**The Asian Climate during the Paleogene: Early Monsoons, Proto-monsoons, or no monsoon?**

Alexis Licht

Aix-Marseille University

This talk will first explore the different climatic regimes proposed for the Asian climate preceding the Neogene onset of modern monsoonal circulation. I propose a three-stage scenario for the Cenozoic history of the South Asian monsoon: no monsoon, proto-monsoons driven by land-sea distribution, to modern monsoons driven by topography. I will then synthesize ten years of paleoclimatic investigations in Myanmar. Paleoenvironmental data from central Myanmar suggest modern monsoons already active in the early Miocene. By contrast, Middle and Upper Eocene data support a dynamic proto-monsoonal regime driven by the migration of the intertropical convergence zone and highly sensitive to orbital and pCO2 forcing. The shift from proto-monsoons to modern monsoons can thus be tentatively dated to sometime between the Upper Eocene and the Early Miocene in South Asia. The age and early history of proto-monsoons remain unclear.

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**From Monsoons to Desert: 50 Million Years of Australian Climate History**

Stephen Gallagher

University of Melbourne

The Australian monsoon is part of the Asian monsoon, however due to their hemispheric positions, the dry (wet) Australian winter (summer) monsoon coincides with the wet (dry) summer (winter) Asian monsoon. The Australian monsoon controls rainfall distribution in the northern tropical region (400,000km2) of Australia where over 80% of the median annular rainfall (>350mm- >1200mm) occurs from December to March, the summer wet season. The modern climatology of the Australian monsoon has been extensively researched, however, its paleohistory is not as well-known, especially in continental Australia as seasonally harsh arid climatic conditions often destroys evidence of fluvial/lacustrine activity making archives difficult to date and interpret. It has been speculated that the histories of the Australian and East Asian monsoons are linked and that they originated prior to 7 Ma. Others suggested (in the absence of any definitive northern Australia pre-Quaternary records) that “the (Australian) monsoon is of great antiquity” due to the marked diversity and strong adaptations of biota to the wet-dry tropical climate and their enhanced general adaptability. Significant progress has been made in the last two decades investigating Quaternary monsoonal influenced cave, lake shoreline and fluvial facies in northern and central Australia where pre-Quaternary archives are rare or absent. Other archives offshore northeast and northwest Australia cored by the International Ocean Discovery Program are now revealing longer term Neogene records of monsoonal climate. Various proxies are used to interpret the paleomonsoon, however, most indicate relative precipitation and few are able to distinguish monsoonal seasonality in deep time. Thus, older pre-Quaternary records generally are interpreted in terms of humidity and aridity. Nevertheless, these records show the likely intensification of the Australian monsoon in the middle Pliocene.

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**Sedimentary record of Eocene East Asian summer monsoon in the Bohai Bay Basin**
Majie Fan
The University of Texas at Arlington

Abstract: Recent studies of paleoclimate proxy records and simulations suggested monsoon climate in Asia as early as the Eocene. In eastern Asia where East Asian summer monsoon prevails in the late Neogene, record of Paleogene seasonal climate that is characteristic to monsoon climate is rare. Here I present a record from the Shahejie Formation in the Bohai Bay Basin in eastern China to discuss the middle Eocene paleoclimate and its variability. The study integrates lithofacies analysis and carbonate stable isotope data of authigenic carbonates of a sequence of lacustrine deposits. The sequence contains two major lithofacies, including the laminated mudstone deposited in a shallow lake and the massive mudstone deposited in a deep lake. The δ18O values of authigenic carbonate that was deposited in minimally evaporated lake water display frequent variations, up to 3‰, most of which can be attributed to variations of lake water δ18O values induced by changing amount of summer monsoonal precipitation. In two periods of the studied interval, the lake water experienced periodic intense evaporation, causing high Mg/Ca ratios and dolomite contents. These drying events likely reﬂect millennial-scale droughts that are common today to the East Asia summer monsoon because of warming in the Indo-Paciﬁc Warm Pool.

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**From Desert to Monsoon: Irreversible Climatic Transition at ~36 Ma in Southeastern Tibetan Plateau**

Hongbo Zheng
Yunnan Key Laboratory of Earth System Science, Yunnan University, Kunming, 650500, China.
School of Earth and Environmental Sciences, The University of Queensland, Brisbane Qld 4072, Australia.

Abstract: Although there is increasing evidence for wet, monsoonal conditions in Southeast Asia during the late Eocene it has not been clear when this environment became established. Radiometrically dated Cenozoic sedimentary rocks from the Jianchuan Basin located in the southeast flank of Tibetan Plateau now provide a section whose facies and climatic proxies constrain this evolution. Semi-arid conditions had dominated the region since Paleocene, culminating in mid Eocene when desert dunes developed. This region belonged to a much broader arid zone across East Asia, which was formed under the influence of northern Westerly Jet when Tibetan Plateau was not high and extensive enough to obstruct the general circulation. From 36 Ma onwards, the basin began to accumulate swamp sediments with coals, together with synchronous braided river deposits, indicating significant increase in precipitation. This remarkable and irreversible transition from dry to wet conditions precedes the E/O boundary at 34 Ma, thus excluding general global cooling as a prime driver. We propose that uplift of Tibetan Plateau might have reached a threshold elevation by that time, deflecting/obstructing the Westerly Jet and thus giving way to monsoonal rains to penetrate into this downwind locality.

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**Asian Monsoon: Australia’s connection and contribution**
Beth Christensen

School of Earth and Environment, Rowan University, Glassboro, NJ, USA

Abstract: This talk will discuss the onset of the modern Australian monsoon and its role in the Asian Australian monsoon system. The onset of the modern Australian monsoon is tightly linked to the progressive closure of the Indonesian Throughflow, and drove Australia from humid Pliocene to an arid Pleistocene. Subsequent studies have refined our initial estimates of timing.

The northward motion of Australia led to significant circulation changes in the Indian Ocean, in particular the onset of an intermediate water return pathway of global thermohaline circulation, Tasman Leakage at ~ 7Ma. Once Australia was far enough north to permit the onset of the Tasman Leakage, a lot changed, including regional bottom sediment erosion and onset of OMZ-like conditions at the Broken Ridge. We suggest an alternative explanation for previously hypothesized extension of the Arabian Sea OMZ in the Pliocene; upwelling of low oxygen Indian Deep Water associated with a more northernly subtropical front near the Broken Ridge.

Chasing the story of the Asian Monsoon includes re-examining our understanding of the Indian Ocean, made both more complex and more exciting by the extensive drilling around the edges of the basin. Without high resolution core in the middle of the Indian Ocean, however, we are left with many questions. Recovering new core on the Broken Ridge and in the Arabian Sea will fill in some of the current knowledge gaps, leading to answers, and most definitely more questions. Thus, the time is right for a return to drilling in the Indian Ocean, fostered by an upcoming MagellenPlus workshop, IO-DIP. <http://indian-ocean.uni-graz.at/>

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**Is one paleogeography better than another? Monsoons though the Mesozoic and Cenozoic using three different paleogeographies (Getech, Scotese and Roberstons).**

Alex Farnsworth

University of Bristol

How and why has the East Asian summer monsoon evolved through time has been a topic of controversy for many decades. Once believed to be a Miocene phenomenon, recent work has been pushing this boundary further back in time. With the increase in computational resources the use of paleoclimate models is now highly widespread. However, the computational cost of running these models has meant a tradeoff between running long integrations of simulations to ensure an equilibrium climate state versus running many time periods to assess temporal evolution through geologic time versus running different paleogeographic reconstructions. Here, we investigate the evolution of the East Asian monsoon system using three different paleogeographic reconstructions (Getech Plc, Roberstons Plc and Scotese) through the Cretaceous to the Modern (145 Ma – 0 Ma) where the mean climate state has reached equilibrium and compare with a compilation of proxy data. Further, a problem with many legacy as well as contemporary paleoclimate models is the inability to capture higher latitude warmth as reconstructed by various paleo-proxies. Using an improved version of HadCM3/L we analyse the impact of improved model physics that better capture higher latitude warmth and its impact on the East Asian Monsoon evolution.

