The African Humid Period: A Regional Modeling Study

During the last glacial period, dry conditions prevailed over Saharan and Sahelian Africa, somewhat drier than today. But beginning around 14,500 years ago (14.5 kyr), the region became progressively more moist. Numerous large lakes dotted the landscape of what is now the Sahel until about 5.5 kyr (Gasse 2000). Being able to capture this signal in a climate model, and to explain it, will strengthen our understanding of African climate variability and our confidence for predicting future climate.

The African Humid Period occurred at a time of higher summertime insolation in the Northern Hemisphere. Due primarily to changes in the precession component of the orbital forcing, solar insolation at the top of the atmosphere at 15ºN in summer was approximately 5% greater than today. This forcing is the external cause of the African Humid Period. However, GCM simulations suggest that a consideration of additional factors and/or feedbacks within the climate system is required to understand the African Humid Period (Joussaume et al. 1999). For example, there is strong evidence that SSTs off the west coast of Africa were considerably cooler than today, perhaps 5 K cooler, in conjunction with enhanced upwelling (deMenocal et al. 2000). There is weaker evidence that the Gulf of Guinea was somewhat (~1 K) cooler near the equator, although this cooling may have been confined to the winter season. Certainly land surface attributes over large regions of northern Africa were different, with grasslands extending about 5º of latitude farther north than today. And, of course, atmospheric CO_2 concentrations were at their pre-industrial value of about 280 ppmv.

We have developed a regional climate model (RCM) based on MM5 (Vizy and Cook 2002) and applied it to the African Humid Period to distinguish the roles of the various factors in establishing the wetter climate. By modeling climate on smaller space scales (10's of kilometers) than is possible with a GCM, the space scale of the modeling is brought close to that of the geological record. This provides a better opportunity for model validation, and for modeling to aid in the interpretation of geological evidence. Also, the RCM provides an improved simulation of the present day climate of northern Africa, since the physical parameterizations can be optimized for the region and the strong surface moisture, wind, and temperature gradients that characterize this region are resolved. The model domain, topography and present-day SSTs are shown in Figure 1.

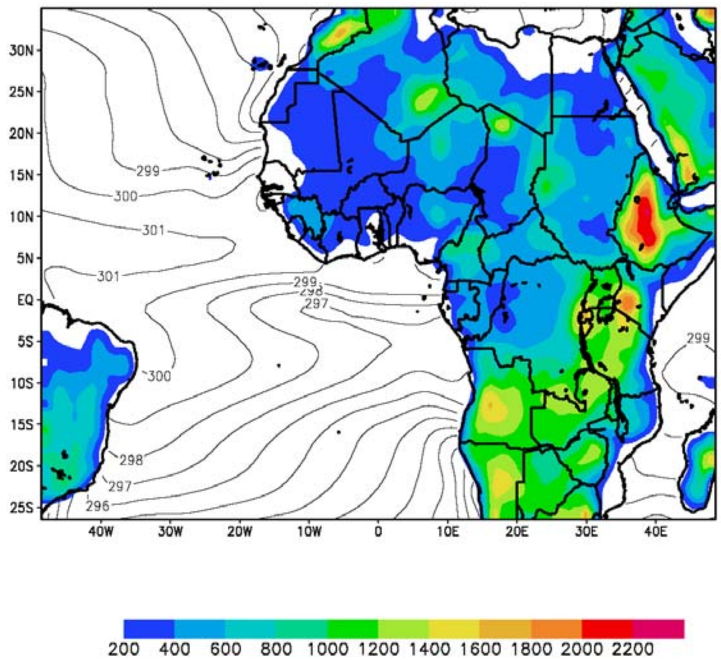

Figure 1. Regional climate model domain for the African Humid Period simulations. Shading on Africa denotes topography, with the elevation scale in meters indicated in the color bar. Contours are present day SSTs as resolved in the model.

A series of RCM integrations is used to compare the African climate of 6 kyr with today's climate, and to explore the sensitivity to various assumptions about surface boundary conditions. Solar forcing alone causes increases in precipitation, and a northward retreat of the desert by about 2º latitude, significantly less than that indicated by the geological record. Similarly, imposing changes in surface vegetation alone, guided by observations, moistens the region, but not sufficiently. Reasonable increases in precipitation occur only when both solar forcing and vegetation differences are applied together.

