COMPARISON OF CLIMATE MODEL PRECIPITATION FORECASTS WITH NORTH AMERICAN OBSERVATIONS

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ABSTRACT

A comparison is made between observed and forecasted precipitation from 18 global climate models for the period 1979 to 2000 in three regions of North America. The comparison is motivated by an interest in the potential for global climate models to serve as practical tools for water resource planners. Precipitation averaged over monthly, seasonal and annual time periods is considered. The three regions encompass western, central and eastern North America excluding Alaska, northern Canada and Latin America. Most models compare well with observed precipitation for the central and eastern regions at all time scales. For the western region, all models over-predict precipitation at most time scales. Further improvements in GCMs can be expected from the climate modeling community. New methods are needed to better assimilate the inter-model variability of GCM output to create useful information products for water resource planners.

1. INTRODUCTION

A changing climate will present enormous challenges to water resource planners. As precipitation, wind and temperature patterns shift, water availability and demand by humans and other ecosystems will change. These shifts have the potential to impact water supply, agriculture, forestry and all non-human natural systems [Maurer and Duffy, 2005;Stewart et al., 2004].. Many large scale water resource projects, such as reservoirs, distribution systems, groundwater recharge facilities and desalinization systems can take many years to plan and construct. Shifting the location of agricultural activities may also require long planning times. Models are needed to forecast trends in climate at the decadal time scale and at appropriate space scales for rational planning of water resource systems. For future regional impact assessment it is important to have meaningful forecasts of precipitation at multiple time scales, including monthly, seasonally and annually, that impact different water-dependent systems. They must also provide an indication of the permanence of these changes, to distinguish them from temporary excursions from the climate under which industrial civilization has evolved.

The current generation of global climate models (GCMs) have the potential to be useful tools for water resource planning under a changing climate. The most sophisticated of these models (AOGCMs) solve simultaneously for atmospheric and ocean circulation patterns. All models have some form of land-surface representation. In this paper, an intercomparison study is conducted of the ability of the most recent generation of GCMs to replicate observed precipitation for the period 1979-2000. The skill of these models at reproducing past climate can give some suggestion of their ability forecast future climate scenarios. Model intercomparison also gives an indication of the degree of inter-model variability.

2. ANALYSIS PROCEDURE

In preparation for the Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) has assembled a database of AOGCM output. The IPCC database is maintained by the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory and includes results from an earlier intercomparison study, CMIP2+ [Gleckler et al. 2005], and more recent contributions. This database is available to any interested researcher. A subset of the contributors to this database are listed in Table 1. Monthly averaged output of the 20C3M experiment (the best effort of each modeling group to represent the climate of the 20th century) for those models listed in Table 1 has been used in the present analysis. When a modeling group provided multiple realizations of their models, the first realization is used.

Model Name	Sponsor
CCSM3	National Center for Atmospheric Research (USA)
CGCM3.1(T47)	Canadian Centre for Climate Modelling & Analysis
CGCM3.1(T63)	
CNRM-CM3	Météo-France / Centre National de Recherches Météorologiques
ECHAM5/MPI-OM	Max Planck Institute for Meteorology (Germany)
FGOALS-g1.0	LASG / Institute of Atmospheric Physics (China)
GFDL-CM2.0	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory (USA)
GFDL-CM2.1	
GISS-AOM	NASA / Goddard Institute for Space Studies (USA)
GISS-EH	
GISS-ER	
INM-CM3.0	Institute for Numerical Mathematics (Russia)
IPSL-CM4	Institut Pierre Simon Laplace (France)
MIROC3.2(hires)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (Japan)
MRI-CGCM2.3.2	Meteorological Research Institute (Japan)
PCM	National Center for Atmospheric Research (USA)
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research / Met Office (UK)
UKMO-HadGEM1	

TABLE 1: Model name and sponsoring research institution for the global climate models considered in this study.

