The Interaction of the Throughflow with Small Scale Variability

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LONG-TERM GOALS

The long-term goal of this award is to understand the processes that control the generation, evolution and distribution of small-scale, time-dependent features within straits, and how these features interact with the large-scale sub-tidal throughflow within which they are embedded. The effort will focus on a multi-year time series from an ocean sensor array of moored ADCP and temperature-conductivity sensors, and pressure gauge observations in the internal straits of the Philippine seas. The aim is to characterize the spatial and temporal variability of the small-scale features and how they may vary seasonally to interannually as the remote and local (monsoonal) forcing changes. We wish to understand the relative roles of the tidal signal within the straits, as well as the large-scale currents that may flow from the boundaries through the archipelago, in generating and maintaining the major flow features within the straits. Ultimately, this will enable a better representation and prediction in numerical and theoretical models of the structure and evolution of the small-scale features common to sea straits, including their time-dependent variability.

The original proposal was entitled “The Interaction of the Indonesian Throughflow with smaller scale variability in Lombok Strait” and reflected the original Indonesian site for the DRI “Characterization and Modeling of Archipelago Strait Dynamics". The site was re-located to the Philippines in late 2006.

OBJECTIVES

The goal of the ocean sensor array is to improve our understanding of the oceanographic processes that lead to small-scale variability in the flow structure of straits. Specifically, the main objectives are:-

1. To examine the relative roles of the tidal and longer timescale flows in the generation and evolution of the small-scale dynamical flow features in straits,

2. To determine how the small-scale features evolve with observed across- and along-strait variation in sea-level and the corresponding strength and direction of the mean flow,

3. To identify how the small-scale flow structures and sea-level variability may be modulated by both the remote and the local forcing, particularly in response to the seasonal reversal in the monsoon winds.

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APPROACH

As part of the "Characterization and Modeling of Archipelago Strait Dynamics" DRI, an ocean sensor array of moorings and pressure gauges were deployed within the straits of the Philippine archipelago. Having an array of moorings and pressure gauges within these straits, that resolves both the along-strait and the cross-strait variation in flow and properties, enables us to observe any possible localized or isolated response in the circulation patterns related to the mesoscale and submesoscale processes. The moorings consist of bottom mounted ADCPs and discrete Temperature-Salinity sensors. Upward-looking ADCPs will provide direct velocity measurements of the whole water column within the expected more active flow path of the strait. SBE37 Microcat CTDs with pressure sensors will be scattered along the mooring chain to resolve the stratification. The pressure gauge array will help resolve the sea level signal associated with the tidal forcing (to assist with the validation of the barotropic tidal models) and long planetary waves at the boundaries of the Philippines seas. SBE37 CTDs co-located with the shallow pressure gauges will also add some information on surface temperature and salinity variability. The moorings will provide direct measurements of the velocity, temperature and salinity at sampling rates of ~ 0.5 hours, while the Paroscientific quartz pressure sensors return high precision (0.3 mbar) data with sampling periods of seconds to accurately resolve the tidal flow and changes in sea level (pressure) along and across the strait.

The ocean sensor array was constructed and assembled by engineers and marine technicians at the Scripps Institution of Oceanography (SIO) Hydraulics Laboratory, under the guidance of Senior Development Engineer Mr. Paul Harvey.

The shallow pressure gauge array has been deployed at 6 locations around the Philippines with the assistance of Dr. Cesar Villanoy at the University of the Philippines.

It is envisaged that the ocean sensor array will also provide temporal context for the “synoptic” shipborne flow and property measurements, as well as ground-truthing of high frequency radar and SAR images for other DoD funded researchers of the ONR DRI program, “Characterization and Modeling of Archipelago Strait Dynamics". The high-frequency time series data will also provide a test for evaluating and refining of models and their predictions that are not possible from shipborne observations alone. This will enable a better representation and prediction of the structure and evolution of the small-scale features.

