Tropical climates in the game of two hemispheres revealed by abrupt climatic change

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ABSTRACT

The climatically sensitive equatorial regions provide important information for evaluation of the phasing between high- and low-latitude climate variability. A high-resolution pollen record from northern Brazil demonstrates a significant abrupt and rapid environmental change associated with the Northern Hemisphere Younger Dryas temperature reversal. This finding is consistent with the model in which the Younger Dryas had a stronger influence on temperature in the Northern Hemisphere than south of the equator because of the larger temperature gradient between pole and equator in the Northern Hemisphere than in the Southern Hemisphere. One consequence of the Younger Dryas changes would be the location of the Intertropical Convergence Zone in a southern position, so that even tropical regions would have been under Arctic influence.

Keywords: palynology, lacustrine environments, Brazil, Intertropical Convergence Zone, abrupt climatic change, Younger Dryas, temperature gradient.

INTRODUCTION

Understanding the precise phases between tropical and high-latitude climate variability during the late glacial interval is crucial if we are to gain insight into the mechanisms of global climate changes. Evidence has been provided for a bipolar seesaw in air temperatures and oceanic teleconnections (Blunier and Brook, 2001); this evidence indicates the major role of the tropics in driving air-mass exchange between the two hemispheres (Labeyrie, 2000). Studies in tropical oceans have shown synchronization of paleoclimatic changes at high latitudes, such as between Greenland and Antarctica (Bard et al., 1997; Hughen et al., 2000; Lea et al., 2000), and antiphasing between the northern and southern tropics was related to differences in insolation (Seltzer et al., 2000). However, the timing, rate, and magnitude of this antiphasing are unclear. For example, the Younger Dryas temperature reversal is not clearly demonstrated in the pollen records of tropical lowlands close to the geographic equator. Moist forests appear to be have been well developed in these regions at that time; the data show few signs of short-term environmental fluctuations that might correlate with the North Atlantic climatic cooling (Absy et al., 1991; Bush et al., 1992). In contrast, pollen records from the high northern Andean and Central American cordilleras show multiple stepwise vegetation changes during the late glacial that suggest repeated temperature reversals (van der Hammen and Hooghiemstra, 1995). Similar patterns of temperature reversals are recorded in ice core records from Huascaràn, Peru (Thompson et al., 1995), and Sajama, Bolivia (Thompson et al., 1998), and are suggested by past changes in the glaciers of the Andean cordilleras (Osborn et al., 1995). Synchronization of the Younger Dryas oscillation has been demonstrated for Greenland, the Cariaco Trench, the Amazon Fan, and the Andean cordilleras (Hughen et al., 1996; Maslin and Burns, 2000; Stuiver et al., 1995).

We present here a high-resolution pollen record from a climatically sensitive area, located close to the geographic equator on the edge of the Amazon Basin in the Maranhão State, Brazil (2°58′S, 43°25′W; 120 m elevation) (Fig. 1A).

MODERN SETTING

The Lagoa do Caçó is an extended lake, 3 km long and 0.5 km wide, that occupies a small closed basin covering an area of ~15 km^2. The modern-day vegetation in this area is diverse, including Restinga, the steppe vegetation typical of coastal areas of Brazil, Cerrado, consisting of a woody savanna containing species from the Restinga growing on eolian sand, and gallery (riparian) forests containing Amazonian rainforest species. Botanical inventories were undertaken in all the various ecosystems from the lake to the coast, covering a distance of ~100 km, in November 1998, the end of the dry season, and April 1999, at the end of the rainy season. (Material is available at the Herbarium of the Botanical Department of the University Federal of Paraná, in the city of Curitiba, Brazil.) These inventories include the following species. (1) In the lake, the aquatic species present are predominantly *Nymphaea* sp. *Nymphoides* sp., *Sagittaria*, *Cabomba*, and *Montrichar-*

