Tropical isotope dendroclimatology in montane cloud forests

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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
- Tropical Pacific role in reorganizing atmosphere-ocean circulation on longer timescales? *(Pierrehumbert, 2000)*
- Are observed trends actually trends? Or part of multidecadal variability?

*Fig. 3. Simulated, annually averaged surface temperature (left) and precipitation (right) anomalies for the 4-year period June 1998–May 2002. Results are based on atmospheric GCMs forced with the observed, monthly varying SST and sea ice anomalies of the period. Three different models, each run in ensemble mode, were combined to yield a 50-member grand ensemble. Temperature departures are degrees Celsius computed relative to the models’ 1971–2000 climatology. Precipitation departures are mm/year computed relative to the models’ 1971–2000 climatology. The largest warm and dry departures are highlighted in red.*

*(top) Evans 2006, (bottom) Hoerling and Kumar 2003*
Why tropical trees?
Why tropical trees?

- Multicentury records
- Replication
- Potential to close paleo-observational gaps in the terrestrial tropics

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.
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Evans and Schrag [2004]
Why not tropical trees?
Why not tropical trees?

- Chronology not established in many (most) species and environments
- Species diversity a challenge to almost every stage of the process
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.

Evans and Schrag [2004]
Tropical isotope dendrochronology

A stable isotope-based approach to tropical dendroclimatology
Evans and Schrag 2004, GCA, 68, 16

“[Establish] a strategy to develop chronometric estimates in tropical trees lacking demonstrably annual ring structure, using high resolution stable isotopic measurements in tropical woods.”
Stable oxygen isotope systematics

Fig. 3.8 Schematic representation of a simplified (non-recycling) Rayleigh model applied to evaporation from the ocean and global precipitation. Water vapour originating from oceanic regions with strong evaporation moves to higher latitudes and altitudes with lower temperatures. The vapour gradually condenses to precipitation and loses H$_2^{18}$O more rapidly than H$_2^{16}$O, because of isotope fractionation, causing the remaining vapour and also the "later" precipitation to become more and more depleted in both $^{18}$O and $^2$H.

Gat et al. 2001
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Gat et al. 2001
Stable oxygen isotope systematics

An example of the amount effect from Costa Rica

Lachniet and Patterson, AGU [2004]
Stable isotope model

Roden et al. (2000) Oxygen Isotope Model

\[ \delta^{18}O_{\text{cellulose}} = f_O \cdot (\delta^{18}O_{\text{wx}} + \varepsilon_O) + (1 - f_O) \cdot (\delta^{18}O_{\text{wl}} + \varepsilon_O) \]

How much evaporation is there?

Oxygen isotope ratio of xylem water?

✓ 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).
**Chronology from trees without rings**
Paleoclimatology from trees without rings

![Diagram showing the relationship between evapotranspiration, mean, and δ¹⁸O in rainy and dry seasons.](image)

- **Evapotranspiration** increases during the rainy season and decreases during the dry season.
- **Mean** values remain relatively constant throughout the year.
- **Δ¹⁸O** in cellulose shows a difference between rainy and dry years, indicating climatic conditions.

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**Rainy season**
- Higher evapotranspiration
- Less δ¹⁸O variation

**Dry season**
- Lower evapotranspiration
- Greater δ¹⁸O variation

**Rainy year**
- Higher mean values

**Dry year**
- Lower mean values
Tropical isotope dendrochronology

Continuous flow IRMS

Oxygen isotope composition of organic matter
throughput: 150 100ug sample / day
Precision: <0.3 ‰ on standard materials
NEW: High-Temperature Generator &
‘Cold Pyrolysis’ [Evans et al. in preparation]

Thanks! Bruno Lavetre (Costech Analytical), H. Poisl (UA), A. Weimer (CU), C. Sideridis (Ferro-Ceramic), S. Dierks (ESPI Metals) …

Alpha-cellulose processing chemistry

Brendel et al. 2000, Evans and Schrag 2004,
Gaudinski et al. 2005, Anchukaitis et al. 2006 submitted
Process small samples (100 – 150 ug); Next-day cellulose
Non-toxic, easy, cheap
Faster than existing method (80-160 samples/person/day)
Reduced sample loss
Methodology

Field collection of cores and cross-sections, including sampling from monitored plantation sites, trees of known age and death date, or trees from sites with growth rate information, for calibration of the age model and climate signal.

