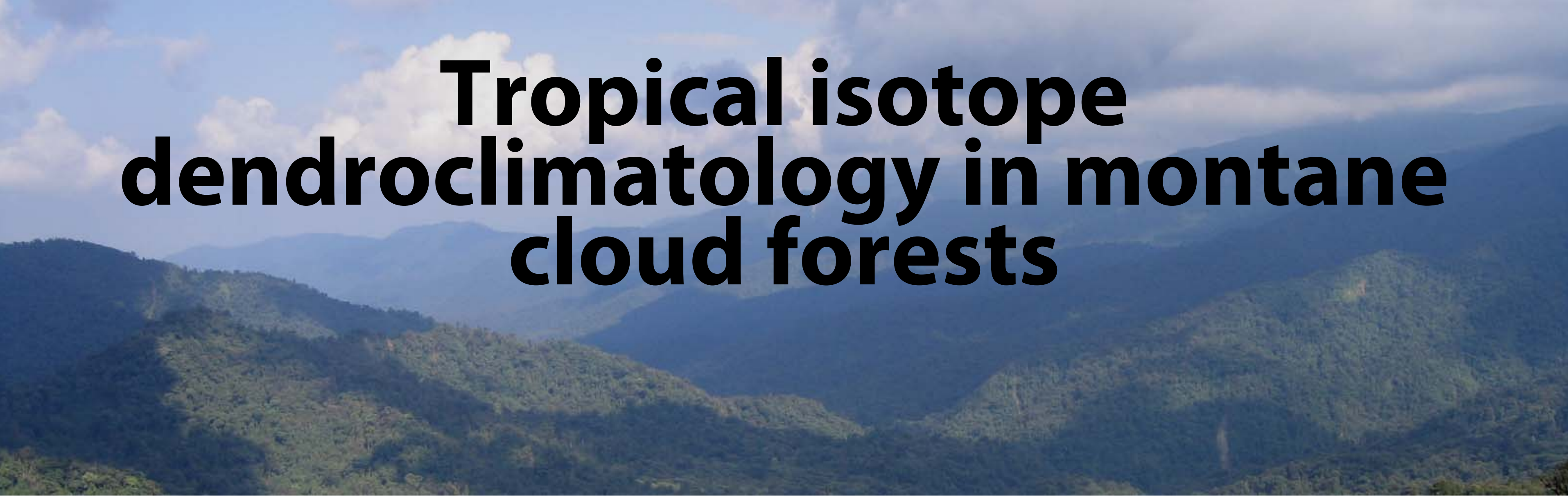

Tropical isotope dendroclimatology in montane cloud forests

Kevin J. Anchukaitis[1], Michael N. Evans[1], Nathaniel T. Wheelwright[2]
and Daniel P. Schrag[3]

[1] University of Arizona, Laboratory of Tree-Ring Research, Department of Geosciences
[2] Bowdoin College, Department of Biology
[3] Harvard University, Department of Earth and Planetary Sciences

Acknowledgements & Collaborators

J. Buchanan (Physics & Math, Arizona), **G. Eischeid** (Harvard EPS), **MC Foo** (MCE, Arizona), **F. Joyce** (Monteverde), **A. Pounds** (TSC Monteverde), **P.F. Poussart** (Princeton, WHOI), **R. Rodriguez** (Monteverde), **R. Adams** (LTRR Arizona), **B. Muhlenkamp** (Geosciences, Arizona), **D. Smith** (Chemistry, Arizona), **T. Lange** (AMS, Arizona), **C. Jones** (Hydrology Arizona), **R. Rodriguez** (Piura, Peru), **S. Leavitt** (LTRR Arizona), **J Betancourt** (USGS, Arizona), **M. Hughes** (LTRR, Arizona), and **T. Dawson** (Berkeley)

J. Gaffney (DOE, ANL), **M. Constantin** (DOE, ORAU), and **M. Kinney** (DOE, ORAU)

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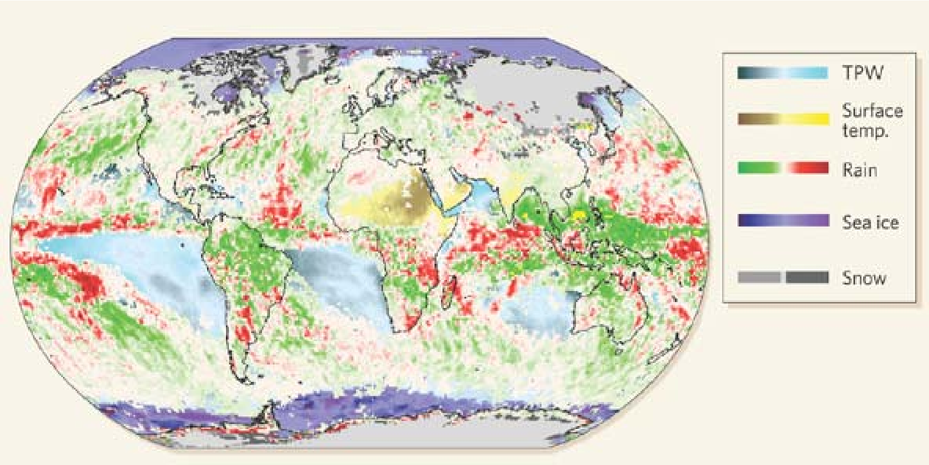
Do The Tropics Rule?

(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?

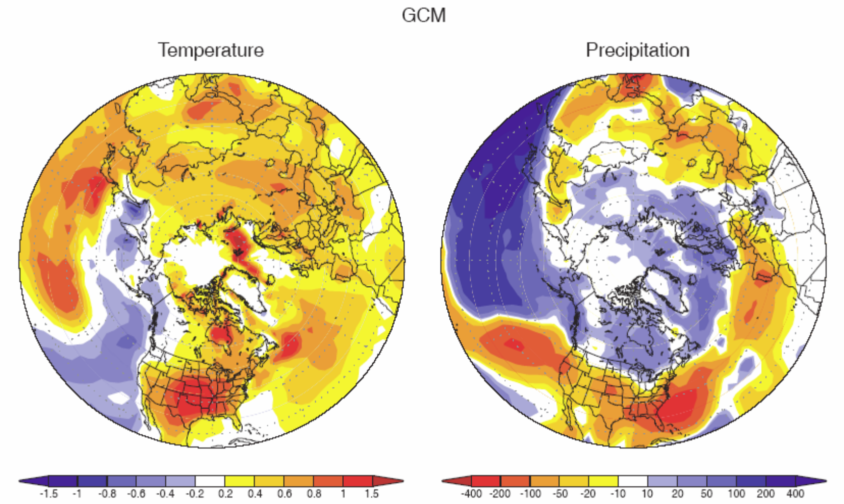


Fig. 3. Simulated, annually averaged surface temperature (**left**) and precipitation (**right**) anomalies for the 4-year period June 1998–May 2002. Results are based on atmospheric GSMs forced with the observed, monthly varying SST and sea ice anomalies of the period. Three different models, each run 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?

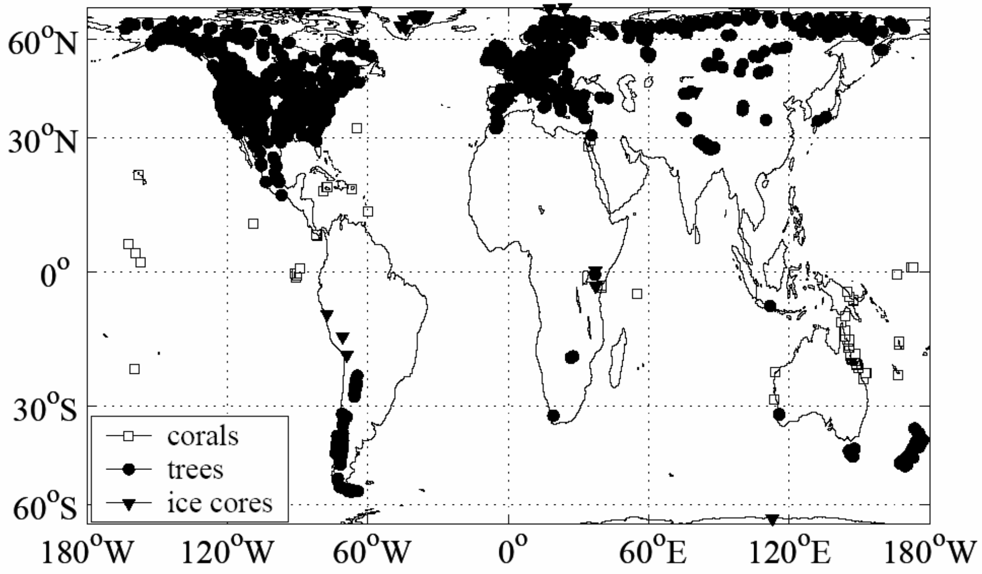
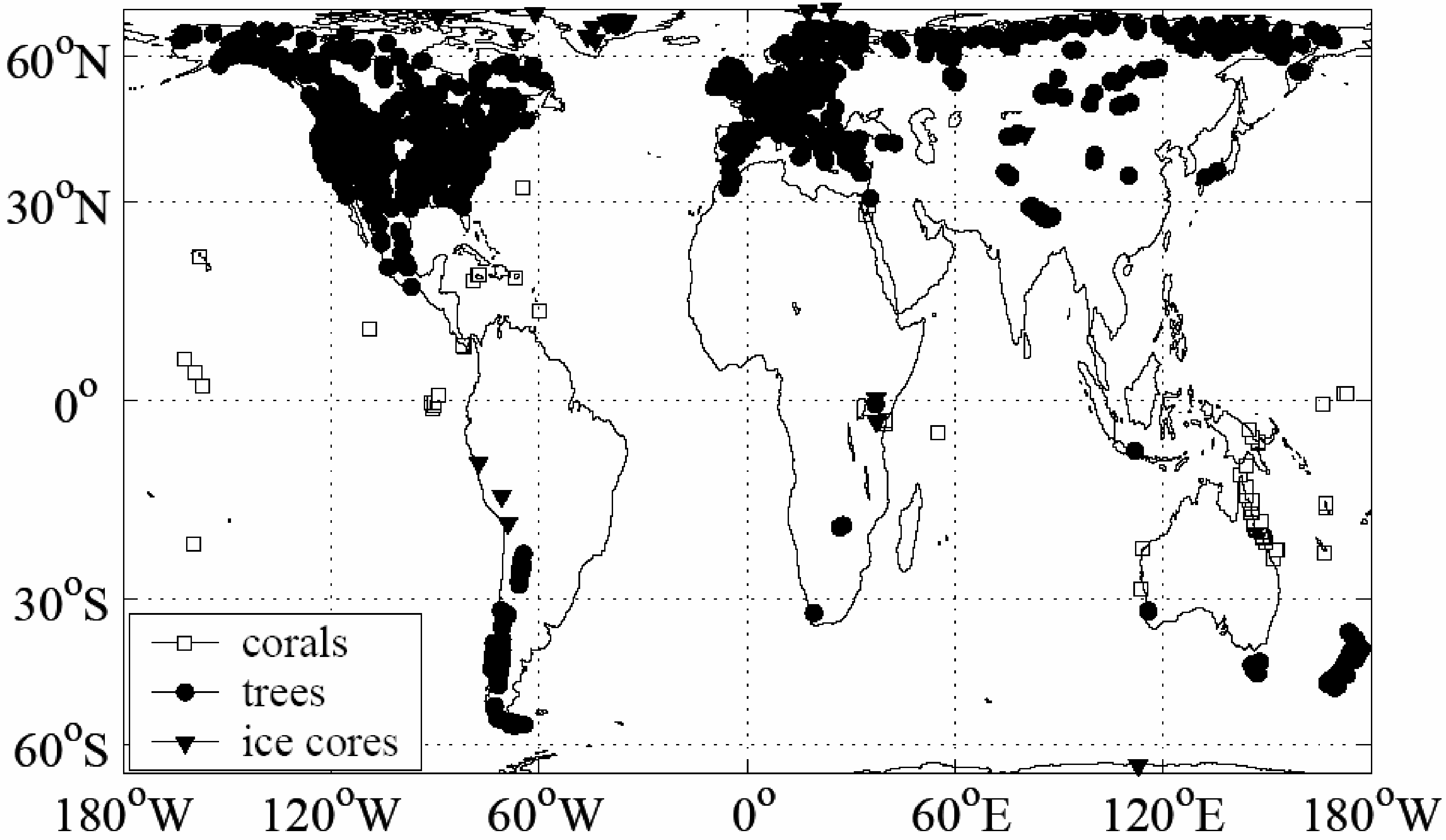


Fig. 1. Equal-area map of locations of high resolution coral and tree-ring paleoclimate data currently in the NGDC World Data Center-A for Paleoclimatology electronic database (http://www.ngdc.noaa.gov/paleo/). Plots as of June 2003.

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



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Evans and Schrag [2004]

Why not tropical trees?

Why not tropical trees?

