WORKSHOP ON

Climatic Changes in the Last 1500 Years: Their Impact on Pacific Islands

East–West Center, University of Hawaii at Manoa
Honolulu, Hawaii

November 13–14, 2007
AGENDA

Tuesday, November 13

08:00  *Transportation to East-West Center*

08:30  *Onsite registration*

09:00  Welcome and Introduction — Jay McCreary, Henry Diaz

Session 1. *Paleoenvironmental studies: archives, proxy records, pre-history, and early history of Pacific Island societies*

09:15  *A Shock to the system: Climatic disruption of Pacific Island societies around AD 1300*  Patrick Nunn

10:00  Environmental change and cultural response in the Pacific Islands over the last millennium  Simon Haberle

10:45  *Coffee Break*

11:10  Temperature and hydrology of the central Tropical Pacific during the last millennium: Testing the "ENSO-like" paradigm on decadal to centennial variability  Kim Cobb

11:45  Large climate changes in the Tropical Pacific during the last millennium from sedimentary lipid D/H Ratios  Julian Sachs

12:20  *Lunch*

13:40  1500-year climate and environmental ice-core records from the Tropical Pacific Rim  Lonnie Thompson

14:15  A history of ENSO events since A.D. 1525: Evidence from tree-ring, coral, ice-core, and documentary paleoarchives  Joëlle Gergis

15:50  *Adaptation of paleoclimate reconstructions for interdisciplinary research*  Oliver Timm

16:25  *Coffee Break*

16:45  Exploring the spatial patterns of changing surface ocean conditions in the Tropical Atlantic and Pacific  Hali Kilbourne
Session 2. *The modern climate record and modeled climates of the Pacific Island region*

17:20 Why we might expect Medieval climate change in the western Tropical Pacific  
*Nick Graham*

17:55 *Adjourn for the day*

18:00 *Reception at Queen Lili’uokalani Center, University of Hawaii at Manoa*

20:30 *Transportation to Hotel*

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**Wednesday, November 14**

08:30 *Transportation to East-West Center*

09:00 *Announcements and Brief Review*

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Session 2. *The modern climate record and modeled climates of the Pacific Island region (continued)*

09:10 The monsoon circulation, typhoon activity, and island rainfall in the western North Pacific during the past 50 years: Recurring patterns and extreme events  
*Mark Lander*

09:45 The role of ENSO in regulating its background state  
*Dezheng Sun*

10:20 The role of internally generated megadroughts and external solar forcing in long-term Pacific climate fluctuations  
*Jerry Meehl*

10:55 *Coffee Break*

11:20 What role can climate models play in understanding the Pacific climate history?  
*Caspar Ammann*

11:55 ENSO's sensitivity to past and future climate change  
*Axel Timmermann*

12:30 Tropical Indian Ocean SST and Northern Hemisphere circulation  
*H. Annamalai*

13:05 General Discussion and Wrap-up

13:15 *Workshop ends – Lunch Break*

14:45 Guided tour at the Ulupo Heiau/Kawainui Marsh: Introduction into its geological and cultural history (Speakers: Dr. Chuck Burrows, president of 'Ahahui Malama i ka Lokahi', Dr. Paul Brennan, archaeologist).

17:30-18:30 Return transportation to Hotel
Workshop on

Climatic Changes in the Last 1500 Years: Their Impact on Pacific Islands

Background

Recent studies highlight the strong nexus between human behavior and natural hazards in causing what are known as “natural” disasters. Most disasters involve increased vulnerability to natural hazards as a consequence of human actions—see, for example, *Catastrophe and Culture: The Anthropology of Disaster* (S. M. Hoffman and A. Oliver-Smith (eds.), School of American Research Press, 2002). The literature is quite extensive in suggesting that climate fluctuations on regional to continental scales have had profound impacts on many ancient societies [see, e.g., P. Nunn (1999)1, R. Grove and J. Chappell [eds.] (2000)2. M. Davis (2001)3, B. Fagan (2003)4]. These effects take a variety of forms, and operate through famine, disease, and social upheaval commonly through the agency of environmental transformation. Historical and archaeological research has highlighted cases in which profound societal changes are associated temporally with major climatic anomalies. At the same time, what is now known as “Historical Disaster Research” with an emphasis on the human dimensions of disasters has also advanced, establishing that it is often difficult to establish that cultural shifts are a response to climate changes because the timing of these cannot usually determined accurately.

