Stable isotope chronology and climate signal calibration in neotropical montane cloud forest trees

K. J. Anchukaitis,[1,2,3] M. N. Evans,[1,2] N. T. Wheelwright,[4] and D. P. Schrag[5]

Received 3 October 2007; revised 21 April 2008; accepted 15 May 2008; published 30 August 2008.

[1] Tropical montane cloud forests are ecosystems intrinsically linked to a narrow range of geographic and meteorological conditions, making them potentially sensitive to small changes in precipitation or temperature. We investigate the potential application of stable isotope analysis to cloud forest dendroclimatology at Monteverde in Costa Rica in order to be able to extract both chronological and paleoclimate information from trees without annual growth rings. High-resolution δ^{18}O measurements are used to identify regular cycles in wood of up to 9 %, which are associated with seasonal changes in precipitation and moisture sources. The calculated annual growth rates derived from the isotope time series match those observed from long-term basal growth measurements. Interannual variability in the oxygen isotope ratio of lower forest trees is primarily related to interannual changes in wet season precipitation. Forward modeling independently supports our detection of both annual chronology and a climate signal. The confirmation of annual chronology and sensitivity to interannual climate anomalies suggests that tropical cloud forest dendroclimatology can be used to investigate local and regional hydroclimatic variability and change.

Citation:

forest biogeography [Pounds et al., 2006]. A rise in tropical air temperatures above 1000 meters has been observed since 1970 [Diaz and Graham, 1996]. Climate change appears to be exposing plant and animal communities to increased environmental stress, which may exacerbate other proximal threats, including disease and habitat destruction [Root et al., 2003; Pounds et al., 2006].

[

and ϵ_o is the fractionation that results from the synthesis of cellulose. This model shows that α-cellulose δ^{18}O is influenced primarily by the δ^{18}O of the source water taken up by the plant, and by the amount of isotopic enrichment of

30 cm diameter. Increment cores from O. tenera were collected in February 2004 from the Trostles (NWT-) and Hoges (NWH-) experimental plots. These plots were established in 1981 and 1984, respectively, and are situated in shaded secondary forest with emergent canopy trees [Wheelwright and Logan, 2004]. Three cores were obtained from the Trostles plot, with two collected from a single tree (NWT02A/B), and one from a separate individual (NWT01A). A fourth core was collected from the Hoges plot (NWH03A). This sampling approach was designed to evaluate the fidelity and consistency of the chronological and climatic signal both within and between trees, and among sites. Annual diameter measurements made at a height of 1 m with calipers in February or March are available for all three trees since 1988 [see Wheelwright and Logan, 2004].

[17] In addition, to the trees from the experimental plots, nine additional cores or entire cross-sectional discs were also opportunistically collected in and around the Monteverde Cloud Forest Reserve (1500–1660 m) from mature unmonitored canopy trees, many which had been felled in a December 2003 windstorm. This group included individuals from the genus Quercus (oaks) as well as from the cosmopolitan Sapotaceae and Lauraceae families. The forest trees were sampled along a rudimentary transect up the Pacific slope toward the continental divide. This strategy was intended to accomplish two complementary goals. First, it permits discovery of sites or species that have maximum sensitivity to both annual and interannual changes in cli-

of condensation temperature and the isotopic fractionation related to the vapor–liquid phase change [Gonfiantini et al., 2001], although in practice a simpler Rayleigh model (δ^{18}

humidity corresponding to the location of Monteverde from the NCEP II reanalysis (Figure 3). However, the individual δ^{18}O series maxima at the calibration site do not in turn mirror the large interannual dry season anomalies seen in

Sapotacae family. Samples from this tree (MV12A and MV15C) showed coherent annual cycles over their entire length.

[37] There is a distinct and statistically significant pattern (

The NCEP data results in a slightly better match to the actual, observed isotope time series, particularly the annual maxima δ^{18}

mately -0.20 % for every percent increase in relative humidity.

[40] When compared over the limited period for which both climate data and volume-weighted seasonal δ^{18}O of meteoric waters at Monteverde are available, the forward model simulations using calculated and observed source water isotope ratios show similar seasonal patterns and amplitudes (Figure 8c). The amount effect model (equation 5) reproduces the seasonal pattern of observed meteoric water δ^{18}O on which it was based, with a slight loss of variance at the annual maxima and minima (Figure 8c). The modeled α-cellulose δ^{18}O cycle amplitude is also similar whether observed or modeled source water is used, and irrespective of the relative humidity data set. However, uncertainties in model parameters can result in a confidence interval up to 1.5 % wide, particularly at the local maxima and minima of the simulated annual δ^{18}O cycles. The seasonal pattern and mean annual isotope cycle in both simulated and observed O. tenera are quite similar, with an apparent age model bias of ±1 month (Figure 8d). Some of this phase offset could be due to the necessary but probably simplistic assumption that growth rates are constant over the course of a year. In the absence of more frequent basal measurements, however, this assumption is reasonable and moreover does not influence our climatic interpretations.

5. Discussion

5.1. Annual Oxygen Isotope Cycles

[41] Annual δ^{18}O cycles are clearly present in our set of O. tenera trees, and are sufficiently large and well defined that they are easily distinguished from the occasional smaller positive excursions at the time of the annual minima, which are probably the result of the existence

with overall mean δ^{18}O values substantially lower than other species, and a smaller average amplitude in MV05. Collectively, these data suggest that our Quercus preferentially sample soil water with a more negative δ^{18}O. This could arise if the trees did not add basal growth during part of the transition or dry season, when δ^{18}O values are higher. If Quercus ceased growth during part of the dry season, both the mean isotopic value and the annual cycle, where present, would preferentially reflect the more negative δ^{18}O during the rainy season. Alternatively, this species may have access to some deeper soil water sources, which would also explain the suppressed amplitude of the mean annual cycle. Finally, if transpiration were more restricted in Quercus, potentially through particular physiological characteristics or structure of the leaves, enrichment of the source water in the leaves would be limited and the resultant cellulose would have a more negative δ^{18}O value. In general, though there are several possible reasons why some of the forest trees studied here do not display annual cycles, the simplest cause may be that our sampling interval of 200 μm failed to adequately resolve the annual cycle in very slow growing trees.

[46] Two robust features characterize the annual cycles in the forest trees considered here. The amplitude of the annual cycle decreases with elevation, and the ratio of the variance

of the time series variance. Additional uncertainty arises from the derived amount effect relationship, which accounts cally achieved. The result is relatively large uncertainties (several years) in the age modeled chronologies. However, as demonstrated by McCarroll and Pawellek [1998] and Gagen et al. [2004], stable isotope ratios in tree ring chronologies often have a higher signal-to-noise ratio that ring width data. As a consequence, fewer chronologies may be required to achieve a robust common signal. For the Monteverde O. tenera chronology, 3 trees over the common period of overlap are sufficient to meet an Expressed Population Signal threshold (EPS [Wigley et al., 1984]) of 0.85. Furthermore, the protocols allow for the development of high-resolution terrestrial proxy records that bypasses some of the extant challenges to developing tropical ring width chronologies, and can be applied even when appro-

M. N. Evans, Laboratory of Tree-Ring Research, University of Arizona, 105 West Stadium, Tucson, AZ 85721, USA.

D. P. Schrag, Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138, USA.

N. T. Wheelwright, Department of Biology, Bowdoin College, 230B Druckenmiller Hall, Brunswick, ME 04011, USA.