U.S. Atlantic CLIVAR PALEO-TAV Workshop

Developing Paleoclimate Records and Model Experiments for Understanding Tropical Atlantic Variability

Organizers: Larry C. Peterson, RSMAS-University of Miami
John C.H. Chiang, University of California, Berkeley
Jean Lynch-Stieglitz, Georgia Institute of Technology

Summary

This document summarizes discussions held at the one-day PALEO-TAV workshop that followed the CLIVAR Atlantic Science Conference on 3 February 2005 in Miami, FL. The goal of this workshop was to bring together modelers, experts in modern climate dynamics, and paleoclimatologists to discuss the better integration of paleoclimate research into the US CLIVAR Atlantic science program. Though time was limited, it was concluded that paleoclimate data can enhance our understanding of tropical Atlantic variability through: 1) time-slice reconstructions of marine and terrestrial climate variables at key time intervals designed to address patterns of tropical Atlantic climate change; 2) time-series reconstructions from carefully targeted, well dated sites with resolution sufficient to study century to millennial-scale variability and combined with studies using regional climate models; and 3) a review and synthesis of existing tropical Atlantic paleorecords in order to develop one or more internally robust data sets that serve as test targets for climate model studies. For progress to continue, it is recommended that smaller working groups be formed to begin the development of coherent science proposals within each of the identified themes.

Report

With support of the U.S. CLIVAR Office, a one-day PALEO-TAV workshop was held on 3 February 2005 at the Rosenstiel School of Marine and Atmospheric Science (University of Miami). This workshop immediately followed the three-day U.S. CLIVAR Atlantic Science Conference held from 31 January- 2 February on the RSMAS campus. The PALEO workshop was convened in order to bring together a small group of researchers with interests and/or expertise in tropical Atlantic climate variability on pre-instrumental time-scales, divided roughly between data-oriented paleoclimatologists and paleoceanographers, modelers (both paleo and modern), and those interested in modern climate processes. The goal of the workshop was to foster interactions between the modern and paleo communities and to initiate the development of an integrated research plan for studying past variations in the state of the Tropical Atlantic Ocean-Atmosphere system. The exercise was timely given the increased prominence of the tropical Atlantic in the context of abrupt climate change and recent model studies of the climate impacts of changes in the Atlantic's meridional overturning circulation, almost all of which show substantial changes in the tropical Atlantic and in particular the Intertropical Convergence Zone (ITCZ).

The PALEO workshop began with a brief introduction to the goals and objectives of the workshop and was then followed by a series of presentations by the major participants. Speakers were asked to limit their comments to about ten minutes in order to allow time for discussion, and to direct the presentations towards their temporal counterparts; i.e., those working in the modern were asked to pitch their talks to the paleo scientists, and vice versa. Given the limited one-day format, it was fully expected that much of the workshop would be spent in mutual education by the two communities. This was clearly the case as discussions during and after each presentation were lengthy and wide ranging.

Though there was insufficient time at the end of the day to develop a mature implementation plan for how paleo data and modeling can together contribute to a better understanding of tropical Atlantic climate, a number of observations and recommendations emerged from the discussion that will help guide future interactions.

I). Spatial Reconstructions

A central theme that emerged from the discussion was that modelers need more spatial reconstructions produced from paleo-data. In addition, it was emphasized that having information on regional distributions of climate constrained to narrow time-slices, preferably at key periods in the Earth's climate history, is far more useful than having single, widely-spaced records. It has been nearly thirty years since the CLIMAP Project published its well-known reconstruction of global sea surface temperatures (SST) at the Last Glacial Maximum (LGM). However, with the exception of CLIMAP and several more recent efforts to refine LGM SST estimates using improved paleo proxies, there exist almost no global, or even basin-scale, reconstructions that modelers can turn to in order to test model behavior. With the advent of new proxies, increased sample and data coverage, and knowledge gained in the years since CLIMAP, the opportunity exists to develop new, thoughtfully targeted time-slice reconstructions that directly address questions of tropical Atlantic variability.

Many of the abrupt climate events now so well-known from high latitude ice cores have been clearly shown to be recorded in sites in and around the tropical Atlantic (e.g., Cariaco Basin). The nature of the linkage, however, is far from clear and the available proxies and distribution of sites are at present too limited to be able to evaluate key climatic variables and spatial patterns of change that might provide clues to mechanisms. Two interrelated research questions that could be addressed with a focused synoptic mapping effort are:

1) *What was the spatial pattern of changes in tropical Atlantic climate during abrupt climate events of the past?*

2) *What is the response of the hydrological cycle in the tropics to a shutdown of the meridional overturning circulation (MOC)?*

For marine archives such as sediments and corals, the coupled use of new proxies allows for separation of SST and sea surface salinity (SSS) signals. The extraction of SSS signals is especially crucial as SST in tropical regions tend to be significantly smaller than in the extratropics, whereas hydrological changes are far more pronounced. Techniques now also exist to evaluate thermocline structure across the width of ocean basins. On the continents, pollen and geochemical records from lakes and bogs, and isotopic records from cave deposits (speleothems), directly address hydrologic conditions within drainage basins in the past. Nearshore marine settings can integrate both marine and terrestrial signals, including records of riverine run-off that reflect rainfall over the adjacent continent and of upwelling that provides indications of changing wind strength. The availability of new tools and techniques to paleoclimatologists and paleoceanographers opens the door to time-slice reconstructions of multiple climatically important variables.

