Subsurface Fluxes Beneath Large-Scale Convective Centers in the Indian Ocean: Coupled Air-Wave-Sea Processes in the Subtropics

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LONG-TERM GOALS

Long-term objectives are to assess the generation, evolution and breakdown of oceanic small-scale processes and how these contribute to larger-scale dynamics. A particular goal is to quantify the effects of such processes on mixing the ocean, both in redistributing heat, salt and chemical constituents and in redistributing momentum. Related to this goal is the quantification of energy losses due to turbulence dissipation and to internal wave radiation. To accomplish these goals, our group has developed various forms of unique observational instrumentation for use at sea, on ships, moorings and autonomous vehicles; this instrumentation has proven itself over many experiments. An emphasis is placed on fostering physical insight through analysis and development of simple physical models. Close collaborations with modelers (of both small and large scales) has led to deeper insight into many problems over the years.

OBJECTIVES

Specifically, the objectives of this project are to:

- quantify the detailed vertical and time-varying structure in both velocity and stratification of the Wyrtki jets. This measurement leads to estimation of *Ri* and potential parameterization of mixing;

assess negative feedbacks to atmospheric convection

- quantify sea surface cooling rates due to wind mixing and diurnal cooling;
- quantify sea surface cooling rates due to shear instability created by the highly-sheared currents, particularly the Wyrtki jets; and

assess positive feedbacks to atmospheric convection

- quantify sea surface heating rates (from both above and below) in thin near-surface fresh layers deposited by convective precipitation.

Significantly, such a detailed process experiment *has never been attempted in the equatorial Indian Ocean*

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APPROACH

Extensive measurements of upper ocean currents, stratification and turbulence were made from R/V Roger Revelle over the fall 2011 MJO period in the equatorial Indian Ocean. These included measurements from customized instrumentation to include a clear depiction of the upper 5 meters of the ocean undisturbed by ship wake.

WORK COMPLETED

As part of DYNAMO, Revelle's primary function was to occupy the NE component in the main array of 4 sounding stations and as a base for C-band radar observations of precipitating cloud activity. As part of LASP, Revelle was the principal observational base for investigation of air-sea interactions associated with initiation and propagation of the Madden-Julian Oscillation (MJO) across the equatorial Indian Ocean.

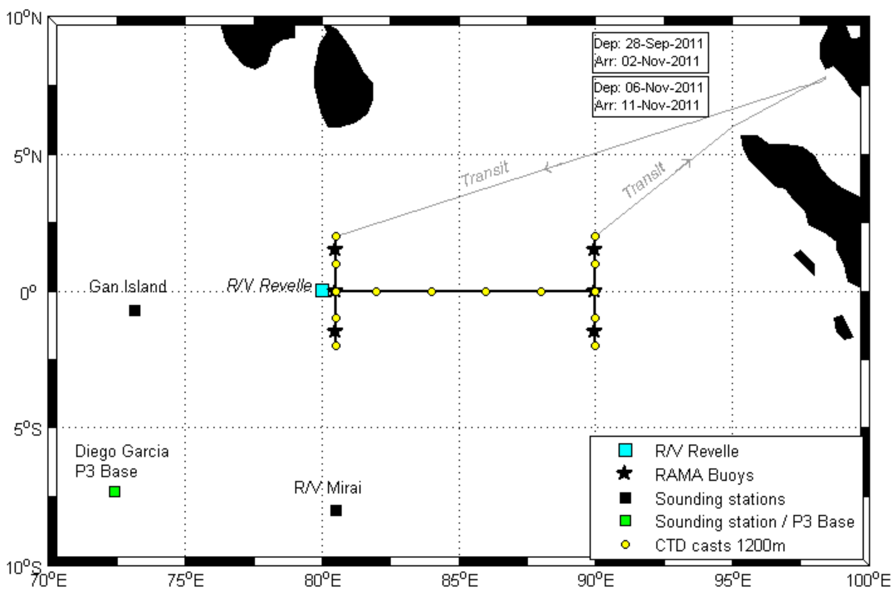

Figure 1 – Cruise track LASP / DYNAMO Leg3.

Revelle left Phuket, Thailand 06 Nov 2011, and proceeded directly to 2N, 80.5E (Figure 1). An ADCP/XBT survey was conducted along 80.5 E from 2N to 2S to map out cross-equatorial current structure. Revelle returned to 0, 80.5E to conduct a 22-day time series that included measurements of surface fluxes, wind profiles, C-band radar, atmospheric soundings (8/day), aerosols, sonar-based ocean profiling and profiling of ocean structure including turbulence. These measurements included:

- continuous velocity profiling from 1 km below to 10 km above the sea surface;
- 80 CTDs;
- 3250 temperature/conductivity/turbulence upper ocean profiles to 300 m depth (using Chameleon);
- high-resolution eddy-correlation flux measurements from bow mast.