Over the past couple of decades, a large amount of high-resolution paleoclimate research has been undertaken using tree rings, tropical corals, speleothems from cave deposits, and other natural archives (K.D. Alverson, R.S. Bradley, and T.F. Pedersen (eds.), 20035). This research demonstrates that large-scale climatic phenomena, such as the El Niño-Southern Oscillation (ENSO), and other modes of inter-annual, decadal, and longer-scale climate variability, can have profound and widespread effects on the climate of many regions of the globe (Diaz and Markgraf, eds., 20006). The ENSO phenomenon has been identified as the major factor controlling climate variation in the circum-Pacific region on multiple time scales (Nichols, 19887).

There have been significant advances in understanding the nature and causes of climatic variations, as well as substantial progress in establishing the timing of severe and prolonged climatic anomalies detected in the paleorecord. At the same time modeling studies have shown promise in simulating inferred climate patterns for different times in the past. Paleorecords can be calibrated with socially relevant variables such as seasonal precipitation,

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1 Environmental Change in the Pacific Basin. Wiley, Chichester UK.
stream flow, and crop yields. Determination of the precise timing of significant climatic events during the course of the past millennium, together with exploratory climate model simulations of key periods of climatic instability in the past allow robust interpretations of climate-culture interactions during those times.

There is a significant amount of published work on the impact of natural climate-driven events in the tropical Pacific Islands region, in particular with regards to a major reconfiguration of climate patterns around AD 1300 (cooling of equatorial Pacific SST, changes in sea level, rainfall shifts, etc.). Recent work with equatorial Pacific corals indicates that SST during the so-called Medieval Warm Period (MWP) in the central and eastern equatorial Pacific may have been as much as 2°C below modern averages, while the western Pacific may have been as much as 1.5°C above modern averages. Surface temperatures cooled rapidly after about AD 1300 as the global climate cooled during the Little Ice Age (LIA). It has been shown that these rather large changes in the climate of the region had large impacts in other regions of the world through the process of atmospheric teleconnections, such that during the MWP, severe and sustained drought affected Central America and the western US.

We propose to bring together anthropologists, historians, and paleo-climatologists to examine the available data from well-dated prehistoric/historic cultures and paleo-environmental records throughout the Pacific Islands. The objective will be to identify accurately the timing of sustained, severe climatic conditions, e.g., prolonged drought, over the past 1500 years or so. We note that a workshop to explore similar interactions between human society and climate, with the emphasis on climatic events and culture in the Americas was held in spring of 2005; a special issue of the journal *Climatic Change* focused on this topic was published in July of 2007 (see footnote 10).

**Approach**

Hypotheses about major climate changes that are thought to have had pivotal roles in shaping societal responses, possibly including cultural collapses, have been recorded in many of the proxy records that have been developed in the last couple of decades. Advances in paleoclimate reconstruction, climate modeling and geoarchaeological work suggest a continuing need to promote a dialogue and collaboration among the various disciplines involved in climatology, paleoclimatology, historical, anthropological and archaeological analysis.

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We propose to convene an interdisciplinary workshop of climatologists, paleo-climatologists, anthropologists, archaeologists, and historians working in the Indo-Pacific to accomplish the following goals:

• Define the history of extreme annual, decadal, and multi-decadal droughts in the main cultural areas of the region, with the highest dating accuracy and precision possible. Evaluate the registration of these drought events in multiple historical and paleoclimate proxies.

• Evaluate the pre-instrumental, record of ENSO events in the context of the high-resolution regional paleoclimate records from the region, such as tree rings, ice cores, etc.

• Explore means to incorporate high-resolution paleorecords to define periods of persistent and anomalous climate that could be independently, or by means of teleconnections and model simulations be related to ENSO variability in the last 1500 years.

• Attempt to understand the history of sea-level changes in the Pacific over the past 1500 years and agree the likely effects of these changes on coastal societies in the Pacific Islands.

