WORKSHOP REPORT

Land-Ocean Interactions Across the Indian Ocean: Toward Regional Integration of Recent Drilling Results

University of Rhode Island, Narragansett, RI
July 10-12, 2017

Conveners: Peter D. Clift, Rebecca Robinson, Liviu Giosan,
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SUMMARY

Between 2013 and 2016 the International Ocean Discovery Program (IODP) drilled in the Indian Ocean and adjacent regions. Forty-three US and international scientists met between July 10 and 12, 2017 at the University of Rhode Island to review results of this recent regionally-focused scientific drilling. Participants debated ideas on optimally designing regionally-dedicated campaigns, presented and discussed new science, and sought pathways toward integrating results into meaningful syntheses. Finally, ideas for future drilling in the Indian Ocean and adjacent regions were proposed, based on the recently acquired experience in the region.

Discussions first underlined the importance of planning meetings as proposals reach maturity for a given region before regional drilling is undertaken. Similarly post-drilling meetings emerged as a potentially critical tool for regional integration and synthesis. Such workshops inventory the science undertaken helping the community to focus on commonalities and differences at regional scale. Early and continued coordination between scientists from various expeditions of the campaign can also lead to ways to maximize the use of the existing funding toward regionally consistent results.

The overall success of regional drilling was seen as dependent on insuring balanced teams of scientists across geoscience disciplines from the early proposal stages to the synthesis phase. As more and more IODP proposals target continental margins within Exclusive Economic Zones (EEZs) access to EEZs becomes crucial and should be better addressed. Regional campaign objectives depend in large part on detailed post-cruise age models, which should be a priority to allow proxy records to be compared between expeditions. Regional science synthesis was seen as an extensive effort that could provide IODP benchmarks for its future science and insure full use of legacy cores.

Participants discussed the emerging science in the Indian Ocean and adjacent areas and identified the problem of coupling-decoupling of monsoon precipitation to monsoon winds as a potentially unifying framework idea for the region. The network of new paleoreconstructions should ultimately pave the way toward a synoptic understanding of paleoclimate and paleoceanography of the Indian Ocean. Deconvolution of climate from tectonic signals and vice versa is now within reach as records from sites located distally to tectonically active regions can be used as baselines for detecting changes in tectonic regime and/or events at more proximal sites. Drilling on the Australian and African margins emphasized changes in the ocean circulation and connectivity between the Pacific and Indian and Indian and Atlantic Basins, respectively, with implications for the large scale overturning circulation and climate. Ultimately, the new knowledge produced during the Indian Ocean regional drilling campaign in conjunction with results from adjacent regions will contribute to tackling feedback links between the carbon cycle, climate and tectonics at the global scale. Last but not least, synthesizing the results of the campaign will help to spark new ideas and to design future drilling campaigns after 2022 when JR will return to the region.

SCIENCE MOTIVATION

The goal of this workshop was to review results of the recent regionally-focused scientific drilling expeditions in the Indian Ocean, to propose possible paths for an integrated understanding of the role and response of climate in regulating hydrology, hydrography, sedimentation, and biogeochemistry in and around the Indian Ocean, and to synthesize practical lessons for future scheduled and proposed regional IODP drilling campaigns.

Interactions between the land and ocean can provide important feedbacks to climatic evolution and surface processes. The Asian monsoon is an impressive example of these interactions, and is a major component of Earth's climate, affecting over half of the world population. In the Indian Ocean sector, interactions between physical and biogeochemical processes and the tectonics of the India-Eurasia collision zone may have controlled both regional and global climate during the Cenozoic. The record of such interactions is best preserved in the ocean and was the target of recent scientific drilling across the region. Land-ocean interactions also play a critical role in modulating climate over Africa where complex interactions between the Indian monsoon and Atlantic occurs.

Between 2013 and 2016 IODP expeditions drilled in the Indian Ocean and Western Pacific oceans covering the Asian and Australian monsoon domains and adjacent regions. Reconstruction of the paleomonsoon was a leading objective for the following expeditions: IODP 346 (Sea of Japan and East China Sea), 353 (Bay of Bengal and Andaman Sea), 354 (Bengal Fan), 355 (Indus Fan), 356 (northwestern Australian continental margin), and 359 (Maldives). Expedition 361 offshore East Africa was designed to reconstruct evolving southern African environmental conditions during the Neogene and in particular to look at the history of the Agulhas Current system since around 5 Ma. The global reach of this current system may in turn play into the modulation of the monsoons.

