THE AFRICAN AND AMERICAN SOUTHERN TROPICS: HOW WERE POST-GLACIAL CLIMATIC CHANGES RELATED?

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The mechanisms connecting the low and high latitude climates of both hemispheres at the millenial scale are still a matter of debate. Recent works on polar ice cores (Blunier et al., 1998) and Atlantic deep sea cores (Charles et al., 1996; Vidal et al., in press) have shown that the northern hemisphere climate fluctuations lagged those of the southern hemisphere by 1.5 ka. However, some records from the southern Indian Ocean (Bard et al., 1997) and from coastal Antarctica (Steig et al., 1998) suggested an interhemispheric synchrony of the major deglacial warming at the onset of the Bölling-Allerod period. These results lead to three hypotheses regarding the mechanisms of millenial climate fluctuations in the tropics: (i) did global climate reorganisations originate in the North Atlantic region; (ii) did the tropics respond to the early warming following the Last Glacial maximum (LGM) registered in Vostok and Byrd ice cores around 20-19 ka, and interrupted by the Atltantic Cold reversal (ACR) between 15 and 13 ka; (iii) what was the influence of the tropics and what role did they play on rapid changes in the climate system during the last deglaciation (Cane, 1998; Stocker, 1998)?

We intend to investigate the climate variability at low southern latitudes through a comparison of continental records from southern Bolivia and southern Africa. Our goal is to better understand potential links between the two continents, marine circulation, and high latitude climates. We focus on hydrological changes inferred from well-dated lake and diatom records, complemented by other data (e.g. pollen records). Sites are located in Figure 1. Below, ka means 10^3 cal. yr. B.P.

Southern Tropics of South America

At high altitudes in the southern tropics of South America, hydrological changes are documented by diatom records from outcrops and shorelines on the margin of the Salar of Uyuni-Coipasa (Servant et al. 1995; Sylvestre et al. 1999). The elevation of dated lacustrine deposits above the present bottom of the Salar of Uyuni (3653 m) reflects paleolake levels. The lake level chronology is based on 44 radiocarbon dates on inorganic carbonates. Radiocarbon ages validity has been checked by comparison with 6 $^{230}Th/^{234}U$ ages. The lacustrine chronology suggests that a lake-level rise (Tauca phase) started at about 18.8 ka, reaching a hydrological optimum between ca. 14 and 15.2 ka. This water-level rise is interrupted by a lake-level stabilisation between ca. 17.2 and 15.2 ka, as suggested by finely laminated sediments consisting of epiphytic diatom floras. Then, low altitude fluvio-lacustrine sediments rich in benthic diatoms suggest a sudden lake level drop (Ticaña event), recorded between <14 and >10.5 ka. During the early Holocene, a slight positive lake level oscillation (Coipasa event) took place between 10.5 and 9.4 ka.

The humid Tauca stage (ca. 18.8-14 ka) occurred at Lake Titicaca (e.g. high percentage of freshwater algae; Sylvestre et al., 1999), but apparently not at Laguna Lejía in the northern Chilean Altiplano, which rose to levels higher than modern during the late glacial and early Holocene (Geyh et al., 1999). At Siberia, on the eastern slope of the Amazonian Andes, after a dry LGM, a return towards more humid conditions is evidenced at about 18.8 ka. Humid/warm conditions seem to be completely established by 14.6 ka and persist until 12.4 ka (Siffedine et al., 1998).

During the Holocene, the southern Altiplano is characterized by extreme aridity, recorded by the presence of polyhalite in the Salar of Uyuni (Risacher and Fritz, 1992). This event remains undated, but seems to be contemporaneous with other dry events occurring in highlands of the South America southern tropics. At ca. 9.4-8.9 ka, all the lakes from the Bolivian and Chilean Altiplano recorded low stands until 4.4-3.1 ka. This tendency toward Holocene aridity started on the eastern slope of the Amazonian Andes at 12.4 ka and persisted until 5.1ka with an intensification at 8.9 ka (Siffedine et al., 1998). At Lake Titicaca, a dry period occurred between ca. 12.4 and 8.9 ka, probably interrupted by a slight oscillation at 10.5 ka (e.g. increase of freshwater algae; Sylvestre et al., 1999). A first flooding appeared at ca. 8.9 ka, a second at 4.3 ka (Mourguiart et al., 1998). However, during the Holocene, Lake Titicaca remained under its modern lake-level which was not reached until 0.6 ka. On the Chilean Altiplano, the early Holocene humidity ended around 8.9 ka, and very shallow hypersaline lacustrine conditions prevailed during the mid-Holocene until ca. 3.8 ka. Modern conditions were reached at ca. 3.1-4.4 ka (Valero-Garcès et al., 1996; Grosjean et al., 1997; Schwalb et al., 1999).