These major goals and objectives are illustrated schematically below:
Key Workshop Questions

What do we know about climate patterns during the MWP & LIA? How different are they from the 20th Century?

What do we know about socioeconomic changes during that time?

Can a better understanding of climate-society interactions during the MWP-to-LIA epochs help us plan for future climate change effects?
What Role Can Climate Models Play in Understanding the Pacific Climate History?

Caspar Ammann

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Abstract

This contribution attempts to develop guidance to the problem of recognizing past Pacific Basin-wide climate variability and to its geophysical understanding. The latest reconstruction methodologies that are suitable for a regional field reconstruction are presented, and minimum requirements for successful basin-wide pattern recognition are identified. These are then compared with the proxy record covering the past centuries to evaluate how much of true climate variability is likely to be within our reach. The second part then explores the question of what part of the variability is system inherent, quasi-periodic or quasi-random, and what fluctuations would—in theory—be "predictable" (in a hindcast way) if we include our knowledge of external forcing factors on the climate system. The latter, which are they themselves reconstructed, are the key to understanding the historical climate and for linking past cultural hardship or collapse to the relevant climate variations in cases where such a link indeed exists. Based on consistent impacts in the past, one can then test climate models if they are able to reproduce the dominant processes that drive the basin-wide variability in a similar fashion. Only based on successful comparison of real world with model response can one then use the model to evaluate how future climate changes might affect the basin and its surroundings. One general question is if climate models are in fact capable of generating the full range of variability as indicated by the proxy records, and more specifically, if the models can actually reproduce conditions that were involved in causing hardship or even cultural collapse.
Tropical Indian Ocean SST and Northern Hemisphere Circulation

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Abstract

Two atmospheric general circulation models (AGCMs), differing in numerics and physical parameterizations, are employed to test the hypothesis that El Niño-induced sea surface temperature (SST) anomalies in the tropical Indian Ocean impact considerably the Northern Hemisphere extratropical circulation anomalies during boreal winter (JFM +1) of El Niño years. The hypothesis grew out of recent findings that ocean dynamics influence SST variations over the Southwest Indian Ocean (SWIO), and these in turn, impact local precipitation.

Model solutions reveal that the root-mean-square error in the simulated 500hPa height anomalies over the Pacific North American sector is substantially reduced when the contribution from tropical Indian Ocean SST anomalies are considered together with those from the tropical Pacific (Annamalai et al. 2007, J. Climate). Motivated by these findings, Annamalai and Hafner (manuscript in preparation) further investigated if the SWIO SST anomalies impact rainy days in Hawaii during El Niño winters. They performed ensemble simulations with the MM5 regional model for which lateral boundary conditions from ECHAM5 simulations were used. They compared the model solutions with observed daily station rainfall data over the Hawaiian Islands, global daily OLR, and reanalysis products. Both model solutions and observational diagnostics indicate that intense rainfall events over the Hawaiian Islands could well be due to circulation anomalies forced by SWIO SST anomalies.
Temperature and Hydrology of the Central Tropical Pacific During the Last Millennium: Testing the "ENSO-like" Paradigm On Decadal To Centennial Variability

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Abstract
Coral data suggests that ocean-atmosphere interactions in the tropical Pacific played a key role in the centennial-scale climate anomalies observed in the circum-Pacific during the last millennium. Specifically, the Medieval Warm Period was characterized by cooler/drier mean conditions in the central tropical Pacific, reminiscent of La Niña-like conditions, which would have dramatic consequences for precipitation patterns throughout the Pacific basin. Conversely, a series of very strong El Niño events occurred during the Little Ice Age, perhaps contributing to an overall reduction in the tropical Pacific zonal SST gradient. New coral Sr/Ca data allow for the separation of sea surface temperature (SST) and hydrological anomalies during these key intervals of climate, providing for a rigorous test of the assumption that cool SSTs are accompanied by dry conditions during the MWP, and vice versa during the LIA. Furthermore, quantifying the SST changes that occurred in the central tropical Pacific during the MWP and LIA is critical to developing an accurate dynamical framework for these climate extremes, including the strength of teleconnected responses in the circum-Pacific and beyond.
A History of ENSO Events Since A.D. 1525: Evidence From Tree-Ring, Coral, Ice-Core, and Documentary Palaeoarchives

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Abstract

Climatic extremes including drought, flooding, bushfires, dust storms and tropical cyclone activity across vast areas of the Earth are modulated by fluctuations in El Niño-Southern Oscillation (ENSO). Despite significant advances in the reconstruction of global temperatures of the past millennium, relatively little attention has focused on the apparently anomalous ENSO behaviour witnessed in recent decades.