WORK COMPLETED

Three bottom-mounted ADCP moorings were deployed in Panay Strait (sill depth ~ 580 m); Dipolog Strait (~480 m); and Surigao Strait (~166 m) during the Exploratory Cruise in the Philippines Seas in June-July 2007. The Panay mooring was deployed initially for a three-week period, recovered and velocity data downloaded, and then redeployed at the end of the cruise.

During this report period, the Panay, Dipolog and Surigao moorings were recovered and redeployed during the Joint US-Philippines cruise on the R/V Melville in November-December 2007. PI Sprintall and Marine Engineer Spencer Kawamoto participated in this cruise. The Panay and Dipolog ADCP instrumentation successfully returned 100% of data over the 6-month deployment time period. Unfortunately, the internal card recorder on the ADCP deployed in Surigao Strait malfunctioned and only ~3 days of usable data was returned. Subsequent efforts by the manufacturer RDI Teledyne to recover any other data were not successful. Moorings were redeployed at Panay, Dipolog and Surigao, and new moorings were deployed at Tablas and Mindoro Straits. Shortly after their deployment in December 2007, the acoustic releases on the redeployed Surigao mooring failed. Thankfully the whole mooring instrumentation was recovered by fishermen on Negros Island, and is presently being shipped to SIO where we will attempt to diagnose the reason for the malfunction.

The shallow pressure gauge array of 6 gauges, were deployed with the help of University of the Philippine colleagues Drs. Cesar Villanoy and Laura David. Sprintall and her marine Engineer (Paul Harvey) visited the Philippines in July 2007 to help with site selection and instruction on assemblage of the pressure gauges. Deployment sites and available data (absolute pressure, temperature and salinity) periods are:-

1. San Jose, Mindoro Island (deployed 11 December 2007);
2. Coron, Calamian Island group (15 September 2007 – 15 December 2007; redeploy 2 February 2008)
3. Pandan, Panay Island, collocated with HF radar (21 October 2007 – 24 April 2008; redeployed 24 April 2008);
4. Tobias Fornier, Panay Island, collocated with HF radar (12 August 2007 – 3 May 2008; redeploy 3 May 2008);
5. Dapitan, Apo Island, Bohol Sea (6 October 2007 – 1 July 2008; redeploy 1 July 2008);
6. Surigao, Mindanao Island, Pacific boundary (lost; redeploy 1 June 2008).

RESULTS

The mooring deployments provide the first time series that measure the flow and properties in these southern Philippine straits. During this report period, preliminary results were presented at the Western Pacific Geophysics Meeting in Cairns, Australia in July 2007.

A. Panay Strait: The 6-month mooring deployment at Panay Strait shows an exceptionally vigorous benthic layer (Figure 1). The flow in the lower 100 m is consistently directed toward the southeast, the along channel direction, and suggests a strong spill-over into the Sulu Sea. The zonal flow component (Figure 1a) is maximum (~ 0.7 ms^{-1}) at the sea floor, whereas the meridional component (Figure 1b) is maximum (~ 0.8 ms^{-1}) around 50 m above the sea floor. It is likely this difference is due to bathymetric effects from the deepening of the southern channel bank rather than bottom friction effects.

Beginning in mid-September 2007, regular monthly strong pulses of along-strait flow are evident in the lower 150 m that extend upwards in the water column to 200 m depth (Figure 1). There is a hint of fortnightly modulation of these pulses in the lower boundary layer. A temperature sensor located at the depth of the ADCP at ~ 560 m shows that these strong southward pulses are associated with cooler water. The pulses play a strong role in ventilating the depths of the Sulu Sea. Previous studies have suggested that they may be related to episodic typhoon events in the South China Sea, although preliminary studies suggest that this is not the case during the PhilEx deployment period. The time scale and their regularity suggest that the pulses may be related to interaction of the M2 and S2 tidal frequencies as observed in the Indonesian seas, although this mechanism remains to be more fully explored.

In the surface layer, the flow is primarily northwards, and intensifies in the upper 100 m during the later part of the deployment period as the south-eastward winds of the summer monsoon begin to strengthen. Weak flow is found in the thermocline at ~ 140 m depth. On tidal time scales, the diurnal lunar and fortnightly tides clearly dominate.

