

**Impact of the
Megalake Chad on
climate and
vegetation**

C. Contoux et al.

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Impact of the Megalake Chad on climate and vegetation during the late Pliocene and the mid-Holocene

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Abstract

Given the growing evidence for megalakes in the geological record, assessing their impact on climate and vegetation is important for the validation of paleoclimate simulations and therefore the accuracy of model/data comparison in lacustrine environments.

5 Megalake Chad (MLC) occurrences are documented for the mid-Holocene but also for the Mio-Pliocene (Schuster et al., 2009). The surface covered by water would have reached up to $\sim 350\,000\text{ km}^2$ (Ghienne et al., 2002; Schuster et al., 2005; Leblanc et al., 2006) making it an important evaporation source, possibly modifying the climate and vegetation in the Chad basin. We investigated the impact of such a giant continental water area in two different climatic backgrounds within the Paleoclimate Model Intercomparison Project phase 3 (PMIP3): the late Pliocene (3.3 to 3 Ma, i.e. the mid-Piacenzian warm period) and the mid-Holocene (6 kyr BP). In all simulations including a
10 MLC, precipitation is drastically reduced above the lake surface because deep convection is inhibited by colder air above the lake surface. Meanwhile, convective activity is enhanced around the MLC, because of the wind increase generated by the flat surface of the megalake, transporting colder and moister air towards the eastern shore of the lake. Effect of the MLC on precipitation and temperature is not sufficient to widely impact vegetation patterns. Nevertheless, tropical savanna is present in the Chad Basin in all climatic configurations, even without the MLC presence, showing that the climate
15 itself is the driver of favourable environments for sustainable hominid habitats.

1 Introduction

The Chad basin is a vast endorheic basin located in North Central Africa, between 5° and 25° N (Fig. 1), covering approximately $2.5 \times 10^6\text{ km}^2$. At present, the climate is sub-desertic to soudanian, with precipitation ranging from 0 to 900 mm yr^{-1} . Wind regime
25 is dominated by the Harmattan northeasterly wind during the dry season (November to March) and the monsoon southwesterlies during the wet season (from June

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to September). A Harmattan wind pattern is inferred from coastal morphosedimentary structures for the mid-Holocene (Bouchette et al., 2010). Present day lake Chad is mainly fed by the Chari-Logone river system coming from the southern part of the basin (82 % of total inputs, Leblanc et al., 2011). Because the Chad basin is endhoreic and relatively flat, climatic variations have an important impact on the lake extent as evidenced by seasonal fluctuations as well as by historical and geological archives. Since 1960, lake Chad shrunk from 25 000 to 6000 km² on average, mainly because of a decrease in rainfall and associated Chari-Logone river flow to the lake (Olivry et al., 1996). At longer time-scales like precession cycles, lake Chad extent has proven to vary considerably. The presence of a Megalake Chad (MLC) in the mid-Holocene is widely attested from lake deposits and from coastal morphosedimentary structures (e.g. Tilho, 1925; Pias and Guichard, 1957; Grove and Pullan, 1963; Maley, 1977; Kusnir and Moutaye, 1997; Ghienne et al., 2002; Schuster et al., 2003, 2005, 2009; Drake and Bristow, 2006; Leblanc et al., 2006; Bouchette et al., 2010). This large water body reached more than 350 000 km² (Ghienne et al., 2002; Schuster et al., 2005; Leblanc et al., 2006) with wind-driven hydrodynamics (Bouchette et al., 2010). Similar MLC episodes are thought to have occurred during the Miocene and the Pliocene (Schuster et al., 2001, 2006; Griffin, 2006), supposedly linked to a northward shift of the west-african monsoon system. In particular, sediments from the northern Chad basin describe lacustrine occurrences from 7 to 3 Ma (Schuster et al., 2001, 2006, 2009; Lebatard et al., 2010), associated to the presence of fossil vertebrate fauna and two hominids (*Sahelanthropus Tchadensis*, 7 Ma, Brunet et al., 2002, and *Australopithecus Bahrelghazali*, 3.6 Ma, Brunet et al., 1995), in a mosaic vegetation landscape (Brunet et al., 1997). Climate models for the mid-Holocene (Braconnot et al., 2007) and the Pliocene (Haywood et al., 2013) generally simulate more precipitation in North Africa, allowing drainage systems reactivation and large lakes development for these periods.

Investigating potential climate and vegetation perturbations induced by open continental water surfaces is the subject of many studies (e.g. Coe and Bonan, 1997; Broström et al., 1998). The impact of the dessication of preindustrial lake Chad