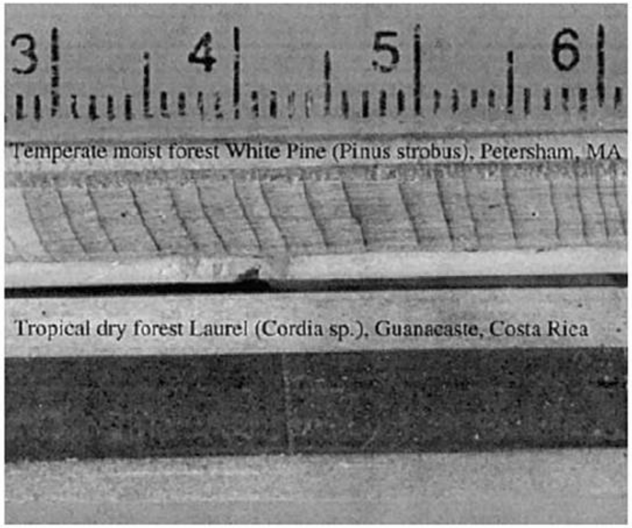
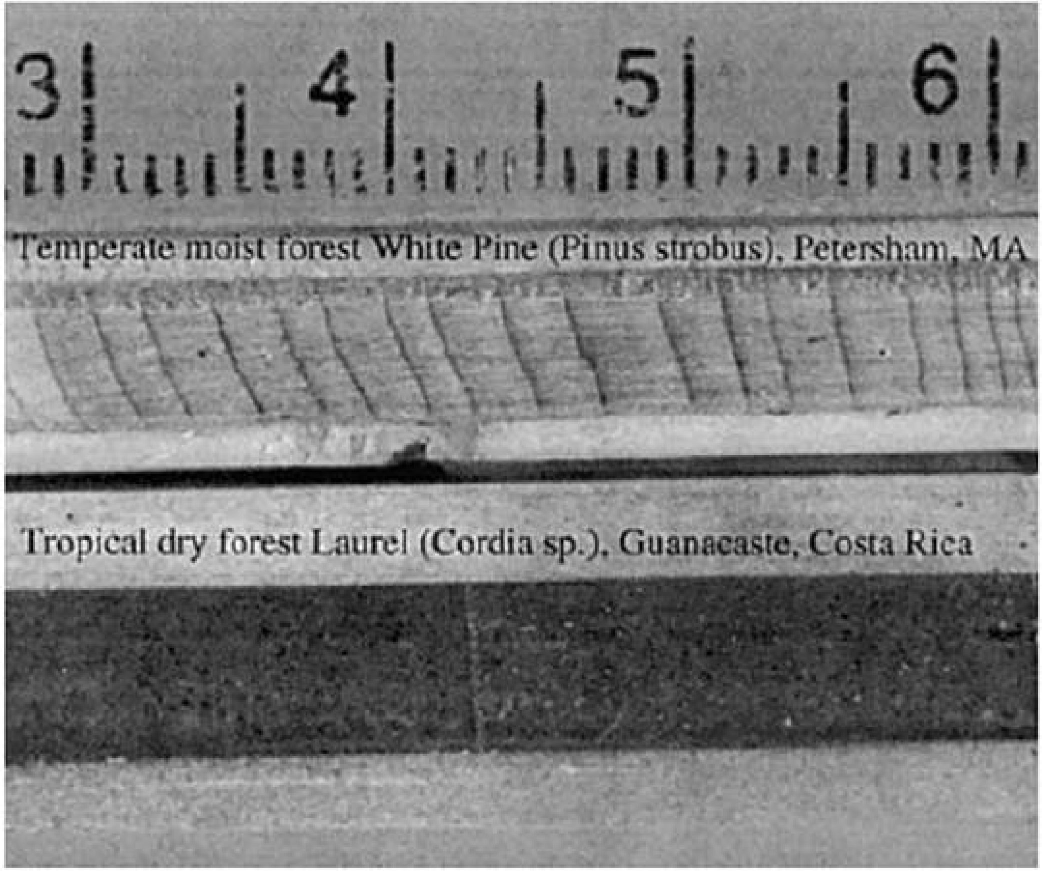


Fig. 2. Photographs of 5 mm-diameter increment core sections taken from extratropical and tropical tree species. Top: Harvard Forest (Petersham, MA, USA) Pinus strobus (White Pine). Bottom: Costa Rican dry forest Cordia sp. (Laurel). The scale is in centimeters. Both cores are mounted onto blond wood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

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



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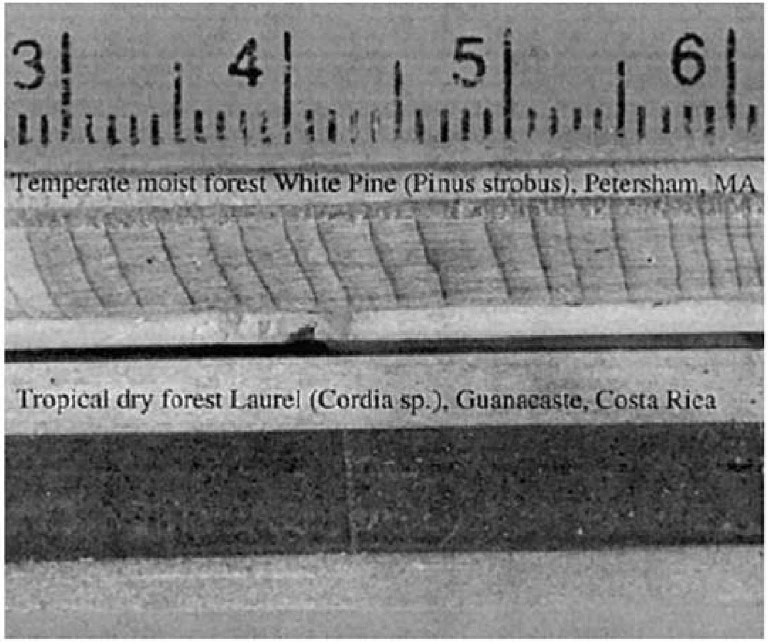
Evans and Schrag [2004]

Tropical isotope dendrochronology



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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

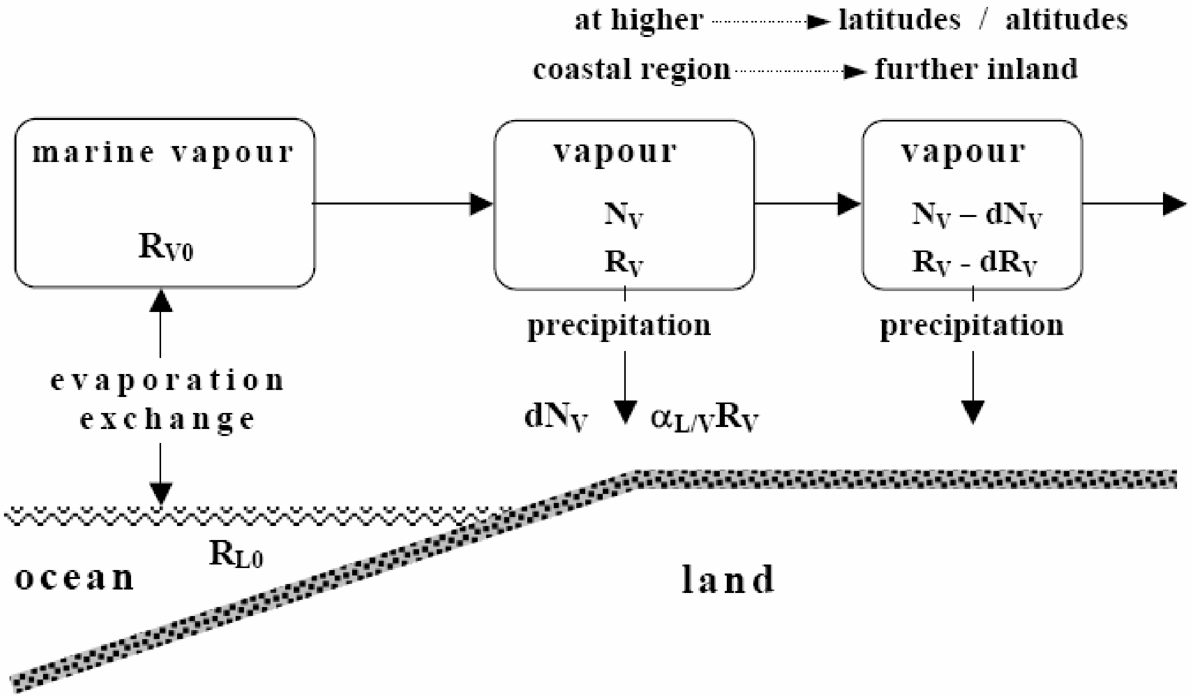
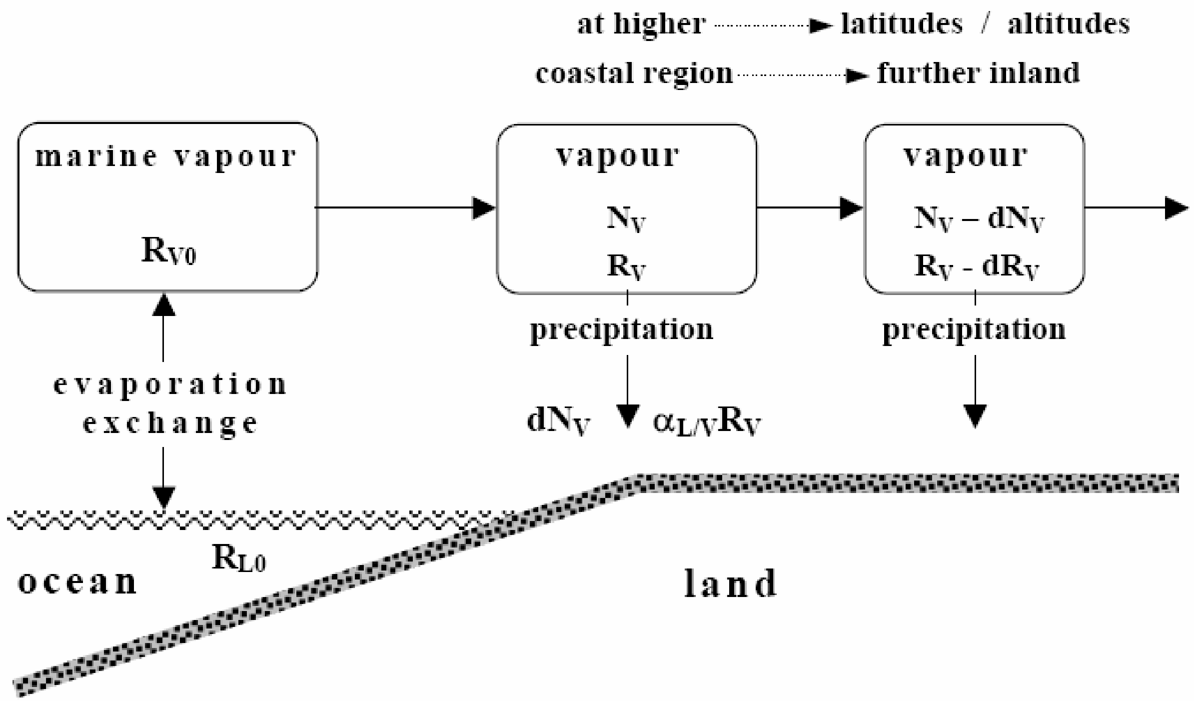


Fig.3.8 Schematic representation of a simplified (non-recycling) Rayleigh model applied to evaporation from the ocean and global precipitation. Water vapour originating from oceanic regions with strong evaporation moves to higher latitudes and altitudes with lower temperatures. The vapour gradually condenses 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 ^2H.

Gat et al. 2001

Stable oxygen isotope systematics

- rain **+ rain** **'Amount Effect'**



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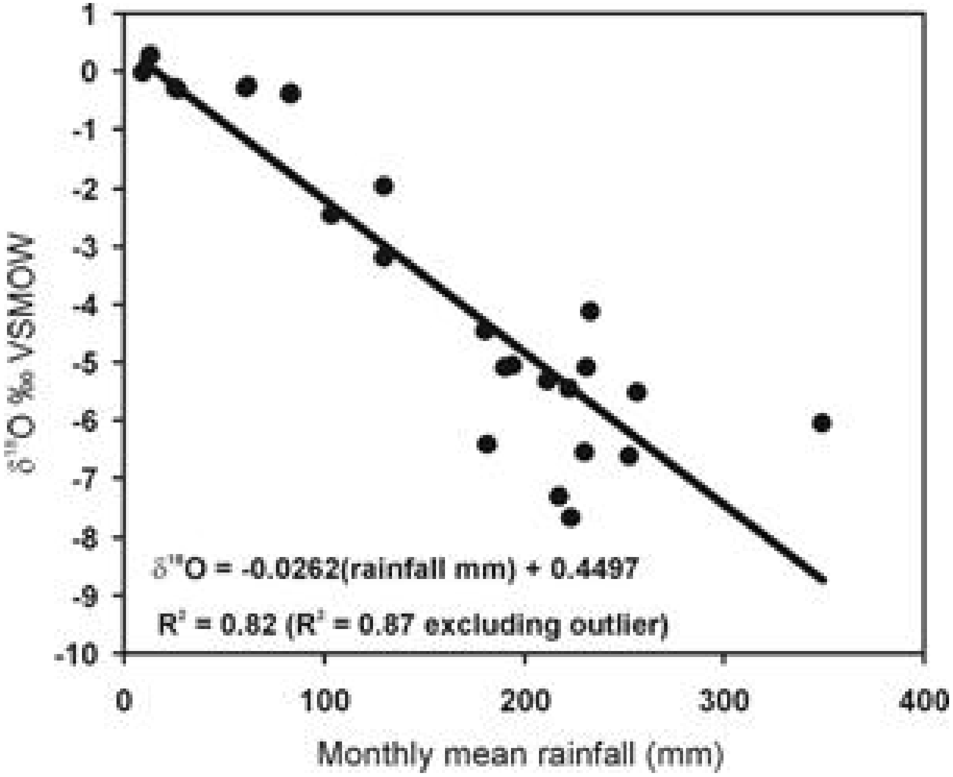
Stable oxygen isotope systematics