In tropical lowlands of South America, palynological studies suggest from NW Amazonia (e.g. Lake Pata) that no drastic vegetation changes during late-glacial time and early Holocene occurred (Colinvaux et al., 1996). From SE Amazonia (e.g. Serra dos Carajás), a hiatus between ca. 23.6 and 15.2 ka is interpreted as a drying of the lake (Absy *et al.*, 1991; Sifeddine *et al.*, 1994). At ca. 15.2 ka, the appearance of lacustrine deposits indicates wetter conditions. From ca. 15.2 to 11.5 ka, a steady increase in arboreal taxa implies increased moisture, but pollen assemblages are still dominated by savanna taxa. Between ca. 10.5 and 8.9 ka, the pollen assemblages are strongly dominated by forest taxa, indicating humid conditions. The last retreat of the forest is recorded between 8.9 and 4.4 ka, the return to the modern conditions appeared after 4.4 ka. In tropical Brazil (10°-20°S, 60°-40°W), late-glacial and Holocene records were obtained on several swampy sites. At Salitre, between ca.15.2-12.8 and 11.5-8.3 ka, moister conditions are indicated by the development of forest (Ledru, 1993). The very low percentage of arboreal taxa ca. 12.4 ka indicates short and intense vegetation and climate changes (long dry season, low temperature). In the others pollen records from central and southern Brazil (e.g. Fig. 1: sites 7, 8, 9; Salgado-Labouriau, 1997; Behling, 1998), cooler and drier conditions prevailed since the Full Glacial to the Middle Holocene. Between 11.5 and 7.8 ka (Ledru et al., 1997), pollen spectra and sediment gaps witness dry climatic conditions, except in some local areas located along the trajectory of polar airmass advections (e.g. Salitre). After 7.8 ka, moisture is recorded and the forests start expanding. This moisture increase continues during the last 4.4 ka until reaching modern levels ca. 2.6 ka.

Southern Tropics of Africa

In the southeastern tropics, climatic changes are documented by a pollen and diatom record from Lake Tritrivakely in the Madagascar highlands (Gasse and Van Campo, 1998). Mountain forest plants, mainly Ericeaceae which survive thermic/hydric stresses and seasonal soil desiccation, dominated the terrestrial vegetation during glacial times until 17 ka. Pollen, diatoms, as well as other proxies (Williamson et al., 1998; Sifeddine et al., 1995) indicate that the site was at least seasonally dry during the LGM. The major deglacial event is an abrupt warming between 17 and 16.5 ka, when mid-altitude forest taxa and wooded grassland replaced the Ericaceae bush. After a return to LGM thermic conditions, interglacial vegetation had reappeared by 15 ka. The overall warming ended around 10 ka. In the lake, conditions favourable to aquatic life re-established around 17.5 ka. The diatom flora suggests maximum P-E in the interval 17.5-15 ka, although interrupted by a drier episode around 16.5-16 ka. From 15 to 11 ka, the mean sedimentation rate and time resolution are very low. Diatoms of temporary or subaerial habitats tend to replace permanent water diatoms, suggesting short desiccation episodes. A Cyperaceae bog established. Aquatic plants of shallow open water developed until 10 ka and then declined. A maximum in aridity is suggested by the pollen record around 4.2 ka. An early-wetting event during the last deglaciation, and early Holocene dry conditions, are in overall agreement with terrestrial records in eastern South Africa (e.g. Partridge, 1997).

At Lake Malawi, a highstand from about 32.5 to 11.5 ka suggested by sedimentological studies (Finney et al., 1996) appears as an exception within the southern tropics. An early Holocene low lake-level at -100, -150m is consistent with orbital forcing, as in South Africa.

