PP22B-03 1405h INVITED

CO_2 as a Primary Driver of Phanerozoic Climate Change

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Recent studies have purported to show a closer correspondence between Phanerozoic records of cosmic ray flux and temperature than between CO_2 and temperature. The role of the greenhouse gas CO_2 in controlling global temperatures has therefore been questioned. Here we review the geologic records of CO_2 and glaciations and find that CO_2 was low during periods of long-lived and widespread continental glaciations and moderately-high to high during other, warmer periods. The CO_2 record is likely robust because independent proxy records are highly correlated with CO_2 predictions from geochemical models. The Phanerozoic shallow water $\delta^{18}O$ temperature record has been used to quantitatively test the importance of potential climate forcings, but it fails several first-order tests relative to well-established paleoclimatic indicators: both the early Paleozoic and Mesozoic are calculated to be too cold for too long. We explore the possible influence of seawater pH on the $\delta^{18}O$ record and find that a pH-corrected record matches both the glacial and CO_2 records much better. Periodic fluctuations in the cosmic ray flux may be of some climatic significance, but are likely of second-order importance on a multi-million year timescale.

PP22B-04 1420h INVITED

Global warming in the early Eocene: was it driven by carbon dioxide?

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A wide variety of geological evidence indicates Earth experienced extreme global warmth 50 million years ago. But proxy indicators generally suggest carbon dioxide levels similar to today's value. What, then, drove global warming in the Eocene ? We present a process-based earth systems modelling analysis of this Eocene climatic puzzle. In our atmospheric chemistry calculations, trace gas emissions from terrestrial ecosystems lead to significantly higher atmospheric methane and tropospheric ozone levels compared to the pre-industrial situation. Climatic feedback experiments, quantifying the radiative forcing of these gases, and stratospheric water vapour, demonstrate substantial land surface warming. We suggest therefore that the trace gas composition of the ancient atmosphere provides a coherent climate forcing mechanism accounting, in large part, for the global warmth of the early Eocene.

PP22B-05 1440h

Continental Break-up And Global Climatic Evolution

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The global cooling of the Earth at the end of the Proterozoic (750-550 Ma), possibly resulting in successive global glaciations, has been linked to the concomitant fragmentation of the long-lived supercontinent Rodinia. By coupling an ocean-atmosphere climate model to a global carbon cycle model, we show that the breakup of Rodinia induces a significant decrease in atmospheric pCO2 of 1320 ppm due to the intense runoff occurring in a dispersed continental configuration, and results in a progressive transition from a greenhouse' to an icehouse' climate.

PP22B-06 1455h

A Prominent Rise in Tropical SST during the Paleocene-Eocene Thermal Maximum as inferred from Mg/Ca, Isotope, and other data

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The Paleocene-Eocene Thermal Maximum (PETM) has been attributed to a rapid rise in greenhouse gas levels, possibly via extensive dissociation of marine clathrate. If so, warming should have theoretically occurred at all latitudes, though amplified toward the poles. Oxygen-isotope records reveal that high latitude sea surface temperature (SST) warmed by as much as 10^{o}C, while worldwide bottom water temperatures increased by 5^{o}C. To date, however, the character of the tropical SST response during the PETM remains unconstrained. Here we address this deficiency by measuring both the oxygen isotope and minor element (magnesium/calcium) ratios of planktonic foraminifera from a tropical Pacific deep-sea core to estimate changes in SST and sea-surface salinity (SSS). The core is from ODP Site 1209 located on Shatsky Rise. The P/E boundary layer is represented by a dark horizon imbedded in a carbonate-rich nannofossil ooze. Samples were collected at high-resolution across this layer for a variety of analyses. Stable isotope analyses of single specimen mixed-layer foraminifera, *Morozovella velascoensis* and *Acarinina soldadoensis* show the classic -3.0$^{o}/_{oo}$ δ^{13}C excursion as well as a -0.7$^{o}/_{oo}$ δ^{18}O excursion. Minor element analyses of the same species reveal a prominent excursion in Mg/Ca ratios from 3.6 to 5.5 mmol/mol. The excursions in the isotope and Mg/Ca records appear to initiate a few cm below the sharp lithologic contact that marks the base of the clay rich layer, peak about 20 cm above. Sr/Ca ratios on the other hand remain constant. Other proxies of preservation show no correlation to the Mg/Ca. Thus, the combined isotope/minor element proxies imply a 4.5-5.0^{o}C rise in Pacific SST during the PETM. From the residual in the oxygen isotope record, we estimate an SSS increase of 1-2 ppt. These results, when considered with SST data for high-latitudes, are consistent with model simulated tropical SST response to roughly a doubling of atmospheric pCO_2.