Our knowledge of present-day climate variability in the tropical Atlantic gives us an initial blueprint towards making spatial reconstructions of past Atlantic climates. Interannual-decadal variations in the tropical Atlantic are dominated by two modes of behavior: 1) the Atlantic 'Nino' which is analogous to the ENSO mode in the tropical Pacific and that involves variations in the Atlantic cold tongue SST and near-equatorial surface circulation, and 2) the 'meridonal' or 'interhemispheric' mode, which is characterized by a meridional gradient in SST and associated cross-equatorial flow. Both modes result in substantive changes to the convective rainfall in the tropical Atlantic and neighboring regions, including northeast Brazil and the equatorial Amazon. Knowledge of these modern modes will help us, on the one hand, to locate key regions for paleoproxy information gathering, and on the other, allow us to make initial guesses of the basin-wide nature of climate given sparse information. This of course hinges on the assumption that the present-day modes are applicable to climate changes in the past, but given our lack of knowledge at this point may be the best way to proceed.

A number of time intervals were discussed as possible targets. During the Younger Dryas Cold Period, for example, good evidence exists for a pronounced reduction in the strength of Atlantic overturning. In the circum-Caribbean region, dry conditions have been interpreted to reflect a southward shift in the mean position of the Intertropical Convergence Zone (ITCZ). In southern Amazonia, indications of wetter conditions at the same time are consistent with a southward redistribution of moisture over the South American continent. Are these hydrologic changes the result of movements of the ITCZ or related instead to changes in the South American monsoon? Is there evidence of a southward shift in the marine ITCZ that can be detected from open marine records? Is there an associated change in the cross-equatorial SST gradients that accompanies this shift? What is the distribution of salinity and how is this impacted by changing inputs from major rivers? Such questions could be answered with a systematic effort to map tropical Atlantic SST and SSS using marine archives, and to couple these with paleohydrologic reconstructions of the adjacent continents. Other time slices of potential interest include the early Holocene (a period of wet conditions over northern South America and in the Sahara), the LGM, and the peak of the last interglacial (~120-125 kyrs BP), a possible analog for a warmer future world.

II). Time-Series Reconstructions

While time-slice reconstructions are key to assessing spatial patterns of change, time-series studies are critical for assessing the patterns of temporal variability and for evaluating linkages between regions. Instrumental data at best allow study of climate behavior at multidecadal time-scales. For many regions of the tropics, long records are sparse; modelers working on the Amazon region, for example, have been limited to modeling interannual variability due to the short duration of the existing instrumental records.

The resolution afforded by geologic archives can be highly variable and there are clear trade-offs between resolution and record length. Corals can offer monthly resolution of near surface conditions but record lengths are typically limited to a few centuries at most. At the other extreme, sediments in the deep open ocean typically accumulate at rates of a few cm per thousand years, providing long records of orbital-scale climate change but little resolution of suborbital variability. That such suborbital variability exists in the tropics is no longer an issue despite long-held perceptions of tropical stability; a small number of high quality paleo records have already clearly shown that variability over 10^2-10^3 year time-scales is an important part of the climate spectrum and that abrupt climate shifts correlative to those in Greenland have a tropical Atlantic expression.

Questions that could be addressed with the focused study of a targeted suite of sites include:

1) *How does climate vary on century to millennial time-scales in key regions that define the present-day modes of tropical Atlantic variability?*

2) *What is the temporal relationship between changes in these key regions and regions outside of the tropical Atlantic, including Greenland, Antarctica, the tropical Pacific, and areas affected by the Asian monsoon? Are the temporal relationships consistent with changes driven by the Atlantic meridional overturning circulation (MOC), or by some other mechanism (like response to a changing tropical Pacific climate)?*

The answers to these questions will come from the acquisition and development of paleo time-series having sufficient resolution to study centennial-millennial variability. A focus should be on the collection of multiple paleo proxies in well-dated sites in order to characterize key environmental measures. It was generally felt that results from intensive investigations of single sites should be combined with studies using regional climate models (RCMs) to investigate potential forcing mechanisms and model sensitivity. It was also recognized that the development of a detailed history of the MOC will be critical to assessing the response of the tropics to potential future changes in Atlantic overturning.

III). Data Syntheses and Quality Control

One of the clearest complaints heard from modelers attending the workshop was that the modeling community often has a hard time assessing the robustness of paleo observations that their model results are asked to be compared to. It was noted that a useful thing for the paleo community to do would be to develop criteria, or some sort of "key test", that would let modelers have an idea of the degree of confidence associated with paleo observations (i.e., what paleo people are sure of, kind of sure of, not so sure of). This would help modelers evaluate the paleo variables that might be altering the outcome of their models when disagreements arise between model results and paleo observations.