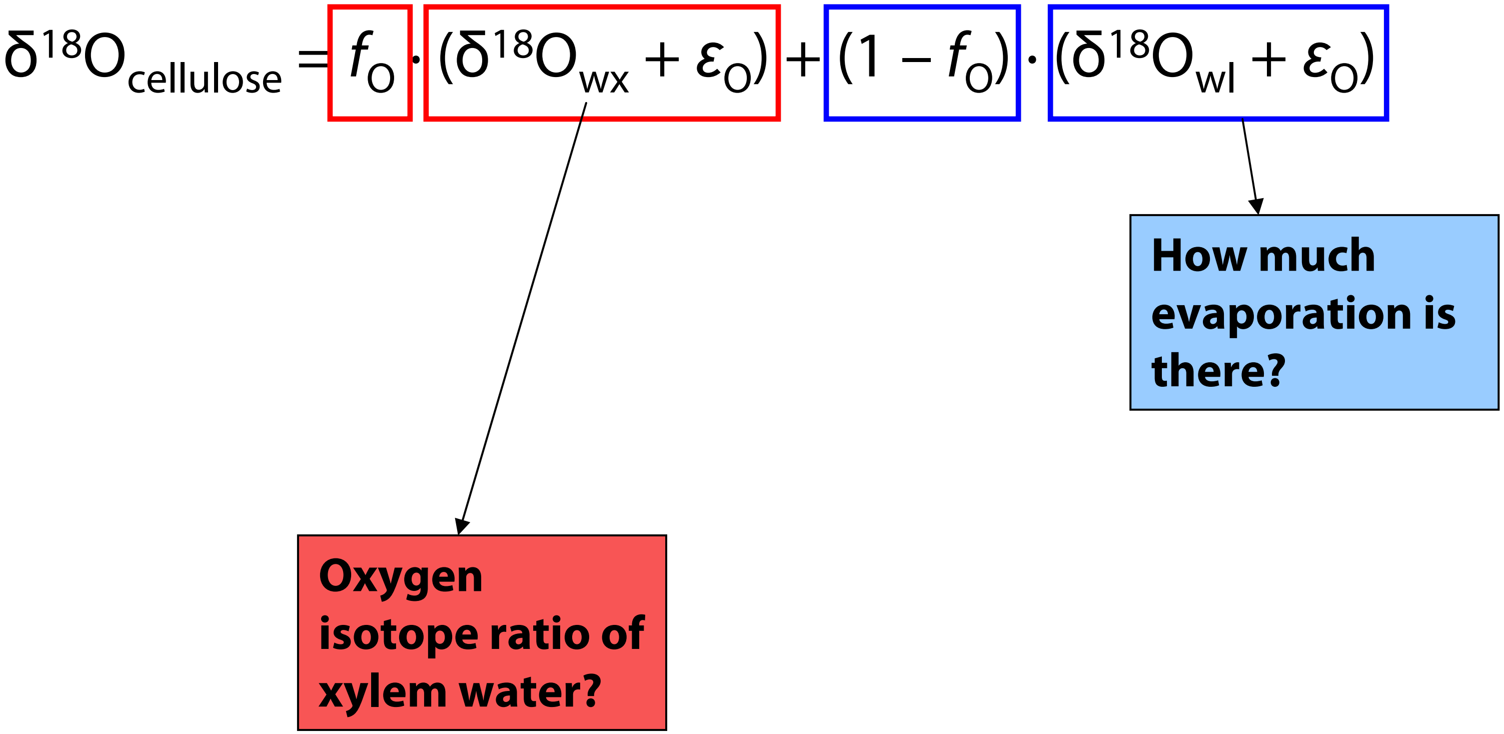


An example of the amount effect from Costa Rica

Lachniet and Patterson, AGU [2004]

Stable isotope model

Roden *et al.* (*2000*) Oxygen Isotope Model



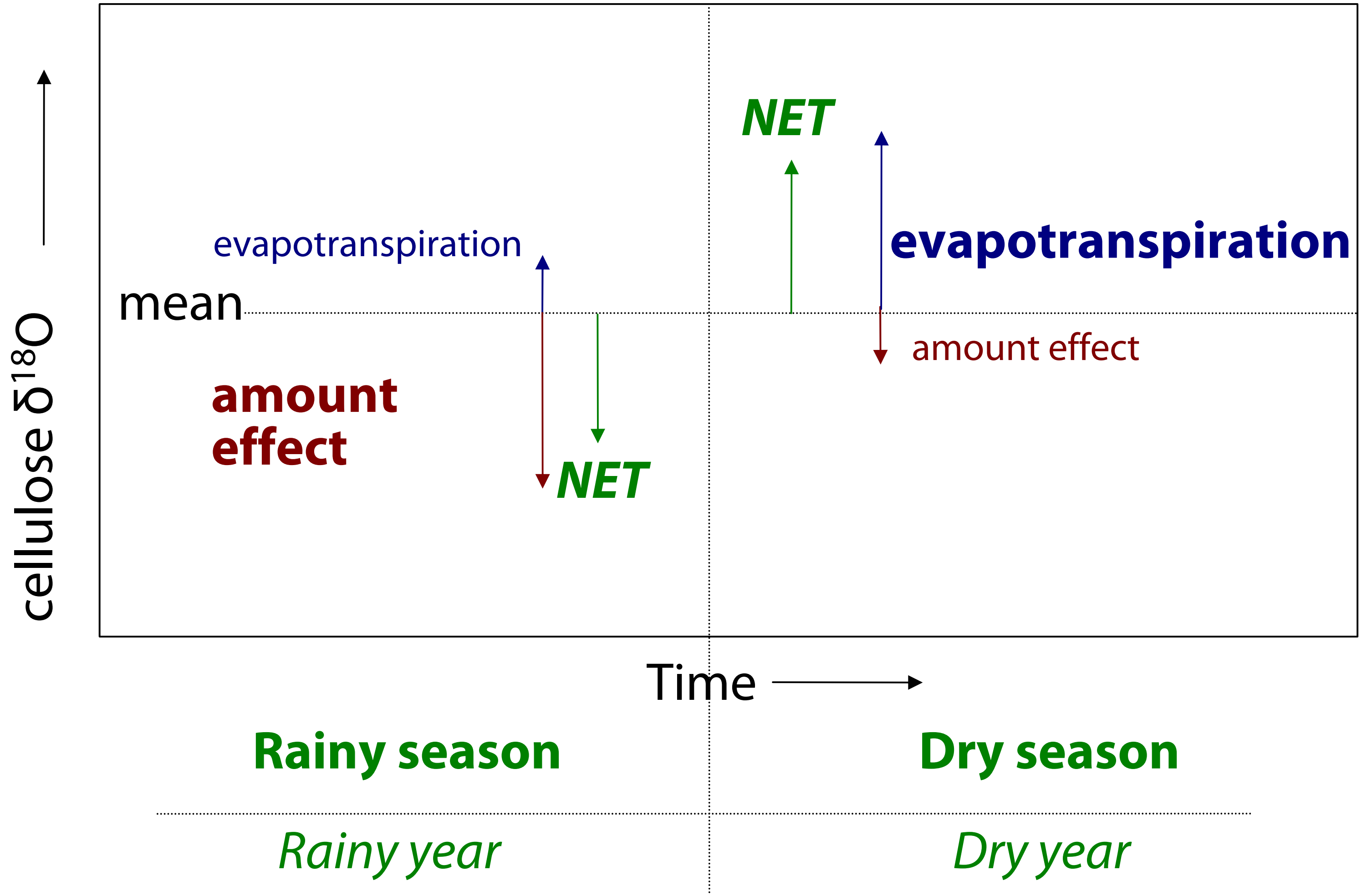
$$\delta^{18}O_{cellulose} = \boxed{f_O} \cdot \boxed{(\delta^{18}O_{wx} + \varepsilon_O)} + \boxed{(1 - f_O)} \cdot \boxed{(\delta^{18}O_{wl} + \varepsilon_O)}$$

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



cellulose $\delta^{18}O$

mean

evapotranspiration

amount effect

NET

NET

evapotranspiration

amount effect

Time

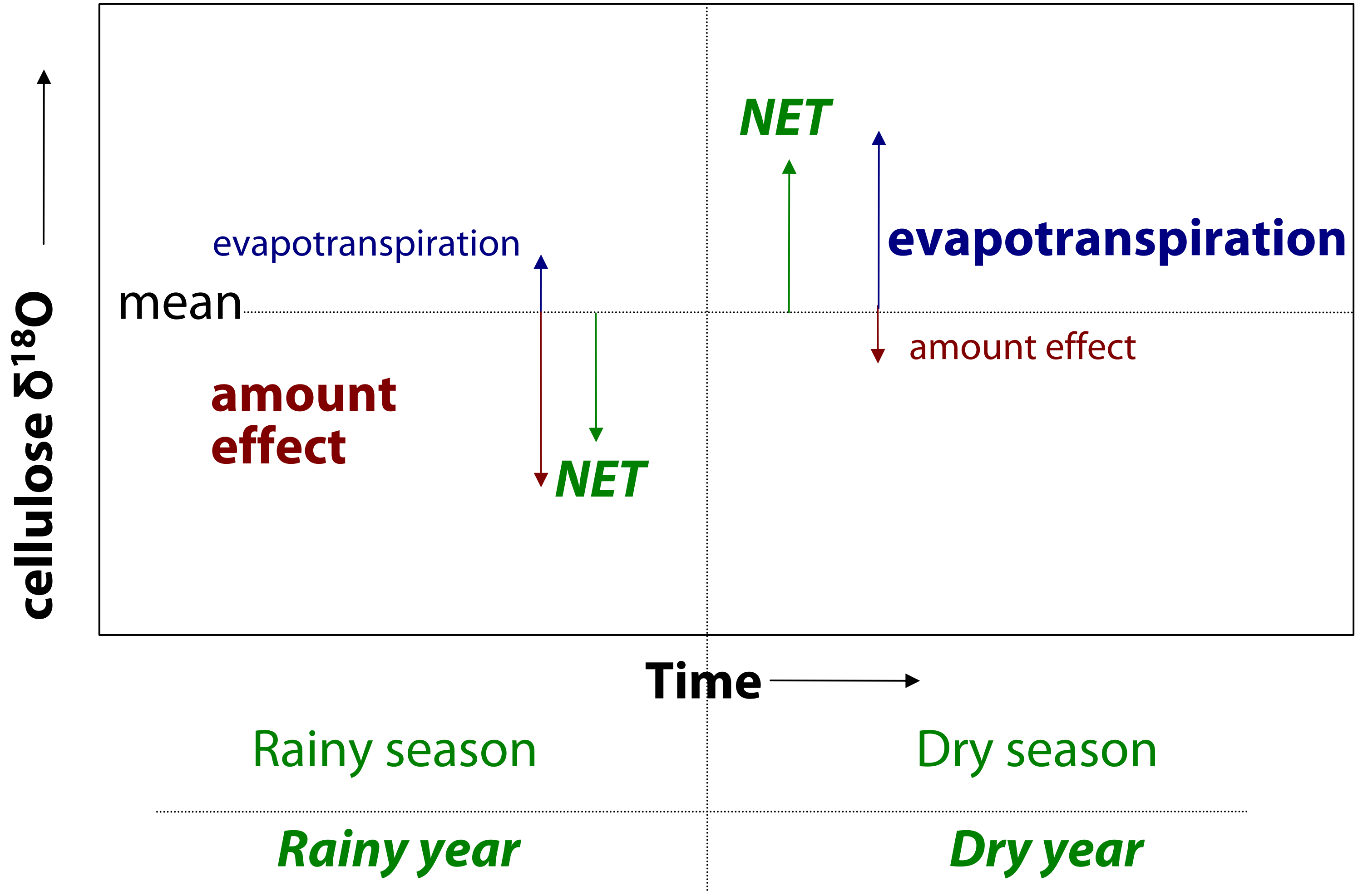
Rainy season

Dry season

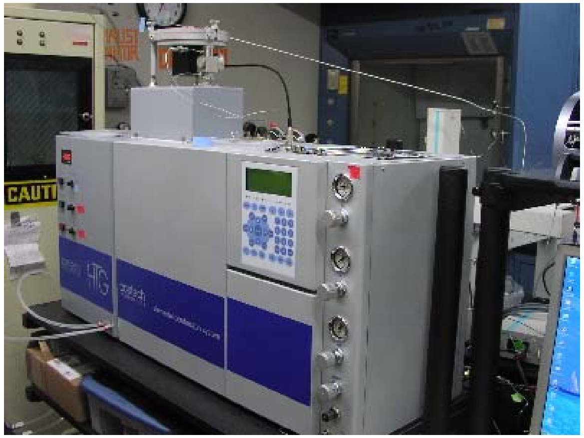
Rainy year

Dry year

Paleoclimatology from trees without rings



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 Lavettre (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 *u*g); Next-day cellulose

Non-toxic, easy, cheap

Faster than existing method (80-160 samples/person/day)

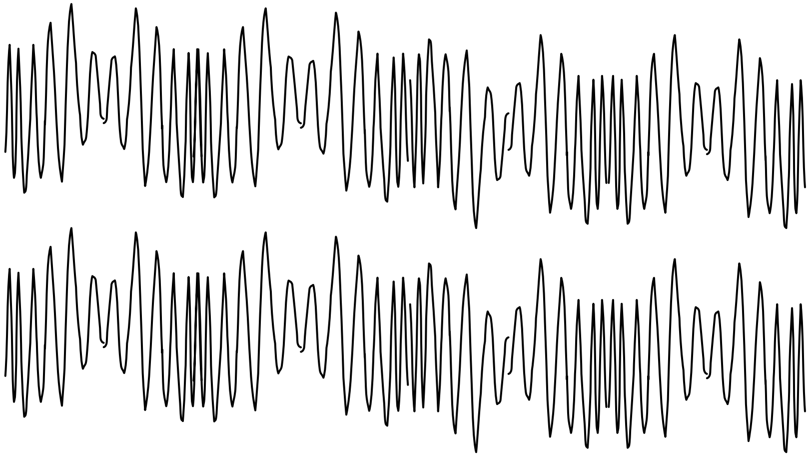
Reduced sample loss

Evans and Schrag 2004, Anchukaitis et al 2006, submitted, Evans et al. 2006, in preparation