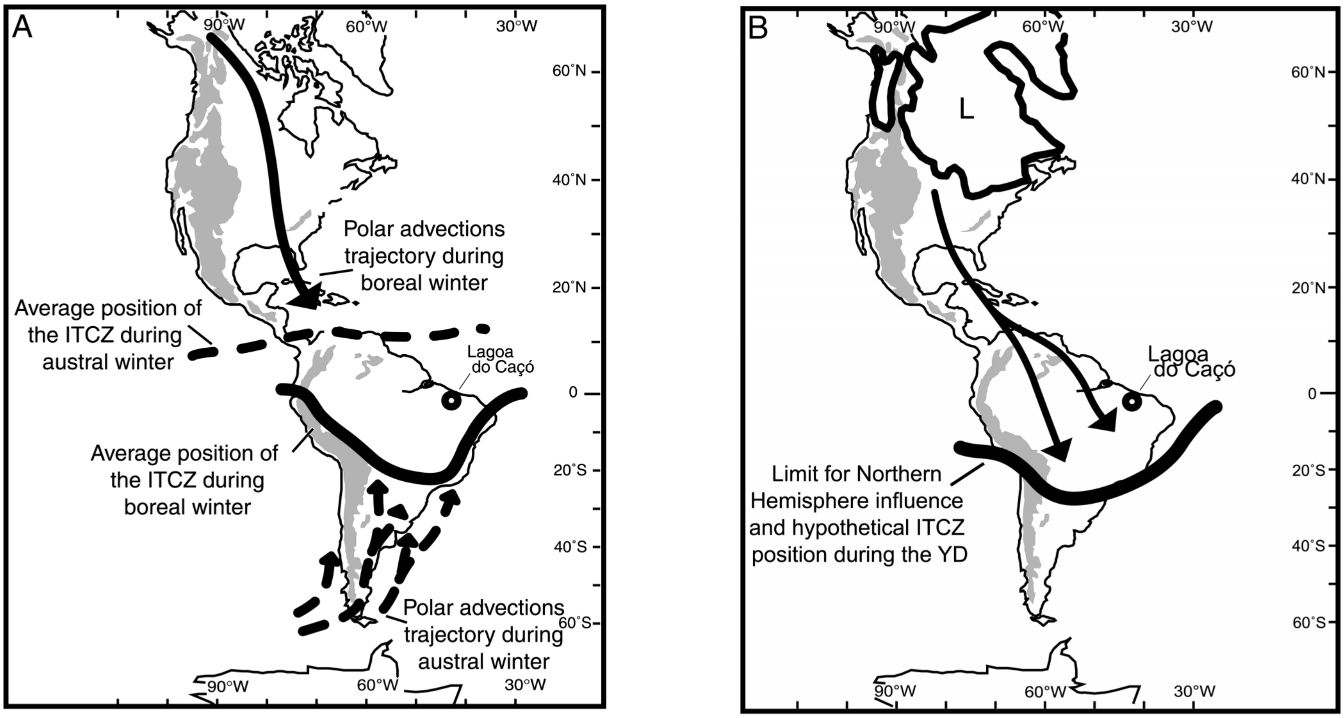

Figure 1. A: Location of Lagoa do Caçó in context of seasonal shifts of Intertropical Convergence Zone (ITCZ). Arrows show trajectories of winter polar advections in Northern and Southern Hemispheres induced by winter temperature gradient between pole and equator. B: Impact of Northern Hemisphere Younger Dryas climate oscillation on tropical regions. Size of Laurentide glacier (L) at time of Younger Dryas event is indicated as well as geographic limit for Northern Hemisphere climate-reversal influence. ITCZ is Intertropical Convergence Zone; YD is Younger Dryas.

dia linifera. (2) The lake margins are occupied by herbaceous plants of Cyperaceae (*Eleocharis* sp.), Orchidaceae, and Eriocaulaceae, *Mauritia flexuosa* (a palm that forms large mixed colonies in seasonally flooded marshland with *Xylopia*), and trees from the gallery forest (Melastomataceae, *Tapirira guianensis*, *Vochysia tucanorum*, *Cordia nodosa*, *Casearia* spp., *Ficus* spp., and *Picramnia* spp.). (3) The Cerrado profiles vary according to the density of the trees, including *Stryphnodendron adstringens*, *Parkia pendula*, *Qualea grandiflora*, and *Curatella americana*. (4) The coastal vegetation (Restinga) was encountered on the dunes and included small trees and shrubs (e.g., *Byrsonima* spp., *Copaifera* spp., *Hymenaea* sp., *Caryocar coriaceum*, and many Bromeliaceae), the dominant herbaceous plant being *Chamaecrysta flexuosa*. (5) The mangrove association on the littoral stretches is composed of *Rhizophora mangle*, *Avicennia nitida*, *Laguncularia flexuosa*, and *Conocarpus erectus*.