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**Emerging perspectives on Asian Cenozoic landscape and monsoon evolution**
Bob Spicer

Open University

Non-marine (terrestrial) climate multiproxy comparisons are meaningless without some knowledge of the palaeo-surface height at which they formed. Continents are inherently 'bumpy' and this topographic complexity influences profoundly land surface interactions with the atmosphere and the biota they support. The orography of the Tibetan region (the plateau, Hengduan Mountains and the Himalaya) has long been thought of as a primary driver of Asian monsoon dynamics, but until recently the complex topographic evolution of the Tibetan region has largely been overlooked, especially by climate modellers, and surface heights poorly quantified. All that is now changing, and in this talk I review recent advances in quantifying surface height changes within the Tibetan region over time, and show how plant form tracks and records the evolution of Asian monsoon. I examine the middle Eocene monsoonal climate of Central Tibet, the rise of the Hengduan and Himalaya mountain systems, and how monsoons over India changed throughout the Cenozoic.

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**Evolution of the East Asian monsoon from tectonic to glacial timescale: perspectives from weathering records in the Asian margin**

Shiming Wan
Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China

 Abstract: Continental erosion and weathering are the key processes that shape Earth's landscape, control the delivery of sediments and solutes to the ocean, and affect carbon cycle over geological time scales. Climate, as represented by temperature and precipitation, has in turn been identified as critical factor influencing silicate weathering. Therefore, the terrigenous records in the Asian margins have been used to trace past changes of weathering in source region and links to evolution of Asian monsoon. We present long-term erosional record of South China in the South China Sea since 35 Ma. Weathering proxies suggest that monsoon rainfall was strong during the warming periods in the late Oligocene to early Miocene and generally weakened since the middle Miocene, pacing with the deep-sea oxygen isotope record. We conclude that global ice-volume and temperature changes, rather than Tibetan uplift controlled the long-term evolution of East Asian summer monsoon at least since the late Oligocene. On glacial-interglacial timescale, the links between offshore weathering record and monsoonal climate is illusive because of influence of cyclic sea-level change with wide continental shelf in East Asia. The river mouth records show stronger continental weathering of East Asia at the Holocene than glacial, suggesting monsoonal climate forcing. In contrast, deep-sea records reveal strengthened weathering and erosion during glacial, implying subaerial exposure and weathering of shelf sediments during sealevel lowstands. Thus enhanced silicate weathering of tropical shelf sediments during glacial represents a significant mechanism of the glacial-interglacial carbon cycle.

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**Establishing a new orographic barrier – the middle Miocene rise of the Greater Himalaya**

Rasmus Thiede

University of Kiel

The Himalaya is the highest and steepest mountain range on Earth and an efficient north-south barrier for moisture-bearing winds. The close coupling of changes in topography, erosion rates, and uplift has previously been interpreted as an expression of a climatic control on tectonic deformation. Here, we present 17 new zircon U/Th-He (ZHe) bedrock-cooling ages from the Sutlej Valley that – together with >100 previously published mica 40Ar/39Ar, zircon and apatite fission track ages – allow us to constrain the crustal cooling and exhumation history over the last ~20 Myr. Using 1D-thermal modeling, we observe a rapid decrease in exhumation rates from >1 km/Myr to <0.5 km/Myr that initiated at ~17-13 Ma across the entire Greater and Tethyan Himalaya, as far north as the north-Himalayan Leo Pargil gneiss dome. This decrease is recognized both in the hanging and footwall of major Miocene shear zones and suggests that cooling is associated to surface erosion rather than to tectonic unroofing. We explain the middle Miocene deceleration of exhumation with major reorganization of Himalayan deformation and the onset of the growth of the Lesser Himalayan duplex. This resulted in accelerated uplift of the Greater Himalaya above a mid-crustal ramp, and thus forming a new efficient orographic barrier. The period of slow exhumation in the upper Sutlej Valley coincides with a period of internal drainage in the south-Tibetan Zada Basin further upstream, which we interpret to be a consequence of tectonic damming of the upper Sutlej River. Interestingly also new radiogenic isotope time series of clays delivered to the Bay of Bengal during the middle Miocene show much higher variability during Miocene Climate Optimum (around 16-15 Ma) and across major global cooling (~13.9-13.5 Ma), than during younger time intervals – indicating a major shift sediment source region.

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**Evolution and development of the South Asian Monsoon during the middle Miocene**

Stephan Steinke

Xiamen University

During the middle Miocene, Earth's climate changed from a global warm period (Miocene Climatic Optimum) into a colder one with the expansion of the Antarctic ice sheet. This prominent climate transition (Middle Miocene climate transition, MMCT) was also a period of drastic changes in global atmospheric circulation. The Miocene history and evolution of the South Asian Monsoon (SAM) however, is not well understood and mainly derived from records of wind strength. Data for Miocene changes in rainfall are virtually non‐existent for peninsular India and the Arabian Sea prior to 11 Ma, although this is the other important variable that defines the monsoon. This talk will present and discuss recent findings of the evolution and development of the SAM during the middle Miocene.

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**Reconstructing paleoclimate seasonality from late Oligocene wood fossils: insights into the nascent East Asian Monsoon**

Bill Lukens

James Madison University

Model simulations and paleoclimate proxies indicate that modern-like monsoon circulation in East Asia was established by the early Miocene at the latest. Uncertainty about the timing of East Asian Monsoon evolution remains due to a paucity of proxy records from the Oligocene. In this talk, I will discuss the results of ongoing efforts to read seasonal paleoclimate signals from late Oligocene wood fossils preserved in the Santang Lagerstätte, a fossil assemblage near Nanning in southern China. Ongoing work from our research collaboration suggests that southern China had summer-dominated rainfall with possibly higher mean annual precipitation and similar temperatures to current conditions.

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**On links between development of global climate, oceanic biogenic blooms, and the monsoon during the middle-late Miocene**

Dick Kroon

University of Edinburgh

Abstract: The evolution of the Cenozoic Icehouse over the past 30 million years (Myr) from a unipolar to a bipolar world is broadly known. The exact development of orbital-scale climate variability is less well understood. Highly resolved carbonate (CaCO3) content records can provide insight into the evolution of global and regional climate, cryosphere, and carbon cycle dynamics. Separating changes in global climate from regional climate may be difficult and there may be links between the two. In today’s lecture, I will attempt to link global and monsoon climate using IODP bore holes drilled in the S-Atlantic and northern Indian Ocean.

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**Australasian Monsoon variability on a warmer Miocene Earth**

Ann Holbourn

University of Kiel

The long-term history of the Australasian Monsoon and the primary controls on its variability remain issues of intense debate. Here, we focus on the middle to late Miocene period, an extended interval of global warmth encompassing several major climate transitions that ushered in fundamentally different regimes of variability. Continuous sediment successions recovered by the International Ocean Discovery Program in the South China Sea, Bay of Bengal and Timor Sea closely track regional evolution on orbital timescales. This integrated perspective provides insights into the drivers of variability and the inter-hemispheric linkages between monsoonal subsystems.

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**Millennial- to orbital-scale variabilities of east Asian summer, winter, and inter-monsoons recorded in a set of sediment archives drilled from the Japan Sea**

Tomohisa Irino

Hokkaido University

Expressions of east Asian monsoon variability in far east Asian margin are characterized by heavy precipitation in summer and autumn, severe cooling and strong northwesterly in winter, and dusty westerly influence in spring. These summer, winter, and inter-monsoons climate have provided their own characteristic sediments to the Japan Sea, which have been widely used to reconstruct the past east Asian monsoon variability. Sedimentations in the Japan Sea are expressed as biological production promoted by summer nutrient supply, overturn and ventilation of the deeper water column as well as sea-ice rafted detritus in winter, and eolian dust supply from inland China and Mongolia in spring. Therefore, disentangling such complex mixtures of seasonal signals recorded in the Japan Sea sediments is a very interesting puzzle to solve. IODP Exp. 346 in 2013 collected 7 mostly perfectly continuous sediment sequences which could be correlated among others in millennial time scale utilizing cyclic deposition of dark and light color sediments formed by basin wide synchronous production-decomposition of organic matter (TOC). Since the depth distribution of TOC flux in the Japan Sea was controlled by summer production and winter decomposition by ventilation, it may be possible to reconstruct summer and winter monsoon intensity through evaluation of the spatiotemporal variation of TOC flux. In this presentation, the result of TOC flux analysis will be compared with sea-ice rafted detritus variation in the northernmost Site U1422 and previously reconstructed eolian dust variability form the Japan Sea sediments.

