High Spatial Grid Resolution of Hydrodynamic Numerical Modeling for Sea Current Energy Site Selection in Indonesia

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***Abstract*—The need for renewable energy in Indonesia has increased constantly as a part of Indonesia's agenda to meet energy demand while reducing the over-dependency on fossil fuel. Tidal sea current energy is one of the technologies which offers a huge and predictable energy resource. This paper presents the assessment utilized 2-dimensional numerical models of sea tidal current velocities in the vicinity of Galang Island, Riau Archipelago Province, Indonesia. Simulations were carried out by applying an open source model, Delft3D modeling system. To assess hydrodynamic flow models results in accordance to the standards of sea current energy device development, this result demonstrates information at a high spatial grid resolution of 44 m to 52 m and a sequential resolution for the suitability assessment within the area of interest. It performs that the potential areas of sea current energy generation possibilities in the vicinity of Galang Island have a current speed greater 2.5 m/s.**

***Index Terms*—Indonesia; Numerical Modeling; Renewable Sea Current Energy; Site Selection.**

I. INTRODUCTION

In 2015, Renewable energy's contribution in Indonesia was expected to be at 17% of the total national primary energy [1]. The need for renewable energy in Indonesia has constantly increased in order to meet energy demand while reducing the over-dependency on fossil fuel. In fact, Indonesia is still using oil as an energy source and the problems are even worsened by the recent rise of oil price which forces almost all provinces in Indonesia to familiar with electricity blackout [2]. On the other hand, practical experiences in the commercial application of marine renewable energy, including tidal energy have proved that in the long term, these technologies can compete with conventional power plants [3].

As the largest archipelagic country, Indonesia has a huge potential for development of sea current energy sites to its narrow channels and straits between the islands. Tidal sea current energy is one of technology which offers a huge and expected energy resource and a sustainable alternative to conventional source and a predictable alternative to other renewable energy technologies as well as always available [4-5]. It is a need to carry out an appraisal of marine energy potential for site selection of available sites and suitable capacities for marine energy exploitation and utilization as well as in determining the most appropriate type of energy converters. Whilst, the determination of the geographical distribution of sea current flow velocities and the characteristic parameters of sea current flow are important to the success of sea current energy devices [4-5].

Gross energy content of sea currents within a certain zone can be determined by modeling the sea current flow. But, the lack of measurements data in remote areas has been a major problem since many years ago. This resources can be determined by an application of the numeric mathematical model of the marine current flow which illustrates the physical process of domain area. Thus, in order to identify suitable locations of marine current energy devices within the area of interest, 2-dimensional hydrodynamic numerical models with a high resolution of sea tidal current velocities in the vicinity of Galang Island, Riau Archipelago Province is presented.

II. METHODOLOGY

A. *Study Area of Galang Island (0º45'N 104º15.1E)*

As a part of the Riau Archipelago, Galang Island has become the 32nd Indonesian Province in accordance with the Act No. 25 in force since 2002. The island covers an area of about 80 km^2. It is located in the southern part of the Malacca Strait, in the southern part of the South China Sea, and about 40 km southeast of Kota Batam. The island is currently under the administration of Kecamatan Galang Kota Batam, Batam City, Riau Archipelago Province. The sub-district Galang comprises 120 islands covering the total area of 14,610 km^2. Only 36 islands are populated. About 14,600 inhabitants live in Galang Island [6].

B. *Model Solver*

Flow models were developed to simulate water levels and current velocities. Simulations were carried out with the two-dimensional depth-integrated model developed by Delft Hydraulics in the Netherlands [7] with respect to 5 years data simulation (2005-2009), then we determine the significant period of two weeks simulation. Delft3D-Flow forms the center of the model for the simulation of water motion due to tidal and meteorological forcing by solving the unsteady shallow water equation for the primitive variables of velocity and water level. Staggered finite difference grids with a terrain-following sigma-coordinate system in the vertical as well as fixed vertical coordinate are used. The model solver has the capability to simulate flow conditions based either on a rectilinear or a curvilinear grid system in the horizontal plane. In this study, sub-domain decomposition was used to avoid the inherent problems associated with the local refinement of structured grids and to reduce computing time. The model solver is based on the Alternating Direction Implicit method [8-9].