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

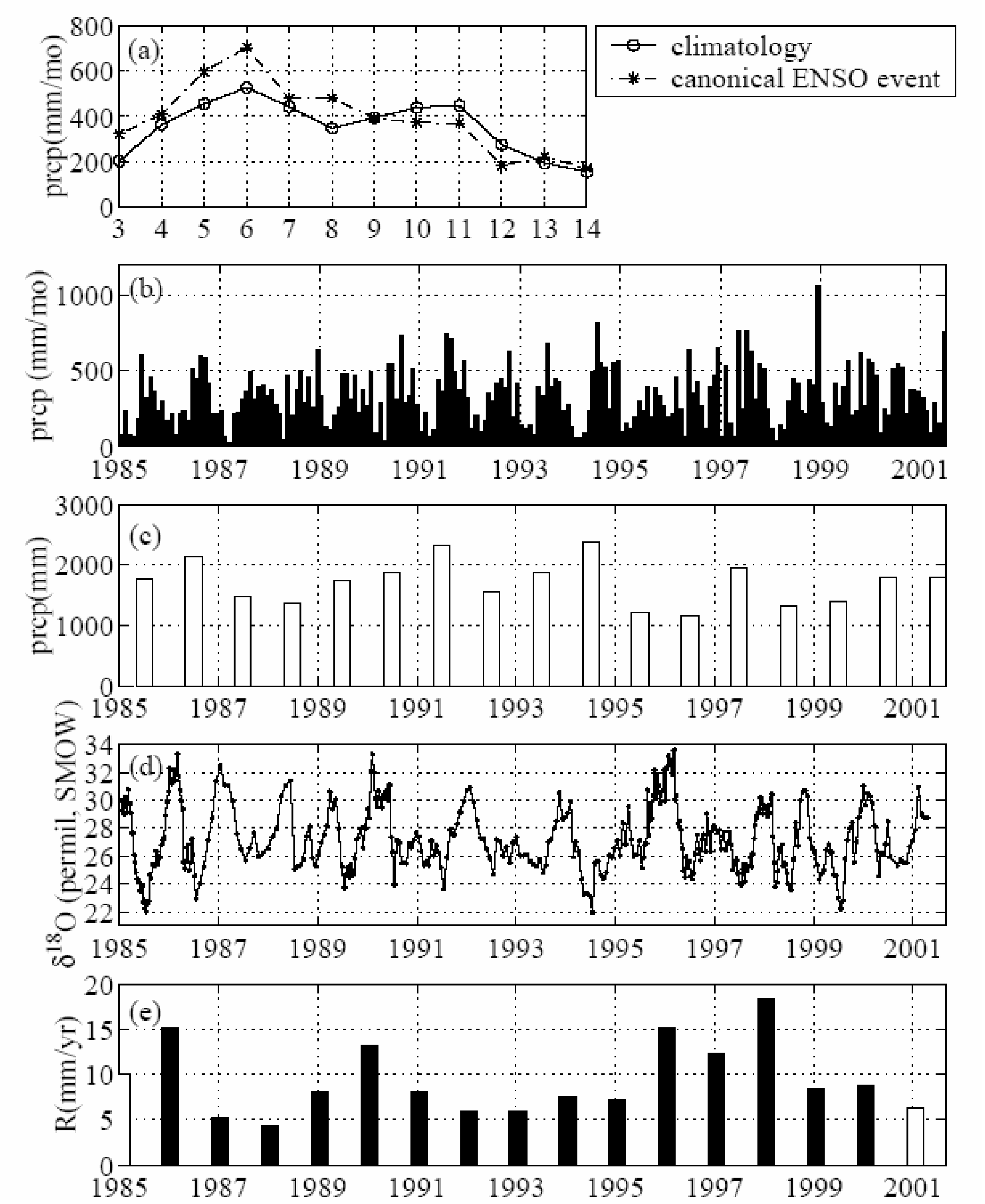


CF-IRMS, ~100ug samples
~0.3 ‰ precision on lab standards

Oxygen Isotope Time Series

Sample Replication

Calibration of age model and climate signal
Forward Modeling



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 δ^{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 δ^{18}O values, and is consistent with a rainy dry season in winter 1990-1991.

Prosopis sp.

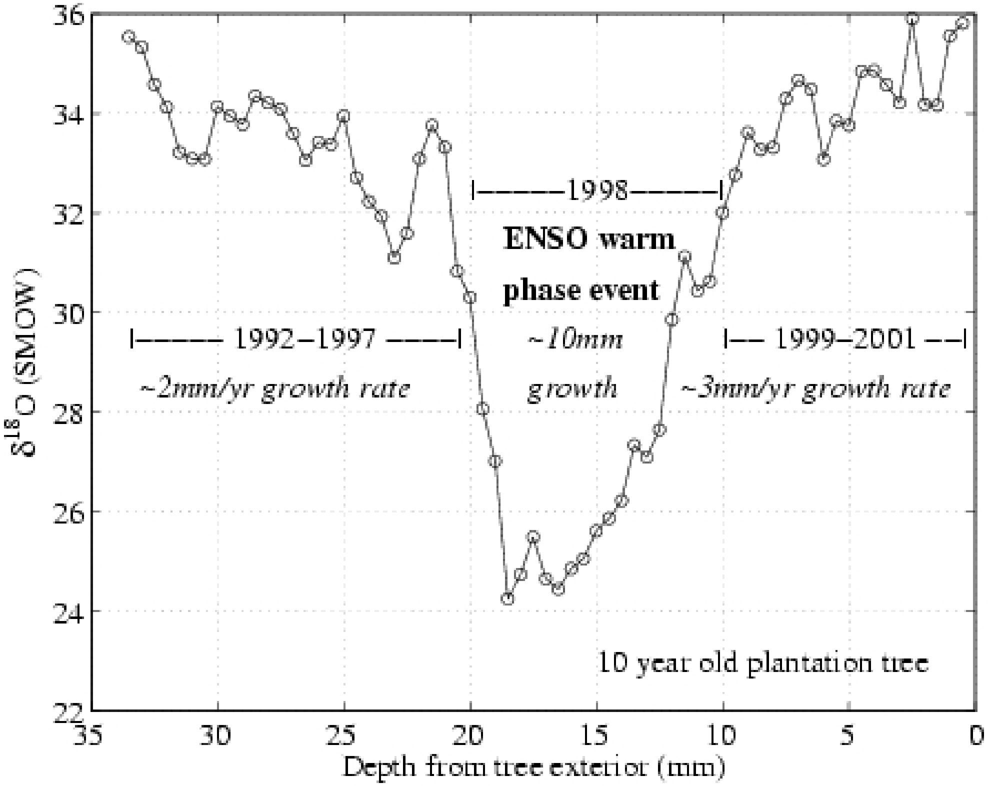
Piura, Peru

(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.**

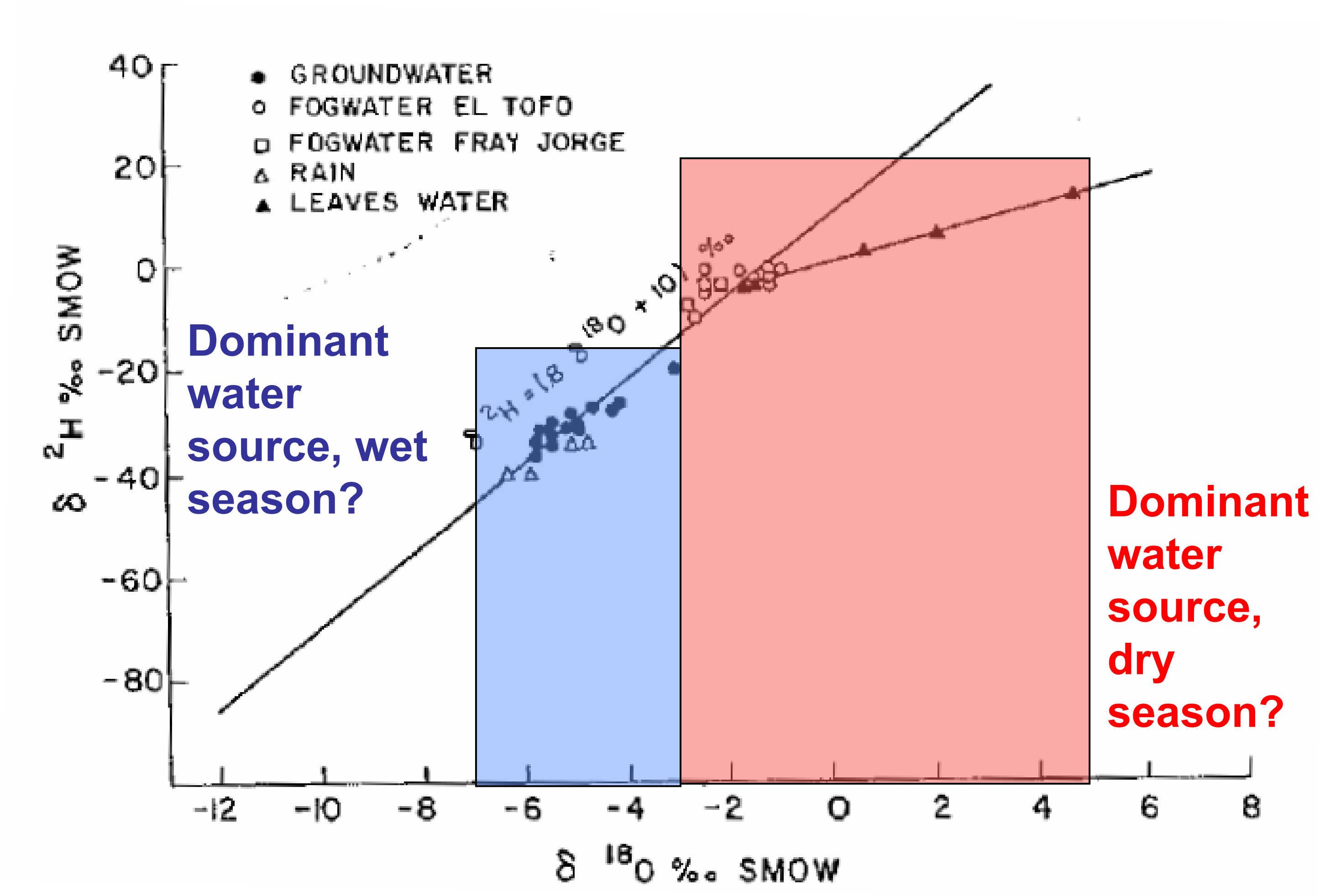
Shallow rooted trees = minimal lag between rainfall and water uptake, minimal buffering of climate signal by stored soil or ground water, **trees respond quickly to change in climate and annual cycle.**

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



Dominant water source, wet season?

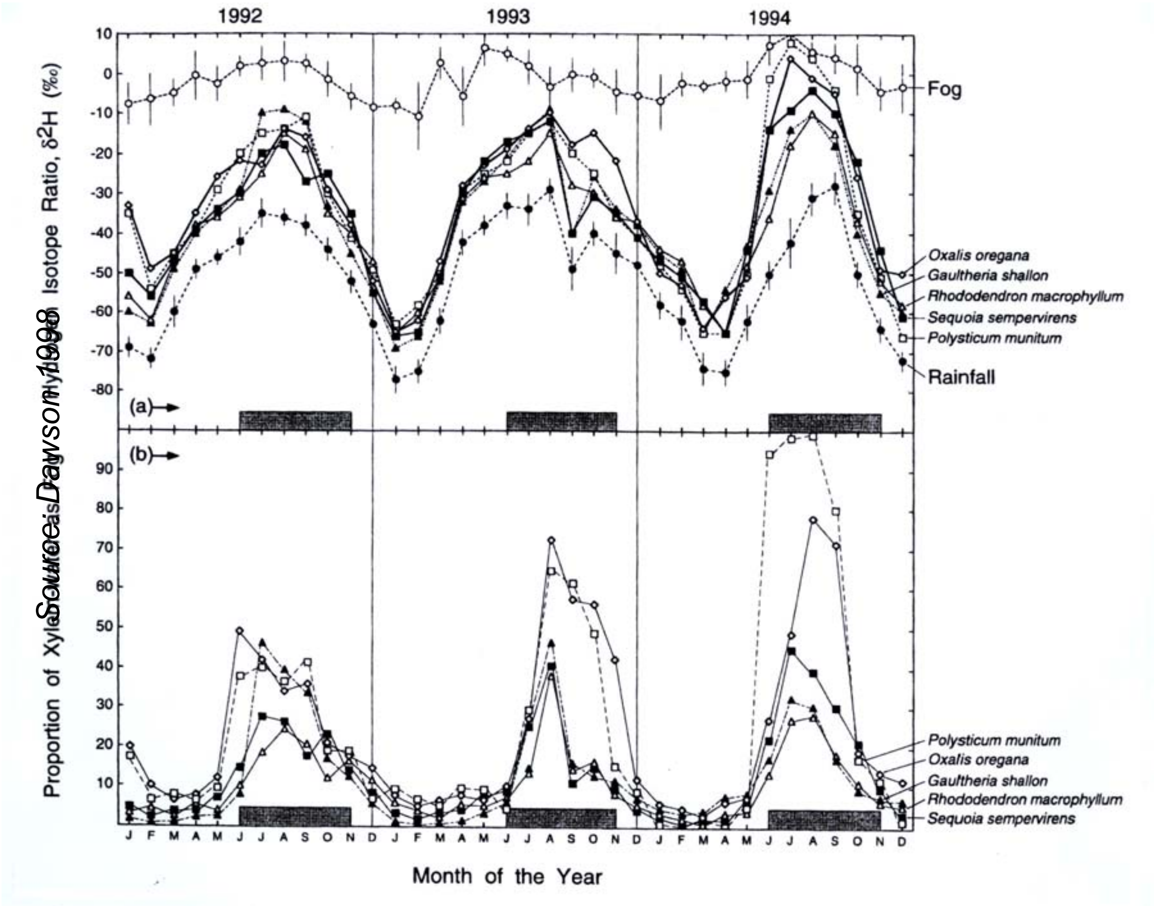
Dominant water source, dry season?

