San Bernardino Strait Hydrodynamic Modeling for yield assessment and optimization

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Abstract- SABELLA and H&B plan to develop Southeast Asian first ocean power plant which will power up off-grid areas in Capul island in San Bernardino Strait in Philippines. This work presents the hydrodynamic modeling in San Bernardino strait, an effort aiming to support the choice of the best site for the tidal stream power turbines. The hydrodynamic model is based on a high resolution bathymetry for the specific areas of interest as well as three ADCP measurements, both high valuable datasets for model set-up and calibration.

Keywords-Yield assessment, Hydrodynamic Model, Tidal energy, ROMS, Phillipines.

I. INTRODUCTION

San Bernardino Strait is a narrow passage on the northeastern side of the Philippine Archipelago that presents very strong currents. It is composed of four channels between islands - Samar, San Antonio, Capul, Calitaan and Luzon - by which tidal flow and a strong archipelago throughflow interacts with complex bathymetry to produce a very energetic flow regime [1,2]. Tides are by far the most energetic process in the region generating oscillating currents with very high intensity while the Indonesian Throughflow (ITF) is responsible for the large scale flow with an unidirectional, southward transport - from Pacific to the Philippines Archipelago [3,4,5].
Modeling the circulation within the Philippine archipelago is very difficult for large scale models due to the narrow straits, unknown sills depths, and inadequate horizontal resolution. For example, two analyzed models with 1/12° and 1/25° presents very different mean transport over the San Bernardino straits (-0.13 and -0.33 respectively) and the authors discuss the role played by the increased numerical accuracy at higher resolution, reduced horizontal friction, better resolved sill depths among other [4,5].
Measures at San Bernardino Strait during neap tides captured 2-3 m/s tidal currents in the sill between Capul and Luzon [1] and currents of nearly 4.5 m/s have been reported [6] near the southern tip of Capul Island.

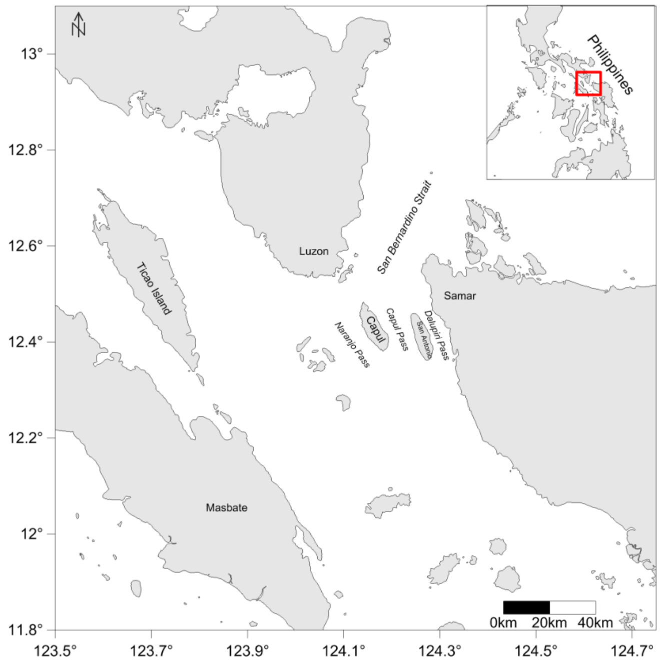

Figure 1: Study area.

II. MODELING STRATEGY

In order to account for the detected forcings and to simulate the currents at such small scale channels reaching the required resolution for yield assessment (25 m), a one-way, offline nesting approach was required. The hydrodynamic modeling is based on the Regional Ocean Modeling System (ROMS), a free-surface, hydrostatic, primitive-equation, terrain-following numerical ocean model widely used by the scientific community. The system encompasses a suite of embedded ocean models with four nested levels, one 400 m grid (N1), one 100 m grid (N2), three 50 m grids (N3) and three 25 m grids (N4). The N1 grid is used to introduce information from large scale circulation (mainly the ITF) to the regional model domain with refined coastline, bathymetry, and tidal forcing. N2 grid has sufficient horizontal resolution for solving the three larger channels circulation feature and N3 and N4 grids refine the flow at specific desired sites. Large scale dynamics are derived from Mercator 1/12° global ocean model, tides are from TPXO8

1/30° global tidal model and winds are from NCEP R2. Model was integrated over one year (2015).

