microalgae as extracellular carbohydrates that apparently tightly coupled to heterotrophic dynamics. Sedimentary organic carbon utilization by benthic consumers is strictly influenced by its biochemical composition mainly consisting of proteins followed by lipids and water-soluble carbohydrates. Potential organic carbon (OC) turnover is generally rapid (7-14 d^{-1}) suggesting freshly produced material to the sea floor. The faster turnover times corresponde to greater DOC benthic efflux confirming an efficient bacterial decomposition. On the other hand, vertical fluxes provide very low OC inputs that cannot explain the values of benthic production observed. The microphytobenthic production is a potentially important alternative OC source for benthic consumers. Total autochthonous production however is unable to sustain the benthic community metabolism neither in net photoautotrophy conditions therefore important allochthonous inputs (i.e. material brought from the river or by lateral advection) must be present.

OS31I HC: 318 A Wednesday 0830h

Paleoceanography of Warm and Cold Climates During the Cenozoic Cooling Trend

Presiding: **D Seidov,** Pennsylvania State University**; E Barron,** Pennsylvania State University**; L Sloan,** University of California, Santa Cruz Cruz

OS31I-01 0830h

What can we Learn About the Oceans Role in Climate From the Cenozoic Cooling Trend? An Introduction

Eric J Barron (814-865-1619; eric@essc.psu.edu)

Penn State University, EMS Environment Institute 2217 Earth-Engineering Sciences Bldg, University Park, PA 16802, United States

The Cenozoic contains a rich record of climate change, including a cooling trend occurring over tens of millions of years and a number of abrupt steps or transitions. Observations suggest that the Late Cretaceous and Early Cenozoic deep ocean temperatures were as high as 15 degrees C, a condition not to be found subsequently. Transitions at key intervals, such as the Paleocene/Eocene boundary, provide strong evidence of large-scale changes in ocean circulation, its biota and in indicators of the character of the atmospheric circulation. The development of continental scale glaciation coincides with significant changes in the character and intensity of the ocean circulation. The mechanisms responsible for the cooling trend remain the subject of intense debate, but the role of the ocean is central in the majority of the hypotheses. This introduction provides an overview of the modeling efforts designed to simulate the global change in response to the evolution of the Earths surface since the Cretaceous. Three factors are considered: (1) Both land-sea distribution and the role of ocean gateways are key elements of model studies and in hypotheses of long-term climate change, (2) Carbon dioxide is believed to be a major contributor to the evolution of the Earths temperature and carbon dioxide is likely to be closely coupled to global tectonics. (3) Freshwater impacts in high latitudes could accompany and strongly influence cryosphere development during the Cenozoic cooling trend. Recent computer simulations indicate that these impacts could be an important element of the long-term climate change. These studies emphasize the role of the coupled ocean-atmosphere system in transporting heat poleward and the role of changes in continental configuration or freshwater inputs in altering the nature of the ocean circulation.

OS31I-02 0900h INVITED

Tropical Temperatures in Ancient Greenhouse Climates

Paul N Pearson (44-117-9545444; Paul.Pearson@bristol.ac.uk)

University of Bristol, Dept. of Earth Sciences Queen's Road, Bristol BS8 1RJ, United Kingdom

There is abundant geological evidence for warm, mostly ice-free poles in ancient warm climate phases such as in the Late Cretaceous and Paleogene periods. Two broad classes of explanation may account for this, namely a more efficient system of atmospheric and oceanic circulation and/or higher overall global temperatures, possibly due to an enhanced greenhouse effect. Previous investigations of sea surface temperatures (SSTs) in the tropics using the oxygen isotope ratio of planktonic foraminifer shells have tended to suggest relatively cool values (typically around 20 degrees or less), leading to the suggestion that a different arrangement of ocean currents may have warmed the poles while cooling the tropics. Such a climate system has been difficult to model, however. This "cool tropic paradox" and has forced all investigators to reconsider their data. For example, it has long been known that most planktonic foraminifer shells from deep-sea cores are recrystallized on a micron scale, a process that could potentially bias palaeotemperature measurements toward "cool" values. Recent investigation of exceptionally well-preserved Cretaceous and Eocene assemblages from Tanzania and elsewhere suggests much warmer temperatures than previously obtained (around 30 degrees or more). Furthermore, we have obtained very large inter-species carbon isotope differentials between species, which is consistent with the idea that the more normal recrystallized assemblages from deep sea chalks are generally affected by a very substantial diaagenetic overprint. The warm tropical SST values we have measured are consistent with climate models under enhanced greenhouse conditions and some other proxy data from exceptionally well preserved carbonates, and suggests that ancient warm climates may be a better analogue for future global warming than generally believed.

