solar activity during the interglacials. Varying solar activity changes the upper atmospheric density profile, which will likely change the peak temperature, and consequently the He loss, experienced by IDPs during atmospheric entry heating. As a result, a 100 ka solar cycle could potentially change the $^3$He flux reaching the Earth's surface even if the IDP accretion rate from space remains constant. Hence, it is important to explore the consequences of varying atmospheric density on the use of $^3$He as a constant flux proxy in paleoclimatological applications. I also investigate whether atmospheric density changes driven by the 100 ka solar cycle may explain the discrepancy between the theoretical calculations of the IDP accretion rate and that derived from measurements of $^3$He in sediments. The theoretical calculations indicate that IDP accretion rate has varied by a factor of two over the past million years, with higher fluxes during the glacial periods. However, He measurements indicate that the IDP flux is probably constant, or possibly higher in the interglacial periods. As a starting point for modeling the effect of varying atmospheric density, I have investigated the expected variability in the $^3$He flux over a solar cycle, when the difference in atmospheric densities above 150 km can be greater than a factor of two between periods of low and high solar activity. At altitudes below 100 km the variability in density is less than 20%. The atmospheric density profiles for high and low solar activity were obtained from the MSIS-E-90 model atmosphere. The continuous distributions of the IDP size, velocity, and entry angles were discretized into bins. A total of 12240 entry heating simulations, representing all possible permutations of the size, velocity, and entry angle bins, were run for the two atmospheric density profiles. Initial results indicate that the expected variability in $^3$He flux is likely to be 10% over a solar cycle. The detailed results from the above simulations will be presented.

### PP12A-0235 1330h POSTER

## Calcium Isotope Fractionation in Ca-Bearing Phases of Marine Evaporites

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Calcium isotope fractionation recorded in calcium bearing phases (gypsum, anhydrite) of marine evaporites may give useful clues to the changing chemistry of concentrating brines through evaporative cycles. In order to understand the behavior of calcium isotopes within a brine, seawater evaporation experiments have been preformed to ascertain the fractionation factor of calcium isotopes (d44Ca value) with regard to precipitated anhydrite as the brine concentrates through the anhydrite saturated zone of evaporating seawater. These experiments show that the first anhydrite crystals precipitated from modern seawater at 40°C have a d44Ca value of -1.025 +/- 0.20 per mil, while subsequent generations of crystals have progressively heavier values up to -0.27 per mil, at which point halite begins to precipitate and Ca-sulfate precipitation decreases dramatically. Fractionation follows a predicted Rayleigh Fractionation pattern if a -1.0 per mil initial fractionation factor is used. Application of these Calcium isotope fractionation experiments to ancient marine evaporites, such as the Mediterranean evaporite deposits of the Messinian, could track oscillating brine chemistry through calcium dominated massive gypsum and anhydrite deposits. In this case, the isolation of the Mediterranean basin during the Messinian from the influence of Atlantic waters presents a unique case study for the effect of brackish and riverine waters on calcium isotopes in a closed ocean basin. In theory, the calcium isotopes of the evaporites should reflect the composition of the waters in which they precipitated and will indicate the relative importance of fresh or saline waters into the basin throughout evaporitic cycles in the Messinian.

# PP21A MCC: 3004 Tuesday 0800h

## ITCZ Dynamics of Past Climates I

*(joint with A, H, OS, C, GC)*

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

### PP21A-01 0800h INVITED

## On the Location of the ITCZ

George S. Philander (609-258-5683; gphlder@splash.princeton.edu)

To arrive at a coherent and consistent picture of climatic conditions at a certain time in the past, information concerning the location of the ITCZ at that time needs to be complemented with additional information concerning parameters such as the intensity of equatorial upwelling, the depth of the thermocline and the period of El Nino. The integration of such diverse observations requires theoretical studies that explore why, over the tropical Pacific Ocean today, the location of the ITCZ and the associated surface wind patterns depend mainly on sea surface temperature (SST) patterns, which in turn depend on the winds. This result implies that ocean-atmosphere interactions amount to positive feedbacks. These feedbacks, unlike those involved in El Nino, are antisymmetrical about the equator and displace the ITCZ poleward. Their intensity decreases as the depth of the thermocline increases. These theoretical results imply that if, at a certain time in the past, the ITCZ was in a northerly position, then there should also be evidence of a shallow thermocline, low surface temperatures and increased upwelling near the equator, and a decrease in the period of El Nino. The possible reasons for inconsistencies between observations and theory (at the time of the Last Glacial maximum for example) will be discussed.

