ASIRI: Remote Sensing of Atmospheric Waves and Instabilities (RAWI)

H.J.S. Fernando
University of Notre Dame
Departments of Civil and Environmental Engineering and Earth Sciences
And Aerospace and Mechanical Engineering
Notre Dame, IN 46556
Tel: 574-631-9346 and 574-631-3052; Fax: 574-631-9236
e-mail: hfernand@nd.edu

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www.nd.edu/~dynamics
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LONG TERM GOALS

The long-term goal of our research program is to understand subseasonal processes in the equatorial Indian Ocean, with the goal of contributing to improved prediction of atmospheric and oceanic weather of the Indian Ocean (IO) and beyond. The strong ocean-atmosphere coupling in the region and its role in world's climate have prompted detailed observations on either side of the sea surface, covering a swath of scales and interactions. Capturing subseasonal variability of key signals carried by oceanic currents and atmospheric circulation, and delineating their role in phenomena of significance, will be of interest. Some examples include Madden Julian Oscillation (MJO), planetary waves, transients of Hadley circulation, Kelvin-Rossby wave packets in the atmosphere and the seasonally reversing current systems and upwelling in the ocean, all of them are strongly coupled. It is hypothesized that smaller scale processes such as convection in the atmospheric boundary layer and turbulent entrainment, which have received scant attention hitherto in the context of larger scale processes, play a key role. Thus, coupled observations are of primary interest. Close partnerships with IO countries are sought to help develop integrated research programs, and enlisting of other US agencies such as National Oceanic and Atmospheric Administration (NOAA), Army Research Laboratory (ARL) and Naval Research Laboratory (NRL) is highly perused with respect to instrument deployment, regional atmosphere-ocean coupled model simulations and capacity building of partnering countries.

OBJECTIVES

The atmosphere-ocean interaction in the IO occurs over a continuum of scales, from regional-scale heat transport by the (occasionally reversing) Walker circulation down to local heat fluxes contributed by entrainment of warm air from aloft to the sub-cloud layer, which in turn affect local air-sea fluxes. The aim of the ASIRI-RAWI project, funded under the Northern Arabian Sea Circulation Autonomously Researched (NASCAR) DRI, is to make observations of circulation patterns in the middle and lower atmosphere, instabilities and vertical transport processes and the interaction of deep convection with such processes. Of particular interest are the instabilities of the atmosphere up to the level of tropopause, downward heat transport associated with them as well as their relation to Kelvin wave propagation in the equatorial IO, MJO and other subseasonal phenomena. Given the logistical and financial constraints, the intensive operational period (IOP) is confined to six to eight weeks, with some routing monitoring for a year. The international partners of the project are the Singapore National University, National Aquatic Resources and Research Agency NARA (Colombo, Sri Lanka) and Better Life Foundation and Meteorological Office of Seychelles.

APPROACH

During the period February 01 – March 15, 2015, simultaneous observations were made in the island nations of Seychelles (Mahe Island), Sri Lanka (Colombo) and Singapore. Several weeks were needed for set up (e.g., permits, land clearing, deployment) and tear down. The experiments were designed to capture small-scale events pertinent to the propagation of westerly disturbances originating in the western equatorial IO. The US partners included NOAA (Earth Systems Research Laboratory), ARL, NRL, and UCSD. The participants and details of instrumentation are listed in the website listed above, and in general the deployments included 2-3 daily radiosonde soundings (released at WMO stations 43466 and 63985 respectively), Lidar, Microwave Radiometer (MWR), sky camera, sonic anemometers, LICOR H_2O/CO_2 gas analyzers, T/RH probes, net radiometers for incoming and outgoing short/longwave radiation, barometers, rain gages and thermocouples. Each station was manned by both US and domestic personnel, with NOAA stationing one person and ARL rotating the resident personnel. UCSD deployed X-MET stations in Seychelles and Singapore, and NRL deployed a long-term monitoring station in Beruwela, Sri Lanka. Some of the instruments (e.g., Lidars, MWR) were remotely controlled, as was the data acquisition. Other data were locally collected (data loggers) and transferred to a data base at Notre Dame.

The capacity building component includes participation of scientists and students from partnering countries as well as training of graduate students at University of Notre Dame in analyzing oceanographic and atmospheric data. A group of technicians and engineers from the US are also conducting hands-on training of partner-country technical personnel in setting up and operating state-of-the-art instruments.