On 02 December, a large-scale CTD/ADCP transect was begun to map out the larger structure of equatorial currents as well as Kelvin and Rossby wave propagation between 80E and 90E (Figure 1).

RESULTS

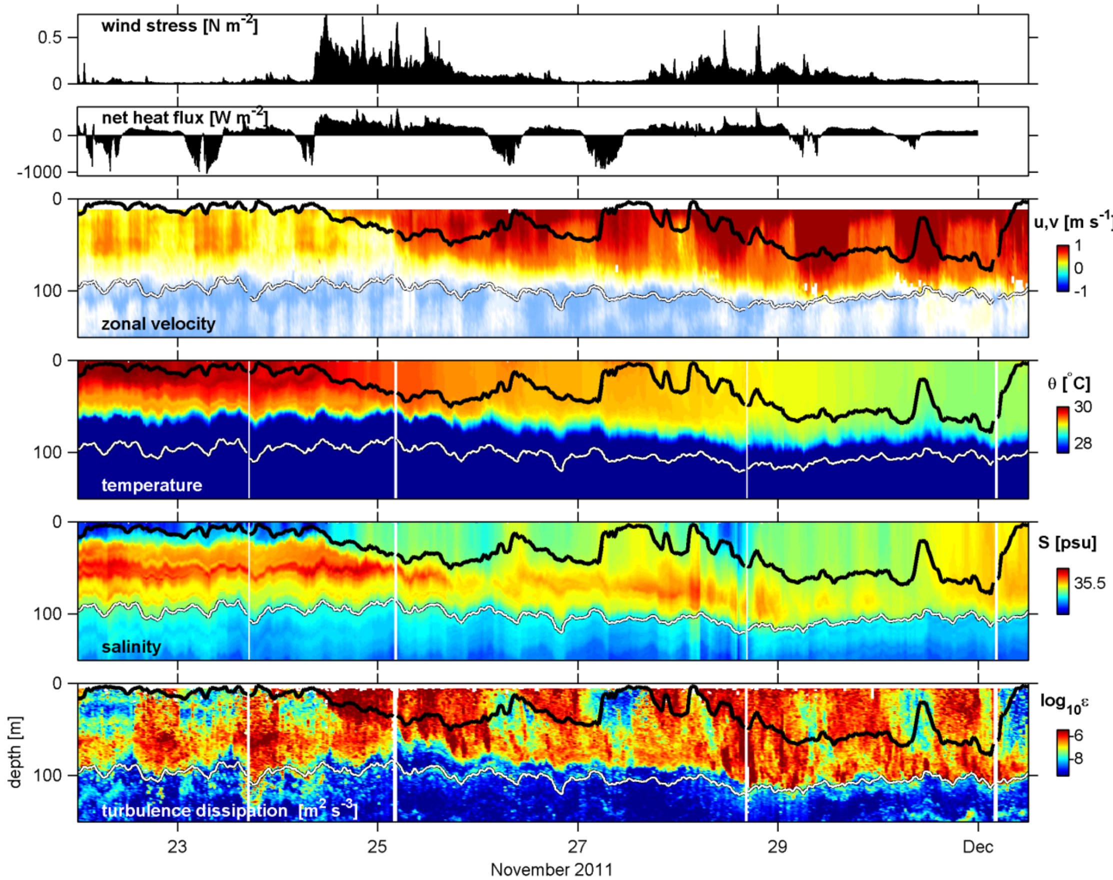

Figure 2 – Summary time series of the passage of the cyclone-assisted MJO wind burst past R/V Revelle on 24 November 2011. The wind stress appears as a step-function change from < 0.05 Pa to > 0.5 Pa in a few minutes. Net surface cooling lasted for more than 1 day, a rarity at the equator. The eastward surface current (the Wyrtki Jet) accelerated from < 0.5 m/s in about 1 day, deepening with time. The mixed layer is indicated by the black line, the potential density surface 24.75 by the white line. Mixed layer cooling was driven by combined atmospheric and subsurface cooling. Salinification of the surface was driven by excess of subsurface mixing over precipitation. Intense turbulence (lower panel) caused directly by surface forcing on 24 November was followed by shear-driven mixing at the base of the Jet (to 100 m depth).

A highlight of this experiment was the full observation of a cyclone-assisted MJO wind burst at Revelle. Excess surface heating over cooling caused increased sea surface temperatures prior to 24 November. On 24 November, the arrival of MJO-related winds/convection in the west juxtaposed with Tropical Cyclone 05-A from the NE resulted in a rapid increase of wind stress at Revelle from near-zero to 0.35 Pa sustained over the next 24 h. The step function in wind stress as well as net surface heating and the ocean's response are illustrated in Figure 2. Despite significant precipitation, subsurface mixing caused surface salinity to increase rather than decrease. Combined atmospheric cooling from above and ocean cooling from below caused rapid sea surface cooling. And in perhaps the simplest dynamical air-sea interaction response possible, the surface Wyrtki Jet was accelerated from <1 kt to > 2.5 kts in the period of a day by the excess of wind stress over turbulence friction at the base of the Jet. The Jet response is seen in the time series in Figure 2. The large-scale Jet response is seen in the pair of zonal transects made before and after the MJO wind burst (Figure 3).