It was generally felt that one valuable outcome of this workshop might be to initiate a review of existing tropical Atlantic paleorecords in order to develop a single, more reliable data set that modelers could turn to in order to test their models. One possible way to do this would be to identify and quantify a key set of regional indices that characterize the large-scale structure of the tropical Atlantic. Examples of features that might be focused on include SST in the Atlantic cold tongue, the meridional SST gradient over the equatorial Atlantic, and rainfall over NE Brazil, the Sahel, and the equatorial Amazon. Though the requirement of assessing data quality would of necessity apply as well to all time-slice and time-series reconstructions that might arise as future outcomes of this workshop, attendees recognized that an abundance of data already exist that modelers turn to on a regular basis. In cases where reported observations appear to be contradictory, this may represent real regional variability or differences in the quality of the proxies used. The latter is better assessed by the paleo community, though few systematic efforts to do so have been made.

A final recommendation from this workshop is that a systematic review and evaluation of existing tropical Atlantic paleo data be initiated in order to produce a coherent and internally robust data set that serves as a test target for climate model studies. Given the abundance of data that already exist, the relative ease in identifying the stratigraphic level, and the pronounced climatic contrast with the present, the last glacial maximum (LGM) might be the most appropriate target for such a synthesis. This effort would benefit from recent studies that have re-evaluated tropical SST during the LGM but would incorporate and critically assess other available marine data as well as continental paleo-records from the circum-Caribbean region, South America, and Africa. As future time-slice studies provide new data (e.g., SSS), these could be assessed and incorporated into the test target reconstruction.

The PALEO Workshop was formally adjourned at 5:15 PM. A list of participants is attached as Appendix 1 and a record of discussion is attached as Appendix 2.

Appendix 1

CLIVAR Atlantic Paleo Workshop February 3, 2005

<u>List of Attendees</u> (both whole-day and drop-in visitors)

Dr. Larry Peterson	Rosenstiel School of Marine and Atmospheric Science, University of Miami
Dr. John Chiang	University of California, Berkeley
Dr. Jean Lynch-Stieglitz	Georgia Institute of Technology
Dr. Walter Robinson	University of Illinois, Champaign-Urbana
Dr. Kerry Cook	Cornell University
Dr. Rong Fu	Georgia Institute of Technology
Dr. Athanasios Koutavas	Lamont-Doherty Earth Observatory, Columbia University
Dr. David Black	University of Akron
Dr. Howie Spero	University of California, Davis
Dr. David Hodell	University of Florida
Dr. Peter deMenocal	Lamont-Doherty Earth Observatory, Columbia University
Dr. Yochanan Kushnir	Lamont-Doherty Earth Observatory, Columbia University
Dr. Rong Zhang	Geophysical Fluid Dynamics Lab, Princeton University
Dr. Peter Swart	Rosenstiel School of Marine and Atmospheric Science, University of Miami
Dr. Amy Clement	Rosenstiel School of Marine and Atmospheric Science, University of Miami
Dr. Ping Chang	Texas A&M University

Dr. Wei Cheng	JISAO, University of Washington
Dr. Claes Rooth	Rosenstiel School of Marine and Atmospheric Science, University of Miami

<u>Graduate Students in attendance</u>

Ms. Melany McFadden (Meeting scribe)	Rosenstiel School of Marine and Atmospheric Science, University of Miami
Mr. Christopher Moses	Rosenstiel School of Marine and Atmospheric Science, University of Miami
Mr. Brad Rosenheim	Rosenstiel School of Marine and Atmospheric Science, University of Miami

Appendix 2

CLIVAR Atlantic Paleo Workshop February 3, 2005

Note: The following record of discussion comes from notes taken by the meeting scribe, Ms. Melany McFadden (U. Miami graduate student)

Morning Session

8:45 am Opening Remarks (Peterson)

Workshop Concept: The goal of this one-day workshop is to bring a small group of paleoclimatologists and climate modelers working in the Atlantic together to discuss major science issues centered around tropical Atlantic climate variability. Brainstorm, mutual education, and start to develop an integrated science plan for how paleo-based studies can contribute to CLIVAR goals.

- Paleoclimatologist share favorite Atlantic data sets, summarize what can be done with them (e.g., data limitations), and pose questions that have been raised.
- Modelers discuss model capabilities, share what problems they are facing, educate paleoclimatologists as to what is needed to test models, and identify areas where paleo time-series of climate and ocean variability are most critical for understanding mechanisms.

9:10 am Larry Peterson (UM, RSMAS)
Cariaco Basin

Cariaco = Anoxic basin off northern Venezuela, high sedimentation rates, little or no bioturbation, near-annual resolution, laminated sediments
Sensitive to both regional and global climate change, especially changes in ITCZ
Sediment reflectance (light vs. dark sediment) correlates remarkably well with Greenland ice core $\delta^{18}O$ records back to 90 kyrs ("Tropical ice core equivalent").
Reflectance controlled in part by organic matter production and terrestrial matter input.
Cariaco record is a tropical record that shows abrupt climate changes (e.g., Younger Dryas and D/O events), in phase with polar records within limits of respective age control.
Scanning XRF studies have proven a useful method to determine iron and titanium at high-resolution. This provides a terrigenous/riverine input signal that records the hydrologic balance over northern South America.
Warm Greenland=more riverine input to Cariaco, more rain, average position of ITCZ more to the north.
Cold Greenland= less Riverine input to Cariaco, dry regional conditions, southward shift of ITCZ position.

