the past 4,000 years, the two locations has had similar temperature variations with five distinct warming trends, but a different moisture variability which is probably more sensitive to local atmospheric circulation changes than temperature. In general, it was relatively dry during the Medieval Warm Period and wet during the Little Ice Age in eastern China. Of the five warming trends, the most recent one is the strongest.

PP71C-10 1105h

SST variability in the Western Pacific Warm Pool During the Past 2000 Years

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A series of marine cores collected in 1998 by the IMAGES program from the Indonesian archipelago, at center of the western Pacific Warm Pool, have been used to reconstruct sea surface temperature histories for the past few thousand years. Radiocarbon chronologies developed for the cores indicate nearly linear accumulation rates of approximately 100 centimeters per thousand years for several of the cores. The core top ages of several cores are indistinguishable from modern indicating a nearly continuous sediment record is preserved. From centimeter scale samples we have analyzed the d18O and Mg/Ca of Globigerinoides ruber (white), a surface dwelling planktonic foraminifera in order to reconstruct SST variability in the Pacific Warm Pool. Here we present a SST reconstruction at decadal resolution. These records resolve a warming trend that began 2000 years ago that culminated in the warmest SST values between 900 and 1500AD. The warmest Mg/Ca paleotemperatures are recorded in the period between 900 and 1100AD, reaching values of about 30oC. This period of maximum warmth is followed by cooling of SSTs that extended to the beginning of the 20th century. Hence, we suggest that these tropical SST records capture the pattern of tropical SST warming and cooling that has been referred to as Medieval Warm Period and Little Ice Age. What is striking about the records is that the warmth of the Medieval SST exceeds modern temperatures and the Little Ice age temperatures were colder than modern temperatures. A companion study of these cores that extends the paleo-SST records back thousands of years also indicate that the warming and cooling attributed to Medieval Warm Period and Little Ice Age are not unique and only the most recent manifestations of a recurring centennial and millennial scale pattern of SST variability in the Western Pacific Warm Pool.

PP71C-11 1120h

The Asian Summer Monsoon During the Last Millennium

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Reconstructing the Asian summer monsoon during the past millennium has relevance to process-oriented studies as well as efforts to predict future climate change. We reconstructed the Asian summer monsoon winds for the last 1,000 years using fossil Globigerina bulloides abundance in box cores from the Arabian Sea. The Arabian Sea sediments are nannofossil-rich foraminifer oozes, and the low oxygen content of the Arabian Sea minimizes the bioturbation that would otherwise smooth the record. The composite record based on two cores shares several similarities with the time series of northern-hemisphere warming, namely weaker winds between 1000-1600 AD with a brief increase 1200-1400, a minimum around 1600, and an increase during the past 4 centuries. This is not surprising because both model and observation-based studies reveal a link between cooling/ increased snow cover over Eurasia, and a weaker monsoon the following summer. Alternately, the forcing implicated in the recent warming trend (volcanic aerosols, solar output, greenhouse gases) may directly affect the monsoon. Either interpretation is consistent with the hypothesis that the SW monsoon strength will increase during the coming century as greenhouse gas concentrations continue to rise and northern latitudes continue to warm. Preliminary study of the longer Holocene interval indicates 8 intervals of weaker monsoon winds that are correlated with cooling events in the North Atlantic. We infer that the observed link between Eurasian warmth/ snow cover and the SW monsoon persists on the millennial scale.

PP71C-12 1135h INVITED

Tropical and Subtropical Ice Core Climate Records of the Last Two Millennia

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Climate records from eight low-latitude, high elevation ice cores covering the last two millennia are compared and contrasted to provide a long-term perspective for 20th century climate change. This comparison is based largely on the standard temperature proxy, the oxygen isotopic ratio (δ^{18}O) for these cores. Additional data, such as dust concentrations, aerosol chemistry, and accumulation rates, are often combined with the δ^{18}O to provide deeper insight to the regional climate conditions. Separate composite δ^{18}O profiles are produced for the South American and Tibetan Plateau cores. These regional composites display some major differences on both decadal and century scales. On the Tibetan Plateau the δ^{18}O histories from Dasuopu, Puruogangri and Dunde contain broadly similar trends, while those on Guliya appear largely disconnected. However, since 1800 all four δ^{18}O histories show a consistent trend of isotopic enrichment, suggesting that a large spatial-scale warming has affected the region. The greatest isotopic enrichment (warming) is at the highest elevation site, Dasuopu, along the southern edge of the Tibetan Plateau, suggesting an amplification of warming at higher elevations on the Plateau. Some observational evidence exists to support this enhanced warming. Moreover, the Tibetan composite based on all four cores shows that the greatest δ^{18}O enrichment (warming) in the last two millennia occurs in the 20th Century. In the tropical Andes the δ^{18}O records from Huascarán and Quelccaya, both in Peru, show a 20th Century enrichment and a "little ice age" isotopic depletion (cooling), neither of which appears in the cores from Sajama in Bolivia. An abundance of evidence is accumulating for a strong warming in the tropics in the second half of the 20th century. The recent retreat of the tropical and subtropical glaciers is discussed relative to the climate perspective provided by the glacier record of the last two millennia.

PP71C-13 1150h INVITED

The Big Chills

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At the end of the last glacial, the Earths climate system abruptly shifted into the Younger Dryas, a 1500-year long cold snap known in the popular media as the Big Chill. Following an abrupt warming ending the Younger Dryas about 11,600 years ago, the climate system has remained in an interglacial state, thought to have been relatively stable and devoid, with possibly one or two exceptions, of abrupt climate change.

A growing amount of evidence suggests that this benign view of interglacial climate is incorrect. High resolution records of North Atlantic ice rafted sediment, now regarded as evidence of extreme multiyear sea ice drift, reveal abrupt shifts on centennial and millennial time scales. These have been traced from the end of the Younger Dryas to the present, revealing evidence of significant climate variability through all of the last two millennia. Correlatives of these events have been found in drift ice records from the Arctics Laptev Sea, in the isotopic composition of North Grip ice, and in dissolved K from the GISP2 ice core, attesting to their regional extent and imprint in proxies of very different origins.