OS31I-03 0915h INVITED

Coupled Atmosphere-Ocean Models of the Cretaceous

Paul J Valdes[1] (44 118 9316517; P.J.Valdes@reading.ac.uk)

Paul Markwick[2] (44 1492 581811; paul.markwick@robresint.co.uk)

[1]Department of Meteorology, University of Reading, PO Box 243, Reading RG6 6BB, United Kingdom

[2]Robertson Research International, Tyn-y-coed Site, Llanrhos, Llandudno LL30 1SA, United Kingdom

We will present results from a coupled atmosphere-ocean climate model simulation of the Cretaceous. We use the low resolution version of the latest Hadley Centre climate model. Realistic paleogeography, topography, and bathymetry were used. Carbon dioxide concentrations were set to 4 x pre-industrial concentrations. The ocean component was spun-up for 7000 years, and then run coupled to an atmosphere. The model simulates a very warm ocean, with tropical sea surface temperatures exceeding 33C in places. In addition, the deep ocean reaches temperatures in excess of 10C. The processes involved will be explained, and the implications for the terrestrial and marine data will be discussed.

OS31I-04 0930h

Model predicted ocean and atmosphere heat transport 50 million years ago: Implications for role of the ocean heat transport changes in past climates.

Matthew Huber[1] (rop@dcess.ucsc.edu)

Lisa Sloan[2] (lcsloan@es.ucsc.edu)

[1]DCESS, Juliane Maries Vej 30, 2100 Copenhagen O, Denmark

[2]Earth Sciences, University of California, Santa Cruz, Santa Cruz, CA 95064, United States

One mechanism by which the oceans have been proposed to be important for understanding the nature of past climates is through the impact of ocean circulation changes on poleward heat transport. Ocean heat transport has been especially implicated in attempts to understand the presence of polar warmth and small meridional thermal gradients found in the Early Paleogene (65-40 Mya). We compiled datasets for topography, bathymetry, and vegetation for early Paleogene conditions and incorporated these in two simulations of early Paleogene climate using the latest version of NCARs CSM (v. 1.4), a fully coupled (ocean, atmosphere, land surface, sea-ice) general circulation model. The simulations were integrated for several thousand years in the deep ocean. For the first time, Paleogene climate has been simulated with a fully coupled model, and atmospheric and ocean heat fluxes are predicted in a self-consistent and coupled manner. Numerous differences between the early Paleogene cases relative to modern conditions, including the presence of a circum-tropical seaway, the absence of an Antarctic Circumpolar Current, and concentrations of carbon dioxide twice pre-industrial values, have little effect on the general pattern of poleward heat transport in the ocean or the atmosphere. Sensitivity tests reveal that this prediction is extremely robust with respect to changes in initial conditions and even to between-simulation differences in the general flow patterns. These results do not support the role of major changes in ocean heat transport as causing past global climate changes, although support for regional climatic effects is found. Results from previous studies that used uncoupled ocean models may need to be reexamined in light of these results. These results challenge existing paradigms about the role of ocean heat transport in past warm climates.

