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Using Climate Model Output to Assess the Impacts of Climate Change on Water Resources

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Abstract

The use of general circulation models (GCMs) to provide climate data for regional assessments of the impacts of changing climate on water resources stretches the limits of what the models were designed for. Problems that must be addressed include disagreement on a regional scale among GCMs and between the modeled and observed climate; coarse spatial resolution of the models; and simplistic representation of surface hydrology. It is important that continued progress be made in developing the methodology for using GCM output in climate-impact assessments.

Introduction

Using GCM output, many investigators have examined how changing climate could affect water resources (broadly defined). The use of GCMs to provide mesoscale climate data for regional (i.e., subcontinental) assessments stretches the limits of what the models were designed for. Yet, it is regional-scale or even smaller-scale climate information that is needed for resource impact evaluations. This paper describes some of the shortcomings of GCMs that must be addressed when using the model output in regional assessments and examines the procedures that have been used by climate-impact analysts to adapt the GCM output for use in such assessments.

Examples of the Use of Climate Model Output in Water-Resource Assessments

GCMs from the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), the National Center for Atmospheric Research (NCAR), and Oregon State University (OSU) have been commonly used for climate-impacts analyses. Gleick (1987) used the output from the GISS, NCAR, and GFDL GCMs to quantify changes in runoff and soil moisture in the Sacramento Basin; McCabe and Ayers (1989) used the output from the GISS, OSU, and GFDL GCMs to study the same two variables in the Delaware River Basin. Cohen (1986) used output from the

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GISS and GFDL GCMs to study how changes in surface runoff and lake evaporation could affect the amount of water leaving the Great Lakes Basin (*i.e.*, the Net Basin Supply). Miller and Brock (1988) analyzed the effect of climate change, based on the GISS GCM, on the multipurpose Tennessee Valley Authority (TVA) reservoir system. Using the GISS, OSU, and GFDL GCMs, Chang and Railsback (1990) described the effect of climate change on habitat for striped bass in a TVA reservoir. Cooter and Cooter (1990) used results from the GISS, GFDL, and OSU GCMs to study the effects of climate change on water temperature and quality in the southern United States.

Rising sea level associated with global warming – especially if coupled with changes in stream runoff – could also affect coastal water resources: water supplies could be affected by saltwater intrusion and infiltration (Titus 1986) and drainage and sewerage systems could become less dependable (Titus *et. al.* 1987, Niemczynowicz 1989). These kinds of impacts of climate change on water resources have not yet, to my knowledge, been quantified based on the output from GCMs.

<u>GCMs and Regional Climate-Impact Analyses</u>

GCMs are the most detailed and sophisticated of the models used to simulate global climate change. These three-dimensional models provide the spatial and temporal information lacking in simpler one- and two-dimensional climate models. The output from GCMs includes information on surface air temperature, rain and snow, wind, runoff, soil moisture, and other important variables for water-resource analyses. They are, therefore, most attractive for providing scenarios of climate change for use in water-resource assessments, although there are also approaches based on hypothetical climate changes or historical climate analogs. GCMs have proven useful in studies of the mechanisms of climate and climate change – for example, climate change from the uplift of mountain ranges (Ruddiman *et al.* 1989) or a hypothetical nuclear war (Covey 1987). However, GCMs were not intended, and are not completely appropriate, for use in detailed predictions of the local or regional impacts of climate change on the human environment. Nevertheless, impacts from climate change will be realized, and impact analyses are being conducted, on such scales.

On a regional scale, the various GCMs disagree on the possible changes in temperature and precipitation (Cushman and Spring 1989), and they also fail to correctly simulate all features of the current climate. In particular, simulations of precipitation may not be as accurate as those of temperature (Mitchell 1989). Because the spatial resolution of GCMs is coarse (typically 4° by 5° to 8° by 10° latitude-longitude) and their representation of geography and topography is only approximate, it is difficult to relate the model output to actual locations on the Earth's surface. The current generation of GCMs does not capture the role of soil and biota in controlling surface processes of significance to climate. Some processes that function at subgrid scales, such as cloud formation and surface hydrology, are represented statistically (parameterized). Of particular importance to analyses of water resources, the models' representation of surface hydrology (soil moisture, evaporation, and runoff) is simplistic, and the best means to derive estimates of changes in streamflows is not clear. Soil moisture in GCMs is often simulated as a "bucket" 15 cm deep; when precipitation and snowmelt, less evaporation, cause soil moisture to exceed 15 cm, the excess becomes runoff (Meehl and

Washington 1988). The improvement of this parameterization in GCMs is a topic of current research (*e.g.*, Entekhabi and Eagleson 1989).