Measurements of Mg/Ca ratios in planktic foraminifera over the last two millennia in the eastern North Atlantic demonstrate that increases in drifting multiyear sea ice were accompanied by abrupt decreases in sea surface temperatures, especially during the Little Ice Age. Estimated rates of temperature change are on the order of two degrees centigrade, more than thirty percent of the regional glacial to interglacial change, within a few decades. When compared at the same resolution, these interglacial variations are as abrupt as the last glacials Dansgaard-Oeschger cycles. The interglacial abrupt changes are especially striking because they occurred within the core of the warm North Atlantic Current. The changes may have been triggered by variations in solar irradiance, but if so their large magnitude and regional extent requires amplifying mechanisms that have not yet been identified.

While the Younger Dryas event is dramatic, the Big Chills of the Holocene are clearly significant abrupt changes in their own right. Because they were a recurring feature of the interglacial climate we live in presently, they are especially relevant to the prediction of sudden changes in the future, more so probably than abrupt changes during the last glacial which took place within boundary conditions that are not likely to occur again soon, perhaps within tens of thousands of years.

PP72A MCC: Hall D Sunday 1330h

The Climate Record of the Last Two Millennia II Posters *(joint with A, OS, GC)*

Presiding: **L Stott,** University of Southern California**; B Buckley,** Lamont-Doherty Earth Observatory of Columbia University

PP72A-0414 1330h POSTER

USING PALEOCLIMATIC RECONSTRUCTIONS OF ENSO VARIABILITY DURING THE PAST FEW CENTURIES TO RE-EXAMINE THE 'VOLCANO-ENSO' HYPOTHESIS

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Using newly available paleoclimatic reconstructions and assessments of past volcanic forcing, we re-explore the previously posed hypothesis that explosive volcanic forcing influences the behavior of El Nino. Recent modeling experiments suggest a transient response of the Bjerknes mechanisms that favors a La Nina like (El Nino like) response to a positive (negative) imposed tropical surface radiative forcing anomaly. Our 'Volcano-ENSO' hypothesis thus posits a multi-year El Nino-like warming response in the eastern tropical Pacific to sufficiently explosive tropical volcanic eruptions that impart a significant negative tropical surface radiative forcing. Past analyses employing a 'Superposed Epoch Analysis' (SEA) technique to establish a statistical connection between the timing of explosive volcanic eruptions and large El Nino events have proven, at best, indeterminate, owing to the limited sample size available from the instrumental record. Recent reconstructions of El Nino indices and volcanic activity now permit an extension of these analyses further back in time, allowing for an independent test of the Volcano-ENSO hypothesis. Using two independent eruption reconstructions (i.e. IVI and VEI), the SEA is performed for multi-century reconstructions of the Nino3 Index, the Southern Oscillation Index, and global surface temperature reconstructions. The results of these extended analyses appear to substantiate a significant (lagged, multi-year) El Nino-like response sequence to explosive tropical eruptions.

PP72A-0415 1330h POSTER

A Revised Set of Dendroclimatic Reconstructions of Summer Drought over the Conterminous U.S.

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We describe a revised set of dendroclimatic reconstructions of drought patterns over the conterminous U.S back to 1700. These reconstructions are based on a set of 483 drought-sensitive tree ring chronologies available across the continental U.S. used previously by Cook et al [Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland, Drought Reconstructions for the Continental United States, Journal of Climate, 12, 1145-1162, 1999]. In contrast with the "Point by Point" (PPR) local regression technique used by Cook et al (1999), the tree ring data were calibrated against the instrumental record of summer drought[June-August Palmer Drought Severity Index (PDSI)] based on application of the "Regularized Expectation Maximization" (RegEM) algorithm to relate proxy and instrumental data over a common (20th century) interval. This approach calibrates the proxy data set against the instrumental record by treating the reconstruction as initially missing data in the combined proxy/instrumental data matrix, and optimally estimating the mean and covariances of the combined data matrix through an iterative procedure which yields a reconstruction of the PDSI field with minimal error variance [Schneider, T., Analysis of Incomplete Climate Data: Estimation of Mean Values and Covariance Matrices and Imputation of Missing Values, Journal of Climate, 14, 853-871, 2001; Mann, M.E., Rutherford, S., Climate Reconstruction Using 'Pseudoproxies', Geophysical Research Letters, 29, 139-1-139-4, 2002; Rutherford, S., Mann, M.E., Delworth, T.L., Stouffer, R., The Performance of Covariance-Based Methods of Climate Field Reconstruction Under Stationary and Nonstationary Forcing, J. Climate, accepted, 2002]. As in Cook et al (1999), a screening procedure was first used to select an optimal subset of candidate tree-ring drought predictors, and the predictors (tree ring data) and predictand (instrumental PDSI) were pre-whitened prior to calibration (with serial correlation added back into the reconstruction at the end of the procedure). The PDSI field was separated into 8 relatively homogenous regions of summer drought though a cluster analysis, and three distinct calibration schemes were investigated: (i) 'global' (i.e., entire conterminous U.S. domain) proxy data calibrated against 'global' PDSI; (ii) regional proxy data calibrated against regional PDSI, and (iii) global proxy data calibrated against regional PDSI. The greatest cross-validated skill was evident for case (iii), suggesting the existence of useful non-local information in the tree ring predictor set. The resulting reconstructions of drought were compared against the previous reconstructions of Cook et al (1999) back to 1700, with very similar results found for the domain mean and regional mean time series. Cross-validation results based on withheld late 19th/early 20th century instrumental data [and a regionally-limited extension of cross-validation results back to mid 19th century based on long available instrumental series] both suggest a modest improvement in reconstructive skill over the PPR approach. Differences at the regional scale are evident for particular years and for decadal drought episodes. At the continental scale, the 1930s Dust Bowl remains the most severe drought event since 1700 within the context of the estimated uncertainties, but more severe episodes may have occurred at regional scales in past centuries.

