Hydrologic Sensitivity to CO_2-Induced Global Warming

Investigating the real and potential hydrologic effects of climate change on a global or regional basis requires the development of a reasonably accurate model of the environment.

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The subject of possible hydrologic change in response to a CO_2-induced warming of the earth's atmosphere has received increasing attention at various scientific institutions in North America and Europe. Because changes of precipitation and evaporation could have a major impact on various aspects of our environment, scientific investigations have been concentrating upon the geographical details of CO_2-induced changes of hydrology. In order to better determine the effects of this warming, global circulation models provide a means of obtaining results that can be employed in the analysis of climatic changes.[1,2]

Employing Global Circulation Models

The mathematical model of climate used herein consists of a three-dimensional model of the atmosphere that is coupled with models of the land surface and a simple mixed layer ocean. It includes the effects of solar and terrestrial radiation and the hydrologic cycle. It also explicitly calculates the general circulation in the atmosphere using the hydrodynamical equations. It has been shown that this type of climate model successfully simulates the seasonal and geographical distribution of various climate parameters. The impact of increased concentrations of greenhouse gases on climate was evaluated by comparing the model climates that were generated from a normal and above-normal concentration of atmospheric carbon dioxide, respectively.

Summer Soil Moisture Changes

A map of the CO_2-induced change of soil moisture for the June-July-August period is illustrated in Figure 1. This figure indicates that in the summer soil becomes drier over very extensive mid-continental regions of North America, Southern Europe and Siberia in response to the doubling of atmospheric carb-

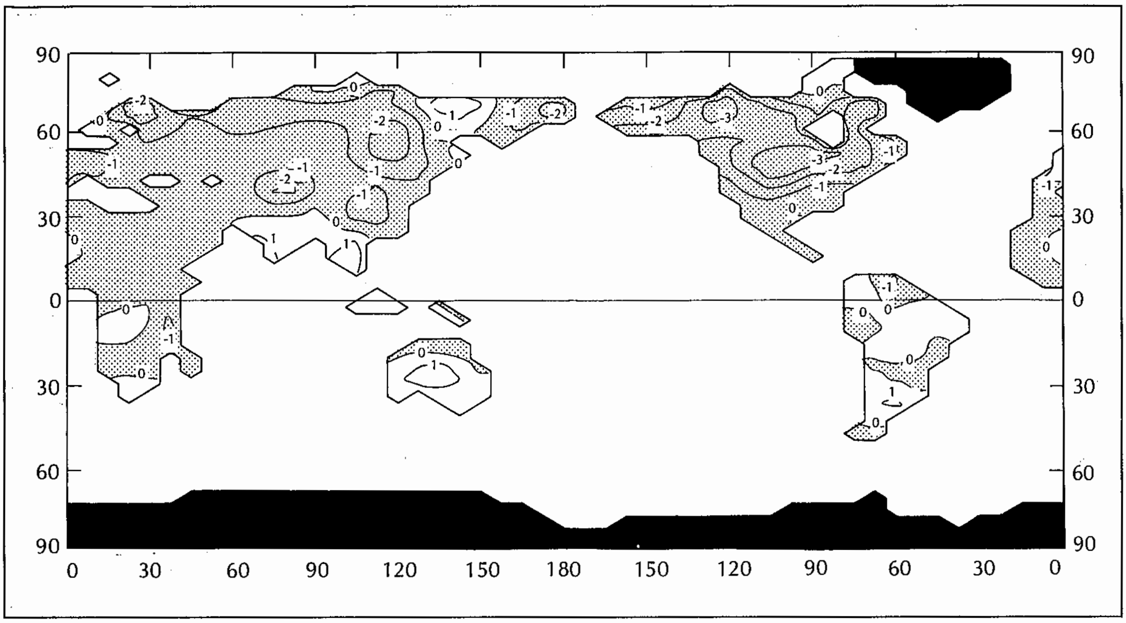

FIGURE 1. The geographical distribution of the difference in soil moisture (cm) between high-CO_2 and normal-CO_2 experiments for the June-July-August period.

on dioxide. In some regions, the reduction amounts to a substantial fraction of the soil moisture present in the normal-CO_2 case.

Over Siberia and Canada, changes in snow cover are responsible for the CO_2-reduction in soil moisture. In these regions, extensive snow cover prevails during the winter before melting in the late spring. Since snow cover reflects a large fraction of insolation, its disappearance increases the absorption of solar energy by the land surface to be used as latent heat for evaporation. Thus, the end of the spring snowmelt season marks the beginning of the seasonal drying of the soil that takes place in summer. In the warmer high-CO_2 integration, the snowmelt season ends earlier, bringing an earlier start of the spring to summer reduction of soil moisture. As a result, the soil becomes drier in higher latitudes during the summer.

Over the Great Plains of North America, the earlier snowmelt season also contributes to the CO_2-induced reduction of soil moisture in summer. In addition, changes in the mid-latitude precipitation pattern also contribute to the reduction of soil wetness in summer over North America and Southern Europe. Both of these regions are under the influence of a rainbelt associated with the typical path taken by mid-latitude cyclonic disturbances. In the high-CO_2 atmosphere, warm moisture-rich air penetrates further north than in the normal-CO_2 atmosphere. This penetration is caused by the greater transport of moisture from lower to higher latitudes in the warmer model atmosphere. Thus, the precipitation rate increases significantly in the northern half of the mid-latitude rainbelt whereas it decreases in the southern half. Since the rainbelt moves northward from winter to summer, a mid-latitude location lies in the northern half of the rainbelt in winter and in its southern half in summer. At such a location, the CO_2-induced change in precipitation becomes negative in early summer, contributing to a reduction of soil moisture. The summer dryness is enhanced further due to the increased insolation reaching the ground as reduced evaporation from the drier continental surface causes a decrease in cloudiness.