GCM output is reported as monthly average values on a cartesian latitude-longitude grid. Grid spacing is typically quite large, relative to the needs of water resource planning. For the models listed in Table 1, grid spacing ranges from about 1 degree to 4 degrees. At mid-latitudes, 1 degree spacing corresponds to over 100 km on the land surface.

AOGCM output is compared with data from the CPC Merged Analysis of Precipitation (CMAP) [Xie and Arkin 1997]. CMAP data covers the period 1 January 1979 to

2004 and consists of monthly total precipitation on a 2.5° by 2.5° grid. For North America the error in the CMAP data, relative to the mean, is estimated to be approximately 10% [Figure 6, Xie and Arkin, 1997]. The comparison is conducted for the period 1 January 1979 to 31 December 1999, corresponding to the temporal overlap between available CMAP data and available AOGCM output. Observed and model monthly precipitation is averaged over the entire 21 year period and compared. Comparisons are conducted at three time scales; annual, seasonal and monthly.

Average precipitation over a region is determined by assuming that the grid point flux values are uniform over the cell in which the grid point is centered and performing an area-weighted integration of these values. To make a comparison of model output across the different model-specific grids it is necessary to remap these results onto a common grid system. Model-specific grids are remapped onto a common 1.25° by 1.25° Cartesian grid using a bilinear interpolation routine [Jones, 1998]. This grid is finer than all but one of the GCM grids analyzed. The center points of the CMAP grid fall on longitudes beginning at 1.25E and continuing at increments of 2.5. Similarly, latitudes of grid points begin at 88.75S and continue at increments of 2.5 degrees. The remapping grids have a spacing of 1.25 degrees with grid points that begin at longitude 0.625E and latitude 89.375S and continue in both directions at increments of 1.25. The CMAP and common grids are oriented so that every CMAP cell contains four of the cells from the 1.25° grid.

The comparison of AOGCM results is conducted over three regions of North America at an averaging scale typical for regional studies and with similar extent to those used by Giorgi and Francisco [2000]. The three regions lie south of 55°N, which excludes Alaska and northern Canada. The three regions are depicted in Figure 1 and are bounded on their east and west sides by longitude lines 70°, 90°, 105° and 125° west The southern boundary

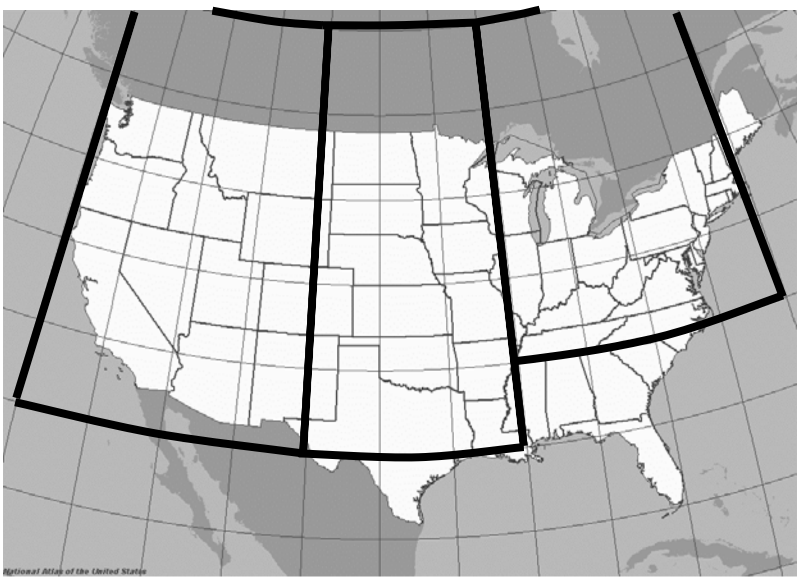

FIGURE 1: Outlines of the three regions of North America considered in this study.

of the eastern North America region (ENA) extends to 35°N while the southern boundaries of the central and western North American regions (CNA and WNA) extend to 30°N. The boundaries of these regions are selected to align with the CMAP 2.5° grid and the common 1.25° grid onto which model results are mapped. Note that some portions of WNA and ENA include precipitation that falls over the ocean.