Microtomed at very fine intervals (200 um)
Processed to alpha-cellulose
CF-IRMS, ~100ug samples
~0.3 ‰ precision on lab standards

Oxygen Isotope Time Series
Sample Replication
Calibration of age model and climate signal
Forward Modeling
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 δ¹⁸O values.


Evans and Schrag 2004
**Prosopis sp.**
Piura, Peru
*(tropical dry forest)*

- No isotopic seasonality... taprooted species, shallow water table?

- 1997-98 ENSO warm phase event: 8-10 permil anomaly?

- 1997-98 ENSO warm phase event: tripling of growth rate?

*Evans and Schrag 2004*
Moving upslope: a stable isotope approach to dendrochronology and paleoclimatology in neotropical montane cloud forests
Why use cloud forest trees for dendroclimatology?

Soil moisture available in all months, stable temperature and day length = no reason to stop growth? **Consistently resolve annual isotope cycle to establish chronology.**

Shallow rooted trees = minimal lag between rainfall and water uptake, minimal buffering of climate signal by stored soil or ground water, **trees respond quickly to change in climate and annual cycle.**

**Broad-scale surface air and sea surface temperature changes** may alter cloud cover and influence annual oxygen isotope cycles

Importance for local, regional water cycle
"isotopic seasonality"

Why Cloud Forests?
Rainfall vs. Fog Water Isotope Values

Source: Aravena et al. 1989
Trees in “fog-dependent” ecosystems with wet-dry seasonality rely on cloud-water inputs during the “dry” season and precipitation during the rainy season.
Annual cycle from difference in precipitation and cloud $\delta^{18}$O and possibly changes in relative humidity

Interannual variability from changes in precipitation and relative humidity driven by surface and sea surface temperature influences on cloud base height
Pilot Study Results
*Ocotea tenera*
Monteverde, Costa Rica

Plantation and wild monitored *Ocotea tenera* (Lauraceae) with annual or interannual diameter measurements and for trees of known age

Trostles (lower) and Hoges (upper) sites

*O. tenera* phenology and growth
*Wheelwright et al. 2005, PNAS*
Wettest Dry Season
Driest Wet Season
Particularly Wet Rainy Season (verification)
Dry-Wet-Dry Sequence, Potential for Crossdating (identify missing years)

Anchukaitis et al., 2006
Age modeling and crossdating

Similar to tree-rings, overall patterns are similar but not identical – age model error, site and individual differences, analytical error and precisions?

Anchukaitis et al., 2006, in preparation
**crossdating**

*Annual features* matching peak and trough (maxima and minima) amplitudes

*Intra- and Interannual variability* due to common climate forcing, precipitation and relative humidity changes

Missing ring detection possible with replicated overlapping cores, but its more difficult than traditional dendrochronology!

Juvenile effect?
Process modeling of isotopic records

- Oxygen isotopic composition of α-cellulose (e.g. Barbour et al., 2004 and many others):

\[ \Delta_{CX} = \Delta_L (1-p_{EX} p_X) + \varepsilon_o \text{ [relative to } \delta^{18}O_{WS}] \]

- Parameterizations:
  - \( \delta^{18}O_{WX}(P) = \delta^{18}O_{WS}(P) \) [Lachniet and Patterson, 2005]
  - \( T_L = f(T_A) \) [Linacre, 1964]
  - \( \delta^{18}O_{WV} = f(T_A, T_C, \delta^{18}O_{WS}(P)) \) [Gonfiantini, 2000; Majoube, 1971]

- Two component soil water-precipitation mixing model

- Drive Barbour et al. (2004) model (\( P, T, RH \) from Campbell data set and Guswa RH calibration) for \( \delta^{18}O_{CX} \) & compare to observations
Process modeling of isotopic records

- Monthly **precipitation** and **temperature** data from daily Campbell dataset (Pounds et al., 1999)

- **Relative humidity** from multiple linear regression of RH on daily maximum temperature and total precipitation data for 2005 and 2006 (Guswa et al. 2006) ($R^2 = 0.48$); mean & variance adjustment.

