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# Scientific Prospects for Weather to Climate Prediction and Services

Jiayu Zhou, S&TI Climate Mission, Office of Science and Technology
Wayne Higgins and Jin Huang, Climate Prediction Center/NCEP
Fiona Horsfall, Climate Service Division/OCWWS

*NOAA's National Weather Service*

## 1. Introduction

The National Weather Service (NWS) Mission for Science & Technology Infusion is an agency-wide collaborative effort among planning, operations and services, with support by strategic community partners. A prominent focus is to enhance the connection between weather and climate for the advancement and provision of integrated services. This is a summary based on presentations for NOAA CTB Joint Seminar Series, Joint Center for Satellite Data Assimilation Workshop, Climate Prediction Application Science Workshop, Ensemble User Workshop, NCEP/EMC Seminars and COLA Seminars in 2010-2011. It highlights recent progresses and challenges in three key development areas: 1) unified modeling, 2) seamless prediction, and 3) integrated services.

## 2. Unified modeling

Modeling of weather and climate fluctuations and their interactions with the Earth system are integral to the simulation/prediction problem. A unified modeling approach can be used to address common processes in both classes of models, such that the progress in short-range weather forecasts will translate into improvements in long-range climate predictions and vice-versa.

*NASA/Goddard multi-scale modeling system (MMS) with unified physics*

The Goddard MMS shown in Figure 1 consists of the Goddard Cumulus Ensemble Model (GCE, a cloud-resolving model), the NASA unified Weather Research and Forecasting Model (WRF, a regional-scale model), and the coupled fvGCM-GCE (the GCE coupled to a general circulation model). The same cloud microphysical processes, long- and short-wave radiative transfer and land-surface processes are applied in all of the models to study explicit cloud-radiation and cloud-surface interactive processes and identify the optimal grid size and physical process. By incorporating the physical packages originally developed for high-resolution process model into both NWP and GCM, it demonstrated significant reduction of model biases and more realistic simulation of weather and climate, such as diurnal variation of precipitation systems, Typhoon, etc.

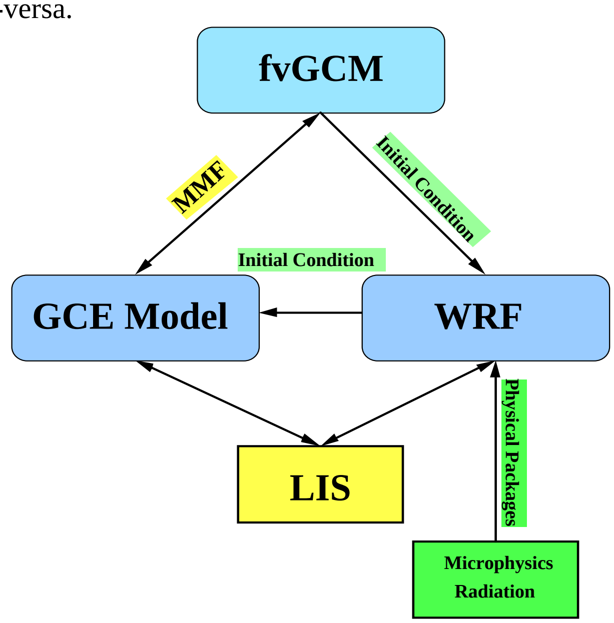


**Fig. 1** Schematic diagram of the Goddard Multi-scale Modeling System with unified physics. (Tao 2010)

*UMD/ESSIC CFS-CWRF nested system with optimized physics*

The Climate extension of the WRF model (CWRF) developed in the Earth System Science Interdisciplinary Center (ESSIC), the University of Maryland inherits all WRF functionalities for numerical

Correspondence to: Jiayu Zhou, Office of Science and Technology, NOAA's National Weather Service, Silver Spring, MD 20910; E-mail: jiayu.zhou@noaa.gov.

weather prediction while enhancing the capability to predict climate. The CWRF incorporates a grand set of physics schemes, which contain more than $10^{24}$ of alternative configurations, representing interactions among surface, planetary boundary layer, cloud, aerosol, and radiation. An optimized physics (geographically dependent) ensemble approach is applied to improve weather forecasts and climate prediction along with reliable uncertainty estimates.

The CWRF model has been nested in the National Centers for Environmental Prediction (NCEP) operational Climate Forecast System (CFS). The Figure 2 shows significant improvement of cold season precipitation prediction over the United States by downscaling.