PP72A-0416 1330h POSTER

Climatic and Environmental Changes of the Past 1000 Years

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We review the 1000-year climatic and environmental history of the Earth contained in various proxy records. As indicators, the proxies duly represent local climate. Questions on the validity of locality paradigm will become sharper as climatic changes on timescales of 50-100 years or longer are being pursued. This is because the thermal and dynamical constraints imposed by local geography will become increasingly important as the air-sea-land interaction timescale increases. Because the nature of the proxy climate indicators are so different, the results cannot be combined or compared into a hemispheric or global quantitative composite. However, considered as an ensemble of individual expert opinions, the assemblage of local representations of climate establishes both the Little Ice Age and Medieval Warm Period as climatic anomalies with world-wide imprints, extending earlier results by Bryson et al. (1963), Lamb (1965), and numerous intervening research efforts. Furthermore, the individual proxies can be used to address the question of whether the 20th century is the warmest of the 2nd millennium locally. Across the world, many records reveal that the 20th century is probably not the warmest nor an uniquely extreme climatic period of the last millennium, although it is clear that human activity had impacted many microscopic realms of the climate and environment.

PP72A-0417 1330h POSTER

History of the Energy Balance at the Earth's Surface in Canada: Spatial and Temporal Variability

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Past changes in the Earth's surface energy balance are recorded in the ground as perturbations of the subsurface thermal regime. Here we reconstruct ground surface temperature histories and surface heat flux histories from temperature versus depth profiles measured in boreholes at 400 sites distributed across southern Canada. We show that the ground has warmed about 1.0 K in the last 100 years and that during the past 50 years the heat flowing into the ground has been about 30 mWm^{-2}. Spatial variability is important with the largest warming trends in the southern areas of Canada.

URL: http://geophysics.stfx.ca/public/borehole/borehole.html

PP72A-0418 1330h POSTER

Sea Surface Temperature Variability in the Northeastern Pacific During the Past 600 Years-a Perspective on the 20th Century Climate Record

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Within the context of the past millennium, the late 20th century warming in the Northern Hemisphere has been attributed to an increase in anthropogenic activities and their adverse effects during that time. Interannually laminated marine sediment records from the Santa Monica Basin and annually varved sediments from the Santa Barbara Basin are used to resolve the extent to which this late 20th century warming is unique in the northeastern Pacific. A collection of multicores from these basins contains high-resolution records representing approximately the last 600 years. We present Mg/Ca and $\delta^{18}O$ paleotemperatures reconstructions of sea surface temperature variability from the calcite of the surface dwelling foraminifera *Globigerina bulloides*. Historical data from Scripps and Santa Monica Piers extending through the last 80 years are used to test the accuracy and usefulness of these paleoproxies for the Northeast Pacific.

Mg/Ca based sea surface temperatures (SSTs) for *G. bulloides* from the Santa Monica Basin record the April upwelling temperatures whereas in Santa Barbara Basin the foraminifera record the April through June upwelling season. Sediment trap studies in Santa Barbara indicate that the basin experiences maximum productivity between April and June (Thunell et al. 1995). These months represent the upwelling season that is characterized by an increase in *G. bulloides* productivity and deposition. Comparisons between the Santa Monica and Santa Barbara Basins demonstrate that the longer term temperature changes are comparable between the basins indicating regionally consistent patterns of variability through time. Both of these basin records resolve the occurrence of warming in the late 20th century but a long high resolution SST record spanning the last 600 years will give some indication of how unique this phenomenon actually is.

PP72A-0419 1330h POSTER

Latest Holocene Climate Variability Revealed by a High-Resolution Multiple Proxy Record off Lisbon (Portugal).

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The North Atlantic Oscillation (NAO) is known to have a major influence on the wintertime climate of the Atlantic basin and surrounding countries, determining precipitation and wind conditions at mid-latitudes. A comparison of Hurrells NAO index to the mean winter (January-March) discharge of the Iberian Tagus River reveals a good negative correlation to negative NAO, while the years of largest upwelling anomalies, as referred in the literature, appear to be in good agreement with positive NAO. On this basis, a better understanding of the long-term variability of the NAO and Atlantic climate variability can be gained from high-resolution climate records from the Lisbon area.

Climate variability of the last 2,000 years is assessed through a mutiple proxy study of sedimentary sequences recovered from the Tagus prodelta deposition center, off Lisbon (Western Iberia). Physical properties, XRF and magnetic properties from core logging, grain size, $\delta^{18}O$, TOC, $CaCO_3$, total alkenones, n-alkanes, alkenone SST, diatoms, benthic and planktonic foraminiferal assemblage compositions and fluxes are the proxies employed. The age model for site D13902 is based on AMS C-14 dates from mollusk and planktonic foraminifera shells, the reservoir correction for which was obtained by dating 3 pre-bomb, mollusk shells from the study area.

Preliminary results indicate a Little Ice Age LIA alkenone derived SSTs around 15°C followed by a sharp and rapid increase towards 20°C. In spite the strong variability observed for most records, this low temperature interval is marked by a general increase in organic carbon, diatom abundance and total alkenone concentration pointing to higher upwelling related productivity. Major peaks in magnetic susceptibility and grain size are interpreted as the record of flood-like events that are likely to reflect times of primarily negative NAO.

