Holocene climate instability during the termination of the African Humid Period

Hans Renssen
Faculty of Earth & Life Sciences, Vrije Universiteit Amsterdam, The Netherlands
hans.renssen@geo.fsw.vu.nl

Victor Brovkin
Potsdam Institute für Klimafolgenforschung, Germany

Thierry Fichet and Hugues Goosse
Institut d’Astronomie et de Géophysique G. Lemaire, Université Catholique de Louvain, Belgium

Model and experimental setup
To elucidate the termination of the African Humid Period (~9-6 kyr BP), we have simulated the climate evolution of the last 9 kyr with the ECBilt-CLIO-VECODE three-dimensional, global model that describes the coupled atmosphere-sea-ice-ocean-vegetation system. The model consists of three components:
1) ECBilt, an atmospheric model (T21, three layers) based on quasi-geostrophic equations;
2) CLIO, an oceanic general circulation model coupled to a comprehensive dynamo-thermodynamic sea-ice model; and
3) VECODE, a model that describes the dynamics of grassland and forest, and desert as a dummy-vegetation type.

Example of proxy evidence
Summary pollen percentage diagram derived from a former lake bed in the Western Sahara (Chermchane, Mauretania, 20°16’N, 12°13’W, redrawn from Lézine et al. 1990), showing the Early-to-Mid Holocene evolution of four major non-arboreal taxa (Typha, Cyperaceae, Gramineae, Acanthaceae), Chorographeaeaceae, arborescent pollen (AP), and sum of all others. Note the strong fluctuations of Typha (associated with freshwater lake environments) between 8 and 6.5 14C kyr BP.

Stability of the green and desert states
This stability diagram for the precipitation-vegetation system in the Sahara-Sahel region is constructed following Brovkin et al. (1998). To construct this diagram, we have performed four sensitivity experiments of 200-yr duration in which we prescribed the vegetation cover (either 100% desert or 100% grass) in the Sahara region during the first 100 years, after which the vegetation model was allowed to adjust to the different atmospheric conditions during the remaining 100 years. The four experiments can be characterized as follows:
1) desert 9 kyr BP,
2) desert 6 kyr BP,
3) green 6 kyr BP, and
4) green 0 kyr BP.

Response of the coupled system in the Western Sahara region
These figures shows the simulated climate evolution during the last 9 kyr.

In the first 5 kyr of our run, the Northern Hemisphere’s summer temperature gradually declines by 0.9°C under the influence of the decreasing CH4 and CO2 concentration. In the last few thousand years, a small warming of 0.3°C is simulated, which follows the 200-ppmv increase in CH4 level.

Phase 1: 9.7-5.5 kyr BP, ‘green’ state
In the Western Sahara-Sahel region the model simulates from 9 to 7.5 kyr BP a ‘green’ equilibrium characterized by a mean annual precipitation of 250 mm/yr and a vegetation fraction of 70%. This green state is in contrast with a ‘desert’ state, which is the western Sahara thermal gradient, which strengthens the summer monsoons, leading to an increased transport of humid air towards the continent and enhanced convective precipitation over land.

Phase 2: 7.5-5.5 kyr BP, intermediate unstable state
After 7.5 kyr BP, precipitation and vegetation concentration decrease to values of 210 mm/yr and 50%, respectively. In addition, the variability in vegetation fraction increases significantly (standard deviation is 9.2% for 9.7-5 kyr BP and 12.2% for 7.5-5.5 kyr BP). The time period separating the “green” spikes ranges from 110 to 370 years, which is similar to the lake-level fluctuations observed in high-resolution palaeodata from the Western Sahara region (see polliendogram to the left).

Phase 3: 5.5 kyr BP to present, desert state
After 5.5 kyr BP, the variability decreases substantially and the system approaches a desert state. At 1 kyr BP, annual precipitation is as low as 60 mm/yr and vegetation fraction is only 10%.

Summary
This simplified diagram gives an overview of the non-linear system dynamics in the Sahara-Sahel region during the Holocene. Hypothetically, the climate-vegetation system possesses multiple steady states, desert and ‘green’. Potential minima, marked by black balls, correspond to equilibria that are stable in the absence of perturbations. Precipitation fluctuations induced by large-scale atmospheric and oceanic variability perturb the stable state, and a positive feedback between vegetation and atmosphere amplifies external variability. Grey balls and arrows indicate the maximum range of system variations.

References