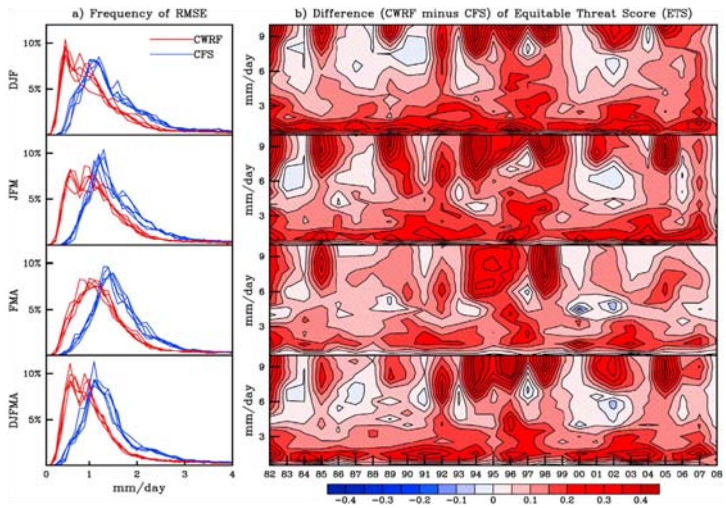


**Fig. 2** (a) Frequency distributions of root mean square errors (mm/day) predicted by the CFS and downscaled by the CWRF and (b) CWRF minus CFS differences in the equitable threat score for seasonal mean precipitation interannual variations. The statistics are based on all land grids over the entire inner domain for DJF, JFM, FMA, and DJFMA from the 5 realizations during 1982–2008. (Liang 2011)

## 3. Seamless prediction

The seamless prediction concept emphasizes the importance of scale interconnectivities and puts the stress on the weakest link of the prediction chain. In forecast practice, reducing biases and better representing uncertainties are the common foci of both weather and climate predictions for improvement. Enhanced cooperation and exchange of experiences between the two communities would accelerate progress for both.

*Progress in satellite data assimilation - Land surface data improvement*

The amount of satellite data assimilated over land in the Gridpoint Statistical Interpolation (GSI) was found to be far less than over ocean. Figure 3 shows a reduction of errors in simulated brightness temperature and an increase in the number of observations (NOAA-18 AMSU-A) assimilated in GSI, especially over forest regions, by using new roughness lengths formulations in the Global Forecast System (GFS) and updated microwave land emissivity model in the Community Radiative Transfer Model (CRTM).

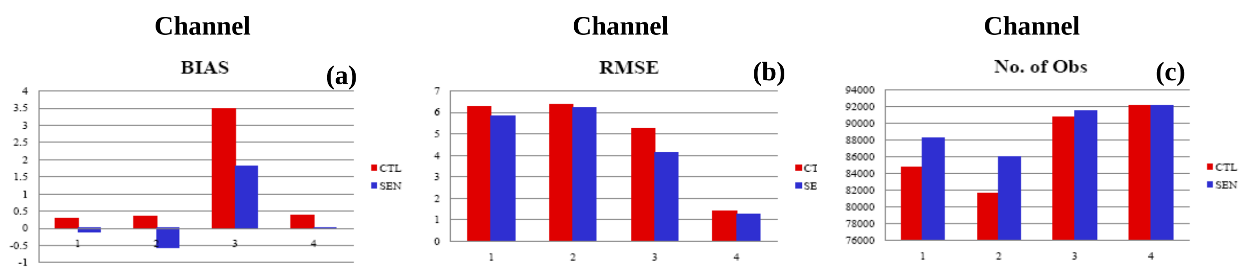


**Fig. 3** Comparisons of brightness temperature (Tb) over land at 12Z assimilated by GSI averaged over the period of 1-31 July 2010, (a) bias, (b) RMSE and (c) the number of observations assimilated. (Zheng 2011)

*Challenges of decadal simulation for CFS*

Based on the analysis of NCEP Climate Forecast System (CFS v2) decadal runs for CMIP5, Figure 4 reveals that the simulation of Atlantic Meridional Overturning Circulation (AMOC) is weak and its 10-year trend is larger than that in the GODAS assimilation. Since the AMOC is related to the Atlantic Multidecadal

Oscillation, which can modulate ENSO activity (Te Raa *et al.* 2009), it has become a focus in CFS development to improve ENSO prediction.

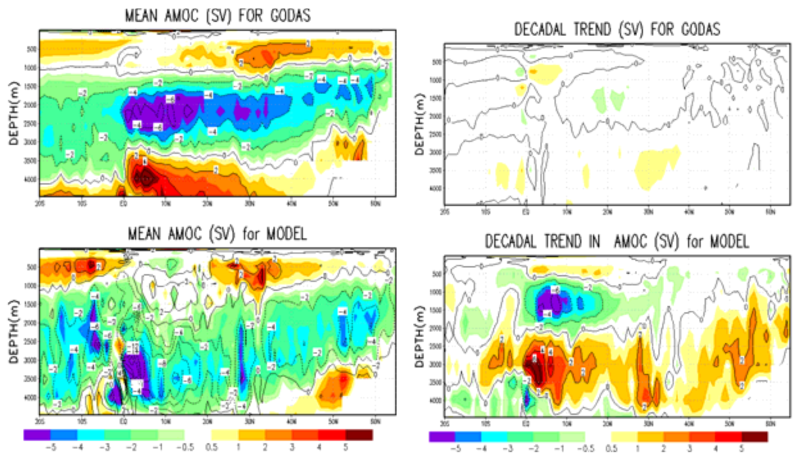


**Fig. 4** Comparisons of NCEP CFSv2 decadal runs for CMIP5 (bottom) with GODAS (top). The left shows the mean AMOC; and the right: the decadal trend. (Nadiga and Wang 2011)