3. RESULTS AND DISCUSSION

Figure 2 depicts the relative deviation of model-forecasted average precipitation from the CMAP precipitation. Deviation is computed as the 21-year average model value minus the CMAP 21–year average value with the difference divided by the CMAP value. The five stacked plots represent deviations averaged over the year and for each of four seasons. The shaded bars represent each of the three averaging regions. Figure 3 depicts average monthly precipitation, starting with January, for the three regions considered in this study. Presented are the CMAP values, mean of all 18 models, the maximum and minimum of the models in each month and the monthly averages for the three models that have the lowest root mean square difference (RMS). RMS values are computed between the monthly average precipitation and the corresponding CMAP value. The minimum, maximum and average RMS (mm/day) for WNA is 1.24, 5.57 and 3.04; for CNA 0.70, 3.43 and 1.81; for ENA 1.08, 3.22 and 1.86, respectively.

Model results compare well for the CNA and ENA regions. Many models have deviations of less than 0.1 especially in the MAM, JJA and SON seasons. Deviations of less than 0.1 are within the approximate error range of the CMAP data. Several models are consistently superior to other models across time scales and averaging regions. These include MRI-CGCM2.3.2 and CGCM3.1 (T47).In Figure 3 the model mean and three superior models track the observed magnitude and phase quite well for the CNA and ENA regions. The results for the WNA region are less successful. In Figure 2, the black bars that represent WNA are much larger than those for other regions for nearly all models and all time periods. The RMS values are highest in WNA over all models and the monthly observed precipitation depicted in Figure 3 falls out of the range of model results for all but the summer months.

The relative difficulty that the models have with the WNA region is consistent with those from several other studies of earlier generations of GCMs. Giorgi and Francisco [2000] determined model deviation from precipitation observations over 1961-1990 for five model results and found that largest magnitude deviations for their WNA, CNA and ENA regions were approximately, 1.0, 0.2 and -0.25 for DJF and 0.6, 0.4 and 0.6, for JJA, respectively. In the CNA and ENA regions, some model results were within 10% of observations in both time periods, while the smallest deviations for the WNA region were about 0.2. Gleckler et al. [2005] present results comparing observed CMAP precipitation with precipitation averaged over 11 AOGCMs in the CMIP2+ model set for North America that generally show substantial over-prediction in WNA and moderate under- and over-prediction for CNA and ENA. Similar results are also presented by Dai et al. [2001] in a comparison of CMAP data with the NCAR Climate System Model.

