PP21D-07 1150h

SPCZ- and ENSO-related Salinity Variations Recorded in the Skeletal Geochemistry of a Porites Coral from Espiritu Santo, Vanuatu

K. Halimeda Kilbourne[1] (727-553-1017; hali@marine.usf.edu)

Terrence M. Quinn[1] (727-553-1658; tquinn@marine.usf.edu)

Frederick W. Taylor[2] (512-471-0453; fred@utig.ig.utexas.edu)

Thierry Delcroix[3] (33(0)5 61 33 30 01; delcroix@notos.cst.cnes.fr)

Yves Gouriou[4] ((687) 26 07 28; gouriou@ird.fr)

[1]University of South Florida, College of Marine Science, 140 7th Ave. South, St. Petersburg, FL 33701, United States

[2]Institute for Geophysics, The University of Texas at Austin, 4412 Spicewood Springs Rd, Austin, TX 78759-8500, United States

[3]Département milieux et environnement, LEGOS, 18 Avenue Edouard Belin 31401 Toulouse cedex 4, Tolouse 31401, France

[4]IRD de Noumea, BP A5, 98848 Nouméa cedex, Noumea 98848, New Caledonia

Variations in sea surface temperature (SST) and sea surface salinity (SSS) are important components of climate variability in the tropical ocean-atmosphere system. Instrumental SST time series are much more readily available than are instrumental SSS time series, which are exceedingly rare. SSS variations are strongly linked to seawater δ^{18}O variations in the tropics, thus coral-based reconstructions of seawater δ^{18}O offer an opportunity to reconstruct the history of SSS variations in the tropical oceans. Seawater δ^{18}O is obtained by combining coral skeletal δ^{18}O, which varies in response to changes in seawater δ^{18}O and SST, with coral skeletal Sr/Ca, which varies in response to SST changes. This method has great potential for reconstructing past salinity variations. We explore this potential using a monthly-resolved, 65-year record of skeletal δ^{18}O and Sr/Ca variations in a Porites coral from Espiritu Santo, Vanuatu (16.0°S, 166.7°E). Santo is well positioned for such a study because ENSO-related climate variability strongly influences local salinity through changes in the position of the center of South Pacific Convergence Zone (SPCZ) convection/precipitation and associated salinity front movements. Moreover, a 24-year record of SSS variations is available from this region, which permits a ground-truth assessment of the robustness of the coral-based seawater δ^{18}O-SSS reconstruction. Investigation into different methods of combining coral δ^{18}O and Sr/Ca to reconstruct SSS reveals that the coral δ^{18}O anomaly time series provides the best fit to the SSS time series. A post-1976/1977 freshening trend in the δ^{18}O anomaly time series, which has been documented in other proxy time series, increases our confidence that this time series accurately reflects changes in the hydrologic balance in the western tropical Pacific. The Vanuatu coral δ^{18}O anomaly time series also correlates strongly with the Southern Oscillation Index, the Niño 3.4 SST anomaly time series, and with a SPCZ index derived from rainfall records. The results of this study confirm that coral geochemical records from Espiritu Santo, Vanuatu are climatically significant and that longer modern coral records and fossil coral records from this area contain a robust archive of past variability in SSS, SPCZ and ENSO.

PP21D-08 1205h

A Paleoclimate Record of the Great Australian Bight Provides Tropical-Extratropical Linkage for the Past 18,000 Years

Miriam S Andres[1,2] (mandres@rsmas.miami.edu)

Stefano M Bernasconi[2] (stefano@erdw.ethz.ch)

Judith A McKenzie[2] (sediment@erdw.ethz.ch)

Ursula Roehl[3] (uroehl@rcom-bremen.de)

[1]University of Miami RSMAS/MGG, 4600 Rickenbacker Causeway, Miami, FL 33149, United States

[2]Geological Institute ETH Zurich, ETH-Zentrum, Sonneggstr. 5, Zurich 8092, Switzerland

[3]Geoscience Department, Reseach Center for Ocean Margins, Bremen University, PO Box 330440, Bremen 82334, Germany

Present climate in southern Australia is dominated by the strength and position of the subtropical high-pressure belt (STHB) and mid-latitude Westerlies. The STHB, in turn, is powered by the position and strength of the Intertropical Convergence Zone (ITCZ). Shifts in strength and position of either the STHB or Westerlies, results in significant changes of rainfall over southern Australia. A sediment core from the Great Australian Bight (GAB) is used to evaluate the position, strength and influence of these climate regimes during the past 18,000 years. ODP Leg 182 Site 1127 provides a record with high sedimentation rates and abundant planktic foraminifers allowing a 14C-dated chronology and paleoceanographic reconstruction. Its coastal proximity links the terrestrial and oceanic climate evolution using the sedimentary iron content. Iron is a major constituent of dust and only reaches the GAB if entrained in pre-frontal northerly dust plumes that are subsequently scavenged by precipitation related to westerly low-pressure systems over the Bight. Very little iron reached the GAB during the last glacial maximum when strong Westerlies blew dust offshore into the Tasman Sea and Southern Ocean. Stepwise deglacial warming and increasing dust deposition reversed during the Younger Dryas implying a return to dry and windy conditions. High Fe values during the early Holocene coincide with warm and wet conditions related to low summer insolation and reduced seasonality. Reduced ITCZ migration south allowed for northerly penetration of rainbearing Westerlies. In contrast, decreasing Fe input since 7000 years coincides with aridification related to increasing seasonality and large latitudinal migration of the ITCZ. Holocene climate variability is the result of insolation-driven seasonality producing the large-scale features of atmospheric circulation and climate characteristics of southern Australia today. Sensitive to changing influence of Westerlies and Hadley circulation, this record provides evidence for a tropical-extratropical teleconnection.