If we are to make significant progress in understanding the climate and oceanography of the Indian Ocean region then a synthesis of results following exchange of information and debate is crucial.

WORKSHOP OBJECTIVES

While each expedition has made progress toward achieving its individual scientific objectives, any serious attempt to understand long-term evolution of the Asian monsoon, and its impact on neighboring climate systems, requires a more regional synthesis because the monsoon spans much of the Indian Ocean and Asian continent, but is manifested in different ways in different geographic areas. For example, the monsoon in the Arabian Sea is characterized by strong winds, with the neighboring land masses tending to be relatively dry. This contrasts with the much wetter conditions around the Bay of Bengal. Such differences can lead to some apparently contradictory results, such as the wind record in the Maldives and the upwelling offshore Oman being different in timing and direction compared to the environmental conditions reconstructed in the

Himalayan foreland basin. How the South Asian monsoon relates to the climatic evolution of the East Asian monsoon, or the migration of the Intertropical Convergence Zone over Africa is something that simply cannot be attempted without detailed comparison of results between the different expeditions.

This workshop drew together researchers across all these expeditions, to discuss key results and the central issues that have inspired this campaign of drilling. We aimed for a broader regional perspective that would help build connections between groups of researchers that might otherwise not come together. The workshop provided the community with an opportunity to synthesize results from different parts of the Indian Ocean and to build a more powerful, all-encompassing climatic model for the Cenozoic.

The campaign of drilling across the Indian Ocean also provides an important series of lessons for future sets of expeditions, such as those now planned for the Atlantic in 2019 and beyond. Many of the Indian Ocean expeditions considered different aspects of the Asian monsoon and together provide the chance to make some significant advance within a large topic in the Earth sciences. The ability to draw together and synthesize lessons learned from different expeditions is central to meeting the goals of the program as laid out in the IODP Science Plan. This same need to make substantive progress on large questions, beyond what is possible with regular funding or single drilling expeditions, while addressing the community goals will be significant for future campaigns of scientific drilling.

Exchange of scientific and logistical ideas in this workshop provided useful lessons for developing programs involving multiple expeditions in the future. We discussed how the stated goals of the Indian Ocean drilling campaign, prior to operations, compared with the actual results. We want to understand whether a series of linked expeditions was more successful as a result of their association. Do they really represent a coherent campaign? Where did the program exceed expectations? Where did we fail to make the advances we were aiming for and why? How can we maximize the long term scientific impact by facilitating the exchange of ideas and data?

WORKSHOP OUTCOMES

Participants to the workshop debated ideas on optimally designing regionally-dedicated drilling campaigns with a focus on the recent series of expeditions in the Indian Ocean. Pathways toward integration of the resulting new knowledge into a meaningful synthesis of land-ocean interactions in this region were explored. Finally, new ideas for future drilling in the Indian Ocean and adjacent regions were proposed, based on the recently acquired experience in the region.

Designing Regional Drilling Campaigns

The first attempts to design a campaign of drilling in this region date from 2007 when an integrated “Mission Monsoon” proposal was submitted. It tied together six different individual proposals spanning objectives in the western Arabian Sea, Bay of Bengal, the

onland/shelf delta - deep sea fan systems of the Red and Mekong Rivers, the East China Sea, as well as the Sea of Japan. The "Mission Monsoon" umbrella proposal resulted in a Detailed Planning Group that convened in April 2008 and made recommendations for regional efforts to understand monsoon-related science across Asia.

Discussions in Rhode Island underlined the importance of such previous work including the Goa-based IODP workshop on the subject of scientific drilling in the Indian Ocean. The 2011 workshop successfully led to better coordination of proposals already in the system and spurred new proposals that together amounted to a regionally-significant campaign. Such meetings should be employed in the future when enough proposals reach maturity for a given region.