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**Drivers of Asian Monsoon rainfall evolution**

Pallavi Anand

Open University

The evolution of Asian Monsoon over the past 30 million years (Myr) is driven by multiple forcing factors including tectonics and climate. Our current understanding of long-term Asian monsoon evolution, inferred from wind strength and erosion-based proxies records, have been shown to be mainly linked to tectonics and climate drivers. However, challenges exist for both capturing true monsoon rainfall signal as well as teasing apart different drivers, often co-occurring, of monsoon evolution. In this talk, I will discuss our attempt to evaluate multiple forcing factors and their interactions that have contributed to the East Asian and Indian Monsoon rainfall evolution over the past 30 Myr. I will also show that a data-model integration approach is needed, and possible with data density, to further improve our understanding of past monsoon dynamics.

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**Clay mineralogy and Asian monsoon climate: A case study of the South China Sea**
Zhifei Liu
State Key Laboratory of Marine Geology, Tongji University, Shanghai 200092, China

 Clay minerals play an important role in paleoenvironmental studies of almost all sedimentary environments because time-series variations of clay mineral assemblages are usually interpreted as chemical weathering associated with contemporaneous climate change in the source region. Illite and chlorite are primary minerals, formed by direct physical erosion or weak hydrolysis of the rock, while kaolinite and smectite are secondary minerals, formed by strong hydrolysis in warm and humid climates. Therefore, the transition between the two assemblages is usually used to study the changes of cold/dry and warm/wet climate and environment at various time scales of the Earth's surface. However, due to the complicated formation processes of clay minerals through chemical weathering and the influence of source to sink transport processes, the application of clay minerals to climate change indicators has always been debatable. In this talk, I will take the South China Sea study as a case to first describe the role of clay minerals as an indictor of modern monsoon climate variation based on time-series sediment trap samples, and then discuss the possibility of a proxy of paleo-monsoon evolution on late Quaternary millennial and glacial/interglacial timescales.

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**A Neogene Indian Ocean carbonate platform record of the South Asian Monsoon**

Christian Betzler

University of Hamburg

Complete and extended records of Neogene environmental changes in the Indian Ocean are scarce. The Maldives carbonate platform, a giant natural sediment trap, cored during the International Ocean Discovery Program (IODP) Expedition 359, in parts fills this gap. The platform growth was marked by stratigraphic turning points related to global sea-level changes and to changes in the regime of the monsoonal-driven ocean currents. The first turning points during the early and middle Miocene are related to sea-level changes. These are reliably recorded in the stratigraphy of the carbonate sequences, in which sequence boundaries provide the ages of the sea-level lowstand. An abrupt change in sedimentation pattern is recognized across the entire archipelago at a sequence boundary dated as 12.9–13 Ma. At this turning point, the platform sedimentation switched to a current-controlled mode when the monsoon-wind-driven circulation started in the Indian Ocean. The similar age of the onset of drift deposition from monsoon-wind-driven circulation across the entire archipelago indicates an abrupt onset of monsoon winds in the Indian Ocean. Ten unconformities dissect the drift sequences, attesting changes in current strength or direction that are likely caused by the combined product of changes in the monsoon-wind intensity and sea level fluctuations in the last 13 Ma. A major shift in the drift packages is dated with 3.8 Ma that coincides with the end of stepwise platform drowning and a reduction of the oxygen minimum zone. The Maldives carbonates also bear a unique record of atmospheric dust transport over the northern Indian Ocean during the past 4 Myr. Grain-size data provide proxies for dust flux (controlled by source area aridity) as well as wind transport capacity (wind speed). Dust flux and the size of dust particles increased between 4.0 and 3.3 Ma, and there is no clear trend in dust flux between 3.3 and 1.6 Ma, whereas wind transport capacity decreased. Between 1.6 Ma and the Recent, dust flux increased and shows higher variability, especially during the last 500 kyr. Transport capacity increased between 1.2 and 0.5 Ma and slightly decreased since then.

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**Climatic controls of weathering of the Himalayas at millennial to orbital time scales - New constraints from neodymium isotopes in foraminiferas**

Christophe Colin,

University Paris-Saclay

Abstract: Chemical weathering of silicate rocks on continents is thought to have played an important role in the evolution of past atmospheric carbon dioxide. However, the detailed links between continental weathering and climate change and their impact on sediments transfer to the ocean, remain poorly understood. I will present an overview of recent results of Nd isotopic composition obtained in seawater as well as biogenic and authigenic fractions of marine sediments from the Bay of Bengal to better constrain the Nd cycle of the northern Indian Ocean and reconstruct past Nd isotopic compositions during the late Quaternary and the last 35 Myr. I will show you that past seawater Nd isotopic composition of the Bay of Bengal is mainly controlled by weathering of the Himalayas and present variations link to changes of the intensity of the Indian monsoon rainfall at orbital to millennial time scales.

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**Neogene variations of the Indian Summer Monsoon Recorded in the Bengal Fan**

Valier Galy

Woods Hole Oceanographic Institution

A pressing challenge in climate research is understanding the temporal evolution of the Indian monsoon system; its response to global and regional climatic controls (including warming); as well as implications in terms of vegetation (C4 expansion), erosion of the Himalaya and carbon sequestration in the Bengal Fan. Studies on climate dynamics have recently offered new insights into the mechanistic controls on the monsoon: the tectonic boundary of the Himalaya is implicated as the major control on Indian summer monsoon dynamics today. Since this region has been uplifted since at least the late Oligocene, it is possible to test the response of monsoon precipitation to global and regional climate change, and also understand feedbacks on the climate system via carbon sequestration in the Bengal Fan. The evidence for monsoon intensity changes across the Miocene and Pliocene is currently incomplete given temporal uncertainty and diagenesis in terrestrial records; biases in the records reconstructed from the distal fan; and conflicting evidence from wind speed and aridity metrics for a stronger or weaker monsoon. Our alternative approach is therefore to study the basin-wide hydrological changes recorded in a multi-proxy, multi-site study of the marine sediments of the Bengal Fan recovered during IODP expedition 354.

In turbiditic sediments of Himalayan origin, the late Miocene C4 expansion is well recorded in all three long records recovered during expedition 354 based on stable carbon isotope composition of bulk organic carbon and terrestrial leaf-wax compounds. Cores from sites U1455 and U1450 provide the highest resolution record of the C4 transition, which appears to occur within relatively continuous series of turbiditic sequences dated to ca. 5.8-6 Ma. The hydrogen isotopic composition of the same leaf-wax compounds reveals a remarkably stable hydroclimate across the late Miocene C4 expansion. The abundance of pyrogenic carbon inferred from specific biomarkers however reveals an increase in fire intensity and/or frequency at or slightly before the C4 expansion, suggesting fires played a key role in initiating the ecological transition. A low resolution record across at least the last 18 Myrs reveals the persistence of a strong summer monsoon throughout the Miocene. In comparison, the mean summer monsoon intensity appears to have declined as climate and sea level became more variable during the Pleistocene.

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**Chinese loess and paleomonsoon variability**

Youbin Sun

Chinese Academy of Sciences, Beijing

Abstract: Chinese loess has been investigated intensively as a unique continental archive to infer the history and variability of East Asian paleomonsoon since the late Oligocene. The loess-paleosol sequence can well document alternations between cold-dry glacial and warm-wet interglacial during the Quaternary. In this talk, I will first give a general introduction of Chinese loess, including its temporal and spatial distribution, and features of several classic loess and red clay profiles. Then I will present several high-sedimentation-rate loess records to address orbital and millennial monsoon variability. New high-resolution loess proxies reveal that both precession signals and millennial oscillations were persistent in the East Asian monsoon system during the Pleistocene.