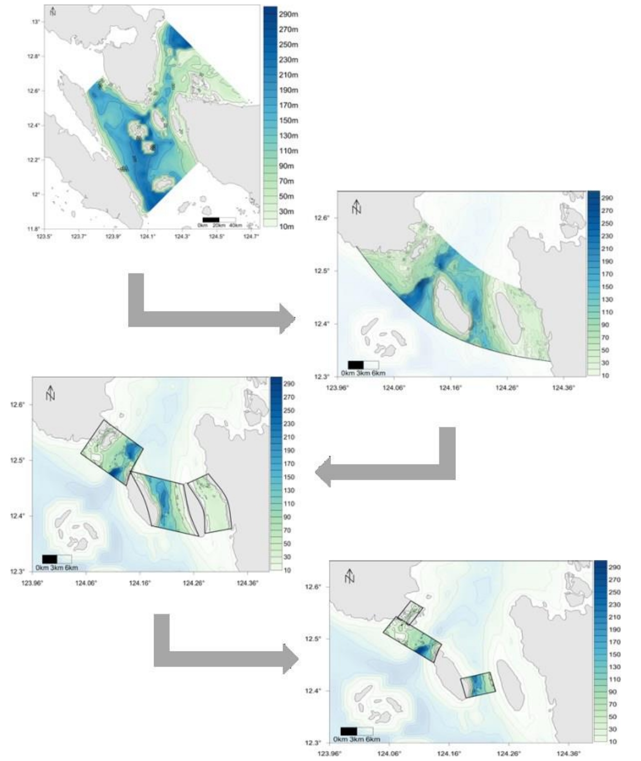

Figure 2: The high resolution models were obtained through grid nesting technique, in with lower resolution grids (parent grids) supply boundary conditions to the higher resolution ones (child grids).

The studied area presents a complex bathymetry, with islands inlets, steep variations of the sea bottom and deep passages between islands. In order to best represent the bathymetry-driven currents at a very fine scale, a bathymetry compiled from a hydrographic survey at very high resolution has been provided by Sabella Energy Inc., for the specific areas of interest (passages between islands). As the provided bathymetric survey naturally does not cover the whole domain, alternative bathymetry data was used. After a careful analysis, the best options were the SRTM30, and a nautical chart for the region (National Mapping & Resource Information Authority, Joins Chart 4220) with scale of 1:100,000. Ordered by higher resolution, the bathymetric information was interpolated in the model grid and then smoothed to maintain hydrostatic consistency at ROMS. The set of bathymetric points used in the process can be seen in Figure 3.

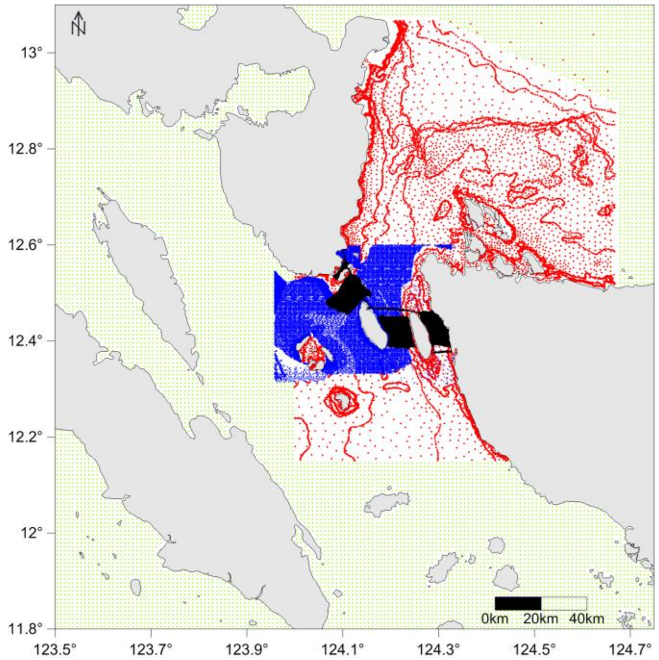

Figure 3: The set of bathymetric information used on the Digital Elevation Model. Green dots are from SRTM30, red dots are from nautical chart (NAMRIA 4220 – 1:100000), blue and black dots are from bathymetric surveys provided by Sabella Energy Inc..

The execution of the eight model grid runs were accomplished using the Amazon´s Extended Cloud Computing (EC2). Cloud computing offers the advantage of easily extending the computational effort required, without the need for prior mobilization.

