A COMPARISON OF THE SIMULATED SURFACE WATER AREA IN NORTHERN AFRICA FOR THE 6000 YR BP PMIP EXPERIMENTS

Michael T. Coe (1) and Sandy Harrison (2)

(1) Center for Climatic Research-Institute for Environmental Studies, 1225 W Dayton St., Madison, WI. 53706, mtcoe@facstaff.wisc.edu

(2) Sandy Harrison Max Planck Institute for Biogeochemistry, Tatzendpromenade, 07745, Jena, Germany, sandy.harrison@bgc-jena

1. INTRODUCTION

Observational evidence indicates that surface water levels in northern Africa were, in general, high relative to present from about 10,000 to 5,000 years before present. Perennial and seasonal river systems, lakes, and wetlands were present throughout much of northern Africa (e.g. Jolly et al., 1998). Some of these lake and wetland systems were quite large, for example Lake Chad was about 350,000 km^2 in area (Schneider 1967).

Simulations with global climate models have demonstrated that the wetter conditions in northern Africa were primarily a result of changes in the Earth's orbital parameters (Kutzbach, 1981). In the early and middle Holocene perihelion occurred in northern summer resulting in an increased amplitude of the seasonal cycle of solar radiation. As a result the summer land/ocean temperature and pressure contrast was increased. The increased temperature and pressure gradient led to increased moisture convergence over northern Africa, greater precipitation, and increased moisture availability for the formation of rivers, lakes, and wetlands.

In this study we use the output from 17 PMIP GCM simulations to drive a land surface hydrology model (HYDRA; Coe 1999). HYDRA is an effective diagnostic tool because it provides a method of integrating the affects of moisture balance changes over entire river basins. The simulated surface hydrology (rivers, lakes, and wetlands) provides physical features that can be compared more directly to observations.

2. METHODOLOGY

The results of the GCM simulations have been translated into surface water area and volume using HYDRA. HYDRA simulates the spatially explicit distribution, storage, and flow of water in terrestrial hydrological systems, including rivers, wetlands, and lakes (Coe, 1998, 1999). This model currently operates on the global scale at 5 minute (~10 km) resolution. The model derives river paths and potential lake and wetland volumes from high-resolution digital elevation model (DEM) representations of the land surface. The derived hydrological network is coupled to a generalized water transport model to simulate the discharge of rivers and the volume and spatial distribution of large lakes and wetland complexes. HYDRA requires the following boundary conditions: topography (from DEMs).

precipitation, evaporation from water surfaces (estimated from an energy balance model using temperature and cloudiness) and total runoff (all supplied by the GCMs).

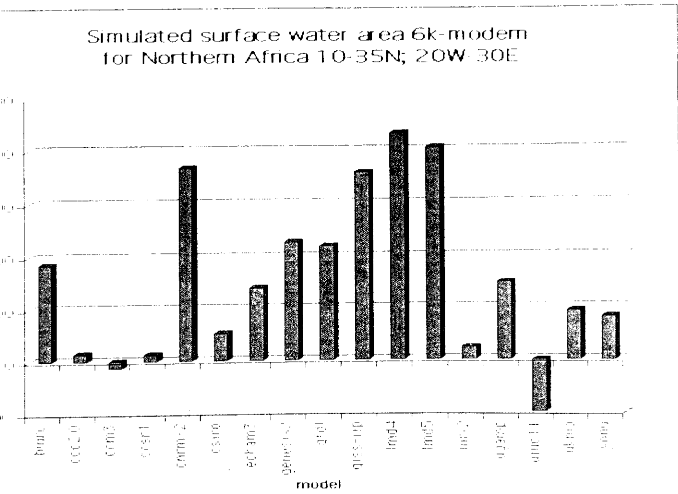
A modern control simulation was performed by forcing HYDRA with annual mean estimates of runoff (Cogley, 1991), precipitation (Legates and Willmott, 1990), and surface water evaporation. The modern surface water evaporation was calculated from the Penman formulation (Peixoto and Oort, 1992) which relates equilibrium evaporation to net surface radiation. The observed monthly average surface temperature (Legates and Willmott, 1990) and potential sunshine (Leemans and Cramer, 1990) are linearly interpolated to quasi-daily values and are used to derive the net radiation. The daily equilibrium evaporation is then averaged to an annual mean. The 6k yr BP simulations were achieved by forcing HYDRA with the GCM simulated absolute anomalies (6k-modern) of the annual mean of P-E, precipitation, and calculated evaporation added to the modern observed annual mean estimates. An analysis of the individual model-simulated 6 yr BP surface water areas in comparison to the modern simulation and paleo-observations follows.