The lack of ENSO-sensitive proxies for the Southern Hemisphere has meant that data used for previous ENSO reconstructions have been geographically biased toward East Pacific teleconnection regions, with little representation of sites influenced by the western Pacific warm pool. This research represents the first large-scale Southern Hemisphere effort to reconstruct ENSO using an expanded network of recently developed western Pacific palaeoarchives.

Here we introduce the Coupled ENSO index (CEI) as a baseline for the calibration and inter-comparison of proxy records. The CEI is a composite index for the identification of both atmospheric (Southern Oscillation Index) and oceanic (Niño 3.4 region SST) anomalies. Since the CEI maintains information about both ENSO components, the examination of decoupled events, and/or the presence of lead/lag event signatures from proxy records are possible. Of the observational ENSO events identified using the CEI, 50% of all extreme events occurred in the post-1970 period.

To assess whether late 20th century ENSO variability was unprecedented within existing palaeoarchives, high-resolution proxy-climate records (tree-ring, coral, ice-core and documentary) from Western and Eastern Pacific locations were examined to isolate signals associated with both phases of ENSO. A number of threshold dependent ENSO reconstructions were investigated to allow late 20th century ENSO variability to be assessed from multi-centennial reconstructions with various degrees of certainty. Methods for the quantification of event magnitude and reconstruction uncertainty for both ENSO phases are discussed.

A total of 92 (82) El Niño (La Niña) events were reconstructed since A.D. 1525, expanding upon the discrete ENSO event chronologies provided by previous researchers. Significantly, we introduce the most comprehensive La Niña event chronology compiled to date. This record now provides an independent means of verifying model simulations, continuous palaeo-reconstructions of ENSO indices, and is of use to archaeologists and social scientists interested in human responses to climatic events.

A marked change in the frequency and intensity of ENSO begins ~A.D. 1850, coinciding with the end of the Little Ice Age (LIA) and the boom in global industrialisation. Although extreme ENSO events are seen throughout a 478-year discrete event analysis, 43% of extreme, 20% of very strong and 28% of all protracted ENSO events occur within the 20th century. Of the total number of extreme event years reconstructed, 30% of all reconstructed ENSO event years occur post-1940 alone suggesting that recent ENSO variability appears anomalous in the context of the past five centuries. These results suggest it is likely that ENSO operates differently under natural (pre-industrial) and human-influenced influenced background states. Given the large-scale socio-economic impacts of ENSO events, future investigations into the implications of an increasingly anthropogenically warmed world may have on ENSO are vital.
Why We Might Expect Medieval Climate Change in the Western Tropical Pacific

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Abstract

Proxy evidence from central tropical Pacific corals and from marine sediment cores in the eastern and western tropical Pacific suggest that the base state climate of the tropical Pacific was marked by cooler SSTs (relative to modern) in the central and eastern ocean and warmer SSTs in the western ocean, i.e., something like the modern La Niña state, during Medieval time. Intriguingly, evidence from climate proxies from elsewhere around the Pacific sector, and beyond, indicate regional climate changes consistent with idea of a cool tropical Pacific during the centuries centered around 1000 years BP. Perhaps the largest and most self-consistent body of such evidence is that for arid conditions and Medieval drought in the western US. These data include tree rings (moisture stress), relict vegetation (low lake levels), sediment core charcoal and tree fire scars (elevated fire frequency), dune mobilization, marine sediment cores (cool coastal SSTs) and estuarine diatoms (increased salinity). In other regions there is evidence for drought in central East Africa, reduced flood frequency in central Chile, and increased European winter temperature, all of which are consistent with a cool tropical Pacific.

