A Research and Education Program in Dynamical Paleoclimatology

PI: Michael Evans, Laboratory of Tree-Ring Research, University of Arizona

Funded by: NSF
CAREER grant, 2004

Directorate: Geosciences
Organization: Atmospheric Sciences
Program: Paleoclimate

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CAREER: A Research and Education Program in Dynamical Paleoclimatology

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Project summary

I propose to develop a research and education program in dynamical paleoclimatology – the study of paleoclimatic observations within the context of modern physical climatology. The systematic assimilation of paleoproxy observations into model physical systems permits concise testing of competing hypotheses for the processes responsible for paleoclimate variations. It also provides unique opportunities to investigate the fundamental biogeophysical controls on proxy formation and to improve the precision and accuracy of proxy-based paleoclimate reconstructions. This initiative requires expertise in the biogeochemistry of proxy archives, statistical analysis, meteorology, climatology, and oceanography – a multidisciplinary environment in which I hope to train members of the next generation of paleoclimatologists and science teachers. Toward this goal I will pursue the following integrated education/research program and expected synergistic outcomes.

1. Development of new proxy rainfall data from replicated, high-resolution stable isotope measurements made on tropical trees in northwest coastal Peru. *Additional data will improve the precision and accuracy of tropical climate field reconstructions by alleviating spatial and temporal gaps in coverage in the terrestrial tropics.*

2. Interpretation of newly-developed paleoclimate data using a process (forward) model of stable isotopic composition of wood. *The intercomparison of forward and inverse (statistical) proxy models will improve our ability to reconstruct paleoclimates by improving the multivariate interpretation of the proxy dataset.*

3. Paleoclimatic model-data syntheses using multiproxy data networks and simple models of large-scale climate dynamics. *The interpretation of proxy observations within state and phase-space dynamical frameworks will help identify avenues for future research, and train students to be both "modelers" and "observationalists".*

4. Development, implementation and assessment of a graduate-level survey course in paleoclimatological techniques. *The course will encourage communication and collaboration among University of Arizona paleoclimatologists. It will encourage students to employ a suite of readily available tools to the pursuit of broad, outstanding paleoclimate research questions.*

5. Development, implementation and assessment of an introductory course in weather and climate, whose content is sensitive to the worldview of the Tohono O'odham Nation, to be taught at the Tohono O'odham Community College (TOCC). *The course will enhance the science curriculum at TOCC, create a mentored pathway for O'odham students to pursue 4-year degrees and research opportunities at the UA, enhance diversity at the UA, and provide me experience mentoring students from groups under-represented in science.*

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Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Results from prior NSF support

1. **Grant:** NSF/MRI 03-21348, Acquisition of an Analytical Facility for High Resolution Paleoclimatology, 8/1/03-7/31/04, $339,915, PI: M.N. Evans; Co-PIs: J.W. Beck, J.E. Cole, M.K. Hughes, J.T. Overpeck.

   Summary of results. A suite of five new instruments (scanning μ-X-ray fluorescence spectrometer, particle size analyzer, digital densitometer, inductively-coupled plasma atomic emission spectrometer, continuous flow isotope ratio mass spectrometer) dedicated to high-resolution paleoclimatological studies will provide much needed analytical capacity for the paleoclimate research community at the University of Arizona, and facilitate the development of new cross-disciplinary collaborative research and training efforts.

   Relation to proposed work. The continuous flow isotope ratio mass spectrometer will be initially dedicated to the development of projects in tropical isotope dendroclimatology described in the Project Description.

2. **Grant:** NSF/ESH ATM 02-14130, Collaborative Research: Pilot Study in Tropical Isotope Dendroclimatology, 9/1/2002-8/31/2004, $148,038 (UA component: $57,900), PIs: M.N. Evans, D.P. Schrag.

   Summary of results. We have developed a methodology for reconstructing paleo-rainfall estimates from tropical trees which may or may not have annual ring structure. We resolve the annual cycle of tropical rainfall via its "amount effect" and evaporative signatures in the δ^{18}O of α-cellulose. This approach to chronology development has now been successfully tested in a variety of tree genera from Costa Rica, Peru, Brazil, Indonesia and Thailand [*Evans and Schrag*, 2003; *Poussart and Schrag*, 2003].

   Publications.

   Evans, M. N. and D. P. Schrag, Tracking ENSO with Tropical Trees: Progress in tropical isotope dendroclimatology, *Geochim. et Cosmochim. Acta*, 2003, submitted.

   Poussart, P. F. and Schrag, D. P., Multi-decade high-resolution cellulose oxygen isotope records from Indonesian and Thai trees: Environmental and physiological insights, *Earth and Plan. Sci. Lett.*, 2003, submitted.

   Relation to proposed work. The pilot project provides the methodological basis we will apply in proposed projects in tropical isotope dendroclimatology.

3. **Grant:** NOAA/ESH 98-09140/GC98-657, Methodology and Application of Objective Analysis Climate Field Reconstruction from Proxy Data, 8/1/1998-7/31/2001, $374,821, PI: M.A. Cane.

   Summary of results. We developed a methodology for the reconstruction and validation of paleoclimatic field estimates and errors, employing objective analysis techniques. We focused primarily on the coral stable isotope (δ^{18}O) database and sea surface temperature (SST) fields. An equatorial set of hypothetical coral δ^{18}O data series provides pre-instrumental period SST reconstructions with least error [*Evans et al.*, 1998]. Thirteen actual coral δ^{18}O data sets resolve 2 SST patterns; these resemble ENSO and a near-global warming in which the eastern equatorial Pacific cools [*Evans et al.*, 2000]. The methodology [*Evans et al.*, 2001c, 2002] was applied to reconstruction of gridded Pacific SSTs, from coral δ^{18}O data and a Pacific-influenced set of tree-ring indicators [*Villalba et al.*, 2001]. Errors are large but decades in which the coral-reconstructed frequency of ENSO warm phase events is high appear to coincide with tree-ring-reconstructed decadal warming of the Pacific mean state. An independently-derived proxy reconstruction of decadal Pacific SST variability [*Linsley et al.*, 2000] is significantly correlated with the tree-ring based Pacific SST reconstruction [*Evans et al.*, 2001a]. The result supports the idea that Pacific decadal variability is a basin-wide phenomenon originating in ENSO physics.

Publications.

Evans, M.N., A. Kaplan, and M.A. Cane, 1998: Optimal sites for coral-based reconstruction of sea surface temperature, *Paleoceanography*, 13, 502-516.

Evans, M.N., A. Kaplan, and M.A. Cane, 2000: Intercomparison of coral oxygen isotope data and historical sea surface temperature (SST): Potential for coral-based SST field reconstructions, *Paleoceanography*, 15: 551-563.

Cane, M.A. and M.N. Evans, 2000: Do the Tropics Rule? *Science* 290: 1107-1108.

Evans, M.N., A. Kaplan, M.A. Cane, and R. Villalba, 2001: Globality and optimality in climate field reconstructions from proxy data, in V. Markgraf (ed.) *Inter Hemispheric Climate Linkages*, Cambridge University Press, p. 53–72.

Evans, M.N., M.A. Cane, D.P. Schrag, A. Kaplan, B.K. Linsley, R. Villalba and G.M. Wellington, 2001: Support for tropically-driven Pacific decadal variability based on paleoproxy evidence, *Geophys. Res. Lett.* 28: 3689–3692.

Evans, M.N., A. Kaplan, and M.A. Cane, 2002: Pacific sea surface temperature field reconstruction from coral δ^{18}O data using reduced space objective analysis, *Paleoceanography*, 17: DOI 10.1029/-2000PA000590.

Kaplan, A., M.A. Cane, and Y. Kushnir, 2003: Reduced space approach to the optimal analysis of historical marine observations: Accomplishments, difficulties, and prospects, *WMO Guide to the Applications of Marine Climatology*, World Meteorological Organization, Geneva, Switzerland, in press, available at: http://rainbow.ldeo.columbia.edu/∼alexeyk/CLIMAR99/wmogr.pdf.

Data products. Reconstructions of Pacific annual SST anomalies (110^{o}E-67^{o}W, 52^{o}N-52^{o}S, 5$^o \times$5^o) using corals and tree-ring data are deposited at the World Data Center-A for Paleoclimatology in Boulder, CO, and are available via Internet from: http://www.ngdc.noaa.gov/ paleo/recons.html.

Relation of the completed work to the proposed work. We identified the primary limitations on climate field reconstruction skill. These problems are (1) weakness of statistical procedures of proxy calibration, (2) the frequency-selective nature of proxy response to climate, (3) observational error in the proxy observations, and (4) low data availability in large parts of the tropics. A subsequent proposal funded by NOAA has permitted us to begin to explore the first three issues; this proposal addresses the fourth.

Career Development Plan

Scientific Objectives

It is increasingly clear that the past century may be one of change and reorganization in the climate system [*Watson and the IPCC Core Writing Team*, 2001; *US Climate Change Science Program*, 2002] in response to steadily increasing anthropogenic forcing. The tropics in particular comprise an enigmatic component of the climatic response to greenhouse forcing. How will increases in atmospheric greenhouse gas concentrations affect the frequency and amplitude of El Niño-Southern Oscillation (ENSO) warm and cold phase events [*Timmerman et al.*, 1999]? How stable is the mean state of the tropical ocean-atmosphere system, from the base of the thermocline to the top of the troposphere [*Clement et al.*, 1996; *Ramanathan and Collins*, 1991]?