Source: Aravena et al. 1989

tree-water relationships

Dawson [1998]

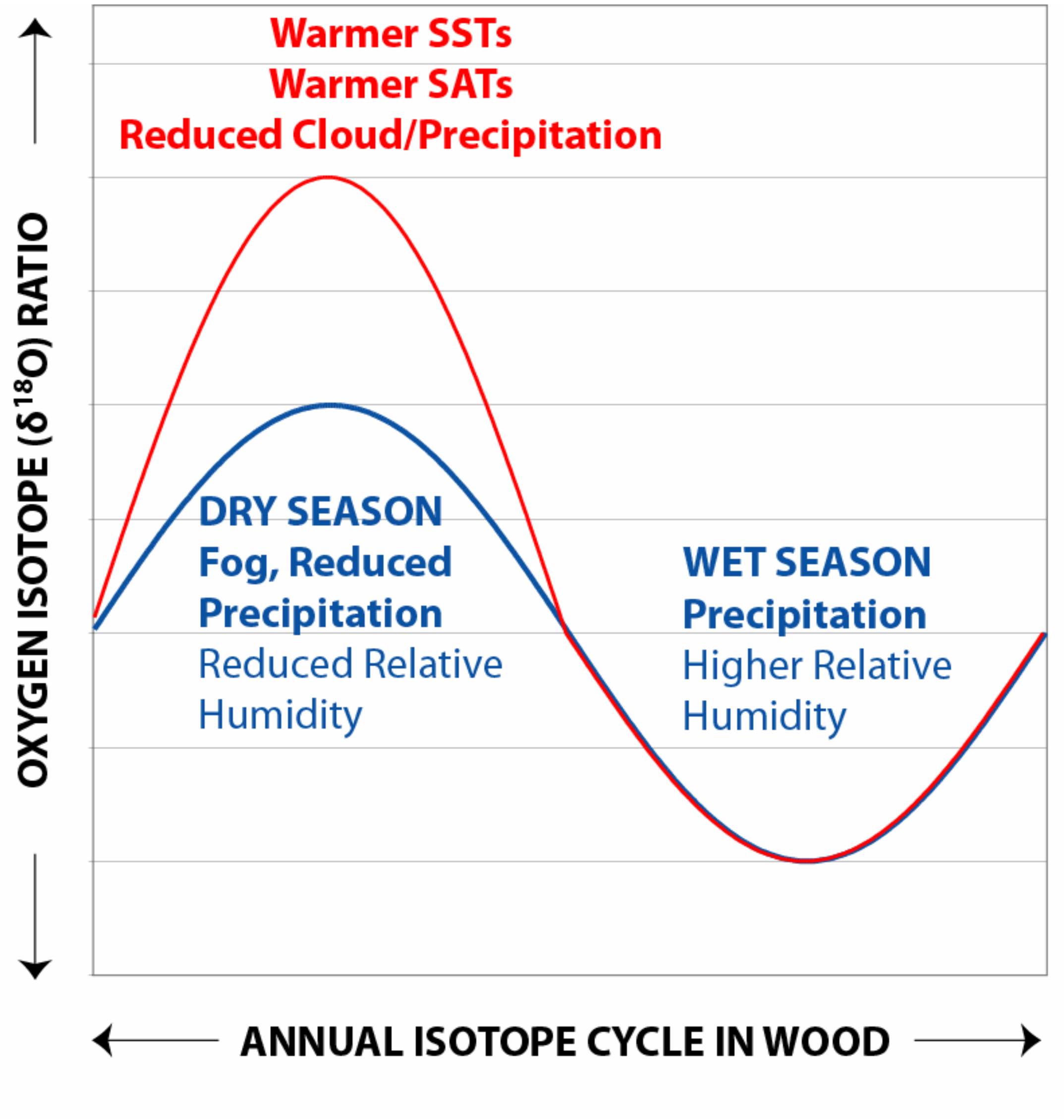
Precipitation vs. Fog Water Use in
Sequoia-dominated ecosystems



Source: Dawson 1998

✓ Trees in “fog-dependent” ecosystems with wet-dry seasonality rely on cloud-water inputs during the “dry” season and precipitation during the rainy season.

conceptual model



Annual cycle from difference in precipitation and cloud δ^{18}O and possibly changes in relative humidity

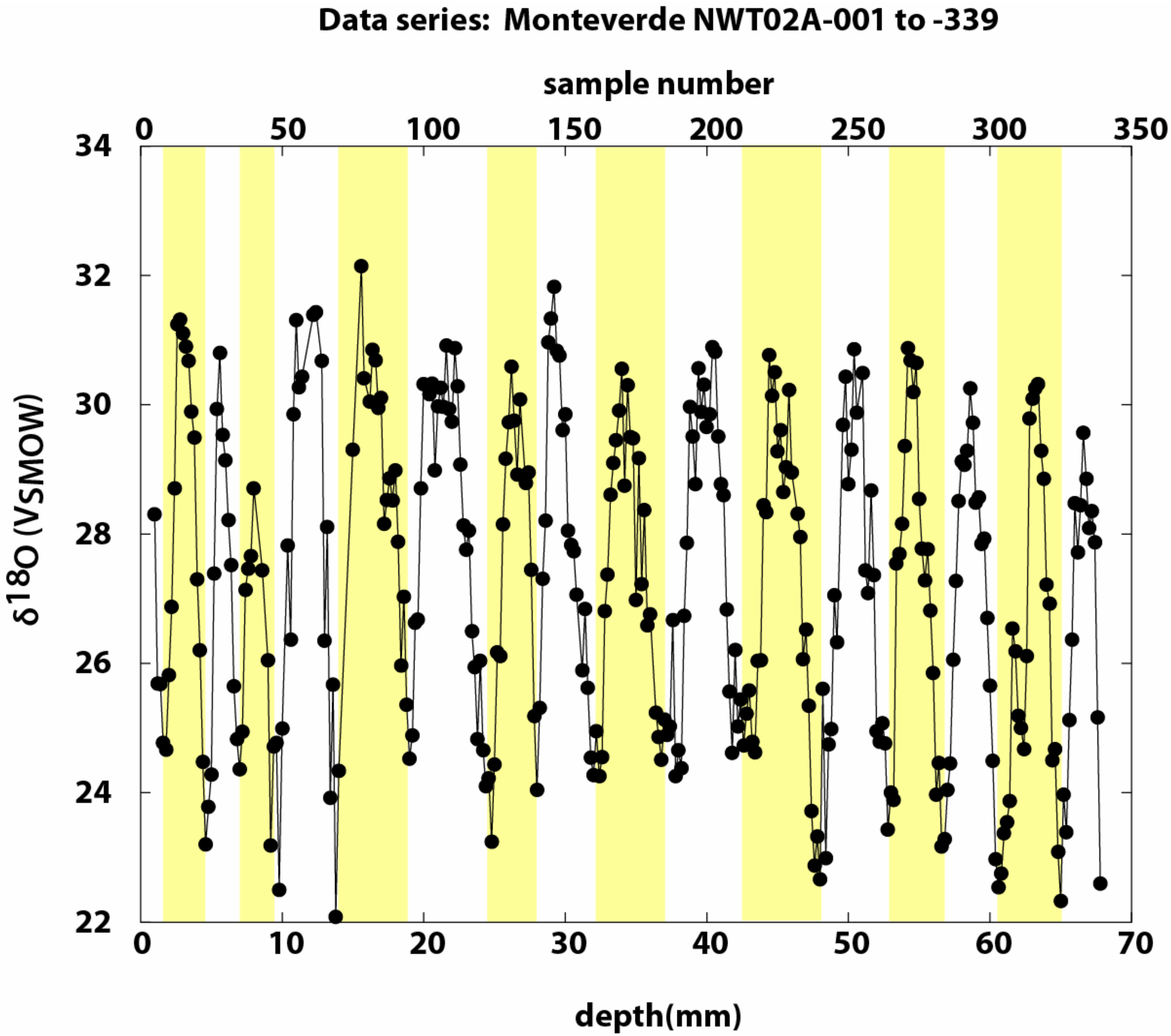
Interannual variability from changes in precipitation and relative humidity driven by surface and sea surface temperature influences on cloud base height

Pilot Study Results
Ocotea tenera
Monteverde, Costa Rica

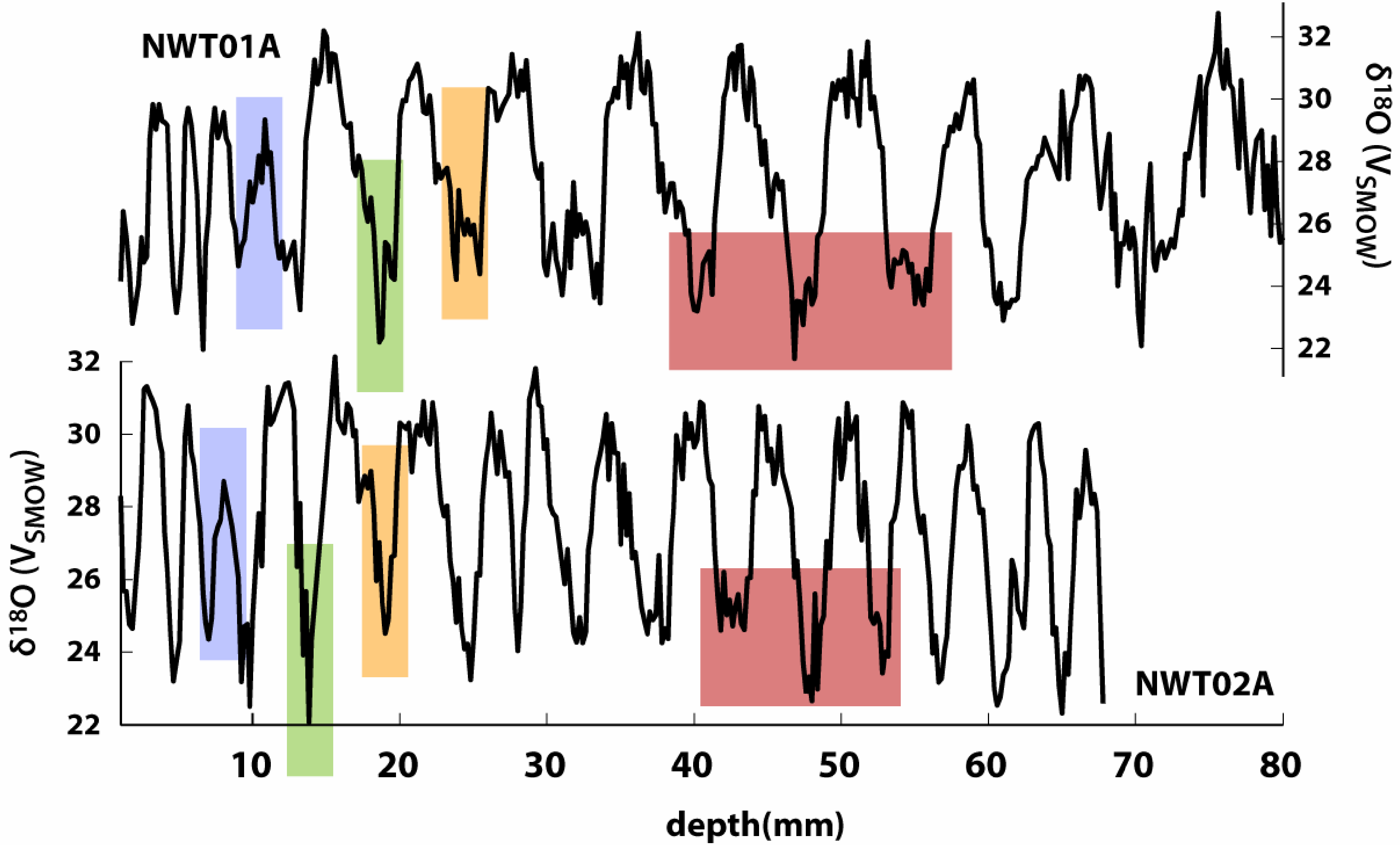
Plantation and wild monitored *Ocotea tenera* (Lauraceae) with annual or interannual diameter measurements and for trees of known age