OS31I-05 0945h

The Warm Deep?Ocean Conveyor During Cretaceous Period Driven by Surface Salinity Contrasts

Bernd J Haupt[1] (814-865-8188; bjhaupt@psu.edu)

Dan Seidov[1] (814-865-1921; dseidov@essc.psu.edu)

[1]EMS Environment Institute, Pennsylvania State University, 2217 Earth Engineering Science Bldg., University Park, PA 16802, United States

The warm deep ocean during the Cretaceous (65–130 Ma ago) has traditionally been explained by increased poleward oceanic heat transport. However, increased heat transport is difficult to explain in itself. It is unlikely that a heat transport far stronger than today existed with reduced oceanic thermal contrasts, causing a weak meridional overturning in the ocean. The presence of a warm, ice–free ocean during the Mesozoic–Cenozoic time period thus presents the most challenging problem in explaining of how a warm polar climate with very small meridional and vertical thermal gradients in the world ocean could be maintained by ocean circulation. Usually, atmospheric feedbacks in conjunction with increased atmospheric concentrations of greenhouse gases are employed to explain the warm equable Cretaceous–Eocene climate. The assumption of equatorially symmetric high–latitude sea surface temperatures is often used in atmospheric modeling and implicitly in data interpretation. However, no feasible physical mechanism – sea–water density depends on both temperature and salinity – could maintain warm subpolar surface oceans in both hemispheres. Our study exploits new interpretations of the geologic record as well as results of paleoclimate modeling, which indicates that the southern subpolar ocean was warmer than the northern oceans. We show that, assuming an asymmetry in sea surface thermohaline conditions between the Northern and Southern Hemispheres, a warm deep ocean could coexist with a relatively cool subpolar (high–latitude) sea surface in one hemisphere and a warmer subpolar sea surface in another hemisphere. The presence of a relatively cool high–latitude sea surface in at least one hemisphere is sufficient to drive the strong meridional overturning and corresponding poleward heat transport that kept the abyssal ocean warm during the Cretaceous and other warm–climate periods in geologic history.

URL: http://www.essc.psu.edu/∼bjhaupt

OS31I-06 1020h INVITED

Warm Low-Latitude Temperatures in the Eocene: Evidence from the Oxygen Isotopic Compositions of Mollusks

Ethan L. Grossman[1] (979 845-0637; e-grossman@tamu.edu)

Takuro Kobashi[1] (858 534-0961; tkobashi@ucsd.edu)

David T. Dockery[2] (601 354-6328; David_Dockery.DEQ@deq.state.ms.us)

Thomas E. Yancey[1] (979 845-0643; yancey@geo.tamu.edu)

[1]Texas A&M University, Dept. of Geology and Geophysics, College Station, TX 77843, United States

[2]Mississippi Dept. of Environmental Quality, P.O. Box 20307, Jackson, MS 39289, United States

Oxygen isotopic data from planktonic foraminifera suggest that tropical sea-surface temperatures in the Eocene, a time of high-latitude warmth, were cooler than at present. This temperature distribution has been difficult to explain by climate models invoking high pCO2 or increased latitudinal heat transport. The "cool tropics paradox" has lead authors to question the fidelity of the planktonic foraminiferal isotopic record and to propose diagenetic influences (Pearson et al., 2001, Nature 413:481-487). To evaluate Eocene low-latitude temperatures and Paleogene cooling, we produced isotopic records of seasonal temperature variation in serially-sampled mollusks from the U.S. Gulf Coast (Mississippi, Alabama). We analyzed fossils from ten stratigraphic units ranging in age from about 54 to 30 Ma. The depositional environment for all but two units is confirmed as shallow based on foraminiferal assemblage and lithology. More than 2600 analyses were performed on 51 specimens of the gastropods *Conus, Turritella,* and *Mesalia*, and the bivalve *Venericardia* from normal marine salinity waters. Deposition in normal marine salinities is supported by carbon isotopic compositions.

