Title of Abstract: Multi-Model Ensemble Simulations of the North American Monsoon System

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Introduction

Ability to depict the North American monsoon system (NAMS) is essential for seasonal prediction of warm-season precipitation over much of the North American continent. Given inevitable uncertainties in predicting the nonlinear evolution of the atmosphere on seasonal time scales, an ensemble approach is appropriate. This project explores the utility of predicting the NAMS by an ensemble approach in which multiple numerical models are used.

Project Goals

Ensemble simulations will be produced using regional climate models nested within global analyses. Considerable emphasis will be devoted to evaluating model results, using a number of different verification measures such as mean error, mean square error and its components, and relative operating characteristic. Additional insight will be gained using self-organizing maps and animated visualization techniques. Results will be examined to determine the minimum number of ensemble members needed to obtain benefits from the ensemble approach, and recommendations will be made for implementing a multi-model ensemble in operational prediction.

Method

Building on our prior experience in the Project to Intercompare Regional Climate Simulations (PIRCS; Takle et al. 1999) we will construct multi-model ensemble simulations of the North American monsoon for the period spanning at least 1987-1990, using a domain covering the continental U.S., most of Mexico, and portions of the adjacent oceans. Basic steps in the project as originally proposed include the following:

1. Assemble input data sets for the regional models and supply them to participating groups. The baseline case will be taken from the NCEP reanalysis-II with supplementary high-resolution data as necessary (e.g., sea-surface temperatures in the Gulf of California). The reanalysis-II version will be used because of its superior representation of soil moisture compared to the original NCEP/NCAR reanalysis. Given that the NAMS region is relatively data-sparse, as an adjunct to the project we will perform some shorter-term (seasonal) runs that compare results obtained using the NCEP/NCAR reanalysis for initial and boundary conditions with those obtained using other reanalyses for initial and boundary data (e.g., the original NCEP/NCAR reanalysis, Kalnay et al. 1996; and ECMWF/ERA).

2. Assemble observed data sets for evaluation of model output. Owing to the limited observational data for the NAMS area we will focus mainly on comparison of predicted precipitation to observed precipitation. Precipitation data from Mexico recently have become accessible and will be included in the evaluation.

3. Collect and archive model results from participating groups. The PIRCS team will perform error-checking and reformatting as required so that all models can be manipulated using a common set of analysis tools.

4. Construct and evaluate the ensemble forecasts. Both simple ensemble means and statistically-derived "superensembles" will be constructed. Simulations will be evaluted in both probabilistic and deterministic frameworks. Evaluation will include both conventional verification measures (Brier skill, bias, etc.) and other techniques that are especially useful for ensemble forecasts (such as relative operating characteristic).

Results and Accomplishments

- *Comparison of observed and simulated temporal-spatial scales of central U.S. precipitation:* We compared simulated and observed precipitation intensity spectra for a central U.S. region in a 10-yr regional climate simulation accumulation periods from 6 hr to 10 days. Model agreement with observations depends on the length of precipitation accumulation period, with similar results for both warm and cold halves of the year. Simulated and observed spectra show little overlap. For 6-hr and 12-hr accumulation periods. For daily and longer accumulation periods, the spectra are similar for moderate precipitation rates, though the model produces too many low-intensity precipitation events and too few high-intensity precipitation events for all accumulation periods. The spatial correlation of simulated and observed precipitation events indicates that the model's 50-km grid spacing is too coarse to simulate well high-intensity events. Comparative spatial correlations including and omitting very light precipitation indicate that coarse resolution is not a direct cause of excessive low-intensity events. The model shows less spread than observations in its pattern of spatial correlation versus distance, suggesting that resolved model circulation patterns producing 6-hourly precipitation are limited in the range of precipitation patterns they can produce compared to the real world. The correlations also indicate that replicating observed precipitation intensity distributions for 6-hr accumulation periods requires grid spacing smaller than about 15 km. This result suggests that models with grid spacing substantially larger than this will be unable to simulate the observed diurnal cycle of precipitation.
- *Examination of a seasonal precipitation deficit:* Analysis of our longest regional climate simulation over the continental U.S. includes a precipitation deficit in the south central United States that emerges in September and lingers through February. Deficient precipitation for this region and time of year is also evident in other simulations, indicating a generic problem in climate simulation. We examined this deficit using three complementary analyses: self-organizing maps, bias scores and arithmetic bias. Terrestrial and atmospheric water balances show that the error results primarily from a deficit in horizontal water vapor convergence. However, the fall-only 10-yr average suggests that the primary contributor is a deficit in evapotranspiration. Evaluation of simulated temperature and soil moisture suggests the model has insufficient terrestrial water for evaporation during fall. Results for winter are mixed; errors in both evapotranspiration and lateral moisture convergence may contribute substantially to the precipitation deficit. The model reproduces well both the time-average and time-filtered large-scale circulation, implying that moisture convergence error arises from error in simulating mesoscale circulation.
- A meeting of potential participants was held in October, 2002 at an international workshop “Detection and Modeling of Regional Climate Change” at the International Centre for Theoretical Physics, Trieste, Italy. There we showed some preliminary results and solicited interest from other modeling groups. At least 6 modeling groups expressed strong interest in performing the simulations.