How do the mean state and the variability of the tropical ocean and atmosphere interact on seasonal to centennial timescales [*Gu and Philander*, 1995; *Fedorov and Philander*, 2001]? What are the mechanisms which explain observed decadal variability in the tropical ocean and atmospheres [*Karspeck and Cane*, 2002; *Kushnir et al.*, 2002]?

The answers to these questions are non-trivial pieces of the greenhouse warming puzzle. Many relevant components of the climate system, such as tropical ocean-atmosphere dynamics, the atmospheric hydrological cycle, tropical-extratropical atmospheric energy, moisture and momentum transports, ocean-land surface interaction, and tropical ocean thermocline ventilation all exhibit various degrees of nonlinear behavior [*Gill*, 1982; *Peixoto and Oort*, 1992]. Because aspects of the tropical climate system are highly nonlinear, climate "surprises" may result from even gradual changes in the mean climate state which are already underway [*Pierrehumbert*, 2000; *National Research Council Committee on Abrupt Climate Change*, 2002], and they may cause far greater societal impacts than would linear mechanisms.

Research Strategy

There is much potential for positive synergy in an emerging continuum of climate science ranging from meteorology to glacial-interglacial paleoclimatology. We may begin the study of a climatic phenomenon of interest with an admittedly incomplete mental, analytical or numerical model of the critical system components. The model(s) may be used to produce clearly stated hypotheses concerning system response to the forcing of interest. Relevant historical and proxy paleoclimate observations may be reviewed for consistency, and modeling of the proxies themselves, based on historical climate observations, permits estimation of their precision and accuracy. If necessary, new data may be developed from regions and time periods which clearly will/will not lend the hypothesis support. Conversely, proxy paleoclimate observational networks may be used to test the ability of model physics to simulate climate states far different than the modern conditions under which the model was developed. I call this linked strategy *dynamical paleoclimatology*. It is the overarching theme of the research element of my career development plan.

Many breakthroughs have arisen from dynamical paleoclimatology. For instance, consider the range of ideas developed at workshops in which climate dynamicists, proxy paleoclimatologists, and historical climatologists converge on a question of mutual interest, in the process developing a common, multidisciplinary dialect [*Berger and Labeyrie*, 1985; *Anderson and Willebrand*, 1996; *Clark et al.*, 1999; *Markgraf*, 2001]. The exchange of ideas across disciplines in several of these workshops I have attended (*Intercomparison of Proxy and Instrumental Data*, JISAO, June 1997; *Pole-Equator-Pole Paleoclimate of the Americas (PEP-1)*, Merida, May 1998; *ENSO: Past, Present, Future*, Seabrooke Island, March 2000; *Tropical Paleoclimate Initiative Workshop*, USC, June 2003) has been and remains essential to development of my scientific interests and my approach to education.

Educational Strategy

Dynamical paleoclimatology offers many opportunities to train the next generation of multidisciplinary climate scientists. Such students will be grounded in fundamental principles of physical climatology and they will be able to interpret spatiotemporal proxy data networks within the context of clear climate dynamics hypotheses. They will not think of themselves as "observationalists" or "modelers", but simply as climatologists who work on a broad range of time scales. They will catalyze collaboration between paleoclimatologists and atmospheric scientists across the University. Bringing graduate students together in a paleoclimatology tools course, to look across disciplines for answers to big questions, is the goal of the first element of the educational component proposed here.

Another set of opportunities is in development of compelling and relevant science courses for undergraduates from groups under-represented in the sciences. Environmental science lends itself to inquiry-based learning, and I have found that the relevance of the questions we discuss appeals to a broad spectrum of students. I am a highly collaborative scientist and I recognize the value of having a diversity of ideas represented in my research group. Hence, a career goal has become to promote diversity in my research group and University by learning how to effectively mentor and teach students with life experiences vastly different than mine. The careful development of an introductory weather and climate class whose content and delivery is sensitive to the cultural worldview of Tohono O'odham Community College students is the second element of the education program proposed here.

Prior research and educational accomplishments

Research

Tropical isotope dendroclimatology: First results. A particular gap in the network of high resolution proxy data used to study long-term climate variations is in the terrestrial tropics. Annual-resolution paleoclimate data derived from tropical trees is an untapped source of information about past climates. We have developed a methodology for extracting seasonal resolution paleo-rainfall/evapotranspiration records from tropical trees, using high resolution oxygen isotopic measurements on the α-cellulose component of wood. The approach circumvents obstacles faced by traditional dendrochronological methods in the tropics [*Stahle*, 1999; *Biondi*, 2001] such as lack of annual ring structure and high species diversity [*Evans and Schrag*, 2003; *Poussart and Schrag*, 2003].

We call this approach "tropical isotope dendroclimatology". The strategy exploits recent advances in mechanistic modeling of the oxygen isotopic composition of the α-cellulose component of wood [*Roden et al.*, 2000]; a rapid protocol for extracting the α-cellulose component of wood from very small samples [*Brendel et al.*, 2000; *Evans and Schrag*, 2003]; and on-line, continuous flow mass spectrometric techniques [*Brand*, 1996]. We have now proven the chronological development in several tree genera from the rain forests of eastern Costa Rica, Thailand, and Brazil [*Evans and Schrag*, 2003; *Poussart and Schrag*, 2003] and have initiated development of multidecadal, replicated paleoclimatic data series [*Evans and Schrag*, 2003; *Poussart and Schrag*, 2003, Figure 1][1]. In the result illustrated in Figure 1, the age model is based on annual cycle in the isotope record and is confirmed within error by the known age of this plantation tree. The highest JJAS rainfall totals correspond to low isotopic values in 1986, 1991, 1994 and 1997, which are all ENSO years.

Objective interpretation of paleoproxy data. Interpretation (calibration) of proxy data in terms of large-scale spatiotemporal climate variation is perhaps the most subjective step in current paleoclimate reconstruction procedures, and it undercuts the reliability of the reconstructions and their uncertainty estimates. We have applied a relatively simple process model of seasonal tree-ring width formation [*Shashkin and Vaganov*, 1993], which uses the principle of limiting factors [*Fritts*, 1991] common to tree-ring interpretation [*Stokes and Smiley*, 1968] together with nonlinear descriptions of the dependence of tree growth on temperature, moisture, and light, to the simulation of 210 tree-ring records in North America and Russia [*Reichert et al.*, 2003]. The results are astonishingly robust to variation in mean environmental conditions, species, and intraseasonal variation in limiting growth dependence. The latter feature of the model permits it to be more stable than classical multivariate linear regression-based proxy calibration techniques [*Fritts et al.*, 1991] to interannual, decadal, and transient changes in mean climate experienced by the trees. The results (Figure 2) suggest that the process model may be used to improve tree-ring data error estimates, invert for multivariate climate reconstructions, and to predict the fingerprint of future climate variability on temperate conifer forests using climate model forecast output [*Reichert et al.*, 2003]. The results also

[1] Preprint available at: http://www.ltrr.arizona.edu/∼mevans/trp/ES_060303_ms.pdf.

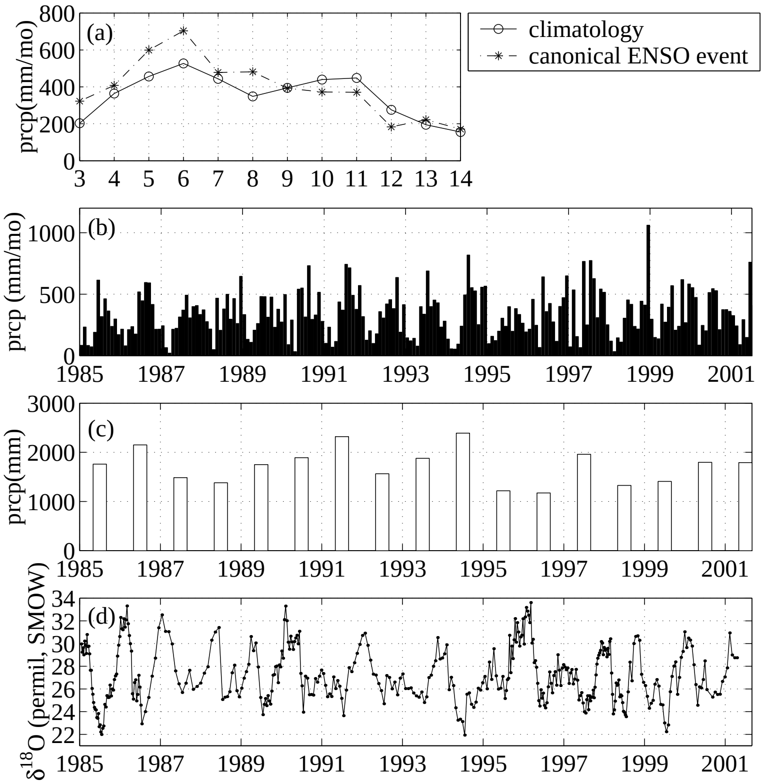

Figure 1: Age modeled La Selva (84^{o}W,10^{o}N, 40m) isotopic data and climatic interpretation. **(a)** Climatological rainfall at La Selva Biological research station, 1957–2003 (open circles) plotted vs. month, from April (3) to March of the subsequent year (14). Plotted on the same time scale is monthly rainfall at La Selva Station during ENSO years between 1957-2003 (1957-8, 1965-6, 1969-70, 1972-3, 1976-7, 1982-3, 1986-7, 1991-2, 1997-8, 2002-3). Rainfall data are from *Brenes* [2003]. **(b)** Monthly rainfall at La Selva station vs time. **(c)** June-September summed La Selva rainfall. **(d)** Age modeled δ^{18}O data from *Hyeronima alchorneoides* samples.

suggest that process modeling isotopic records from tropical trees may become an important component of their interpretation and application [*Anderson et al.*, 2002].