Winter Soil Moisture Changes

The summer reduction of soil wetness does not continue through the winter season. In response to the increase of atmospheric carbon

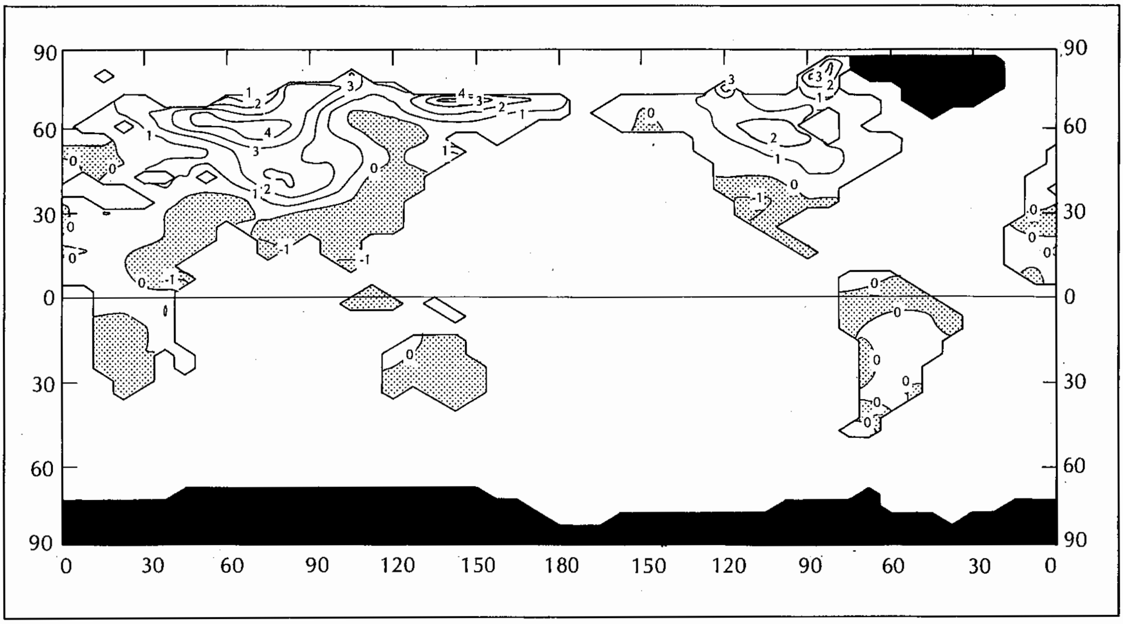

FIGURE 2. The geographical distribution of the difference in soil moisture (cm) between high-CO_2 and normal-CO_2 experiments for the December-January-February period.

dioxide, soil wetness increases during the December-January-February period over extensive mid-continental regions of middle and high latitudes (as indicated in Figure 2). In middle latitudes, this increase is mainly due to greater precipitation in the northern half of the middle latitude rainbelt. In high latitudes, a larger fraction of the total precipitation occurs as rainfall, making the soil wetter. Figure 2 also indicates that soil wetness is reduced during winter around Southern California and Mexico. The reduced rainfall in the southern half of the middle latitude rainbelt is again responsible for this enhanced dryness in these latitudes.

Summary

Only the very broad scale, features of the soil moisture changes in middle latitudes are significant when viewed in terms of the information presented in Figures 1 and 2. For example, many of the small-scale features in the tropics and in the Southern Hemisphere are not regarded with much confidence. This conclusion is drawn partly because the climate models used in this study have a coarse computational resolution and fail to accurately simulate the small-scale features of the hydrologic change. Furthermore, the detailed features of the CO_2-induced change are often obscured by large natural fluctuations of soil moisture, thereby making the identification of these features very difficult.

In addition, the various groups performing research on soil moisture are not in complete agreement on the issue of the mid-latitude continental summer dryness.[3,4] Results from more recent studies by Mitchell, and Schlesinger and Zhao,[5,6] appear to agree better than with earlier studies such as those described by Kellog and Zhao.[7,8] A major difficulty in estimating future hydrologic change is the limited ability to incorporate, in a realistic way, relevant physical processes such as the land surface water budget, cloud formation and ocean-atmosphere interaction into a general circulation model. Nevertheless, the summer reduction of mid-continental soil moisture seems to result from global warming and appears to be a very large scale phenomenon. The physical processes that have been found to be responsible for this enhanced dryness appear to be both reasonable and logical.

More recently, another CO_2-sensitivity study was performed using a version of the model in which the computational resolution of the general circulation model was doubled that of the previous versions (*i.e.,* 2.25 degrees latitude by 3.75 degrees longitude instead of 4.5 degrees latitude by 7.5 degrees longitude). It was found that the simulation of the hydrologic processes over the major continental regions was markedly better than that produced by the models with a more coarse resolution. This fact suggests that a more accurate estimate of regional CO_2-induced hydrologic change can be obtained than was possible with the earlier versions of the model.

In general, the results from this latest experiment substantiate the main conclusions made in earlier studies: namely, a tendency to produce hotter and dryer summers and warmer and wetter winters over most of North America and Europe. However, there are additional regional changes of hydrology that require further analysis to evaluate more fully. These changes include increased soil wetness in India and the southern portion of the United States along the Gulf Coast during the summer season. This experiment is currently the subject of an extensive ongoing investigation.

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