### PP21A-02 0815h INVITED

## A Recurrent Super ENSO-Like Climate Pattern during the Holocene Affecting the Interbasinal Salinity Gradients

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We present evidence that sea surface temperatures and salinities in the western Pacific have varied significantly over the past 15 thousand years on time scales of decades to millennia. Combining decadally resolved δ18O and Mg/Ca measurements on pelagic carbonates we find SSTs between 6oN and 11oS in the western tropical Pacific were an average of 1oC warmer and 1ppt saltier in the early Holocene and have decreased progressively through the Holocene. Superimposed on this long term trend were 10 millennial length oscillations in temperature and salinity, the most recent coinciding with the Medieval Warm Period and Little Ice Age. The available evidence from sites in the Pacific and Atlantic suggests that these salinity oscillations involved sustained shifts in the mean position of the ITCZ that affected the transport of vapor between ocean basins and altered the salinity gradients between the basins, which maintain convective overturning in the North Atlantic.

### PP21A-03 0830h

## Tracking Past Shifts in the Eastern Pacific ITCZ With Foraminiferal Oxygen Isotopes and Mg Paleothermometry

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A sensitive coupling between sea surface temperature (SST) and wind stress in the eastern tropical Pacific allows robust predictions of shifts in the mean latitude of the Intertropical Convergence Zone (ITCZ) to be made given the prevailing pattern of SST and its cross-equatorial gradient. We use modern oceanographic data to demonstrate this principle on seasonal to interannual timescales, and apply it to proxy data spanning the last 30,000 years. Oxygen isotopic and Mg/Ca compositions of planktonic foraminifera are used to constrain variability in the cross-equatorial front of the eastern Pacific and to infer relative ITCZ movements. The data are consistent with a southward displacement of the Pacific ITCZ during the last glacial maximum relative to the Holocene, and a more northern ITCZ position in the early/middle Holocene relative to the late Holocene. A progressive equatorward approach of the mean ITCZ position over the last 7,000 years may be related to a strengthening of ENSO over the same interval, and is consistent with orbital forcing. These results provide support for persistent ocean-atmosphere linkages in the eastern Pacific ITCZ-cold tongue-ENSO system beyond interannual timescales and underscore the need to better characterize and integrate the dynamics of this system in the framework of past (and future) global climate variability.

### PP21A-04 0845h INVITED

## Variability in the Mean Latitude of the Atlantic ITCZ as Recorded in Cariaco Basin Sediments

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Climate variability in the tropical Atlantic is largely forced by changes in the strength and position of the Intertropical Convergence Zone (ITCZ). The Cariaco Basin, located on the northern margin of Venezuela, is sensitive to tropical Atlantic climate change and its sediments provide a record of past ITCZ behavior. Today, the Cariaco Basin has two distinct seasons that reflect the annual migration of the ITCZ. Between January-March, when the ITCZ lies south near the equator, northeasterly trade winds sit directly overhead Cariaco Basin and coastal upwelling and high surface productivity dominate. Beginning in June-July, as the ITCZ moves north to near the Venezuelan coast, local rainfall reaches a maximum and upwelling diminishes or disappears. The impact of ITCZ motion on local sea surface temperatures (SSTs), rainfall, primary production and Cariaco sediment properties is marked, with varved sediments preserved during anoxic intervals the result of the seasonal contrast between biogenic input during the upwelling season and detrital input from rivers during the wet season. Here we review data from Cariaco Basin and other localities which suggest a coherent climatological response in the tropical Atlantic triggered by a pattern of ITCZ migration that mimicks the seasonal cycle. During periods of cooler North Atlantic SSTs, on time-scales ranging from the Little Ice Age to the Younger Dryas to the cold stadials of the last glacial, evidence suggests a southward shift in the mean latitudinal position of the ITCZ. During warm interstadials and periods of Holocene and deglacial warmth, northward shifts in ITCZ position and its belt of convective rainfall are inferred from increased detrital delivery. The apparent synchronization of changes in Cariaco sediment properties with changes recorded in Greenland ice imply a tight teleconnection between the tropical and high latitudes of the North Atlantic. Whether the rapid shifts in ITCZ position reflect a response to forcing originating in the high latitude Atlantic or to forcing potentially sourced in the tropics is a key question yet to be answered.