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**Strontium and neodymium isotopes from the separated clay fraction in sediments from the Indus Fan**

Sam Carter

Ohio State University

Reconstructing the provenance of siliciclastic marine sediment is important for understanding sediment pathways and constraining palaeoclimate and erosion records. However, physical fractionation of different size fractions can occur during sediment transport, potentially biasing records derived from bulk sediment. Here, records of radiogenic Sr and Nd isotopic composition of the separated clay fraction are presented, measured from deep-sea sediments recovered from IODP Sites U1456 and U1457 in the Arabian Sea. These new records are compared with published bulk sediment records to investigate the influence of sediment transport on these proxies and to constrain provenance evolution and its relationship to climate variability since middle Miocene time. Correlations between grain size and the bulk sediment isotopic composition confirm that transport processes are influencing the bulk sediment record. This relationship, although present, is not as strong in the clay-fraction isotopic records. Heterogeneity of bulk sediment likely drives differences between bulk and clay records, thought to be largely controlled by sediment transport processes. The isotopic records reveal variations in provenance that correlate with climatic change at 8–7 Ma, as well as an increase in overall provenance variability beginning at ~3.5 Ma, likely linked to monsoon strength and glacial–interglacial cycles. The clay-fraction records highlight the potential value of measuring proxy records from multiple size fractions to help constrain provenance records as well as investigate sediment transport and/or weathering and erosion processes recorded in deep-sea sediment archives.

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**Monsoon controls on weathering and erosion style in the Himalaya**
Christian France-Lanord

CRNS, University of Nancy

In Himalaya, the monsoon precipitation and tectonic processes shape the erosion regime. Tectonic indeed maintain over geologic time scale rapid uplift that lead to high erosion rate of the range. The monsoon through the seasonal precipitation ensures landslide movements and efficient transport of sand-rich sediments throughout the basin despite thousands of km in flat floodplain and delta. Rapid transport also acts as a limiting factor for weathering as it reduces residence time in the floodplain.

IODP Expedition 354 drilled the Bengal Fan and compose a comprehensive record of Himalayan erosion over the Neogene and Quaternary from the seven sites drilled along a 320 km E-W transect at 8°N. Sediments are predominantly composed of turbidites generated from the Ganga-Brahmaputra shelf. The deepest Site U1451 on the Eastern end of the transect reach the base of the fan, marking the onset of fan deposition on this flank of the Ninetyeast ridge around 20 Ma. Turbiditic sediments show mineralogical, geochemical and isotopic characteristics which reveal a close analogy with the modern Ganga-Brahmaputra sediments. Sand deposition is important and is expressed in sand lobe as well as in levee turbidites. Drilling data show it is perennial since 20Ma. Cosmogenic 10Be concentrations of the quartz sand reflect high and steady erosion rates since the Late Miocene. Major and trace element geochemistry shows relatively stable compositions throughout the Neogene and Quaternary. They reveal a weak regime of weathering with limited variation through time. The record of detrital carbonate deposition varies with higher concentrations during the Miocene than during the Plio-Pleistocene. This suggests either a geological change in the Himalayan source or lower weathering during Miocene. Exp 354 record contrasts with that of Leg 116 at 1°S in the distal fan, which from 7 to 1 Ma shows an apparent high degree of weathering associated with lower accumulation rates. The record at 8°N indicates that these variations do not reflect change in the continental source basin but rather reflect a change in the turbiditic export.

Overall, the record of erosion at 8°N reveals that a relatively steady erosion regime dominated by physical erosion was established since Miocene. By comparison, the modern period appears one with higher intensity of chemical erosion. These observations suggest that erosion sustained by a highly seasonal climate able to ensure rapid transport of sand-rich sediments and to limit the weathering such as the monsoon was already active 20 Ma ago

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**Evolution of the Asian Monsoon and its Impact on Erosion and Tectonics of the Himalaya**

Peter Clift

Louisiana State University

The intensity of the South Asian monsoon is known to vary strongly through the Cenozoic, potentially starting in the Late Eocene with increases after 24 Ma, a peak around 15 Ma and then declining strength, especially after 8 Ma. This history is linked to global climate but also to the uplift of topography in the Himalayas and Tibetan Plateau. Slab break-off starting around 24 Ma progressively migrated from the syntaxes towards the central Himalayas, resulting in uplift of ~1 km and monsoon strengthening. The stronger erosion that this generated is believed to be a critical to the exhumation of the Greater Himalayan Series and motion along the Main Central Thrust. Declining erosion from the Mid Miocene to the Pliocene is accompanied by reduced intensity of chemical weathering and a lower chemical weathering flux at least in the Indus, Mekong and Pearl River basins. This suggests that chemical weathering of the Himalayas is not the primary driver of CO2 drawdown and global cooling during the Neogene.
 Study of the Indus basin shows a strong monsoon and sea level control on the sediment flux to the ocean. During times of weak monsoon erosion is focused in the Karakoram but becomes more Himalayas as summer rains increase. During the Holocene 75% of the sediment reaching the ocean comes from bedrock sources or proximal moraines with significant additional flux from the Thar Desert and from the incision of flood plains. Half the sediment flux is stored on the continental shelf but deep sea sedimentation is restricted to glacial times. The Indus fan turbidites are however mostly reworked from earlier high stand deposits that were eroded when the monsoon was strong.
 New IODP core from the Arabian Sea shows a peak in erosion from the Karakoram around 10 Ma then a shift to more Himalayan sources after ~6 Ma and especially after 3 Ma when the Inner Lesser Himalaya were unroofed over a wide area of the Indus catchment. Unlike the Greater Himalayas any link to monsoon strength is unclear although feedback between duplexing, surface uplift, focused erosion and further thrusting is inferred. In contrast to the eastern Himalaya the Nanga Parbat syntaxes is shown to contribute only ~10% of the total sediment flux to the ocean accounting for an average rate of 3 km/y of exhumation driven by erosion. The lower contribution compared to Namche Barwa and the Brahmaputra likely reflects the drier climate of northern Pakistan.

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**Petrographic and heavy mineral composition of turbiditic sediments of Bengal-Nicobar Fan**

Mara Limonta

University di Milano-Bicocca

The Bengal Fan is the largest turbiditic fan in the world (~ 3,0\*106 km2, Curray et al., 2002). Most of the sediment mass it contains represents erosional products generated in the Himalayas. The Fan covers the entire Bay of Bengal, from the continental margins of India and Bangladesh to the sediment-filled Sunda Trench offshore Myanmar and the Andaman Islands, and along the western side of the Ninety East Ridge to as far as ~7°S. The Nicobar Fan is a secondary lobe spreading southeast of the Ninety East Ridge. The northeastern part of the fan has been subducted, and some of the Cenozoic turbidites cropping out in the Indo-Burman Ranges of Myanmar, the Andaman and Nicobar Islands, and the outer-arc ridge off Sumatra are interpreted as old Bengal and Nicobar Fan sediments (Curray, 2005).  Petrographic, mineralogical, geochemical and geochronological signature of sediments (silt and sand) of the turbiditic depositional system of the Bengal Fan (IODP Expeditions 353 and 354) and Nicobar Fan (IODP Expedition 362) allow us to reconstruct the sedimentary evolution of Bengal and Nicobar Fans from the collision between India and Asia and throughout Neogene, to recognize the most significant erosional events from the Miocene to the Present, to identify the contribution of different Himalayan tectonic domains and their evolution with time, to define the interrelationships between tectonic activity and climate during the initiation and strengthening of the Indian monsoon. Both fans were predominantly supplied by Himalaya-derived material from the main tectono-stratigraphic sequences as well as the Gangdese arc. A lack of volcanic material in the Nicobar Fan rules out sources from the Sumatra magmatic arc. Overall, the petrographic data shows a progressive decrease in sedimentary detritus and corresponding increase of higher-grade metamorphic detritus up- section. Changes in sediment provenance and exhumation rates in the Himalaya are seen to track changes in sediment accumulation rates. High sediment accumulation rates in the Bengal Fan occurred at ~13.5–8.3 Ma, and in the Nicobar Fan from ~9.5–5 Ma. Both fans show peak accumulation rates at 9.5–8.3 Ma (but with the Nicobar Fan rates being about twice as high), and both record a sharp drop from ~5.5–5.2 Ma, that coincided with a change in river drainage associated with the Brahmaputra River diverting west of the uplifting Shillong Plateau. At ~5 Ma, the Nicobar Fan was supplied by an eastern drainage route that finally closed at ~2 Ma, when sediment accumulation rates in the Nicobar Fan significantly decreased. Sediment provenance record these changes in routing whereby Bengal Fan deposits include granitoid sources from the Namche Barwa massif in the eastern syntaxis that are not seen in the Nicobar Fan, likely due to a more localised eastern drainage that included material from the Indo-Burman wedge. Prior to ~3 Ma, source exhumation rates were rapid and constant and the short lag- time rules out significant intermediate storage and mixing. In terms of climate versus tectonic controls, tectonically driven changes in the river network have had most influence on fan sedimentation.