WORK COMPLETED

The meteorological instruments were deployed from February 01 through March 2015 in Seychelles (4°40'43.4"S, 55°31'50.2E), Sri Lanka (6°58'30.20"N, 79°52'12.80"E), and Singapore (1°17'57.13"N, 103°46'16.50"E). In Sri Lanka and Seychelles, the sites were located in coastal towns and hence the flux footprint was mixed. Measurements included the vertical profiles of temperature, humidity, wind speed/direction, vertical velocity, and cloud intensity. The Singapore urban site featured a Lidar and two daily sounding (at WMO 48698). All sites had a flux tower (10 - 13 m) for momentum and heat flux measurements (3-D sonic anemometers at multiple levels), and in two sites infrared gas analyzers and net radiometers were deployed for moisture fluxes and solar radiation measurements. Further details can be found at http://ceees.nd.edu/research-facilities/projects/asiri-rawi./

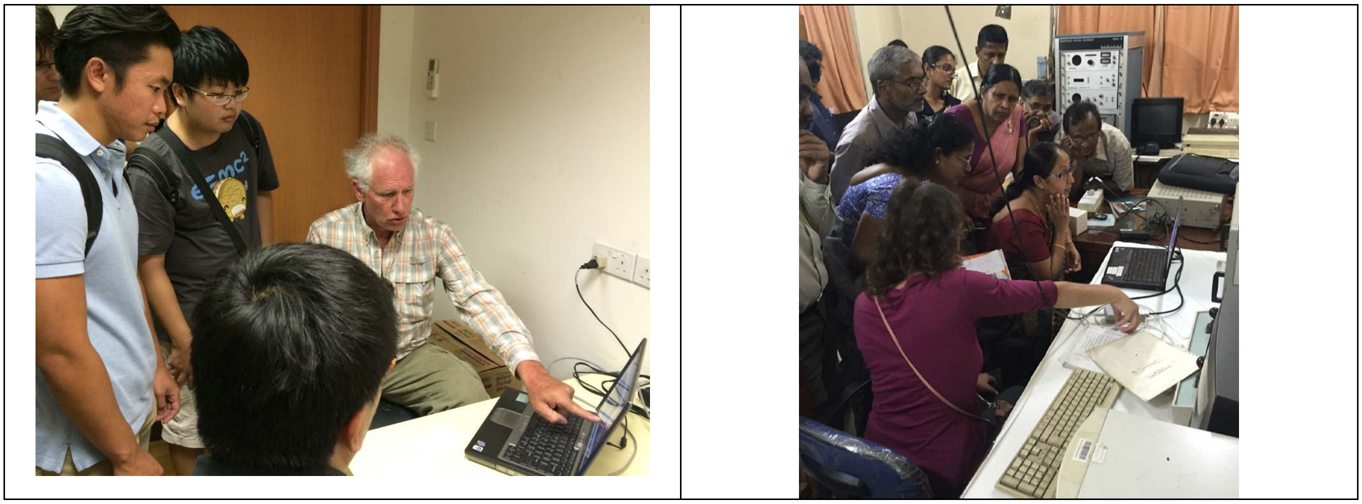

Figure 1: Instrumentation training sessions in Singapore by ARL (left) and Sri Lanka by Notre Dame.

The beginning of ASIRI-RAWI campaign coincided with the decaying phase of MJO signal over the tropics according to the RMM Index (Wheeler & Hendon 2004), thus permitting observations of subseasonal non-MJO phenomena. For example, both the Seychelles and Singapore observations showed consistent high speed (~5 m/s) packets of zonal wind (jet) of wavelength ~10000 km propagating westward at ~ 15 km height, suggesting their similarity to equatorial Kelvin waves. Their influence propagated to the ground level through quasi-periodic bi-weekly breakdown of the lower boundary of the zonal jet, possibly by shear, resulting in ground level wind bursts.

In each site, training sessions were held for local participants to appraise of the project progress and to help them familiarize with instrumentation, especially Lidar, MWR and InterMet radiosonde launches. These training sessions received kudos from local communities, especially young scientists (Figure 1).

RESULTS

As mentioned, the Seychelles and Singapore observations showed packets of zonal wind (jet) of wavelength ~10000 km, propagating westward at ~ 15 km height, suggesting their similarity to equatorial Kelvin waves. Their influence propagated to the ground level through quasi-periodic bi-weekly breakdown of the lower boundary of the zonal jet. Such quasi-periodic motions, however, were less evident at the Sri Lanka site (Figure 2a). Figure 2b-c shows time series taken in Colombo, where the zonal jet is at ~ 15 km and meridional jet at ~ 10 km (9 February). The downward descent of the zonal (westerly) jet occurred rapidly until ~ 5 km (on 11th February) under weakly stable atmospheric conditions prone to shear instabilities (i.e., low gradient Richardson number Ri). A very stable layer centered on ~ 4 km with maximum $Ri \sim$ 10-15 (Fig. 2f) impeded the descent, though downward mixing may have continued at a slower rate. By 15 February, maximum Ri decreased substantially to 3-4, approaching $Ri \sim 1$ at the edges of the stable shear layer. Note that the condition $Ri \approx 1$ corresponds to the maximum rate of stratified turbulent mixing (Strang & Fernando 2001), and hence $Ri \to 1$ is favorable for enhanced vertical mixing through the stable layer. Note that the low vertical measurement resolution (~25 m) of radiosonding technique may have overestimated Ri (De Silva et al. 1999). The enhanced mixing transported significant amounts of dry air towards the surface from aloft;