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climate, we have the opportunity to test the impact of a MLC in a new climatic context. We investigate the MLC impact on climate and vegetation in the mid-Holocene (6 kyr BP) and in two configurations of the mPWP using the LMDZ4 AGCM including a lake surface module (Krinner, 2003). It is possible to study the regional impact of a MLC thanks to the zoomed grid of the LMDZ model. While the African Humid Period of the mid-Holocene is well driven by orbital forcing, the mPWP time slice is much longer (from 3.3 to 3 Ma) and contains several orbital cycles. Indeed, it is known that precession can favor a northern position of the ITCZ, thus deeply modifying the monsoon pattern during the mid-Holocene (Marzin and Braconnot, 2009), coinciding with the last occurrence of the MLC. Before 2.8 Ma, African monsoon is thought to have been controlled by precession as well, with higher humidity when perihelion coincides with boreal summer (deMenocal et al., 1995, 2004). Considering that the impact of a MLC might be different in different climatic backgrounds, and varying with monsoon intensity, two climatic configurations of the late Pliocene are investigated: one uses SSTs calculated in the frame of the PlioMIP, i.e. using late Pliocene boundary conditions and pre-industrial orbital configurations, the other uses SSTs calculated using late Pliocene boundary conditions and an orbital configuration with perihelion in summer, corresponding to the maximum of insolation at 30° N between 3.3 to 3 Ma. These climate simulations will help clarify the feedback role of the MLC on climate, by testing this impact in a new climatic context, the late Pliocene. The simulated climates are then used to force the vegetation model BIOME4 (Kaplan et al., 2003), which is widely used to simulate paleovegetation with GCM outputs (e.g. Harrison et al., 2003) and accounts for CO₂ concentration variations. This study investigates the local and regional feedbacks of the MLC on climate and vegetation, in different climatic backgrounds and orbital configurations for which results are compared in order to exhibit common robust features and if possible background climate-dependent features. In this aspect, it is the first time that the impact of the MLC is investigated in the late Pliocene climate.

2 Models description

2.1 LMDZ4_LAKE atmospheric model

We use the LMDZ4 Atmospheric General Circulation Model (AGCM) (Hourdin et al., 2006) including a water surface module (Krinner, 2003) composed of 8 layers, which represent the thermal and hydrological processes occurring above and beneath continental water surface. The model explicitly represents the penetration and absorption of sunlight into the lake levels, heat conduction, convective overturning, water phase changes, sensible and latent turbulent surface heat fluxes and water balance (Krinner, 2003). Lake surface is fixed and is an additional surface type to the LMDZ4 scheme already including ocean, sea ice, land ice and land. In this study, vegetation is prescribed through albedo and roughness boundary conditions, and surface scheme is a bucket model. Although water balance of the lake is calculated, the absence of a surface water routing scheme makes it inappropriate to use the model for prediction of lake level and extent. This model can then only be used as a predictor of lake impact on climate. Resolution is zoomed to ~ 100 km on the lake Chad region, and mean grid spacing is $3.75^\circ \times 2.5^\circ$. The atmosphere has 19 vertical layers. Parameterization of convection is the Emanuel scheme (see Hourdin et al., 2006). Previous studies used this model to investigate the climatic impact of MLC in a preindustrial context (Sepulchre et al., 2009) and during the mid-Holocene (Krinner et al., 2012).

20 BIOME4 vegetation model

BIOME4 is an equilibrium biogeography model developed by Kaplan et al. (2003), based on BIOME3 (Haxeltine and Prentice, 1996). It is widely used for the simulation of equilibrium vegetation in past climates, including the pre-Quaternary climates of the Tortonian (Pound et al., 2011) and Piacenzian (Salzmann et al., 2008; Kamae and Ueda, 2012) and the more recent mid-Holocene (Kaplan et al., 2003; Krinner et al., 2012). This model simulates the equilibrium distribution of 28 biomes. This potential

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natural vegetation is determined by the ranking of 12 plant functional types (PFTs) which have different bioclimatic limits (temperature resistance, moisture requirement, sunshine amount). Competition between the PFTs is a function of net primary productivity (NPP) and uses an optimization algorithm to calculate the maximum sustainable leaf area index (LAI). NPP, LAI and mean annual soil moisture are then classified empirically to determine the predominant biome (Haxeltine and Prentice, 2003). Input data of the model include the mean monthly climate (temperature, precipitation, sunshine and minimum temperature), soil physical properties and atmospheric CO₂ concentration.

3 Experimental design and boundary conditions

3.1 AGCM experiments

Three climatic configurations are investigated: two are late Pliocene (mPWP) experiments (Plio and Plio_max simulations), one is mid-Holocene (6 kyr, MidHol simulations). The two late Pliocene experiments differ by the imposed SSTs and orbital configuration, which are described in Sect. 3.1.2. For each simulation, integration time is 70 yr, and climatologies are performed on the last 50 yr. To study the impact of the lake on these past climates, we carry out two simulations for each climatic configuration (except the control): one with imposed MLC surface (Fig. 1, “lake” simulations), the other one with a single grid point defined as a lake surface, which roughly corresponds to the present-day lake Chad. Lake depth is fixed to 20 m at the beginning of the simulation. In total, six climatic simulations plus the control run were carried out. All these simulated climate anomalies are then used to force the BIOME4 vegetation model. A summary of the boundary conditions for each simulation can be found in Table 1. Orbital parameters for each simulation can be found in Table 2. For the mid Holocene at 6 kyr, they are defined following the PMIP3 protocol. For Plio simulations, they are set to preindustrial values. For Plio_max simulations, they correspond to the maximum of insolation of the PlioMIP interval at 30° N at summer solstice.

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3.1.1 Control 0 kyr simulation

For the control simulation, boundary conditions (i.e. albedo, roughness, topography and ice sheets) are set to modern. Imposed SSTs are the climatological mean value for 1988–2007 from the AMIP 2 dataset (Fig. 2a). Greenhouse gases, solar constant and orbital parameters are set to pre-industrial values as required by CMIP5/PMIP3, i.e. solar constant is 1365 W m^{-2} , CO_2 content is 280 ppm, CH_4 content is 760 ppb, and N_2O content is 270 ppb.