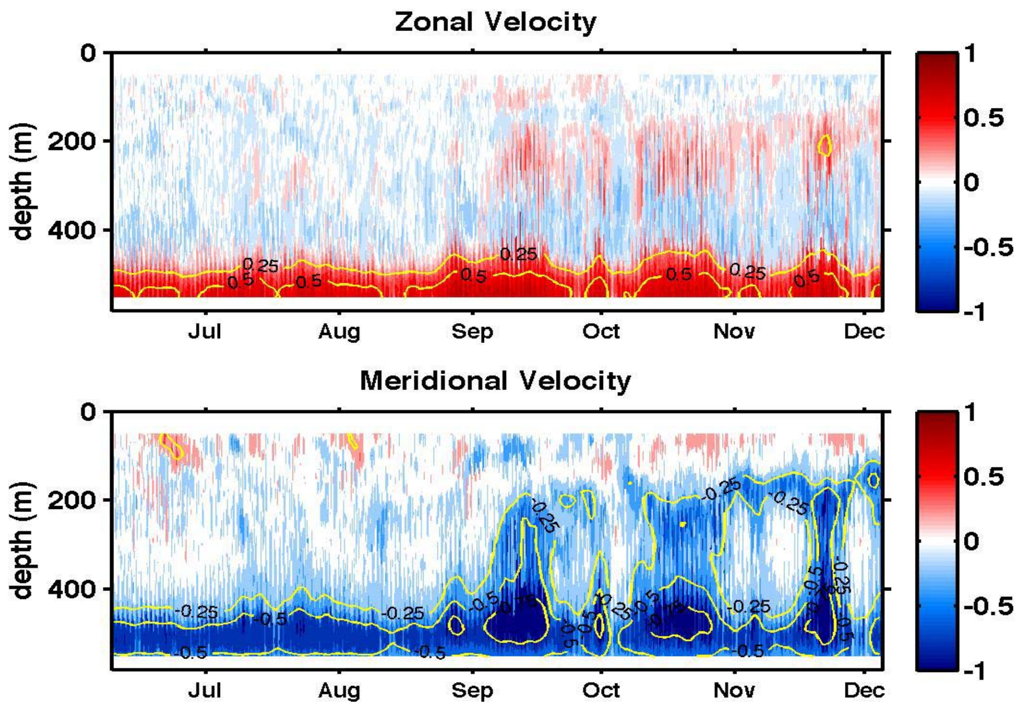

Figure 1: Zonal (top) and meridional (bottom) velocity from the mooring deployment in 2007 in Panay Strait, Philippines. Strongest flows are found in the bottom 150 m, with fortnightly pulses evident from September 2007 through the end of the time series.

