Disponible en ligne sur www.sciencedirect.com
ScienceDirect
C. R. Geoscience 341 (2009) 671–688
Comptes Rendus Geoscience

Surface geosciences (Palaeoenvironment)

Climate and vegetation: Simulating the African humid period

Christelle Hély [a,*], Pascale Braconnot [b], Julie Watrin [b], Weipeng Zheng [b,c]

[a] Centre européen de recherche et d'enseignement des géosciences de l'environnement, CNRS, CDF, IRD, université Aix-Marseille, BP 80, 13545 Aix-en-Provence cedex 04, France
[b] Laboratoire des sciences du climat et de l'environnement, UMR 1752 CNRS, CEA, Orme-des-Merisiers, 91191 Gif-sur-Yvette cedex, France
[c] LASG/IAP, State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Received 12 December 2008; accepted after revision 27 July 2009
Available online 8 September 2009

Written on invitation of the Editorial Board

Abstract

The outputs of the climate simulated by two General Circulation Models (GCMs), (IPSL and UGAMP) have been used to force a vegetation model (LPJ-GUESS) to analyze the Holocene African humid period (AHP) and related vegetation changes over the 18°W-35°E, 5°S-25°N region. At the continental scale, simulations with the two models confirm the intensified African monsoon during the Holocene as compared to now, and the early but gradual termination of the AHP in eastern regions as compared to western regions. At the regional scale, the two GCMs results present important differences in the timing of the AHP, its spatial extent and the summer rainfall amplitude. Consequently, the vegetation model simulates changes that are globally in agreement with pollen data, but with large differences according to the region and the model considered. During the AHP, the IPSL climate induced proper vegetation changes in the eastern Sahara and in the Sahel, whereas the UGAMP climate induced correct changes in the western Sahara and in the equatorial zone. ***To cite this article: C. Hély et al., C. R. Geoscience 341 (2009).***

Résumé

Climat et végétation : simulations de la période africaine humide. Les résultats de deux modèles de climat (IPSL et UGAMP) ont été utilisés pour forcer un modèle de végétation (LPJ-GUESS) pour analyser la période humide africaine à l'Holocène et les changements de végétation associés sur la zone 18°O-35°E, 5°S-25°N. À grande échelle, les résultats des deux modèles confirment l'intensification de la Mousson Africaine Holocène (AHP), comparée à l'actuelle et la fin précoce mais graduelle de l'AHP à l'est comparée à l'ouest. À une échelle plus régionale, les simulations IPSL et UGAMP diffèrent beaucoup dans le rythme des phases de l'AHP, leurs étendues spatiales et l'amplitude des pluies estivales. En conséquence, le modèle de végétation prédit des changements qui sont globalement satisfaisants avec les données polliniques, mais régionalement différents selon le modèle de climat considéré. Au cours de l'AHP, le climat simulé avec le modèle IPSL induit des changements de végétation conformes dans l'Est du Sahara et dans la bande Sahélienne, alors que celui simulé avec

* Corresponding author.
E-mail address: hely@cerege.fr (C. Hély).

1631-0713/$ – see front matter
doi:10.1016/j.crte.2009.07.002

le modèle UGAMP est satisfaisant dans l'ouest du Sahara et la zone équatoriale. ***Pour citer cet article : C. Hély et al., C. R. Geoscience 341 (2009).***

Keywords: Holocene; Sahel; Sahara; General Circulation Model; Leaf Area Index; African Pollen Database; Biomization method

Mots clés : Holocène ; Sahel ; Sahara ; Modèles de circulation générale ; Indice de surface foliaire ; Banque africaine de données polliniques ; Méthode de biomisation

1. Introduction

The Pan-African North Equatorial region is very sensitive to the distribution of precipitation determined by the seasonal and interannual variations of the Intertropical Convergence Zone (ITCZ). Today, the southern part of the region extending from 5°S to 25°N and from 18°W to 35°E is under the influence of the African monsoon climate (Fig. 1). The core of the rainbelt is located around 10°N during summer (JJAS), during which the Sahelian region further north receives its annual amount of precipitation. The northern part of the region is under desert climate with sporadic low annual rainfall ($<$ 50 mm/year in average and up to 200 mm/year maximum in northern Chad). Therefore, the distribution of vegetation in this region is constrained by water availability, as attested by the zonal distribution from forest in the south to desert in the north. The Sahel region is particularly vulnerable to changes in the hydrological cycle, and there is still much uncertainty about the future evolution of water resources [22]. There is thus a need to better understand how the vegetation and hydrology respond to long-term climate fluctuations, and what their complex interactions are.

Past climate indicators show that this region experienced large changes in the hydrological cycle and the vegetation during the Holocene. In particular, lake level, pollen, and other macrofossil data suggest that this area was moister and the vegetation cover, including grasses and trees, was denser during the first half of the Holocene than today [e.g. 23]. Data analyses and modelling studies have shown that these changes are linked to changes in insolation resulting from the long-term variations of the Earth's orbital parameters. In particular, a decrease in obliquity during the Holocene, which affected the latitudinal temperature gradients, and precession led to a 180° shift of the location of the vernal equinox on the Earth's orbit during the Early Holocene, so that the seasonal cycle of insolation was enhanced in the Northern Hemisphere and damped in the Southern Hemisphere at that time. Changes in the precession during the Holocene alter the shape and the amplitude of the seasonal cycle as well as the length of the seasons [8,24]. Because of the enhanced seasonal cycle of insolation, both the interhemispheric and the land-sea temperature gradients were enhanced during boreal summer, which favoured the inland penetration of the monsoon flow and produced high summer precipitation in regions that are now arid in the Sahel and Sahara [12,25]. However, model-data comparisons of the Mid Holocene performed as part of the Paleoclimate Modeling Intercomparison Project (PMIP) show that most models simulate an enhanced monsoon at that time, but that they fail to produce the amount of precipitation needed to sustain any vegetation as far as 23°N [7,19,25]. This drawback is a combination of systematic model biases that lead to an incorrect location of the monsoon rain belts over the continent, and of deficiencies in producing the right sensitivity of the hydrological cycle to the insolation forcing. Moreover, several studies have shown that the response of the ocean and of the vegetation to the Mid-Holocene insolation forcing both contribute to enhance the monsoon flow by positive feedbacks to the atmosphere [5].

Some paleo records suggest a rapid termination of this moist period (called the African humid period, AHP) after 5500 yr BP [13]. This abrupt shift from moist to arid conditions resulted from seasonal, as well as interannual and long-term, climate changes (ocean, soil humidity) caused by external forcing such as from Earth orbital parameters. Simulations with intermediate complexity models indicate that the vegetation feedback had a major contribution in the end of the AHP [11,32,47], while simulations with General Circulation Models (GCM) suggest that the rapid change in the vegetation is caused by a non-linear response of vegetation threshold in the presence of high climate variability [33]. Differences in the proposed mechanisms may result in part from the representation of vegetation in the models, or from differences in the representation of interactions between the land surface and the atmosphere. Although the different simulations provide possible reasons for a rapid decrease in precipitation (ending the AHP), they do not consider