Multiproxy paleoclimate reconstructions: Pacific basin SST. We have focused much effort over the past several years to the development of robust, verifiable Pacific basin sea surface temperature (SST) reconstructions from corals and tree-rings, using an approach derived from reduced space objective analysis techniques [*Cane et al.*, 1996; *Kaplan et al.*, 1997, 1998; *Evans et al.*, 2001a, 2002]. Finding the least-squares fit to non-locally calibrated proxy data [*Evans et al.*, 2000] and a statistical representation of the large-scale patterns of SST variability within observational error produces fields and error estimates for the period over which the proxy data are available [*Evans et al.*, 2002]. Subsequent experiments employing the growing network of proxy observations of Pacific SST variability suggest that closing spatial and temporal data gaps will continue to improve the SST field reconstructions (Figure 3). Therefore, additional proxy data from poorly-observed regions should improve the results further [*Evans et al.*, 1998] if the data are unbiased, have relatively small observational error, and represent local responses to large-scale features of the climate system [*Evans et al.*, 2000].

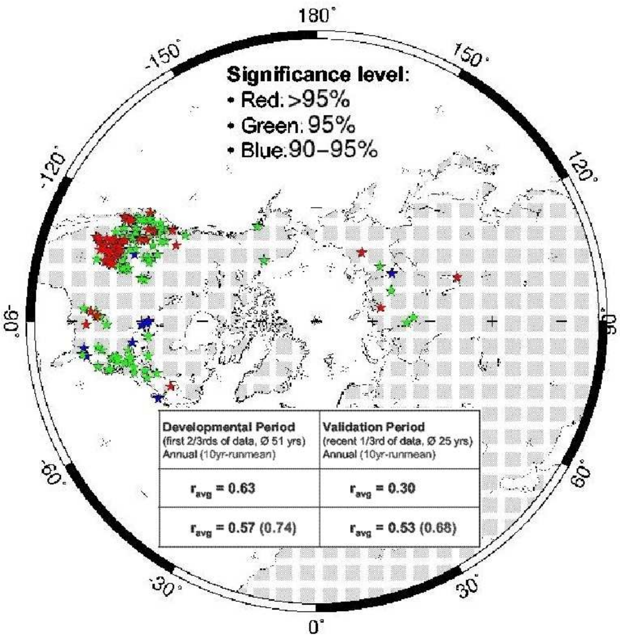

Figure 2: Significance of correlations between 210 tree-ring width chronologies [*Mann et al.*, 1998; *Vaganov*, 2002] and model simulations based on daily meteorological station data [*Baker et al.*, 1995]. All 210 chronologies were simulated at or above the 90% level of significance [*Reichert et al.*, 2003]. *Note: Reported significances are preliminary pending further analysis.* Inset table: Comparison of forward model and classical statistical modeling results for "calibration" (statistical model development) and "verification" (statistical model-independent) periods.

Education

Graduate seminar: ENSO: Past, Present, Future. While the present-day dynamics of the El Niño-Southern Oscillation (ENSO) phenomenon are broadly understood, predictability is limited, the long-term natural variability is poorly known, and the effect of greenhouse warming on the tropical ocean-atmosphere system is much debated. This course[2], which was inspired by a workshop held in March 2000, begins with review of ENSO phenomenology, dynamics and predictability. With this grounding we examine evidence for paleo-ENSO activity. We conclude with a discussion of the interaction between ENSO dynamics and global warming. Homework data exercises give students experience analyzing climatological and proxy data relevant to course themes. Student in-class presentations are evaluated in accordance with a grading rubric by means of oral and written assessment. A project developed by UA masters student Cristina S. Luis on the character of the 2002-3 ENSO warm phase event, and a review by this year's class of ENSO dynamics during the LGM, are in preparation for submission to peer-reviewed journals [*Luis et al.*, 2003; *Evans et al.*, 2003]. The course has broadened students' awareness of some major paleoclimate research questions and it has inspired them to think more broadly about the tools they might bring to bear on their own research topics.

Undergraduate course: Introduction to Global Change. The goal of this course[3] is to ground current and compelling environmental issues firmly in their fundamental underlying scientific principles. To do so we study linked components of a complex and dynamic earth system. Rather than attempt a survey of the

[2]Materials available online at: http://www.u.arizona.edu/ic/geos595e/enso.html
[3]Materials available at: http://www.ltrr.arizona.edu/∼ic/nats101c/ ; userid: nats101029; password: 9Career0.

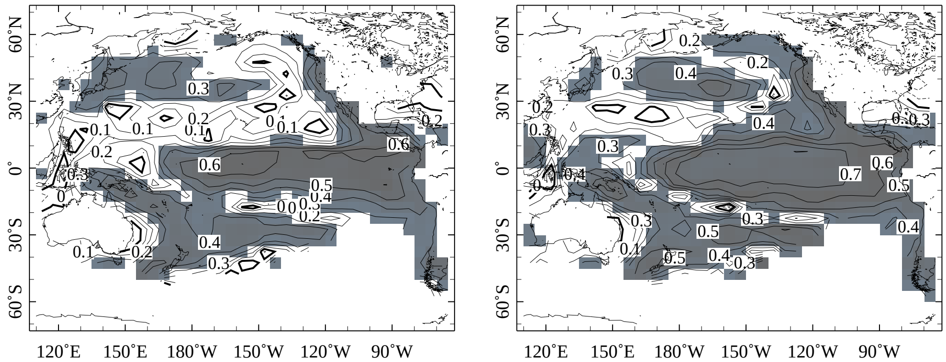

Figure 3: Verification (1856–1922) correlation of reconstructed SST fields from proxy data with historical SST analysis of *Kaplan et al.* [1998]. Left: Reconstruction from 13 coral δ^{18}O data series [*Evans et al.*, 2002]. Right: Reconstruction from 29 coral δ^{18}O 1 Sr/Ca and 35 calcification rate dataseries [*Evans et al.*, 2001b].

entire global change research effort, we investigate a few topics – climate change, biodiversity, fresh water resources, and a topic chosen by students – in detail. Class time is divided between lecture, hands-on activities and discussion. Typically, a 75 minute class meeting is divided into a 20 minute lecture, 30 minute activity, and a 25 minute discussion/summary. Along the way we meet University-mandated Tier I Natural Sciences General Education requirements[4]. I offer the course in alternate years as a small Honors section. The design of the course is constantly updated as I experiment with pedagogical recommendations [*Mathieu*, 1996; *Allen-King et al.*, 2002; *Mathieu*, 2003]. The lessons I have learned working with non-science major undergraduates having diverse learning styles will be useful as I co-develop the Tohono O'odham Community College Weather and Climate course proposed here.

Proposed Research

Overview

As the tropical climate system contain nonlinearities, I believe the characterization of its behavior is best observed via state or phase space portraits [*Strogatz*, 1994; *Sugihara and May*, 1990; *Fedorov and Philander*, 2001] derived from observations and relatively simple models of the climate system. For instance, a simple hypothesis we may test with the results of improved Pacific SST field reconstructions is shown in Figure 4, which suggests the 2002-3 ENSO warm phase event was unprecedented in the structure of SST anomalies across the central and eastern equatorial Pacific [*Hoerling and Kumar*, 2003]. But was the event unusual over the past 3 centuries?

Due to the strong coupling of coastal sea surface temperatures (SSTs) to atmospheric convection in the equatorial Pacific, the northwest coastal Peru/Ecuador region (e.g. 79-81^{o}W, 0-5^{o}S) experiences perhaps the world's greatest interannual variability of rainfall. During normal years, coastal upwelling maintains SSTs of 18-23^{o}C, which is relatively cold for the tropics. Consequently, only about 75mm precipitation is typically received between December and February, when SSTs are seasonally highest, and surface winds and upwelling are seasonally weakest. During ENSO warm phase event years, the seasonal cycle of winds, SST and precipitation is greatly amplified. During the very strong 1997-8 ENSO warm phase event, for example, coastal SSTs reached 28^{o}C [*Reynolds*, 1988], and the December–February precipitation total in nearby Piura, Peru (80^{o}W, 5^{o}S) was 900mm – more than ten times the climatological average [*Xie and Arkin*, 1996]. Societal impacts were severe: flooding and contamination of the water supply caused cholera and malaria

[4] http://w3.arizona.edu/∼uge/gened/guidlnst1d.htm

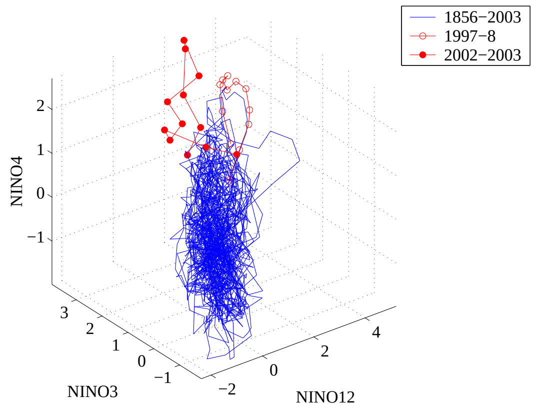

Figure 4: State space portrait of the spatial structure of central, eastern and coastal equatorial Pacific SST anomalies, as illustrated by the 3-plot of index-area averages (NINO12 [0-10^{o}S,80^{o}W-90^{o}W],NINO3 [150^{o}W-90^{o}W, 5^{o}N-5^{o}S],NINO4 [160^{o}E-150^{o}W, 5^{o}N-5^{o}S]). All indices have been standardized by the variance in the NINO12 index. Data from *Kaplan et al.* [1998]. Note that in this picture the warm of the central equatorial Pacific relative to the coastal zone is unprecedented in the historical record. From: *Luis et al.* [2003].

rates in Piura in 1998 to be respectively double and ten times the incidence rate of 1997 [*Ponomareva*, 1998]. While the 1997-8 ENSO event was successfully predicted six months in advance, its strength was unanticipated. Yet the failure of the subsequent 2002-3 warm phase event to give rise to warmer NINO12 SSTs, and therefore and wetter conditions in coastal Peru, was unprecedented in over a century of historical SST analyses [*Luis et al.*, 2003, Figure 4]).