PP22A MCC: Level 2 Tuesday 1330h

ITCZ Dynamics of Past Climates III Posters *(joint with A, H, OS, C, GC)*

Presiding: **A Koutavas,** Massachusetts Institute of Technology**; G Haug,** GeoForschungsZentrum Potsdam

PP22A-1192 1330h POSTER

Linking Surface Hydrology in the Tropical Indian Ocean, Ocean Circulation, and Atmospheric Methane Over the Last two Climatic Cycles

Claire Waelbroeck[1] (claire.waelbroeck@lsce.cnrs-gif.fr); Jerome Chappellaz[2] (jerome@lgge.obs.ujf-grenoble.fr); Frederic Parrenin[3] (Frederic.Parrenin@notos.cst.cnes.fr); Montse Ferrer[4] (mfcqam@iiqab.csic.es); Camille Levi[5] (levi@lsce.cnrs-gif.fr); Nick Shackleton[6] (njs5@cam.ac.uk); Joan Grimalt[4] (jgoqam@iiqab.csic.es); Laurent Labeyrie[1] (labeyrie@lsce.cnrs-gif.fr); Jean Jouzel[1] (jouzel@lsce.saclay.cea.fr)

[1]LSCE, Domaine du CNRS, bat.12, Gif-sur-Yvette 91198, France

[2]LGGE, 54, rue Moliere, St-Martin d'Heres 38402, France

[3]LEGOS, 18, av. E. Belin, Toulouse 31400, France

[4]CSIC, Jordi Girona, Barcelona 08034, Spain

[5]Rudgers University, Dudley Road, 71, New Brunswick, NJ 08901, United States

[6]Godwin Laboratory, Pembroke Street, Cambridge CB2 3SA, United Kingdom

Core MD 98-2165 (9°38'96 S, 118°20'31 E, 2100 m) from the tropical Indian Ocean has been studied at a time resolution of about 200 y over the two last climatic cycles within the POP project. Oxygen and carbon isotopic composition (δ^{18}O and δ^{13}C) of benthic and planktonic foraminifera has been measured. The benthic d18O record is remarkably similar to Antarctica ice deuterium (δD) or δ^{18}O records. 15 AMS ^{14}C dates covering the last 26 kyrs allowed us to verify that our benthic δ^{18}O record is perfectly synchronous with the ice records. This finding indicates that the impressive similarity found between a benthic δ^{18}O record from the Iberian Margin and Vostok δD (Shackleton, 2000) between 24 and 64 kyrs BP, is not restricted to this particular deep sea core and to marine isotopic stage 3. Correlating our high resolution benthic δ^{18}O records to Dome Fuji ice δ^{18}O record dated by the inverse approach of Parrenin et al. (2001), we obtain a high resolution marine time scale which is consistent with the Antarctic ice cores time scales. Moreover, the error on the relative age of the marine versus ice core records is necessarily lower than the duration of the millennial events recognised in both records, hence yielding a great improvement in our ability to compare marine and ice records over the last two to three climatic cycles. In this new marine chronology, we examine the relative timing of changes in surface and deep-water variability in the tropical Indian Ocean with respect to the air temperature and atmospheric methane concentration records from Antarctic ice cores. Our results highlight a tight correspondence between sea surface salinity in the tropics and atmospheric methane concentration. In contrast, the millennial scale climatic variability characterising glacial periods does not exhibit a clear relationship between sea surface salinity in the tropical Indian Ocean and atmospheric methane concentration.

PP22A-1193 1330h POSTER

Atlantic Intertropical Convergence Zone Variability: a Clay Mineralogy Study of Cariaco Basin Sediments Over the Last 1000 Years

Kyle A. Schuch[1] (330-620-5987; kas50@uakron.edu)

David E. Black[1] (330-972-5489; dblack1@uakron.edu)

Annabelle Foos[1] (330-972-7991; afoos@uakron.edu)

[1]University of Akron, 252 Buchtel Common, Akron, OH 44325, United States

The Cariaco Basin's high deposition-rate laminated sediments make it one of the best recorders of tropical Atlantic climate and Intertropical Convergence Zone (ITCZ) variability. Different drainage basins within the South American continent and the clays that are fluvially transported from them should be affected as the position of the ITCZ and its associated rainfall migrates through time. Over glacial-interglacial time scales it has been suggested that variations in the paleoposition of the ITCZ influences the suite of clay minerals deposited in Cariaco Basin sediments. Here we present results of much higher resolution clay mineralogy analyses of box and gravity core sediments deposited in the basin over the last 1000 years to examine ITCZ variability on sub-decadal to century time scales. Continuous sampling of well-dated box and gravity core sediments at consecutive 1-mm intervals provides a record with a temporal resolution of 1-3 yrs for the time period ca. A. D. 1000 to 1990. The clay and fine silt size fraction (<10 μm) was analyzed using x-ray diffraction for semi-quantitative and qualitative analysis. Kaolinite and illite co-vary over the length of the record suggesting that variations in these minerals are indicative of fluctuations of terrigenous input to the basin rather than changing weathering regimes. Between A. D. 1000 and 1550 variations in quartz, kaolinite, and illite positively correlate with a prior study of sediment titanium content, an inferred indicator of terrigenous input to the Cariaco Basin. However, the clay/titanium correlation becomes strongly negative between A. D. 1550 and 1990 suggesting a possible change in the source region, and hence paleoposition of the ITCZ, for either the clays or the titanium fraction over this interval. In contrast, chlorite is negatively correlated to sediment titanium percentages over the entire length of the record.

PP22A-1194 1330h POSTER

Seasonal Variability in Terrigenous Input to the Cariaco Basin, Venezuela.

Nahysa C Martinez[1] (617-353-4075; nahysa@bu.edu)

Richard W Murray[1] (617-353-6532; rickm@bu.edu)

Robert C Thunell[2] (803-777-7593; thunell@sc.edu)

Larry C Peterson[3] (l.peterson@miami.edu)

Frank E Muller-Karger[4] (carib@seas.marine.usf.edu)

[1]Boston University, Dept. of Earth Sciences, Boston, MA 02215, United States

[2]University of South Carolina, Dept. of Geological Sciences., Columbia, SC 29208, United States

[3]University of Miami, Rosenstiel School of Marine Sciences., Miami, Fl 33149, United States

[4]University of South Florida, Institute for Marine Remote Sensing. College of Marine Science., St. Petersburg, Fl 33701, United States