PP72A-0420 1330h POSTER

Sedimentological Evidence For The Last Interglacial (Sensu Lato) From El'gygytgyn Crater Lake

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During May of 1998 a 13.0 m sediment core was retrieved from Elgygytgyn Crater Lake, located 100 km north of the Arctic Circle in northeast Siberia. The lake was formed by a 3.6 million year old meteorite impact, which generated a crater roughly 20 km in diameter. Geochronological age models of sediments from this core suggest that the upper 6.5 meters of the core represents ~150 ky of paleoenvironmental change from northeast Siberia (Nowaczyk et al., in press). The magnetic susceptibility record from the 1998 core shows a strong pattern of correlation with the Greenland Ice Sheet stable isotope record (GISP2) in the upper 6.0 meters of the core where significant age control exists, based upon optically stimulated luminescence ages (Forman and Pierson, unpublished data), magnetic events (Nowaczyk et al., in press), and significant shifts in pollen (Lozhkin et al., 2001). The marine isotopic stages derived from SPECMAP have been correlated to the magnetic susceptibility record of the

1998 core. Much of the current terrestrial study of marine isotopic stage 5 (MIS 5) and the Last Interglacial (LI, substage 5e) are confined to a few distinct long continental records predominately in Europe. The research presented here summarizes the LI signal from a key Arctic location. The climate signal contained within the sediments of the LI are particularly important, as the extensive length of the sediment record may provide a high resolution archive of interglacial climate patterns for comparison with the Holocene. As a result, a sedimentological record has been constructed for the interval spanning the LI. The core is almost entirely composed of silt and clay (25-85% silt and 20-75% clay) with a few intervals containing sand. Moreover, no significant correlation between grain size and magnetic susceptibility exists, as is the case in many lacustrine environments. Clay mineralogy analyses using x-ray diffraction show that the abundance of chlorite increases during colder periods within the upper 200 cm of the core, representing roughly the last 40ka (Asikainen, in progress). This work has been expanded to include the interstadial/stadial substages of MIS 4-6. The behavior of illite-smectite and chlorite during MIS 5 suggests that the warm/wet conditions associated with interglacials may not be as pronounced at high latitudes. An additional gravity core was recovered in 2000 and used for comparison with the LI sediments obtained in 1998. Detailed grain size measurements also yielded no significant correlation with magnetic susceptibilty. A high-resolution archive of petrographic thin sections has recently been constructed to explore changes on a much finer scale.

PP72A-0421 1330h POSTER

Faunal and Isotopic Evidence of the Medieval Warm Period in San Francisco Bay, California

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A 3,800-year sediment record was obtained from a 3.52 m core (DJ6-93SF-6) which was recovered from south San Francisco Bay, CA (37°37.83N, 122°21.99W) in order to reconstruct the Quaternary climatic history of the region. The microfaunal assemblage of the core contains abundant subtidal estuarine benthic foraminifers found today at shallow water depths (<10 m) in the bay.

A Q-mode cluster analysis of the samples grouped them into two clusters and one outlier. Cluster A is dominated by *Elphidium excavatum*; its abundance often comprises ∼70-90% of the foraminiferal assemblage. Today, the species typically resides in cold, estuarine waters. Its dominance in the core from 352-150 cm (∼1870 B.C. to ∼A.D. 680) and 88-18 cm (∼A.D. 1270 to ∼A.D. 1990) suggests that this area of the bay has remained relatively cold and shallow for ∼3300 years out of the last four millennia. Cluster B, the *Ammonia beccarii-Elphidium gunteri* association, occurs from 150-88 cm in the core and is interpreted as representing warmer climatic conditions from ∼A.D. 680 to ∼A.D. 1270. The outlier, Cluster C (∼A.D. 1990 to present), is attributable to the recent appearance of the invasive Japanese species *Trochammina hadai*.

Oxygen isotope values were measured in specimens of *Elphidium excavatum* var. *selseyensis* at ∼10 cm intervals throughout the length of the core. From 150-88 cm (∼A.D. 680 to ∼A.D. 1270), δ^{18}O values (mean = -3.81 mil) average 0.3 and 0.2 mil lighter than below and above this interval, respectively, corresponding to an increase in water temperature of ∼1°C in the bay. The timing of the increased water temperature correlates well with records of the Medieval Warm Period acquired from tree stumps in the California Sierra Nevada mountain range by Stine, who found warm/dry periods from ∼A.D. 892 to ∼A.D. 1112 and ∼A.D. 1209 to ∼A.D. 1350. At 69 cm, following the culmination of this interval of increased water temperature, the δ^{18}O value is the heaviest recorded in the core (2.31 mil). These data, associated with a 2.5 times increase in sedimentation rate from 88 to 58 cm, suggest that the drought had ended and increased river runoff contributed to a heightened sedimentation rate at the core site.

PP72A-0422 1330h POSTER

High-Resolution Geochemical and Paleoecological Records of Climate Change Since the Late Glacial at Lake Tanganyika, East Africa

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We used high-resolution geochemical and paleoecological records from shallow-water sediment cores to refine previous descriptions of climatic conditions at Lake Tanganyika, East Africa, for the period from the Late Glacial to the present. Radiocarbon and ^{210}Pb dating were used to establish chronologies for the cores. Sedimentological changes indicate that lake level has risen approximately 50-70 m since the Late Glacial. A depositional hiatus occurred between 6.4 and 11.4 ka BP (all dates in calendar years) in several of the shallow-water cores. Elemental abundance (%C, %N) and stable isotopic (δ^{15}N, δ^{13}C) data for one core suggest that substantial changes in primary productivity and nutrient recycling regimes have occurred since 6.4 ka BP. Carbonate and ostracode crustacean preservation were low and nil, respectively, prior to 2.4 ka BP. Generally, these data support previous interpretations of regional paleoclimate and lake conditions, with wet and warm conditions during the interval from 6.4 to 4.0 ka, and increasingly arid conditions since 2.4 ka. However, for the interval from 4.0 to 2.4 ka, paleoenvironmental indicators (δ^{15}N, reduced carbonate and ostracode preservation) suggest that the central part of Lake Tanganyika was stably stratified at a shallower depth than present as a result of diminished southerly trade winds. After 2.4 ka BP, sedimentary carbonate concentrations increase, and δ^{13}C values become enriched, suggesting that lacustrine productivity increased with the resumption of deeper wind-driven mixing, lasting until 1 ka BP. For post-2.4 ka samples, species abundance data for ostracodes were used to generate an ostracode water depth index (OWDI). OWDI indicated that severe drought conditions were persistent or recurred at Lake Tanganyika between 1550 and 1850 A.D. Droughts resulted in marked lowstands at Lake Tanganyika at 1580±15 A.D., 1730±35 A.D., and 1800±30 A.D. These data contribute new information on the timing of Little Ice Age droughts and Mid-Late Holocene changes in trade wind intensity in tropical East Africa.