I propose to develop new estimates of paleo-rainfall from the ENSO-sensitive northwest coastal region of Peru and Ecuador, using methods developed by *Evans and Schrag* [2003] and applied by *Poussart and Schrag* [2003]. The approach exploits the seasonality of the tropical hydrological cycle (*Peixoto and Oort* [1992]; Figure 5) to develop seasonally-resolved proxy climate records from high resolution stable isotope measurements of the α-cellulose component of tropical wood. The proxy data developed in this study will be analyzed within the context of an explicit process model modified from *Roden et al.* [2000]. The process modeling will enable us to develop uncertainty estimates for age model and proxy rainfall estimates. Finally, the proxy rainfall data will be entered into the network of high resolution proxy observations used to reconstruct Pacific Basin SST. The results of reconstruction efforts will be used to further define the state space that the ENSO system has occupied over the past several hundred years, as part of the ongoing effort to disentangle natural variability from modern response of the system to greenhouse warming.

Paleodata acquisition: Tropical isotope dendroclimatology in Peru

In a recent set of careful greenhouse, field and modeling studies, Roden and colleagues [*Roden and Ehleringer*, 1999a, b, 2000; *Roden et al.*, 2000] showed that the oxygen isotope composition of the α-cellulose component of wood depends primarily on the oxygen isotopic composition of source waters and evaporative enrichment at the leaf where photosynthate is produced. In this model, the oxygen isotopic composition of α-cellulose is a weighted average of two components: the unmodified isotopic composition of soil moisture and the isotopic composition of leaf water, which is modified by the process of evapotranspiration. Both components are offset by the biochemical fractionation associated with formation of α-cellulose [*Sternberg and DeNiro*, 1983].

The Roden-Lin-Ehleringer (RLE) model gives us the mechanistic underpinning to resolve time in tropical trees which lack annual rings. This is because the tropical precipitation and evapotranspiration fields show marked seasonality [*Peixoto and Oort*, 1992, Figure 5], which is reflected in the oxygen isotopic composition of tropical wood. The δ^{18}O of precipitation from tropical convective systems over a range of time scales is largely explained by the “amount effect” [*Gat*, 1996]. In this model, the process of precipitation preferentially removes ^{18}O-labeled water from an air mass, leaving subsequent precipitation isotopically depleted. Consequently we expect that heavy precipitation falling at the height of the rainy season will reflect decreased δ^{18}O, relative to that of lighter precipitation falling at the outset of the rainy season. The amount effect drives the δ^{18}O of tropical wood lower during the rainy season (Figure 4). The seasonal cycle in humidity affects the oxygen isotopic composition of plant waters, through the preferential evapotranspirative loss of ^{16}O-labeled water to the atmosphere. During the dry season, lower environmental specific humidity causes increased leaf water δ^{18}O due to evaporative enrichment (Figure 4). During the rainy season, increased atmospheric moisture minimizes the evaporative enrichment of leaf water δ^{18}O by reducing the specific humidity gradients between leaf and air (Figure 4) [*Roden et al.*, 2000, their equation 2]. Together we expect the seasonality of precipitation evaporative isotopic effects on the δ^{18}O of plant water to result in a well-defined cyclicity in the δ^{18}O of α-cellulose formed by tropical trees (Figure 4). Similarly, RLE also predicts that oxygen isotopic measurements should permit the study of interannual climate variability in trees from northwestern coastal Peru (Fig. 4). Analogous to the seasonal cycle hypothesis outlined above, unusually rainy years should be reflected by α-cellulose δ^{18}O values offset lower with respect to the climatological seasonal cycle, and unusually dry years should be reflected by α-cellulose δ^{18}O values offset higher with respect to the climatological seasonal cycle.

In the northwest coastal tropical lowlands of Peru, we expect to see high rates of isotopically-depleted precipitation during ENSO warm phase events. Negligible precipitation during the ENSO cold phase will be relatively isotopically enriched (Figure 4). We further expect to observe evaporative effects that are complementary to this rainfall-driven amount effect: lower evaporative enrichment during rainy, high humidity, low wind periods, and higher evaporative enrichment during dry, high wind intervals (Figure 4). Hence, in addition to providing a chronological tool, high resolution δ^{18}O measurements from tropical trees from the ENSO-sensitive northwest coastal region of Peru should be useful for obtaining paleoclimatic rainfall/humidity estimates [*Evans and Schrag*, 2003].

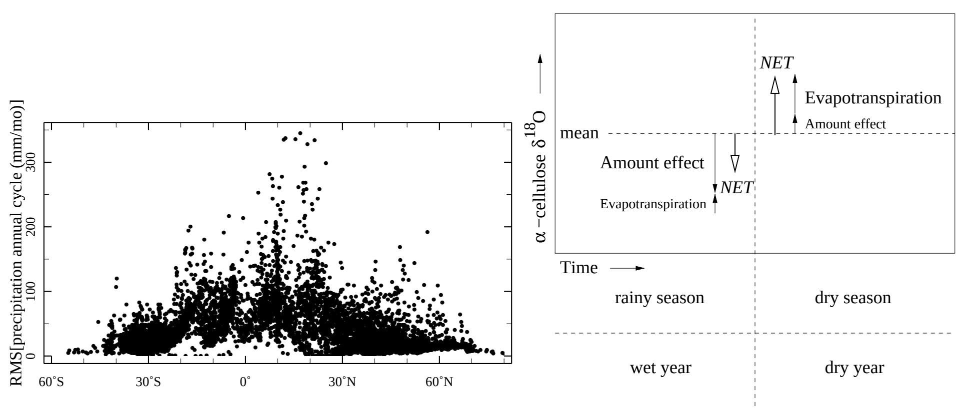

Figure 5: Left: Amplitude of the precipitation seasonal cycle at stations having at least 30 years of monthly observations, as a function of latitude, from *Baker et al.* [1995]. Many of the highest amplitude seasonal cycles are in the terrestrial tropics. Right: Schematic diagram of expected isotopic effects in tropical tree α-cellulose as a function of the annual cycle and interannual variations of tropical convective rainfall (see text for description).

These new data will be developed from promising sites and species identified in a 2002-3 pilot study funded by the University of Arizona (Table 1). Continuing a collaboration begun in that study, Dr. Rodolfo Rodriquez of the Universidad de Piura has agreed to participate in additional sampling expeditions in Peru. He has identified several promising locations for sample generation and is currently making seasonal growth rate measurements on trees from these sites (Table 1). As part of this project we will also try to identify additional sampling sites. We will use the *Brendel et al.* [2000] procedure modified for throughput and sub-milligram sample size [*Evans and Schrag*, 2003] to prepare 200 samples daily for isotopic analysis. Isotopic measurements will be made with a Delta Plus XP continuous flow mass spectrometer coupled to a Costech Analytical ECS4010 pyrolysis reactor modified for high temperature pyrolysis of 100μg organic samples [*Kornexl et al.*, 1999, B. Lavettre, pers. comm., July 2003]. The mass spectrometer, which will be purchased and installed in Fall/Winter 2003-4, will enable generation of multidecadal, replicated isotope data series with external precision of 0.3‰or better.

Table 1: Potential locations and species for isotope dendroclimatology in northwest coastal Peru

Name	Location (lon, lat)	Genus/Species	Common name
Las Lomas	80.6^{o}W, 4.6^{o}S	*Eryotheca ruizii*	Pasaiyo
Chaylo	80.5^{o}W, 4.3^{o}S	*Eryotheca ruizii*	Pasaiyo
Salcecitos	80.7^{o}W, 4.5^{o}S	*Loxopterygium huasango*	Hualtaco
Poechos	80.8^{o}W, 4.4^{o}S	*Bursera graveolens*	Palo Santo
Km 941 Pan-Am Hwy.	80.6^{o}W, 5.5^{o}S	*Capparis angulata*	Sapote
Univ de Piura	80.6^{o}W, 5.2^{o}S	*Prosopis*	Algarrobo

Paleodata interpretation: Forward modeling of stable isotope data from tropical trees

Isotopic data series we generate will be interpreted within the context of the forward model of the oxygen isotopic composition of α-cellulose modified after *Roden et al.* [2000] and *Anderson et al.* [2002]. Here we will seek to transform rainfall and relative humidity variations into simulated isotopic records which can be compared to the actual data we collect (**Paleodata Acquisition**). The RLE model is:

$$\delta^{18}\mathrm{O}_{cx} = f_o\cdot(\delta^{18}\mathrm{O}_{wx} + \epsilon_o) + (1 - f_o)\cdot(\delta^{18}\mathrm{O}_{wl} + \epsilon_o)\ [\mathit{Roden\ et\ al.,\ 2000}] \tag{1}$$

where $\delta^{18}\mathrm{O}_{cx}$ is the isotopic composition of the tree-ring cellulose, $\delta^{18}\mathrm{O}_{wx}$ is the δ^{18}O of tree xylem water, $\delta^{18}\mathrm{O}_{wl}$ is the δ^{18}O of leaf water, and ϵ_o is the isotopic fractionation factor for the enzyme-mediated exchange or addition of oxygen to synthesized cellulose (+27‰) [*Roden et al.*, 2000]. The dimensionless constant weighting term f_o gives the proportion of cellulose oxygen which undergoes exchange with stem or leaf water (≈0.42; [*Roden et al.*, 2000]. The δ^{18}O of stem water does not undergo fractionation during uptake, and is therefore equal to the δ^{18}O of the mixture of ground and meteoric waters that are taken up by the tree through its roots. The δ^{18}O of leaf water, on the other hand, is modified by evaporation in the leaf prior to photosynthetic production of sucrose subsequently used to make xylem α-cellulose.