Abstract. Previous studies have interpreted variation in Cariaco Basin sediments as representing paleoclimatic changes related to meridional shifting of the Intertropical Convergence Zone and its effect on the relative amount and composition of the terrigenous and biogenic components deposited there. We report results from major, trace, and rare earth element analysis of sediment trap material gathered as part of the CARIACO Time Series Program from two traps (275 m

and 425 m, i.e. immediately above and below the redox interface) over a two-year period (November, 1996, to October, 1998). Our goal is to provide insight into Holocene and older paleoceanographic records (e.g., ODP Site 1002) that record climatic changes in terrigenous provenance. We interpret our results along with the main components of opal, calcium carbonate, TOC, and total terrigenous matter, in the context of instrumental records of precipitation, wind stress, and upwelling. Preliminary results show that the detrital component has its highest concentration (weight percent) during rainy periods (wet season), but the terrigenous flux does not show a clear seasonal pattern. Elemental ratios conventionally used as chemical tracers of terrigenous provenance (e.g., Fe/Al, Ti/Al, K/Al, Cr/Al) indicate seasonality in the source of the material. The changes in provenance are decoupled from the changes in terrigenous flux but can be correlated with terrigenous material concentration and with some instrumental records (e.g., SST). The values of Fe/Al and Ti/Al fluctuate between those of Post Archean average Australian Shale (PAAS) and Upper Continental Crust (UC), trending toward PAAS in rainy seasons and UC in dry periods. The seasonal range of Ti/Al is significantly smaller than the glacial-interglacial changes potentially caused by varying input of Saharan eolian material (Yarincik et al., 2000, Paleocean., 15, 210-228). The identification and quantification of the potential end-member sources and their seasonal variability will be better constrained once new data from local sources are obtained.

PP22A-1195 1330h POSTER

Millennial-Scale ITCZ Variability in the Tropical Atlantic and Dynamics of Amazonian Rain Forest

Xianfeng Wang[1] (1-612-626-7663; wang0452@umn.edu); Augusto S. Auler[2] (aauler@zaz.com.br); R. Lawrence Edwards[1] (edwar001@umn.edu); Hai Cheng[1] (cheng021@umn.edu); Chuan-Chou Shen[3] (river@ccms.ntu.edu.tw); Peter L. Smart[4] (p.l.smart@bristol.ac.uk); David A. Richards[4] (David.Richards@bristol.ac.uk)

[1]Department of Geology & Geophysics, University of Minnesota, Minneapolis, MN 55455-0219, United States

[2]CPMTC, Instituto de Geociências, Universidade Federal de Minas Gerais, Av. Antonio Carlos 6627, Belo Horizonte, MG 31270-901, Brazil

[3]Department of Geosciences, National Taiwan University, Taipei 106, Taiwan

[4]School of Geographical Sciences, University of Bristol, Bristol BS8 1SS, United Kingdom

Precipitation in the Amazon Basin is largely related to the intertropical convergence zone (ITCZ) in the tropical Atlantic which undergoes a regular seasonal migration. We chose a site south of the present day rainforest in semiarid northeastern Brazil, in order to study the timing of pluvial periods when the southern extend of the ITCZ would have been much further south than today. Shifts in the ITCZ position may have influenced the dynamics of rain forest and species diversity. We collected speleothems from northern Bahia state, located southeast of Amazonia. Age determinations with U-series dating methods show that samples grew rapidly during relatively short intervals (several hundreds of years) of glacial periods in the last 210 kyr. In addition, paleopluvial phases delineated by speleothem growth intervals show millennial-scale variations. Pluvial phases coincide with the timing of weak East Asian summer monsoon intensities (Wang et al., 2001, Science 294: 2345-2348), which have been correlated to the timing of stadials in Greenland ice core records and Heinrich events (Bond and Lotti, 1995, Science 267: 1005-1010). Furthermore, these intervals correspond to the periods of light color reflectance of Cariaco Basin sediments from ODP Hole 1002C (Peterson et al., 2000, Science, 290: 1947-1951), which was suggested to be caused by a southward shift of the northernmost position of the ITCZ and decreased rainfall in this region. Abrupt precipitation changes in northeastern Brazil may be due to the southward displacement of the southernmost position of the ITCZ associated with atmosphere-ocean circulation changes caused by (1) an increase in northern high latitude-tropical temperature gradient (Chiang et al., 2003, Paleoceanography, in press), and/or (2) the bipolar seesaw mechanism (Broecker et al., 1998, Paleoceanography 13: 119-121) during these Heinrich events. Pluvial phases are also coincident with higher insolation at 10°S during austral autumn. This association implies that insolation may contribute to the southward shift of the ITCZ and enhanced precipitation in northeastern Brazil. The mean latitudinal migration of the ITCZ in the tropical Atlantic may force Amazon rain forest dynamics. Fossils and geomorphologic evidence found nearby indicate much wetter climates and possible tropical rainforest expansion to this locality in the past (Auler and Smart, 2001, Quaternary Research 55: 159-167). Furthermore, low δ^{13}C (around -11$^{o}/_{oo}$) values in speleothems suggest an extensive C3 forest coverage, different from current drought-resistant caatinga vegetation. During time of high rainfall, northeastern Brazil may act as a migration corridor between two species-rich communities, the Amazon Rain Forest and the Atlantic Rain Forest.

PP22A-1196 1330h POSTER

Neotropical Climate Change Related to Intertropical Convergence Zone Migration During the Last Deglaciation

Michael B Hillesheim[1] (mbhilles@ufl.edu); David A Hodell[1] (dhodell@geology.ufl.edu); Jason H Curtis[1] (curtisj@ufl.edu); Mark Brenner[1] (brenner@ufl.edu); Thomas P Guilderson[2] (tguilderson@llnl.gov); Christina Gallup[3] (cgallup@d.umn.edu); Douglas W Schnurrenberger[4] (schno005@tc.umn.edu); Flavio S Anselmetti[5] (flavio@erdw.ethz.ch); Daniel Ariztegui[6] (daniel.ariztegui@terre.unige.ch); Michael F Rosenmeier[7] (mrosenme@pitt.edu); David G Buck[1] (dgbuck@ufl.edu)

[1]Department of Geological Sciences, University of Florida, 241 Williamson Hall, Gainesville, FL 32611, United States

[2]Center fo Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, 7000 East Ave L-397, Livermore, CA 94550, United States

[3]Large Lakes Observatory, University of Minnesota-Duluth, 10 University Drive, Duluth, MN 55812, United States

[4]Limnological Research Center, University of Minnesota-Twin Cities, 310 Pillsbury Dr. SE, Minneapolis, MN 55455, United States

[5]Geological Institute, Swiss Federal Institute of Technology ETH, Sonneggstrasse 5, Zurich 8092, Switzerland