PP22B-07 1510h

Equilibrium Tropical Climate Sensitivity Determination from Paleoclimatic Data

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The key scientific uncertainty in the global warming debate is the equilibrium climate response to a doubling of atmospheric carbon dioxide. Coupled atmosphere-ocean general circulation models predict a wide range of equilibrium climate sensitivities (2.0 to 5.1 deg C), with a consequently large spread of societal implications. Comparison of models with instrumental data have not been able to reduce the uncertainty in climate sensitivity. An alternative way to gauge equilibrium climate sensitivity is to use paleoclimatic data. Two recent advances, the development and application of proxy recorders of tropical sea surface temperature (SST) and the synchronization of the deep-sea and Antarctic ice-core time scales, make it possible to directly relate past changes in tropical SST to atmospheric carbon dioxide levels. A detailed 360 ky record of past tropical SST variations in the warm (modern SST = 26.2 deg C) eastern equatorial Pacific waters north of the Galapagos Islands was previously obtained from core TR163-19 (2 deg N, 91 deg W: 2348m) (Lea et al., 2000). A new age model has been developed for this record by aligning the benthic O18 record of TR163-19 to nearby core V19-30, which itself has been aligned to Vostok air O18 (Shackleton, 2000). Using this age model, the coherency between the TR163-19 SST record and Vostok CO2 is 0.98 at 100k and 0.94 at 41k (0 phase lag). The strong correspondence of tropical Pacific SST and Vostok CO2 leads to the hypothesis that atmospheric carbon dioxide variations are the dominant control on tropical climate on orbital time scales (100k, 41k). Calibration of the influence of past greenhouse gas variability (CO2 and methane) on tropical SST indicates a tropical climate sensitivity equivalent to 4.4 plus/minus 1 deg C for a 4 W per sq. m radiative increase from doubling of atmospheric pCO2. This result suggests that the equilibrium response of tropical climate to atmospheric CO2 changes might be similar to the upper end of available predictions from coupled models. The two key uncertainties in this study are: 1) the degree to which factors other than greenhouse gases (e.g., ice volume) affect tropical SSTs, which could be tested by GCMs; and, 2) the reliance on a single site with potential regional sensitivity, which could be improved by using multiple tropical SST records.

URL: http://www.geol.ucsb.edu/faculty/lea/

PP22B-08 1525h

Estimating climate sensitivity from paleo-data.

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For twenty years estimates of climate sensitivity from the instrumental record have neen between about 1.5-4.5^{o}C for a doubling of CO2. Various efforts, most notably by J. Hansen, and M. Hoffert and C. Covey. have been made to test this range against paleo-data for the ice age and Cretaceous, yielding approximately the same range with a "best guess" sensitivity of about 2.0-3.0^{o}C. Here we re-examine this issue with new paleo-data and also include information for the time period 1000-present. For this latter interval formal pdfs can for the first time be calculated for paleo data. Regardless of the time interval examined we generally find that paleo-sensitivities still fall within the range of about 1.5-4.5^{o}C. The primary impediments to more precise determinations involve not only uncertainties in forcings but also the paleo reconstructions. Barring a dramatic breakthrough in reconciliation of some long-standing differences in the magnitude of paleotemperature estimates for different proxies, the range of paleosensitivities will continue to have this uncertainty. This range can be considered either unsatisfactory or satisfactory. It is unsatisfactory because some may consider it insufficiently precise. It is satisfactory in the sense that the range is both robust and entirely consistent with the range independently estimated from the instrumental record.