The first term in the RLE equation for δ^{18}O of α-cellulose can be approximated using rainfall data if we assume that the amount effect is the dominant control on the isotopic composition of rain water in northwest coastal Peru:

$$\delta^{18}\mathrm{O}_{wx} = F_1(P) \tag{2}$$

where F_1 is an empirically determined, local function [*Gat*, 1996], and P is monthly or seasonally-averaged precipitation. Although there are no isotope data from rainwater samples collected in northwest coastal Peru, data from the Galapagos Islands and the Pacific coasts of Costa Rica, Panama, and Ecuador may be representative of the region [*Gat*, 1996], and will be used to construct an amount effect curve for the greater region [*Gat*, 1996; *IAEA/WMO*, 2003]. In collaboration with Dr. R. Rodriguez at the Universidad de Piura, we have set up rainfall collection stations in the Piura vicinity to augment this database.

The second term, representing evapotranspiration at the leaf, cannot easily be determined *a posteriori*. The modification of leaf water δ^{18}O is modeled after *Craig and Gordon* [1965]: fractionation of leaf water is due to equilibrium exchange with atmospheric water vapor and kinetic fractionation due to diffusion through stomata and in the leaf boundary layer. We will investigate using station or high resolution gridded estimates of evaporation to predict the second term of Equation 1, using Equation 1 from *Anderson et al.* [2002]:

$$\delta^{18}\mathrm{O}_{wl} = (1 - f_o)[\epsilon_e + \epsilon_k(1 - h) + h(\delta^{18}\mathrm{O}_{wx} + 8)] + f_o\delta^{18}\mathrm{O}_{wx} \quad (3)$$

where f_o is assumed known and constant as in Equation 1, ϵ_e and ϵ_k are known equilibrium fractionation factors, h is relative humidity, $\delta^{18}\mathrm{O}_{wx}$ is the δ^{18}O of source water, and the δ^{18}O of atmospheric water vapor has been approximated as 8‰ enriched relative to precipitation [*Fairbanks et al.*, 1997].

We will also investigate measuring evapotranspiration indirectly by means of paired measurements of the δ^{18}O and δ^{13}C of wood α-cellulose. The δ^{13}C of plant organic material in arid environments is strongly influenced by stomatal conductance [*Farquhar et al.*, 1982; *Leavitt et al.*, 2002; *Saurer et al.*, 1995], which is in turn proportional to evaporation of water vapor through the stomata [*Duquesnay et al.*, 1998]. However, this approach is problematic if δ^{13}C reflects more generally the plant water stress. Since water stress also depends on soil moisture, δ^{13}C variability may be collinear with the precipitation amount effect we expect to see in the δ^{18}O measurements.

Paleodata assimilation: climate field reconstructions from multiproxy data.

Newly developed proxy rainfall data will be added to high resolution paleodata network employed to reconstruct paleoclimate fields, using robust objective analysis techniques [*Kaplan et al.*, 1998; *Evans et al.*, 2001a, 2002]. In this approach we seek the least squares fit to a statistically-calibrated candidate set of proxy observations and a statistical model of the large-scale patterns of spatial climate field variation, with the constraints weighted by estimates of the observational and model errors, respectively. The equations governing the solution are in *Evans et al.* [2001a]. Given explicit assumptions the analysis produces field and error estimates which may be checked for consistency with prior error assumptions and withheld proxy or direct observations. Proxy data are calibrated against the leading principal components of the target climate field. This permits the proxy data to resolve non-local climate information. For instance, proxy rainfall/humidity data from northwestern coastal Peru are expected to resolve not only local rainfall but also SST in the NINO12 region. We will apply these data to ongoing Pacific basin SST field reconstruction efforts [*Evans et al.*, 2001b].

Previous work has shown [*Kaplan et al.*, 1999; *Evans et al.*, 2001a, 2002] that the major source of uncertainty in paleoclimate reconstruction efforts is the empirically-determined and difficult-to-validate calibration of the proxy observations. We will use process modeling of proxy data to support definition of the statistical calibration and its error estimate [*Bradley et al.*, 2003; *Reichert et al.*, 2003].

Proposed Education Program

Overview

The proposed education program proposed here consists of two modules which contain the following common elements. Lessons from the 2003 NAGT/NSF Workshop on Course Design in the Geosciences[5], July 27-31, 2003 will be used to further sharpen the design of the course I describe below.

1. Clearly-stated course goals and structure [*Allen-King et al.*, 2002].

2. Inquiry-based, active learning [*Mathieu*, 1996; *Ireton et al.*, 1996].

[5]http://www.dlesecommunity.carleton.edu/NAGTWorkshops/coursedesign03/

3. Concise, “response-style” writing assignments [*Mathieu*, 1996]

4. Fewer, in-depth topics [*Allen-King et al.*, 2002].

5. “Authentic” assessment [*Allen-King et al.*, 2002; *Mathieu*, 2003]: Are the students learning what I want them to learn? (Application of concepts in new contexts) [*Mathieu*, 2003].

Topics, Tools and Techniques in Paleoclimate Research

The goals of this course are to

1. Encourage graduate students to consider grand questions in paleoclimatology.

2. Foster collaboration amongst University of Arizona paleoclimatologists.

There are over three dozen faculty and research scientists and about as many students in ten departments at the University of Arizona who do paleoenvironmental research, or work in related fields[6]. However, as is the case for many large universities, there are few mechanisms for bringing scientists together to discuss various disciplinary perspectives on common but multidisciplinary areas of research focus such as paleoclimatology. With the support of the University of Arizona’s Institute of the Study of Planet Earth (See **Supporting Letters**). I would like to develop a course whose larger aim is to foster intramural collaborations which support the study of paleoclimatic dynamics.

I propose to begin this effort by organizing a 1-credit graduate seminar, to be led by invited lecturers selected from UA faculty and research staff involved in paleoclimate research and related supporting fields such as atmospheric science, geosciences, hydroclimatology, biogeochemistry, applied math, and geography. Based on paleoclimate interests expressed by faculty across the University of Arizona, an underlying theme will be chosen to link the seminars, and to encourage continuing participation of the speakers in the full seminar series. As I myself continue to learn about all of the paleoclimate-relevant activity on campus, I will implement ISPE Director Overpeck’s suggestion to compile lecture notes into an online primer on paleoclimate research and techniques at the University of Arizona. This might become a resource for scientists from the UA and beyond, who are interested in but unfamiliar with paleoclimate research, to introduce themselves to the field.

Speakers will be asked to give an hour’s lecture, beginning at a general level with discussion of the paleoclimatological questions at hand, the fundamental principles, assumptions and uncertainties inherent in the disciplinary tools applied to the problem, and a vision for future advances in the topic. Speakers will be encouraged to develop thought experiments and to raise “What if?”-style questions, to develop lively discussion of the various approaches participants might bring to the problem. Student participation will be encouraged by a collaborative, informal meeting tone, and a well-chosen, well-advertised, centrally-located and comfortable venue.

Subsequent offerings in the third and fifth years of the proposed education program will be developed into a 3 point course traveling weekly to major climate/paleoclimate research groups around the University. In addition to the weekly seminar meeting, an additional block of time will be spent in selected laboratory or computational facilities. An in-class exercise will introduce students to the operation of the facility and the reduction of the raw data. The exercise will be designed such that students completing the class will have as product a set of short summaries of the uses of each facility. These will serve as a useful shelf reference as they continue their research programs and consider new measurements or approaches to their chosen research questions, as the course itself will serve as an introduction to the various resources available

[6]See http://www.ispe.arizona.edu/faculty/index.html for a listing.

on campus. Assessment will be via term projects, in which students develop proposals for pilot studies using data collected in at least two research facilities. The best projects will be carried out *gratis*. I expect student-led pilot projects in multiproxy paleoclimatology to be generated by this course.

Introduction to Weather and Climate at Tohono O'odham Community College

A second educational module is designed to teach environmental science in a culturally-sensitive way to students at Tohono O'odham Community College (TOCC; http://www.tocc.cc.az.us). The goals of this project are the following:

1. Produce at least one carefully designed, implemented and assessed science course for Tohono O'odham Community College students in a desired subject area.
2. Provide practical support to TOCC students interested in completing their bachelor's degrees at the UA by formulating such a course to satisfy UA transfer credit requirements.
3. Catalyze further development of the science curriculum at TOCC.
4. Provide opportunities for TOCC students to explore careers in research science through paid summer internships in my research laboratory at the University of Arizona.
5. Give me experience mentoring students from very different traditions and backgrounds from my own.
6. Improve diversity at the Laboratory of Tree-Ring Research and the University of Arizona's College of Science by encouraging Tohono O'odham students to complete 4-year degrees, research internships, and pursue graduate degrees in science.