All grids were initialized from rest condition with constant zero values for momentum fluxes and for surface elevation. Time of initialization was December 15th, 2014, as the period of interest is 2015. The fifteen initial days of simulation were enough for model kinetic energy to be stabilized, as the region is widely tide dominated.

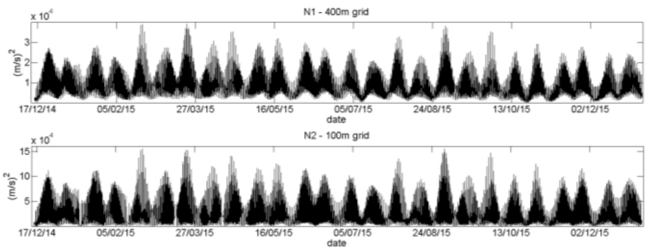

Figure 4: Kinetic energy evolution for N1 and N2 grids

III. RESULTS

The monthly residual surface currents were obtained in order to evaluate the representation of the ITF. The averaged current field filters the tidal currents and only the residual flow can be observed. As expected, all months presented very similar residual fields, only with magnitude differences. Boreal winter months presents stronger residual flow than summer months a pattern that can be related to the monsoon wind reversing cycle [5].

Analyzing instantaneous current fields at spring tide and neap tide during ebb and flood moments, current velocity during flood are higher than during ebb due to the ITF extra flow rate. During flood, a current of 5 m/s is observed at a very shallow specific point but current velocities higher than 3.5 m/s are well spread over the domain.

Velocities greater than 1 m/s and up to 3.5 m/s can be observed during flood in the Capul pass. Dalupiri and Calitaan pass presents slightly lower velocities reaching 2.5 m/s during spring, flood tides. At ebb tides, Capul pass and the channel between Capul and Luzon presents similar velocity ranges with currents reaching 4 m/s at specific points but mostly presenting currents in the range from 1 to 3.5 m/s.

A specific analysis was conducted to map areas with occurrence of currents above specific values. It can be observed that there is just a few regions in which currents doesn´t exceeds 1m/s and that the centers of the three biggest channels presents currents above 1m/s for more than at least 50% of the time. Specific sites presented approximately 40% of currents above 3 m/s time percentage occurrence.

IV. MODEL ASSESSMENT

ADCPs were located at the east coast of Calitaan Island (ADCP_1), Capul Island (ADCP_2) and San Antonio Island (ADCP_3) (Figure 5).

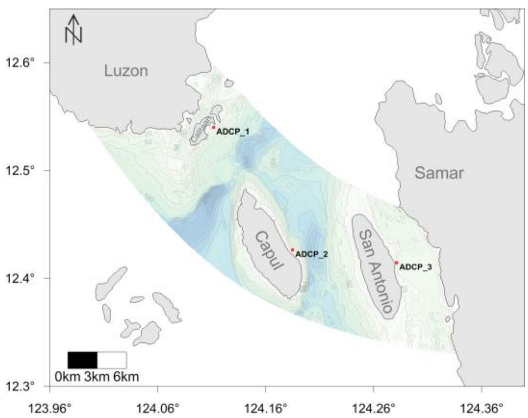

Figure 5: ADCPs positions (red dots) over digital elevation model for N2 grid (100m resolution

ADCPs data spans approximately one month each, from march to july (Table 1).

Table 1: ADCPs depth and period of data acquisition.

ADCP	Depth	Start Date	End date
ADCP_1	18m	02-mar-2015	10-apr-2015
ADCP_2	30m	25-may-2015	08-jul-2015
ADCP_3	25m	12-apr-2015	24-may-2015

As observed in Figure 5, the ADCPs are placed near the coast at low depths and far from the center of the channels, where the most energetic currents are. Low velocities sites are naturally difficult to precisely simulate in models due to greater turbulence and directional spread but for the three ADCPs sites the main directions of the flow as well as its intensities classes were captured by the model (Figure 6).