Lagoa do Caçó has a mean annual precipitation of ~1400–1500 mm and a mean annual temperature of ~25 °C. Its seasonal climate is controlled by the position of the Intertropical Convergence Zone, or meteorological equator, that divides the year into two main seasons. Variations in the convergence zone positions are determined by the temperature gradient between pole and equator. Consequently, the convergence zone occupies its northernmost position when the winter temperature gradient between the Antarctic and the equator is the greatest, from June to September, and its southernmost position when the winter temperature gradient between the Arctic and the equator is the greatest, between December and March (Fig. 1A).

MATERIAL AND ANALYSIS

A 345-cm-depth sediment core was collected with a Vibracorer in 1997 from an area close to the center of the lake (water depth 12 m). Sediment samples (8 cm^3) were processed by standard methods (Faegri and Iversen, 1989). Fossil pollen was identified with a reference pollen collection of ~1000 taxa collected from various herbaria. A chronologic framework for the sedimentary sequence was provided by 15 conventional and accelerator mass spectrometer (AMS) radiocarbon dates (Fig. 2A; Table 1). Radiocarbon dates were calibrated into calendar years before present (Bard et al., 1993; Stuiver and Reimer, 1993). The sediment record spans at least the past 18 k.y. During the full glacial, the residual vegetation at Lagoa do Caçó was dominated by grasses (Poaceae), halophytes (Chenopodiaceae, *Alternanthera*, and *Gomphrena*), and herbaceous plants (*Richardia*, Cyperaceae). These taxa are typical of an open and dry vegetation type. Rapid reforestation began ca. 14 000 ^{14}C yr B.P. with the arrival and expansion of *Didymopanax*, Myrtaceae, Melastomataceae-Combretaceae, Moraceae, *Myrsine*, and *Podocarpus*. This plant community and the high percentages of tree pollen (80%) are typical of modern pollen spectra from gallery forests in the Brazilian highland Cerrado (savanna) vegetation. They are associated with moist and cold winter conditions. The arrival of *Picramnia* and Mimosaceae and the decline of *Podocarpus* ca. 12 000 ^{14}C yr B.P. suggest an increase in temperature. This trend toward forest development ended abruptly, between 11 000 and 10 000 ^{14}C yr B.P. (Fig. 2B). Gallery-forest plant communities were then replaced by *Cecropia*, a pioneer species associated with the drastic destruction of moist tropical forests. The pollen record contains a strong fire signature and high percentages of grass pollen (60%) for this time of deforestation, showing that the dominant landscape vegetation of the area became a savanna subject to frequent fires. The pollen spectrum gradually changed during the Holocene (after 10 000 ^{14}C yr B.P.). It became first dominated by Poaceae (50%) and *Picramnia* (~10%), suggesting restructuring of the gallery forest around the lake and the dominance of open savanna communities. The landscape became more forested ca. 7500 ^{14}C yr B.P. as other tree species expanded (*Byrsonima*, *Curatella*, Mimosaceae). These taxa include species abundant in the Cerrado to-