3.1.2 Pliocene experiments

For Pliocene experiments, we investigated two different climatic configurations. First, the standard late Pliocene (mid-Piacenzian) simulations, called Plio, have anomalies of SSTs and sea-ice cover calculated with the IPSL-CM5A AOGCM, in the PMIP3/PlioMIP framework (Fig. 2b). This AOGCM simulation is described in detail in Contoux et al. (2012) and corresponds to PlioMIP experiment 2 (Haywood et al., 2011). Because precession parameter varies during the late Pliocene time slab of 300 kyr, and can favor a more northern position of the ITCZ (e.g. deMenocal, 2004), we investigated a second climatic configuration called Plio_max. SST anomalies for this simulation are calculated with the IPSL-CM5A model, starting from a previous Pliocene run, changing the orbital configuration to the maximum of insolation during summer solstice at 30° N between 3.3 and 3 Ma (Table 2), based on Laskar (2004). The calculated SSTs are then imposed as anomalies in the LMDZ4 simulation (Fig. 2c), which is also forced with this orbital configuration (Tables 1 and 2). All Pliocene SSTs show an important warming in the North Atlantic and a moderate warming in the Gulf of Guinea (from 1 to 2.5° C), an area possibly impacting moisture amount in the Chad region (e.g. Sepulchre et al., 2009).

For all Pliocene experiments, albedo and roughness are calculated from the mid-Piacenzian biome vegetation dataset of Salzmann et al. (2008). The main features of this vegetation reconstruction are the reduction of deserts and the northward shift of

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capacity were not changed compared to the present. CO₂ is specified to 405 ppm for all the Pliocene experiments, and to 280 ppm for the Mid-Holocene experiments. BIOME4 is run on a 0.5° × 0.5° grid.

4 Results

4.1 North African rainfall in the control run

Annual mean and June to September precipitation over North Africa simulated for the control run are compared to GPCP Version 2.2 dataset (Adler et al., 2003; Huffman et al., 2009) on Fig. 3. The model overestimates annual mean precipitation in the equatorial zone (from 0° to 7° N), but well represents the transition from soudanian to desertic zones (from 10° N to the Sahara desert), although with a slight underestimation. Regarding monsoon precipitation, the model is in good agreement with GPCP data on the equatorial zone, but from 10° to 25° N, precipitation is also slightly underestimated, particularly from 12° to 16° N (−1 mm day^{−1}). It means that for the sahelian zone, the annual amount of precipitation is correctly represented but is too widely distributed throughout the year. Summer precipitation response to a given perturbation might thus be slightly underestimated in the model.

4.2 North African rainfall in the late Pliocene and mid-Holocene

Over North Africa, simulated summer temperature and precipitation anomalies for the mid-Holocene without a MLC surface are comparable to the PMIP2 multi-model mean (Braconnot et al., 2007). Simulated annual temperature and precipitation anomalies for Plio simulation are comparable to the multi-model mean for Pliocene coupled model experiments (Haywood et al., 2013). This gives us good confidence regarding the use of this model for these paleoclimates. Mean annual precipitation in function of latitude for each simulation is shown on Fig. 4. First, all simulations are more humid than the control between 10° to 20° N. Plio configuration is generally more humid than the control,

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except between 30° to 40° N (Fig. 4, red line). Plio_max configuration is characterized by a much broader ITCZ, hence reduced precipitation in the equatorial zone between 3° to 12°, but much wetter tropics and subtropics from 12° to 30° N (Fig. 4, blue line) compared to the control run. MidHol simulation is more humid than the control except slightly drier from 6° to 9° N. MidHol simulation is also more humid than Plio from 10° to 20° N. Despite these changes, the Chad basin is still influenced by southwesterly monsoon winds in summer (Fig. 5, left) and northeastern Harmattan wind in winter for all simulations (Fig. 5, right).

During summer months, in Plio simulation, there is an increase in precipitation over the eastern part of the Chad basin, and over central Africa compared to the control run. In Plio_max simulation, summer monsoon over west Africa is shifted several degrees northward, while over central and eastern Africa, precipitation increases particularly between 15° to 22° N. Precipitation is increased by more than 5 mm d⁻¹ over the central eastern Chad basin. In the MidHol simulation, patterns are similar to Plio_max, but with lesser intensity (up to +2.5 mm d⁻¹ in the Chad basin). West African summer monsoon is shifted several degrees northward, with local increases up to 3.5 mm d⁻¹ over west Africa. Summer precipitation also increases in the eastern part of the Chad basin, up to 2 mm d⁻¹. Concerning winter monsoon (Fig. 5, right), precipitation increases in the Plio simulation. In contrast, in Plio_max and MidHol simulations, precipitation front is narrower and shifted southward, though with lesser intensity in the MidHol simulation. A common feature of these simulations is the northward shift of the ITCZ during summer months compared to the control run, controlled by the reduced latitudinal temperature gradient in the Northern Hemisphere (Davis and Brewer, 2009), with increased southwesterlies over Central to Eastern parts of the Sahara (Fig. 5, left). Similarly to the present, precipitation falls on the Chad basin only during summer months. Increased precipitation over the Chad basin in all the simulations agree with the possibility of a MLC in the basin. We will now investigate the impact of such a water surface area on climate and vegetation, in order to understand its role in the development of sustainable conditions for hominids presence.