A global climate model (GCM) was forced with a pattern of changes in SST designed to be consistent with those seen in the tropical proxy records noted above and with typical patterns seen in modern climate (i.e., El Niño and La Niña variability). Not surprisingly, the results produce changes consistent with many of the proxy records, and further emphasize the fact that any substantial change in eastern equatorial Pacific SSTs would be accompanied by major changes in the climate of the western tropical Pacific. Perhaps most dramatically, these changes include much increased in rainfall (as much as twice modern values) in the off-equatorial western tropical Pacific with corresponding decreases closer the equator and extending into the central equatorial ocean. Using modern climate as a guide, changes in wind patterns and increased sea level (on the order of 10-20 cm) over the western tropical Pacific can also be inferred (again, relative to modern climate).

The proxy climate records suggest that the cool Medieval SSTs warmed (perhaps over a period of a few decades) to values more typical of modern times around AD 1300. If such a shift occurred, it would have been accompanied by major decreases in rainfall and lower sea levels over the western Pacific. Such a climate shift would surely have affected regional cultures and eco-systems. It is interesting to surmise then that this climate shift and the close of the Medieval Climate Anomaly is the root of the widespread and abrupt ecological and cultural changes over the western Pacific (“the A.D. 1300 event”) reviewed by Nunn (2000).

Environmental Change and Cultural Response in the Pacific Islands Over the Last Millennium

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Abstract

To test the hypothesis that abrupt climate change leads to significant cultural responses in the Pacific over the last millennium it is becoming increasingly clear that significant progress in climate quantification and geochronological control is urgently required. The development of high-resolution multi-proxy records of natural and human induced environmental change are essential in order to unravel cause and effect in the palaeoecological and archaeological records. In this paper we present a summary of fine-resolution palaeo-environmental data from the western and eastern Pacific derived from sediment (pollen, insects, charcoal, humification, and XRF analysis) and coral records that point to a high degree of spatial and temporal variability in environmental change in the Pacific over the last millennium. An assessment of archaeological data across this vast region also points to non-linear and variable trajectories in cultural responses to local environmental change over the same time period. The evidence suggests that the greatest challenge faced by the island inhabitants was one created through their own influence on islands ecosystems (soil erosion, land degradation, deforestation and resource depletion), rather than from external influences such as climate change. While notions of heightened vulnerability and even societal "collapse" in the face of rapid environmental change in small islands should not be ignored, this model has tended to overshadow the truly remarkable story of how people adapted and persisted on islands in the Pacific despite the challenges, both created and encountered.
Exploring the Spatial Patterns of Changing Surface Ocean Conditions in the Tropical Atlantic and Pacific

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Abstract

Paleoclimate data are used to explore linkages between climate in the tropical Pacific and Atlantic through time. Recently produced paleoclimate records document conditions in the tropical Atlantic region during the last 1000 years. The most recent 600 years are fairly well understood, but more data are needed for earlier centuries. Multiple lines of evidence from corals, marine sediment cores and sclerosponges indicate that sea surface temperature (SST) in the Caribbean was significantly cooler than today during the 1600s and 1700s. This cool period was preceded by a period of relatively warm SST centered on the early to mid 1500s. Northeastern tropical Pacific SST may have mirrored the Caribbean, at least back to 1700, as shown by a coral δ18O record from Panama.

Relative to a 1900–1950 baseline, 18th century coral geochemical records from around the globe indicate that the southwestern Pacific experienced anomalously warm conditions on average, whereas the Caribbean experienced anomalously cool conditions. Understanding the spatial patterns of climate change is key to testing hypotheses about the mechanisms involved. Potential mechanisms for the observed spatial pattern will be discussed.
The Monsoon Circulation, Typhoon Activity, and Island Rainfall in the Western North Pacific During the Past 50 Years: Recurring Patterns and Extreme Events