Designing a regional campaign can be thought of as comprising several stages. At the proposal stage, it is important to insure a balanced team of proponents that cover all disciplines that are likely to be involved in planning, drilling and, ultimately, the use of drilling data and recovered materials. That includes non-traditional scientists (e.g., palynologists, modelers), who do not usually sail but should be given the same rights as shipboard scientists when they are key to the success of the integrated science. To prevent delays and the cancellation of drilling sites more effort should be dedicated to insure, well ahead of time, access to the Exclusive Economic Zones (EEZ) of countries where drilling will take place. This should be done immediately after the proposal is promoted to drillable status. This effort should involve a team that includes both proponents and IODP officials. The Indian Ocean campaign has demonstrated that successful reconstructions of land-ocean interactions depends on drilling continental margin sites in shallower water as well as deep basin sites and as such require access to EEZs.

Nonetheless, at the cruise stage, before sailing, each expedition should have clear backup plans that include non-EEZ sites to insure that the expedition objectives are reached. Communications between successive expeditions of the regional campaign can be improved by dedicating and requiring a full day overlap between key expedition participants (e.g., lab leaders) in addition to chief scientists. This overlap day would allow the oncoming group to be educated about technical issues but also address science questions of common interest that may have emerged during the completing expedition.

After the campaign stage, workshops similar to the present one were seen as very useful. Despite the fact that some expeditions finished only recently such a regional gathering has many advantages. First, the meeting acts as an inventory of the science proposed and in part undertaken and so helps focus on commonalities and differences at regional scale. Second, proxy development, including protocols, pitfalls, and alternative interpretations are discussed early and adapted to reach a more regionally consistent picture. It was recognized that postcruise funding is insufficient to produce the results anticipated during the cruise and planned in the proposal. Therefore, early coordination between scientists from various expeditions of the campaign may lead to ways to maximize the use of the existing funding toward regionally consistent results. Expedition and regional campaign objectives depend in large part on the rapid development of post-cruise age models that

allow proxy records to be compared between expeditions. More resources should be dedicated to producing such robust age models immediately after the cruise. For each expedition communication can be significantly improved before the postcruise science meeting via teleconferences every 3-4 months to assess progress and coordinate postcruise research.

Participants agreed that the present workshop should be seen as just the beginning of a coordinated effort that will ultimately lead to a novel regional synthesis spanning the Indian Ocean. In addition to meetings linked to major conferences, such workshops should be continued by a series of dedicated forums (such as within the AGU's Chapman or GSA's Penrose series) that would be amenable to focused discussions. Regional syntheses could take more classical forms such as volumes, monographs or special journal volumes (including online collections such as those produced by GSA's Geosphere or by EGU journals). Alternatively, papers spread across a number of journals could be curated electronically by IODP. Writing of such regional science syntheses should be at least in part financially supported by IODP to provide the benchmark for its future science in various regional drilling campaigns and to insure the full use of legacy cores collected in these regions.

Emerging Science after the Indian Ocean Campaign

The Indian Ocean monsoons (Asian, Australian, African) remain the overarching theme for research in the region. However, other important themes, such as ocean circulation, the carbon cycle, and ecosystem evolution were also highlighted. The monsoons are usually regionally defined and their definitions are goal-dependent (e.g. time scale dependent; local proxy dependent). The problem of coupling-decoupling of monsoon precipitation to monsoon winds emerged as a potentially unifying framework idea. The Indian Ocean campaign, in conjunction to drilling in the immediately adjacent basins (W Pacific; S Atlantic), provides the first truly regional opportunity for assessing commonalities in terms of mechanisms and manifestations for both rain and wind monsoon patterns. The "monsoon erosion pump" concept introduced during the workshop holds the potential to reconcile apparently conflicting records of the monsoon by considering the modulating role of climate-controlled vegetation landcover on erosion and weathering. More rainfall does not necessarily lead to more erosion and chemical weathering so that apparent mismatches between wind and environmental proxies need not be in conflict.

The Indian Ocean campaign recovered records at strategically located sites that allow for a meaningful comparison between terrestrial and marine monsoon reconstructions (e.g., terrestrial vegetation, erosion, weathering vs. marine salinity, productivity, circulation) at the scale of the entire basin. This network of paleoclimate and paleoceanographic reconstructions from continental margins, deep sea fans, as well as tectonic/biogenic plateaus and ridges should ultimately pave the way toward a synoptic understanding of the monsoon (e.g., Australian vs. Asian vs. African). Similarly, this same network can be used to reconstruct the yet under-characterized oceanic circulation in the Indian Ocean at surface, intermediate and deep-water settings. The workshop highlighted the early

success of the campaign in reconstructing the emergence of C_4 vegetation in the region. Such synoptic reconstructions should explore the means for climatic signal propagation between timescales: from multiannual phenomena such as El Nino-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Indonesian Throughflow, or the Atlantic Tropical Seesaw, through orbital timescale insolation-driven variability to converge into regionally coherent responses at tectonic timescales.