PP72A-0423 1330h POSTER

Climate from Borehole Data: Energy Fluxes and Temperatures since 1500

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Variations in the Earth's surface energy balance are recorded in the ground as perturbations of the subsurface thermal regime. Here I apply singular value decomposition (SVD) inversion methods to 826 temperature-depth profiles distributed world wide, in order to reconstruct ground surface temperature histories (GSTH) and surface heat flux histories (SHFH) from the temperature and heat flux anomalies detected in the shallow subsurface. Inversions yielded a mean ground surface temperature and surface heat flux histories for the Earth's continents for the last 500 years. Results indicate that the global average ground temperature and ground heat flux have increased an average of 0.45 °K and 18.0 mWm^2 respectively over the last 200 years, and 0.9 °K in the last five centuries.

URL: http://geophysics.stfx.ca/public/borehole/borehole.html

PP72A-0424 1330h POSTER

Scottish Sea Lochs: High Resolution Archives of North Atlantic Climate

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The sea lochs (fjords) of NW Scotland bridge the land-ocean interface in a region of Europe which is particularly well situated to monitor changes in westerly air flow. Inter-annual atmospheric circulation changes at this latitude are largely governed by the North Atlantic Oscillation (NAO), in turn influencing both westerlies and precipitation. Comparing two extreme recent NAO years, circulation modelling results from Loch Sunart, NW Scotland, reveal a clear response to freshwater runoff and wind forcing in both magnitude and rate of deep-water renewal events.

Scottish fjords, because of the relatively small impact which salinity has on d18Owater (0.18 per salinity unit), potentially provide NW Europes most useful study sites in coastal palaeoclimate research, particularly where palaeotemperature is the primary record of interest.

New data from a high-resolution record (7 yr sample resolution), spanning the last two millennia, from the deepest part of the main basin of Loch Sunart illustrate significant multi-decadal to centennial scale variability in the sedimentary and stable isotope record of epibenthic foraminifera Cibicides lobatulus. The long-term pattern in benthic d18O appears to reflect bottom water temperature differences of 1-2C, resolving climatic periods such as the Medieval Warm Period and the Little Ice Age. Since the core site is connected with shelf waters (i.e. no shallow sill) it seems likely that this paleotemperature reflects changing shelf water, not the exchange process as a function of long-term runoff/wind forcing. Grain size data and XRF data point to catchment-wide responses (weathering and erosion) which appear to show the largest variability during the last millennium, driven either by rainfall and temperature and/or land-use. Pb-isotope data, constraining the modern and industrial period, suggest accelerated sedimentation rates over this interval. On-going work attempts to calibrate proxy data with instrumental historical data.

PP72A-0425 1330h POSTER

Detection of climate modes as recorded in a seasonal-resolution coral record from the northern Red Sea

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The time series of oxygen isotopes (δ^{18}O) from a northern Red Sea coral is used to identify atmospheric circulation and sea surface temperature anomaly patterns related to interannual to decadal variability during different seasons of the year. We make use of seasonal resolution coral data for the period 1751-1994 and various instrumental climate data sets.

It is shown that during the cold season (January to April) the coral δ^{18}O variability at interannual time scales is related to a Northern Hemisphere atmospheric circulation mode similar to the Arctic Oscillation. Physically consistent large-scale sea surface temperature anomaly patterns are detected. In summer and fall interannual coral δ^{18}O variability is related mainly to regional processes.

We detected also the El Niño-Southern Oscillation (ENSO) signal in the interannual component of the coral record. The ENSO signal is non-stationary. Positive SST anomalies in the tropical Pacific, i.e., El Niño conditions, are associated with positive anomalies in coral oxygen isotopes for the last three decades, while for the period of the 1920s to 1960s the reversed correlation is detected. This shift in correlation can be attributed to changes in the atmospheric circulation and ENSO teleconnection pattern over Europe and the Middle East during the 1970's.

The Arctic Oscillation appears to be the dominant atmospheric circulation pattern which controls decadal variability in this coral record in almost all seasons.

We suggest that the δ^{18}O signal of corals from the northern Red Sea can be used to extract information on the regional and large-scale processes associated with climate variability over Europe and the Middle East during the preinstrumental period.

PP72A-0426 1330h POSTER

Temperature and Hydrologic Variability in the Tropical North Atlantic for the Last 2000 Years

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The role of the tropics in climate change on a variety of time-scales has become increasingly important. The Cariaco Basin is well-known as a recorder of Atlantic climate variability, and given its location, is particularly sensitive to fluctuations in tropical conditions.

AMS-dated box and gravity cores from the Cariaco Basin were sampled at consecutive millimeter intervals resulting in time series with temporal resolutions of one to three years spanning approximately the last 2000 years. Each sample was analyzed for foraminiferal census data, stable oxygen and carbon isotopes, and Mg/Ca ratios. The Mg/Ca ratios from *G. bulloides* were calibrated to instrumental temperature records and show a strong correlation to not only local SSTs, but also to a much wider region of the tropical North Atlantic. *Globigerina bulloides* δO^{18} values also exhibit a regionally significant correlation with instrumental SSTs, but only for the period 1950 to 1990 AD - correlation coefficients over the period of instrumental overlap prior to 1950 drop to near-zero suggesting regional variations in Atlantic surface salinity during this period. Fortunately, this discrepancy provides the opportunity to calibrate the combined Mg/Ca and δO^{18} data to regional salinity records, where available. Results from applying the newly-developed Mg/Ca and δO^{18} calibrations to the entire 2000 year-long sediment record will be presented.