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Abstract

Climatic charts of the tropical western North Pacific show weak pressure gradients and light winds throughout the region for all months. This charted tranquility belies substantial month-to-month and year-to-year variations of the wind flow pattern, rainfall distribution, and tropical cyclone activity. For example, the mean surface wind on Guam during the summer months is less than 5 m s$^{-1}$. During some years, however, the southwest monsoon extends to Guam and can be at near-gale force (>30 mph) for a week or more. During August of 1974, a prolonged strong monsoonal flow created hazardous sea conditions that sank a ship (for a $3.3 million loss), and caused many small craft to break mooring and run aground. During other years, such as 1988, the southwest winds of the monsoon do not extend to Guam, or to other islands where they are common. Light easterly winds prevail all the time, typhoon activity is shifted westward towards the Asian mainland, and there are few extreme rainfall events (e.g., greater than 4 inches in 24 hours for Guam). Typhoon activity in the western North Pacific basin undergoes substantial variation in numbers of cyclones, and in the preferred tracks of systems. During 1996, for example, the JTWC numbered 43 cyclones (33 of them were tropical storms or typhoons), and just two years later (1998) the JTWC annual total was 27 numbered cyclones, of which only 18—a record low—were tropical storms or typhoons. For at least 50 years, typhoon activity, the monsoon circulation, and rainfall at several Pacific Island locations has been carefully observed. Substantial variations are noted in all time series. The annual numbers of typhoons and number of intense typhoons have varied by at least a factor of two. The annual rainfall at many island locations has varied by a factor of three (on Guam, the range of the annual rainfall is approximately 50 inches to 150 inches). This report examines the variations of typhoon activity, monsoon flow, and rainfall throughout the tropical western North Pacific, with an emphasis on the islands of Micronesia. The hazards associated with observed climatic extremes of these variables are examined. Possible changes to the typhoon, monsoon, and rainfall climate are discussed in relation to plausible scenarios obtained from an analysis of observed extreme events.
The Role of Internally Generated Megadroughts and External Solar Forcing in Long-Term Pacific Climate Fluctuations

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Abstract

Model studies have shown that a dominant pattern of sea surface temperatures with an alternating El Niño-like and La Niña-like characteristics is an inherent feature of decade-to-decade variability of the Pacific climate system, and is associated with megadroughts in the western U.S. and south Asia. Other modeling studies have demonstrated that the Pacific climate response to increases in solar forcing is a La Niña-like pattern. Therefore, inherent multi-decadal variability and changes in external forcing from the sun can produce similar patterns in the tropical Pacific sea surface temperatures and associated drought conditions over the U.S. and southern Asia. These patterns extend over the entire tropical Pacific, and can influence weather and climate over a very large area. In order to interpret past climate fluctuations in the Pacific region, variability from these natural and inherent sources must be taken into account. An understanding of the processes that produce such patterns can enable us to better account for the timescales and mechanisms associated with tropical Pacific climate variability.
A Shock to the System: Climatic Disruption of Pacific Island Societies Around AD 1300

Patrick D. Nunn

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Abstract

Around AD 1300 the entire Pacific Basin (continental Pacific Rim and oceanic Pacific Islands) was affected by comparatively rapid cooling and sea-level fall, and possibly increased storminess, that caused massive and enduring changes to Pacific environments and societies. This period of rapid change is named the AD 1300 Event. For most Pacific societies, adapted to warmer, drier and more stable climates of the preceding Medieval Climate Anomaly (AD 750–1250), the effects of the AD 1300 Event were profoundly disruptive, largely because of the reduction in food resources available in coastal zones attributable to sea-level fall of 70–80 cm. This disruption was manifested by the outbreak of persistent conflict, shifts in settlements from coasts to refugia inland or on unoccupied offshore islands, changes in subsistence strategies, and an abrupt end to long-distance cross-ocean interaction during the ensuing Little Ice Age (AD 1350–1800). The AD 1300 Event provides a good example of the disruptive potential for human societies of abrupt short-lived climate changes.
Large Climate Changes in the Tropical Pacific During the Last Millennium from Sedimentary Lipid D/H Ratios

