ASIRI: Air-Sea Interactions in Northern Indian Ocean (And it's Relation to Monsoonal Dynamics of the Bay of Bengal)

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LONG-TERM GOALS

Monsoons are caused by large amplitude land-ocean temperature differentials resulting from the seasonal cycle of solar forcing on oceans and land. One of the most prominent is the Indian Ocean Monsoons (IOMs), which affect the lifestyles of more than a billion people in Southeast Asia. The IOMs are strongly modulated by air-sea interactions, particularly in the Bay of Bengal (BOB), thus determining sub-seasonal variability of the region. The summer monsoons are southwesterly, the resulting BOB circulation is anticyclonic, and strong upwelling occurs along the western boundary of BOB. Modulations of air-sea interactions, among other factors, lead to recurring monsoon breaks sandwiched between active wind periods. In the autumn, the monsoon winds switch to northeasterly, leading to the reversal of ocean currents, which occurs through a set of dynamical adjustments arguably involving coastal Kelvin waves and Rossby wave radiation. Notwithstanding their contributions to monsoonal dynamics and regional ocean-atmosphere processes, air-sea interactions in BOB have not been studied in depth. In particular, the available measurements are meager compared to modeling studies. The broad goals of this project is to (i) undertake a comprehensive review of previous studies on air-sea interactions in BOB during monsoonal period, (ii) identify critical science issues that may underpin a future comprehensive oceanographic research program on BOB, (iii) identify and initiate collaboration with a group of regional (Indian and Sri Lankan) scientists who may partake in a joint research effort, (iii) visit key institutions in India and Sri Lanka to initiate collaboration, covering both administrative and scientific realms, (iv) initiate a scientific personnel exchange program with these countries and the USA to cross-pollinate scientific expertise, (v) identify and address key administrative and intergovernmental bottlenecks for future research partnerships, (vi) help organize scientific meetings in India and Sri Lanka to plan for future collaborative programs of mutual interest, and (vii) initiative outreach and capacity building efforts.

OBJECTIVES

The current project seeks to identify key scientific issues that may drive a future ONR initiative on BOB, establish research cooperation with Southeast Asian partners India and Sri Lanka, initiate three-way exchange programs and organize scientific workshops to address issues that may stymie future research efforts. Given the multinational nature of anticipated BOB program, which involves working

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in the Exclusive Economic Zones (EEZ) and interfacing with governmental security agencies and research organizations, overcoming of certain administrative hurdles will be necessary. The science component of the current project includes preparation of a review (journal) article as well as initiating laboratory experiments dealing with circulation induced by mountains due to differential thermal forcing, as encountered in IOMs.

APPROACH

The proposed work will constitute the following tasks: (i) establishing a steering group consisting of US scientists with ties to India and Sri Lanka, (ii) arranging visits to partner countries and establishing contacts with relevant agencies, ministries and NGOs, (iii) initiation of exchange visits between key institutions, which will cover training of individuals as needed and preparation of a review article, (iv) identifying and addressing critical logistical issues and show-stoppers of future activities, and (v) conduct of laboratory experiments and theoretical analysis on flow induced by differential heating of a model topography.

WORK COMPLETED

Streering Group: The steering group assembled comprised of Dr. H.J.S. Fernando (University of Notre Dame); Dr. Iossif Lozovatsky (University of Notre Dame); Dr. Amit Tandon (University of Massachusetts, Dartmouth); Dr. Hemantha Wijesekara (NRL, Stennis); Dr. Amala Mahadevan (Woods Hole); and Dr. Subhas Karan Venayagamoorthy (Colorado State University). Representing the ONR are two program managers, Drs. Terri Paluszkiewicz and Scott Harper. The initial meeting was held on August 4, 2010, followed by a meeting of a smaller group on August 30, 2011.

Figure 1: The steering group (missing: Dr. Wijesekera)

Figure 2: Venn diagram of the current plan

Prefatory visits to India and Sri Lanka: The steering group and ONR program managers visited India and Sri Lanka during January 28-February 4, 2011. Meetings were held at the Indian Ministry of Earth Sciences, Delhi (January 31), National Institute of Oceanography (NIO), Goa (February 1), Indian Institute of Sciences (IIS), Bangalore (February 2) and at the National Aquatic Resources Agency (NARA), Colombo (February 3).

Discussions on a US-India-Sri Lanka Program: During the steering committee visit to Asia, extensive discussions were held with regard to possible bi-national and tri-national research collaborations. The US personnel presented their vision for a future BOB air-sea interaction program, noting that theirs is mainly driven by scientific needs, with some emphsis on outreach and developing global partnerships. The meetings also included presentations from domestic scientists and dicussions on further action.

Summer visit to India and Sri Lanka: The PI made visits to Sri Lanka (NARA) and India (IIS) during July 19 to 24th, 2011, and continued discussions on establishing MOUs, three-way collaborations, possibility of interfacing Indian Monsson mission and Sri Lanka BOB Circulation and Internal Waves program with a possible ONR initiative (ASIRI). Exchange programs, organization of meetings, and development of joint scientific documents were also agenda items. In Sri Lanka, the PI made presentations at the IOMAC (Indian Ocean Marine Affairs Cooperation) postgraduate institute and finalized the MOU between NARA and University of Notre Dame.