The idea of teaching earth and environmental science in a culturally-sensitive way at tribal colleges is not new, but would borrow general principles from Steven C. Semken at Diné (Navajo Community) College in Shiprock, New Mexico [*Semken*, 2001]. These principles were described in a seminar given by Dr. Semken at the 2002 NAGT-NSF Workshop for Early-Career faculty in the Geosciences [*Allen-King et al.*, 2002], and I was fortunate to discuss the general sense of this project with him at that workshop.

TOCC began offering courses in 2000 at its campus in Sells, Arizona, about 60 miles west of Tucson. The TOCC mission statement includes the goal of becoming the center of higher education within the 24,000 member Tohono O'odham Nation, and to offer courses that integrate the Tohono O'odham *Himdag*, or Desert People's Way (Table 2), which makes the O'odham Nation unique [*Tohono O'odham Community Action (TOCA)*, 2003; *Tohono O'odham Community College*, 2003]. TOCC currently has 160 enrolled students. There is enthusiastic support for the development of a Himdag-sensitive TOCC course in Weather and Climate from TOCC administrators, whose assistance will be essential to this project's success (see Letters of Support).

Here I propose to develop an introductory course in Weather and Climate whose content is compatible with O'odham Himdag (Table 2).

The exact formulation of course content and structure will be the subject of discussion with TOCC faculty and administration during the first year of the proposed project. Because the course will be developed for TOCC students, ultimately to be taught by TOCC faculty, TOCC will have control over all aspects of the course, and its integration into their present curriculum and future goals. I envision construction of a course in Weather and Climate that will merge common and complementary aspects of Himdag and the "environmental science worldview" (Tables 2 and 3). There appears to be synergy between these "worldviews", which might result in innovative lessons in practical weather forecasting, climate and environmental history of the Southwest, and the study of global climate change. A pilot short course will serve as a testbed for

Table 2: Elements of Tohono O'odham Himdag (Desert People's Way).

Arts (Basketry, contemporary and traditional music, etc.)
Beliefs
Community (Tohono O'odham Community College, Tohono O'odham Nation, Family)
Harvesting, traditional foods and hunting
Language (incorporates songs and ceremonies)
Land, environment, seasons (Winter, Spring, Summer, Fall) and elements (Earth, air, fire, wind)
Medicinal plants
Mobility (walking, running, horses and wagons)
Past, future, a journey in life
Relatives (Akimel O'odham, Hia Ced O'odham, Kinship)
Songs
Storytelling
Spirituality/Religion (Healing, curing and traditional songs)
Sensitivity
Values (respect)
Sources: *Tohono O'odham Community College* [2003], *Tohono O'odham Community Action (TOCA)* [2003].

Table 3: Elements of an Earth and Environmental Sciences "Worldview".

Systems approach[*Kump et al.*, 1999]
Models: process, feedback, coupling, complexity
Spatial scales: Local and regional through global
Temporal scales: Daily, seasonal, annual through geological
"Sense of place": integrated picture of the local natural environment [*Kresan and Burgess*, 2002]
Scientific method: iterative hypothesis testing
Uncertainty: science as process rather than a set of facts
Experimentation: inquiry-based learning: the Earth System as a natural laboratory
Skills: Inference from incomplete and noisy data on a variety of scales
Skills: Qualitative and quantitative reasoning, graphical analysis, abstraction
Skills: Library and internet research, referencing and citation, concise writing, oral argument
Topics: Global change, water resources, biodiversity, climate, population, energy, ...

these ideas, and will be offered as part of a summer enrichment program for Indian students organized by the American Indian Studies Program (AISP) at the University of Arizona (See **Work Plan**). Assessment of student learning will include use of "concept maps", in which graphs are used to demonstrate conceptual understanding, weekly reports on the clarity of course content, and "performance assessments" using practical, in-the-field problems [*Mathieu*, 2003]. Overall, we will design the course to satisfy General Education Physical Sciences Tier I requirements. This goal is intended to make it easy for TOCC students to gain transfer credit for the course should they decide to pursue bachelors' degrees in the Arizona State University System.

This idea has support of TOCC President Bob Martin. At the University of Arizona, AISP Director and Ambassador of the University to Indian Nations, Mary Jo Fox will provide assistance and support. Claudia Nelson, who is the Coordinator of the AISP Community Development Program, has offered close assistance with course development and adaptation to the needs of TOCC students. Bill Fee of the UA General Education Program has promised help with making the course eligible for UA transfer credit. Dr. T.W. Swetnam, Director of the Laboratory of Tree-Ring Research (LTRR), has promised release time for 1 to 3 fall semesters for me to devote to TOCC course development and practice, as well as assistance running field trip visits from TOCC to the LTRR. The 5-year timescale of the CAREER program allows key continuing support as we test ideas, assess outcomes, revise the offering, and develop a product wholly owned by TOCC faculty.

Work Plan

Year 1. Research: Establishment of the isotope lab; first sampling expedition to Peru (June 2004); exploratory data acquisition to determine the most likely sample sets for intensive isotopic data acquisition. Gathering of meteorological data forming basis of process modeling of the stable isotope data. Education: Organization of the seminar version of the paleo-tools course at the University of Arizona (Spring 2004). Discussion with TOCC administration and staff to determine the content and structure of the Weather and Climate course, and to establish Himdag requirements for the course (Spring 2004). I will take TOCC's Introduction to O'odham Culture and History Course. A pilot short course will be offered as part of the summer enrichment program to be run by the American Indian Studies Program at the University of Arizona for local Indian students (Summer 2004). Development and teaching of the first iteration of the TOCC Weather and Climate course (Fall 2004).

Year 2. Research: Development of stable isotope data series from candidate samples from northwest coastal Peru identified in year 1. Replication of the data series, development of chronology, and estimation of chronological error. Process modeling to determine proxy calibration error. Statistical calibration studies using local station meteorological data and regional gridded data products. Identification of future sampling sites and replication needs. Year 2 Education: Evaluation and revision of the first offering of the TOCC Weather and Climate course (Spring 2005). Offering of the second iteration of the course, incorporating improvements in content, structure, and assessment of student learning (Fall 2005). Evaluation of the paleo tools seminar course (Spring 2005); development of an on-line resource for paleoclimatologists at UA (Fall 2005). Development of the 3-unit version of the paleo-tools course involving hands-on laboratory activities. Undergraduate research internships.

Year 3. Research: Development of long, replicated isotopic data series from samples collected in Year 1; development of chronology and error estimates. Second sampling expedition to Peru to further replicate and extend data series (Summer 2006). Manuscript preparation describing results of calibration and replication studies. Education: Evaluation and revision of the second offering of the TOCC Weather and Climate course (Spring 2006). Offering of the third iteration of the course, incorporating improvements in content, structure, and assessment of student learning (Fall 2006). Offering of the second iteration of the paleo-tools course with laboratory component (Spring 2006). Undergraduate research internships.

Year 4. Research: Development of long, replicated isotopic data series from samples collected in Year 3; development of chronology and error estimates. Development of state and phase space portraits of aspects of the ENSO system using historical observations and multiproxy data including newly generated datasets. Education: Evaluation and revision of the third offering of the TOCC Weather and Climate course (Spring 2006). Fourth offering of the course, to be taught solely by TOCC faculty and staff. Assessment of the second offering of the paleo-tools course (Fall 2007). Undergraduate research internships.

Year 5. Research: Analysis of the long-replicated isotopic time series. Analysis of phase and state space portraits. Manuscript preparation describing results and future work. Education: Evaluation of the fourth offering of the TOCC course (Spring 2007). Third offering of the paleo-tools course (Fall 2007). Possible manuscript preparation with TOCC faculty, describing experiences developing and teaching TOCC Weather and Climate course.

References

Allen-King, R., R. H. Macdonald, D. W. Mogk, R. M. Richardson, S. C. Semken, and B. J. Tewksbury, Workshop for Early Career Faculty in the Geosciences: Teaching, Research and Managing your Career, National Science Foundation and National Association of Geophyscience Teachers, William and Mary College, Williamsburg, VA, 2002, prepared handouts and personal notes.

Anderson, D. L. T., and J. Willebrand (Eds.), *Decadal Climate Variability: Dynamics and Predictability*, vol. 44 of *NATO ASI Series I: Global environmental change*, Springer-Verlag, New York, 1996.

Anderson, W. T., S. M. Bernasconi, J. A. McKenzie, M. Saurer, and F. Schweingruber, Model evaluation for reconstructing the oxygen isotopic composition in precipitation from tree ring cellulose over the last century, *Chem. Geol.*, *182*, 121–137, 2002.

Baker, C. B., J. K. Eischeid, T. R. Karl, and H. F. Diaz, The quality control of long-term climatological data using objective data analysis, in *Preprints of AMS Ninth Conference on Applied Climatology, Dallas, TX., January 15-20*, 1995, Data accessed via the LDEO climate server (http://ingrid.ldgo.columbia.edu/SOURCES/.NOAA/.NCDC/.GCPS/).

Berger, W. H., and L. D. Labeyrie (Eds.), *Abrupt Climate Change: Evidence and Implications*, vol. 216 of *NATO ASI Series C: Mathematical and Physical Sciences*, D. Reidel, Dordrecht, 1985.