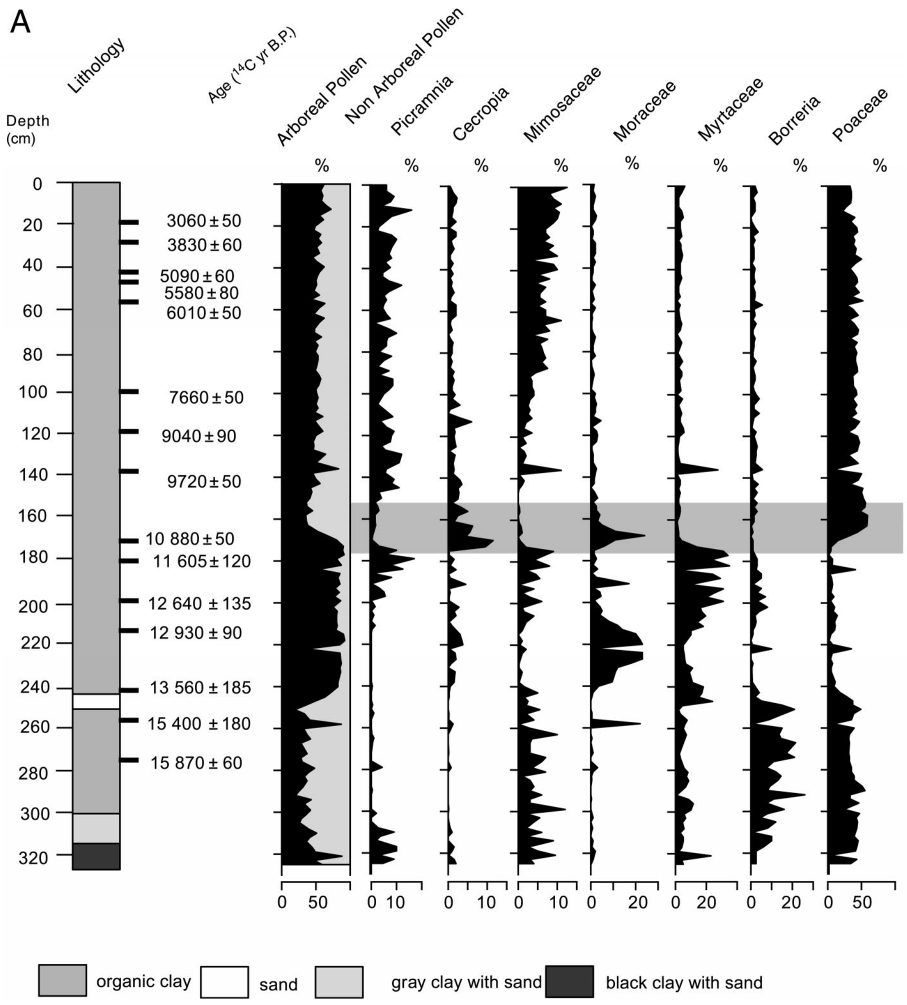

Figure 2. Summary pollen percentage diagram for Lagoa do Caçó. Percentages are expressed as proportion of total land pollen (at least 300 grains), excluding fern spores and aquatic taxa (e.g., *Botryococcus* and *Pediastrum*). Analysis of pollen-concentration data showed that these percentage changes are not statistical artifacts, but instead represent real vegetation changes. Depth of 0 cm corresponds to interface between sediment and water. Younger Dryas chronozone is shown by gray band. A: Only most abundant taxa from full complement of 237 pollen types are shown. B: Principal groups of ecological indicator taxa are shown. Halophytes are represented by Chenopodiaceae, *Alternanthera*, and *Gomphrena*; cold-adapted gallery-forest indicators are *Podocarpus* and *Myrsine*; warm-adapted gallery-forest indicators are *Picramnia* and Mimosaceae.