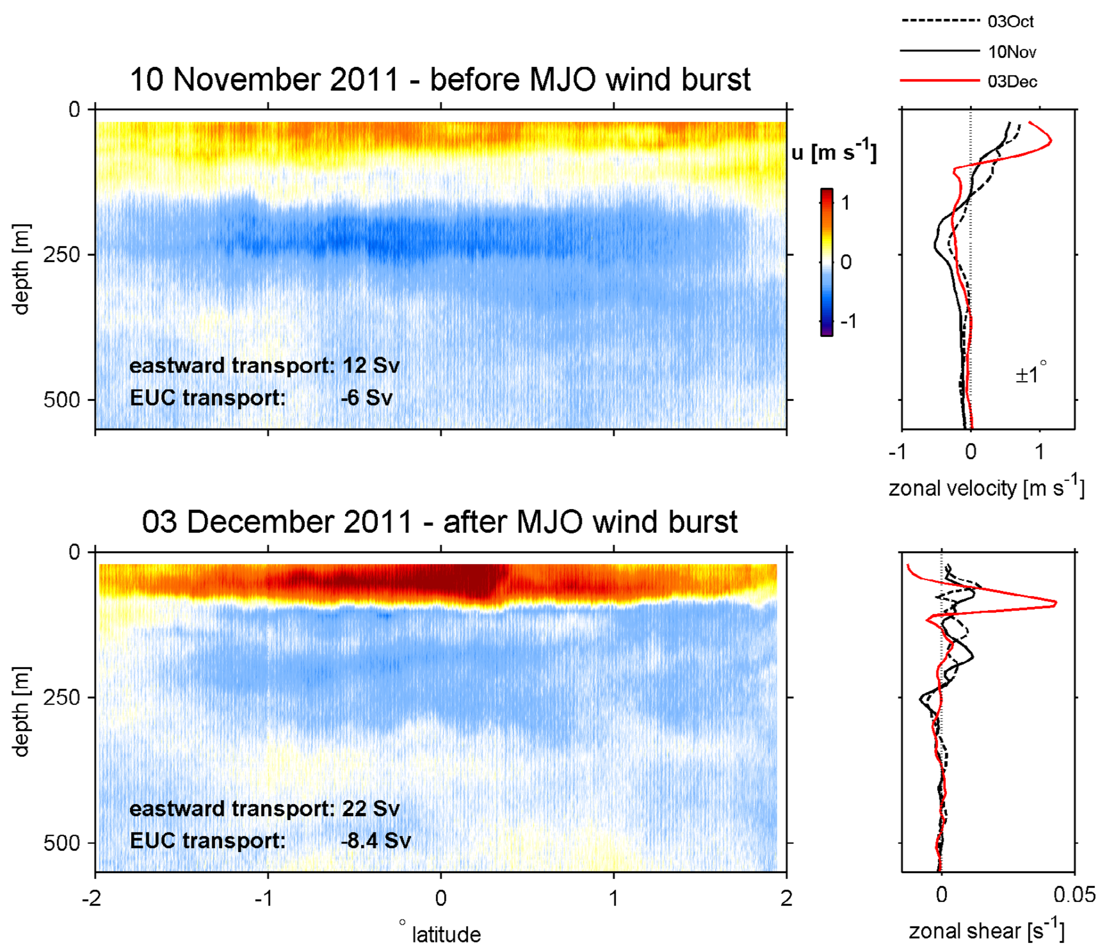

Figure 3 – Cross-equatorial structure of the Wyrtki Jet before and after passage of the cyclone-assisted MJO wind burst. Images are zonal currents between 2S and 2N along 080 30.0'E. Eastward transport increased by a factor of 2 following the wind burst. This is equivalent to a quadrupling of surface ocean kinetic energy. Mean vertical profiles of zonal currents (upper right) and current shear (lower right) provide a direct comparison of the intensification between 1S and 1N.

A bow-mounted temperature-conductivity chain reveals the details of near-surface heating and vertical redistribution of this heat by mixing following onset of wind forcing (Fig. 4). An examination of variations in this due to freshwater pools laid down by precipitating convective cloud systems associated with the MJO and the dynamics of these freshwater pools form the core of the PhD thesis of Aurelie Moulin.