[6]Institut Forel and Dept. of Geology, University of Geneva, 10, Route de Suisse, Geneva 1290, Switzerland

[7]Department of Geology and Planetary Science, University of Pittsburgh, 200 SRCC Building 4107 O'Hara Street, Pittsburgh, PA 15260, United States

The transition from the arid last glacial maximum to the moist Holocene represented a profound change in the Neotropics compared to the relatively small amplitude of climate variablity during the past 10 kyrs. Few lacustrine records of the last delgaciation exist from Central America because most shallow lakes were dry during the last glacial period. Lake Peten-Itza, Guatemala, is the largest (100 km^2) and deepest (160 m) lake anywhere in the Neotropics. Paleoshorelines observed in seismic surveys document lake level lowering to 58 m below modern level during the Last Glacial Maximum (LGM) indicating that Peten-Itza did not completely dry during this period. Climate in the Peten (17deg N) is influenced by the same seasonal variations in Trade Wind intensity and precipitation, associated with the migration of the intertropical convergence zone (ITCZ) and Azores-Bermuda high-pressure system that affect the Cariaco Basin off northern Venezuela (11° N). Thus a similar climate record is expected between Lake Peten-Itza and the Cariaco Basin. For these reasons, Peten-Itza is an attractive target for paleoclimatic study that may provide additional information on past ITCZ behavior during the last glacial-to-interglacial cycle. In May 2002, sediment cores were retrieved from the deep basin of Lake Peten-Itza with some cores extending back to the last delgaciation. We analyszed physical properties, stable isotopes, elemental geochemistry, and mineralogy across Termination I. Glacial-aged sediment in deep cores (>50 m) are composed of gypsum sands with high 18O values of bulk carbonate. In shallow cores, the last glacial is represented by a soil horizon indicating subaerial deposition. At the Pleistocene/Holocene boundary, Peten-Itza began to fill rapidly in response to increased precipitation expressed as a 4$^{o}/_{oo}$decrease in δ^{18}O and a mineralogic shift from gypsum to aragonitic and calcareous silty-clays. However, the transition from glacial to interglacial climate was not smooth and considerable structure exists in density, magnetic susceptibility, sediment color, δ^{18}O, sulfur content, and percent carbonate signals. The Younger-Dryas is marked by enriched, δ^{18}O that remain high until the onset of the Holocene "thermal maximum". Density, percent carbonate, and sulfur content were highly variable and may indicate short-term changes in moisture availability. The "8.2 ka event" is expressed as a $> 1^{o}/_{oo}$ increase in δ^{18}O concurrent with increases in density, susceptibility, and carbonate content as well as a distinct color change in lithology. Sediment color and density in the Peten-Itza core are well correlated with the Cariaco Basin titanium signal, indicating that both records respond to past changes in latitudinal migration of the ITCZ.

PP22A-1197 1330h POSTER

Tropical African climate variability during the last glacial/interglacial transition: the molecular record from Lake Malawi

Isla S Castañeda[1] (1-218-726-7396; cast0150@tc.umn.edu)

Josef P Werne[1] (1-218-726-7435; jwerne@d.umn.edu)

Thomas C Johnson[1] (1-218-726-8128; tcj@d.umn.edu)

[1]Large Lakes Observatory, University of Minnesota, Duluth, 10 University Dr, 109 RLB, Duluth, MN 55812, United States

In general, information regarding tropical African climate variability is relatively limited, especially in comparison with high-latitude studies. Unlike the high-latitudes where climate change is often expressed by fluctuations in temperature, low-latitude climate change is often expressed as variability in zonal circulation, which can result in hydrological fluctuations. Lake Malawi, situated in low-latitude tropical Africa (9-14° S), contains a continuous and high-resolution sedimentary record of the past 22ka BP and is anoxic below 250m, which enhances preservation of organic matter (OM). For these reasons, L. Malawi is an excellent location to examine the response of low-latitude African climate to global climate change. The climate of Malawi is strongly influenced by the position and seasonal migration of the ITCZ. During the rainy season from November to March, the ITCZ is positioned over L. Malawi (12-13° S) and the dominant winds are weak and northerly. Between April and May the ITCZ moves northward towards the equator and strong southerly winds prevail (Jury & Mwafulirwa, 2002). Previous studies of L. Malawi have shown responses to global climatic events, such as the Younger Dryas. Additionally, studies have demonstrated the response of L. Malawi to local or regional events, such as variability in the ITCZ. Based on BSi MAR, diatom, phosphorus, and trace metal data, Johnson et al. (2002) proposed that at times more frequent or stronger northerly winds promoted upwelling in the northern basin of L. Malawi, and suggested more southerly migrations of the ITCZ (reaching latitudes of >13°S) as the cause of these increased winds. Additionally, a recent study of L. Malawi based on multiple bulk geochemical proxies provides evidence for both southward and northward displacements of the ITCZ during the past 23ka BP (Filippi and Talbot, submitted). In this study the molecular biomarker record of L. Malawi is examined. Previous studies of Lake Malawi have been based on bulk geochemical parameters, which are indicators of the type of OM preserved in sediments. These studies indicate that variations in primary productivity likely have occurred during the past 22ka BP, however, these bulk geochemical analyses have also yielded ambiguous results and have failed to adequately distinguish terrestrially and aquatically derived OM. Presently, the algal community of L. Malawi is dominated by four major groups: diatoms, cyanobacteria, dynoflagellates, and green algae, with diatoms being the major contributor to primary productivity. Each of these algal groups has characteristic biomarkers, therefore, from the molecular record we will examine primary production as a whole within L. Malawi. Molecular reconstructions will provide information on the response of the L. Malawi algal community to hydrological variations, which may be linked global climate events or to smaller regional events, such as fluctuations in position and intensity ITCZ.

