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Holocene dynamics of vegetation change in southern and southeastern Brazil is consistent with climate forcing

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ABSTRACT

At mid to high northern latitudes postglacial vegetation change has often occurred synchronously over large regions triggered mainly by abrupt climate change. Based on 19 pollen diagrams from southern and southeastern Brazil we explore if similar synchronicities in vegetation change were also characteristic for the vegetation dynamics in low latitudes. We used sequence splitting to detect past vegetation change in the pollen diagrams and computed principal curves and rates of change to visually evaluate the changes in composition and dynamics. The results show that vegetation change occurred mostly during the second half of the Holocene with distinct episodes of change. The character of vegetation change is generally consistent with shifts to wetter conditions and agrees with inferred shifts of the South American Monsoon. Speleothems as well as the titanium record from the Cariaco Basin indicate several episodes of rapid shifts in the precipitation regime, which are within the dating uncertainty of the here detected periods of vegetation change (8900, 5900, 2800, 1200 and 550 cal yrs BP). Our results indicate that low latitude vegetation composition follows precession forcing of the hydrology, while change is often triggered and synchronized by rapid climate change much like in high and mid latitudes. Pollen diagrams document changes in the abundance of individual taxa and changes in the amount of woodland cover, while small compositional changes indicate a regional stability of vegetation types during the Holocene.

1. Introduction

Already 100 years ago Lennart van Post documented that Holocene vegetation change across southern Scandinavia occurred at more or less the same time at different sites within a region (von Post, 1918). He assumed that large scale climate change controlled the shifts in vegetation composition so that they were synchronous also between regions where different taxa were involved in the change (von Post, 1946). Not all Holocene regional vegetation changes turned out to be synchronous (Smith and Pilcher, 1973) while some stood the test of time (Giesecke et al., 2011). Especially the climate forcing of the 8.2 event finds its representation in many pollen diagrams, particularly on both sides of the Atlantic (e.g., Shuman et al., 2002; Seppä et al., 2007; Tinner and Lotter, 2001).

At mid to high latitudes glacial-interglacial cycles caused continental scale shifts in biomes and the resetting of soil developments though glacial drift, cryoturbation and loess deposition. Postglacial colonization of trees, soil development and climate change caused major shifts in vegetation composition with glacial interglacial cycles (e.g. Birks and Birks, 2004; Cheddadi et al., 2005), often leading to parallel developments in vegetation change over large regions. The vegetation at low latitudes was less severely affected by glacial-interglacial cycles with comparably small change in biome distributions, apart from vertical movements of vegetation belts in the mountains (Marchant et al., 2009). While glaciations make phosphorous available which is then rapidly leached from the soils geologically older surfaces are depleted in phosphorous leading to a gradual slow decline in plant biomass in the absence of disturbance (Wardle et al., 2004; Boyle et al., 2013). Thus without resetting soil formation in the low latitudes soil development though time may have had a negligible effect on vegetation change. In addition to temperature changes associated to glacial interglacial cycles, low latitudes were influenced by

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changes in precipitation following the changes in solar insolation, mainly determined by the precession component of Earth's orbital variability. The importance of precession forcing for hydrology in low latitudes has been demonstrated using climate models (Clement et al., 2004) and documented in analysis of lake sediments (Verschuren et al., 2009) and speleothems (Wang et al., 2007).

Changes in climate driven by Earth's orbital variation are gradual and would not necessarily lead to synchronous shifts in vegetation composition in ecosystems consisting of long-lived woody species. Climatic excursions, or rapid shifts in ocean or atmosphere circulation are necessary to break the inertia of woody plant communities and cause synchronous changes over large regions. These causalities have been interpreted for Europe and North America where synchronous and parallel changes in vegetation composition have been documented (Giesecke et al., 2011; Grimm and Jacobson, 1992; Shuman et al., 2002), but little is known whether regionally synchronous shifts in vegetation composition have characterized vegetation dynamics in species diverse low latitude ecosystems.

South America stretches over both hemispheres from the low to the high latitudes so that the different beats of orbital cyclicity and their combinations may have influenced vegetation dynamics in different regions (Fontana et al., 2012). A marked and rapid shift in vegetation composition in the low latitudes of South America is the expansion of the *Araucaria* forest in southern Brazil. This southern region of the Atlantic Rainforest (Mata Atlântica) in eastern Brazil was characterized by species rich campos (grasslands) during the last glacial which changed little in composition until the mid-Holocene (Behling et al., 2004; Pieruschka et al., 2012). The expansion of the forest is interpreted to result from increased moisture availability (Behling, 2002) and this interpretation is generally consistent with the oxygen isotope record from Botuverá Cave (Wang et al., 2006). However, while the isotope data indicate a general increase through the Holocene pollen data document a rapid change (Behling et al., 2007b). The rapid vegetation change may be a threshold response of the vegetation or the result of a fast shift in precipitation regime, which may have been short lived or sustained. In the case of a fast shift in climate, synchronous changes in vegetation composition may be expected over a larger region, while a threshold response should find expressions in diachronous changes.