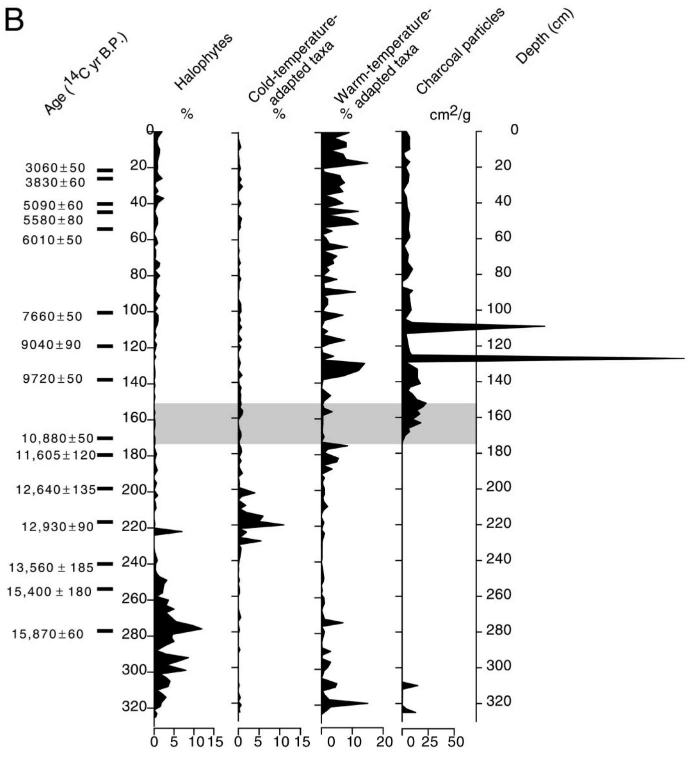

Figure 2. Continued.

day and indicate a seasonal climate (dry season up to 5 months, mean winter temperatures above 15 °C) (Ledru, 1993).

YOUNGER DRYAS IN NORTHERN AND SOUTHERN HEMISPHERES

The abrupt, rapid climatic change observed in the late Pleistocene in the Brazilian record may be related to the North Atlantic Younger Dryas event. Pollen records from the same latitude in Peru indicated that temperature dropped by 2 °C at this time (Ledru and Mourguiart, 2001). The beginning of the charcoal records is evidence of an element

TABLE 1. RADIOCARBON AGES OF TOTAL ORGANIC MATTER FROM CORE MA97-1

Age (^{14}C yr B.P.)	Depth (cm)	Lab number	Age range* (cal yr B.P.)
3060 ± 50	18–23	Beta 110192	3370–3080
3830 ± 60	31–32	AA 32146	4410–4000
5090 ± 60	40–45	Beta 115180	5980–5660
5580 ± 80	48–49	AA 32147	6520–6200
7660 ± 50	95–100	Beta 110193	8540–8370
9040 ± 90	118–120	AA 32148	10 040–9920
9720 ± 50	135–140	Beta 110194	11 220–10 880
10 880 ± 50	172–174	Beta 110195	13 130–12 650
11 605 ± 120	178–180	AA 32149	13 910–13 170
12 640 ± 135	200–202	AA 32150	15 750–14 180
12 930 ± 90	215–218	Beta 115181	16 040–14 480
13 560 ± 1185	241–242	AA 32151	16 920–15 680
15 400 ± 180	259–260	AA 32153	19 130–17 740
15 870 ± 60	275–277	Beta 110196	19 570–18 370

*Range at two standard deviations with error multiplier of 1.0.

that could have prevented the return of the previous dense gallery forest and allowed another type of more open vegetation to dominate. The human impact on these fires is still debated (Haberle and Ledru, 2001). Several polar records suggest that the climatic signatures were opposite in the two hemispheres (Blunier and Brook, 2001; Jouzel et al., 1995), i.e., Younger Dryas cooling in Greenland and warming in Antarctica (Broecker, 1998). This climatic opposition could relate to orbitally determined seasonal insolation variation that caused an insolation near its maximum in the Northern Hemisphere and an insolation near its minimum in the Southern Hemisphere summers at the time of the Younger Dryas event. The climatic changes observed in southern Argentina, Chile, and New Zealand (Markgraf, 1991; Heusser, 1995; Singer et al., 1998; Bennett et al., 2000) are consistent with this opposition of the climatic signatures in the two hemispheres. Oceanic influence, specifically changes in the intensity of the thermohaline circulation, cannot be inferred to have caused such a short, rapid, and interhemispheric climate change. An atmospheric mechanism is thus inferred to explain how Arctic cold air was pushed at least as far south as the equator and probably farther south (Fig. 1B). The observed vegetation change would thus be accounted for by the greater penetration of cold air (Leroux, 1998; Marengo and Rogers, 2001). Records for high latitudes in the Northern Hemisphere indicate cooling, whereas those for high southern latitudes indicate warming at that time. More frequent Arctic cold-air advection would have been the response to a steeper temperature gradient between pole and equator in the Northern Hemisphere. This would result in maintaining the Intertropical Convergence Zone (or meteorological equator) at a position south of the geographic equator, and Arctic influence extending as far as the tropical regions of South America.

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