PP72A-0427 1330h POSTER

Holocene Forest Fire Records as Evidence of Millennial-Scale Climate Change in the Northwestern United States

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Both modern observations and Holocene fire proxy records indicate that the magnitude and timing of wildfires is significantly affected by climatic change. Continental-scale drought episodes appear to be linked strongly to temperature, so that in 2002 and other recent warm years, major fires occurred in a variety of coastal and interior forest ecosystems despite regional precipitation differences and land management effects. We examine the timing of Holocene fires in central Idaho and Yellowstone National Park through interpretation and radiocarbon-dating of burned soil surfaces and fire-related sediments preserved in small alluvial fans. A large sample of alluvial fan stratigraphic sections within each region provides an essentially continuous and high-resolution record of fire-related sedimentation, including indications of fire severity. Major fire-related sedimentation occurred in cool, high-elevation mixed-conifer forests of Yellowstone between 1250 and 730 cal yr BP. In lower and warmer ponderosa forests in Idaho, at least 4 sites experienced fire-induced debris flows between 950 and 730 cal yr BP. Dates from these fire-related sedimentation events correspond to the Medieval period, as does evidence of synchronous fires in diverse climatic zones and ecosystems from other studies in the western U.S. Throughout the Holocene, minima in fire-related sedimentation in Yellowstone correspond with maxima of ice-rafted debris and cool episodes on 1500 year cycles in the North Atlantic (Bond et al., 1997). At these times, floodplain widening along streams in Yellowstone and low-severity fires in Idaho are consistent with higher effective moisture and cooler conditions. Even though these studies cannot reconstruct absolute variations in temperature and precipitation, they reflect millennial-scale temperature variations in the western U.S. that are clearly consistent with the North Atlantic cycles. Other paleoclimate proxies from the western U.S. including lake-level fluctuations, paleovegetation records, and glacial advances also provide evidence of notable warm and dry episodes in the Medieval period as well as Little Ice Age cooling. Nonetheless, late 20th-century warming and fires may exceed previous episodes in extent and severity.

URL: http://epswww.unm.edu/facstaff/gmeyer/ynp/ynpchron.gif

PP72A-0428 1330h POSTER

Borehole Temperature Observations Compared to Synthetic Subsurface Temperatures Generated by Proxy Climate Reconstructions

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The array of proxy climate reconstructions for the Northern Hemisphere over the past millennium (Briffa and Osborn, Science 295, 2002) are all consistent in their representation of the 20th century warming, but diverge in their representations of the 11th through 19th centuries. The 'end-member' reconstructions of this array are represented by the MBH history (Mann, Bradley and Hughes, Geophys. Res. Lett. 26, 1999) which shows a slow cooling from 1000-1900, and the ECS history (Espers, Cook and Schweingruber, Science 295, 2002) which shows a net warming over much of that time interval. Temperature changes at the surface impose a downward-propagating thermal anomaly on the subsurface temperature field. Implicit in every proxy history of surface temperature is a subsurface temperature anomaly generated by the surface temperature model. We have calculated synthetic subsurface temperature anomalies for these 'end-member' proxy reconstructions, and compare the synthetic anomalies to borehole temperature observations. For this comparison we have selected 213 borehole sites, all logged in the 1990s and well-distributed longitudinally over the continents of the Northern Hemisphere. The synthetic subsurface temperature anomaly profile generated by the ECS reconstruction is close to the borehole observations, whereas the subsurface anomaly associated with the MBH reconstruction is significantly different. Because of its long multi-century cooling trend, the MBH model predicts a negative subsurface temperature anomaly below a depth of about 70m, a characteristic that is absent in both the ECS subsurface signature and in the borehole observations. We recognize that both the ECS reconstruction and the borehole temperatures are essentially extra-tropical records restricted to the continents, whereas the MBH reconstruction utilizes both tropical and extra-tropical data from both continents and oceans. However, to reconcile the significant difference between the negative subsurface thermal anomaly predicted by the MBH model and the positive thermal anomaly associated with the ECS reconstruction and observed in the boreholes would require an extraordinary climatic contrast between the extra-tropical continents and the rest of the hemisphere.

PP72A-0429 1330h POSTER

Late Holocene Environmental and Hydrologic Conditions in Northwestern Florida Derived from Seasonally Resolved Profiles of $\delta^{18}O$ and Sr/Ca of Fossil Bivalves.

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We reconstruct environmental conditions of coastal Northwestern Florida from combined measurements of $\delta^{18}O$ and Sr/Ca of fossil marine bivalves deposited in an archeological site during the late Holocene period.

We first investigated the environmental controls of seasonally resolved records of $\delta^{18}O$ and Sr/Ca of modern *Mercenaria mercenaria* and *Mercenaria campesiensis* collected live from five coastal sites along the east coast of North America. Seasonal profiles were obtained by subsampling the incremental growth layers of aragonite and were compared with in situ historical records of temperature and salinity. We show that these bivalves precipitate their shell in isotopic equilibrium with the water in which they grew and that the $\delta^{18}O$ records are not affected by variations in growth rate. Winter growth appears to be interrupted or strongly reduced below water temperatures ranging from 7 to 18°C, depending on latitude. The annual average $\delta^{18}O$ decreases with latitude, reflecting both the parallel trend of freshwater $\delta^{18}O$ with latitude over the North American continent and the reduced winter growth rate. The Sr/Ca records of the 5 modern bivalves also exhibit seasonal variations can be correlated to water temperature. However, contrary to corals, the Sr/Ca ratio is considerably lower than the average sea water Sr/Ca composition and is positively correlated to the water temperature.

We dated and measured the $\delta^{18}O$ and Sr/Ca of 30 fossil *M. campesiensis* from an archeological site close to Cedar Key, in the Gulf of Mexico. Accelerator Mass Spectrometry ^{14}C dates obtained for each shell show ages which cluster between 1100 to 1400 and 2300 to 2600 ^{14}C years BP corresponding approximately to two historical warm periods known as the Medieval Warm Period (∼ 1300-900AD) and the Roman Warm Period (∼ 250AD-200BC). The average annual and summer Sr/Ca of 4 fossil shells are higher than that of modern bivalves from the same location suggesting that annual coastal water temperatures were 3 to 4°C warmer than today. The bulk $\delta^{18}O$ values show a marked trend towards more positive values. 24 fossil shells have bulk $\delta^{18}O$ values $0.2^o/_{oo}$ to $0.7^o/_{oo}$ more positive than modern bivalves from the same location. These results suggest that the coastal waters off northwest Florida were warmer and less saline compared to today and attest of considerable differences of the regional climate and hydrological balance during the Medieval Warm Period and Roman Warm Period.