Deconvolution of climate from tectonic signals and vice versa is now within reach as records from sites located distally to tectonically active regions can be used as baselines for detecting changes in tectonic regime and/or events at more proximal sites. Feedbacks between tectonics and climate through orogenesis, erosion-weathering, oceanic gateway changes, sea level and accommodation changes, and drainage capture will soon be reassessed using the newly recovered sediments of the Indian Ocean science network. The reconstruction of fluxes, rather then relative values, for materials transported from land to the ocean, whether particulate or dissolved, emerged as key in evaluating questions of signal buffering and conflicting hypotheses on the links between tectonics and climate. Although such fluxes may not be easily reconstructed for complex depositional systems such as the megafans of the Bay of Bengal and Arabian Sea, non-volumetric proxies for erosion (e.g., cosmogenic isotopes; exhumation proxies) may be employed in parallel. Using such fluxes, the new knowledge produced during the Indian Ocean regional drilling campaign will ultimately contribute to tackling feedback links between the carbon cycle, climate and tectonics at the global scale.

Drilling on the Australian and African margins emphasized changes in the ocean circulation and connectivity between the Pacific and Indian and Indian and Atlantic Basins, respectively, with implications for the large scale overturning circulation and climate. Questions related to ecosystem evolution included African and Indian-Asian hydroclimate variations, vegetation-climate linkages, and human evolution. Links between the carbon cycle and climate were discussed as part of the larger monsoon discussion, including the relative roles for organic carbon burial and chemical weathering, the strength of the oxygen minimum zone, and the role of the high latitude Southern Ocean in modulating productivity in the Indian Ocean.

Future Drilling in the Indian Ocean

Preliminary results from the recently completed regional drilling campaign in the Indian Ocean can already be used to plan for potential new drilling targets in the future. Higher sedimentation sites (Bengal and Indus Canyons; fan levees; sedimentary drifts) and key sites for human evolution (Gulf of Aden) are high priority for their potential to address anthropogenic impacts and human history. Reaching the Paleogene remains an as yet unfulfilled goal for the monsoon reconstructions in the region, for assessing the age of inception for the Bengal, Nicobar and Indus megafans as well as for links between climate and the construction of the Greater Himalaya. This could be accomplished by deeper drilling on Indian Peninsula margins (e.g., the Kerala-Konkan Basin site abandoned due to EEZ problems before Expedition 359; the Cauvery Basin), African margin (Tanzania, Mozambique Channel), and Australian margins, together with new

drilling at the toes of fans where sedimentation rates are low, or on raised features such as the Murray Ridge. Such sites together with new locations e.g. in the Andaman Sea/Irrawaddy Fan, Gulf of Thailand/Sunda Shelf, and within the tectonically distal Equatorial Indian Ocean (Mascarene Plateau, Diego Garcia) would expand the synoptic network for reconstructing both the paleoclimatic and paleoceanographic history of the Indian Ocean.

Workshop Agenda

Monday July 10, 2017
Coastal Institute Auditorium, Graduate School of Oceanography

8:20-8:30 Introduction

Session 1: Paleoceanographic Records
Chairs: Ann Dunlea and Peter Clift

8:30-9:15 Steve Clemens
Unraveling orbital-scale links between the South Asian and East Asian monsoon systems
9:15-9:30 Ian Hall
South African Climates: Highlights From International Ocean Discovery Program Expedition 361
9:30-9:45 Pallavi Anand
Evolution of Indian Summer Monsoon dynamics: preliminary results from the Bay of Bengal (Expedition 353)
9:45-10:00 Steve Philips
Interpretation of terrestrial lithogenic and marine biogenic sediment fluxes at Indian Ocean margins as monsoon proxies
10:00-10:15 Tomo Irino
Establishment of perfect stratigraphic records, precise inter-site correlation, and their uses for reconstruction of the ocean circulation in the Japan Sea in relation to the east