*Shared focus areas with weather ensemble forecast development community*

How does weather forecast handle uncertainty? Why seasonal and decadal forecasting is possible, despite the limits to atmospheric predictability suggested by Lorenz? How should uncertainty be addressed in climate prediction and projection? These are issues fundamental for forecasters to understand to make reliable prediction with confidence. Here are some common focus areas learned from the 5th Ensemble User Workshop.

1. Ensemble configuration and ensemble forecast
    - Ensemble initializations
    - Multi-model, multi-physics and stochastic physics for ensemble perturbation
    - True coupled initialization
2. Statistical post-processing
    - Lead-time dependent systematic errors
    - Non-stationarity of real climate and changes of model-error statistics
    - Relating model variables to sensible weather
    - Choice of proxy of truth - error variance and ensemble of analyses to represent uncertainty
3. Issues to consider
    - Forecast of joint probability, *e.g.* “What is joint probability of heavy precipitation and strong winds?”
    - Better ways to make members (representativeness vs. ensemble size and resolution), not only for simple statistics but also for higher order statistical moments
    - Resolution change in mid-run
    - Resource allocation for real-time fore- vs. hind-casts

**4. Integrated services**

Regional services need reliable climate predictions integrated with weather and water information as long term adaptation is inseparable from near term decisions. Figure 5 shows that short-term variability becomes more significant compared to the long-term trends at smaller spatial scales. This information is critical when attributing anthropogenic causes to local climate variations.

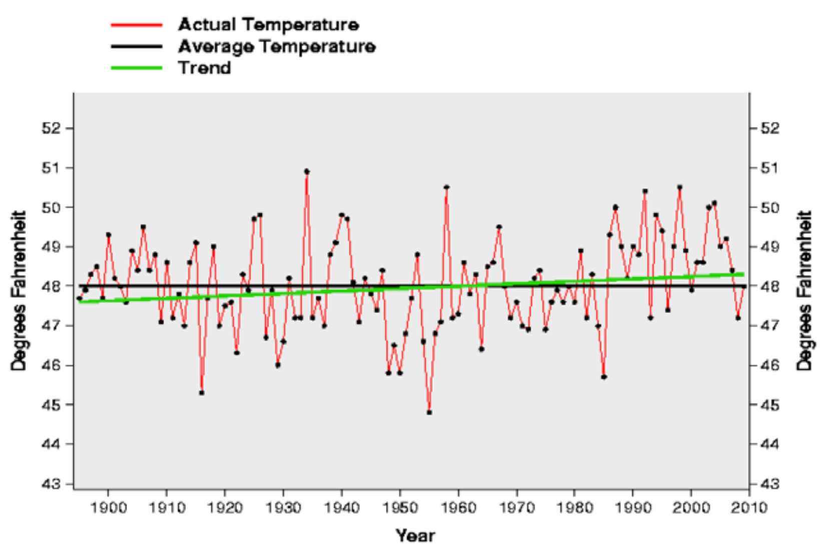


**Fig. 5** Washington state temperature trend and annual variation (1895-2009). (Sarachik 2011)

*Water supply forecasting for the Colorado*

To meet stakeholder demands for climate information, the Colorado Basin River Forecast Center (CBRFC) supported by collaborative research with academic partners has launched a seasonal to year-two streamflow forecast intercomparison effort that has the most impact on Colorado River management (Werner 2011). CBRFC has also implemented an ensemble forecast technique developed at the NWS Office of Hydrologic Development to create a streamflow forecast ensemble based on GFS and CFS output. It is a centerpiece of the nascent NWS Hydrologic Ensemble Forecast Service.

*Climate Change Impact Assessments for International Market Systems (CLIMARK) project*

With broader spatial perspective and greater incorporation of temporal dynamics, new researches in climate impact assessment employed complex integrated models, which contained system components and included feedbacks. A conceptual framework for a dynamic and statistical hybrid modeling system was developed by the CLIMARK project (Winkler 2011) to make industry-wide assessments for market systems with multiple production regions. Its application to assess the impact of climate change on the tart cherry international market demonstrated impressive improvement.

*Questions and concerns from local users*

Local users are asking:

1. What reliable decision-support tools could be designed and deployed at current skill levels and uncertainty of climate predictions?
2. How well could climate projections predict local trends for the next 10 – 20 years? How could best practices be developed for use of projections in decision making and preparation for change?

Our regional climate service advancement is awaiting significant research progresses.

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