- Monte Carlo (20% parameter variance, 1000 random draws)

- Variance-scaling vs. simple soil water model (‘leaky bucket’)?

- Mean state simulations vs. observed for sensitivity analysis with precipitation, temperature, and relative humidity

*Evans 2006, in review, Anchukaitis et al. 2006, in preparation*
Process modeling of isotopic records

Anchukaitis et al., 2006 in preparation
Wettest Dry Season (2000)
Driest Wet Season (1997)
Particularly Wet Rainy Season (1998)
Dry-Wet-Dry Sequence, Potential for Crossdating (1987 – 1989?)
Interannual Pattern (1998,1999)
Problems?

Anchukaitis et al., 2006, in preparation
Pilot Study Results – Progress and Problems

Age model confirmation – one cycle of 5-9 ‰ is equal to a single year of growth

Local minima appear to correspond to wet/dry rainy seasons as predicted by conceptual and process model

Local maxima in some cases correspond to anomalous dry seasons, but the signal maybe be more complicated – role of soil dampening?

Crossdating difficulty – identifying ‘missing’ years difficult, even with replicated series. There will always be age model error (more like corals, ice cores, or speleothems than tree-rings!), challenge to direct statistical calibration with meteorological data

Sufficiency of the forward model at this site – accounting for influence of fog, accuracy of meteorological data, robustness of relative humidity estimates; perhaps as large as 1‰ difference as a function temperature or relative humidity
Searching for the longer climate signal
Monteverde, Costa Rica

Salvage collection (cross sections and cores) from canopy trees

*Quercus, Sideroxylon, Pouteria, Pseudolomedia,* among others

Elevation transect from below cloud base to continental divide
MV05 *Quercus insignis*

- Cycles small (~3 ‰) and inconsistent
- Not continuous growth? Access to stream or groundwater?
- Site too cloudy?
- Growth too rapid?
Annual cycles of up to 5-6 ‰, potential for ~70 year record
MV12
Sideroxylon capiri
(Tempisque)

Annual cycles of 4+ ‰

Known death date, large tree collected from near Campbell weather station

Potential for 50+ year record?
What’s next?

- Crossdating and chronology development
- Complete ‘wild’ tree analyses
- Radiocarbon verification of age model in ‘wild’ trees
- Robust climate calibration
- Local and regional (?) paleoclimate reconstruction
Summary and Future Directions

• Annual isotope chronology identified and verified across a range of species and tropical environments
• Evidence of climate, precipitation paleoclimate signal

Next steps in tropical isotope dendroclimatology will benefit from:

• Exploitation of forward proxy models to improve data calibration, interpretation, and error analysis.
• Community efforts to build (and build upon) observational networks.
Observational network

- Indonesia, SE Asia (Poussart, Schrag, Gagen)
- Brazil (Saleska)
- Costa Rica (Anchukaitis, Evans)
- Panama (Westbrook)
- South India (Martinez)
- Peru/Ecuador (Evans)
- East Australia
- East Africa
**Cordia sp.**

Liberia, Costa Rica
(*tropical dry forest*)

- 33 – 40 cycles, 700 isotope measurements; 3 – 5‰ cycles consistent with IAEA rainfall measurements.
- May – December growth
- Modeled growth rates (mean = 9.5 mm/yr) consistent with measured tree-growth rates from same region
- Some coherency between ENSO years with rainfall anomalies and low $\delta^{18}O$ cellulose years, with given age model, but not perfect (But “ENSO signal” in rainfall isn’t perfect either …)
Results: Amazon Rain Forest *Erisma uncinatum*

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