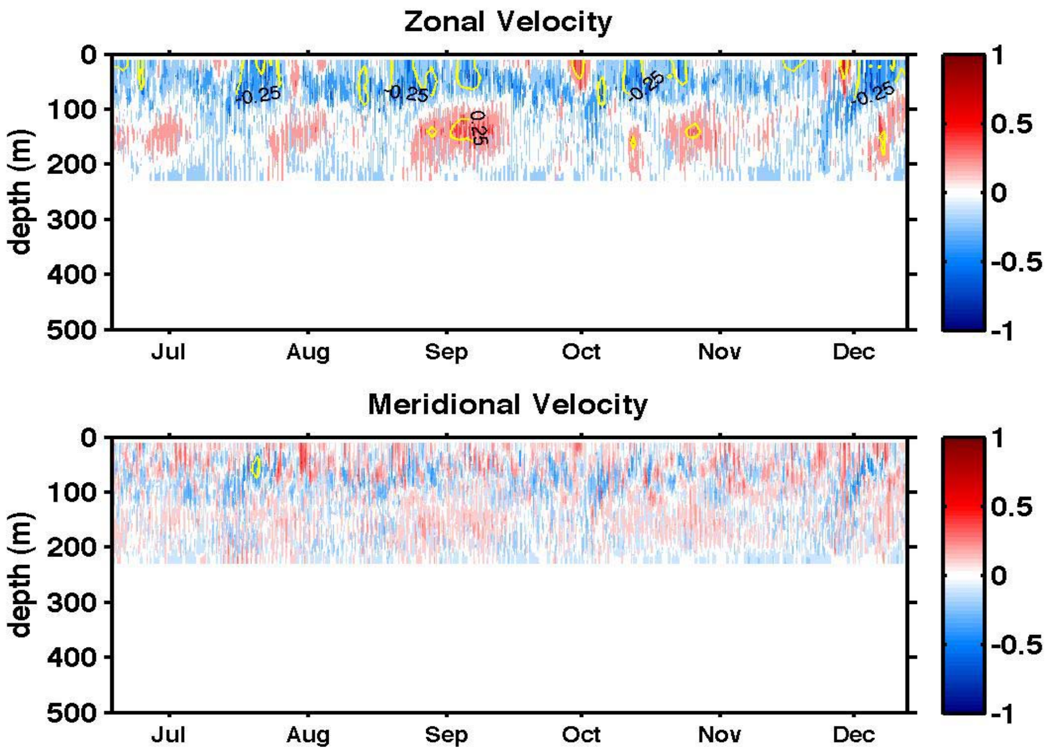

Figure 2: Zonal (top) and meridional (bottom) velocity from the mooring deployment in 2007 in Dipolog Strait, Philippines. Zonal flow reversals are prominent in the 0-100 m layer and the 100-250 m layer.

B. Dipolog Strait: In Dipolog Strait, the ADCP measurements only cover the upper 250 m depth during this first 6-month deployment period (Figure 2). The upper 100 m and lower 100-250 m layers clearly act out of phase. The upper layer is westward toward the Sulu Sea, while the lower layer is mostly eastward and punctuated by clear strong pulses every 30-40 days. Reversals in both layers are evident.

All moorings will be recovered during the IOP2 cruise proposed for March 2009.

C. Shallow Pressure Gauges: The high-resolution measurements (absolute pressure, temperature and salinity) of the shallow pressure gauge array are presently being processed in conjunction with Dr. Cesar Villanoy and his student Leilani Solera.

IMPACT/APPLICATIONS

The high-resolution time series data can be used to test the veracity of numerical models of the Philippine region, with obvious application to other archipelago straits characterized by small-scale processes. In particular, the site selection of the pressure gauge component of the ocean sensor array has been designed specifically to provide sea level data to help validate the barotropic tidal model Typically many of the available models resolve the narrow straits with only a few grid points, thus providing little spatial information about the internal dynamics and local complexities that occur on short time scales. The high-frequency time series observations will provide a test for evaluation and refinement of all models and their predictions that are not possible from shipborne observations alone. This will enable better representation and prediction of the structure and evolution of the small-scale features such as internal waves, sidewall eddies and separation of filaments, including their time-dependent variability in a region that has few previous subsurface oceanographic measurements.

The regular pulses evident in the Panay Strait velocity data have never been described before, and the models will be instrumental in helping to interpret the mechanisms that lead to this variability. Initial results from the HYCOM model (Metzger, personal communication) suggests that only models that include tidal forcing produce these strong regular bottom flows. This aspect will be explored more fully, using the complete 18-month velocity and property data record to be recovered from Panay Strait in March 2009, along with the 12-month record from the moorings in Tablas and Mindoro Strait.

RELATED PROJECTS

An expansion proposal (N00014-06-1-0690, Modification Number P00003) entitled “A pressure gauge array for observing sea level variability within the Philippines Seas” was funded in April 2007 in order to fulfill the need to expand the pressure gauge array within the Philippines Seas as directed by the DRI. Progress and results of the pressure gauge array deployment are reported above.

A DURIP proposal (N00014-06-1-0814) entitled “An ocean sensor array to detect small-scale variability” was awarded in March 2006 that funded the instrumentation and hardware for the project.