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**The Indian summer monsoon rainfall/runoff response to orbital and internal forcings; proxy synthesis and proxy model comparisons**

Steve Clemens

Brown University

South Asian precipitation amount and extreme variability are predicted to increase due to thermodynamic effects of increased 21st-century greenhouse gases, accompanied by an increased supply of moisture from the southern hemisphere Indian Ocean. We reconstructed South Asian summer monsoon precipitation and runoff into the Bay of Bengal to assess the extent to which these factors also operated in the Pleistocene, a time of large-scale natural changes in carbon dioxide and ice volume. South Asian precipitation and runoff are strongly coherent with, and lag, atmospheric carbon dioxide changes at Earth’s orbital eccentricity, obliquity, and precession bands and are closely tied to cross-equatorial wind strength at the precession band. We find that the projected monsoon response to rising carbon dioxide levels is consistent with dynamics of the past 0.9 million years.

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**Enhanced terrigenous input into the tropical Pacific and Indian Oceans during the Quaternary glacial periods: Forcing mechanisms and implications for atmospheric CO2 sink**

Zhaokai Xu and Hongjin Chen

Chinese Academy of Sciences, Qingdao

Continental surface erosion and weathering are the key processes that shape Earth's landscape, control the delivery of terrestrial sediments and solutes to the ocean, and affect global carbon cycle over various geological timescales. Climate, as represented by temperature and precipitation, has in turn been identified as a critical factor for influencing continental surface erosion and weathering. Therefore, terrigenous records in the Asian margins, especially for the tropical marginal seas surrounding landmasses characterized by high rates of physical erosion and chemical weathering, have been used to reconstruct past changes of physical erosion and chemical weathering in the continental source regions and their links to evolution of the Asian monsoon.

Here, we present comprehensive records of continental surface erosion and weathering, terrestrial supply, hydrological environment, marine productivity, and organic carbon burial in the distal Arabian Sea, Bay of Bengal, South China Sea, and Philippine Sea during the Quaternary. These records exhibit noticeable variations in the abovementioned indicators over orbital timescales, predominantly controlled by the Asian monsoon intensity and sea-level fluctuation. As a result, the links between offshore erosion and weathering record and monsoonal climate might be illusive because of influence of cyclic sea-level variation on the wide continental shelf surrounding Asia. During glacial periods, the enhanced Himalayan and Tibetan highland surface erosion and activation of deep-sea channels surrounding these landmasses significantly increased inputs of terrigenous detritus, nutrients, and organic carbon into the Arabian Sea and Bay of Bengal, whereas strengthened chemical weathering of unconsolidated sediments on the exposed wide continental shelves and organic matter preservation occurred in the South China Sea and Philippine Sea. Conclusively, our integrative proxies in the study area demonstrate, for the first time, pronounced glacial burial pulses of organic carbon (~1.12 × 1012 mol/yr), dominantly originating from the highland surface erosion and associated marine productivity. Together with the increased silicate weathering on the exposed tropical continental shelves like the South China Sea and in the tropical volcanic arcs like Luzon, the enhanced burial flux of organic carbon in the tropical marginal seas, therefore, highlights that tropical regions were an important contributor (~1/4) to the decrease in the greenhouse gas CO2 concentration during glacial periods and thus significantly regulated the global carbon cycle and climate.

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**Orbital-scale hydroclimate variability in the Western Pacific Warm Pool over the last 2 Myrs**

Samantha Bova

San Diego State University

The Western Pacific Warm Pool (WPWP) is a major source of heat and moisture to the atmosphere and a location of deep convection and heavy rainfall. However, the relative importance and impact of extra-tropical (e.g., equator-to-pole temperature gradient) vs. tropical controls (e.g. SST patterns and zonal winds) on WPWP precipitation is still a matter of debate. Changes in Earth’s orbital configuration, which alter the spatial and temporal distribution of solar insolation, offer the means to test the impacts of tropical vs. extratropical forcing on rainfall in the heart of the WPWP. Using x-ray fluorescence core scanning we generated a 2.3 Myr record of paleo-runoff from IODP site U1486, recovered offshore of two major rivers draining the northern highlands of Papua New Guinea. The intensity of the carbonate free basis Ti, Fe, and K concentration (Ticfb, Fecfb, Kcfb), indicators of the river particulate fraction, all display significant and coherent power at 23 and 41 ky over the past 800,000 years, while Fecfb and Kcfb also exhibit a prominent 100 ky response. Differences between the terrestrial proxies at the 100 ky band are still being explored, but could indicate that additional factors, such as sea level and/or source rock variations, contribute to variations in sediment transport to our core site across glacial-interglacial cycles. At the precession band, however, peak Ticfb, Fecfb, Kcfb, and thus rainfall over northern PNG, is 180° out of phase with precipitation records from China and Australia at the precession timescale, suggesting that the Indo-Pacific ITCZ expanded and contracted in response to regional interhemispheric temperature gradients. Although the records from the northern and southern margins are limited to the past 640 ka and 410 ka, respectively, rainfall over PNG exhibits a consistent phase lag to the precessional forcing over the full 2.3 My record, suggesting the response of the Indo-Pacific ITCZ to precession, i.e. expansion and contraction, has remained constant across the Pleistocene. At the obliquity band, records from the northern and southern margins are antiphased, but rainfall in the heart of the WPWP exhibits a distinct phase response. These relationships indicate that, while rainfall at the northern and southern margins of the WPWP are linked via the N-S migration of the ITCZ at the obliquity band, rainfall in the heart of the WPWP is not.

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**Monsoon-induced millennial scale changes in the water column hydrography of the Arabian Sea**

Arun D. Singh

Banaras Hindu University

The Arabian Sea is uniquely suited to develop paleo-monsoon records, as seasonally reversing air flow of the Indian monsoon produces spatial changes in surface circulation, hydrography and biological productivity. Paleo-monsoon reconstructions on high resolution time scale using a large suite of proxy data from the western and northern Arabian Sea have strongly improved our understanding of summer southwest monsoon (SWM) variability and its dynamics on orbital to sub-orbital time scales. SWM variation on glacial/interglacial scale is generally explained by the orbital precession. The response of SWM to the abrupt millennial scale climatic changes recorded in Greenland ice core records are well documented. However, recent studies also suggest an influence of southern hemispheric temperature changes on the Indian SWM on sub-orbital scale. The current picture of the seasonal monsoon variability remains incomplete because the temporal dynamics of the winter northeast monsoon (NEM) on shorter timescales has not been fully investigated. The eastern Arabian Sea is sensitive to both the NEM and the SWM circulations, therefore ideal to investigate seasonal variations in the Indian monsoon system and associated paleoceanographic changes. The seasonal patterns of eastern Arabian Sea (EAS) hydrography is mainly controlled by the strength of northeasterly winter monsoon winds and fluvial runoff associated with the summer southwesterly monsoon winds. EAS is characterized by a pronounced mid-water oxygen minimum zone (OMZ), which impinges on its eastern margin. The relative importance of monsoon vs. ocean driving changes in OMZ intensity and thermocline ventilation is not well understood.

 We developed multiple micropaleontological (planktic foraminifera, pteropods, benthic foraminifera, coccolithophores, dinoflagellates), isotopic and geochemical proxy records from the central Indian margin to reconstruct changes in sea surface temperature and salinity, upwelling/vertical mixing, mixed layer nutrient condition, productivity, water column oxygenation, OMZ intensity and denitrification. We document millennial scale rapid switches in water column structure in concert with the global climatic events. We also asses role of winter NEM in modulating pattern of variations in productivity, OMZ intensity and denitrification across the basin both in time and space by comparing our Indian margin records with proxy records from the western and northern Arabian Sea. Our study provides insights into the relative importance of monsoon vs. ocean driven changes for the OMZ intensity and mid-water ventilation and its atmospheric and oceanic tele-connections.