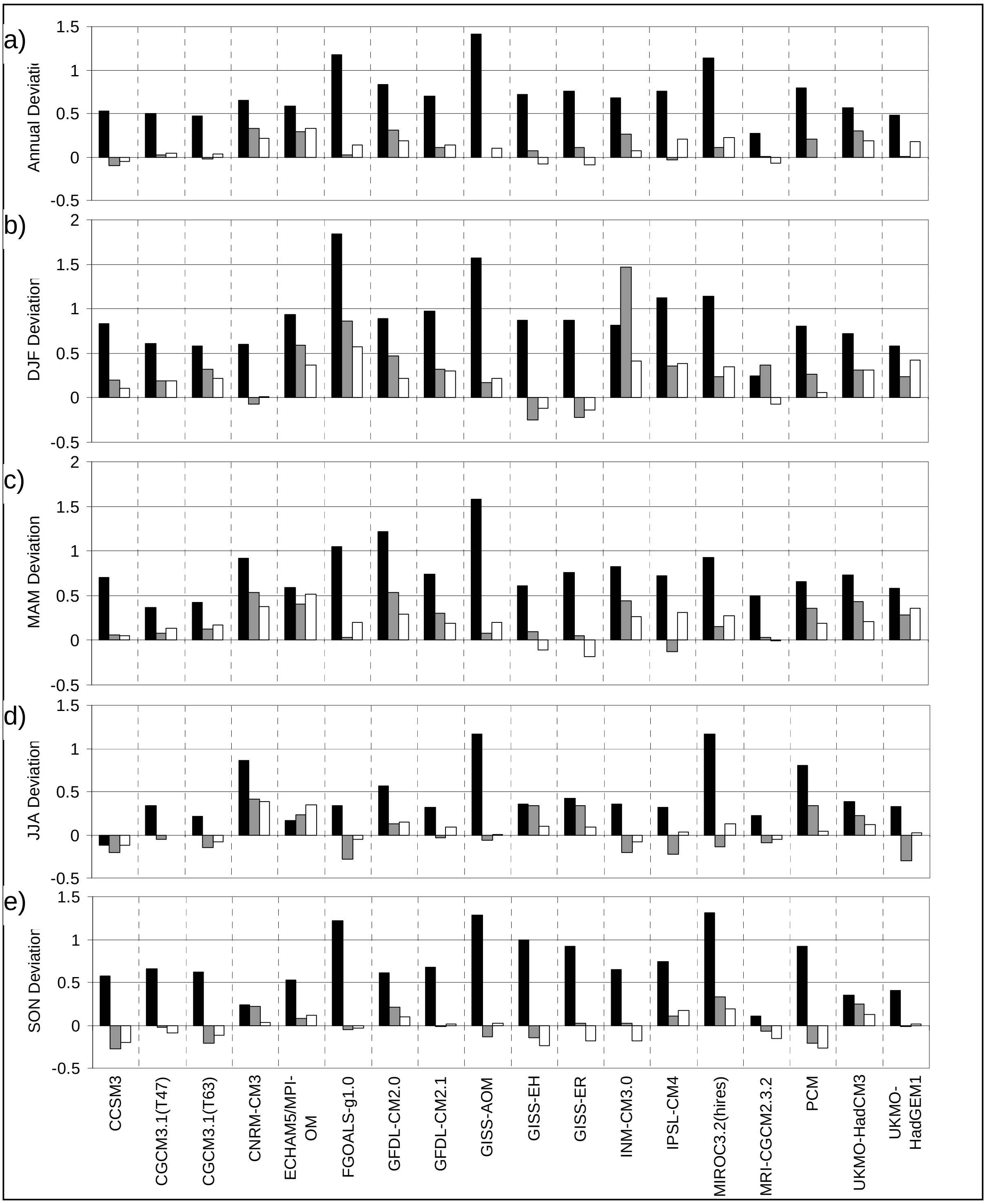

FIGURE 2: Relative deviation of model forecasted average precipitation from the CMAP precipitation for time periods: a) annual, b) December-January-February (DJF), c) March-April-May (MAM), d) June-July-August (JJA) and e) September-October-November (SON). For each model and each time period the bars represent WNA (black bars), CNA (gray bars), ENA (open bars).

