The Los Alamos General Circulation Model Hydrologic Cycle

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Introduction

As the global population has increased, so have human influences on the global environment. From various modeling studies, we know the almost inevitable global rise in CO_2 and other trace gases will cause an increase in global temperature (see, *eg*, Kellogg 1991). Along with this temperature increase, modeling studies have also suggested the global hydrological cycle will intensify and result in increased precipitation and evaporation. This postulated overall intensification of precipitation may not be entirely beneficial. Surface moisture necessary to sustain productive agriculture may still decrease. Dry surface regions may expand to cover larger land areas and, while wet regions may become wetter, they may shrink to smaller areas over the ocean.

A few general circulation model (GCM) sensitivity experiments (*eg*, Manabe and Wetherald 1987) suggest evaporation will intensify over North America and Europe relative to precipitation (even if precipitation increases), resulting in drier mid-latitude continents. However, other GCM sensitivity studies have found the opposite behavior. Meehl and Washington (1988) showed a moister North American continent could result from the intensified hydrological cycle. The difference in sensitivity apparently depends on soil moisture storage, ground water runoff, and spring rainfall and snowmelt, as well as the other components of the heavily parameterized hydrologic cycle.

Observations are consistent with the idea that precipitation and perhaps other components of the global hydrologic cycle are increasing. Roads and Maisel (1991) and Vinnikov *et al* (1990) suggested precipitation over the United States may have increased during at least the past few decades. Bradley *et al* (1987) and Diaz *et al* (1989) further indicated that precipitation appears to have increased in almost all mid-latitude temperate land zones. At the same time, precipitation appears to have decreased over tropical land regions. Over the oceans, the changes are unknown. Observations are also consistent with the idea that soil moisture may, in fact, be increasing. Vinnikov and Yeserkepova (1991) showed there was an increasing trend of soil moisture over most of the Soviet Union and attributed this increasing trend to the increasing trend of precipitation over the region.

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Although it is tempting to ascribe recent continental desiccations to greenhouse radiative forcings, droughts have occurred in the past and will occur in the future as the global hydrologic cycle undergoes its natural variations. For example, Trenberth *et al* (1990) and Namias (1991) suggested the 1988 summer drought over the Midwest region of the United States was due to forcings by oceanic and land surface variations rather than to greenhouse radiative forcings. Chen *et al* (1991) suggested even surface forcings may be irrelevant to large interannual variations in the US West Coast hydrologic cycle; the recent California drought was simulated with an atmospheric GCM overlying a fixed ocean and land surface.

How can we better understand and predict these natural and potential anthropogenic variations? One way is to develop a model that can accurately describe all the components of the hydrologic cycle, rather than just the end result variables such as precipitation and soil moisture. If we can predict and simulate variations in evaporation and moisture convergence, as well as precipitation, then we will have greater confidence in our ability to at least model precipitation variations.

Therefore, we describe here just how well we can model relevant aspects of the global hydrologic cycle. In particular, we determine how well we can model the annual and seasonal mean global precipitation, evaporation, and atmospheric water vapor transport. Seasonal variations are about the largest short-term climate variation we can easily observe. If we can globally model these large amplitude variations correctly, we will have greater confidence in our ability to globally model and predict the more subtle variations associated with forced and natural interannual variability.

A prototypical model of the global hydrologic cycle is the Los Alamos GCM (see Kao *et al* 1990), which is a derivative of the original National Center for Atmospheric Research (NCAR) GCM. We compare aspects of the hydrologic cycle in a 10-year simulation with this GCM to global observations. Global observations of the water vapor, water-vapor flux, and water-vapor flux divergence are derived from the National Meteorological Center's final analysis for 1986 to 1990. The new precipitation dataset of Legates and Willmott (1990) is used for global precipitation observations. Global evaporation is derived as a residual of the precipitation and water-vapor flux divergence.

All of the observations can have non-negligible errors. Therefore, the GCM output reciprocally aids in our understanding of the observed hydrologic cycle.

Results

Overall, comparisons between the LANL GCM and observations are quite good. Most of the large-scale features, as described by the moisture flux stream function, moisture flux potential, precipitation potential, and evaporation potential, are quite close. Seasonal cycle variations are quite reasonable. Even smaller scale features, such as the moisture flux convergence, precipitation, and evaporation, are well simulated. We are, in fact, quite pleased with most of the simulation. Certain aspects of the simulation may, therefore, be studied further to determine characteristics of the global interannual variability; interannual variations are much more difficult to examine with the presently incomplete observations.