Oxygen isotopic values increase roughly $1.5^{o}/_{oo}$from middle Eocene to early Oligocene and generally correlate with the benthic foraminiferal isotopic record. To determine paleotemperatures, we estimated seawater $\delta^{18}O$ from Lear et al. (2000, Science, 287: 269-272) using the latitudinal correction of Zachos et al. (1994, Paleoceanography 9:353-387). The isotopic records show a warm early Eocene tropical climate (mean annual temperature = 26-27 ^oC) with a seasonal temperature range (seasonality) of about 6 ^oC, followed by cooling and an Oligocene paratropical climate (22-23 ^oC) with a seasonality of about 8 ^oC. These results are generally consistent with paleobotanical data, but suggest that seasonality increased at least sporadically prior to the Eocene-Oligocene boundary. The warm Eocene temperatures and cooling trends, with more significant winter cooling (5 ^oC) than summer cooling (3 ^oC), support the contention that atmospheric CO2 change was a major factor controlling Paleogene climate change.

OS31I-07 1035h INVITED

Influence of Ocean-Atmosphere Feedbacks on Warm Climates

Christopher J Poulsen (2137407952; poulsen@usc.edu)

University of Southern California, Department of Earth Sciences, Los Angeles, CA 90089, United States

The role of ocean circulation in maintaining warm climates remains one of the outstanding questions in paleoclimatology. This debate has focused largely on the mode of the deep circulation during warm climates. However, feedbacks between the surface ocean and atmosphere cannot be overlooked. As exemplified by the modern ENSO phenomenon, relatively small surface ocean perturbations can have a powerful influence on atmospheric circulation and the transports of sensible and latent heat. The narrowing of the Pacific Ocean over the last 100 million years almost certainly yielded much larger changes in the surface climate of the ocean than that caused by ENSO variability.

To explore this topic, a series of Cretaceous simulations has been completed using the Fast Ocean Atmosphere Model, a fully coupled general circulation model. The Cretaceous simulations include paleogeography for 100 Ma, elevated atmospheric CO_2 concentrations (1380 ppm), and a reduced solar luminosity (99% of modern). The Cretaceous experiments were run in fully coupled and uncoupled modes. (In the uncoupled mode, a simple slab ocean model is used as the lower boundary condition to the atmospheric model.) These experiments will be compared to demonstrate the effect of dynamic oceanic circulation on the Cretaceous atmospheric circulation. Preliminary results indicate that feedbacks between the ocean and atmosphere play an important role in the maintenance of a warm Cretaceous climate. It is hypothesized that changes in the ocean-atmosphere feedbacks may have contributed to the Cenozoic cooling trend of the last 55 million years.

OS31I-08 1050h

Glacial-to-interglacial-to-glacial climate change inferred from subarctic deep water $\delta^{18}O$ records

Henning A. Bauch[1] (+49 431-600-2856; hbauch@geomar.de)

Helmut Erlenkeuser[2] (+49 431-880-3896; herlenkeuser@leibniz.uni-kiel.de)

[1]GEOMAR, Wischhofstrasse 1-3, 24148 Kiel, Germany

[2]Leibniz Laboratory, Kiel University, Max-Eyth-Strasse 11, 24098 Kiel, Germany

Benthic foraminiferal $\delta^{18}O$ data from sediment cores of the deep Nordic seas were investigated, in combination with proxy records of carbonate content, iceberg-rafted debris (IRD), and planktic foraminiferal $\delta^{18}O$, to reconstruct and interpret some major ocean changes in this climatically sensitive region over the last 5 climate cycles. In particular, complete interglacial cycles were studied in more detail, i.e., time intervals that always include a glacial maximum, the ensuing peak warm period, and the inception of glacial conditions. Marine isotope stages (MIS) 11, 5e, and 1 have been identified as the three most pronounced interglacial periods. Of the three glaciations (MIS 12, 6, 2) that preceded these warm climate intervals, MIS 12 is recognized as the one when ice volume was largest and, consequently, sea level lowest. Of all peak interglacial periods studied, MIS 5e had the smallest ice volume whereas interglacial intervals MIS 11 and 1 show similar $\delta^{18}O$ values, indicating ice volumes and sea levels of comparable magnitude. The early parts of the interglacial-to-glacial transitions, which followed upon the peak interglacial interval in MIS 11 and 5e, show the first significant increase in benthic $\delta^{18}O$ almost time-coeval with a recurrence of IRD. A similar finding is noted in the proxy records from the youngest Holocene sediments. From this it may be concluded that the present oceanic conditions in the Nordic seas are in such a critical state that significant effects on the thermohaline system cannot be precluded for the time to come.