PP22A-1198 1330h POSTER

Hydrologic Variability During the Last 10,000 Years in the Tropical Andes

Geoffrey Seltzer[1] (goseltze@syr.edu)

Donald Rodbell[2]

Stephen Burns[3]

R. Lawrence Edwards[4]

Hai Chen[4]

[1]Dept. Earth Sciences, 204 Heroy Geology Lab Syracuse University, Syracuse, NY 13244, United States

[2]Dept. Geology, Union College, Schnectady, NY 12308, United States

[3]Dept. Geoscience, University of Massachusetts, Amherst, MA 0.003, United States

[4]Dept. Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, United States

The apparent increase in frequency of strong El Niño events in the mid Holocene as recorded around the tropical Pacific (e.g., Moy et al., 2002, Nature) has prompted the search for additional records to help identify the mechanism(s) behind tropical climatic variability on interannual and longer time scales. Lake Junin is a large lake (300 km2) in the Peruvian Andes (11°S,

4100 masl) that has rapidly accumulated authigenic carbonate over the last 10,000 years. A 14C and U/Th dated time series of δ18Ocalcite with an average sample spacing of ~30 years shows up to $\pm 2^{o}/_{oo}$ (VPDB) deviations from an overall decreasing trend. The δ18O of source precipitation to the region, as recorded in the Nevado Huascaran (9°S) and Nevado Sajama (18°S) ice-cores, reveals no decadal-centennial changes over the same time period and a long-term Holocene trend of $<3^{o}/_{oo}$ (VSMOW). It is likely that large changes in the hydrologic balance (precipitation minus evaporation) of Lake Junin led to relatively rapid and large changes in δ18Ocalcite . The hydrologic changes at Lake Junin can be correlated with El Niño events recorded in lake sediments in southern Ecuador, lake level records from Lake Titicaca, and the amount of ice-rafted debris in North Atlantic sediments. The variability in precipitation in the tropical Andes is likely a result of the interplay between air masses that deliver moisture to the Andes from the east and the upper tropospheric westerlies that are impacted by sea-surface temperatures in the eastern tropical Pacific(Vuille et al., 2000, JGR). Climatic conditions are generally drier in the tropical Andes during intervals marked by an increased frequency in El Niño Southern Oscillation warm events and cooler North Atlantic sea-surface temperatures.

PP22A-1199 1330h POSTER

A model for carbon and oxygen isotope co-variation in closed lakes based on study of Lake Junin, Peru

Stephen J Burns[1] (sburns@geo.umass.edu)

Geoffry Seltzer[2] (goseltze@syr.edu)

Donald Rodbell[3] (rodbelld@union.edu)

[1]Department of Geosciences University of Massachusetts, Morrill Science Center, Amherst, MA 01003, United States

[2]Dept. of Earth Sciences, Syracuse University, Syracuse, NY 13244, United States

[3]Geology Department, Union College, Schenectady, NY 12308, United States

In closed lake systems C and O stable isotope ratios often co-vary, although it is seldom clear why. Based on results from Lake Junin, Peru (11° S, 4100 masl), we have developed a simple C mass balance model that treats the lake as C-limited by low influx of dissolved bicarbonate. The model can explain both the highly enriched C isotope values of the sediments and the strong correlation between O and C isotopes, and is a good general explanation for co-variation in C and O other closed lakes. The sediment record from Lake Junin, Peru, provides an unusual opportunity to reconstruct tropical climatic variability through the analysis of authigenic lacustrine carbonates. Carbonate-rich sediments have been accumulating rapidly in the lake since shortly after deglaciation of the region (Seltzer et al., 2000). We have made a several hundred measurements of O and C stable isotopes of both authigenic calcite and ostracods from the lake. During the Late Glacial, C isotope values are around +8 to + $9\ ^{o}/_{oo}$, and at around 12 ka increase to between + 13 to + $15\ ^{o}/_{oo}$ until around 8 ka. From 8 ka to about 3 ky BP, C isotope values decreases to a low of $+3\ ^{o}/_{oo}$, then increases again to around + $8\ ^{o}/_{oo}$. Throughout the core, the C isotope values very closely track oxygen isotope values ($r^2 = 0.9$). Carbon isotope ratios of lacustrine carbonates are often interpreted in terms of changes in lake productivity, yet organic C concentrations and accumulation rates in lake Junin are relatively constant and are not correlated to carbonate C isotope values. A C isotope mass balance model for the lake suggests that the C isotope values are instead controlled by the flux of bicarbonate to the lake from surface inflow, which controls the degree of drawdown of dissolved CO_2. The model treats the dissolved CO_2 as susceptible to isotopic enrichment through a Rayleigh fractionation process as the light isotope is lost to organic matter. Variation in the isotopic ratio of dissolved carbon is driven not by changes in organic C burial, however, but by variation in the rate of resupply of bicarbonate. Wetter climate conditions result in both lower O isotope ratios because a smaller fraction of water lost is to evaporation, and lower C isotope ratios because of an increased flux of dissolved inorganic C.

PP22A-1200 1330h POSTER

Deuterium and Deuterium Excess in Current Bolivian Precipitation: Towards Improvement in Andean ice Cores Interpretation

Francoise Vimeux[1] (33 1 69 08 57 71; vimeux@lsce.saclay.cea.fr)

Robert Gallaire[2] (rgallaire@mail.megalink.com)

Sandrine Bony[3] (sandrine.bony@lmd.jussieu.fr)

[1]IRD-LSCE, CE Saclay Orme des Merisiers Bat 709, Gif-sur-Yvette 91191, France

[2]IRD, CP9214, La Paz 00095, Bolivia

[3]LMD, 4 place Jussieu, Paris 75252, France

Two ice cores studies have been carried out in Bolivia (Sajama and Illimani) for the last few years. Although the long term trend of water stable isotopes records clearly reflect well known periods (deglaciation, period associated to the Younger Dryas cooling in the North Atlantic sector, Holocene optimum), the interpretation in terms of climate changes is difficult because of the complexity of the hydrological cycle in the tropics and subtropics (cloud convection, recycling over Amazonia, partial evaporation of droplets at the based of the cloud). Indeed, a remarkable common signal has been pointed out from deuterium records over the last century and the interpretation of such a signal is currently discussed in terms of precipitation amount variations. To better understand the seasonal isotopic signal recorded in those ice cores, we need to calibrate the isotope content of precipitation regarding local and/or regional and/or source meteorological parameters. In this context, a network sampling either each event of precipitation or monthly precipitation has been set up for more than 4 years in Bolivia. We present here analyses for both deuterium and deuterium excess regarding local meteorological data, reanalysis, satellite data and atmospheric general circulation model outputs.

PP22A-1201 1330h POSTER

A Holocene Sediment Record From Lake Elsinore, Southern California: Evidence for Relative Lake Level Change and the Onset of ENSO.