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Abstract

The climate of the last millennium was punctuated by two prominent events: the Medieval Warm Period (MWP) from 800-1300 A.D. and the Little Ice Age (LIA) from 1400-1850. The impact of, and evidence for these events derives almost exclusively from the middle latitudes of the Northern Hemisphere continents, largely from tree rings and mountain glaciers. Remarkably little attention has been given to the tropical climate of the last millennium and its potential impact on the middle and high latitudes even though massive fluxes of latent heat, moisture and momentum derive from there. Indeed, proxy records of the ENSO system, the monsoons of Asia and India, and the position of the Intertropical Convergence Zone (ITCZ) indicate that the last 1,000 years were a time of profound change in the tropical climate globally. Here we present evidence from D/H ratios in lipids from lake and ocean sediments in Palau, the Galapagos, and Christmas and Washington Islands (Northern Line Islands) that the LIA was a time of marked change in rainfall patterns. Specifically, our data (1) strongly imply that the ITCZ was poleward of 5 degrees north latitude for at least 2,500 years prior to 1600 A.D., and (2) are consistent with a frequency and/or intensity of El Niño that was high during the Little Ice Age compared to the rest of the last millennium.
The Role of ENSO in Regulating its Background State

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Abstract

A nonlinear aspect of the El Niño—Southern Oscillation (ENSO)--its regulatory effect on the background state (the climatological state)--is described. In particular, it is shown that ENSO acts as a basin-scale heat “mixer” that prevents any significant increase from occurring in the time-mean difference between the warm-pool SST (Tw) and the temperature of the thermocline water (Tc). When this temperature contrast is forced to increase, the amplitude of ENSO increases—El Niño becomes warmer and La Niña becomes colder. A stronger La Niña event results in more heat transported to the subsurface of the western Pacific. A stronger El Niño event then warms the eastern Pacific and cools the western Pacific. The effect of a stronger La Niña event does not cancel the effect from a stronger El Niño event. The long-term mean effect of ENSO—the recurrent occurrence of El Niño and La Niña events--is to mix heat downward across the equatorial Pacific and prevent the time-mean difference between Tw and Tc from exceeding a critical value.

The results have implications for several climatic issues and these implications are discussed. In particular, it is noted that our existing paradigm to understand the response of ENSO to global warming needs to be modified. It is emphasized that it is the tendency in the stability forced by an increase in the greenhouse effect, not the actual changes in the time-mean climate, that ENSO responds to. Changes in the latter—changes in the mean climate—are a residual between the effect of the changes in the radiative forcing and the effect of the changes in the ENSO behavior.
1500-year Climate and Environmental Ice-Core Records from the Tropical Pacific Rim

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Abstract

New ice core records from the 5670 m asl Quelccaya ice cap in Peru provide annual time series of tropical climate and environment variations extending back to 315 AD as recorded in the measurements of oxygen and hydrogen isotopic ratios ($^{18}$O and D) and concentrations of mineral dust and ions of soluble aerosols (fluoride, chloride, nitrate, sulfate, sodium, ammonium, potassium, magnesium and calcium). On the larger scale the record offers a detailed documentation of the conditions in the tropical Andes during the “Little Ice Age” and “Medieval Warming” periods. Moreover, new records from the higher, colder and drier Coropuna ice fields (6450 m asl), 350 km southwest of Quelccaya and only 70 km from the Pacific Ocean, provide much longer but lower resolution histories spanning more than 16,000 years. El Niño-Southern Oscillation (ENSO) variations are pronounced at both sites, but have different signatures. For example, during La Niña events the west side of the Andes where Coropuna is located receives more wet season (November through March) precipitation from the Pacific Ocean, while the consistent source for the precipitation on Quelccaya is the Atlantic Ocean.

On the other side of the Pacific, ice cores recovered from the Dasuopu ice fields (7200 m asl) in the central Himalaya provide a high-resolution record, which reveals that this site is sensitive to fluctuations in the intensity of the South Asian Monsoon. Reductions in monsoonal intensity are recorded by insoluble dust and chloride concentrations. The deeper, older sections of the Dasuopu cores suggest many arid periods in the region, but none have been of greater intensity than the drought of 1790 to 1796 A.D. This event is also prominent in the soluble aerosol record in the Quelccaya and Coropuna cores, suggesting decadal-scale teleconnections between these regions. Only one other comparable chloride event occurs in the last 1700 years and is centered on 1350 AD.