Biondi, F., A 400-year tree-ring chronology from the tropical treeline of North America, *Ambio*, *30*, 162–166, 2001.

Bradley, R. S., M. Vuille, D. Hardy, and L. G. Thompson, Low latitude ice cores record pacific sea surface temperatures, *Geophys. Res. Lett.*, *30*, 2003, art. no. 1174.

Brand, W. A., High precision isotope ratio monitoring techniques in mass spectrometry, *J. Mass Spectrom.*, *31*, 225–235, 1996.

Brendel, O., P. P. M. Iannetta, and D. Stewart, A rapid and simple method to isolate pure α-cellulose, *Phytochemical Analysis*, *11*, 7–10, 2000.

Brenes, T., Meteorological data at La Selva Biological Station. Long term records since 1957, 2003, on-line public database accessed via Internet, 20 April 2003: http://www.ots.ac.cr/en/laselva/metereological.shtml.

Cane, M. A., A. Kaplan, R. N. Miller, B. Tang, E. C. Hackert, and A. J. Busalacchi, Mapping tropical Pacific sea level: Data assimilation via a reduced state space Kalman filter, *J. Geophys. Res.*, *101*, 22,599–22,617, 1996.

Clark, P. U., R. S. Webb, and L. D. Keigwin (Eds.), *Mechanisms of Global Climate Change at Millennial Time Scales*, vol. 112 of *Geophsyical Monographs*, American Geophysical Union, Washington, D.C., 1999.

Clement, A. C., R. Seager, M. A. Cane, and S. E. Zebiak, An Ocean Dynamical Thermostat, *J. Climate*, *9*, 2190–2196, 1996.

Craig, H., and L. I. Gordon, Deuterium and Oxygen-18 variations in the ocean and the marine atmopshere., in *Proceedings of a Conference on Stable Isotopes in Oceanographic Studies and Paleotemperatures*, edited by E. Tongiorgi, pp. 9–130, Spoleto, Italy, 1965.

Duquesnay, A., N. Bréda, M. Stievenard, and J. L. Dupouey, Changes of tree-ring delta ^{13}C and water-use efficiency of beech (Fagus sylvatica L.) in north-eastern France during the past century, *Plant, Cell and Environment*, *21*, 565–572, 1998, dOI: 10.1046/j.1365-3040.1998.00304.x.

Evans, M. N., and D. P. Schrag, Tracking ENSO with tropical trees: Progress in tropical isotope dendroclimatology, *Geochim. et Cosmochim. Acta*, 2003, submitted.

Evans, M. N., A. Kaplan, and M. A. Cane, Optimal sites for coral-based reconstruction of sea surface temperature, *Paleoceanography*, *13*, 502–516, 1998.

Evans, M. N., A. Kaplan, and M. A. Cane, Intercomparison of coral oxygen isotope data and historical sea surface temperature (SST): Potential for coral-based SST field reconstructions, *Paleoceanography*, *15*, 551–562, 2000.

Evans, M. N., M. A. Cane, D. P. Schrag, A. Kaplan, B. K. Linsley, R. Villalba, and G. M. Wellington, Support for tropically-driven Pacific decadal variability based on paleoproxy evidence, *Geophys. Res. Lett.*, *28*, 3689–3692, 2001a.

Evans, M. N., A. Kaplan, and M. A. Cane, Pacific basin SST reconstruction from coral data: Update through october 2001, in *First ARTS Open Sciences Meeting*, edited by T. Corrège, R. Dunbar, M. Eakin, B. Linsley, and S. Tudhope, p. 34, CLIVAR/IRD/PAGES/NOAA, IRD Research Center, Noumea, New Caledonia, 2001b.

Evans, M. N., A. Kaplan, M. A. Cane, and R. Villalba, Globality and optimality in climate field reconstructions from proxy data, in *Interhemispheric Climate Linkages*, edited by V. Markgraf, pp. 53–72, Cambridge University Press, Cambridge, UK, 2001c.

Evans, M. N., A. Kaplan, and M. A. Cane, Pacific sea surface temperature field reconstruction from coral $\delta^{18}O$ data using reduced space objective analysis, *Paleoceanography*, *17*, 10.1029/2000PA000,590, 2002.

Evans, M. N., K. J. Anchukaitis, M. A. Crimmins, and T. M. Shanahan, ENSO during the Last Glacial Maximum: 2003 Synthesis and Prospects, *Earth and Plan. Sci. Lett.*, 2003, in preparation.

Fairbanks, R. G., M. N. Evans, J. L. Rubenstone, R. A. Mortlock, K. Broad, M. D. Moore, and C. D. Charles, Evaluating climate indices and their geochemical proxies measured in corals, *Coral Reefs*, *16*, S93–S100, 1997.

Farquhar, G. D., M. H. O'Leary, and J. A. Berry, On the relationship between carbon isotope fractionation and the intercellular concentration of CO_2 in leaves, *Austr. J. Plant. Phys.*, *9*, 121–137, 1982.

Fedorov, A. V., and S. G. H. Philander, A stability analysis of tropical ocean-atmosphere interactions: Bridging measurements and theory for El Niño, *J. Clim.*, *14*, 3086–3101, 2001.

Fritts, H. C., *Reconstructing large-scale climatic patterns from tree-ring data: A diagnostic analysis*, University of Arizona Press, London, 1991.

Fritts, H. C., E. A. Vaganov, I. V. Sviderskaya, and A. V. Shashkin, Climatic variation and tree-ring structure in conifers: Empirical and mechanistic models of tree-ring width, number of cells, cell size, cell-wall thickness and wood density., *Climate Research*, *1*, 97–116, 1991.

Gat, J. R., Oxygen and hydrogen isotopes in the hydrologic cycle, *Ann. Rev. Earth Planet. Sci.*, *24*, 225–262, 1996.

Gill, A. E., *Atmosphere–Ocean Dynamics.*, Academic Press, New York, NY, 1982.

Gu, D., and S. G. H. Philander, Secular changes of annual and interannual variability in the tropics during the past century, *J. Climate*, *8*, 864–876, 1995.

Hoerling, M. P., and A. Kumar, The perfect ocean for drought, *Science*, *299*, 691–694, 2003.

IAEA/WMO, Global Network of Isotopes in Precipitation. the GNIP database., *Tech. rep.*, International Atomic Energy Agency, 2003, accessed via Internet, July 2003: http://isohis.iaea.org.

Ireton, M. F. W., C. A. Manduca, and D. W. Mogk, *Shaping the Future of Undergraduate Earth Science Education: Innovation and Change Using an Earth System Approach*, American Geophysical Union, Washington, D.C., 1996, accessed via Internet, July 2003: http://www.earthscape.org/t3/nsf02/nsf02.html.

Kaplan, A., Y. Kushnir, M. A. Cane, and M. B. Blumenthal, Reduced space optimal analysis for historical datasets: 136 years of Atlantic sea surface temperatures, *J. Geophys. Res.*, *102*, 27,835–27,860, 1997.

Kaplan, A., M. A. Cane, Y. Kushnir, A. C. Clement, M. B. Blumenthal, and B. Rajagopalan, Analyses of global sea surface temperature 1856-1991, *J. Geophys. Res.*, *103(C9)*, 18,567–18,589, 1998.

Kaplan, A., M. A. Cane, and Y. Kushnir, Reduced space approach to the optimal analysis of historical marine observations: Accomplishments, difficulties, and prospects, in *Preprints, CLIMAR 99, WMO Workshop on Advances in Marine Climatology*, pp. 275–283, Vancouver, Canada, 1999.

Karspeck, A. R., and M. A. Cane, Tropical Pacific 1976-77 climate shift in a linear, wind-driven model, *J. Phys. Oceanogr.*, *32*, 2350–2360, 2002.

Kornexl, B. E., M. Gehre, R. Höfling, and R. A. Werner, On-line δ^{18}O measurement of organic and inorganic substances, *Rapid Comm. in Mass Spectr.*, *13*, 1685–1693, 1999.

Kresan, P. L., and T. L. Burgess, Geos 195d: A Sense of Place: Spring 2003 Course Advertisement, 2002, available via Internet: http://www.ltrr.arizona.edu/˜ic/nats101c/geos195d.html.

Kump, L. R., J. F. Kasting, and R. G. Crane, *The Earth System*, Prentice Hall, Upper Saddle River, NJ 07458, 1999.

Kushnir, Y., R. Seager, J. Miller, and J. C. H. Chiang, A simple coupled model of tropical Atlantic decadal climate variability, *Geophys. Res. Lett.*, *29*, DOI: 10.1029/2002GL015,874, 2002.

Leavitt, S. W., W. E. Wright, and L. A., Spatial expression of ENSO, drought, and summer monsoon in seasonal delta C-13 of ponderosa pine tree rings in southern Arizona and New Mexico, *J. Geophys. Res.-Atm.*, *107(D18*, 2002, doi:10.1029/2001JD001312.

Linsley, B. K., L. Ren, R. B. Dunbar, and S. S. Howe, ENSO and decadal-scale climate variability at 10^{o}N in the Eastern Pacific from 1893-1994: A coral-based reconstruction from Clipperton Atoll, *Paleoceanography*, *15*, 322–325, 2000.

Luis, C. S., M. N. Evans, and J. E. Cole, Character of the 2002-3 ENSO warm phase event: A state space perspective, *Clim. Dyn.*, 2003, in preparation.

Mann, M. E., R. S. Bradley, and M. K. Hughes, Global temperature patterns over the past five centuries: Implications for anthropogenic and natural forcing of climate, *Nature*, *392*, 779–787, 1998.