Matthew E. Kirby[1] (714 278-2158; mkirby@fullerton.edu)

Steve P. Lund[2] (213 740-8801; slund@usc.edu)

Christopher J. Poulsen[3] (734-615-2236; poulsen@umich.edu)

[1]Cal-State University, Fullerton, Dept. of Geological Sciences, Fullerton, CA 92834, United States

[2]University of Southern California, Dept. of Earth Sciences, Los Angeles, CA 90089, United States

[3]University of Michigan, Dept. of Geological Sciences, Ann Arbor, MI 48109, United States

There are very few complete terrestrial, Holocene paleoclimate records from coastal southwestern North America. Lake Elsinore, located 120km southeast of Los Angeles, represents one of the only natural, non-playa lakes in the region. Furthermore, it is well documented that coastal southwestern North America is highly sensitive to changes in atmospheric circulation and its affect on regional hydrodynamics. As shown by Kirby et al. (in press), modern lake levels at Lake Elsinore respond directly to total annual precipitation, particularly winter season amounts. The lake is also located along the eastern Pacific Ocean where changes in ocean circulation and its thermal structure modulate the overlying atmosphere, and thus the adjacent continental climate. Here, we present two 7 meter sediment core records from Lake Elsinore spanning the entire Holocene. Although the cores are from the lake's littoral zone, they show surprisingly complete records with very little lithologic evidence for major hiatuses. A combination of sedimentological analyses (e.g., mass magnetic susceptibility (CHI); total percent carbonate; total organic matter) and lithologic descriptions provide insight to lake dynamics over the Holocene. Using the historical calibration between magnetic susceptibility and relative lake level (i.e., high lake levels = high CHI values and vice versa) from Kirby et al. (in press), we developed a first-order estimate of Holocene relative lake levels for Lake Elsinore. The historic calibration is extrapolated through the sediment record based on the assumption that, like today, first order lake level change is directly related to precipitation amount. Both total percent carbonate and total organic matter support our historical calibration between CHI and lake level. Our data suggest a relative increase in lake levels during the mid-Holocene (ca. 8,000 cal yr BP) and through to the present day. From this observation, we hypothesize that regional hydrology as linked to precipitation became more vigorous during the mid-Holocene (i.e., an increase in winter precipitation via an increase in the passage of winter cyclones). Because precipitation amount in coastal southwestern North America is so closely linked to ENSO variability, we further suggest that our observations support the hypothesis that modern ENSO variability and conditions developed during the mid-Holocene. This statement is in concert with recent findings from South America and the western Pacific that suggest a mid-Holocene onset of modern ENSO conditions. Our results are also supported by the recently published isotope data from Santa Barbara Basin (Friddell et al., 2003), which indicate an increase in more frequent "warm" ENSO events during the mid-Holocene. Our findings add to the growing number of terrestrial archives that document ENSO related Holocene variability and its timing of onset.

PP22A-1202 1330h POSTER

Drastic change of the subtropical circulation in the super El Niño like condition during late Holocene; evidence from the fluctuation of the Kuroshio Current

Yurika Ujiie[1] (yurika@uclink4.berkeley.edu)

Naoko Watanabe[2] (naoko@nenv.k.u-tokyo.ac.jp)

Minoru Ikehara[3] (ikehara@cc.kochi-u.ac.jp)

Juishiro Ashi[2] (ashi@ori.u-tokyo.ac.jp)

[1]Museum of Paleontology and Integrative biology, University of California-Berkeley, 1101 Valley Life Sciences Building #4780, Berkeley, CA 94720-4780, United States

[2]Ocean Research Institute, University of Tokyo, Minamidai 1-15-1, Nakano-ku, Tokyo 164-8639, Japan

[3]Center for Advanced Marine Core Research, Kochi University, B200 Monobe Nankoku, Kochi 783-8502, Japan

In the northwestern Pacific Ocean, the Kuroshio Current is a main component of subtropical circulation and heat transfer under the monsoon and ENSO system. The Ryukyu Arc region, especially the Okinawa Trough, is a key area for studying past variability of the Kuroshio since it is the area where the current becomes strong after diverging from the North Equatorial Current. In this area, Ujiie et al. (2003) reconstructed time-space changes in the surface water masses after 20 ka based on planktonic foraminiferal assemblage of 15 piston core samples. The fluctuations of the most characteristic species of the Kuroshio Water, which is the *Pulleniatina* group, represent that the effect of the Kuroshio Current diminished twice during the LGM and late Holocene, from 4.5 to 3 ka, respectively. Especially, the latter event (*Pulleniatina* minimum event; PME) has no cooling signal, although other water masses extended over the Ryukyu Arc region. This study focuses on the vertical fluctuations of the Kuroshio Current in the water column, comparing the fluctuations of δ^{18}O and δ^{13}C between surface and sub-surface habitual species in 5 piston core samples. During the PME, the δ^{18}O curves of *Pulleniatina obliquiloculata* and *Neogloboquadrina dutertrei*, which are living in sub-surface water near the thermocline, indicate heavy values, although sea surface temperature estimated by δ^{18}O of *Globigerinoides sacculifer* and planktonic foraminiferal assemblage has no change. At the same period, the differences of δ^{13}C between *P. obliquiloculata* and *G. sacculifer* becomes small. According to the decrease of the abundance of the Kuroshio Water species during the PME, the transport of the Kuroshio Current tends to decrease and then the thermocline is shallower in the Okinawa Trough. At present, the transport of the Kuroshio Current decreases, when the North Equatorial Current bifurcate is at northernmost position prior to the El Niño. Impacts of the PME have been recognized outside of the Ryukyu Arc region including the South China Sea and probably within the equatorial Pacific Ocean. Therefore, the PME is likely a response to a broad scale oceanographic-climatic process of the subtropical and tropical circulation.