PP72A-0430 1330h POSTER

Time Series at Decadal Resolution Show Tropical Influence on Climate Variability in The Eastern Nordic Seas Over the Past 2 Millenia.

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Multi-proxy paleoclimatic time series have been developed from IMAGES Sites and adjacent supplementary cores in the Eastern Norwegian Sea. The records cover the last 2000 years at decadal resolution, allowing for a detailed reconstruction of the surface hydrography of the main path of the northern limb of the north Atlantic circulation cell. Centennial to millennial scale events are recorded, such as the Medieval Warm Phase" (MWP) and the "Little Ice Age" (LIA), which constitute the main long term century scale features. Superimposed on these are multidecadal variability of somewhat less amplitude. There is a close correspondance with continental records reflecting summer temperaure and winter precipitation in western Scandinavia over this period.SST changes are found to be in the range of 1-2 degrees. Significant land-sea correlation is observed. A cold phase in the early 20th Century, a series of cold phases in the LIA and two warm phases in the MWP are observed. There is a strong correlation between records of tropical variability from the Cariaco Basin and the Nordic Seas data, both in the proxy records and in long instrumental time series, indicating a strong tropical influence on high latitude variability.

PP72A-0431 1330h POSTER

Coral Evidence Indicating More Spatially Coherent South Pacific Interdecadal Climate Variability Since ∼1880 A.D.

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We have generated multi-century long, subannually resolved time-series of Sr/Ca and oxygen isotopes ($\delta^{18}O$) from corals growing at the islands of Rarotonga (21°S, 160°W) and Fiji (17°S, 179°E). The longest

record from Rarotonga extends from 1997 back to 1726 A.D. and the δ^{18}O signal since 1874 has been replicated using other corals from the island. At Fiji we have analyzed one core extending from 1997 back to 1780 A.D. As previously reported, at Rarotonga coral Sr/Ca is well correlated to instrumental sea surface temperature (SST) on seasonal and interannual time-scales (Linsley et al., 2000). We find the same degree of correlation between Sr/Ca and SST at Fiji. Coral δ^{18}O at both sites primarily reflects variations in SST and South Pacific Convergence Zone related precipitation. In this study we focus on interdecadal variability in Sr/Ca and δ^{18}O, and compare our results to indices of interdecadal climate variability in the Pacific based on the instrumental record (PDO and IPO), and to published coral δ^{18}O results from New Caledonia (22°S, 166°E), and Maiana Atoll (1°N, 173°E). These records indicate that interdecadal climate variability in the southwest Pacific became more organized and spatially coherent after approximately 1880 A.D, particularly from 1880 to ~1950 A.D. This transition in the late 1800s coincided with a previously reported widespread freshening of surface ocean salinity in the southwest Pacific (Hendy et al., 2002) that may have resulted from a reduction of trade wind and South Equatorial Current influence in the region.

PP72B MCC: 106 Sunday 1330h

Patterns of Holocene and Deglacial Climate Variability in the Tropics and Subtropics II *(joint with C, A, H, OS, GC)*

Presiding: **T Koutavas,** Lamont-Doherty Earth Observatory of Columbia University**; C Farmer,** Lamont-Doherty Earth Observatory of Columbia University

PP72B-01 1330h INVITED

What happened to El Nino during the early Holocene?

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Coral records from the tropical Pacific indicate that interannual fluctuations associated with El Nino today were absent during the early Holocene until approximately 5000 years ago. Some authors claim that, at that time, the waters off Ecuador and northern Peru were permanently warm, but explaining the persistence of arid conditions along the coast is then a problem. Another ossibility, supported by some measurements, is that El Nino occurred less often, every decade or so. To theoreticians, these findings raise two sets of questions. First, El Nino can be regarded as part of a natural mode of oscillation that depends on background conditions such as H the mean depth of the thermocline, TX the intensity of the mean winds etc. What changes in the background conditions, in values of H, TX etc, will result in either permanently warm conditions, or El Nino with a very low frequency? Stability analyses of ocean-atmosphere interactions indicate that if the thermocline was deeper than today, then weak winds would have resulted in permanently warm conditions, but strong trades would have resulted in infrequent El Nino episodes. Next we have to ask why the background conditions changed. During the Holocene precession of the Earths axis caused first the northern hemisphere, then the southern hemisphere to experience warmer summers, colder winters. As a result the Sahara had lakes, Lake Titicaca was dry, and apparently the trade winds were strong during the early Holocene. To test the inference that El Nino became a very low frequency phenomenon during the early Holocene requires information about the depth of the thermocline and the intensity of the trades at that time.

PP72B-02 1345h INVITED

A Super-ENSO pattern of SST and SSS Variability in the Western Tropical Pacific Through the Holocene

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We have analyzed a suite of high deposition rate marine cores collected from the Indonesian archipelago by the IMAGES program in an effort to constrain the history of SST and SSS variability in the Western Pacific Warm Pool. Three of the cores have sediment accumulation rates through the Holocene in excess of 70cm/kyr based on radiocarbon measurements of biogenic carbonate. Measurements of d18O and Mg/Ca of Globigerinoides ruber were conducted at centimeter intervals through the Holocene. This species appears to produce primarily during the summer months. These data are used to infer whether there have been large scale changes in ocean/atmopheric variability over the western tropical Pacific through the Holocene. We find that the Holocene Mg/Ca SSTs averaged between 28.5 and 30oC throughout the Holocene. However, the d18O of G. ruber became progressively lighter through the Holocene, from about -2.2per mil at the end of the Younger Dryas to about -3.0per mil in the most recent sediments. If interpreted as temperature this d18O record would imply a progressive increase in temperature of nearly 4oC. However, this is not supported by the Mg/Ca paleothermometry. We interpret the oxygen isotopic record to reflect a progressive change in the summer surface salinities in the western tropical Pacific. As surface salinities are strongly affected by the strength of atmospheric convection over the WPWP, the progressive change in salinity could be interpreted to reflect a systematic change in atmospheric conditions over the tropics. Superimposed on the long term isotopic trend are millennial-scale oscillations in d18O that are similar in character to those we have previously reported on from the Pleistocene and interpreted to reflect changes in the strength of ENSO. We suggest that the same millennial-scale oscillations in the strength of ENSO have persisted throughout the Holocene, providing further evidence that the tropics and perhaps the entire global climate exhibits a persistent pattern of variability at millennial time scales. This has important implications for assessing the uniqueness of the late Holocene climate changes including the 20th century warming.