4.3 Impact of the MLC on climate

First, the presence of the MLC does not impact zonal average precipitation over the Northern African continent (Fig. 4). In all simulations there is no northward shift of the precipitation front induced by the presence of a MLC. This result is different from Krinner et al. (2012), in which an increase in precipitation due to MLC and wetlands is depicted on the zonal average, especially from 15° to 25° N. Over the Chad basin, wind regime varies throughout the year, and precipitation only falls during the monsoon season under southwesterly winds conditions. During the rest of the year (October to May), the precipitation front does not reach the MLC, and the presence of the megalake does not generate any precipitation. Considering this aspect, we restrict our analysis to summer months means, which display the same patterns as annual means. Regarding the spatial distribution of precipitation (Fig. 6), the most striking impact of the MLC is a reduction of precipitation above the surface of the lake in the three climatic configurations (from -1 to -5 mm d^{-1}). It is consistent with previous studies (Sepulchre et al., 2009; Krinner et al., 2012) and is well explained by the following: since the lake is generally colder than the surrounding environment, low level air becomes cooler and denser (Fig. 7) and stabilizes the atmosphere, preventing deep convection and associated rainfall. This mechanism is observed in both Pliocene simulations and in the mid-Holocene one, suggesting it is a robust feature appearing in different background climates. In the meantime, convective activity increases around the MLC, especially to the east. Southwesterly winds are enhanced above the surface of the lake due to the flat surface reduced roughness length (Figs. 6 and 8), generating convective activity at the northeast of the MLC, in the three simulations. Similarly, the effect of preindustrial lake Chad on climate is to increase convective activity downwind of the lake (Lauwaet et al., 2012). Moreover, the MLC, especially its northern part, is a center of higher pressure (Fig. 7), generating clockwise winds that can be seen on Fig. 7, which are responsible for the increase of precipitation at the southeast of the lake in the three

simulations (Fig. 6). Significant precipitation response outside the Chad basin is variable in the three simulations and generally not above 0.5 mm d^{-1} .

4.4 Biome distribution during the Pliocene and the mid-Holocene

Although there are major changes in the vegetation response between the three different climates, the MLC impact in each climatic context is small (Fig. 9). This result depicts the climate as the main driver of vegetation pattern in the Chad basin during these periods. Plio simulations (Fig. 9a and b) show an extent of tropical savanna up to 15° N , and xerophytic shrubland up to 20° N , which is comparable to the MidHol simulated vegetation (Fig. 9e and f). Plio_max displays a drastic reduction of the Saharan desert to the benefit of xerophytic shrubland, which reaches 23° N on the western coast to 27° N on the eastern coast of Africa. Tropical woodland also covers an important area of central to eastern Africa between 11° to 17° N . A $\sim 1^\circ$ northward shift of tropical savanna and a small patch of tropical deciduous forest/woodland appear at the east of MLC in the Plio_lake simulation (Fig. 9b). For Plio_max simulations, a narrow band of tropical woodland can be seen at the southeast of the MLC, and tropical xerophytic shrubland becomes temperate in the northwest of the Chad basin. In this configuration, small changes outside of the Chad basin are visible and consist in an expense of temperate sclerophyll woodland and temperate xerophytic shrubland at the expense of desert on the west Mediterranean coast, and a slight northern shift of the desert boundary to the Northwest of the Chad basin, when the MLC is present (Fig. 9d). For the mid-Holocene simulation at 6 kyr (Fig. 9e and f), with or without MLC, the simulated climate is not humid enough to reproduce savanna biomes up to 20° N , as suggested by vegetation reconstructions (Hoelzmann et al., 1998). This discrepancy is also seen in the MIROC model (e.g. Ohgaito et al., 2013). Changes induced by the MLC consist in the appearance of tropical woodland at the southwest of the MLC (Fig. 9f).

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5 Discussion

Morphosedimentary archives indicate an active Holocene hydrographic system flowing from the East (south Ennedi) associated to small-scale paleodeltas which argue for riverine and lacustrine conditions (Ghienne et al., 2002; Schuster et al., 2005; Bouchette et al., 2010). For the Mio-Pliocene, fluvial deposits of the Koro-Toro, Kosom Bougoudi and Kollé sites are attributed to ephemeral floods (Schuster, 2002). In a Pliocene context with present day orbital parameters, precipitation front reaches the Ennedi, but total rainfall amount remains small (250 mm yr^{-1}). In Plio_max configurations however, there is important precipitation over the Ennedi (600 mm yr^{-1}), even though the MLC has a negative impact over precipitation in this area. The presence of the MLC, by increasing precipitation in the valley down the Ennedi (Fig. 6b), could have increased the outflow of these potential paleorivers near their outlet into the lake. For the mid-Holocene, mean precipitation over the Ennedi is small (less than 200 mm yr^{-1}). In any configuration, precipitation over the Ennedi is restricted to summer months. Simulations also show that during the Pliocene and mid-Holocene, wind regime throughout the year is comparable to today, only with increased monsoon winds in summer. The MLC amplifies this effect because of its flat surface, helping southwesterly winds to reach the northern shore of the MLC. Similarly in winter, the Harmattan is increased over the lake surface.