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**Extreme Indian paleomonsoon states and productivity collapses in the Bay of Bengal since the Last Glacial Maximum**

Kaustubh Thirumalai

University of Arizona

Indian summer monsoon (ISM) hydrology fuels biogeochemical cycling across South Asia and the Indian Ocean, exerting a first-order control on food security in Earth’s most densely populated regions. Despite projected intensification under greenhouse conditions, substantial uncertainty persists among Earth- system models regarding ISM impacts on marine biogeochemistry. Here we reconstruct centennial-scale runoff into the Bay of Bengal (BoB) since the Last Glacial Maximum and evaluate extreme states relative to modern ISM intensity. We find that ISM runoff strengthened across the deglaciation, albeit with a protracted period of monsoon failure during Heinrich Event 1 (HE1; 17.5-15.5 ka). Freshwater discharge peaked in the early Holocene (10-9 ka) and subsequently reduced to modern values, although the nature of decline does not support a linear relationship between orbital precession and ISM intensity. Counterintuitively, we find that productivity collapsed during both extreme states of monsoon excess and deficit. We demonstrate using individual foraminiferal analyses that both episodes were associated with upper-ocean stratification. Whereas thermal stratification restricted mixing and suppressed nutrients during the HE1 failure, outflow-induced salinity stratification stifled export productivity during the early Holocene intensification. Our finding of non-linear ISM impacts on marine biogeochemistry raise the possibility of future deterioration of BoB primary production under increasing monsoon variance.

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**The South American Summer Monsoon and its impact on sediment transport in the Southern Central Andes**

Stephanie Tofelde

University of Potsdam

The South American Summer Monsoon exerts a first order control on rainfall rates and patterns in the northern part of South America and proxy records from the Altiplano Plateau or Brazil indicate that monsoon intensity has varied through time. In NW Argentina, reconstructions of Pleistocene climate are sparse due to the limited availability of paleo-climatic records. However, many intermontane basins within the Southern Central Andes of NW Argentina are characterized by multiple generations of fluvial-fill terraces, some of which date back several tens to hundreds of thousands of years. I will show that these geomorphic units provide an opportunity to extract information about paleo-climatic conditions.
 Alluvial river long profiles continually adjust to their water discharge (Qw) and sediment supply (Qs). Qw and Qs are in turn functions of local climatic and tectonic conditions. Hence, changes in the prevailing tectonic or climatic conditions will trigger adjustments to channel long profiles, either by channel incision into previously deposited sediments or by sediment deposition. Because fluvial terraces are abandoned floodplains that preserve ancient river elevation profiles formed from past Qs and Qw, they store information on past climatic or tectonic conditions.
 A combination of several geochronological techniques has revealed the history of a >200-m-thick fluvial-fill terrace sequence within the Quebrada del Toro. The terrace sequence experienced alternating episodes of incision and aggradation since at least 500 ka. Subsequent terrace surfaces appear to have formed following a cyclicity of ca. 100 kyr. From detrital sediment within those fill terraces, past Qs could be reconstructed for times of sediment aggradation based on cosmogenic 10Be concentrations. The analyses revealed that over the last ~500 kyr Qs has varied at most by a factor of 4, but overall has been relatively constant. As the slope of a river channel (and likewise, the slope of a well-preserved terrace surface) is a function of incoming Qs and Qw, combining data of terrace slope and past Qs allowed us to reconstruct past Qw for the times represented by the ages of the terrace surfaces, which mark the onset of river incision. The analyses revealed that during these times, Qw was 10 to 80% higher than today. The results are in line with the few existing quantitative estimates of past precipitation changes in the Central Andes, but have the advantage of extending further back in time. Moreover, the widespread occurrence of fluvial-fill terraces throughout the Central Andes offers the opportunity to reconstruct past Qw with high spatial resolution, offering a new perspective regarding the impact of past climate changes on the sediment-routing system through space and time.

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**The impact of Paratethys over the Eurasian climate during the late Miocene**Geanina Butiseacă
Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Senckenberganlage 25, D-60325 Frankfurt am Main, Germany

The late Miocene (15.97‒5.33 Ma) represents the onset of Eurasia as we know it today. Is a period with extreme changes in topography (the alpine orogenesis), precipitation patterns (changes in the Asian monsoon), flora (replacement of forests with open vegetation in southern and central Eurasia) and fauna (major mammal turnovers, extinctions and emergence of new mammal groups). During this time, Eurasia was covered by Paratethys, a large extinct epicontinental sea formed during the Paleogene. Paratethys giant covered a large part of Eurasia, stretching from France (to west) to China (in the east) and was the result of the tectonic closure of the Eocene Peri-Tethys induced by the Eurasia-Afro-Arabia collision that shaped the Alpine-Himalayan belt. This water body is not special only by its size, but also by its geography, Paratethys being rather a puzzle of smaller basins connected in between intermittently through short-lived or sustained gateways.

The combined effects of global climate change and drastic modifications in the distribution and connectivity of paratethyan basins and the Mediterranean, strongly affected the Upper Miocene Eurasian climate patterns. The impact of tectonics and climate-driven changes over these large water masses is still uncertain and remains an important question when discussing links and feedbacks between climate and tectonics and their impact over biota.

Applying biomarker analyses coupled to compound-specific hydrogen, carbon isotope data and charcoal, I track changes in sea surface temperature, mean annual air temperature, hydrological budget and vegetation changes to reconstruct long-term western Eurasian climate conditions between ~13 and 7.5 Ma in the Black Sea/East Paratethys region. Data from Panagia (Russia) indicate overall an increased continentalisation after 10 Ma, associated with major vegetation changes, basinal isolation and increased environmental pressure over biota populating the region. The influence of Paratethys over the global climate is still unknown, but the impact over the eurasian climate and biota was significant, acting as an important source of humidity for Eurasian interior. Drying of Paratethys brought with it a continental temperate climate, with hot summers and harsh winters that stayed with us until now.

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**Indian monsoon evolution after the last glacial period spanning the entire Holocene**

Yama Dixit

Indian Institute of Technology Delhi

The Indian Summer Monsoon that contributes to the socio-economic wellbeing of one-third of the world’s population has been a topic of active research for more than four decades. Despite a wealth of literature on the monsoon variability, there exist an apparent mismatch between marine and terrestrial archives of monsoon variability. This seminar would focus on paleoclimate reconstructions from lacustrine archives from Northwest (NW) India to understand the Holocene monsoon variability recorded in these lakes. Further similarities and dissimilarities between the inferences drawn from NW Indian lake records and other paleoclimate records will be examined.

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**Monsoons, tropical rainfall, and climate change: A paleoclimate perspective from Southeast Asia**

Kathleen Johnson

University of California, Irvine

The Asian Monsoon system is an important component of the global climate system that plays a major role in the transport of heat and moisture from the tropics to higher latitudes. Even small variations in the strength and timing of seasonal rainfall can have significant impacts on the billions of people living within the AM domain, yet climate model projections of future regional-scale hydrologic change still remain uncertain. Paleoclimate records from speleothems have substantially improved our understanding of the timing and mechanisms of past AM variability on orbital to decadal time-scales, but the impact of these variations on regional precipitation patterns remains unclear. This is due in part to the multitude of potential controls on speleothem oxygen isotope composition, but also to the sparse coverage of the paleoclimate record over certain regions, such as Mainland Southeast Asia. To address this, I will present new stable isotope, trace element, and radiocarbon data from speleothems collected from northern Laos spanning the last ~40,000 years. We find robust multi-proxy evidence for dry conditions during millennial-scale events and compelling evidence for dry conditions in Mainland Southeast Asia during the early Holocene insolation maxima when Asian Monsoon intensity was strong.