Exchange program: Mid- to long-term visits of Indian (Dr. G.S. Bhat and Debasis Sengupta from IIS; March – April 2011) and NARA (Mr. Priyantha Jinadasa; August 2011 to February 2012) were finalized. The senior visitors will work on a review paper on BOB monsoons and junior visitors will take academic courses and participate in oceanographic data analysis. Mr. Priyantha Jinadasa arrived in the US on August 23, 2011. His visit is partly funded by a POGO-SCOR fellowship (Partnership for Observation of the Global Ocean), following a successful proposal submitted to SCOR.

A path forward: Considering administrative restrictions, EEZ intricacies and national policies of countries involved in collaboration, the steering committee agreed that the best way forward at present

is a split approach, which is illustrated in Figure 2. Therein, the US participants of an ONR initiative may interface with the Indian Monsoon Mission, which is being orchestrated as a five year program by the Indian Ministry of Earth Sciences. Dr. Debasis Sengupta will lead the effort, and he plans to hold an international workshop in this regard sometime during January-March, 2012. Another meeting at Woods Hole during November 16-18, 2011 will precede this event. A special session on Indian Ocean Monsoons has been organized for the Ocean Sciences Meeting, February 2012.

On the other hand, the US-Sri Lanka program will be an overlap between the ONR BOB initiative (ASIRI), a research effort dubbed E-BOB (Effects of Bay of Bengal Freshwater Flux on Indian Ocean Monsoons) proposed by Dr. Hemantha Wijesekera at NRL and the NARA Indian Ocean Circulation and Internal Waves program. As a part of the latter, NARA has initiated a coastal topographic mapping program using side-scan sonar, and joint field studies between NRL and NARA are planned for 2013. An instrumentation proposal is being submitted to USAID Program in Sri Lanka to garner further support. The MOU between the University of Notre Dame and NARA formalizes this research collaboration. Covered by this MOU are the use of Sri Lanka EEZ, ports and logistical facilities as well as the NRL collaboration. A meeting is planned in Sri Lanka toward the end of February 2012 to further solidify the NARA-ONR-NRL joint effort.

Some possible obstacles for future collaboration were identified during PIs second visit. With respect to India-US collaboration, the use of Indian ports as well as EEZ may become an insurmountable task for US vessels. As an alternative, it was suggested for the US ships to operate in international waters, with Indian scientists working across both zones. Data sharing agreements need to be worked out, especially those taken in the Indian EEZ. Operations in Sri Lanka waters are outlined in the Notre Dame/NARA MOU, and sharing data outside the US and Sri Lankan scientists needs to be worked out. Sri Lanka ports are still listed as 'Risky' by the US Coast Guard, and efforts are afoot to seek removal of this classification. To this end, the PI is working with the Sri Lanka Embassy in Washington DC, and relevant requests have been submitted to the US State Department.

Technical developments: In addition to the preparatory work for a future BOB initiative, fundamental studies are being conducted by a graduate student and an undergraduate on flows induced by differential heating of mountainous terrain. The motive was to understand the extent of circulation cells generated by a heated mountain, with applications to parameterizate the lateral extent of monsoonal circulation induced by mountains alone. These cells ought to be determined by the background stratification, mountain slope as well as the rate and distribution of heating (Chen et al. 1996). A laboratory set up capabale of obtaining a range of heat fluxes as well as slopes was developed. The development of circulation and the nature of plumes above the mountains were monitored using Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV). Theoretical arguments are being developed to explain the results.

RESULTS

Groundwork was laid with regard to BOB collaborative research with India and Sri Lanka, and on-going activities are expected to develop two separate partnerships, US-India and US-Sri Lanka. The review article on monsoons is on-going and will be completed during exchange visits. Other issues of concern are being addressed, including re-classification of Sri Lanka ports to 'Safe' status and organization of international workshops.