PP22C MCC: 3001-3003 Tuesday 1600h

Old World Social Responses to Holocene Abrupt Climate Change Events I *(joint with B, GC, PA, HG)*

Presiding: **H Weiss,** Yale University**; L Ristvet,** Cambridge University

PP22C-01 1600h

Work More? The 8.2 kaBP Abrupt Climate Change Event and the Origins of Irrigation Agriculture and Surplus Agro-Production in Mesopotamia

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The West Asian archaeological record is of sufficient transparency and resolution to permit observation of the social responses to the major Holocene abrupt climate change events at 8.2, 5.2 and 4.2 kaBP. The 8.2kaBP abrupt climate change event in West Asia was a three hundred year aridification and cooling episode. During this period rain-fed agriculture, established for over a millennium in northern Mesopotamia, suddenly collapsed. Irrigation agriculture, pastoral nomadism, or migration were the only subsistence alternatives

for populations previously supported by cereal dry-farming. Irrigation agriculture was not, however, possible along the northern alluvial plains of the Tigris and Euphrates Rivers, where incised riverbeds were several meters below plain level. Exploitable plain-level levees were only accessible in southern-most alluvial plain, at the head of the present-day Persian Gulf. The archaeological data from this region documents the first irrigation agriculture settlement of the plain during the 8.2 kaBP event. Irrigation agriculture provides about twice the yield of dry-farming in Mesopotamia, but at considerable labor costs relative to dry-farming. With irrigation agriculture surplus production was now available for deployment. But why work more? The 8.2 kaBP event provided the natural force for Mesopotamian irrigation agriculture and surplus production that were essential for the earliest class-formation and urban life.

PP22C-02 1615h

Agriculture, Settlement, and Abrupt Climate Change: The 4.2ka BP event in Northern Mesopotamia

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An abrupt aridification event at 4200 BP has been recorded in 41 paleoclimate proxies in the Old World, from Kilmanjaro, Tanzania to Rajasthan, India, East Asia and the Pacific. This event is particularly well defined for Western Asia, where it has been associated with the abandonment of settlements across the Fertile Crescent and the collapse of states on the Levantine coast and in the dry-farming plains of Northern Mesopotamia, including the Akkadian Empire. Adaptations to climate change are constrained by both local environmental and social factors. Agriculturalists, especially those living in pre-industrial societies, are particularly susceptible to changes in precipitation. The Tell Leilan Regional Survey, which systematically studied sites in a 1650km2 area of Northeastern Syria, records one set of adaptations to this event in an area where dry-farming provided the subsistence base. The survey transect crosses ecotones, from the present 500mm isohyet in the North to the 250mm isohyet in the South, and contains diverse wadi systems, ground water resources, soil profiles, and an ancient marsh/lake– all of which allow this region to be taken as a microcosm of Northern Mesopotamia. In order to contextualize our study of human response to abrupt climate change, it is necessary to consider how the economic and social systems that were previously in place were transformed by this event. This study attempts to quantify climate change and model its effects on agricultural, pastoral, and settlement systems in Northeastern Syria from 2400-1700 BC. From 2400-2300 BC, optimal climate conditions coincided with the consolidation of an indigenous state. The next century witnessed the Akkadian conquest and imperialization of the Habur plains, which resulted in both the intensification and extensification of agro-production. During the next 300 years, (2200-1900 BC), rainfall plummeted to 70% of the climatic optimum, triggering the abandonment of cities along with their attendant villages. The survey records an 80% decline in settled hectares from the previous period. The only agricultural villages that remained occupied during this crisis were either concentrated along perennial wadis or located in areas with ample groundwater. Otherwise, the survey recorded the presence of a few temporary sites, probably camps belonging to semi-nomadic pastoralists, a lifestyle which may have begun in response to this event. The precipitation regime stabilized at approximately 1900 BC, allowing for a massive resettlement of the area. This resettlement did not, however, lead to a resumption of third millennium agricultural practices; instead, these villages embraced a flexible economic regime, which emphasized a reliance on pastoral as well as agricultural products, and as such, was well-adapted to the more marginal conditions of the early second millennium BC. This paper, therefore, attempts to quantify the effects of the 4.2 ka BP abrupt climate change event on ancient agricultural systems, settlement patterns, and societies through archaeological survey in northern Mesopotamia.