The results presented above, showing a weak impact of surface conditions on climate are in agreement with several studies (Coe and Bonan, 1997; Broström et al., 1998). However, a recent study by Krinner et al. (2012, hereafter K12) described important feedbacks of lakes and wetlands on the North African climate during the mid-Holocene, particularly by increasing precipitation and reducing droughts. K12 study uses the LMDZ4 model coupled to the land surface model ORCHIDEE with Hoelzmann et al. (1998) water surface conditions, which include a Megalake Chad and some wetlands, and a different boundary layer parameterization compared to our study. Tests carried out with our configuration and the Hoelzmann et al. (1998) water surface

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explains the precipitation increase at the southeast of the MLC. During the dry season, the presence of a MLC does not generate precipitation over the basin. These results are a common feature of all the simulations. Impact away from the Chad basin is very weak and variable. We conclude that while the MLC should be taken into account for its influence on climate in the Chad basin, its influence alone outside the basin is not determinant. The presence of a MLC does not enhance a northward migration of the monsoon, in agreement with Broström et al. (1998). Regarding vegetation distribution, the presence of a MLC has little effect on biomes, although humid biomes are simulated in the Chad basin in all simulations, providing a sustainable environment for hominid populations, even if restricted to the southern part of the basin in the Plio simulation. The fact that environment was favorable for hominids during the Late Pliocene, but that MLC was not a major contribution to these conditions reinforce the hypothesis that climate change is the driver for these conditions, rather than surface hydrology changes. Other megalakes in present day dry climates are documented for the Quaternary, such as megalakes Frome and Eyre in Australia (e.g., Alley 1998; Cohen et al., 2011), megalake Makgadikgadi in the Kalahari (Burrough et al., 2009), and the Darfur megalake in Sudan (Gonheim and El-Baz, 2007) highlighting the importance of studying the impact of such water surfaces on the relatively arid present-day climates of these areas, which can be affected by the northward or southward migration of the monsoon.

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Table 1. Boundary conditions for the simulations. SSTs specified with a * are implemented as anomalies.

Expt	SSTs and sea-ice	CO ₂	Orbital parameters	Ice sheets	Albedo, roughness	Topography	Lake Chad surface
Control	1988–2007 mean	280	Modern	Modern	Modern	Modern	present-day
Plio	From AOGCM*	405	Modern	PlioMIP	PlioMIP	PlioMIP	present-day
Plio_lake	From AOGCM*	405	Modern	PlioMIP	PlioMIP	PlioMIP	MLC
Plio_max	From AOGCM*	405	Insolation max. at 30° N at summer solstice	Antarctica as PlioMIP, no Greenland Ice Sheet	PlioMIP	PlioMIP except for Greenland	present-day
Plio_max_lake	From AOGCM*	405	Insolation max. at 30° N at summer solstice	Antarctica as PlioMIP, no Greenland Ice Sheet	PlioMIP	PlioMIP except for Greenland	MLC
MidHol	From AOGCM*	280	PMIP for 6 kyr	Modern	Mid-Holocene	Modern	present-day
MidHol_lake	From AOGCM*	280	PMIP for 6 kyr	Modern	Mid-Holocene	Modern	MLC

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Table 2. Orbital parameters used for the different experiments.

Expt	Eccentricity	Obliquity	Precession angle
Control, Plio	0.016715	23.441	102.7
Plio_max	0.052115	23.641	271.4
MidHol	0.018682	24.105	0.87

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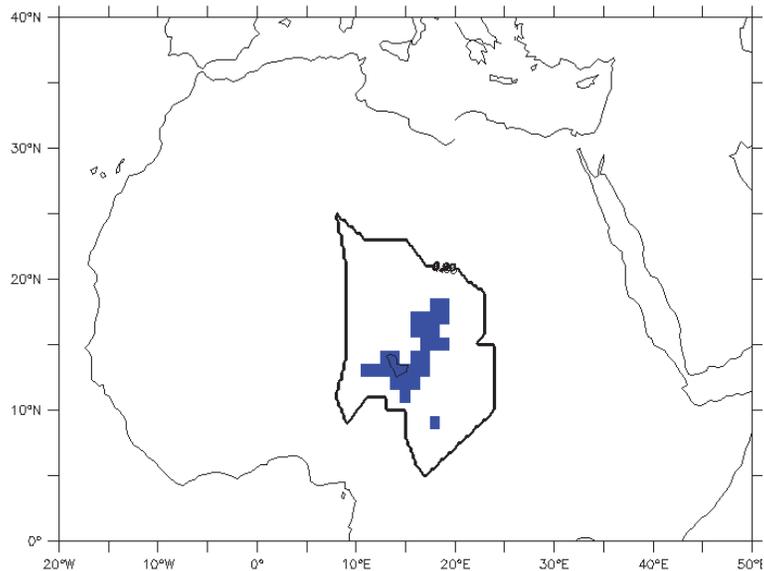


Fig. 1. Imposed lake surface in LMDZ4 for “lake” experiments. The black contour line represents the Chad hydrological basin (catchment) limits.