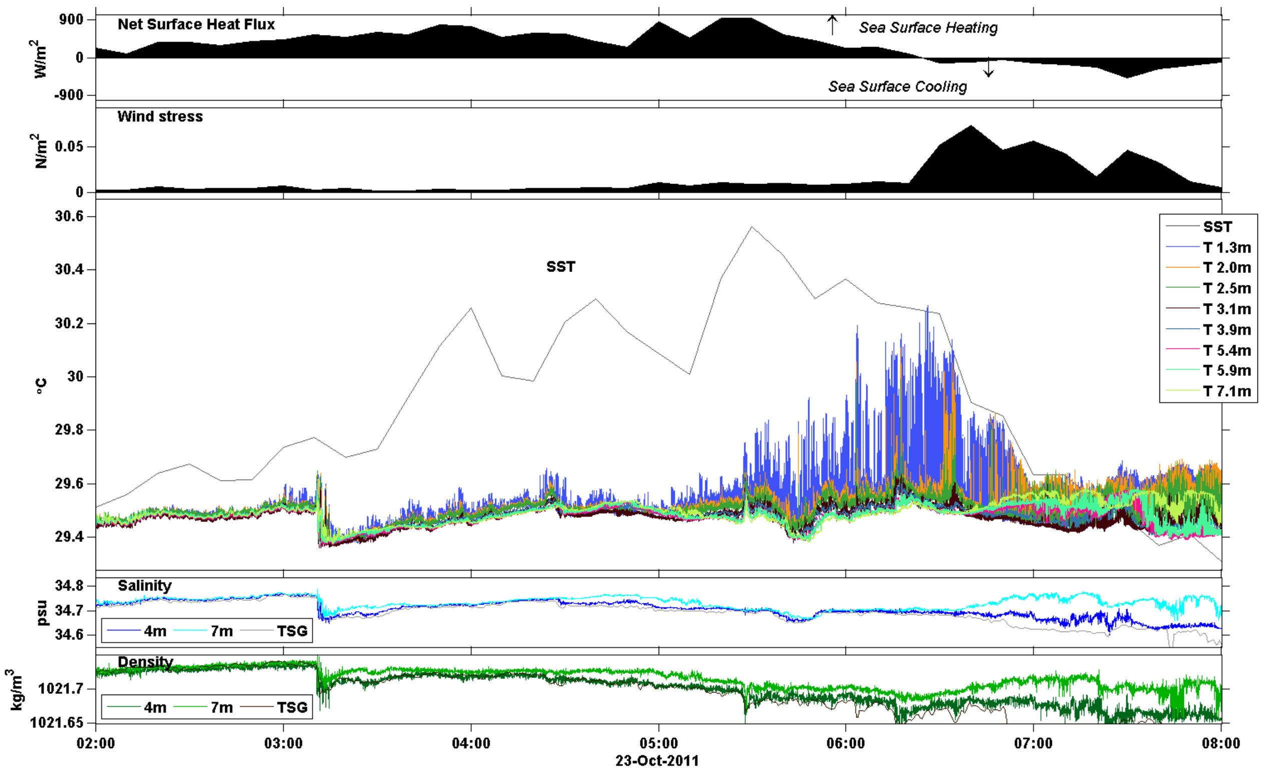

Figure 4 – Detailed measurements of the upper 7 m showing the arrival and superheating of a freshwater pool prior to 06:20. This heat is rapidly mixed downward following the increase in wind stress at about 06:20.

A summary case study of the onset, evolution and oceanic response to the 24 November 2011 tropical cyclone-assisted MJO wind burst that includes atmospheric and oceanic observations plus relevant modeling efforts is being assembled for publication. PI will lead the organizing effort.

IMPACT/APPLICATION

These measurements will represent an important contribution to the long-term DYNAMO effort.

RELATED PROJECTS

The Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011 (CINDY2011), collected in situ observations aboard the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) research vessel *MIRAI* in late fall 2011. A coordinated regional field experiment was conducted in fall 2011 on the Dynamics of the Madden-Julian Oscillation (DYNAMO). The latter experiment was designed to observe the initial development of an MJO in the central Indian Ocean from a 4-month deployment on United States, Australian, Indian and Japanese research vessels. CINDY2011 and DYNAMO have similar scientific goals and observational requirements. The PI is working closely with DYNAMO and CINDY2011 PIs.

PUBLICATIONS

Smyth, W.D. and J.N. Moum, 2012: Ocean Mixing by Kelvin-Helmholtz instability. *Oceanography*, 25(2), 140-149. [published, refereed]

Nash, J.D., S. Kelly, E.L. Shroyer, J.N. Moum and T. Duda, 2012. The unpredictable nature of internal tides on the continental shelf. *J. Phys. Oceanogr.,* doi:10.1175/JPO-D-12-028.1. [published, refereed]

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HONORS/AWARDS/PRIZES

James N. Moum, Oregon State University, Fellow, American Geophysical Union, 2012