Trostles (lower) and Hoges (upper) sites

O. tenera phenology and growth
Wheelwright et al. 2005, PNAS



Anchukaitis et al. AGU, 2005



Wettest Dry Season

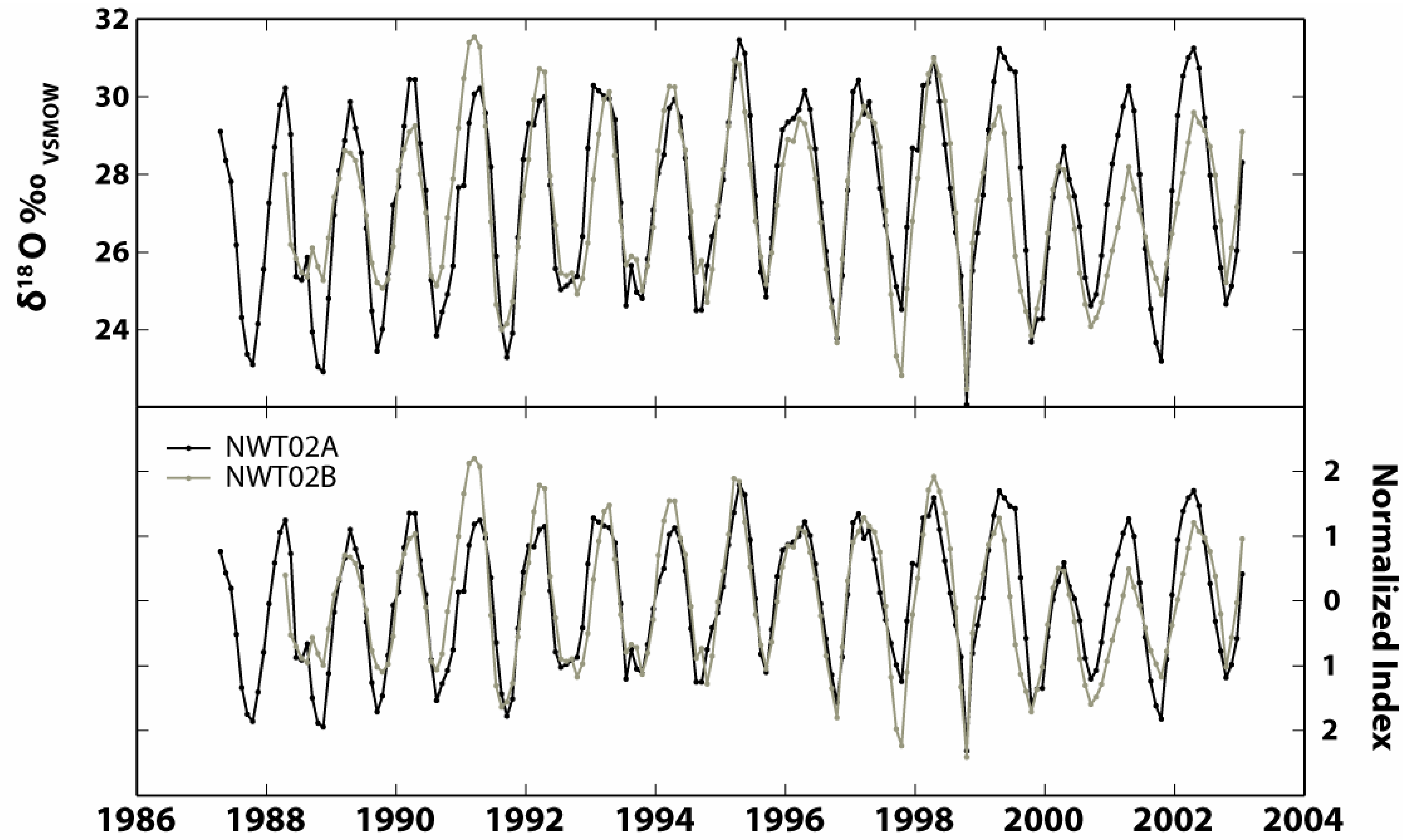
Driest Wet Season

Particularly Wet Rainy Season (verification)

Dry-Wet-Dry Sequence, Potential for Crossdating (identify missing years)

Anchukaitis et al., 2006

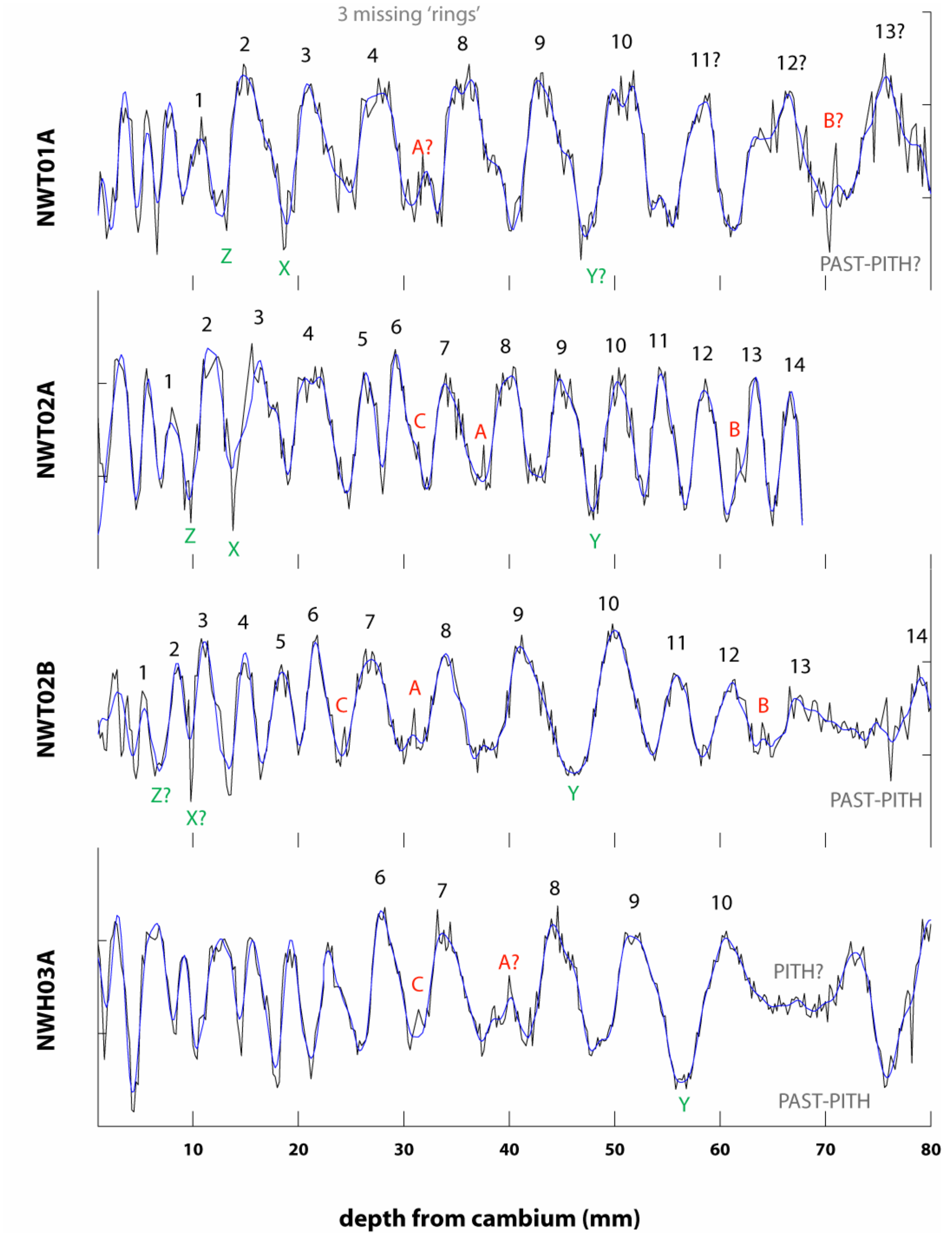
Age modeling and crossdating



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):

$$\Delta_{CX} = \Delta_{L}(1\text{-}p_{EX}p_{X}) + \varepsilon_{o} \; [\textit{relative to } \delta^{18}O_{WS}]$$

- 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*

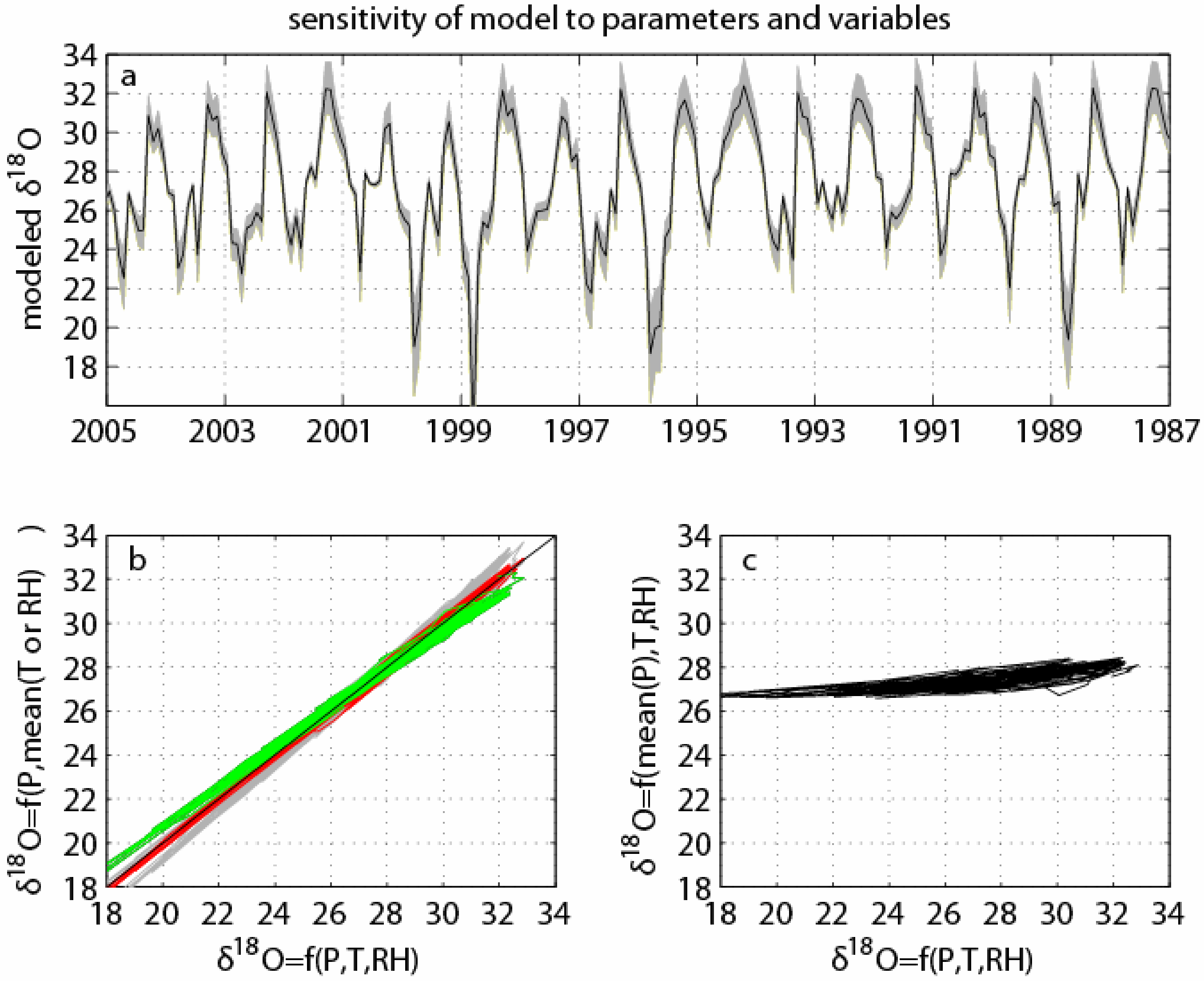
Evans 2006, in review

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*

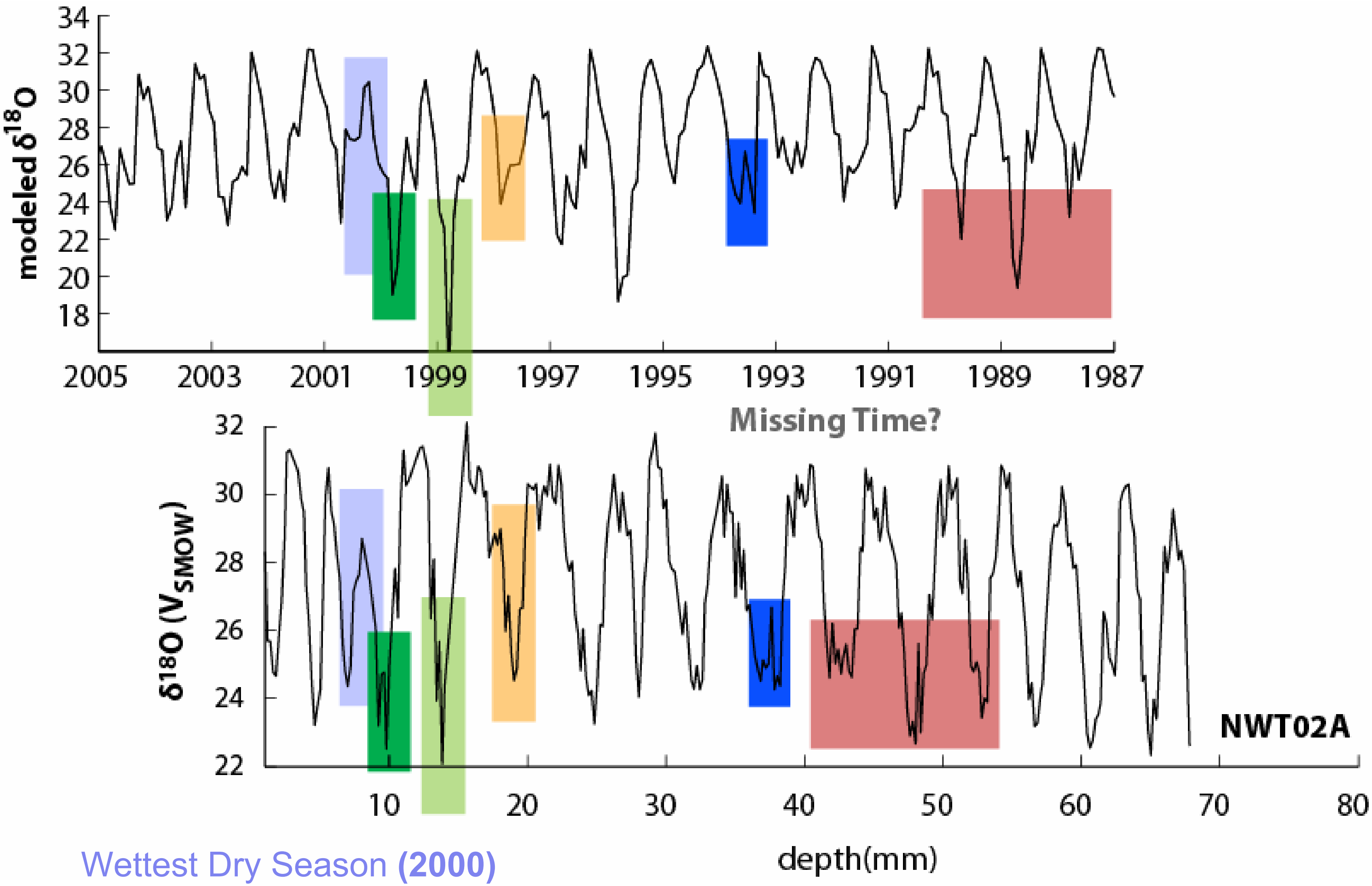
Evans 2006, in review, Anchukaitis et al. 2006, in preparation