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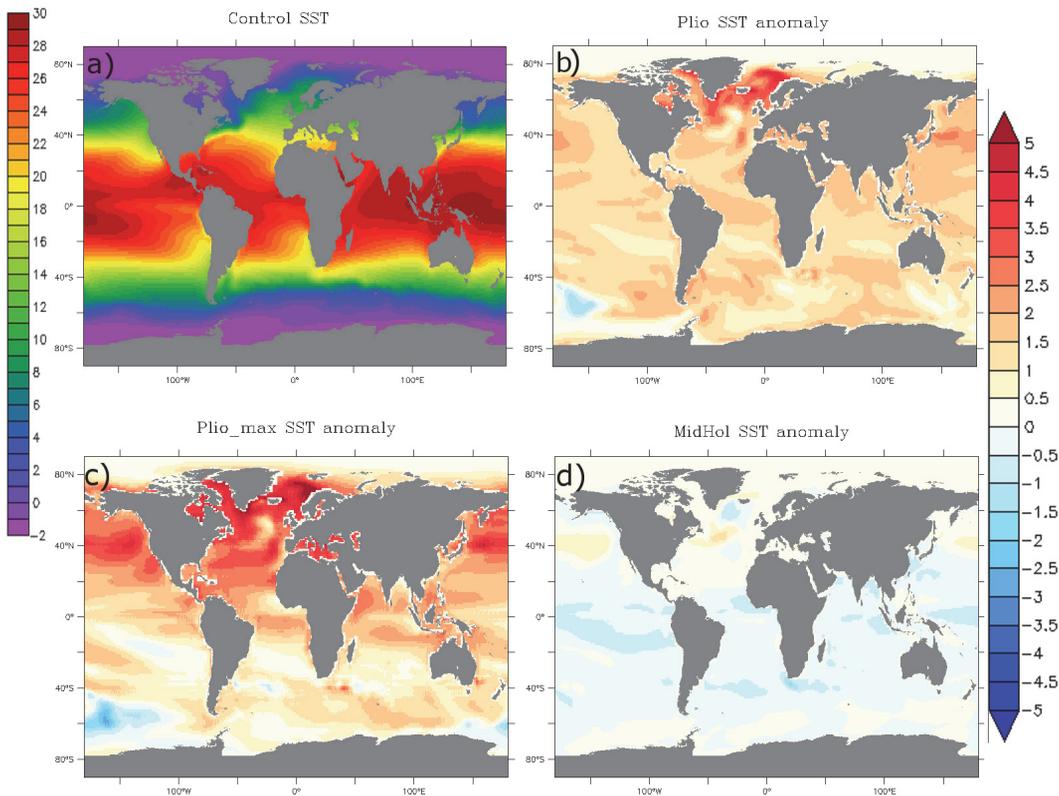


Fig. 2. SSTs imposed in LMDZ4 for (a) Control (b) Plio, (c) Plio_max and (d) MidHol experiments, (b-d) expressed as difference from the Control SSTs (1988–2007 mean), in °C.

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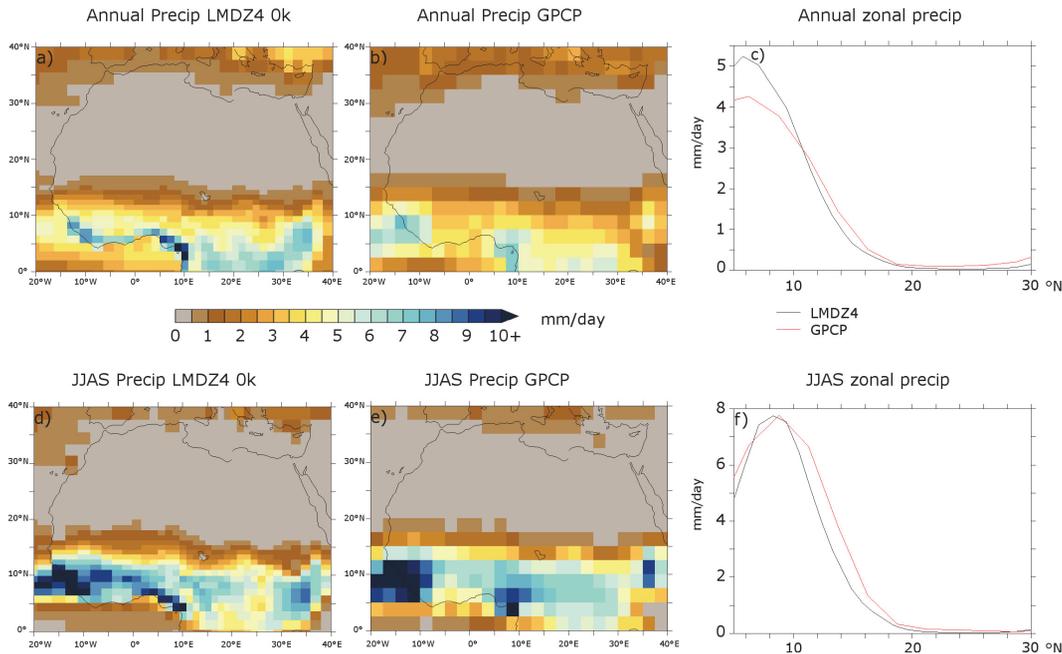


Fig. 3. Top: comparison of annual mean precipitation between the control run (left) and GPCP mean precipitation for years 1979–2010 (center). Bottom: same for June to September mean precipitation.

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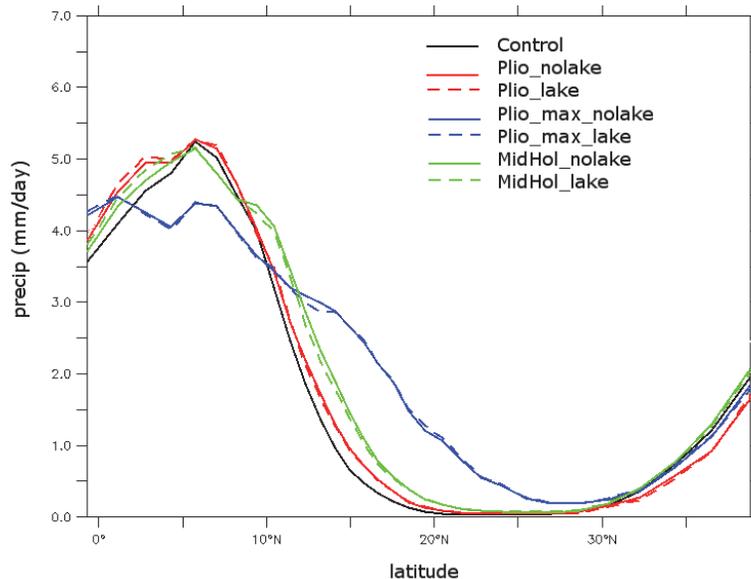


Fig. 4. Mean annual precipitation simulated with LMDZ4 in function of latitude, averaged over 20° W to 40° E.