PP72B-03 1400h

Mechanisms of ENSO Response to Glacial and Milankovitch Forcing in the NCAR Climate System Model

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The tropical Pacific climate response to Holocene/glacial boundary conditions is examined for the last glacial-interglacial cycle with simulations using the fully coupled, non-flux corrected NCAR CSM model. The present-day CSM simulation reproduces both the spatial and temporal character of the observed equatorial Pacific variability quite well. The standard deviation of the model Nino-3 index is 0.68°C, comparable to values calculated from observations. The model simulates weaker El Ninos compared to present for the last 11,000 years (Nino-3 index = 0.54°C at 11 ka) and stronger El Ninos for the Last Glacial Maximum (Nino-3 index = 0.81°C at 21 ka). The changes in intensity for the last 11,000 years are traced to modulation of wind stresses across the tropical Pacific Ocean by the summer Asian monsoon and weakening of the tropical thermocline. Seasonal and annual solar radiation anomalies associated with Milankovitch forcing drive these changes and are shown to dominate the effect of the residual continental ice sheets. For the Last Glacial Maximum, changes in the intensity are traced to a sharpening of the tropical thermocline and weakening of the east-west sea surface temperature gradient. The ocean dynamical thermostat mechanism in the tropics and subduction of colder waters from Southern Hemisphere latitudes associated with the expansion of sea ice are important. Reduced atmospheric greenhouse gases force these ocean temperature changes at the LGM.

Decreased ENSO variability going back to 11 ka, with more occurrences of small and less occurrences of large El Ninos and La Ninas compared to present, agrees with interpretation of laminae changes in an alpine lake in Ecuador by Rodbell and collaborators. The CSM suggests that the reduced amplitudes of glacial ENSO variability documented by Tudhope and collaborators in corals from New Guinea are associated with weaker teleconnections to precipitation changes over the region that occur with a shift eastward of the Walker Circulation and a reduction in mean precipitation amounts at LGM compared to present.

PP72B-04 1415h

Magnitude and Timing of Temperature Change in the Indo-Pacific Warm Pool During Deglaciation

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The ocean-atmosphere interactions presently occurring in the tropical Pacific exert a strong control over global heat and water vapor transport and thus are an important component of the climate system. Specifically, changes in sea surface temperatures (SST) and convection in the tropical Indo-Pacific region are responsible for interannual (i.e. ENSO) to decadal (i.e. NAO and PDO) climate variability observed in extratropical regions. The question to be answered is, what role, if any, do the tropics play in fostering longer term (i.e. millennial and/or orbital scale) changes in global climate. In this study we consider both the magnitude and timing of SST changes at a site in the Indo-Pacific warm pool during the last two glacial-interglacial transitions (Terminations 1 and 2). High-resolution δ^{18}O and Mg/Ca records from the planktonic foraminifer *Globigerinoides ruber* were generated in order to document changes in SST in this region during these periods of deglaciation. As the Mg/Ca of planktonic foraminifer is not influenced by the same parameters as δ^{18}O, it can be used in parallel with δ^{18}O to estimate how much of the isotope signal is due to ice volume. Additionally, by measuring paired Mg/Ca and δ^{18}O on the same sample we can directly determine the phase relationship between SST change and ice volume change, independently of the chronology that is used.

The Mg/Ca results indicate that SST within the Indo-Pacific warm pool increased by 3.5- 4.0 °C during the last two transitions from glacial to interglacial conditions. The warming of this region during deglaciation occurred synchronously with a global increase in atmospheric CO_2 and a warming in the Antarctic but two to three thousand years prior to the melting of the Northern Hemisphere ice sheets. These observations suggest that the tropical Pacific plays a major role in driving global climate change, principally through regulating the poleward flux of heat and water vapor.

PP72B-05 1430h

Glacial-Interglacial Dynamics of the Eastern Equatorial Pacific Cold Tongue-ITCZ Complex.

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Wind-driven upwelling in the eastern equatorial Pacific (EEP) forms a characteristic tongue of cold waters centered just south of the equator, which displaces the region of warmest sea surface temperature (SST) coincident with the Intertropical Convergence Zone (ITCZ) to the north. The cold tongue-ITCZ complex in the EEP is marked by one of the steepest meridional SST gradients observed presently in the tropics, and its dynamics are linked to the coupled ocean-atmosphere interactions that modulate the intensity of upwelling over seasonal and interannual timescales. Cold tongue-ITCZ dynamics are therefore of central importance for the equatorial circulation across the entire Pacific and hence for global climate as well.

Here we use oxygen isotope and Mg/Ca ratios measured on planktonic foraminifera from nine EEP sites to investigate the glacial-interglacial pattern of variation in this system from the Last Glacial Maximum (LGM) through the Holocene. We find that the cross-equatorial hydrographic front separating the cold tongue and ITCZ was attenuated to approximately half its present strength during the LGM. Because the strength of this front is presently related directly to the intensity of upwelling in the cold tongue, we infer reduced upwelling in glacial times, most likely associated with a weakening of the equatorial trade winds. This is in agreement with evidence from land for reduced Hadley circulation in glacial times. We suggest that the dominant mean climate mode in the glacial EEP resembled a quasi-El Niño state, with a less well-developed