storm origins in the CFS (c). (*Schemm and Long*)

2.2.2 Ocean

ENSO (Jin, COLA/GMU)

The CFS has difficulties to reproduce the nonlinear relationship between Nino3 and Nono4 SST anomalies and fails to distinguish between "warm-pool" and "cold tongue" El Nino, suggesting that the transition mechanism associated with the special structure of SST and the relative importance of advective and thermocline feedbacks between the two types of El Nino in nature is not reproduced in the model.

GODAS

GODAS generally presents weaker intra-seasonal variability than observations.

2.2.3 Land

Drought (Mo, CPC/NCEP)

For real-time operation, the precipitation inputs over the western region are sparse, causing significant biases in surface temperature and precipitation after 2004. To improve precipitation analysis is essential to improve N-LDAS and drought monitoring.

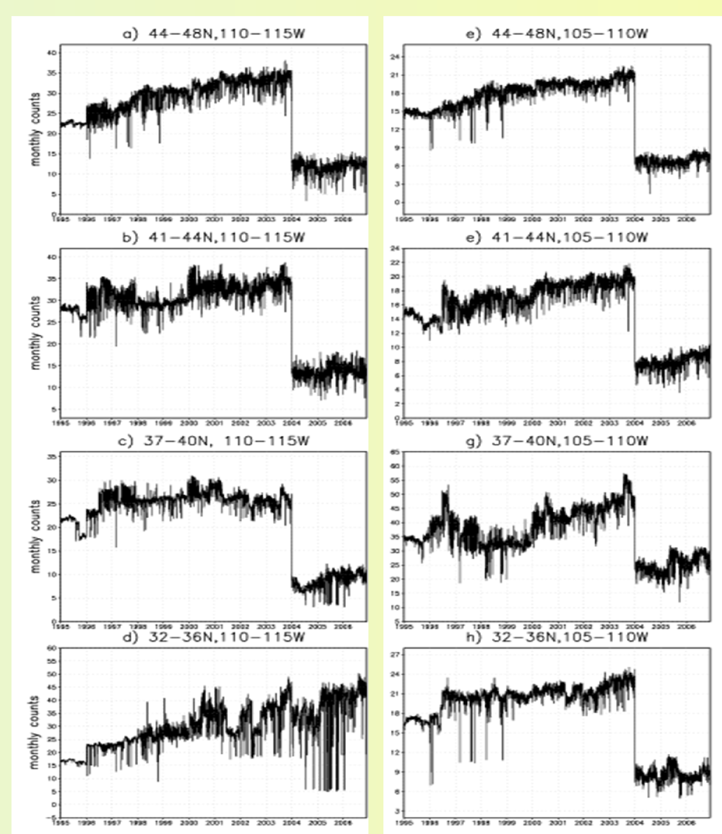


Figure 2 Monthly total P data counts averaged over grid points in 4º x 5º boxes. (*Mo*)

2.3 Application

Amazon Deforestation in CFS (Schneider, COLA/GMU)

Century length control and deforestation simulations are carried out with CFS, showing *model credits* (1) Simulation of current Amazon climate by CFS is realistic compared to many CGCMs, (2) CFS has a 0.5ºC commitment to global warming over about 70 years built in; and *model problems* to be related to the treatment of sea ice. O2R is needed for recent version of CFS coupled with a dynamic-thermodynamic/thermodynamic sea ice model.

The study found (1) The impact of Amazon deforestation would be warmer tropical Pacific. However, these changes are small. ENSO is not noticeably affected. (2) Local response to deforestation is weak warming and drying, which appears to be explained by the Charney albedo mechanism, which is mitigated by the decrease in vegetation resistance.

3. Grand Challenge

3.1 Revolution in Weather-Climate Prediction (Shukla, COLA/GMU)

3.1.1 **"A revolution in climate prediction is necessary and possible."**

- There is now a new perspective of a continuum of prediction problems, with a blurring of the distinction between shorter-term predictions and longer-term climate projections. Increasingly, **decadal and century-long climate projection will become an initial-value problem requiring knowledge of the current observed state of the atmosphere, the oceans, cryosphere, and land surface** in order to produce the best climate projections as well as state-of-the-art decadal and interannual predictions.
- The shorter time-scales and weather are known to be important in influencing the longer-time-scale behavior. In addition, the regional impacts of longer-time-scale changes will be felt by society mainly through the resulting changes in the character of the shorter time-scales, including extreme events. In recognition of this, climate models are being run with the highest possible resolutions.
- Even though the prediction problem itself is seamless, **the best practical approach to it may be described as unified**: models aimed at different time-scales and phenomena may have large commonality but place emphasis on different aspects of the system.
- Since climate in a region is an ensemble of weather events, understanding and prediction of regional climate variability and climate change, including changes in extreme events, will **require a unified initial value approach** that encompasses weather, blocking, intraseasonal oscillations, MJO, PNA, NAO, ENSO, PDO, THC, etc. and climate change, in a seamless framework.