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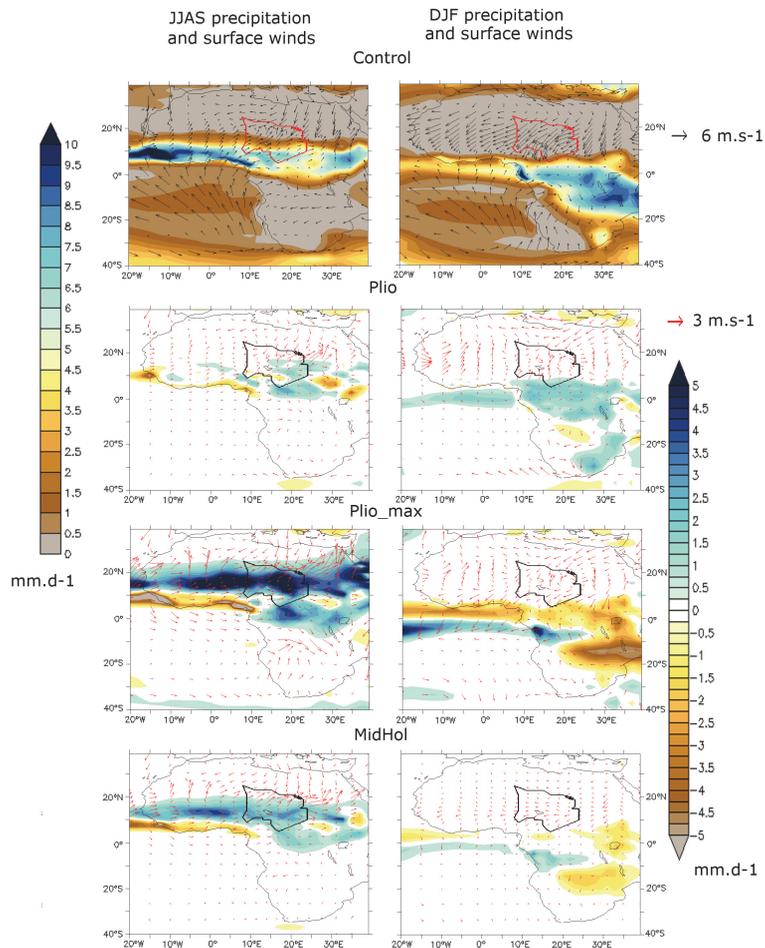


Fig. 5. Left: JJAS precipitation and mean low level winds, anomalies to the control run. Right: same for DJF.

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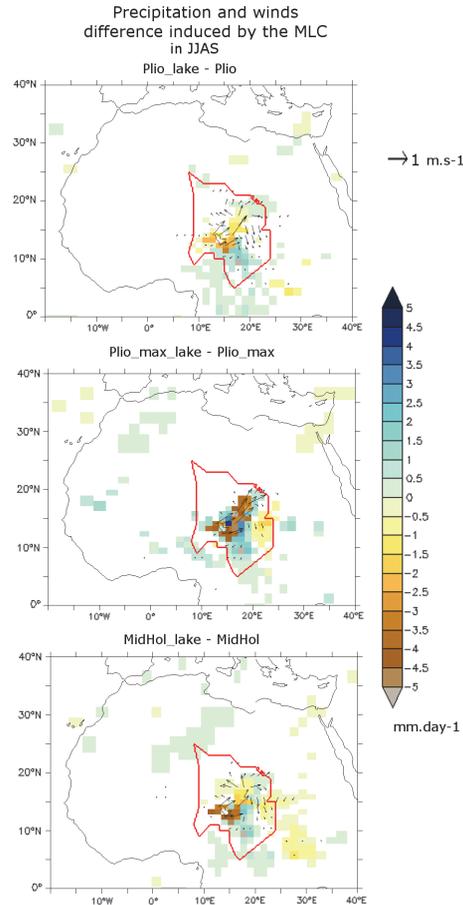


Fig. 6. JJAS precipitation and 10 m winds difference between “lake” experiments and standard experiment for each climatic configuration. Difference is significant at 95 %.