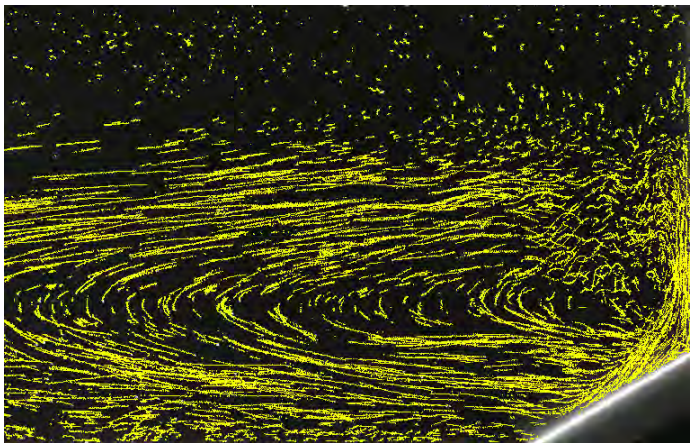

Figure 3a: Streak photos of circulation near a heated laboratroy mountain model

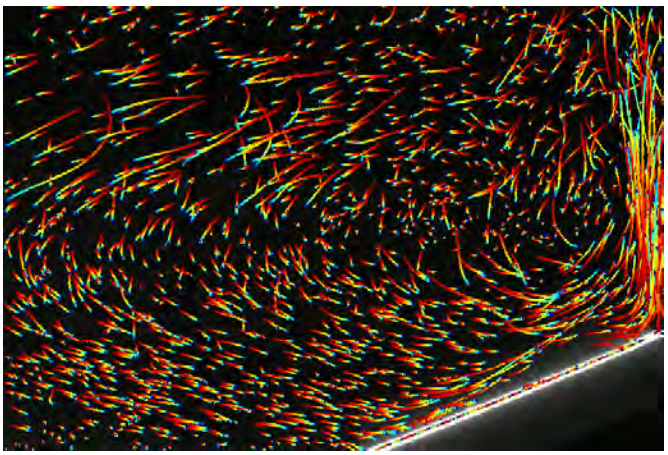

Figure 3b: Same as in Figure 3a, but with streaks near the surface and rising plumes are shown

The work on circulation near heated mountains was motivated in part by the results of numerical climate model experiments, which support the notion that stages in evolution of Asian monsoons are linked to phases of Himalayan–Tibetan plateau uplift and to Northern Hemisphere glaciation (Zhisheng et al. 2001). This suggests a link between Indian summer monsoons and warming of Tibetan/Himalayan mountain range. It is therefore of interest to quantify the role of differential heating on the strength of the flow as well as stabilization of recirculation cells. The combined experimental-theoretical study in progress generates an upslope flow along a heated symmetric mountain located in a 1.25x0.35x0.3 m water tank, with slope angles 10-30^{O}. Under certain condition the flow configuration produces stable circulation cells and rising plumes of finite height. The PIV and PTV as well flow visualization techniques were used to map the velocity field and plume rise (Figure 3a,b). At various parameter ranges different flow structures appear, and these patterns are being investigated in the framework of dimensionless parameters and viable physical processes. The results are being compared with theoretical arguments.

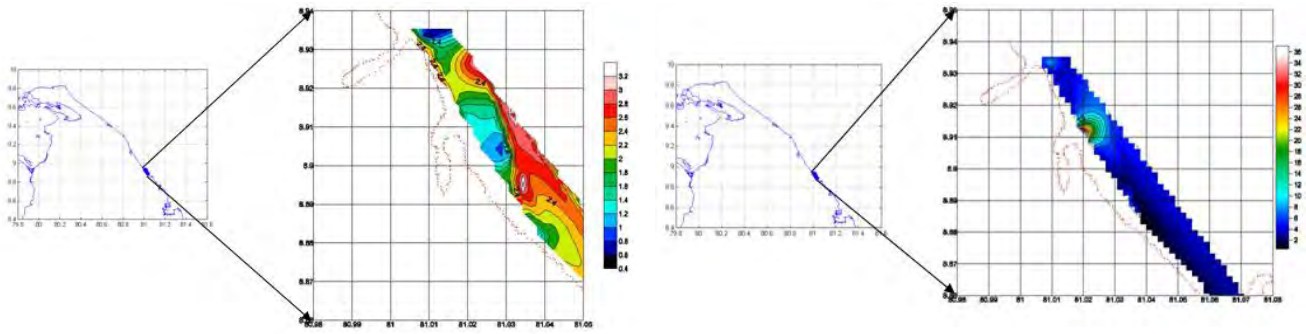

Figure 4: Results of an offshore sediment (left) and placer mineral (right) distribution study along the east coast of Sri Lanka; data are available for a narrow swath just north of Trincomalee. NARA will have increased focused on oceanography of its eastern coast owing to economic interests. The units of the color pane are arbitrary.

The NRL, as a part of E-BOB, is planning studies on boundary transport around Sri Lanka and on air-sea interactions with the aim of understanding water mass exchange between BOB and Southeast Arabian Seas. Previous studies indicate that circulation around Sri Lanka is central to such exchange processes. The low salinity water from BOB enters Arabian Sea via two paths: East India Coastal Current (EICC) that travels along the eastern boundaries of India and Sri Lanka and combined EICC and Winter Monsoon Current south of Sri Lanka. At present NARA is conducting a bathymetric survey in the eastern coast of Sri Lanka to update existing maps (Wijayananda, 1985), and this new data will be available for E-BOB. In addition, NARA is currently mapping the distributions of sediments and placer mineral resources along the eastern coast of Sri Lanka (Figure 4). Mr. Udaya Jinadasa, who is assigned to the ASIRI project by NARA, is playing a leading role in this effort.

IMPACT/APPLICATIONS

This project contributes to a potential ONR initiative dealing with air-sea interactions during Indian Ocean monsoons. It helps establish collaboration between Indian, Sri Lankan and US oceanographic communities.

RELATED PROJECTS

The PI is a co-PI of a project entitled, Mesoscale Dynamics and Lateral and Vertical Mixing in China Seas and Western Pacific, N00014-10-1-0738.

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