it mixed with existing surface moist air (70-90% relative humidity RH), thus reducing the ground level RH, followed by the temperature due to evaporative cooling (cf. 15-17 February in Fig. 2 d-e). The high RH prior to the event appears to have been contributed to by the rain events (9, 10, 11 and 13 February), local urbanization as well as advection of moist air by the near surface northwesterly flow.

The drop of surface temperature impeded the convective activity, as evident from the reduced heat flux and velocity variances (Fig 2e) as well as the height of capping inversion (ceilometer). Reduced moisture led to suppression of rainfall until 25 February, whence the surface moisture increased close to the previous levels and the upper-level moisture has increased substantially to resuscitate rainfall activity. It is interesting that the same patterns for RH and T have been recorded in the RAMA buoy 8°N 90°E in BoB, which is in the same latitudinal band of the Sri Lanka site (not shown).

The above results suggest that the vertical transport phenomena observed in Sri Lanka may also be occurring in the BoB, with modulations of near surface heat and moisture fluxes according to atmospheric activities aloft, thus affecting the air-sea exchange processes. In all, the preliminary results point to the significant role that multi-scale processes, from regional scale upper atmospheric flows to entrainment across stratified layers to turbulence and mixing in the ABL, play in air-sea interactions of BoB.

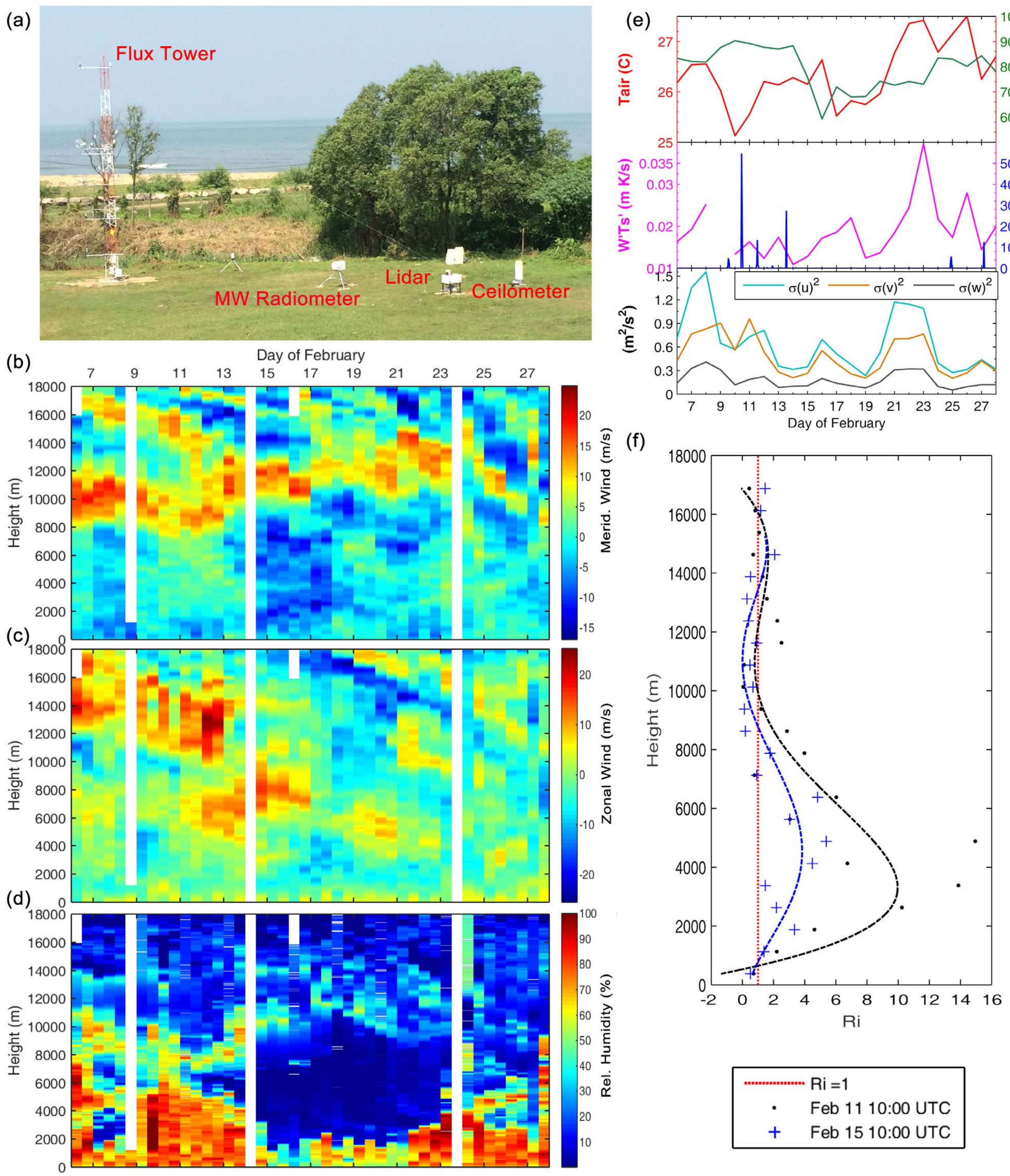

Figure 2: (a) Measurement site in Colombo; Height- time plots of (b) Meridional wind V ; (c) Zonal wind U ; (d) Relative humidity (RH) from the sounding station at the Sri Lanka site; (e) Daily averaged values of RH, air temperature (Tair), rainfall rate (Rain) and streamwise, crosswise and vertical velocity variances $\sigma^2(u)$, $\sigma^2(v)$, $\sigma^2(w)$ measured at the flux tower in Sri Lanka; (f) Vertical profiles of bin-averaged gradient Richardson number in two different representative soundings (calculated as $Ri = N^2/S^2$, where N is Bränt-Väisälä frequency and $S = \sqrt{(\partial U/\partial z)^2 + (\partial V/\partial z)^2}$ the shear measured at 25-m vertical (z) resolution).

The detected planetary wave was propagating at around the tropopause level (16-19 km) throughout the experimental period. Zonal wind and potential temperature anomalies (individual sounding profile with 6-week mean profile removed) at both Seychelles and Singapore sites revealed a wave with period of 14-16 days and amplitude (for zonal wind) of 10-15 m s^{-1}. This period corresponds to that typically observed for Kelvin waves in the lower stratosphere [Andrews et al. 1987, Wallace & Kousky 1968], but additional high-resolution space-time data are needed to determine other characteristics of these waves, given the limitations imposed by rather large distance (~5400 km) between ASIRI-RAWI observational sites.