North of 10°S, in subequatorial East Africa, the most spectacular event is the rift-lake basins refilling around 15 ka.; and the general picture is a high P-E balance during the early-mid Holocene, as in the northern tropics (Gasse, 1989; Johnson et al., 1996; Beuning et al., 1997; Gasse, in press). However, an earlier wetting of minor amplitude is apparent, although poorly dated so far. In the Tanganyika basin, where the lake-level, P, E, and P-E around 21 ka were substantially lower than today (Bergonzini et al., 1997), the diatom record from core MPU XII (Gasse et al., 1989) suggested a first P-E increase between 21 and 15 ka, probably around 17 ka. Deep, open-lake conditions were established by 15 ka. Pollen-based reconstructions from the same core (F. Chalié, pers. comm.) suggest precipitation and temperature increases from about 18-17 ka, before the major step at ca. 15-14.5 ka. A first wet pulse which took place between 18 and 15 ka is also apparent at Lake Victoria and Lake Albert, where it is recorded by lake sediments, bracketed by two paleosoils (Talbot and Livinstone, 1989; M. Talbot, pers. comm., 1999). A dry/cool episode roughly fitting the Younger Dryas (YD) interval, followed by a wet pulse at ca. 11.5-11 ka, arises at several sites in equatorial East Africa, e.g. Lake Kivu (Haberyan and Hecky, 1987) and Lake Magadi (Roberts et al., 1993). A diatom record from Lake Victoria (Stager and Mayewski, 1997) shows a high P/E ratio and a good wind-driven mixing from ca. 11 to 7.8 ka, with a maximum between 8.2 and 7.8 ka. An abrupt decrease in wind activity and in lake-level then occurred, in response to enhanced rainfall seasonality and/or a tendency toward aridity. Lakes Tanganyika, Victoria, Albert overflowed, and supplied the Congo and the White Nile rivers. Lake Kivu rose rapidly by 11.5, and overflowed toward Lake Tanganyika at ca. 10.5 ka. That lake remained high up to ca. 4.5 ka, and then dropped. It was closed again from ca. 3.5 and 1.3 ka (Haberyan and Hecky, 1987). A lowering of water level took place at Lake Turkana from 5 ka and a closed-basin lake status was archived permanently at ca. 4.2 ka (Johnson, 1996).

In the southwest monsoonal domain of Africa, a noble gas and isotope groundwater record in Namibia (25°S) shows a post glacial warming (+5.3°C) between ca. 17.5 and 15 ka, and suggests a climate transition from dry to wet around 7 ka (Stute and Talma, 1998). Off Namibia, a marine pollen record (core GeoB1023) integrates vegetation changes from 21 ka., between 21° and 13°S (Ning Shi et al., 1998). After an LGM colder and more arid than today, the southward retreat of temperate climate vegetation occurred in steps at 19.3-19, 17.5-16.5, and 14.4 ka. At 17.5-16.5 ka, an amelioration both in temperature and wetness is the major deglacial event, and leads to a relatively warm and humid interval from ca. 16.5 to 14.5 ka. Two very dry intervals are recorded at 14.4-12.5 and 10.9-9.3 ka, when climate was probably more arid than at any other period during the past 21 ka. Each of these arid intervals is followed by a phase of intermediate climatic conditions, the warmest and wettest period of the whole record occurring at 6.3-4.8 ka. Cooler/drier conditions in the northern Kalahari took place between 4.8 and 3.3 ka (Ning Shi et al., 1998). Interestingly, the Lake Bosumtwi record, at the limit between the equatorial and the northern monsoonal domains of West (Atlantic) Africa also shows a very arid interval centred around 14.0 ka, but then the lake evolved as those in the northern tropics.