Conceptual model is that this is merely an amplification of the normal seasonal cycle (i.e., cold stadials, cold Northern Hemisphere, dry Cariaco, southward ITCZ – analog to modern winter).
Change in character of metal records ~4000 years ago, increased amplitude of titanium and iron excursions, with more pronounced dry events= timing correlates with other records which indicate the onset of increased ENSO activity (today El Nino events are dry over Venezuela)
Little Ice Age= Quelccaya Ice Core Record ($\delta^{18}O$) correlates with Cariaco Basin titanium record at the multi-decadal level=cold/wet Cariaco, warm/dry Quelccaya=out of phase- fits with idea of ITCZ shift (or at least with a shifting of locus of precipitation).
This out of phase behavior is observed during the last glacial as well: Cold N. Atlantic stadials= dry Cariaco, but wet further south (Brazil, speleothem records; Lake Titicaca, lake levels).

Mechanism=Cariaco is clearly linked with Greenland, but what is the exact nature of the linkage?
Southward shift of ITCZ during THC collapse – modeled, fits with Cariaco record.
One view: Polar regions and North Atlantic - influence Cariaco through changes in meridional SST gradient, accompanied by strengthening tradewinds and shift of ITCZ.
Alternate view: tropical processes (ENSO?) may play a role by affecting salinity through changing riverine input or by altering moisture loss to Pacific across the Central American isthmus; salinity acquired in Caribbean alters or preconditions THC behavior.

Important to consider seasonality (summer vs winter precipitation) and the influence on river input.
Warmest SST during warmest spring/summer insolation. Important because ITCZ controlled in part by temperature.
South American Monsoon (late Aug to late March) is different from ITCZ circulation!
There is a need to better understand and discriminate between phenomena associated with the ITCZ and processes on land affected more by the South American monsoon.

9:45am John Chiang (UC Berkeley)

Model overview – strengths and weaknesses
Different models produce different gradients, ocean resolution different than land resolution. Ocean vs. land precipitation respond differently and are controlled by different things.
ITCZ/South American monsoon movie: different controls of atmosphere versus ocean conditions.
Control of land precipitation vs. control of oceanic precipitation
Land and ocean controls of precipitation are different, ITCZ is an ocean term
Difference in timing of seasonal extent of ITCZ and Monsoon =June/Dec on Land, Oct/April in Ocean
Tropical Atlantic meridional mode, land precip controlled more by monsoon, but also controlled in part by ocean

Meridional mode= North Atlantic Oscillation is major control
Zonal mode=El Nino like variations are major control, extends onto land

Questions
1) What are the large-scale, preferred modes of climate behavior for the tropical Atlantic as indicated by paleo records?
2) Why is there such a clear link between the tropical Atlantic and North Atlantic as indicated by Cariaco and other records?
3) What is the nature of the relationship between North Atlantic and tropical climate in general?
4) Why is meridional mode a good analog for past changes? (It is the leading mode of behavior on interannual-decadal times, hence a good guess for large scale changes).

ITCZ very sensitive to SST: LGM conditions using AtmosGCM, difference between today and LGM, shows shift of ITCZ southward, much drier Caribbean, cooler SST in Atlantic (more cooling in north tropical Atlantic).
Control of changes in temperature and precipitation in Atlantic is primarily the Ice Sheets
Coupled models seem to have problems with tropical precip and wind records
GCM-global connections,
Land vs. ocean precipitation records. Over land=more precessional controls
Regional vs Ocean models = In South America regional models need to be used to determine recycling of moisture.
SOUTH AMERICA is very difficult to model using GCMs due to great topography contrasts
PMIP LGM simulations = meridional model like response is model dependent, north south gradient exist in all models, but there is great difference in magnitude of difference in SST Modelers need the paleoclimatologists to work out what the magnitude of differences in SST and winds should be.

Open Discussion

Over land = not correct to attribute precip changes to ITCZ - it is the South American Monsoon over land
Control on seasonal variability in Caribbean, monsoon
Caribbean is drier in reality than it is in models. Caribbean is a warm pool. “Glob” of precip, not part of ITCZ
Paleo-Good time resolution, need terrestrial locations or a few ocean basins (Cariaco) for high resolution, complicated systems. Ocean sediments (isolated from land) are lower resolution, but simpler systems.
Important to focus on both land and ocean dynamics.

Modern Climate people must work with paleoclimate people. Need for mesoscale modelers to work with these near terrestrial systems (e.g., Cariaco).