Process modeling of isotopic records



sensitivity of model to parameters and variables

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

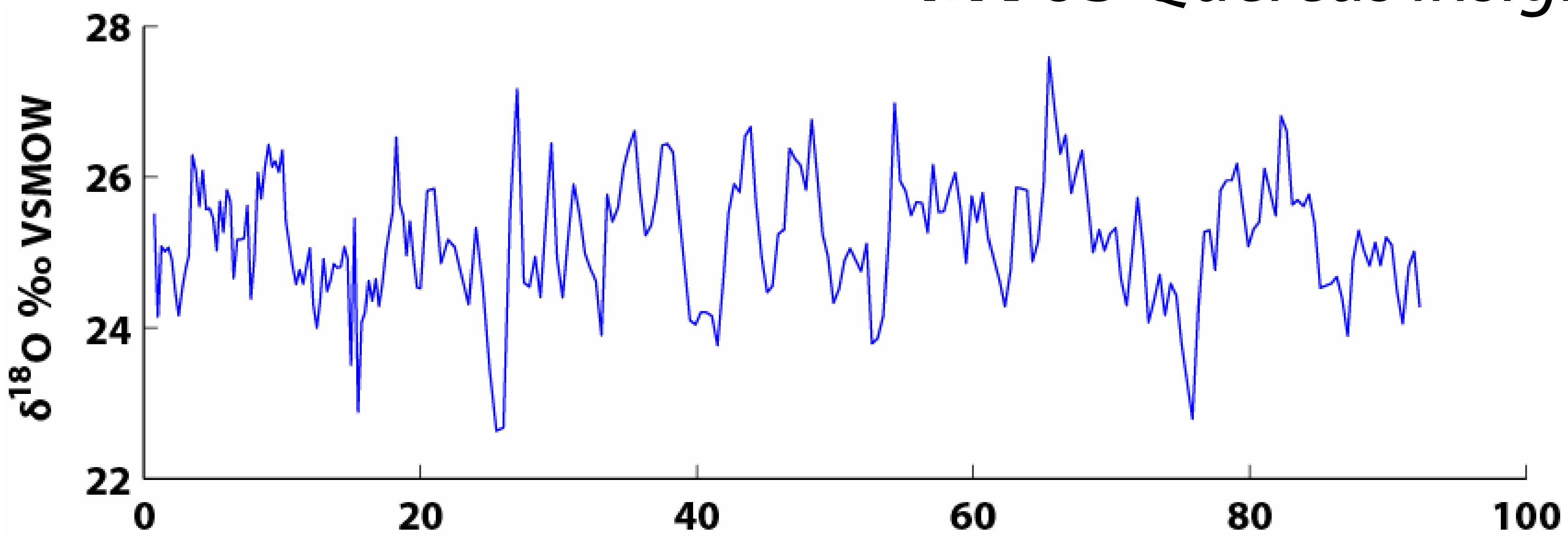
Searching for the longer climate signal Monteverde, Costa Rica

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*



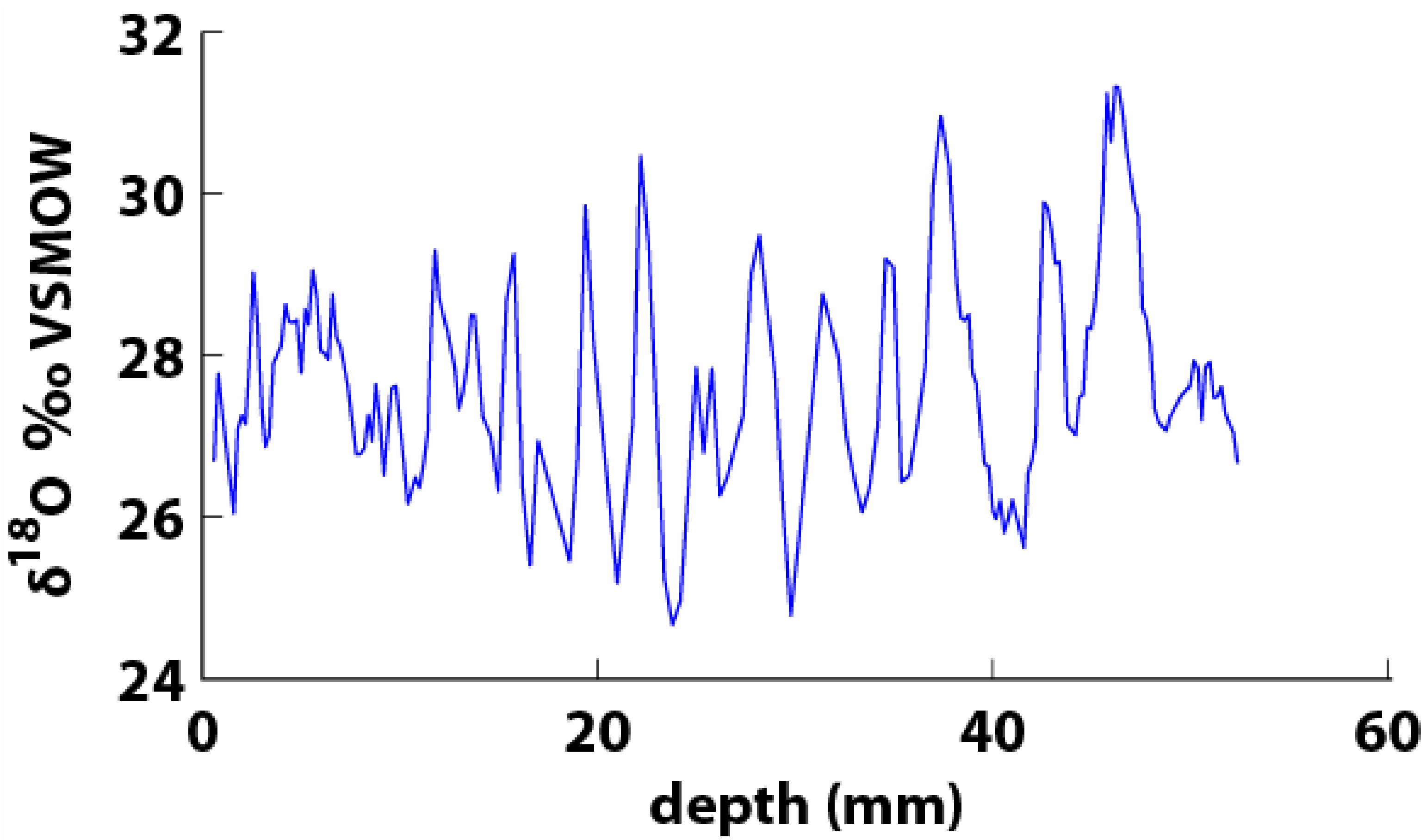
Cycles small (~3 ‰) and inconsistent

Not continuous growth?
Access to stream or groundwater?

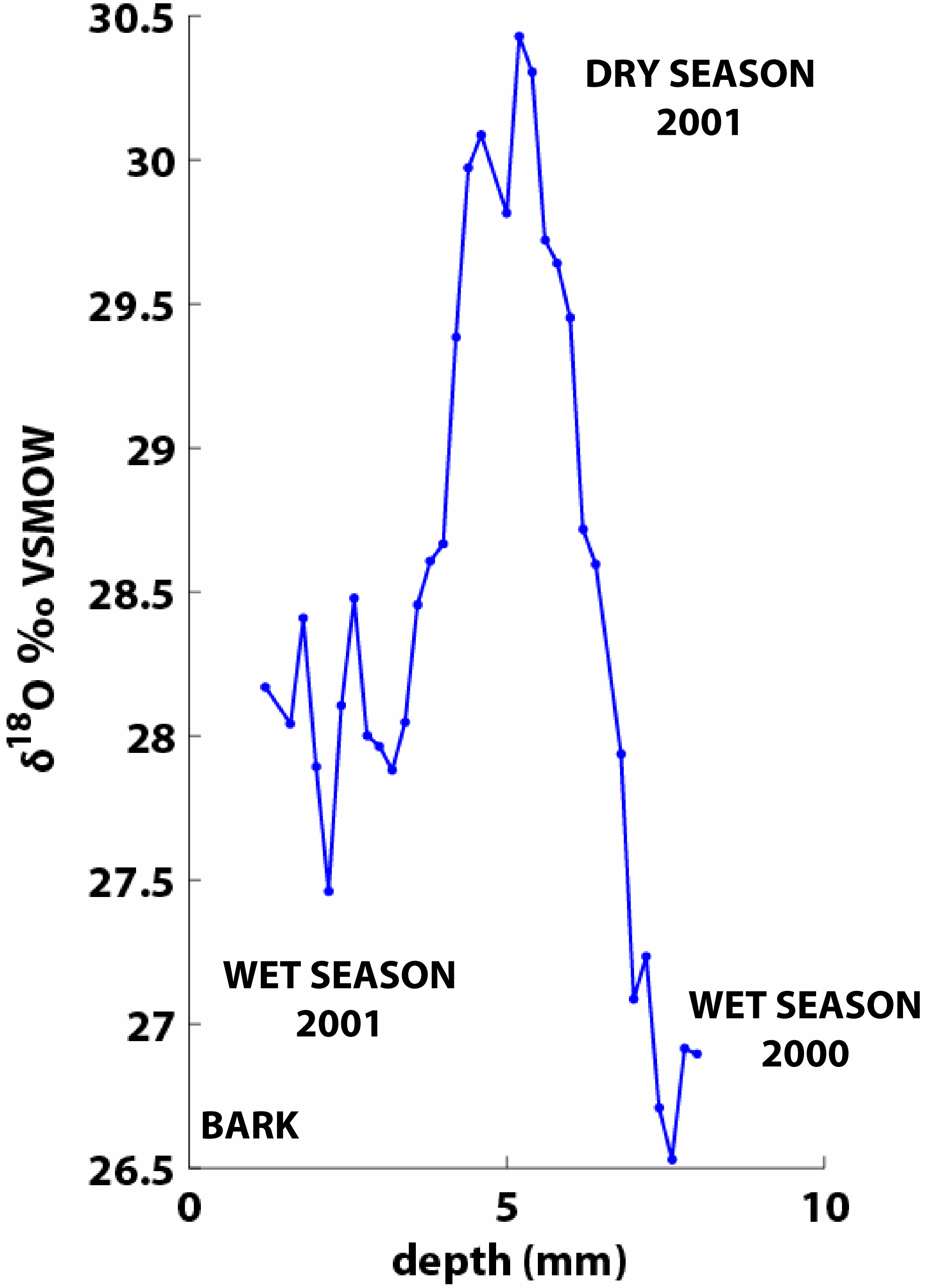
Site *too* cloudy?

Growth too rapid?