PP22C-03 1630h

Archaeological Evidence for Abrupt Cimate Change: Results from Satellite Imagery Analysis and Subsequent Ground-Truthing in the El-Manzalah Region, Northeast Egyptian Delta

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The abrupt global climate changes recorded at 8.2, 5.2 and 4.2 ka BP caused a wide range of transformations within ancient societies, including the focus of this study: ancient Egypt . In the case of the climatic changes that occurred at 4.2 ka BP, scholars have debated hotly the events surrounding the "collapse" of the Old Kingdom. Despite such studies into the Old Kingdom's "collapse", there have been insufficient regional settlement pattern studies in Egypt to augment hypotheses concerning the mechanisms behind the cultural transformations that occurred at the end of the Old Kingdom. Utilizing a combination of satellite imagery analysis and subsequent ground-truthing techniques over a broad region in the East Delta, this study aims to reconstruct pharaonic settlement distributions in relation to the changing northeast delta topography, river courses, marshlands, and coastline. Although geo-political and religious factors played varying roles in settlement patterns, this study overlies the economic and environmental components behind the settlement of individual sites and areas. For instance, prior to the formation of the Manzala lagoon, beginning in the 4th century AD, the Mendesian branch of the Nile flowed past Mendes and its satellite, maritime port at Tell Tebilla: As early as the Old Kingdom, Tell Tebilla provided an ideal location for the formation of a town, being well-located to exploit both riverine and maritime transportation routes through trade, and regional floral and faunal resources from hunting, fishing, cultivation and animal husbandry. Key factors such as long-term fluctuations in precipitation, flood levels, and river courses, can affect dramatically the fortunes of individual settlements, areas, and regions, resulting in the decline and abandonment of some sites and the foundation and flourishing of other sites, especially within marginal regions. The Egyptian delta represents an ideal region for studying the impacts of climatic changes through time since it is particularly sensitive to river changes, coastal expansion, and changes within the floral and faunal resource base available to settlements through time. In order to locate ancient settlements in the northeast delta, this study introduced a variety of innovative techniques involving satellite image analysis through Corona, Spot, Landsat and ASTER images, in conjunction with existing archaeological survey data and maps. All known sites were plotted against the satellite imagery data, in order to ascertain whether the newly designed site identification methods worked. The technique had a 95 percent success rate in locating over 100 previously known sites. This technique was next applied to locate new sites and sites believed to be destroyed. In order to verify the accuracy of this new site locational technique, this writer conducted ground-truthing during the summer of 2003, assessing and photographing over 60 new and little known sites in the East Delta. The surface pottery from each site was examined and photographed, and revealed settlements dating to the Old Kingdom, Late Period and Roman Periods. Each known and newly-discovered settlement will be plotted on maps of the eastern Delta, in order to show site disbursement during the time periods represented, especially in relation to geziras, rivers, canals, marshes and the ancient coastline. The paper demonstrates the affects that abrupt climatic changes had on ancient settlement patterns, and reveals how satellite imagery interpretation is applicable to similar studies in other regions.