Surface temperature and slp difference induced by the MLC
in JJAS

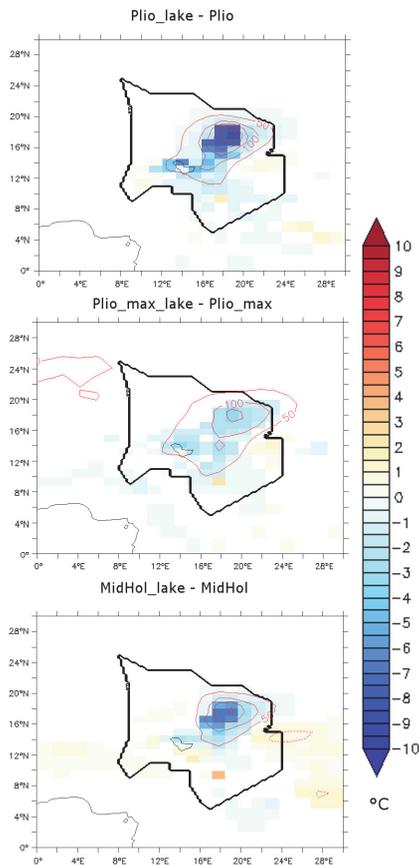


Fig. 7. JJAS surface temperature and sea level pressure (slp) difference between “lake” experiment and standard experiment for each climatic configuration. Temperature difference is significant at 95 %. Sea level pressure difference is expressed in Pa. Isolines every 50 Pa.

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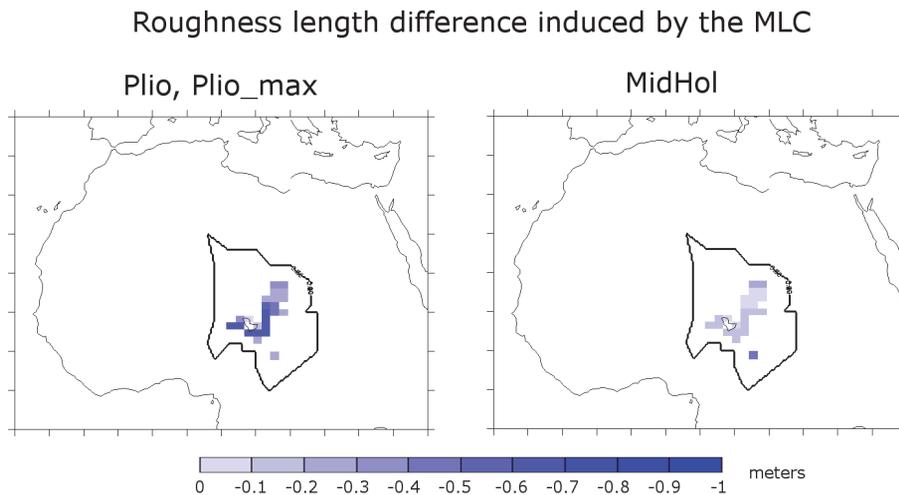
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**Fig. 8.** Roughness length (m) difference between “lake” and standard experiments.[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

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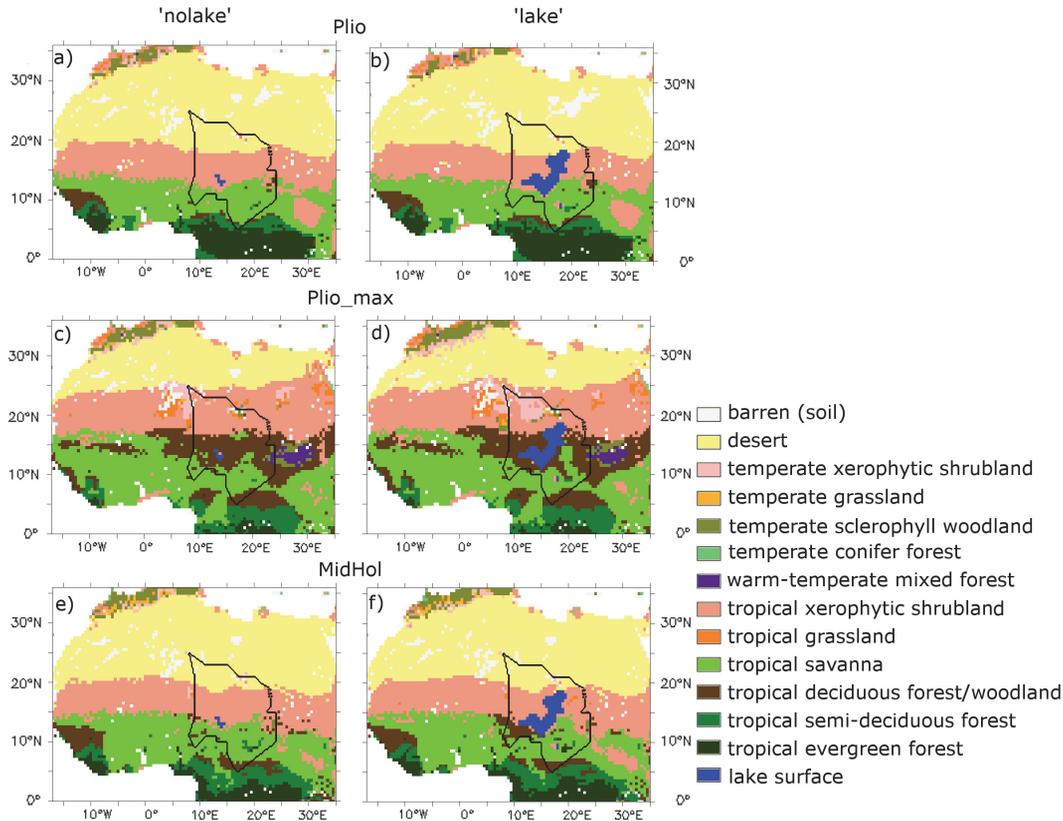


Fig. 9. Left: biome distribution for standard experiments. Right: same for “lake” experiments.

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