MV03 *Unknown species*



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

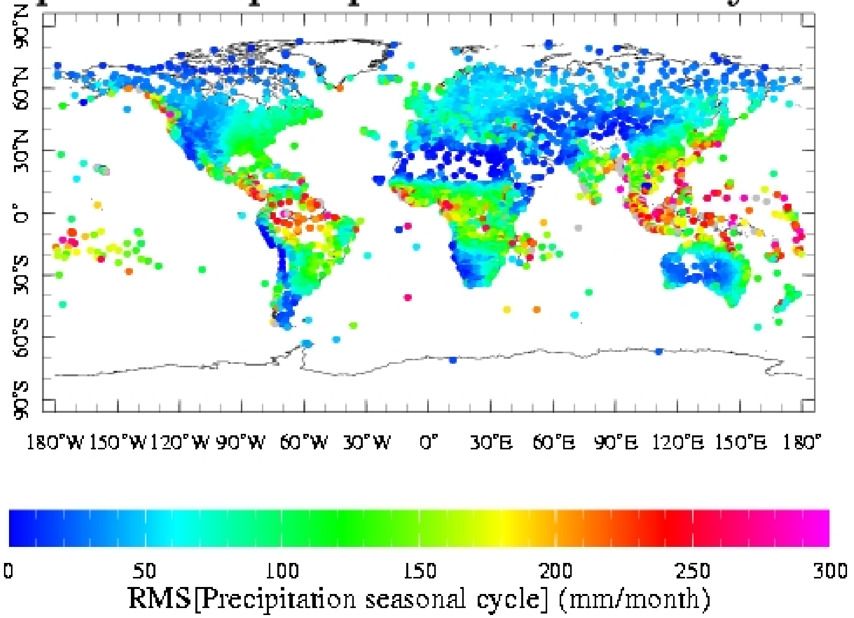
- Annual isotope chronology identified and verified across a range of species and tropical environments
- Evidence of climate, precipitation paleoclimate signal

Next steps in tropical isotope dendroclimatology will benefit from:

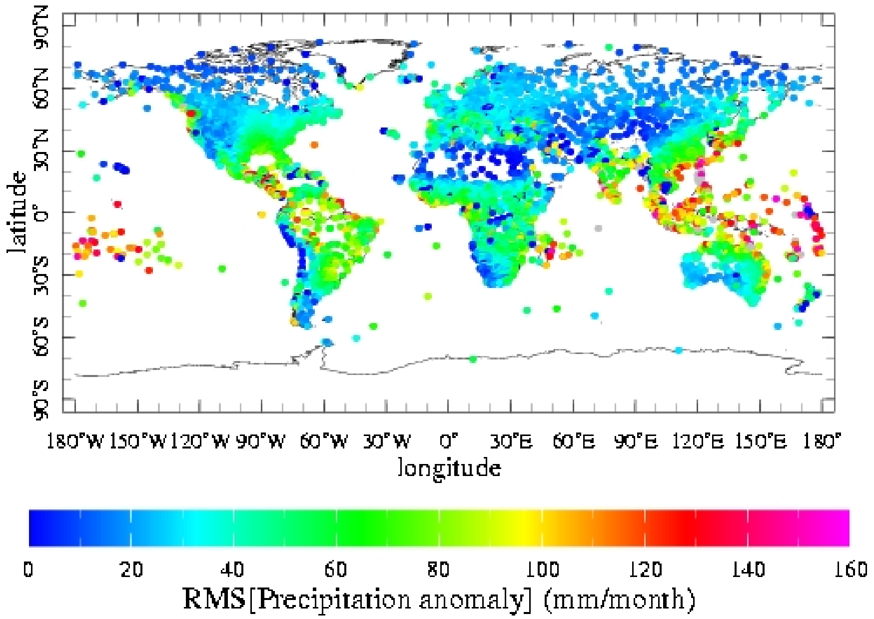
  - Exploitation of forward proxy models to improve data calibration, interpretation, and error analysis.
  - Community efforts to build (and build upon) observational networks.

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**

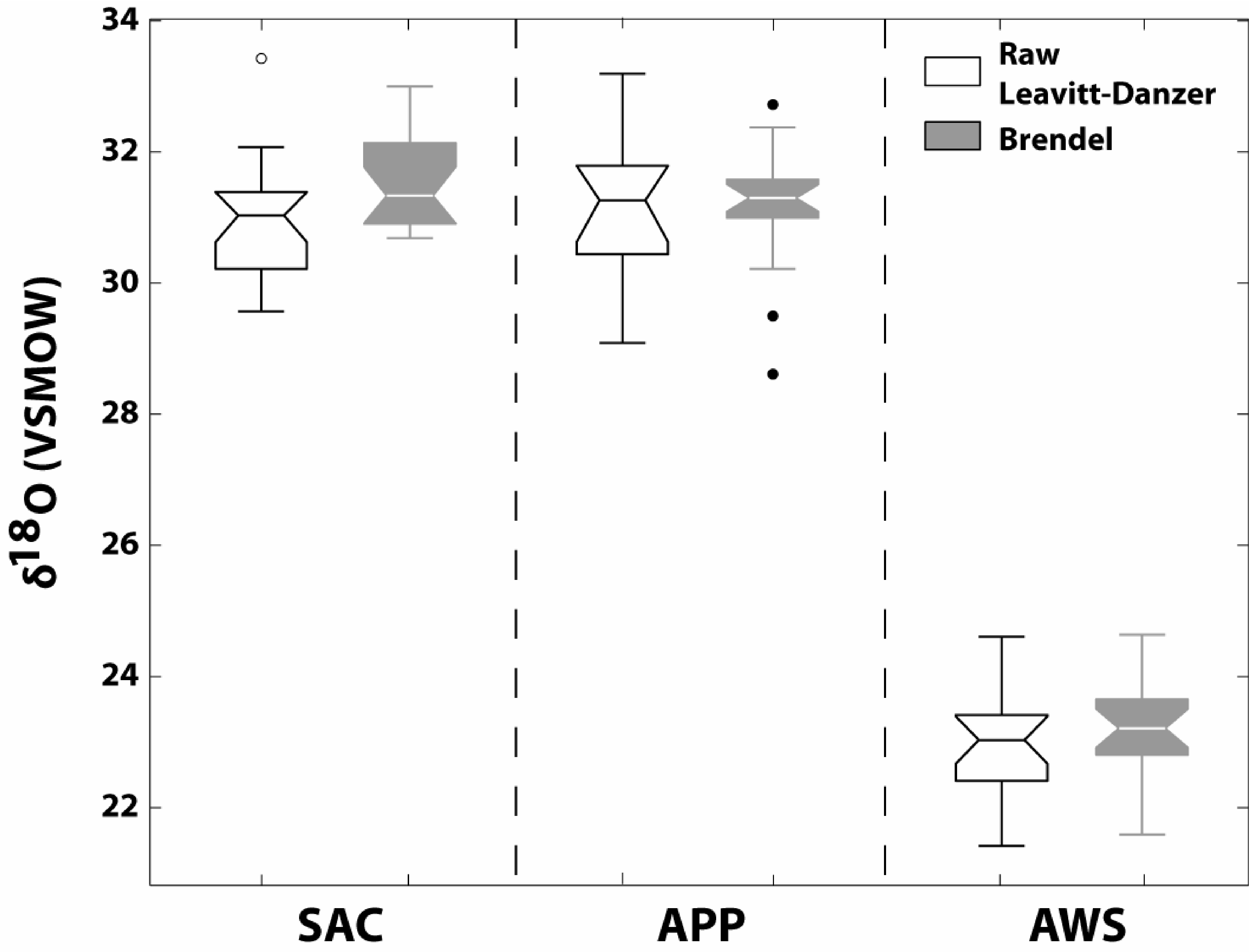


Amplitude of precipitation seasonal cycle

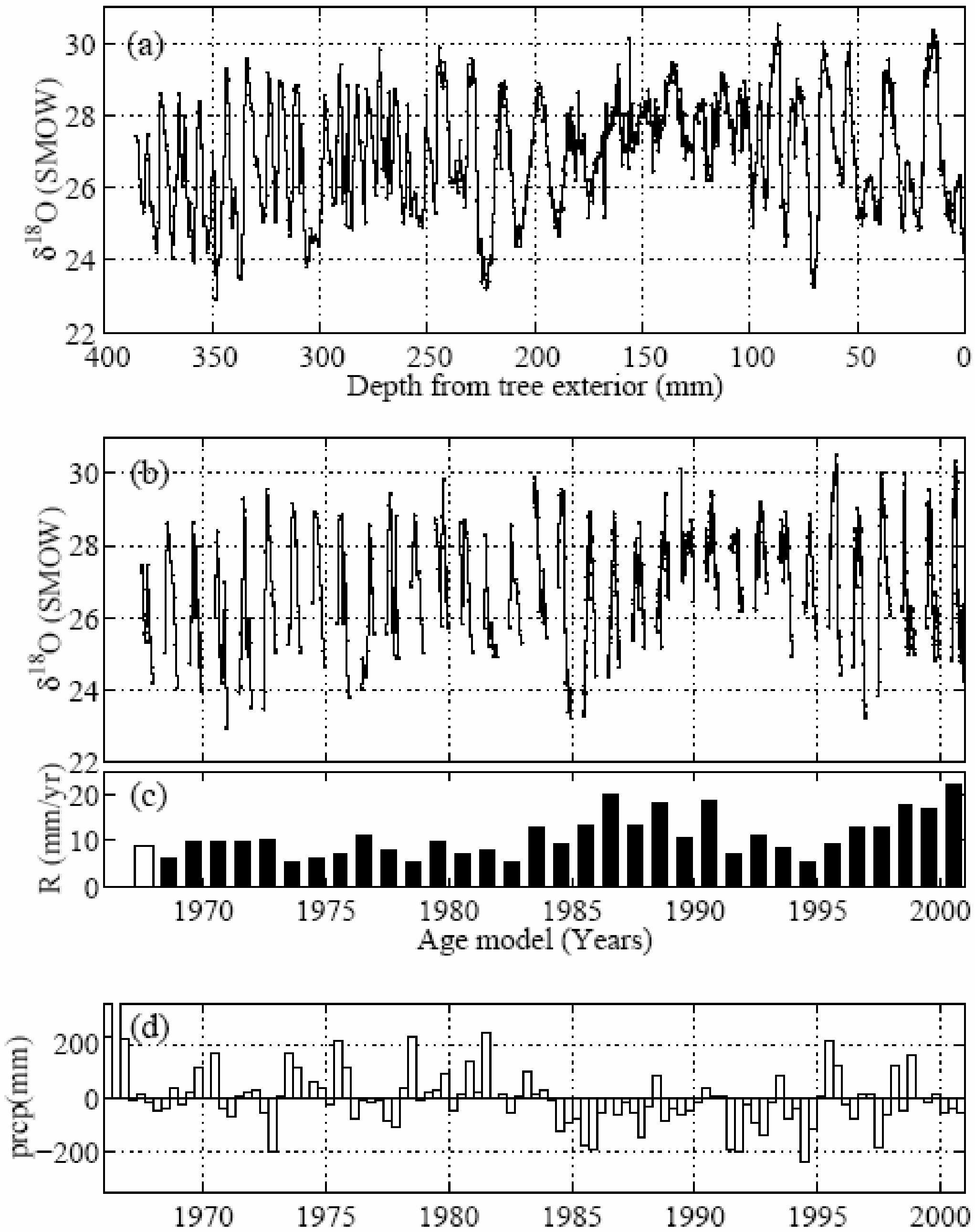


Amplitude of precipitation anomalies

extra slides



34
32
30
28
26
24
22
δ18O (VSMOW)
Raw
Leavitt-Danzer
Brendel
SAC
APP
AWS



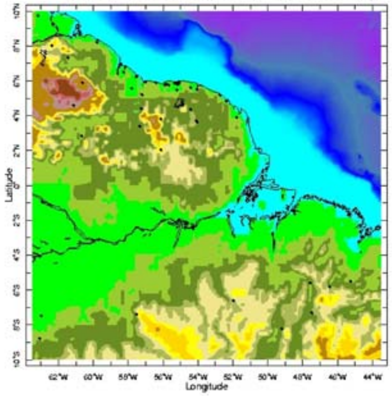
Cordia sp.

Liberia, Costa Rica

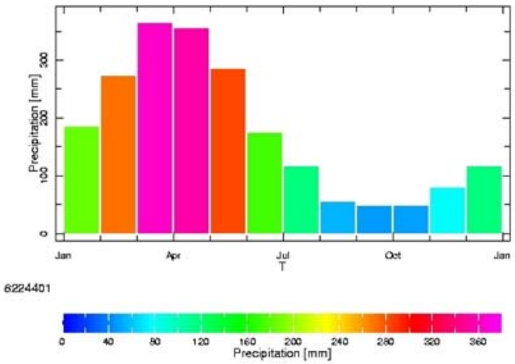
(tropical dry forest)

- 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 …)

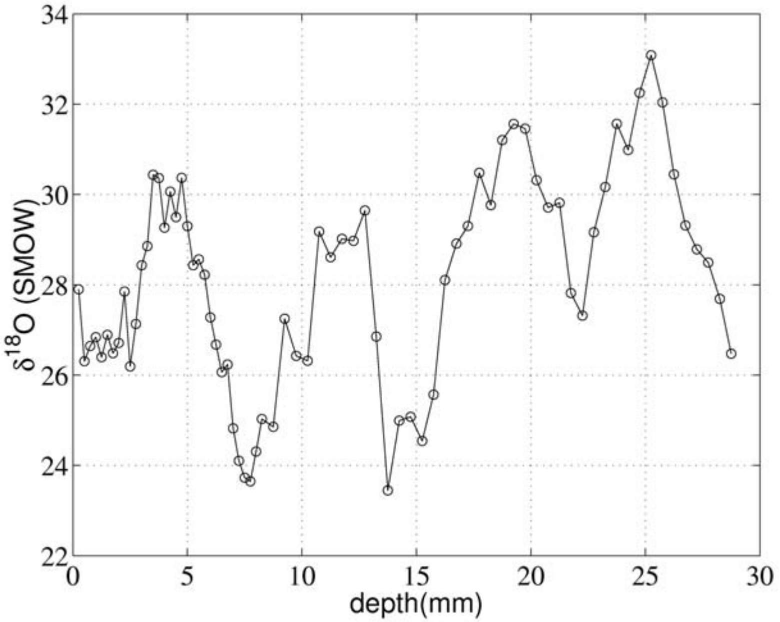
Results: Amazon Rain Forest *Erisma uncinatum*



Santarem (54.7W, 2.5S)



Rainfall Climatology



Depth series

- 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], Saleska unpublished data