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**Late Quaternary Indian monsoon variability and its influence on South Asian societies**
Anil K. Gupta
Indian Institute of Technology, Kharagpur

The journey of South societies from the Bolan Valley (now in Pakistan) to the eastern parts of the Indian subcontinent through the catchments of the Indus and Ganga Rivers during the latest Quaternary is intimately linked to course of the Indian monsoon. The trajectory of human history, socio-economic condition of societies in South Asia - their agricultural practices, and domestication of plants and animals have been governed by monsoon precipitation since the dawn of the civilizations (late Quaternary and the Holocene). Even small-scale sudden changes in monsoon rainfall have cascading effect on ecology, human settlements and infrastructure in South Asia triggered by extreme flash floods and droughts. Recent paleoclimatic records from South Asia have provided significant information about summer monsoon variability on centennial to millennial timescales. However, annual to multiannual scale proxy records of summer monsoon variability are hitherto sparse from the Indian landmass. The high-resolution paleoclimatic records are pre-requisite to understand climate variability linked to changes in both natural and anthropogenic systems. Well-dated proxy record of summer monsoon wind strength from the Arabian Sea and of precipitation changes from the Indian landmass including speleothems and lake sediments indicate repeated occurrences of millennial scale abrupt shifts in the summer monsoon during the Holocene. Following the Younger Dryas, the summer monsoon began to strengthen (the Early Holocene Climatic Optimum) that continued until the middle Holocene (~ 6 kyr). A pervasive and pronounced dry phase in the late Holocene, often known as the 4.2 ka event, is well preserved in a few continental archives that triggered widespread formation of fresh water lakes in the Ganga Basin and migration of population across the Indian subcontinent. Both marine and continental proxy records suggest a wet phase during the Medieval Climate Anomaly and a dry phase during the Little Ice Age. A more recent study from the Rewalsar Lake suggests an intense monsoon phase during the Roman Warm Period (RWP) that enhanced economic growth in South Asia. Earlier marine record from the NW Arabian Sea indicates strong summer monsoon winds during the past four centuries which have been recorded as precipitation changes in some of our newly studied lake archives.

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**Impact of Southern Hemisphere high latitudes on the (South) Asian monsoon**

Jeroen Groeneveld

University of Hamburg and University of Bremen

The mid-Miocene climate transition (MMCT) at ~14 Ma resulted from a major glaciation phase on Antarctica leading to global-wide changes in climate and oceanography including intensification of the Asian monsoon systems. Both modelling experiments and proxy-based reconstructions suggest increases in wind strength and precipitation. However, there are large discrepancies in the timing of said changes in the different proxy records. In this seminar I will present an effort to identify if it is possible to distinguish specific parts of the monsoon system and the Hadley circulation that can be directly linked to Antarctic glaciation or are more likely to be caused by something else. I will present two case studies, one from the core of the South Asian Monsoon (SAM) region, Site NGHP-01 from the eastern Arabian Sea (Yang et al., 2021) that records both precipitation and watermass-related salinity changes, and one from the mid-latitude Southern Hemisphere off southwestern Australia that records precipitation induced by the Westerlies (Groeneveld et al., 2017). Both records show a major increase in precipitation related to the SAM and the Westerlies, resp., but with a 2 Myr offset between them. As moisture transport is geologically instantaneous these major changes in precipitation should have been caused by different processes.

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**Inverse relation between the Indian Summer and Winter Monsoon precipitation during the Late Holocene**

Prosanta Sanyal

Indian Institute of Science Education and Research Kolkata

Abstract:
Indian monsoon is a seasonal reversal of wind which controls the rainfall distribution in the Indian subcontinent. The Indian summer monsoon (ISM) causes rainfall in most parts of India and northeast monsoon (NEM) causes rainfall during winter in the southern parts of India. The gauge rainfall data suggest increase in NEM and decrease in ISM rainfall. In absence of long-term records from the NEM realm, it is remained unclear if the observed inverse relationship between NEM and ISM rainfall is a recent phenomenon. I this talk, I shall report the first Late Holocene reconstruction of NEM rainfall using hydrogen isotopic composition of n-alkane retrieved from a chronologically-constrained lacustrine deposit in southern India. More warming of Arabian Sea compared to Bay of Bengal (BoB) during El-Nino is found to intensify NEM rainfall. El-Nino activity fuels moisture advection from western Pacific that depletes 2H in NEM rain. The inverse relation between ISM and NEM rainfall existed since ~ 3 ka, suggesting recent trends of Indian monsoon are within envelope of natural climatic variables. Mixed layer heat content of south-eastern BoB plays additional role that controls interannual NEM rainfall variability.

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**The Himalayan sedimentary record stored in the Indian Ocean: a mineralogical and petrographic perspective**

Sergio Ando

University of Milano-Bicocca

Provenance analysis of IODP Expedition 355 cores in the Laxmi Basin sheds new light on the erosional evolution of the Himalayan belt and its western syntaxis during the Neogene and on large-scale mass-wasting and magmatic events that affected the western continental margin of India in the mid-Miocene and early Paleocene. Applying a multidisciplinary mineralogical and geochemical approach it is possible to define the different compositional signatures of sand, silt and clay in turbidites from sites U1456 and U1457. We have coupled traditional and innovative bulk-sediment and single-mineral techniques on the same samples, developing an integrated approach using the optical microscope and Raman spectroscopy. Heavy-mineral concentrations are higher in channel-fill than in overbank deposits. Mineralogical and geochemical data concur in revealing that fast-settling ultradense minerals such as zircon are preferentially concentrated in channel-fill deposits, whereas the top of overbank deposits are notably enriched with slow-settling platy phyllosilicates. In the cored Laxmi Basin succession, the occurrence of euhedral aegirine and apatite in lower Paleocene mudrocks can be tied to alkaline volcanism affecting the adjacent western Indian margin during the late stage of Deccan activity.

In the mid-Miocene Nataraja Slide dominant carbonate detritus and depleted heavy-mineral suites (including apatite, garnet, and locally augite or rare aegirine) reveal gravitational failure and sliding of the entire succession of carbonate and siliciclastic Paleogene to lower Neogene strata originally accumulated offshore of the Saurashtra margin of western India.
The overlying upper Miocene to lower Pleistocene turbidite package has the same feldspatho-litho-quartzose to litho-feldspathoquartzose signature of modern Indus fluvio-deltaic sand, indicating that amphibolite-facies metamorphic rocks have been widely exposed in the Himalaya–Karakorum orogen since at least the mid-Miocene.

Pleistocene nannofossil oozes with planktonic foraminifera at the top of the fan contain a very subordinate litho-feldspatho-quartzose terrigenous fraction including augitic clinopyroxene, suggesting mixing of dominant biogenic debris with minor detritus contributed both by the Indus River and by a river draining western peninsular India, possibly the paleo-Narmada or the paleo-Tapti.

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**Major re-organisation in marine ecosystem in the Japan Sea during the Late Miocene Global Cooling caused by changes in major monsoonal mode**

Kenji Matsuzaki

University of Tokyo

The Japan Sea is currently a semi-closed marginal sea sensitive to the dynamics of the East Asian monsoon. During the late Miocene, in particular between 10 and 6 Ma, it was connected to the Northwest Pacific via a deep-seaway in northern Japan, potentially allowing exchanges in deep-water with the North Pacific. This is interesting since between 10 and 6 Ma, the Earth's climate has experienced a strong cooling known as the Late Miocene Global Cooling (LMGC; ca. 7.9 to 5.8 Ma), which was associated with remarkable changes in monsoon dynamics and a “biogenic bloom” in the global oceans. Thus, paleoceanographic studies in the Japan Sea may clarify East Asian Monsoon response to the LMGC in northeast Asia and may allow monitoring changes in regional deep-water circulation triggered by the LMGC. However, because Calcite Compensation Depth is shallow in the Japan Sea during the late Miocene, most of the geochemical proxies based on calcareous microfossils cannot be used. Thus, only sedimentary analyses, other geochemical analyses and changes in assemblage of siliceous microfossils can clarify paleoceanographic changes of the Sea of Japan during the Miocene. Here, we analyzed changes in radiolarian assemblages from sediment retrieved during IODP Expedition 346 in the Japan Sea at Site U1425, where continuous sediment cores covering the last 9 million year were collected. Radiolarians are composed of a test of opaline silica and are thus well preserved in the sediments of the Sea of Japan continuously throughout the Neogene. Here we show high-resolution data of sea surface temperature based on radiolarian species (%) and fluxes of radiolarian species on the high seas between 10 and 5 Ma to clarify regional paleoceanography at this time.