## PP21A-05 0900h INVITED

### Holocene ITCZ Migration Recorded in Stalagmites From Oman (Southern Arabia)

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The latitudinal migration of the ITCZ during boreal summer in response to the annual solar cycle and maximum surface heating determines the start, duration and end of the rainy season from across Northern Africa to India. The Dhofar area in Southern Oman sits at the northern limit of the summer migration of the ITCZ and the associated Indian Ocean monsoon rainfall belt. Annual precipitation in this region is highly seasonal, more than 80% of total annual precipitation falls during the summer monsoon months (July to September) when the ITCZ reaches its northernmost position. To date, the clouds are unable to rise higher than ∼1500 m because of a temperature inversion created by the convergence between the hot dry north-westerly winds and the low-level southwest monsoon winds. As a result, monsoon precipitation occurs as fine drizzle, seldom exceeding more than 5 mm $d^{-1}$. Variations in the mean latitudinal summer position of the ITCZ over Southern Arabia directly affect the height of the temperature inversion. For instance, a northward shift of the ITCZ into the Arabian Peninsula would lead to stronger convective cloud development and higher monsoonal rainfall over Southern Oman. Due to the so-called amount effect, $\delta^{18}O$ values of precipitation become more negative (depleted). Such variations are accurately recorded in high-resolution $\delta^{18}O$ records obtained from three Uranium-series dated stalagmites, which continuously cover the period from 10.3 and 2.7 and 1.4 and 0.4 kyr BP. The oxygen isotope profiles show three distinct features: 1) A rapid northward migration of the ITCZ and increase in monsoon precipitation respectively between 10.3 and 9.8 kyr BP is indicated by a sharp decrease in $\delta^{18}O$ from -0.8$^o/_{oo}$ to ∼-2$^o/_{oo}$. 2) An interval of generally high monsoon precipitation lasting from 9.8 to 5.5 kyr BP with $\delta^{18}O$ values averaging -2$^o/_{oo}$. 3) A long-term gradual southward migration of the ITCZ and decrease in monsoon precipitation starting at around 8 kyr BP is indicated by a slow shift in $\delta^{18}O$ from -2.2$^o/_{oo}$ at 8 kyr BP to ∼-0.9$^o/_{oo}$ (slightly more negative than $\delta^{18}O$ values of modern stalagmites) at 2.7 kyr BP. Superimposed on the long-term trends are distinct decadal to multi-decadal variations in $\delta^{18}O$, which likely reflect changes in the convection activity over Southern Oman

## PP21A-06 0915h

### ITCZ Position Over East Africa Since the Late Glacial: The Lake Malawi Record

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Varved sediments of the north basin of Lake Malawi, the southernmost of the East African Rift lakes, have yielded records of past climate conditions for a range of temporal scales. Profiles of biogenic silica and Nb:Ti spanning nearly 25,000 years in Malawi may be compared with the Cariaco Basin high-resolution records of Haug et al. (2001). During the past 1000 years Nb:Ti and biogenic silica track one another in Malawi sediments, as observed for the Late Glacial (Johnson et al., 2002). These signals are interpreted as a reflection of the intensity or frequency of north winds over the basin. Such winds carry Nb-rich volcaniclastic sediments into the lake and promote upwelling, favorable to diatom productivity. Johnson et al. (2002) attributed the greater frequency of north winds over the Malawi basin during "cold" episodes such as the Younger Dryas to southward shifts in the Intertropical Convergence Zone (ITCZ). Haug et al. (2001) have suggested that southward migration of the ITCZ over South America as such times caused decreased rainfall and delivery of terrigenous clastics rich in Fe and Ti to the Cariaco basin. During the Late Glacial, the trends in the African and South American records are remarkably similar. In addition, they both show evidence for the ITCZ being positioned more to the north during the Medieval Warm Period, more to the south during the Little Ice Age, and subsequently returning to the north. Both records also exhibit greater variability during the LIA, with distinct southerly ITCZ excursions. Twentieth Century climate records indicate that episodes of enhanced north winds over Malawi were dry over the Orinoco basin, suggesting that the mechanism of teleconnection developed from sedimentary evidence for 100 to 10,000 years timescales may also play a role in the modern climate.