The aim of this manuscript is to explore the regional dynamics of vegetation change in southern and southeastern Brazil and to evaluate whether rapid shifts in climate may have caused synchronous patterns in low latitude vegetation dynamics.

2. Study area

The study area comprises tropical and subtropical ecosystems of southeastern and southern Brazil between approximately 18° and 30° southern latitude (Fig. 1). A total of 19 pollen records covering different periods of the Holocene (16 extending over 10,000 years and more, 2 covering at least 3000 and 1 covering at least 6000 years) are used from this region mainly derived from small wetlands and lakes representing vegetation types such as grassland, shrublands, tropical and subtropical forest types (Fig. 1, Table 1).

The vegetation formations include the subtropical forest known as *Araucaria* forest, which is located in the southern highlands where rainfall rates are over 1400 mm per year and annual average temperature is around 15 °C. In the summer, the maximum temperatures can reach 30 °C and the lowest recorded temperature in winter is −10 °C (Nimer, 1989; Veloso et al., 1991). Herb dominated campos vegetation forms a mosaic with *Araucaria* forest, which spreads over large areas on the highlands of southern Brazil, where temperatures can reach 35 °C in summer and the presence of frost is common during the winter (Boldrini, 2009); Nimer, 1989) Small areas of grassland vegetation (campos de altitude) are also found in southeastern Brazil, where it occurs at escarpments, plateaus and mountain tops above 1800 m a.s.l. at Serra da Mantiqueira and Serra do Mar with an annual precipitation rate around 1800 mm and mean temperatures between 16 and 22 °C (Nimer, 1989; Overbeck et al., 2007; Safford, 1999). The mountain chains Serra da Mantiqueira and Serra do Mar divide the coastal and hinterland vegetation associations. The coastal vegetation is formed by closed evergreen forest in general located between 0 and 1000 m elevation with high precipitation rates from Atlantic in consequence of orographic features (Sant'Anna Neto and Nery, 2005; Veloso et al., 1991). In leeward locations of southeastern Brazil, there is the occurrence of semi-deciduous forests, that are characterized by two well defined seasons, one rainy season followed by a long drought period from 3 to 5 months when plants loose between 20 and 50% of their leaves (IBGE, 1995; Nimer, 1989; Veloso et al., 1991).

3. Methods

3.1. Age depth modeling

In order to compare the timing of events between pollen records, we constructed Bayesian age models using Oxcal version 4.2 (Bronk Ramsey, 2009) and SHCal13 calibration curve (Hogg et al., 2013). Considering that deposition though time may have changed randomly, including periods of steady and irregular deposition, we used the Poisson process to describe the sedimentation across profiles as implemented in the deposition model *P_Sequence (name, k0, p, D)*. The parameter *k0* describing the sedimentation rate as the number of accumulation events per unit depth was set to 1. The parameter p (interpolation rate) was set as of 0.2, which means 1 output every 5 cm. *D* describes the possible variation of *k* and setting it to range between −2 and 2 allows *k* to vary between 0.01 and 100 cm^{-1} (Bronk Ramsey and Lee, 2013).

Probability distribution functions (PDF) of entire profiles were built by placing the prior age information for individual depth within paired *Boundary*() functions defining a uniformly distributed group. The upper boundary was constrained by an age for the top sample, which was assumed to represent the year of core collection, described by a normal distribution with a standard deviation of 25 years. The resulting posterior age distributions for individual stratigraphic levels vary greatly, with stratigraphic levels at or near a radiocarbon date being relatively narrow and steep, while probable ages for poorly dated sections are smeared over several thousand years. The final PDF of each depth calculated by Oxcal is based on the Gregorian calendar, however, we transformed all ages to the cal. BP scale by subtracting 1950 years.

3.2. Data treatment

The pollen samples of all 19 records were treated in two steps in order to reduce the noise of the dataset. Initially, pollen counts from Cyperaceae and local fern spores (e.g. *Blechnum* type, *Salvinia* type, *Isoetes* and others) were removed as their counts are highly influenced by local conditions rather than general vegetation composition. Further, within all samples single occurrences were removed, since their true abundance per sample cannot be estimated because they may be chance encounters of rare or distant parent species or a chance underrepresentation of a characteristic taxon from the region. The second step to select the most representative taxa was carried out by removing those taxa with abundance less than 0.5%. Finally, the percentages of the new dataset of each site were recalculated, square root transformed to stabilize the