PP22A-1203 1330h POSTER

Orbital-scale El Niño/Southern Oscillation-Like Variability During the Last Glacial-Interglacial Cycle

Masanobu Yamamoto[1] (+81-11-706-2379; myama@ees.hokudai.ac.jp)

Tadamichi Oba[1] (+81-11-706-2233; oba-tad@ees.hokudai.ac.jp)

Junko Shimamune[1]

Toshinori Ueshima[1] (ueshima@ees.hokudai.ac.jp)

[1]Graduate School of Environmental Earth Science, Hokkaido University, Kita-10, Nishi-5, Kita-ku, Sapporo 060-0810, Japan

How have the changes in the Earth's orbit have driven glacial-interglacial climate changes? Recently, a new hypothesis has been proposed that the tropical Pacific ocean-atmosphere interactions have a strong influence on global climate changes on an orbital timescale (Cane, 1998; Clement et al., 1999; Lea et al., 2000). Nevertheless, the orbital-scale changes in the tropical interactions are less clear, and their impacts on a global climate have not yet been proven. Our study was aimed at understanding whether or not and how the long-term tropical El Niño-Southern Oscillation (ENSO)-like variability has a global impact on orbital-scale climate changes. We generated continuous records of the alkenone sea surface temperature (SST) at the western and eastern margins of the mid-latitude North Pacific (MD012421 and ODP1014) during the last 145,000

years. We found that the difference between the SSTs of the NE and NW Pacific margins (ΔSST) reflected an orbital-controlled ENSO-like variability, and the ΔSST can be used as an indication of the long-term ENSO. The variation of ΔSST was large and pronounced at the 23-kyr cycle during 0-60 ka (MIS-1 to MIS-3) and 120-145 ka (MIS-5e to MIS-6), which agreed well with the long-term ENSO behavior predicted by the Zebiak-Cane ENSO model (Clement et al., 1999), as regards both the timing and frequency. In contrast, the variation was relatively small and pronounced at the 41-kyr cycle during 60-120 ka (MIS-4 to MIS-5d), which disagreed with the model prediction. Our observation also demonstrated that a strongly El Niño-like SST pattern prevailed in the mid-latitude North Pacific during the last two deglaciations. The synchronous warming of the Antarctica (Petit et al., 1999) and the tropical Pacific (Lea, 2000; Koutavas et al., 2002; Visser et al., 2003) prevailed within these strongly El Niño-like intervals during deglaciations. These findings are concordant with Cane (1998)'s hypothesis that a long-term El Niño must have resulted in global heating. Both meridional heat transport and pCO_2 increases might have been accelerated under a strongly El Niño-like condition during the last two deglaciations. These new findings suggest that a strongly El Niño-like condition was essential to the global warming that induced glacial terminations.

PP22A-1204 1330h POSTER

Evidence of Arid to Semi-arid Climate Near Western Pacific Warm Pool During Sea-Level Lowstands: Caliche Surfaces in Late Cenozoic Carbonates of Nansha Islands, South China Sea

Shou-Yeh Gong[1] (886-4-23226940; gng@mail.nmns.edu.tw); Horng-Sheng Mii[2]; Chorng-Shern Horng[3]; Fu-Wen Huang[4]; Wen-Rong Chi[4]; Tzen-Fu Yui[3]; Pei-Keng Torng[4]; Shieu-Tsann Huang[4]; Shi-Wei Wang[1]; Jong-Chang Wu[4]; Kenn-Ming Yang[4]

[1]Department of Geology, National Museum of Natural Science, 1 Kuan Chien Road, Taichung 404, Taiwan

[2]Department of Earth Science, The National Taiwan Normal University, 88 Sec. 4 Tingjou Rd, Taipei 116, Taiwan

[3]Institute of Earth Science, Academia Sinica, NanKang P.O.Box 1-55, Taipei 115, Taiwan

[4]Exploration & Development Research Institute, Chinese Petroleum Corporation, 1 Da Yuan, Wen Shan, Miaoli 360, Taiwan

Whether the climate of tropical seas during glacial periods became cold and dry has been an open debate. Models by different authors proposed the tropical sea-surface temperature (SST) during the Last Glacial Maximum (LGM) to be about 2° lower, or 5-6° lower than present. The controversy partly arise from disparate reconstructions of temperature from stable oxygen isotope archives of marine sediments. In this paper, we provide field evidence of semi-arid or arid climate during late Cenozoic sea-level lowstands from an atoll located in central South China Sea near the Western Pacific Warm Pool (WPWP). Lower rainfall and higher evaporation associated with the dry conditions might have resulted in less meteoric water component in the surface sea-water, and this factor should be taken into considerations in deciphering temperature from isotopic records. Taiping Islet (Itu Aba), located at N10° 23' and E114° 22' is part of the Nansha (Spratly) Islands near the northwestern margin of the Western Pacific Warm Pool. Rock cores of a borehole at Taiping became accessible to the authors in the recent years. We identified at least four subaerial exposure surfaces (SES) in the late Cenozoic carbonates. Caliche deposits are recognized on each of the four surfaces on the basis of alveolar texture, micro-rhizolith, caliche glaebules and corroded limestone nodules in reddish matrix (terra-rossa). Caliche developed on limestones typically forms in semi-arid to arid areas with annual precipitation from about 500 to 1000mm, while the modern annual rainfall of Nansha Island is 1800-2100mm. The occurrence of the Nansha caliche suggests the climate was much drier than present during the sea-level lowstands represented by the four SES. During the sea-level falls, reduced surface area of South China Sea with continental shelves exposed might have resulted in less moistures in the atmosphere and therefore less precipitation and higher evaporation rates. As a result, the reduced amount of meteoric fresh water in the surface sea-water may yield heavier oxygen isotopic compositions. We suggest that paleo-SST interpretations based on oxygen isotope archives in or near South Chine Sea should take the precipitation factor into consideration. Previous studies in Southeast Asian land regions and offshore northern Australia have proposed a scenario of a drier WPWP during LGM. Our data suggest such dry condition may not only occur in LGM but also in the previous glacial periods or sea-level lowstands; may not only in lands, but also in the central South China Sea.