Figure 2a shows differences in precipitation from a present day simulation when 6 kyr insolation, vegetation, and CO_2 differences are applied. In contrast to GCM simulations of the African Humid Period, the RCM produces excessive rainfall over the present-day Sahel and Sahara regions in the 6 kyr case. (GCM simulations uniformly under predict precipitation for the African Humid Period, although some improvement occurs with interactive ocean and/or land surface models.) The addition of colder sea surface temperatures off the west coast and in the Gulf of Guinea improves the RCM's agreement with geological reconstructions for the Sahel, as indicated by the reduction in the precipitation enhancement north of 15ºN in Fig. 2b as compared with Fig. 2a. But the simulation along the Guinea Coast degrades, since the model simulates drying over Ghana where there is evidence of a modest increase in lake levels. Without Gulf of Guinea SSTAs, the RCM simulation produces the simulation of precipitation changes that is most consistent with the geological record. This supports the geological evidence of cooling of the west coast, and suggests that either the Gulf of Guinea was not cooler during the African Humid Period, or that the cooling was confined to the non-monsoon season, or that the region of cooling was too narrow to influence the large-scale monsoon circulation.

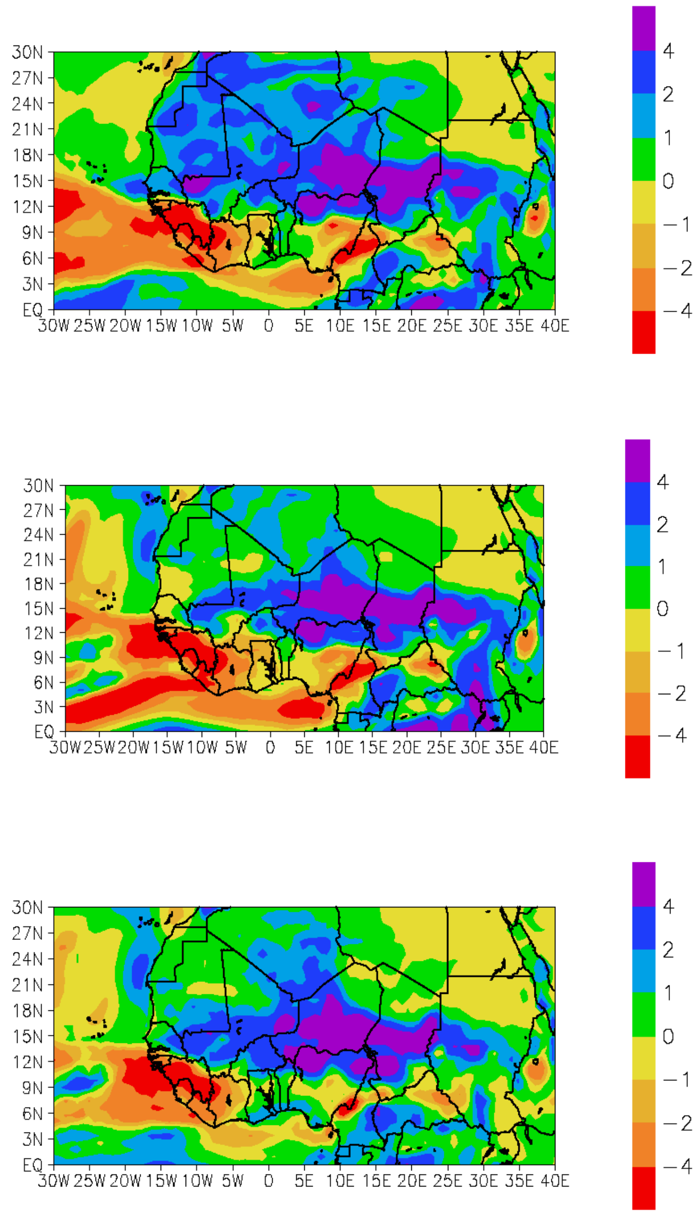

Figure 2. Precipitation differences from present day in the RCM with African Humid Period values of (a) solar forcing, vegetation, and atmospheric CO2 concentrations; (b) SSTAs in the eastern Atlantic and Gulf of Guinea in addition to solar forcing, vegetation, and atmospheric CO2 concentrations; and (c) SSTAs in the eastern Atlantic only plus to solar forcing, vegetation, and atmospheric CO2 concentrations. Contour units are mm/day.

These simulations of the African Humid Period climate provide an opportunity for in-depth analysis of how a different climate regime works. For example, despite the increase in insolation at the top of the atmosphere, the net solar heat input to the surface is *smaller* over most of Sahelian Africa and the southern Sahara during the African Humid Period due to the increase in cloud cover, and the surface temperature is slightly cooler. Enhanced warming of the lower atmosphere is accomplished primarily through increases in latent heating from the wetter surface.

The African Humid Period provides an example of a different climate state and, most importantly, it is a different climate state that can be validated independently of climate models. In addition, the African Humid Period provides a wonderful opportunity to study climate transitions, since the moist period ended quite rapidly as if some threshold were reached at a certain value of the solar forcing. Future work with the RCM will focus on the time-dependent signal, and the results will be brought to bear on understanding the all-important decadal-scale signals, whether natural or anthropogenic, over northern Africa.

References

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