Approaches for Using GCM Output in Regional Climate-Impact Analyses

Analysts have attempted to deal with the limitations of GCMs with respect to regional impact assessments. For example, because of the lack of agreement among climate models, it is common practice to examine a range of climate scenarios by using the output from more than one model. Cohen (1986) found that, according to the GISS GCM climate-change scenario for a doubling of atmospheric carbon dioxide ($2XCO_2$) and no wind change, the Net Basin Supply of the Great Lakes dropped by 20.8%, whereas the decrease based on output from the GFDL GCM was 18.4%. Gleick (1987) reported that $2XCO_2$ climate-change scenarios (temperature and relative changes in precipitation) from the GISS and GFDL GCMs yielded estimated increases in winter runoff in the Sacramento Basin of 81 and 34%, respectively.

Because of the crude geographic resolution and the resulting difficulty in relating the coarsely gridded output to specific locations on Earth, the output for several model gridpoints in the vicinity of the area of interest may be analyzed (*e.g.*, Cohen 1986, Chang and Railsback 1990). Cohen (1986) found that by using the precipitation data from the GISS GCM output one model grid point to the east, west, or north, a range of almost 180 mm in annual basin precipitation was obtained. Both statistical and modeling techniques have been suggested for deriving finer-scale climate information from GCM output. Thomas (1990), in his analysis of how GCM output can be used as input to hydrologic models, recommended that global GCMs provide the boundary conditions for regional (mesoscale) climate models, which would provide the finer-resolution output, especially for precipitation, needed for hydrologic modeling. Most analyses of the effects of climate change on water resources have been performed with the monthly temporal resolution of the GCM output (*e.g.*, Cohen 1986, Gleick 1987). However, the monthly averaged model output may also be converted into a daily time series by using a weather generator; Wilks (1988) gives an example of such a generated time series for use in an agricultural assessment of climate change.

The crude representation of soil moisture and runoff in GCMs has led to difficulties in some analyses. For example, Miller and Brock (1988) found that the GFDL GCM indicated up to 7 months with no runoff in the TVA region. Some analysts avoid using the soil moisture and runoff data from GCM output but use GCM projections of temperature and precipitation to drive a hydrologic model, such as a water balance model (*e.g.*, Gleick 1987).

Because GCM simulations of the current climate are not yet reliable, actual data on present climate, rather than the model simulations thereof, may be used to define the "base case" climate. The differences between the model simulations of the current and changed climate may be applied to the actual current climate to obtain the scenario of the future climate, rather than using the model-simulated changed climate literally. This can be done two ways: (1) add the differences, positive or negative, in the simulated climate data to the actual current climate data or (2) multiply the actual current climate data by the ratio of the modeled changed climate data to the modeled current climate data. The second approach has an operational advantage in that meaningless negative precipitation estimates are avoided, although there is an implicit assumption that the frequency distribution of occurrence of precipitation events will not change.

Discussion

Researchers concerned about the possible effects of climate change on the human environment, especially water resources, have seized upon the availability of the output from sophisticated GCMs, even as these models are being modified and refined by their developers. What many water-resource analysts discover when they undertake climate-impact assessments, however, is that the output from GCMs is not appropriate for direct and literal use in such assessments. The model output must first be interpreted and manipulated before it is ready for use in water-resource analyses; unfortunately, there is no standard methodology for this necessary step, although a wide variety of approaches may be found in the technical literature. Nevertheless, given the interest in the potential effects of climate change on water resources, analysts will probably continue to use the simulations from GCMs, perhaps in combination with hypothetical or historical-analog climate scenarios (*e.g.*, Cohen 1987), as the basis for climate-impact assessments. It is important that continued progress in the methodology for using of GCM output in climate-impact assessments be made, concurrent with progress in hydrologic modeling.

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