OS31I-09 1105h

Low and High Latitude Linkages During the Transition From Early Pliocene Warmth to Northern Hemisphere Glaciation

Ana Christina Ravelo[1] (8314593722; acr@es.ucsc.edu)

Michael W Wara[1] (mwara@es.ucsc.edu)

Dyke H Andreasen[1] (andreasn@es.ucsc.edu)

Christa Ziegler[1] (cziegler@es.ucsc.edu)

[1]University of California, Santa Cruz, Ocean Sciences Department 1156 High Street, Santa Cruz, CA 95064, United States

Continuous well-dated records of oceanic change over the last 5 Ma have been generated from cores recovered by the Ocean Drilling Program from many locations around the globe. Although a large-scale picture of conditions of some intervals within the Early Pliocene warm period (from about 4.6 - 3.1 Ma) exists, the transitions into and then out of this period to the colder period of the Late Pliocene and Pleistocene have only partially been described. The mechanisms of these climate transitions can only be derived from comparing records from high and low latitudes, and from shallow and deep water. In this study we present new data (mostly oxygen isotopes of foraminifera) from tropical and sub-tropical regions in the context of data from other regions. We find that the transition from cooler conditions into the Pliocene warm period (at 4.6 Ma) is marked by an increase in North Atlantic Deep Water (NADW) formation and a reorganization of tropical conditions (the initiation of an El Nino like state). The transition out of the Pliocene warm period is marked by an increase in global ice volume, a reduction in NADW, and an increase in stratification of the North Pacific Ocean. While the thermohaline circulation adjusts in concert with ice sheet development, there is no significant change in low latitude conditions. The increase in the amplitude of ice volume variability at this time is linearly related to the insolation changes. Therefore, the end of the warm period and the onset of larger Northern Hemisphere glaciation at around 3.0 Ma appears to be part of a gradual trend rather than a pronounced change in climate sensitivity. The most dramatic increase in the sensitivity of ice sheet response to insolation forcing actually occurs at around 2.0 Ma when a new state in the sub-tropics and in the tropics is established. For example, Walker Circulation and subtropical circulation that determines California margin dynamics are intensified. These observations suggest that low latitude conditions, with a marked change at 2.0 Ma, play a critical role in shaping climate sensitivity to insolation changes and thus, high frequency variability through the Plio-Pleistocene. The only way to connect the events at the end of the Pliocene warm period at 3.0 Ma to the pronounced change in low latitude conditions at 2.0 Ma is to invoke a non-linear process that links distant regions. We explore the idea that a gradual change in the thermocline, and its non-linear relationship to tropical SSTs, can explain the global array of Pliocene observations.

OS31I-10 1120h

Did an open Panama isthmus prevent the establishment of a meridional overturning cell in the Atlantic Ocean?

Stephen Van Gorder (vangorder@ocean.fsu.edu)

Doron Nof[1] (nof@ocean.fsu.edu)

[1]Florida State University, Department of Oceanography, Tallahassee, FL 323064320, United States

Existing general circulation modeling studies suggest that, prior to the closure of the Panama isthmus, low salinity Pacific ocean water invaded the Atlantic Ocean via the associated gap between North and South America. According to this scenario, the invasion decreased the Atlantic Ocean salinity to the point where deep water formation was impossible and, consequently, no conveyer belt movement was in action.

Using simple dynamical principles, analytical modeling and process-oriented numerical experiments, it is shown that one would normally expect a flow from the Atlantic to the Pacific Ocean (rather than from the Pacific to the Atlantic) through an open Panama isthmus. An analogous present-day situation is that of the Indonesian Throughflow which brings Pacific water to the Indian Ocean rather than the other way around. The direction of the flow in both situations is primarily determined by the wind field to the east of the gaps.