10:30 am Rong Fu (Georgia Tech)

Overview of TAV and climate variability of South American Monsoon
East-south America and northeast= connected to Atlantic ITCZ, western South America (Amazon) is more isolated from oceanic forcing .
Amazon=wet season, variability in onset, trade-wind changes
MODEL=Rainfall seasonality: in austral spring is dominated by TA SST/Altantic ITCZ, removal of TA SST seasonal cycle leads to semi-annual (instead of annual) seasonal patterns in E Amazon
Rainfall climatology in W. Amazon (seasonal, interannual) is relatively stable and insensitive to TAV and Pacific SST
Eastern South America has more response than W. South America
MODEL=Pacific SST can change rainfall in NE Brazil, but so can Atlantic SST
Atmospheric S. Pacific wave train influences Brazil precipitation
Source of influence in Amazon=eastern Pacific ITCZ, N. Atlantic High, Africa?, Atlantic ITCZ, SACZ(South Atlantic Convergence Zone), Rossby Wave Propagation – multiple choices!

Questions to address by paleoclimatologists
What is the extent to which a stable rainfall climatology in W. Amazon can be maintained?
How did extreme climate events (LGM, abrupt changes, YD) affect W. Amazon?
What is the relative role of Atlantic, Pacific, Africa in paleomonsoon in eastern south America?

Modeler question for paleoclimatologist = what are the source regions of Amazon precipitation? Use paleo data to help figure out paleo sources. Better knowledge of paleo data and paleo precipitation sources may help figure out model response.

West Amazon rainfall caused by cold air (50%) intrusion by Rossby Wave propagation and zonal flow over eastern Pacific
Modelers need paleo data to figure out past source regions of precipitation to Amazon.
Tropical Atlantic may influence South America monsoon.
Need better info on Central Pacific ITCZ

10:45am Kerry Cook (Cornell)

Regional Climate model simulations for LGM: have been looking at drying in Amazon
- change orbital parameters, atmCO2, land surface vegetation types, and SST
Difference in Annual Precipitation totals (LGM-present) using regional models
Have shown that GCMs don't work well for South America region - too complex
Regional models (60 km resolution) = domain of only South America, south of Cariaco
Used higher resolution regional model to look at influences of topography on precip., temp

RCM of South America simulates large scale drying throughout the Amazon basin during LGM using regional forcings, SST, reduced CO2
WHY is there big drying in the Amazon overall during glacial periods?

- In LGM in eastern South America = less precipitation due to weaker monsoon, delay in onset of monsoon (due to season length), and more evaporation.
- Western South America = LGM similar strength, but delay of monsoon onset

Overall, during LGM Amazon was drier due to later onset of monsoon period

Moist Static Energy (MSE) - energy content of air

- To connect convective (small scale) precipitation response with large scale circulation and the LGM forcing, need to consider MSE
  MSE increasing with altitude denotes a stable atmosphere.
  Decreases in low-level MSE stabilize vertical column and discourage convection

Is the stability of the atmospheric column (if you get convection, and start of monsoon) controlled by temperature or moisture effect?

- It is moisture effects that dominate the control of the onset of the monsoon, not temperature

Today = March (wet) convection is happening and stabilizing the column so MSE is fairly stable.
Difference between dry and wet season = little temperature change, big moisture change.
Seasonality of convection (MSE)
LGM simulations = decrease in moisture at surface stabilizes column and keeps monsoon from happening, even though model shows increase in temperatures = paleorecords disagree on this!

Model LGM with full forcing (dry Amazon) vs. Model LGM with only LGM SST forcing (dry Amazon). From this the modelers say that it is difference in SST that causes dryness in South America .

QUESTIONS for geologic proxy data community = what would be the effect on the interpretation of the proxy data if the drying in the Amazon basin was caused by having a shorter but equally intense monsoon season vs. a weaker monsoon season overall (as may be implied by annual rainfall reductions)?

How do we reconcile the idea of a drier but warmer climate (e.g. from these model simulations) with the idea of a drier but *cooler* climate (e.g. proxy data interpretations)?

11:21 am Dave Hodell (U. Florida)

Paleolimnology overview

Circum-Caribbean Records = Venezuela, Haiti, Yucatan, Guatemala = oldest record is about 12,000 yrs because all shallow lakes in central America dried during LGM

Lake Peten District = Guatemala, series of lakes

Peten-Itza – large, 120m deep lake. 17degreesN = rare to have such a deep lake in Central America. May have a very long record, possibly to start of Pleistocene

Northern coast of Guatemala - very dry, fairly wet (3-fold increase from coast to lake over 4 degrees of latitude) = very wet in Peten-Itza
Eastern source of moisture to Guatemala (wet Aug-Oct), Caribbean source

Lake Peten-Itza= piston cores and seismic data, 58 m depth-paleoshoreline
- believe lake level was down 58m during LGM – this translates to a 75% reduction in lake level during LGM
Lake level much lower during LGM, flooding surfaces all occur around 10.2, 10.7, 11.2 ka along surface and nearshore
Deeper sediments = LGM sediments are gypsum rich due to calcium sulfate in lake exceeding saturation.

