BRAZILIAN PALEOCLIMATES SINCE THE LAST GLACIAL MAXIMUM

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The first evidences of occurrences of drier paleoclimates during the late Quaternary in Brazil came from geomorphologic records:
- presence of eolian dunes nowadays fixed by rainforest vegetation;
- indications of past slope erosion.

These records, if correctly interpreted, give a good regional representation of dry phase occurrences but do not provide any absolute chronology. The study of lacustrine records allows to better define the paleoclimate characteristics and to date the most recent phases by radiocarbon. A large part of the results presented here have been obtained through a CNPq (Brazil)-IRD (France) cooperation project.

Three main aspects of paleo-environments have often be described in the cores retrieved from Brazilian lakes:
- terrestrial vegetation by pollen analysis and interpretation,
- wetness of the marsh or lake level by micro-fossil studies including organic matter characterization,
- erosion of lake watershed evaluated by clastic sediment input.

Variations of these proxies are generally interpreted in term of paleoclimate changes.

Last Glacial Maximum

The most part of Brazilian lakes and marshes presents a sedimentation hyathus during the Last Glacial Maximum (LGM). Data from the preceding or following periods indicate a dryer climate and the observed sedimentation hyathus correspond then certainly to a complete drying of these aquatic environments (Absy *et al*., 1991, Ledru *et al*. 1996, Salgado-Labouriau *et al*., 1997,...). In western Amazonia, where the precipitation today reaches 3000 mm, a palynological study indicates a permanence of the forest at that time (Colinvaux *et al*.,1996), but the presence of a sandy layer during LGM seems to correspond to a low water level in the lake. Evidences of dryness during the LGM are also reported in other tropical countries and would therefore correspond to a global signal.

Paleovegetation records from Brazil and elsewhere in tropical South-America indicated a 5-7 °C cooling during LGM (Colinvaux *et al*.,1996, Bush *et al.*, in press). These observations were in contradiction with the first General Circulation Model reconstructions but are now in part supported by the most recent models where ocean and atmosphere are coupled. In such models, cold temperatures in tropical oceans and continents decreased ocean evaporation and land-ocean temperature gradient and, consequently, the transfer of moisture from the ocean to the continent, enhancing tropical dryness (e.g. Bush and Philander, 1998, François *et al*., 1999).

Late Glacial

Cool climates are still recorded in Brazil during the Late Glacial (Ledru, 1993; Behling, 1998; De Oliveira *et al*., 1999). This period also corresponds to lake level rise which seems to occur in two steps: the first one at 16,000 and the second one at 13,000 yr. ^{14}C B.P. But the dominant characteristic of the Late Glacial is an intense slope erosion, evidenced by high clastic fluxes as well in lake records (Sifeddine et al., 1994, Bertaux et al., 1998) than in oceanic ones (Harris and Mix, 1999; Artz et al. ,1998). In oceanic records this phase has been generally interpreted as the onset of present-day wet climate on the continent. The clastic fluxes decrease at the beginning of Holocene being related to the sea level rise which retained the sediment input in the inner shelf and in the downstream part of estuarine valleys. As clastic fluxes also decreased in lacustrine environments too far from the ocean to be influenced by sea level, another interpretation is required. These high clastic fluxes can also be explained by a delayed response of vegetation to the climate improvement. A wetter climate would have provoked continental erosion until the installation of the dense forest which afterwards have protected soils against erosion. But different lacustrine indicators show a still low Precipitation / Evaporation budget at that time. Moreover the fact that slope erosion is also recorded in western Amazonia, where the forest cover is maintained, demonstrates that vegetation is not the sole control of erosion which were probably enhanced by more erosive rainfalls. These highly erosive rainfalls could be related to storm events. Such events occur today when cold air masses migrating from the south to the north (cold frontal systems) encounter the warm and wet tropical air mass. The strength of cold frontal systems were probably enhanced during the late glacial by the cold temperature of Antarctica contrasting with the Bolling-Allerod warming observed in the Northern Hemisphere (Steig *et al*., 1998). The cold frontal systems are also responsible for the low temperatures observed in Brazil during that period.

Early Holocene.

The Early Holocene is characterized by high lake levels and vegetation development in Amazonia (Absy et al., 1991) and Nordeste (De Oliveira, 1999). In Central and South Brazil there is some indications of increasing humidity: peat development (Roth and Lorscheitter, 1989; Salgado Labouriau et al., 1997) and forest development (Ledru, 1993, Behling, 1998) but in most sites the climate seems to remain dryer than at present. In the localities where forest developed it is frequently associated with cold taxa which would indicate the influence of cold fronts in these zones. In the southeastern region the " Mata Atlantica " rain forest did not expand markedly and large colluvial deposits are observed. It therefore seems that Late Glacial conditions have persisted in southeastern region during the Early Holocene while other Brazilian regions indicates a more or less marked humidity increase.

Middle Holocene.

In Eastern Amazonia the middle Holocene is characterized by large occurrences of fires attested by the presence of charcoals in soils and lacustrine sediments (Turcq et al., 1997). These fires

do not necessarily correspond to a dryer climate on average but may be related to episodic dry events. Studies of beach ridges in the central part of Brazilian coast witness several reversals of longshore drift at that time. These reversals are due to blockages of cold frontal systems in the southern regions (Martin et al., 1993). These blockages links to the formation of the South Atlantic Convergence Zone may have produced short dry episodes in Eastern Amazonia. This kind of meteorological situation is today enhanced during El Niño years and its past occurrences were formerly attributed to a similar phenomenon called " El Nino-like conditions ". Later data from the Pacific Coast (Ortlieb *et al.*, 1995, Rodbell *et al*., 1999, Fontugne *et al*., 1999) do not indicate stronger or more frequent El Niño during the middle Holocene but during the late Holocene.

Late Holocene.

A new forest development is observed since 4000 years in Amazonia. and the Mata Atlantica rain forest developed simultaneously in southeastern Brazil. Conversely the vegetation was opening in Nordeste (De Oliveira, 1999). In Central Brazil the forests which have developed at the beginning of Holocene now regress (Ledru, 1993, Behling 1998) . But many peat occurrences developed at that time and, in the savanna sites, forest and palms became more important in the vegetation mosaics (Salgado-Labouriau *et al*., 1997, Ledru *et al*., 1998). A last phase of increase wetness is recorded by lake level rise and forest development during the last millennium in all the region with exception of Nordeste.

The paleoclimate changes during the Holocene seems to be in part driven by the insolation changes. The wettest months are presently December and January in most of the Brazilian regions. It is due to the penetration on the continent of the wet air masses coming from tropical Atlantic and Amazonia and stirred by the warming of the continental mass at that time. This process, which presents similarities with the monsoon, has probably continuously increased during the Holocene following January and December insolation increase (Martin et al., 1998). This trend is disturbed by changes in the Cold Frontal Systems dynamics.

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