## PP21A-07 0930h

### Late Quaternary Paleoclimatic History of Tropical South America From Drilling Lake Titicaca and the Salar de Uyuni

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Seven drill cores were recovered from Lake Titicaca during the NSF/ICDP/DOSECC drilling expedition of 2001. Sub-lake floor drilling depths ranged from 53 to 139 m; water depths ranged from 40 to 232 m; recoveries ranged from 75 to 112 percent. Our most detailed multi-proxy analyses to date have been done on Core 2B raised from the central basin of the lake from 232 m water depth, drilled to 139.26 m sub-lakefloor with 140.61 m of total sediment recovered (101 percent). A basal age of 200 Ka is estimated by linear extrapolation from radiocarbon measurements in the upper 25 m of core; Ar-Ar dating of interbedded ashes and U/Th dating of abiogenic aragonites are underway. The volume and lake level of Lake Titicaca have undergone large changes several times during the late Quaternary. Proxies for these water level changes (each of different fidelity) include the ratio of planktonic-to-benthic diatoms, sedimentary carbonate content, and stable isotopic content of organic carbon. The most recent of these changes, has been described previously from earlier piston cores. In the early and middle Holocene the lake fell below its outlet to 85 m below modern level, lake salinity increased several-fold, and the Salar de Uyuni, which receives overflow from Titicaca, dessicated. In contrast, Lake Titicaca was deep, fresh, and overflowing (southward to the Salar de Uyuni) throughout the last glacial maximum from prior to 25,000 BP to at least 15,000 BP. According to extrapolated ages, the penultimate major lowstand of Lake Titicaca occurred prior to 60,000 BP, when seismic evidence indicates that lake level was about 200 m lower than present. Near the end of this lowstand, the lake also became quite saline. There are at least three, and possibly more, older lowstands, each separated temporally by periods in which the lake freshened dramatically and overflowed. These results will be compared with results from previous drilling in the Salar de Uyuni.

## PP21A-08 0945h

### An atmospheric bridge mechanism for sea ice influence on the position of the marine ITCZ

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We identify a mechanism for high latitude sea ice influence on the meridional position of the marine ITCZ in the Community Climate model version 3 coupled to a simple slab ocean model. The marine ITCZ in all three ocean basins shift meridionally away from the hemisphere with imposed additional sea ice. The impact on the ITCZ does not appear to depend on the longitudinal position, nor the hemisphere, of the additional sea ice. Examination of the zonal mean transient response shows the apparent propagation of cooler atmospheric temperature and humidity anomalies, and cooler surface temperature anomalies, from the high latitudes of the additional sea ice to the equator. When the anomalies reach ITCZ latitudes, the resulting meridional gradient in SST formed across that latitude shifts the ITCZ away from the hemisphere with increased sea ice. The resulting change to the Hadley circulation transports moisture away from the drier hemisphere into the moister hemisphere, creating a positive feedback that amplifies the hemispheric asymmetry in atmospheric moisture. We discuss the potential relevance of this mechanism to the 'real' climate, in particular as a candidate for communicating high latitude climate changes to the tropics in the paleoclimate, and also as an influence to present day interannual-decadal variability.

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# PP21B MCC: Level 2 Tuesday 0830h

## Evolution of Earth's Greenhouse Effect I Posters *(joint with A, GC)*

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

## PP21B-1165 0830h POSTER

### The Early Paleogene Greenhouse and PCO2: A Look at the Role and Response of Vegetation

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This study uses the NCAR Community Climate Model (v.3.6.6) (CCM) and dynamic vegetation global model (DVGM) to assess potential responses of Early Paleogene (50-60 Ma) flora to changes in pCO2, and to examine the role that this flora may have had in supporting the warm climate of this time period. We compare the vegetation in model output with the invariable Early Eocene land cover used to drive previous global climate model experiments. The invariable land cover was derived from Paleogene fossil flora and may produce inconsistencies between climate and vegetation in a model, especially in lower pCO2 scenarios, where high latitudes become too cool to support Eocene fossil flora. We drive the DVGM with climate data generated from two experiments with the CCM. In one experiment, pCO2 is set at 560 ppm, and the other, at 1120 ppm. We find that the higher pCO2 experiment allows the plant functional types which favor warmer climates to increase their latitudinal range, and thus become more consistent with proxy interpretations of the distribution of flora during this time period.

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## PP21B-1166 0830h POSTER

### Maximum Entropy Production and the Evolution of the Biotic Carbon Cycle

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The MEP hypothesis states that diabatic processes with sufficient degrees of freedom maintain states at which the rate of entropy production is maximized. A common example in climatology is the application of MEP to poleward heat transport, which leads to predicted equator-pole temperature gradients that are consistent with observations. Here the MEP hypothesis is applied to biotic activity as a diabatic process which affects the atmospheric concentration of carbon dioxide (pCO2) and therefore the strength of the Earth's greenhouse effect. It is first shown with a conceptual climate model that there should be a minimum planetary albedo for which entropy production associated with absorption of solar radiation would be at a maximum as a consequence of the competing effects of surface temperature on the extent of snow cover and convective cloud cover. When pCO2 is simulated by a simple carbon cycle model, it is then shown that the application of MEP to biotic activity leads to an insensitivity of simulated surface temperature to long-term changes