XRF data of Sulfur = proxy for gypsum = high sulfur (gypsum)

- During LGM= 4 cycles of increased sulfur = increased evaporation/dryness (10.4, 10.7, 10.9, 11.2ka)
- In Guatemala-dry conditions in Pre-Boreal period
- 10.2 ka=dramatic shift out of preboreal/boreal period=end of gypsum in Guatemala and shift in Ti in Cariaco

Cariaco Ti record vs Lake Miragoane, Haiti δ18O record
Closed basin lake = high δ18O = dry, low δ18O = wet
Wet early Holocene, dry LGM
Important Point = Good agreement between Cariaco record and Haiti Lake Record, and throughout Caribbean

Goals=Compare future Peten-Itza record to see if similar rapid changes in tropical hydrology occurred during the glacial as in Cariaco

11:50 am Howie Spero (UC Davis; collaborations with Matt Schmidt, David Lea)

Reconstruction of SST in Ocean using Mg/Ca-δ^{18}O approach to calculate SST and $\delta^{18}O_{seawater}$

Long term records = offshore Guatemala and offshore SE America
SST records = warm stage 5
$\delta^{18}O_{water}$ record from foraminiferal δ^{18}O and Mg/Ca ratio
LGM was very salty in Caribbean (~2-3 psu saltier)

Changes in thermohaline circulation = LGM, less north Atlantic circulation, increased salinity in tropics

Dry periods in LGM in Caribbean = ITCZ shifts towards southern Brazil (increased moisture recorded there) = this leaves the Caribbean quite dry
Salinity changes may be due to changes in atmospheric precipitation in region (ITCZ, monsoons) and/or changes in thermohaline circulation and delivery/export of salty water from Caribbean

ODP Site 1060 (offshore N. Florida) = high sed rates = resolution of DO cycles= Large fluctuations in warm species of forams, δ^{18}Ocalcite, δ^{18}O seawater – record decreases and increases of salinity in a century, smaller temperature changes recorded by Mg/Ca (SST)

- stadials = salty gyres; interstadials = less salty due to Mississippi outflow

Use of coupled δ^{18}Ocalcite and Mg/Ca ratio to determine δ^{18}Oseawater and salinity = can be very useful, but method needs to be further improved

RESEARCH NEEDS = good SALINITY maps
Paleocommunity = need both high resolution vs orbital scale records
Have to identify critical time periods for investigation: lower resolution, longer time periods are just as important to study as presently "hot" high resolutions studies. Orbital records are needed to create maps of past conditions.

LUNCH BREAK

1:30pm Peter Swart (UM, RSMAS)

Caribbean Corals and Salinity

Ruth Curry (WHOI) – has documented changes in salinity over 30 yr period from instrumental measurments = increased salinity in subtropical gyre. Can paleo measurements see the same changes?

Work has focused on sclerosponge and coral temperature and salinity records from coupled δ^{18}O and Sr/Ca ratios
Laser-ablation ICP-MS
Sclerosponges are up to 400 years old!!!

Group is looking at Corals and Sclerosponges from Bahamas, off coast of Africa, Lesser Antilles to determine salinity changes

Cape Verde Islands = sit on edge of subtropical gyre. Caribbean sclerosponges sit at deeper site across the basin, but actually get similar water so the two records can be compared.
Salinity records in TOTO (Tongue of the Ocean, Bahamas) and Exuma (140-150 m water depth) correlate well with NAO.

Ruth Curry and Swart's lab have measured an increase in Atlantic salinity since 1950.

NAO signal strongest with deepest sclerosponges. Sclerosponges closer to surface show more temp change and less NAO correlation.

Cape Verde Corals= also have salinity correlation with Curry's work. Oxygen isotope correlation with NAO oscillation. Good correlation only after 1920. Pre-1920 values don't agree. Comparisons with Bahamas sclerosponges indicate that pre-1920 the high salinity gyre might have moved some which would be recorded in Cape Verde, but not in the Bahamas.

Lesser Antilles
Have used corals to examine SST since 1990. $\delta^{18}O$ used to examine changes in salinity.
Differences in salinity between northern and southern Lesser Antilles.
Southern corals are heavily influenced by less saline waters coming across equator = reflects the ITCZ, and affects on distribution of Orinoco and Amazon River water.

2:00 pm Dave Black (U. Akron)

Work has focused on high resolution core sampling in Cariaco Basin (Interannual to centennial)
Temporal Variability and regional connections
Short-time scales = patterns of change are not constant

Sediment records have overlap with historic records (since 1860)
Foraminifer record from planktic species *G. bulloides* – this taxa shows up in tropical upwelling zones = good correlation between *G. bulloides* and wind speed (upwelling)
Also good correlation between *G. bulloides* and SSTA in N. Atlantic = good correlation with high latitudes

Correlation of *G. bulloides* with entire Atlantic SST ==high *G. bulloides*, colder N. Atlantic SST
What is ENSO role with *G. bulloides*?

Seasonal interpretations:
Pink *G. ruber* = summer/fall delta 18O record
G. bulloides = winter/spring record

G. bulloides record back to 1200 AD= see not only decadal, but also trends similar to ENSO variability
G. bulloides (high values) correlates well with N. Atlantic, back to 1300AD

Pre 1300AD =big transition observed to much higher values of *G. bulloides*
Causes=?? decrease in trade-wind upwelling after 1300 AD or decrease in fluvial nutrient input?

Spectral analysis of *G. bulloides* time-series
Post-1300 AD = centennial scale variability, pre-1300 dominated by decadal-scale change
Cold N. Atlantic = increased *G. bulloides*
Pre-1300 high *G. bulloides*, low lake level
Post-1300 high *G. bulloides*, high lake level

IMPT POINT: Temporal modes can change though time!! Modern patterns of variability can not only change, but even shift completely in their phase

Need to understand variations in decade to decade variability and structure of Atlantic SST distribution.