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10:15-11:00 Coffee and posters
Coffee— Coastal Institute Lobby
Posters— Hazard A/B

11:00-11:45 Liviu Giosan
Indian Monsoon: Trends, Rhythms and Thresholds since Eocene
11:45-12:00 Kaustubh Thirumalai
Groundtruthing reconstructions of Indian monsoon variance using individual foraminiferal analyses
12:00-12:15 Katrina Kerr
Upper water column structure in the northern Bay of Bengal during MIS 5: unraveling Indian Summer Monsoon hydroclimate variability
12:15-12:30 Ramesh Singh
Interaction between Land-Ocean-Atmosphere Along East and West Coasts of India

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12:30-2:00 Lunch— Mosby Center

Session 1: Paleoceanographic Records (continued)
Chairs: Tomo Irino and Kautstubh Thirumalai

2:00-2:15 Christian Betzler
Cenozoic Neritic Carbonates in the Maldives Controlled by Sea Level and Ocean Currents (IODP Exp. 359)
2:15-2:30 Yair Rosenthal
Expedition 363: Neogene and Quaternary records of Western Pacific Warm Pool paleoceanography
2:30-2:45 Samantha Carter
Delving into the intricacies of the Asian Monsoon
2:45-3:00 Andrew Henderson
Evolution of the Japan Sea since the late Miocene at Site U1425, IODP Expedition 346

Session 2: Chemical Weathering and Monsoon Records
Chairs: Tomo Irino and Kautstubh Thirumalai

3:00-3:45 Christian France-Lanord
Expedition 354 on the Bengal fan: a Neogene record of Himalayan erosion

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3:45-4:30 Tea and Posters
Tea/Coffee— Coastal Institute Lobby
Posters— Hazard A/B

4:30-4:45 Cecilia McHugh
Miocene wet and extreme arid climatic conditions revealed by the lithology and logs of Roebuck and Perth Basins, Western Australia
4:45-5:30 Sidney Hemming
Weathering and erosion inputs to the greater Agulhas System from terrigenous sediment compositions along the southeastern African margin

5:30-6:00 Discussion

Tuesday July 11, 2017
Coastal Institute Auditorium, Graduate School of Oceanography

Session 3: Climate and Tectonics
Chairs: Valier Galy and Christian Betzler

8:30-9:15 Craig Fulthorpe
Siliciclastic Sedimentary Response to Late Miocene to Recent Climatic Change on the Australian Northwest Shelf: Results from IODP Expedition 356

9:15-9:30 Fenna Bergmann
Channel-levee evolution in the Himalaya-Bengal Fan source-to-sink system – Integrating seismoacoustic data and IODP Expedition 354 results

9:30-9:45 Kevin Pickering
Nicobar Fan and underlying sediments: Preliminary results from IODP Expedition 362, Indian Ocean

9:45-10:00 Kitty Milliken
Petrologic aspects of the Nicobar Fan and underlying pre-fan sediments: Preliminary results from IODP Expedition 362, Sumatra Seismogenic Zone

10:00-10:15 Priyank Jaiswal
Grain rearrangements in Southern Indian Ocean during the Mid-Miocene Climatic Optimum

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10:15-11:00 Coffee and posters
Coffee— Coastal Institute Lobby
Posters— Hazard A/B

11:00-11:15 Chris Mark
The Bengal Fan as an archive of the exhumation of the eastern Himalayan syntaxis: Possibilities and limitations of multi-phase detrital thermochronology

11:15-11:30 Peter Clift
Evolving Continental Erosion and Links to Monsoon Intensity in the NW Himalaya and Large Scale Drainage Capture

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Session 4 Organic geochemistry and terrestrial environments
Chairs: Cecilia McHugh and Rebecca Robinson

11:30-12:00 Richard Norris
Export Productivity in the Western Indian Ocean

12:00-12:15 Katrina Cantu
Lithogenic fluxes and East African Climate over the past 7.5 Ma

12:15-12:30 Pratigya Polissar
Late Neogene vegetation change in northern India as reconstructed from ODP cores on the Bengal Fan