The most noticeable discrepancy between the GCM and observations is in the moisture field itself, which is too small because of a cold bias. This cold bias is smallest in the lower troposphere. However, the dry bias is spread more evenly throughout the troposphere, because of the exponential variation of moisture with temperature. Moreover, the dry bias is really only noticeable in the rotational fluxes. The divergent moisture fluxes are only slightly larger for the slightly more intense GCM hydrologic cycle. Thus, we are almost certain that the GCM dry bias does not have a large impact on the perceived global atmospheric hydrology. Still, we are concerned about a misplaced South Pacific convergence zone over Australia; also nearby is the Indonesian archipelago that has some of the largest values for precipitable water and precipitation in the world. If values in this region are incorrect, these errors may have had wide ramifications elsewhere and may be related to the misplaced South Pacific convergence zone in the GCM. Therefore, it is possible that correction of this GCM dry bias will result in substantial improvements in the GCM's hydrologic cycle here and elsewhere. We are also concerned about the misplaced summertime moist convergence and precipitation over the United States. In essence, both large- and small-scale errors probably need to be corrected so we can have utmost confidence in the ability of this GCM to globally simulate interannual variability.

In any event, there was relative summertime continental dryness in the mid-latitude regions of this model, which is consistent with previous GCM studies. However, the dryness was less, presumably because a 2-bucket model was used here, which may be more realistic. There was also summertime soil moisture saturation in the tropical regions of the model; the opposing soil moisture tendencies are related to monsoon precipitation regimes and global moisture convergence. It is plausible that part of the currently observed mid-latitude precipitation and soil moisture trend is due to a change in moist convergence; that is, more moisture may currently be transported into middle latitudes from tropical latitudes, resulting in increased precipitation in middle latitudes and decreased precipitation in lower latitudes. However, this global variation could be part of the natural variability of the large-scale global hydrologic cycle that is masking a potentially more ominous trend. It is incumbent upon us to learn more about these and other variations in the hydrologic cycle from both observations and models. We will investigate such questions, once we have fixed some of the more serious discrepancies in this GCM's hydrologic cycle.

Further details of this study can be found in Roads *et al* (1991).

References

Bradley, RS, HF Diaz, JK Eischeid, PS Jones, and PM Kelly, 1987. Precipitation fluctuations over Northern Hemisphere land areas since the mid-19th century. *Science*. 237:171-175.

Chen, S-C, DR Cayan, and JO Roads, 1991. Simulation of the California drought. *Science*. To be submitted.

Diaz, HF, RS Bradley, and JK Eischied, 1989. Precipitation fluctuations over global land areas since the late 1800s. *J. Geophys. Res.* 94:1195-1210.

Kao, C-Y, GA Glatzmaier, and RC Malone, 1990. Global three-dimensional simulations of ozone depletion under postwar conditions. *J. Geophys. Res.* 91:1039-1053.

Kellogg, WW, 1991. Response to skeptics of global warming. *Bull. Amer. Meteor. Soc.* 72:499-511.

Legates, DR, and CJ Willmott, 1990. Mean seasonal and spatial variability in gauge-corrected global precipitation. *International Journal of Climatology*. Vol. 10, pp. 111-127.

Manabe, S, and RT Wetherald, 1987. Large-scale changes of soil wetness induced by an increase in atmospheric carbon dioxide. *J. Atmos. Sci.* 44:1211-1235.

Meehl, GA, and WM Washington, 1988. A comparison of soil-moisture sensitivity in two global climate models. *J. Atmos. Sci.* 45:1476-1492.

Namias, J, 1991. Spring and Summer 1988 Drought over the Contiguous United States — Causes and Prediction. *J. Climate*. 4:54-65.

Roads, JO, S-C Chen, J Kao, D Langley, and G Glatzmaier, 1991. Global aspects of the Los Alamos general circulation model hydrologic cycle. *J. Geophys. Res.* Submitted.

Roads, JO, and TN Maisel, 1991. Evaluation of the National Meteorological Center's medium range forecast model precipitation forecasts. *Wea. & Forecasting*. 6:123-132.

Trenberth, K, GW Branstator, and PA Arkin, 1990. Origins of the 1988 North American drought. *Science*. 242:1640-1645.

Vinnikov, KY, PY Groisman, and KM Lugina, 1990. Empirical data on contemporary global climate changes (temperature and precipitation). *J. Climate*. 3:662-677.

Vinnikov, KY, and IB Yeserkepova, 1991. Soil moisture: Empirical data and model results. *J. Climate*. 4:66-79.