A stable isotope dendrochronology approach to reconstructing interannual and interdecadal tropical climate variability

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Summary

• **Challenges and Possibilities for Tropical Dendrochronology**

• **Progress in tropical isotope dendroclimatology**

• “Paradoxical Dendrochronology” – Using Tropical Montane Cloud Forests for Paleoclimatology

• **Theoretical and Technical Considerations for Tropical Dendrochronology in Neotropical Cloud Forests**
**Introduction**

**Do The Tropics Rule?** (Cane and Evans 2000)

*ENSO is dominant mode of interannual climate variability*

- *Tropics have the energy and dynamics to influence global climate*

- *Tropical interannual and interdecadal variability cause anomalous climate patterns around the world through atmospheric teleconnections*

- ✔ *Unfortunately, long instrumental weather records are sparse in the tropics; increased proxy records from the tropics needed*
Fig. 1. Equal-area map of locations of high resolution coral and tree-ring paleoclimate data currently in the NGDC World Data Center-A for Paleoclimatology electronic database (http://www.ngdc.noaa.gov/paleo/). Plots as of June 2003.

Evans and Schrag [2004]
Fig. 2. Photographs of 5 mm-diameter increment core sections taken from extratropical and tropical tree species. Top: Harvard Forest (Petersham, MA, USA) Pinus strobus (White Pine). Bottom: Costa Rican dry forest Cordia sp. (Laurel). The scale is in centimeters. Both cores are mounted onto blond wood core-holders. Rings are clearly visible in the P. strobus core, but the Costa Rican Cordia sp. is a uniform, dark color throughout.
Proxy network (corals) SST field reconstruction: More data is better.

Evans et al. [2002]
Will the true decadal power spectrum please stand up?

Evans et al. [2002]
“[Establish] a strategy to develop chronometric estimates in tropical trees lacking demonstrably annual ring structure, using high resolution stable isotopic measurements in tropical woods.”

Evans and Schrag [2004]
methodology

Very Fine Sampling Intervals

Oxygen Isotope Time Series

AGE MODEL / CHRONOLOGY
(1 cycle = 1 year)

PALEOCLIMATE INFORMATION
1. Mechanistic Model
   [Roden et al. 2000]
   \[ \delta^{18}\text{O}_{\text{cellulose}} = f_\text{O} \cdot (\delta^{18}\text{O}_{\text{wx}} + \varepsilon_\text{O}) + (1 - f_\text{O}) \cdot (\delta^{18}\text{O}_{\text{wl}} + \varepsilon_\text{O}) \]

2. Continuous flow IRMS
   [Brenna et al. 1999]
   • Oxygen isotope composition of organic matter
   • throughput: one 100ug sample / 5 minutes
   • Precision approaching 0.3 ‰ on standard materials

3. Alpha-cellulose processing chemistry
   [modified after Brendel et al. 2000]
   • Non-toxic, easy, cheap
   • Fast: 100 samples/person/4 hours
Most important controls on cellulose oxygen isotope values are source water isotope ratios and the amount of leaf water that experiences evapotranspiration (a function of relative humidity, insolation).
\[
\delta^{18}O_{\text{cellulose}} = f_O \cdot (\delta^{18}O_{\text{wx}} + \epsilon_O) + (1 - f_O) \cdot (\delta^{18}O_{\text{wl}} + \epsilon_O)
\]

Most important controls on cellulose oxygen isotope values are source water isotope ratios and the amount of leaf water that experiences evapotranspiration (a function of relative humidity, insolation).
During the rainy season the amount effect in tropical convective rainfall should dominate over weaker leaf evaporation, leading to lower xylem $\delta^{18}$O values.

During the dry season, leaf evaporation will dominate over the amount effect, leading to higher xylem $\delta^{18}$O values.

Analogous situation in dry vs. wet years.

Evans and Schrag [2004]
Hyeronima alchorneoides
La Selva, Costa Rica
(tropical wet forest)

- 17±2 isotope cycles for 17 year-old trees. 4-6‰ cycles in the series at intervals ranging from 4-18mm.
- The highest JJAS rainfall totals are found in 1994, 1991, 1986, and 1997, and correspond to low $\delta^{18}O$ values.
- A wet period from 1990–1991, corresponds to a damped annual cycle and lower 1990–1991, a wet period, corresponds to a muted annual cycle and low $\delta^{18}O$ values, and is consistent with a rainy dry season in winter 1990-1991.
Results: Amazon Rain Forest *Erisma uncinatum*

Santarem (54.7W, 2.5S)

Rainfall Climatology

- Growth rates in most recent year (5-9mm/yr) consistent with radial growth measurement (5mm/yr) made in year prior to sampling.

Evans et al. [2002]
Moving upslope:
a tropical isotope dendrochronology approach to neotropical montane cloud forest paleoclimatology
Objective

Use *stable isotope dendrochronology* and the *unique hydroclimatic conditions of tropical montane cloud forests* to construct a proxy record of Pacific climate variability from the terrestrial tropics.

- Takes advantage of “*isotopic seasonality*” of cloud forest hydrology for telling time AND reconstructing climate

- Doesn’t require *annual rings*
Neotropical cloud forests

Neotropical Montane Cloud Forest Locations

Source: Kappelle and Brown 2001
“isotopic seasonality”

Why Cloud Forests?
Rainfall vs. Fog Water Isotope Values

Source: Aravena et al. 1989
Theoretical Background

3 CORE ASSUMPTIONS:

[1] Oxygen isotope ratio of tree cellulose records the changes in climate and weather (seasonal and interannual),

[2] Cloud forest trees use different sources of water with distinct oxygen isotope signatures over the course of the year

[3] Sea surface temperature changes will alter atmospheric conditions and water use in cloud forests sufficiently so as to be detected in the oxygen isotope ratio of tree cellulose.
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Cloud water inputs to montane forests compensate for lack of rainfall during regional dry season.

Figure from Cavalier and Goldstein 1989
Precipitation vs. Fog Water Use in *Sequoia*-dominated ecosystems

Trees in “fog-dependent” ecosystems with wet-dry seasonality rely on cloud-water inputs during the “dry” season and precipitation during the rainy season.
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There are more dry days in the Monteverde Cloud Forest in Costa Rica when eastern Pacific Sea Surface Temperatures are higher ($p<0.05$)

Source: Pounds et al. [1999]
Relative humidity decreases during the dry season at cloud forest elevations during warm ENSO events in Central America.

Data source: Kalnay et al. [1997]
In cloud forests, seasonal source water differences should dominate the yearly isotope cycle, while at interannual frequencies, periodic changes in relative humidity related to sea surface temperature variability (including ENSO events) should control isotope ratios in tree cellulose.
Benefits from Cloud Forest Dendroclimatology

[1] Potential for long records because of lower deforestation rates, slow growth rate of trees.

[2] More reliable ENSO signature? (Doesn’t rely on circulation, not subject to proxy instability ?)

[3] Cloud forests sensitive to trends in global climate, including temperature/humidity changes as a consequence of natural or anthropogenic climate change.
The Work Ahead

[1] Age model confirmation
[2] Replication
[3] Calibration, modeling, and chronology development
[4] Integration with mature proxies for climate field reconstruction