C. Domain Decomposition

Domain decomposition was used in the development of the regional models. The approach implemented in Delft3D-Flow is based on a subdivision of the domain decomposition into non-overlapping domains, with the possibility for grid refinement in both the horizontal and vertical direction [7]. The advantages of a multi-domain modeling approach for flow and transport problems are an efficient iterative method which has been used for solving the discretized equations over the domains, modeling flexibility and accuracy. Figure 1 shows the nesting sequence developed for Galang Island. The open boundaries are divided into 7 segments (A, B, C, D, E, F, and G) which are imposed by astronomical constituents to execute the model. They are located on the northwest, north, east, as well as southeast. In Figure 1a, the larger scale model with grid size ranging from 477 m to 1923 m and 236000 grid cells (451 cells x 525 cells) is shown. Figure 1b shows the intermediate grid model with grid size from 183 m to 345 m and 207000 grid cells (451 cells x 461 cells). Finally, in Figure 1c the local model of Galang Island with grid size varying from 44 m to 52 m, with 555450 grid cells (806 cells x 691 cells) is shown. In this figure, six observation points (G1, G2, G3, G4, G5, and G6) are shown. Attention was given to the conditions at the observation points G1 and G2 respectively located on the west and east side of the island. The condition of the bathymetry with respect to Indonesian nautical chart no. 42 can be seen in Figure 2. Generally, the sea water in the vicinity of Galang is categorized as a shallow area and surrounded by coral reef. The depth of seawater in the vicinity Galang Island is mostly less than 15 m, only the eastern area and a small area in the southwest have a depth of about 25 m (see Figure 3).

D. Physical and Numerical Parameters

As can be seen from Table 2, it presents the physical and numerical parameters selected as base input parameters for the Galang Island flows model. Gravity acceleration is set to 9.81 m/s^2, water density 1023 kg/m^3. Manning roughness represents the resistance of the seafloor to the flow of water in it is set to 0.02 $m^{1/2}/s$. A measure of the resistance of seawater fluid which is being deformed by shear stress or tensile stress as well as described as eddy viscosity is computed with 1 m^2/s. Wind-based on NCEP wind data, a measure of the change of the water level as a function of time with characteristic amplitude known as threshold depth is set to 0.1 m. The threshold depth above which a grid cell is considered to be wet [7]. Marginal depth of the water level at the velocity points as default the mean value as -999.99 is used. A velocity point is set to dry when the actual water depth is below of the threshold depth. When the local water depth is above twice the threshold, the velocity point is set again. This is done to prevent drying and flooding in two consecutive time steps. The marginal depth is a default depth value for the model to recognize whether the grid point is active or not. The smoothing time is set to 60 minutes as the time during the assignation of the model's initial water level to imposed boundary water level is enhanced. A velocity point is set to dry when the actual water depth is below that of the threshold depth.

Table 1
Astronomical constituent input for Galang Island Model

A1
Beginning with the first segment

Constituent	Amplitude	Phase
M2	1.470	61.494
S2	0.700	147.794
N2	0.343	114.968
K2	0.287	146.152
K1	0.066	61.868
O1	0.147	82.026
P1	0.026	348.808
Q1	0.007	0.451
MF	0.012	27.551
MM	0.007	16.558
M4	0.069	106.255
MS4	0.040	170.746
MN4	0.032	166.192

A2
End of the first segment

Constituent	Amplitude	Phase
M2	1.283	45.050
S2	0.610	127.271
N2	0.306	95.929
K2	0.249	124.973
K1	0.056	47.019
O1	0.140	73.585
P1	0.026	331.505
Q1	0.006	349.381
MF	0.013	26.309
MM	0.007	15.265
M4	0.039	96.710
MS4	0.024	221.156
MN4	0.023	155.387

Table 2
Physical and numerical parameters of Galang Island Model

Parameter	Setting
Gravity acceleration	9.81 m/s^2
Water density	1023 kg/m^3
Manning roughness	0.02 $m^{1/2}/s$
Horizontal Eddy Viscosity	1 m^2/s
Wind	NCEP wind data
Threshold depth	0.1 m
Marginal depth	-999.99
Smoothing time	60
Interval Data Stored	15 minutes
Simulation Periods	Oct 1st – Oct15th, 2007
Time Step	1 Minute

The required data for the application of the hydrodynamic model is obtained from several sources. Bathymetric data along nearshore areas in Indonesia is usually obtained from nautical charts issued by the Badan Koordinasi Survey dan Pemetaan Nasional (National Coordinating Agency for Survey and Mapping) [10-11]. GEBCO (General Bathymetric Chart of the Oceans) data, issued by the British Oceanographic Data Centre, U.K. [12] which is usually adopted to provide information in deeper areas. The data is provided on a horizontal grid with a resolution of 30 arc-second intervals or about 0.5 nautical miles. For tidal variations and wind characteristics for diving, the numerical models are extracted from *Total Modal Driver* [13]. The data is obtained from the NCEP/NCAR reanalysis database [14] (See Table 3).