3.1.2 Model and Observation Problems vs. Predictability Limit

- The largest obstacles in realizing the potential predictability of weather and climate are inaccurate models and insufficient observations, rather than an intrinsic limit of predictability. **In the last 30 years, most improvements in weather forecast skill have arisen due to improvements in models and assimilation techniques.**
- The next big challenge is to build a hypothetical "perfect" model which can replicate the statistical properties of past observed climate (means, variances, covariances and patterns of covariability), and use this model to estimate the limits of weather and climate predictability. **The model must represent ALL relevant phenomena, including ocean, atmosphere, and land surface processes and the interactions among them.**

4. Summary

4.1 Identified CFS Problems

FY08 List	FY09 Add-ons
1. **Systematic biases in climatology** – SE Pacific and Atlantic warm SST bias – Bias in air-sea coupling (LHF and LHF-SST relationship) – Stratospheric bias (height, SH seasonal circulation transition and poleward heat flux) 2. **Variability deficiencies** – Prediction of ENSO phase change – ENSO-Indian monsoon teleconnection – MJO maritime continent prediction barrier – Indian Monsoon intraseasonal oscillations – GoC LLJ, the Mexican High and the interannual variability of NAM – QBO and Interannual variability in stratosphere – Stratospheric sudden warming – Overconfidence in prediction 3. Initial conditions inconsistency. 4. Dynamical issues – Increased horizontal resolution does not help (Improve MJO forecast skill, reduce errors in the Pacific, improve stratospheric circulation, capture GoC LLJ, improve Indian monsoon rainfall climatology and variability) – Stratosperic dynamics (vertical fluxes of wave propagation)	1. **Systematic biases in climatology** – Weaker wind shear bias over MDR and stronger bias over the Gulf of Mexico and the Atlantic north of 20ºN (TC formation) – Surface temperature and precipitation biases after 2004 induced by sparse precipitation inputs over the western region in real-time drought monitoring. – Annual mean precipitation bias is large 2. **Variability deficiencies** – Annual cycle of precipitation (global monsoon climate) – Nonlinear relationships between Nino3 and Nino4 SST anomaly ("warm-pool" vs. "cold tongue" El Nino) – Transition of MJO wet phase through the Maritime Continent

4.2 Outstanding R&D Needs - Focusing on the weakest link

FY08 List	FY09 Add-ons
1. Coupled data assimilation with 4D constraint 2. Multi-scale modeling framework (MMF) 3. Advanced dynamical core 4. Improved PBL physics 5. Multi-Model Ensembles (MME) 6. Forecast reliability assessment	1. FWF in addition to HF, BF and MF in air-sea coupling 2. Convert identified predictability to forecast tools development 3. Ocean reanalysis 4. Real-time data access

4.3 Important Issues

FY08 List	FY09 Add-ons
1. Research scientists need O2R support from NCEP (a) CFS and supporting datasets; (b) Documentation; (c) Helpdesk facilities; (d) Participation in ongoing discussion on model improvements; (e) Joint proposals 2. Development crosses different perspectives – Research (Univ. & Labs) ~ more science oriented – Operations (NCEP) ~ more engineering focused Even within operations: – Climate model development (EMC) ~ Improve simulations of Wx & Cx as observed in nature. – Climate services (CPC) ~ Improve the skill of climate outlooks (GPRA) to deliver reliable climate information to users. 3. Strategic priorities – O2R is needed to accelerate R2O — essential to advancing ISI prediction. – Maintain a balance between innovation and operations through transition activities.	1. Urgent need of R&D home for systematic development of NOAA operational weather-climate environmental modeling system (WCFS) and prediction tools – Cons of grant programs: • Specific research needs may not be proposed • There is no mechanism to modify the work mid way as new findings emerge. – Support needed to sustain new developments – The revolution for weather-climate prediction is beyond NWS. A national approach is required.

Acknowledgements. This presentation is based on the extended summaries and presentations contributed by the speakers of the FY09 NOAA CTB Joint Seminar Series and supported by Directors J. Kinter (COLA), T. Busalacchi (ESSIC) and J. Carton (AOSC).
~~~~~~~~~~~~~~~~