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**Quaternary Environmental History of Indonesia**

Mahyar Mohtadi

University of Bremen

Paleoclimate research in Indonesia has become increasingly important with growing awareness of the critical role of this region for global climate, and with the recurring model deficiencies in reproducing the complex regional setting and thus, a less reliable simulation of future Indonesian climate. Proxy-based reconstructions and model simulations suggest that melting of the ice sheets and changes in global sea-level and ocean circulation strongly affect the Indonesian climate on millennial to glacial-interglacial timescales. Changes appear more severe in monsoonal south Indonesia compared to the ever-wet equatorial regions, making the Australian-Indonesian monsoon the prime suspect for translating changes in forcing and boundary conditions to environmental changes in and around Indonesia. However, results from simulations and reconstructions disagree on regional scale and indicate fundamental issues related to modern parametrization/calibration of the climate models/proxies.

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**Orbital and millennial-scale changes in tropical South American precipitation: causes and consequences**

Cristiano Chiessi

University of São Paulo

Precipitation projections published in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change show low model agreement over most of tropical South America. Independent of the reasons for the low model agreement, selecting the most probable future scenarios is a necessary task for devising adaptation policies. Data-model validation exercises for different than modern climate conditions may help on the identification of the most skillful models and on the selection most probable scenarios. Comprehensive reconstructions of past changes in tropical South American precipitation for different than modern climate conditions are thus of utmost importance. In this talk, we will assess orbital and millennial-scale changes in tropical South American precipitation. Based on records archived in marine sediment cores, we will scrutinize the causes and consequences of those changes.

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**Local and remote drivers of East Asian millennial-scale climate; monsoon proxy comparison (marine vs. speleothem)**

Yoshimi Kubota

National Museum of Nature and Science (Japan)

Abrupt millennial-scale climate changes during the late Quaternary were widely recognized in East Asian monsoon region from deep-sea sediments in the Japan Sea and more recently from oxygen isotope (δ18O) variability in Chinese speleothems (δ18Osp). The finely U-Th series dating method on the speleothems enables them to compare to climate records from other regions on millennial scale, and there is little doubt that the variability of these δ18Osp records is synchronized with climate perturbation in the North Atlantic high latitude, known as Heinrich events and with Dansgaard-Oeschger oscillations in Greenland. However, mechanisms of the climate response in East Asia remain unclear due to the lack of fundamental agreement on what climate signal δ18Osp represents. A primary impediment to interpreting the variability in δ18Osp is the lack of the means to decompose δ18Osp into constituent components. By contrast, δ18O of calcite skeletons of planktic foraminifers (δ18Op) from nearshore marine sediments can be quantitatively partitioned into sea surface temperature (SST) and δ18Ow of seawater (δ18Ow), a function of sea surface salinity (SSS). In this study, millennial-scale climate variability in East Asia is investigated using 400,000-yr records of SST, δ18Op, and δ18Ow from the East China Sea (IODP U1429). δ18Ow can be interpreted as reflecting SSS, hence rainfall, as the monsoonal runoff from the Yangtze River determines the summer SSS in the northern East China Sea (ECS). Our analysis shows that temperature and rainfall variability revealed from the ECS records are largely asynchronous, with times when the global climate shifts from interglacial to glacial periods being the notable exception. We found that North Atlantic forcing is dominant during these transition periods, while regional variability is predominant during full interglacials and glacial maxima. These findings highlight the importance of both the mean global state and the magnitude of North Atlantic variability in determining the East Asian climate. We suggest that without a strong North Atlantic forcing, the regional feedback system generates the asynchronous temperature and rainfall variations, which is the background climate feature in East Asia. Our results also provide an important perspective for interpreting δ18Osp records in the ECS. In particular, our records have the advantage of covering the interval from 260 to 310 ka, when millennial-scale variability is not well resolved in the δ18Osp record. Indeed, our δ18Opf record is well correlated with the δ18Osp record on a millennial scale except for 260–310 ka. The SST and δ18Ow records also show strong correlations with δ18Osp, although to a lesser extent. This indicates that both SST and δ18Ow are essential components of the δ18Osp signal, and that the global condition, such as sea level, is the crucial factor affecting local rainfall variability in East Asia.

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**East Asian summer monsoon-Westerly Jet connection at millennial-timescales**

Kana Nagashima

JAMSTEC

It has been established that East Asian summer monsoon intensity varies with Dansgaard–Oeschger cycles, suggesting a connection between the climates of East Asia and the North Atlantic on a millennial timescale. However, the dynamics of such a connection are still unsolved. To address this problem, we focused on the linkage between the EASM and westerly jet because meteorological observations and numerical models emphasize that the westerly jet path over East Asia attributes to the existence and maintenance of the EASM rainband (e.g., Liang and Wang, 1998; Sampe and Xie, 2010; Chiang et al., 2015, 2020). By analogy with the present close linkage of the westerly jet path with the position of the EASM rainband, it can be inferred that dynamic changes of the westerly jet path may have played a critical role in generating EASM variation during the last glacial period. Hence we reconstructed the westerly jet path over East Asia during the last glacial period based on the provenance study of Asian dust in Japan Sea sediments (Nagashima et al., 2011). The results exhibit changes of seasonal northward movement of the westerly jet path in harmony with Dansgaard–Oeschger events, suggesting the westerly jet critically affect the teleconnection between the climates of Asia and the North Atlantic on a millennial timescale.
To further understand the seasonal westerly jet path and the EASM precipitation changes on paleoclimate timescales, we then reconstructed Holocene westerly jet variation using Japan Sea sediments (Nagashima et al., 2013). The extracted Holocene millennial-scale variation of the westerly jet path was closely connected to the EASM precipitation pattern, especially its northwest-southeast contrast within China. In the presentation, we will discuss the similarity and difference of the EASM-westerly jet connection between the Holocene and last glacial periods, based on the “Jet Transition Hypothesis” proposed by Chiang et al. (2015).

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**A proxy view on Cenozoic ocean chemistry and continental weathering**

Xiaoli Zhou

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The reconstruction of seawater calcium concentration ([Ca]SW) in the geologic past is crucial to our understanding of long-term changes in the carbon cycle as related to climate and tectonics. Here we propose that because of the long oceanic residence time of Na+ (>>50 Myr), variations in foraminifera Na/Ca offer a new proxy of seawater calcium concentration in the past. We combined evidence from culture experiments on live planktic species, core tops calibrations and down core measurements of benthic foraminifera to generally show a substantial decrease in [Ca]SW over the past 40 Myr. We combined this [Ca]SW record with other foraminiferal-based proxies to evaluate changes in ocean carbonate saturation state. Using this [Ca]SW record with our global reconstructions of Mass Accumulation Rates of the main marine calcifying groups, used to assess variations in alkalinity fluxes from continental weathering and changes in the oceanic calcite compensation depth (CCD), we also examined the possible causes for the observed changes in seawater chemistry.

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**Decadal to millennial variability in the Indian monsoon and its global implications**

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The monsoon is the lifeline of billions of people residing in the Indian subcontinent. Despite the immense technological advancements, agriculture in the Indian sub-continent is still heavily dependent on monsoon precipitation. Any deviation in monsoon intensity has far-reaching implications for the economy of this region. Therefore, immense efforts are made to understand the monsoon dynamics. The reconstruction of monsoon intensity during different boundary conditions in the past helps in better understanding the monsoon dynamics. A large number of rain-fed rivers in the Indian subcontinent ensure the preservation of monsoon signatures in the adjacent Bay of Bengal and the Arabian Sea. The availability of cores with a very high sedimentation rate, along the Indian margins, has helped in reconstructing the high-resolution decadal to centennial-scale changes in the monsoon since the termination of the last glacial interval. The long cores drilled during the International Ocean Discovery Program (IODP) Expeditions 353 and 355 have been used to understand the long-term variability in the monsoon and associated parameters. We demonstrate that the monsoon and associated changes strongly modulate the global climate. This talk will include the work done to evaluate the applicability of the commonly used monsoon proxies, in the Indian Ocean, as well as the sub-centennial to millennial-scale changes in the monsoon, reconstructed by using the marine archives.