225pm Tom Koutavas (Lamont-Doherty Earth Observatory)

Compiled data on migration of Pacific and Atlantic ITCZ over glacial-interglacial time frame

It now seems well established that a southerly shift of Atlantic ITCZ occurred during the LGM and stadials - What happened in the tropical Pacific?

Tropical Pacific has weaker SST gradient in the LGM compared to Holocene
Early-middle Holocene ITCZ was more northerly in Atlantic and stronger zonal SST in the Pacific - above points suggest similar behavior of Pacific and Atlantic ITCZ
QUESTION= what controls the ITCZ in the Pacific vs the Atlantic?

Wet LGM in South America, but dry in the northern part of South America; much of Amazon was wet during LGM, not arid.

Koutavas is focusing on the eastern tropical Pacific, looking for evidence in shift of ITCZ in Pacific

Today = pronounced seasonal cycle in NW South America. Boreal winter, ITCZ is south = reduced temperature gradient. In contrast, strong temperature gradient when ITCZ is north during boreal summer.

Looking at sediment cores, SST, SSS and δ^{18}Oforams.

Contrast between δ^{18}O records shows that sites south of equator versus sites north of equator have much greater Holocene contrast in values than the contrast between the two during the LGM. This is evidence that during LGM the ITCZ was closer to the equator, which would lessen the difference between the northern and southern sites (SHIFT in eastern Pacific ITCZ).

Mg/Ca SST reconstructions: Cross Pacific comparisons = western Pacific warm pool vs. Galapagos = excess SST in western warm side versus more cold tongue in east = offset during early Holocene (11kyrs to 5kyrs) = enhanced zonal SST gradient.
Atlantic records suggest a more northerly ITCZ during early-middle Holocene.
Early-Middle Holocene = show similar shifting happening in Atlantic and Pacific ITCZ.

QUESTION: With modeling can we find a consistent relationship with Atlantic and Pacific ITCZ?

Titanium Cariaco Record, $\delta^{18}O$ foram records in Pacific of ITCZ changes, El Nino pattern - all of these seem to change ~4000 years ago.

Paleo world NEEDS MODELING world to model the difference between early-mid Holocene and Late Holocene

3:00 pm Peter deMenocal (Lamont-Doherty Earth Observatory)

Tropical Atlantic Upwelling and the African Monsoon

Orbital forcing of SST and upwelling over last glacial cycle

- Dominated by precession driven upwelling

Looking at orbital forcing, but also the abrupt transitions between warm and cold, millennial scale variability

Boreal Summer, more north, SST, SE trades during monsoon causes max upwelling,
Boreal Winter, more south, weaker winds and less upwelling
Cold season=6 degrees colder, plus decrease in upwelling and foram deposition

E. equatorial Atlantic SST = most of the variance is due to precession; max boreal summer insolation is when you get warmest SST in Upwelling region – this is opposite of what would be expected.

Note: weak upwelling during max NH summer insolation (Max monsoon)

Tropical Atlantic appears to respond to mainly SEASONAL insolation variability.
Several SST and thermocline indices support this idea.

Deglacial and Holocene Cycle
Atmosphere-Only CM =showed increased summer insolation related to increased monsoon intensity.
Africa was much wetter between 9-5kyrs, Sahara Desert was wet
African Humid Period - Offshore cores with high sed rates due to Saharan Dust Plume and high productivity rates= terrigenous input was highest during the late-Holocene and today. A shift to lower terrigenous values occurred during early-Mid Holocene (13 to

5.5kyrs)….rapid transitions from high to low terrigenous values, low terrigenous periods = African Humid Period

See evidence for VERY RAPID shifts in MONSOON PERIODS

Climate Model Results = CLIMBER2 model = African monsoon has stable wet and dry states, veg-albedo feedbacks promote abrupt shifts, end of African humid period was very abrupt at 5.5kyrs ago.
Changes in Radiation Forcing put into coupled model of monsoon response indicate VEGETATION-ALBEDO Feedbacks.

Israel, Red Sea, Oman records show less abrupt transitions and variation from N. Africa

Model showing DEEP thermocline in tropical Atlantic during Heinrich events (low upwelling). However, this is not yet proved by proxy records. Parts of the western tropical Atlantic may have warmed during YD and H1, but cooling also occurred off NW Africa at YD and H1.
Cariaco = suggests stronger northern trade winds BUT eastern Atlantic is showing decreased upwelling = NEED TO RECONCILE ATMOSPHERE and OCEAN RESPONSE , STRUCTURE OF THERMOCLINE AND WHAT IS INFLUENCING IT

BIG PROBLEM TO WATCH OUT FOR WHEN DOING COMPARISONS - differences in scale of models and paleoproxies.

