African Monsoon Variations

We know from a variety of sources that Northern Africa was much wetter about 6-9 thousand years ago (Street-Perrott and Harrison 1984). There is strong evidence that this is related to the precession cycle, which moves energy from the northern summer to the southern summer hemisphere (Kutzbach and Street-Perrott 1985). When the insolation is greater in the north, the summer monsoon low is stronger, pentrates farther north and produces more precipitation over the central portion of the north African continent, which is now fully desertified, since the southern summer occurs at perihelion now.

A known mode of natural variability is drought in the Sahel region of Africa associated with warmer than normal SST in the north equatorial Atlantic Ocean (Weare 1977, Hastenrath 1978, Hastenrath 1990, Gray and Landsea 1992, Landsea, et al. 1992, Hastenrath and Greschar 1993. Lamb, 1986 #2326. Landsea, 1992 #6369). Sahel rainfall anomalies are substantial and track closely with variations in the north-south gradient of SST in the tropical Atlantic.

Kutzbach and Liu (1997) recently looked at the effect of orbital variations on the African NH summer monsoon. Past experiments had difficulty in producing the observed moistening of the Sahara during the period 6kBP (Brostrom, et al. 1998). By incorporating SST variations in the Atlantic, they were able to increase the precipitation enhancement 6,000 years ago. In their model this worked through (1) direct heating of the tropical NH Atlantic by increased insolation, and (2) reduced evaporative cooling of the tropical Atlantic north of the equator because the wind convergence shifts north, thus reducing the strength of the trade winds north of the equator. Additional modeling in recent years has continued with the notion that transitions in the African monsoon system are a result of complex coupling between orbital parameters, atmospheric circulation, ocean SST, and land hydrology and vegetation dynamics (Brovkin, et al. 1998, Claussen, et al. 1999). As of this time, most all models underestimate the response of the monsoons to orbital parameter forcing compared to what has been inferred from paleo-data (Boqiang, et al. 1998, Harrison, et al. 1998, Joussaume, et al. 1999).

The feedbacks are more-or-less as follows:

1. Increased summertime insolation associated with longitude of perihelion variations make the summer insolation in Northern Hemisphere subtropical latitudes stronger – like 10kbp. This is the forcing, actually.

2. The land surface over the Sahara heats up more, this encourages upward motion and precipitation to get farther north during summer and expands the Sahel vegetation into the region formerly occupied by desert.

3. The Atlantic Ocean north of the equator heats up. This further encourages heavy summertime precipitation in North Africa and alters the circulation to support it.

4. The vegetation and surface water balance over Northern Africa moves from sand to grass to trees and lakes. This gives lower surface albedo, greater rising motion over land and more preciptation, feeding back positively.

5. All of the above are reversed if the precession parameter begins to give less insolation in NH summer in the subtropics – like now.

A recent study of an ocean sediment core drilled in the Atlantic downwind of the Sahara suggests rapid transitions from dry to wet to dry Sahara, with the transitions taking from decades to centuries (deMenocal, et al. 2000). The site has high accumulation rates (18cm/kyr) due to both high ocean productivity associated with

Canary Current upwelling and high windblown dust from the Sahara, so high temporal resolution for the last 23Kyr is possible. The core site is directly under and current flow of dust from the Sahara during NH summer. Current monitoring of interannual dust delivery to Barbados indicates that increased dust is related to drought conditions in North Africa. The core was dated with accelerator mass spectrometer methods. The indicators of wet or dry periods are the ratios of carbonate, and terriginous material – basically the ratio of dust to carbonate. The dust fell about 15Kbp, rose up a little during the Younger Dryas about 12.5kbp, and then rose abruptly to present values about 5.5kbp. This suggests that the north African climate is bi-stable like the north Atlantic ocean circulation climate. It has a dry state and a wet state. The comparison of the core data with orbital parameter-caused variations in insolation suggest that the Sahara switches from dry to wet when the summer season insolation anomaly (JJA average at 20N) crosses a threshold of 4.2% (470 Wm^{-2} compared to 451 Wm^{-2}).

The modeling experiments of Claussen et al.(1999) with a simplified zonally symmetric model produced a rapid transition to desert conditions about 5.5kyr ago in response to slowly declining summertime insolation. This strong transition was traced back to nonlinearities and threshold behavior in the vegetation parameterization. I suspect some tuning was involved to get such good correspondence with the timing of the observed transition.

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