- We ran MM5 for the June-July 1993 central U.S. flood using MM5 with various choices of cumulus parameterizations (e.g., Grell, Kuo, Kain-Fritsch) and compared these to results from 12 different models for the same case. We found that differences between simulations using the same model (MM5) but different cumulus parameterizations were as great as differences between simulations using completely different models. This suggest first, that cumulus parameterization is a large (possibly the largest) contributor to inter-model variability, and second, that use of a single model with different physics may be a viable and much more efficient alternative for construction of ensembles compared to the use of a collection of different models. We note that these results are for a relatively short-term simulation of a summertime episode dominated by convective precipitation. We plan to study this approach further in multi-year simulations to see if land surface modeling differences become important on longer time scales.
- We have completed a baseline simulation for the period 1 June 1986 - 30 November 1990 using NCEP/DOE Reanalysis II as initial and boundary conditions. This covers the 1990 field season of the Southwest Area Monsoon Project (SWAMP) and is also the verification period for the North American Monsoon model intercomparison project (NAMIP) coordinated by D. Gutzler (personal communication).

Future Work

- We are now encouraging other modeling groups to perform the simulations. These groups will do the simulations using their own resources, representing substantial leveraging of our NOAA-allocated funding. After a large amount of exploratory work we have decided to modify the original methodology so that each modeling group will use their own data ingest procedures rather than interpolated data supplied by our group. The new approach has two main advantages: (1) the simulations can be done more quickly, since each group does not have to develop procedures for ingesting our data, and (2) it avoids excessive smoothing caused by multiple interpolations (in both the horizontal and, perhaps more importantly, in the vertical).
- The multi-year simulation using MM5 will be extended to the present day.
- Sensitivity to initial and boundary data source will be tested by re-performing the simulation using NCEP/NCAR Reanalysis I data as initial and boundary conditions for MM5. We are especially interested in sensitivity to initial soil moisture, as the soil moisture representation in the NCEP/DOE Reanalysis II is extensively revised compared to Reanalysis I.
- We will further explore the approach mentioned under "Results and Accomplishments" wherein we construct ensembles using different physical parameterizations in a single regional climate model (here, MM5).

Publications from this project

Gutowski, W.J., Jr., S.G. Decker, R.J. Donavon, Z. Pan, R.W. Arritt and E.S. Takle, 2003: Temporal-spatial scales of observed and simulated precipitation in central U.S. climate. Submitted to *Journal of Climate*.

Gutowski, W.J., Jr., F.O. Otieno, R.W. Arritt, E.S. Takle and Z. Pan, 2002: Diagnosis and attribution of a seasonal precipitation deficit in a U.S. regional climate simulation. Submitted to *Journal of Hydrometeorology*.

Pan, Z., M. Segal and R.W. Arritt, 2003: Role of topography in forcing low-level jets in central U.S. during the 1993 flood: Altered terrain simulations. Submitted to *Monthly Weather Review*.

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