These high-resolution paleoclimate records will be discussed with respect to their similarities and differences over the last 1500 years. Moreover, the $^{18}$O data from the Quelccaya, Coropuna, and Dasuopu cores, when compared with the Niño 4 SSTs since the 1890s, capture the decadal-scale variations in the central tropical Pacific and thus offer the potential for extending the SST record far beyond the instrumental period. The first such climatic reconstructions will be presented and its impacts on Polynesian cultures over the last 1500 years assessed.
Adaptation of Paleoclimate Reconstructions for Interdisciplinary Research

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Abstract

The aim of this talk is to stimulate the interdisciplinary discussion on the problem of how the information exchange between paleoclimatologists and anthropologists, archaeologists, and historians can be improved. This talk introduces the commonly used statistical methods in paleoclimate reconstructions. The basic concepts and statistical models for paleoclimate reconstructions are summarized. The error/uncertainty estimation is discussed. One conclusion is that the 'supplied' reconstruction products are not optimal for interdisciplinary research activities. On the “demand” side a natural interest exists in the uncertainty of paleoclimate information, which is not appropriately satisfied by the reconstruction products. Therefore, this presentation introduces an alternative Bayesian reconstruction approach. The Bayesian reconstruction is illustrated for the ENSO index. The categorical ENSO-index reconstruction is based on a set of coral proxies from the Pacific and the Indian Ocean over the last two centuries. The overlapping period of the coral proxies and the observational ENSO index are used to estimate conditional and prior probabilities for discrete index categories. Given the proxy evidence, the prior probability of the ENSO index categories can be updated for each year where proxies are available. Compared with the standard statistical reconstruction methods the Bayesian reconstruction provides likelihood/uncertainty estimates, which give better guidance in drawing conclusions or making inferences about climatic causes of societal or environmental changes.
Paleo evidence from fossil corals and lake records suggests that ENSO is modulated on orbital timescales. The famous mid-Holocene ENSO suppression, e.g., has been attributed to orbitally-induced background state and annual cycle changes. Using an accelerated orbitally-driven CGCM simulation representing the period from 142,000 years B.P (before present) to 22,900 years A.P. (after present), the fundamental mechanisms are explored that lead to the generation of precessional cycles in the tropics. Due to the mean seasonal cycle of cloudiness in the off-equatorial regions, an annual mean precessional signal of temperatures is generated outside the equator. The resulting meridional SST gradient in the eastern equatorial Pacific modulates the annual mean meridional asymmetry and hence the strength of the equatorial annual cycle. In turn, changes of the equatorial annual cycle trigger abrupt changes of ENSO variability via frequency entrainment, resulting in an anti-correlation between annual cycle strength and ENSO amplitude on precessional timescales.

We furthermore demonstrate that a similar mechanism operates on millennial timescales. Changes of the Atlantic Meridional Overturning Circulation (AMOC), lead to changes of the meridional SST gradient in the eastern tropical Pacific, and hence a modulation of the strength of the annual cycle and via nonlinear frequency entrainment also of ENSO. Analysis of a multimodel-ensemble of “water-hosing” experiments, recently conducted as part of CMIP-2, reveals that a collapse of the AMOC leads to the disappearance of the equatorial Pacific annual cycle and an intensification of ENSO variability.

Both, on orbital and millennial timescales, meridional SST gradients play a crucial role in modulating ENSO variability. Whether this new paradigm is also applicable to future greenhouse warming experiments is still an open question.

Analysis of observational records and reanalysis data suggests that during the second half of the 20th century the equatorial-Pacific intraseasonal surface-wind variability and its nonlinear interaction with the ENSO have intensified substantially. These changes were accompanied by an increase in the ENSO activity and the emergence of a new warm-pool El Niño regime. Using a hierarchy of models we demonstrate that intraseasonal surface-wind variability plays a key role in amplifying the ENSO activity. The recent generation of coupled general circulation models simulates a future enhancement of the intraseasonal surface-wind variability in the equatorial Pacific in response to atmospheric greenhouse gas increase, with potential repercussions for future ENSO activity. However, simulating tropical intraseasonal variability realistically still remains one of the major challenges for state-of-the-art CGCMs.
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