Markgraf, V. (Ed.), *Interhemispheric Climate Linkages*, Cambridge University Press, New York, 2001.

Mathieu, R., *National Science Education Standards*, National Academies Press, Washington, D.C., 1996, accessed via Internet, July 2003: http://www.nap.edu/html/nses/.

Mathieu, R., *Field-tested Learning Assessment Guide (FLAG)*, National Institute for Science Education, University of Wisconsin-Madison, Madison, WI, 2003, accessed via Internet, July 2003: http://www.flagguide.org/.

National Research Council Committee on Abrupt Climate Change, *Abrupt Climate Change: Inevitable Surprises*, National Academies Press, Washington, D.C., 2002.

Peixoto, J. P., and A. H. Oort, *Physics of Climate*, American Institute of Physics, 1992.

Pierrehumbert, R. T., Climate change and the tropical Pacific: The sleeping dragon wakes, *PNAS*, *97*, 1355–1358, 2000, accessed via Internet: http://www.pnas.org/.

Ponomareva, E., Peru: El Niño Floods, *Tech. rep.*, Center for International Disaster Information, Geneva, Switzerland, 1998, media release accessed via Internet, July 20, 2003: http://www.cidi.org/disaster/98a/0088.html.

Poussart, P. F., and D. P. Schrag, Multi-decade high-resolution cellulose oxygen isotope records from Indonesian and Thai trees: Environmental and physiological insights, *Earth and Plan. Sci. Lett.*, 2003, submitted.

Ramanathan, V., and W. Collins, Thermodynamic regulation of ocean warming by cirrus clouds deduced from observations of the 1987 El Niño, *Nature*, *351*, 27–32, 1991.

Reichert, B. K., M. N. Evans, A. Kaplan, E. A. Vaganov, M. K. Hughes, and M. A. Cane, A process-modeling approach to paleoclimatic interpretation of tree-ring data, *Climate Dynamics*, 2003, in preparation.

Reynolds, R. W., A real-time global sea surface temperature analysis, *J. Climate*, *1*, 75–86, 1988.

Roden, J. S., and J. R. Ehleringer, Observations of Hydrogen and Oxygen isotopes in leaf water confirm the Craig-Gordon model under wide-ranging environmental conditions, *Plant Physiology*, *120*, 1165–1173, 1999a.

Roden, J. S., and J. R. Ehleringer, Hydrogen and oxygen isotope ratios of tree-ring cellulose for riparian trees grown long-term under hydroponically controlled environments, *Oecologia*, *121*, 467–477, 1999b.

Roden, J. S., and J. R. Ehleringer, Hydrogen and oxygen isotope ratios of leaf water and tree-ring cellulose for field-grown riparian trees, *Oecologia*, *123*, 481–489, 2000.

Roden, J. S., G. Lin, and J. R. Ehleringer, A mechanistic model for interpretation of hydrogen and oxygen ratios in tree-ring cellulose, *Geochimica et Cosmochimica Acta*, *64*, 21–35, 2000.

Saurer, M., U. Siegenthaler, and F. Schweingruber, The climate carbon isotope relationship and the significance of site conditions, *Tellus*, *47B*, 320–330, 1995.

Semken, S. C., An indigenous physical geology course for Navajo undergraduates, in *Abstracts, GSA Joint Annual Meeting of the 53rd and 35th Sections*, p. Abstract #6183, Albuquerque, New Mexico, 2001, accessed online at: http://gsa.confex.com/gsa/2001RM/finalprogram/abstract_6183.htm, 17 July 2003.

Shashkin, A. V., and E. A. Vaganov, Simulation-model of climatically determined variability of conifers annual increment (on the example of common pine in the steppe zone), *Russ. J. Ecol.*, *24*, 275–280, 1993.

Stahle, D. W., Useful strategies for the development of tropical tree-ring chronologies, *IAWA J.*, *20*, 249–253, 1999.

Sternberg, L. S. L., and M. J. DeNiro, Biogeochemical implications of the isotopic equilibrium fraction factor between oxygen atoms of acetone and water, *Geochim. Cosmochim. Acta*, *47*, 2271–2274, 1983.

Stokes, M. A., and T. L. Smiley, *An Introduction to Tree-Ring Dating*, University of Arizona Press, Tucson, AZ, 1968, reprinted 1995.

Strogatz, S. H., *Nonlinear dynamics and chaos with applications to physics, biology, chemistry and engineering*, Addison-Wesley, New York, 1994.

Sugihara, G., and R. M. May, Nonlinear forecasting as a way of distinguishing chaos from measurement error in time-series, *Nature*, *344*, 734–741, 1990.

Timmerman, A., J. Oberhuber, A. Bacher, M. Esch, M. Latif, and E. Roeckner, Increased El Niño frequency in a climate model forced by future greenhouse warming, *Nature*, *398*, 694–697, 1999.

Tohono O'odham Community Action (TOCA), Community web pages, 2003, accessed via Internet, July 18, 2003: http://www.tocaonline.org/homepage.html.

Tohono O'odham Community College, *College Catalog 2003-2004*, Tohono O'odham Community College, P.O. Box 3129, Sells, Arizona 85634, 2003, internet: http://www.tocc.cc.az.us.

US Climate Change Science Program, Strategic plan for the climate change science program, *Tech. rep.*, US Climate Change Science Program, Washington, D.C., 2002, accessed via Internet: http://www.climatescience.gov/Library/stratplan2003/default.htm.

Vaganov, E. A., Unpublished Russian tree-ring width chronology data, 2002, pers. comm.

Villalba, R., R. D. D'Arrigo, E. R. Cook, G. Wiles, and G. C. Jacoby, Decadal-scale climatic variability along the extra-tropical western coast of the Americas over past centuries inferred from tree-ring records, in *Interhemispheric Climate Linkages*, edited by V. Markgraf, pp. 155–172, Cambridge University Press, Cambridge, UK, 2001.

Watson, R. T., and the IPCC Core Writing Team (Eds.), *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, New York, 2001, 398 pp.

Xie, P.-P., and P. A. Arkin, Analyses of Global Monthly Precipitation Using Gauge Observations, Satellite Estimates, and Numerical Model Predictions, *J. Climate*, *9*, 840–858, 1996.

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Evans, M.N. A. Kaplan, and M.A. Cane, 2002: Pacific sea surface temperature field reconstruction from coral δ^{18}O data using reduced space objective analysis, *Paleoceanography*, 17, 10.1029/2000PA000590.

Evans, M.N., M.A. Cane, D.P. Schrag, A. Kaplan, B.K. Linsley, R. Villalba, and G.M. Wellington, 2001: Support for tropically-driven Pacific decadal variability based on paleoproxy evidence, *Geophys. Res. Lett.*, 28, 3689–3692.

Evans, M.N., A. Kaplan, M.A. Cane and R. Villalba, 2001: Globality and Optimality in Climate Field Reconstructions from Proxy Data, in V. Markgraf (ed.), *Inter-hemispheric Climate Linkages*, Cambridge University Press, pp. 53–72.

Evans, M.N. A. Kaplan, and M.A. Cane, 2000: Intercomparison of coral oxygen isotope data and historical SST: Potential for coral-based SST field reconstructions, *Paleoceanography*, 15, 551-563.

Five other:

Bond, G. C., B. Kromer, J. Beer, R. Muscheler, M. N. Evans, W. Showers, S. Hoffman, R. Lotti-Bond, I. Hajdas, and G. Bonani, Persistent Solar Influence on North Atlantic Climate During the Holocene, *Science*, 294, 2130–2136, 2001.

Black, D.E., L.C. Peterson, J.T. Overpeck, A. Kaplan, M.N. Evans, and M. Kashgarian, M., Eight centuries of North Atlantic Ocean Atmosphere variability, *Science*, 286, 1709–1713, 1999.

Evans, M.N., A. Kaplan, and M. A. Cane, Optimal sites for coral-based reconstruction of sea surface temperature, *Paleoceanography*, 13, 502–516, 1998.

Evans, M.N., R.G. Fairbanks, and J.L. Rubenstone, The thermal oceanographic signal of ENSO reconstructed from a Kiritimati Island coral, *J. Geophys. Res.*, 104, 13,409–13,421, 1999.

Evans, M.N., R.G. Fairbanks, and J.L. Rubenstone, A proxy index of climate teleconnections from the central equatorial Pacific, *Nature*, 394, 732-3, 1998.

Synergistic Activities

Leader: Preparing for an Academic Career in the Geosciences: A workshop for graduate and post-doctoral fellows (R. H. MacDonald and R.W. Dunbar, organizers), Stanford University, Stanford, CA, August 14-17, 2003.

Member: Biogeochronology Science Plan Working Group, Earth Surface Processes Research Insitute, USGS/University of Arizona, 2003.

Mentor: Fundamentals in Science Research Program, Elizabeth Sciacca, Our Lady of Victory Academy/SUNY-Albany, Dobbs Ferry, NY (2000-2002); Advisor on Intel Science Competition project.

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Facilities, equipment and other resources

Full support for this project is in place at the University of Arizona. A stable isotope mass spectrometry laboratory has just been funded and will be set up by the middle of year 1 of the project. Capabilities include carbon and oxygen analyses of organic, carbonate and water samples. Two networked dual processor linux workstations (Pentium II Xeon, Power Macintosh G4 processors) are available for the project, as are networked color and black-and-white laser printers, through the Laboratory of Tree-Ring Research's intranet. Administrative support is from LTRR support staff.