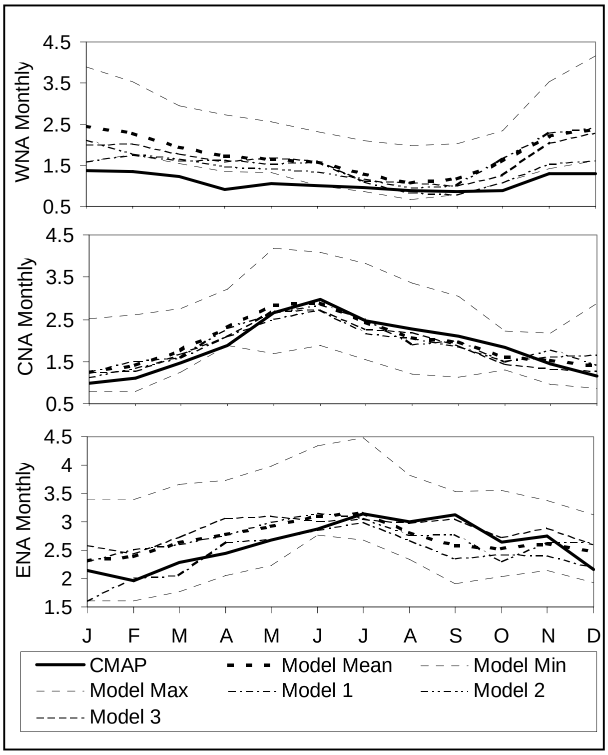

FIGURE 3: Monthly time series of observed precipitation (CMAP), model mean, minimum and maximum and the three models with the lowest root mean square error for; a) western North America, where Model 1 is MRI-CGCM2.3.2, Model 2 is CGCM3.1(T63) and Model 3 is UKMO-HadGEM1, b) central North America, where Model 1 is MRI-CGCM2.3.2, Model 2 is CGCM3.1(T47) and Model 3 is GISS-AOM, c) eastern North America, where Model 1 is MRI-CGCM2.3.2, Model 2 is CGCM3.1(T47) and Model 3 is GISS-AOM. Precipitation is in units of mm/day.

The difficulty that GCMs have with representing precipitation may be related to the varied landscape of this region. WNA includes sub-regions which are dominated by coastal mountain ranges where there is substantial precipitation. WNA also includes the varied landscapes of the Rocky Mountain and Intermontane Plateau Systems where annual precipitation is generally quite small. Preliminary work indicates that most of the GCMs described in this paper have generally reproduce the higher precipitation in coastal regions and lower precipitation in inland regions. Additional work is needed to separate the impact of land-surface parameterization choices within WNA from processes and model-specific parameterization schemes that lie outside the boundaries of WNA [Higgins et al., 2000].

4. CONCLUSIONS

A comparison between precipitation from 18 AOGCMs and observations has been conducted over three regions of North America during the late 20th century. Metrics at different time scales are used. In aggregate, the models compare well with observed precipitation in the eastern and central regions of North America, but less well in the western region. Several models are identified as "superior" based on root mean square error and comparison of regional precipitation performance. Such ranking must be considered approximate and tentative, since the success of a model is ultimately determined by its suitability for the application for which it is intended [Pierce, 2004] and successful matching of a model to one set of observations does not necessarily indicate that the model will perform well when new forcings are imposed [Liang et al., 2002].

Nevertheless, comparisons, such as those presented here, can contribute to screening for those models that hold most promise for subsequent use in regional impact assessment studies and as a starting point for examining the impact of underlying model differences on model results [Liu et al., 2002].These results may be useful for identifying models that are most appropriate for future regional impact assessment studies. The results may also be useful for further analysis of differences in model parameterization that cause the differences in forecast.

The inter-model variability exhibited by the models described here pose a challenge for water resource planners. The differences between GCMs arise from differences in parameterizations, such as those for the land surface, numerical and grid spacing issues, initial conditions and many other factors. When considering future climate forecasts, the differences in model results are further exacerbated by differences in assumptions about future emission scenarios. For a given model and emission scenario, multiple realizations can be produced based on the spin-up or starting conditions used. In effect, an ensemble of model runs, produced by different models and different starting conditions can be viewed as a collection of realizations of possible future climate. Dettinger [2005; in press] uses this viewpoint to construct joint probability distributions for precipitation and temperature for California under future climates. Giorgi and Mearns [2003] propose a method for producing a weighted combination of realizations where the weights are determined by assessing the skill of a model at reproducing past climate. Additional work is needed to further test and develop these and similar methods. With such methods in hand and with continually improved GCMs, water resource planners may look upon these models as useful tools in the decades ahead.

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