URL: http://www.deltasinai.com

PP22D MCC: 3001-3003 Tuesday 1700h

Emiliani Lecture *(joint with A, OS, GC)*

Presiding: **B L Otto-Bliesner,** National Center for Atmospheric Research

PP22D-01 1700h INVITED

The Anthropogenic Era Began Thousands of Years Ago

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The anthropogenic era is generally thought to have begun about 150 years ago when the industrial revolution began producing CO2 and CH4 at rates sufficient to alter atmospheric compositions. The hypothesis proposed here is that anthropogenic emissions first altered atmospheric gas concentrations (and climate) thousands of years ago. This hypothesis rests on three arguments: (1) Cyclic variations in CO2 and CH4 driven by Earth-orbital changes during the last 400,000 years predict decreases of both gases throughout the Holocene, but CO2 began an anomalous increase near 8000 years ago and CH4 about 5000 years ago. (2) Published explanations attributing these Holocene gas increases to natural forcing can be rejected based on available paleoclimatic evidence. (3) Archeological, cultural, historical, and geologic sources provide viable explanations tied to anthropogenic changes that emerged from early agriculture in Eurasia, including forest clearance after 8000 years ago and lowland irrigation for rice farming by 5000 years ago. Prior to the industrial era, these emissions caused a mean-annual warming effect of 0.8oC globally and 1.5-2oC at high latitudes. The early-anthropogenic warming counteracted most of a natural cooling that would otherwise have occurred, and it may have prevented a glaciation in northeastern Canada predicted by two kinds of climatic models. CO2 decreases as large as 10 ppm during the last 1000 years cannot be explained by solar-volcanic forcing without violating constraints imposed by reconstructions of northern hemisphere temperature. The CO2 decreases can be explained by bubonic plague pandemics that the caused widespread abandonment of western Eurasian farms documented in historical records. Rapid regrowth of forests on millions of abandoned farms could have sequestered enough carbon to explain the observed CO2 decreases. Plague-driven CO2 decreases were a significant causal factor in the cooler temperatures of the Little Ice Age from 1300 to 1900 A.D.

PP31A MCC: 3004 Wednesday 0800h

Climate of the Last Glacial-Interglacial Cycle: New Insights From Models and Data *(joint with A, OS, C, GC)*

Presiding: **N S Diffenbaugh,** University of California, Santa Cruz**; C Eakin,** NOAA Paleoclimatology, National Climatic Data Center

PP31A-01 0800h

Polar MM5 Simulations of the Winter Climate of the Laurentide Ice Sheet During the Last Glacial Maximum

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Polar MM5 simulations are conducted using a 60-km domain centered over North America during Last Glacial Maximum (LGM), roughly 21,000 calendar years ago, when much of continent was covered by the Laurentide Ice Sheet (LIS). The objective is to describe the winter atmospheric circulation over North America using a fine-resolution regional climate model that is well suited for high latitude applications. The Polar MM5 LGM boundary conditions include continental ice sheets, appropriate orbital forcing, reduced CO2 concentration, paleovegetation, modified sea surface temperatures, and lowered sea level. Output from a CCM3 (NCAR Community Climate Model version 3) simulation of the LGM is used to provide the initial and lateral boundary conditions for Polar MM5. The model atmosphere responds strongly to the LGM boundary conditions. Cooling over the LIS drives a pronounced wintertime low-level katabatic flow. From November through March the upper level flow is split around a blocking anticyclone over the LIS, with a northern branch over the Canadian Arctic and a southern branch impacting southern North America. This split flow pattern, which is most pronounced in January, has a first order influence on the distribution of precipitation in the model domain and is not present in recent GCM simulations of the LGM. Possible reasons for the presence of the split flow, including ice sheet configuration, model resolution, and model physics, are investigated through a series of sensitivity studies. Each contributes to the winter split jet stream in Polar MM5. Comparisons of model output with available proxy data over North America are also discussed.

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