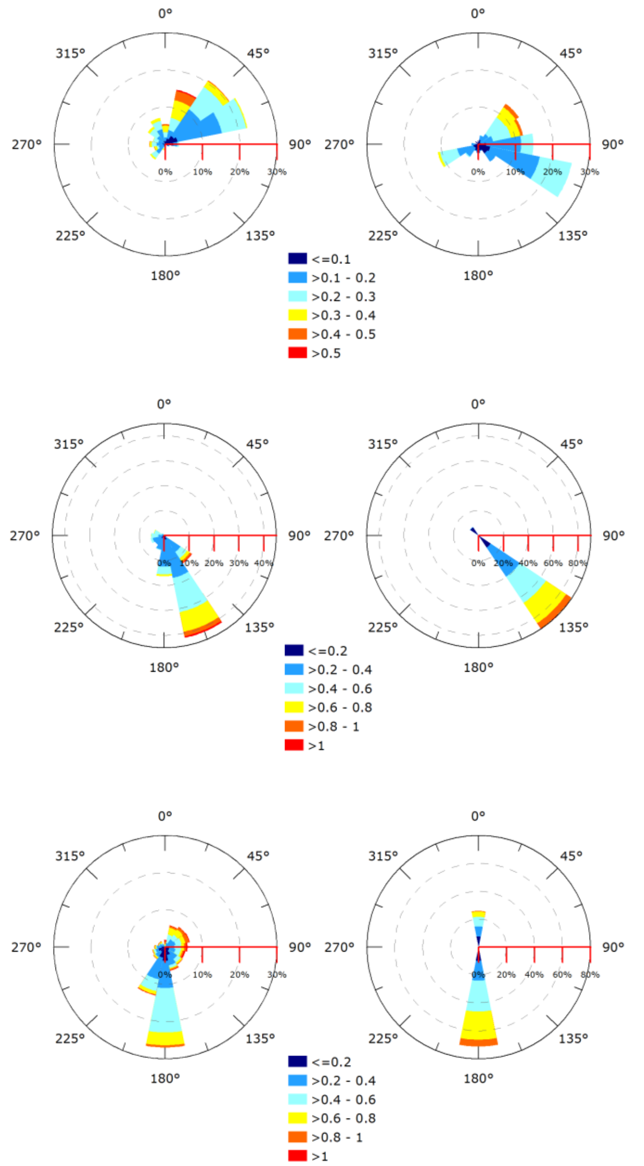

Figure 6: Current roses from ADCP (left) and ROMS (right) for ADCP 1 (top), ADCP 2 (middle) and ADCP 3 (bottom).

Standard deviations, 25, 50, 75 and 90 percentiles are presented for ADCPs and ROMS pairwise grid point (Table 2 to Table 4) and current velocity average error are presented at Table5.

Table 1: Basic statistics and percentils for ADCP 1 and ROMS pairwise grid point.

Source	STD	Prctl 25	Prctl 50	Prctl 75	Prctl 90
ADCP_1	0,10	0,13	0,19	0,26	0,34
ROMS	0,11	0,19	0,28	0,36	0,42

Table 2: Basic statistics and percentils for ADCP 2 and ROMS pairwise grid point.

Source	STD	Prctl 25	Prctl 50	Prctl 75	Prctl 90
ADCP_2	0,19	0,27	0,36	0,50	0,65
ROMS	0,26	0,21	0,38	0,60	0,79

Table 3: Basic statistics and percentils for ADCP 3 and ROMS pairwise grid point.

Source	STD	Prctl 25	Prctl 50	Prctl 75	Prctl 90
ADCP_3	0,23	0,24	0,39	0,57	0,76
ROMS	0,25	0,23	0,45	0,63	0,76

Table 5: Average current velocity error between model results and ADCP measurements.

Source	ADCP 1	ADCP 2	ADCP 3
Mean Error (m/s)	0.08	0.02	0.02

V. CONCLUSION

Results presented a southward residual flow at most part of the domain, in agreement with literature description of the Archipelago throughflow and with ADCPs data. Flood tides presents higher velocities due to the sum of forcings (IT plus tidal current). Most energetic places over time could be located using time percentage of currents above 1 to 4m/s thresholds. Model results current magnitude is well compared with literature description, where 4.5m/s currents are not unusual [1,6].

Although ADCPs are placed in very challenging places in terms of model comparison (shadow zones, shallow bathymetry), results presented well behaved comparisons with data. Model was able to simulate the shadow zones with very similar current intensity ranges. Current rose comparison showed good representation of direction and magnitude percentages. All the percentiles are modelled with good accuracy and difference between model and data are on the second decimal place on most part.

Taking into account the high resolution of the provided bathymetry, the overall good representation of literature related oceanographic processes and the ability of the model to reproduce current magnitude range and overall characteristics of three ADCPs, the model can be considered suitable for the desired purpose. The provided results are a valuable tool to assess the tidal current energy power over the region. New ADCPs campaigns are desirable in order to assess more energetic sites indicated by model high resolution results

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