National Center for Environmental Protection/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis I data at 2.5°×2.5° spatial resolution [Kalnay et al. 1996] characterized the state of equatorial atmosphere during the experimental period. The temporal evolution of zonal wind at 0° latitude and 100 hPa pressure level confirmed the planetary nature and longitudinal extent of this wave, even though beyond 90°E smaller disturbances contaminate the signal. By 130°E the wave was either strongly modified or destroyed, which could be attributed to passing over Maritime Continent that is believed to be a key location for enhanced convection penetrating the tropopause level [Liu & Zipser 2005] and modification of other intraseasonal oscillations like MJO. The wave also exhibited the eastward phase propagation, a characteristic of equatorial Kelvin waves. The horizontal wavelength was estimated from reanalysis data to be 9000 kilometers, so the horizontal phase velocity was calculated as 6.9 m s^{-1}. While this would be a relatively slow-moving wave in comparison to that originally reported by Wallace and Kousky (1968), waves with similar velocity have been observed previously, for instance over the Maritime Continent (Fujiwara et al. 1998).

IMPACT/APPLICATION

The project involves true international collaboration between scientists from the US, Sri Lanka, Seychelles, Singapore and Maldives (Pending). The program also supports logistics of numerous US scientists operating in the Indian Ocean under ASIRI and NASCAR projects. Capacity building is a key component, and to this end we are hosting scientists from NARA, Singapore National University and Seychelles Met Office at Notre Dame. Close involvement of DOD agencies, ARL and NRL, and NOAA are also highlights of the project.

RELATED PROJECTS

The PIs is working on an ONR 322-MMM funded project dealing with radio wave propagation in the marine boundary layer, where our role is intense experimentation and theoretical developments on coastal marine boundary layer (N 00244-14-2-0004).

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HONORS/AWARDS/PRIZES

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Hong Kong University of Sciene and Technology (HKUST) Hong Kong Jockey Club Advanced Institute Distinguised Lecture (December, 2014).