E. Sensitivity Analysis

Sensitivity analysis aims to know the global behavior of the numerical model as well as its response to changes in the numerical and physical parameters. The sensitivity analysis of Galang Island Model with respect to manning roughness along with different domain model and time steps were done.

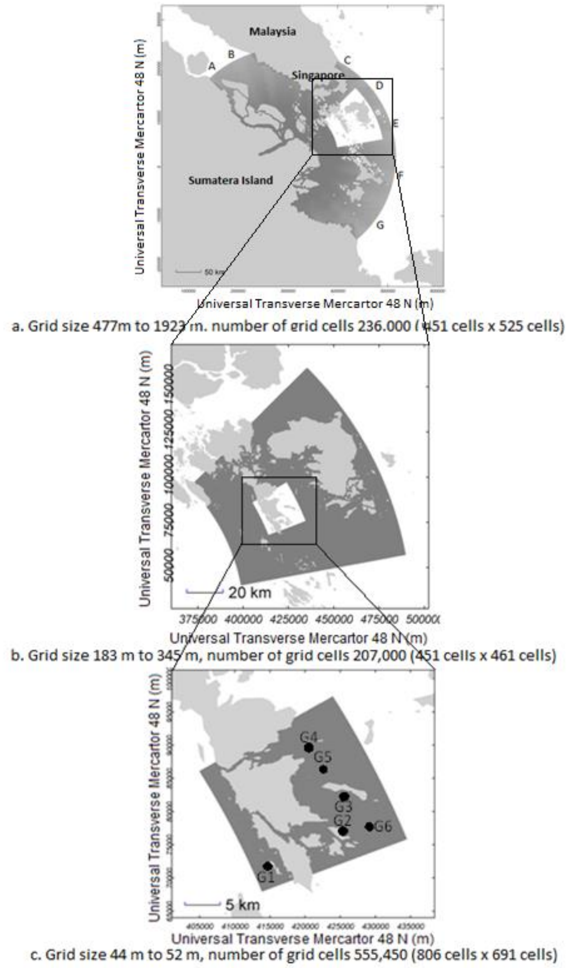

Figure 1: Galang Island Nesting Sequence: Large Scale, Intermediate, and Regional Models

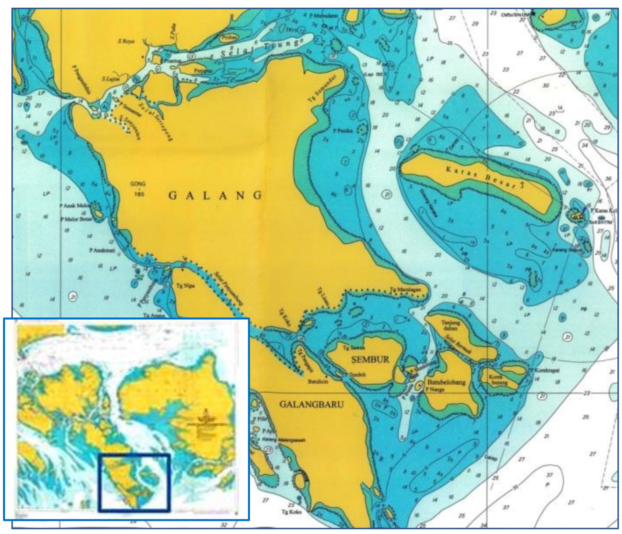

Figure 2: Bathymetry depth with respect to Indonesian nautical chart no. 42

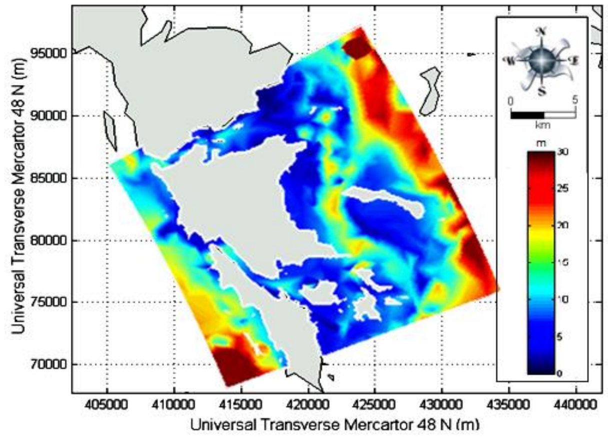

Figure 3: Galang Island-Local Model bathymetry

Table 3
List of data supplies in Study Area

No	Description Physical Process	Galang Island
1	Minimum water depth	Indonesian Nautical chart number: 42
2	Maximum mooring depth	IOC/IHO/BODC. (2003).[a]
3	Flushing	Derived from Physical Models
4	Exposure to currents	Egbert and Erofeeva. (2002)[c]
5	Exposure to waves	Derived from Physical Models
6	Exposure to the wind	NOAA/OAR/ESRLPSD. (2009). NCEP/NCAR Reanalysis 2 data [b].
7	Tides	Derived from Physical Models