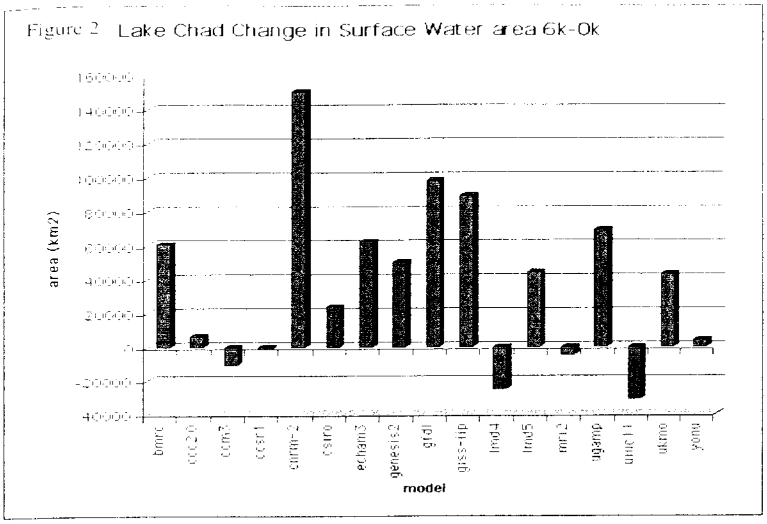
3. RESULTS

The results of the 17 6k yr BP simulations are averaged over northern Africa (10°-35°N; 20°W-30°E) and compared to the simulation of modern conditions. In general, all of the models simulate a northward displacement of the monsoon front at 6k yr BP compared to their modern simulations with increased precipitation and runoff occurring to the south of the advancing monsoon. 15 of the 17 models simulate and increase in the annual mean rainfall rate over northern Africa compared to their individual control runs. The magnitude of the precipitation changed varies from about –20 mm/yr to about 125 mm/yr. The spatial distribution of the precipitation changes also varies from model to model depending on the location of the simulated monsoon front.

The response of the HYDRA surface water area to the GCM simulated climatological changes is complex and depends on the magnitude of the changes to the P-E, precipitation, temperature, and cloud cover over entire river basins. For 12 of the 17 models the changes to the surface climatology result in a relatively large increase in the simulated annual mean surface water area of northern Africa (Figure 1). The output from three of the models results in no significant change to the simulated surface water area while two of the models simulate a decrease in the total surface water area. The surface water area changes vary from about -

Figure 1





50,000 km² to an increase of greater than 200,000 km² compared to modern. The spatial distribution of the simulated 6 yr BP surface water area varies between the individual models and reflects the simulated changes in the position of the monsoon front and the geographic distribution of potential water bodies.

The Lake Chad Basin is an arid to semi-arid drainage basin that covers about 2.5 million km² in north-central Africa. The modern observed surface water area within the basin has varied from about 30,000 km² to 1000 km² in the last 35 years. Observational evidence indicates that Lake Chad was a hydrologically open lake that covered about 350,000 km² and communicated with the Niger River system at 6 ka BP (Schneider, 1967). Despite a general strengthening of the simulated monsoon in most of the 17 GCMs, none produce a change in surface hydrology large enough or in the correct location to maintain Lake Chad at 350,000 km². The output from four of the models results in a decrease in the area of Lake Chad compared to the modern simulated area of about 40,000 km² (Figure 2). Three of the models result in no significant change in the area of Lake Chad. The remaining 10 models produce an increase in the lake area from 20,000 to 150,000 km² greater than the modern simulation. Differences in the response of the simulated surface water areas in the Chad basin and northern Africa for a given model reflect differences in the simulated position of the monsoon front between models. For example, those models with a simulated monsoon front relatively far north may have a large monsoon response at 6k yr BP but relatively little change in the area of Lake Chad (see LMD4 and LMD5 in Figures 1 &2).

This study compliments the study of Jousaume et al. by providing an integrated assessment of the simulated surface water fluxes of the GCMs. The results of this study are also consistent with those of Jousaume et al., (1990) and indicate that despite a general strengthening of the 6ka BP monsoon compared to modern none of the models produced changes large enough to maintain surface waters consistent with observational evidence

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