12:30-2:00 Lunch— Mosby Center

2:00-2:45 Sarah Feakins

Hydrological change and the expansion of C4 ecosystems during the Neogene

2:45-3:00 Ann Dunlea

Sediment provenance and leaf wax δ13C and δD at Site U1445 in the Bay of Bengal to track the Indian Monsoon 0-6 Ma

3:00-3:15 Valier Galy

Mio-Pliocene Variations of the Indian monsoon recorded in the Bengal Fan (IODP Exp354): implications for the burial of terrestrial organic carbon

3:15-3:30 Ken Miller

Changes in global mean sea level determined from deep-sea benthic foraminiferal d18O and Mg/Ca records over the past 40 Myr: Implications for margin and platform

3:45-4:30 Tea and Posters
Tea/Coffee— Coastal Institute Lobby
Posters— Hazard A/B

4:15-6:30
Sub-disciplinary groups meet for discussion of significant recent advances. Scribes take notes

6:30-8:00 Dinner, **Salvation Cafe, Newport, Rhode Island**

Wednesday, July 12, 2017
Hazard A/B, Coastal Institute Building, Graduate School of Oceanography

Session 4: Discussion and Wrap Up
8:30-10:30
Plenary discussion

10:30-11:00 Coffee and posters
Coffee— Coastal Institute Lobby
Posters— Hazard A/B

11:00-12;30
Plenary discussion

12:30
Lunch and adjournment
Boxed Lunches will be available in Coastal Institute Lobby for pickup

Posters

Nagalakshmi Kottapalle, Yogi Vemana University, India
Textural Characteristics of Coastal Sediments of the Swarnamukhi River and Tupulipalem, Nellore, East Coast of India

Niteshe Khonde, WHOI
Provenance tracking for terrigenous sediment fluxes to the Northern Arabian Sea: The Great Rann of Kachchh

Peng Zhou, Louisiana State University
Evolution of Continental Environments and Chemical Weathering in the Western Himalayan Foreland Basin since 11 Ma

Sergio Ando, University of Milano Bicocca
Innovative and classical methods for the study of mineralogy of turbidites in ongoing and future IODP expeditions

Xixi Zhao, Tongji University
Magnetostratigraphy of Sedimentary Units in the South China Sea Basin

Elizabeth Griffith, University of Texas at Arlington
ODP Expedition 355 Arabian Sea Monsoon: Results from an isotope geochemist sailing as a downhole measurements/physical properties specialist

Attendees

Pallavi Anand, Open University, UK
Sergio Ando, University of Milano Bicocca, Italy
Fenna Bergmann, Bremen University, Germany
Melissa A. Berke, University of Notre Dame
Christian Betzler, University of Hamburg, Germany
Katrina Cantu, Scripps
Samantha Carter, University of Texas at Arlington
Steve Clemens, Brown University
Peter D. Clift, Louisiana State University
Ann Dunlea, WHOI
Sarah Feakins, University of Southern California
Christian France-Lanord, University of Nancy, France
Craig Fulthorpe, UTIG
Valier Galy, WHOI
Liviu Giosan, WHOI
Elizabeth Griffith, Ohio State /University of Texas at Arlington
Ian Hall, Cardiff University, UK
Andrew Henderson, Newcastle University, UK
Sidney Hemming, LDEO
Tomohisa Irino, Hokkaido University, Japan
Colin Jones, University of Rhode Island
Katrina Kerr, Open University, UK
Niteshe Khonde, WHOI
Nagalakshmi Kottapalle, Yogi Vemana University, India
Denise Kulhanek, Texas A&M University
Priyank Jaiswal, Oklahoma State University
Chris Mark, Trinity College Dublin, Ireland
Cecilia McHugh, CUNY/LDEO
Ken Miller, Rutgers University
Kitty Milliken, University of Texas at Austin
Sharif Mustaque, CUNY/LDEO
Richard Norris, Scripps
Stephen C. Phillips, University of Texas at Austin
Kevin Pickering, University College, London, UK
Pratigya Polissar, LDEO
Warren Prell, Brown University
Rebecca Robinson, University of Rhode Island
Yair Rosenthal, Rutgers University
Ramesh P. Singh, Chapman University
Angela Slagle, LDEO
Kaustubh Thirumalai, University of Texas at Austin
Xixi Zhao, Tongji University, China
Peng Zhou, Louisiana State University