On this basis it is suggested that if low salinity Pacific water did in fact invade the Atlantic Ocean prior to the closure of the Panama isthmus, then this invasion took place via the Bering Strait rather than through the open Panama Isthmus.

OS31I-11 1135h

Blackbody Temperature in Terms of Orbital Elements and the Milankovitch Precession Index Cycle

David P Rubincam (301-614-6464; rubincam@core2.gsfc.nasa.gov)

Geodynamics Branch, Code 921 Laboratory for Terrestrial Physics NASA/GSFC, Greenbelt, MD 20771, United States

The temperature T of a black or gray body orbiting the Sun can be expressed in terms of spherical harmonics in latitude and longitude, its Keplerian orbital elements, and a variable describing rotation about its axis. Assuming that the Earth is a gray body, the resulting equation for T exhibits previously unrecognized odd-degree zonal terms dubbed Seversmith psychroterms. They cause a hemispheric temperature gradient which depends upon e sin w, where e is the orbital eccentricity and w is the Suns argument of perihelion. The hemisphere containing perihelion is the cooler. For a gray body with the Earths average albedo of 0.3, an emissivity of unity, and an obliquity of 23.5 degrees, the pole-to-pole temperature difference for the combined first and third degree spherical harmonic psychroterms can reach 3.4 K for the present eccentricity of 0.016, and 12.9 K for the maximum eccentricity of 0.06. While a black body with its boiling hot subsolar point and nights at absolute zero is a poor model for the Earth, the Seversmith psychroterms survive in more realistic models (although with smaller amplitudes) because the Earth radiates nonlinearly in T. The psychroterms acts in the direction opposite to the Milankovitch precession index, which also depends on e sin w: by warming the cool northern summers, the psychroterms make it harder for the traditional Milankovitch mechanism to operate. It may in fact be the Seversmith psychroterms which are actually responsible for the ice sheets which cycle with e sin w, instead of the Milankovitch mechanism. By cooling the southern hemisphere when perihelion is in the south, the psychroterms may somehow cause the southern hemisphere to control the northern ice sheets associated with the 19 kyr and 23 kyr periods (kyr = kiloyear), possibly through ice-albedo feedback in the sea-ice surrouding Antarctica.

OS31J HC: 319 A Wednesday 0830h

Synthesis of Pacific Ocean Carbon Cycle Research I

Presiding: **C Sabine,** University of Washington**; F P Chavez,** MBARI

OS31J-01 0830h INVITED

Recent Changes in the AOU of the Upper Thermocline in the North Pacific Ocean

Steve Emerson[1] (1-206-543-0428; emerson@u.washington.edu)

Sabine Mecking[1] (1-221-6738; mecking@ocean.washington.edu)

[1]School of Oceanography, University of Washington P.O. 355351, Seattle, WA 98195, United States

In the year 2001 there were three papers published that reported an increase in the AOU in the upper thermocline of the North Pacific Ocean between the 1980s and 1990s (Watanabe, 2001; Ono, 2001; and Emerson et al., 2001). I use a simple model of the atmosphere and the upper equatorial - subtropical North Pacific Ocean to demonstrate the sensitivity of the ocean and atmosphere reservoirs of oxygen to changes in carbon export or ocean circulation. The model cannot distinguish between an increase in carbon export and a slow down in circulation as the cause of the increase in AOU. Increases in the CFC-determined water mass age on some of the reported transect reoccupations indicate that the circulation has slowed between the 1980s and 1990s. Increases in the primary production and chlorophyll in the subtropical North Pacific suggest the carbon export may also have increased in this time interval. While it is not presently possible to determine the roles of changes in circulation and the biological pump in causing the increase in AOU in the upper thermocline, we know that the nutrient-depleted subtropical upper ocean does not respond as a simple system in which carbon export is limited by nutrient flux from below. An increase in AOU in response to either a slow down in circulation or an increase in the biological carbon pump suggests that circulation and carbon export are uncoupled. The mechanisms causing the change in