PP22A-1205 1330h POSTER

Simulated Response of Tropical Climate to Changes in ice Sheet and Carbon Dioxide Forcings

Thomas M Foster[1] (tmfoster@umich.edu)

Christopher J Poulsen[1] (poulsen@umich.edu)

[1]Department of Geological Sciences University of Michigan, 425 E. University Ave., Ann Arbor, MI 48104, United States

Proxy records indicate that the tropical climate has experienced substantial changes that appear to coincide with Dansgaard-Oeschger and glacial-interglacial climate changes in the northern hemisphere. The source of the tropical climate variability is debated. To date, climate models have exhibited a relatively minor tropical climate response to northern hemisphere extratropical forcing. To further explore the influence of northern hemisphere extratropical forcing on tropical climate, a series of coupled ocean-atmosphere experiments using the Fast Ocean-Atmosphere Model have been performed to test the influence of the Laurentide Ice Sheet, and the post-glacial CO2 rise on tropical climate. The control experiment is a Last Glacial Maximum simulation (including ice-sheet configuration, orbital parameters, land surface characteristics, and trace gas concentrations appropriate for 21k). Two additional experiments have been conducted, the first with an 11k ice-sheet configuration and the second with an 11k ice-sheet configuration and 280 ppm CO2. All other boundary conditions remain constant in these sensitivity experiments. Preliminary model results indicate that the extratropical forcing has a substantial effect on tropical climate and the ITCZ. Deglaciation causes a pronounced (5-10°latitude) northward shift in the position of the ITCZ. This in turn has an effect on SST and thermocline structure in the Pacific, leading to changes in the periodicity and magnitude of interannual and interdecadal variability. The tropical Pacific warms 2-3°C in the LGM simulation compared to the 11k ice-sheet experiment, whereas a cooling of 10°C in the Southern Ocean, south of Australia, occurs between the same two experiments. Furthermore, the Asian monsoon appears to be affected by the change in glacial boundary conditions with stronger convective precipitation during times of full glaciation. Model results demonstrate that extratropical forcing may have caused significant climate changes in the tropics.

PP22A-1206 1330h POSTER

A Meta-analysis of Tropical Surface Temperatures at the Last Glacial Maximum

Ashley Ballantyne[1] (apb14@duke.edu)

Thomas Crowley[1] (tjcrowley@duke.edu)

Paul Baker[1] (pbaker@duke.edu)

Michael Lavine[2] (michael.lavine@duke.edu)

[1]Duke University, Nicholas School of the Environment, Box 90229, Durham, NC 27708, United States

[2]Duke University, Institute of Statistics and Decision Science, Box 90229, Durham, NC 27708

Based on direct measurements of gas trapped in ice cores, we know that fluctuations in CO2 levels and glacial periods are highly synchronous. However, we have no direct means of measuring past temperature, so we must rely on proxies that correlate with temperature to infer temperature variability through time. A concerted effort to measure the change in global temperature since the Last Glacial Maximum (LGM) was undertaken by CLIMAP (1980) who estimated tropical sea surface temperatures during the LGM to be 1.5° ± 1.2 C cooler than today. Since the first estimates of temperature at the LGM, numerous biological, chemical and physical temperature proxies have been developed. Estimates of tropical surface cooling at the LGM from these proxies have varied considerably (0-8°C). Here we conduct a meta-analysis of proxy estimates to arrive at an impartial approximation of tropical cooling at the LGM: 3.3° ± 2.0 C. This approximation of tropical surface temperature would suggest a mid-range climate sensitivity of about 3.5 ° C for the anticipated doubling of CO2. Developing more paleo-temperature proxies and evaluating existing proxies is critical to our understanding of how Earth's temperature responds to changes in CO2.

PP22B MCC: 3001-3003 Tuesday 1340h

Evolution of Earth's Greenhouse Effect II *(joint with A, GC)*

Presiding: **J Kiehl,** National Center for Atmospheric Research**; L C Sloan,** University of California, Santa Cruz

PP22B-01 1340h

Evolution of Earth's Greenhouse Effect

Jeffrey T Kiehl (303-497-1350; jtkon@ucar.edu)

National Center for Atmospheric Research, 1850 Table Mesa Dr, Boulder, CO 80305, United States

The major factors contributing to Earth's greenhouse effect are discussed along with various quantitative methods for determining the greenhouse effect. Earth's greenhouse effect has evolved over geologic time scales and continues to evolve. The magnitude of Earth's greenhouse effect is explored for particular time periods of Earth's evolution from the Neoproterozoic to present. Coupled climate model simulations for these various time periods are used to estimate the magnitude of the greenhouse effect. A comparison is made between the present greenhouse effect and those of past times. The connection between the greenhouse effect and Earth's hydrologic cycle is also discussed. Finally, a comparison is made of between past greenhouse effects and that predicted for the end of the twenty-first century.

PP22B-02 1345h INVITED

Methane Greenhouses and Anti-Greenhouses During the Precambrian

James F Kasting[1] (814-865-3207; kasting@essc.psu.edu)

Alexander A Pavlov[2] (303-492-4765; pavlov@lasp.colorado.edu)

[1]Department of Geosciences Penn State University, 443 Deike, University Park, PA 16802, United States

[2]LASP University of Colorado, 392 UCB, Boulder, CO 80309-0392, United States

Methane was arguably an important greenhouse gas during the Archean and early Paleoproterozoic Eras, prior to the rise of O2 at 2.3 Ga (1,2). Atmospheric CH4 concentrations of 1000 ppmv or more are predicted, assuming that methanogenic bacteria evolved early and that they were widely distributed in the prevailing anaerobic biosphere (2,3). Indeed, previous models (1-3) may have underestimated both the concentration of CH4 and the greenhouse effect itself at this time. Knauth and Lowe (4) have used oxygen isotopes in cherts to argue that the mean surface temperature at 3.2-3.5 Ga was between 55oC and 85oC. The Sun is thought to have been some 23 percent dimmer at that time (5), so this would have required substantial greenhouse warming by both CH4 and CO2. Further constraints are imposed by the formation of hydrocarbon haze, and an accompanying "anti-greenhouse effect", if the CH4 concentration exceeds that of CO2 (2). Thus, only certain combinations of CH4 and CO2 are possible. The rise of O2 at 2.3 Ga destabilized the methane greenhouse, leading to widespread (possibly global) glaciation (1,6). The next 1.5 billion years were warm, however, as evidenced by the absence of glacial deposits and the continuing high temperatures implied by O isotopes in cherts (7). CH4 levels could have remained relatively high during this time, 20-100 ppmv, as a consequence of low concentrations of dissolved O2 and sulfate in the deep oceans, and increased recycling of organic matter by fermentation and methanogenesis (8,9). An increase in either O2 or dissolved sulfate at around 0.75 Ga may have once again decreased atmospheric CH4 levels and triggered the widespread Neoproterozoic glaciations.

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