Our observations suggested the following remarks:

1) During the LGM, most african and american records south of Equator show dry conditions which cannot be accounted for orbital forcing. Tropical climate has rather responded to changes in sea surface conditions, weaker global hydrological cycles and reduced atmosphere water vapor content. This is in agreement with a recent coupled ocean-atmosphere model (Ganopolski *et al.*, 1998).
2) Post-glacial wetting/warming started early. A first temperature and humidity increase is identified at ca. 19 ka in southwest Africa, southern Bolivia, and on the eastern slope of Amazonian Andes. A wetting/warming 17.5-16.5 ka appears as prominent deglacial event in southern Africa. These events are concomitant with a steep temperature increase in south-eastern Atlantic and in Antarctica.
3) Around 15.5-14.5 ka, major increase in moisture is recorded in northern and southern Bolivian Altiplano, SE Amazonia, central Brazil, and north of 10°S in Africa. This event also recorded in northern tropics of Africa, roughly matched the major warming event as recorded in North Atlantic region at the onset the Bölling-Allerod. Conversely, on the Atlantic side of Africa, a dry interval recorded at 14.4 - 12.5 ka, rather appeared coincident with the Antarctic Cold Reversal (ACR).
4) During the Holocene, an East-West antiphasing is observed between southern America and southwest Africa (e.g., wet/dry at ca. 9.5-8.5 and after ca. 4.5 ka, respectively).

During the Late Glacial, our observations suggest a north-south forcing gradient between the high and low latitudes, whereas, during the Holocene, the climate variability seems to be related to a zonal circulation. Recently, in coastal southern Peru (Fontugne et al., 1999), two El Niño events are evidenced at 8.9 ka and after 3.3 ka. If continental records need more well-constrained chronology in order to verify the consistency of our observations, these two El Niño events occurred practically at the same time with the major wet/dry conditions in southern Africa and southern America.

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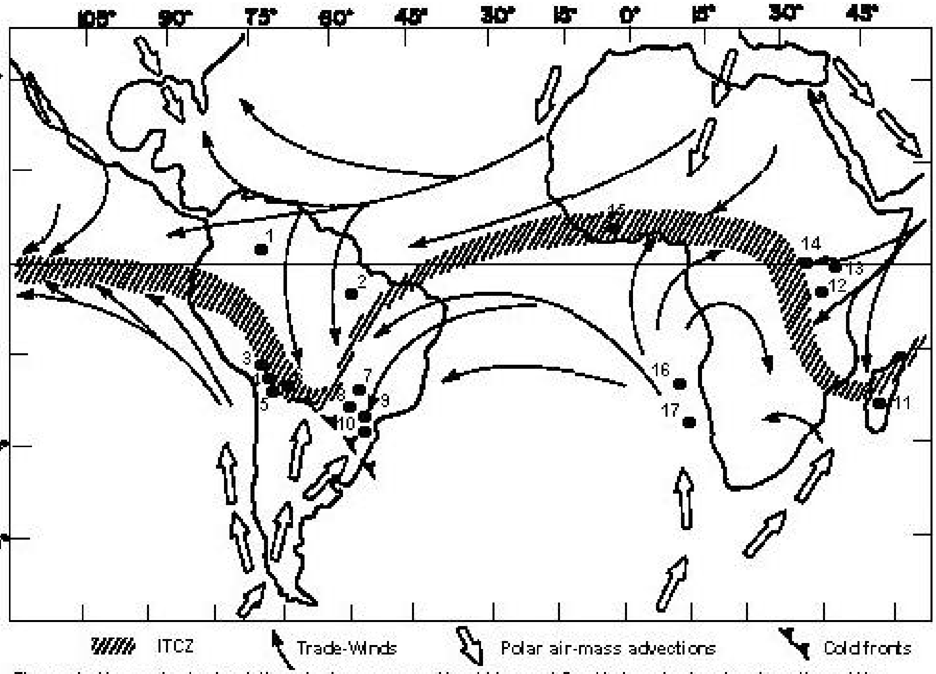

Figure 1: Atmospheric circulations in January over the Africa and South America tropics. Location of the main sites cited in the text: 1. Lake Pata; 2. Carajas; 3. Lake Titicaca; 4. Salar of Uyuni-Coipasa; 5. Laguna Lejia; 6. La Siberia; 7. Aguas Emendadas; 8. Crominia; 9. Lagoa Santa; 10. Salitre; 11. Lake Tritrivakely; 12. Lake Tanganyika; 13. Lake Victoria; 14. Lake Albert; 15. Lake Bosumtwi; 16. core GeoB1023; 17. core GeoB1711.