3:30pm Rong Zhang (GFDL)

Role of Atlantic thermohaline circulation in TAV (tropical Atlantic variability)
THC is important idea for modelers, paleo people

Modern Climate Observations = Meridional Dipole
Decadal time scale, SST dipole anomaly is in phase with Hadley cell circulation in tropics
Coupled Model=shows decadal variability in THC. Correlation of THC and SST. Enhanced THC correlates with increased tropical dipole.

Regression between precipitation and THC during summer vs winter
Weakened THC = drying over Central America, northern Africa, wetting over northeastern Brazil

NAO and THC-coupled model indicate that they may be linked = NAO (+) pattern follows weakening of THC (controlled by melting sea ice).

SST pattern in coupled model = positive NAO is associated with cooling in N Atlantic. Compared with observed still get positive NAO, but get shift of signal to east due to lack of Gulf Stream resolution

COUPLED MODEL - can't resolve Gulf stream Circulation!!

Late Pleistocene Climate Records

- Weaker THC = ocean heat transport is reduced and atmospheric transport increases =compensation = Hadley circulation becomes more symmetrical, get large scale dipole in Atlantic; Indian Monsoon also weakened

TRICKY: temperature changes along equator = warmer south of equator and cooler north equator

Holocene Climate records = Changes in THC still can alter low latitude behavior

PROBLEMS and NEEDS

- Numerical records still have too low resolution and high dissipation = the modeled tropical SST and ITCZ response to THC changes are underestimated.
- Paleo records are needed to estimate phase relationships between THC changes and tropical Atlantic variability
- Amplitudes are also underestimated by GCM

Question for paleo people: Are reductions of NADW correlated with southward shift of the ITCZ over tropical Atlantic?

PROBLEM = Modelers have a hard time evaluating the robustness of the proxies, while paleo people have a hard time picking which model to use.

4:15 pm FINAL DISCUSSION

It is clear that modelers need more spatial reconstructions produced from paleodata.

One immediate goal could be to produce a review of paleorecords to develop a more reliable set of paleodata that modelers could turn to in order to test their model results. Climate variability in Atlantic = test models with various regional paleo records that are picked to evaluate the sensitivity of the particular models. Then use this test to see how models will work to predict the future.

Holocene – a nice system to study because it is stable in the sense that there is no ice sheet and that boundary conditions are similar to today = maybe good to use to test models that are trying to predict anthropogenic changes. Though Holocene records might be good for comparison with models, it is still important to understand/include precessional and orbital changes.

The peak of the last interglacial (120 kyrs BP) might also be a valuable time to focus on because it is also similar to today. Stage 5 - new research indicating that it is very interesting period in Cariaco and Caribbean.

Very Useful Thing to do = Develop a "Key Test" for modelers (what paleo people are sure of, kind of sure of, not so sure of) so that modelers know what paleo variables may be altering the outcome of their models.

**Need to focus on <u>Mechanism</u>, and NOT just Timing using both models and paleo data.
What is connection between THC and Tropical Atlantic?!!!!!
Modelers = actually want REGIONAL DISTRIBUTION of climates
NEED to supply regional climate data distribution for modelers based on paleo data for narrow time periods.

Modelers in Amazon = have been limited to modeling interannual variability due to short duration of instrumental records.

TROPICS – need to determine how things have evolved spatially = develop a basin wide record of SST and thermocline for tropical Atlantic and Pacific during a single time window = good for paleo people to understand the mechanisms, plus good for modelers as they would get time and spatial patterns to compare their models with.

$$ Funding possibilities = generate a large-scale collection of paleo data in Atlantic basin during one time window, evaluate its quality, then use it for modelers to test their models.
Such an effort should also focus on things that have an impact on the terrestrial system where people live.

Paleosalinity information = really need to try to validate climate models against paleo and present salinity values.

Modelers = NEED to get information on how rivers act after they enter the ocean to include this information into their models…they don't have this info today.

SALINITY = something to focus on as an important link between modelers and paleodata.

Interesting for Paleocommunity/Salinity = map differences in salinity changes in eastern Pacific, Caribbean, eastern Atlantic.
Work on pattern shifts in salinity (PALEOSALT)
Look at array of cores throughout Atlantic

Highest confidence in paleosalinity reconstructions would be in regions where flux of forams is annual = Tropical Band, not polar regions where you get some times without rubers

MAPS IN TROPICS OF SALINITY AND TEMPERATURE
What time periods would be useful = glacial vs interglacial
Problems with LGM = more unknowns, but sexy

Early Holocene and Late Holocene = better constrained, but similar to today = small signal; advantage, however, is that there are potentially lots of records, both oceanic and terrestrial.
Stage 5e=more data than MIS 11, also new NGRIP site records Interglacial/Glacial Transition,

WRITE-UP BRIEF ON different time periods = data available, climate conditions, etc.
WRITE UP LIST FOR MODELS = list most important activities (eg ENSO, African Monsoon, etc)

MAPS OF TIME SLICES BUT FOCUS ON A MECHANISM

Remember = two way street – need to understand map, models, model output, and retest of data

Two communities need to work together to figure out one problem to attack.

MODELERS NEED paleoclimate folks to put out summary/review of paleoclimate data so they know which data are most robust and best to test their models against.

Maybe develop some more regional models to help explain the processes occurring in such places as Cariaco where we have great high resolution data sets!!!