Remarks:

[a] IOC/IHO/BODC. (2003). IOC/IHO/BODC. (2003). General Bathymetric Chart of the Oceans British Oceanographic Data Centre, Liverpool, U.K. http://www.gebco.net/data_and_products/gebco_digital_atlas/ Global bathymetric grid at 30 arc-second intervals.

[b] NOAA/OAR/ESRLPSD. (2009). NCEP/NCAR Reanalysis 2 data. http://www.cdc.noaa.gov/Global six hourly reanalysis data with the resolution 1.87 degrees (192 x 94 grids) for wind and sea level pressure

[c] Egbert, G., D., S.Y., Erofeeva. (2002): Efficient inverse modeling of Barotropic Ocean tides, J. Atmos. Oceanic Technol.19 (2):183-204. http://www.esr.org/polar_tide_models/Model_TPXO62.html#EgbertErofeeva_2002. Tide extracted from Total Model Driver

III. Results

The flow simulation results of a model simulation of the Galang Island model can be seen from Figure 4 to Figure 6. These results are obtained from the regional model and local model. As the results of the flow and wave simulation, they show the general water level time series, currents, and significant wave height for 2 weeks (2005 – 2009). In a period of 2 weeks we will cover a neap and spring tide, supposed that we start appropriately with the period of time, then water levels, currents, and waves are presented.

A. Effect of bottom roughness

In this study, the effect of bottom roughness shall illustrate the resistance of the flow model to the bottom seafloor. In order to conduct the sensitivity of the bottom roughness which affecting the model result, we execute by applying various coefficient throughout the model domain. Constant result with regards to difference bottom roughness by comparing the current speed at observation point G1 and G3 for the local model are presented. These figures showed the obvious dependency of the calculated water level and current velocities to bottom roughness. Therefore, it is important to include bottom roughness in the simulation. Information of bottom roughness can be derived from bottom sediment type maps. Thus, for further simulations, we will use the bottom roughness coefficient of 0.02 because the small difference is found.

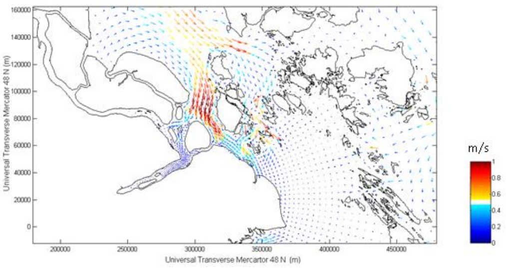

Figure 4: Current magnitude during spring-ebb flow for the regional model at Galang Island

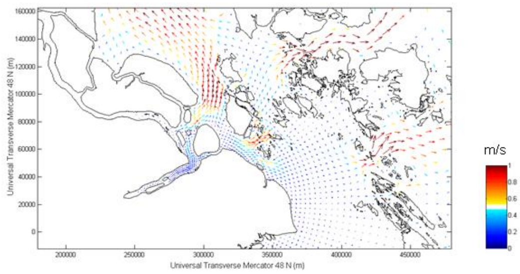

Figure 5: Current magnitude during spring-tide flood flow for the regional model at Galang Island

Regarding regional model results which have grid resolution from 477 m to 1923 m, we can see that the sea current characteristics in the vicinity of Galang Island during ebb encompass direction from south to north with the current speed magnitude of about 0.2 - 0.5 m/s (see Figure 4). In contrast, as can be seen in Figure 5, the current directions have shown an opposite direction during spring flood flow.

On the other hand, to assess the outcomes of hydrodynamic flow model due to the criteria of sea current energy device development, it is needed to carry out the model simulation due to the high-resolution grid. Thus, the result demonstrates information at a high spatial grid resolution of 44 m to 52 m and temporal resolution for the suitability assessment within the area of interest. The condition of water depth in the vicinity of Galang Island is categorized as shallow water area because the maximum depth of about 30 m, whilst, the characteristic of sea current speed is founded suitable for sea current energy generation possibilities development. Figure 6 demonstrates the estimated peak spring tide of current speed from the 2D numerical model in the vicinity of Galang Island which present potential area of sea current greater than 2.5 m/s; and it is indicated by the color of green, yellow and red.

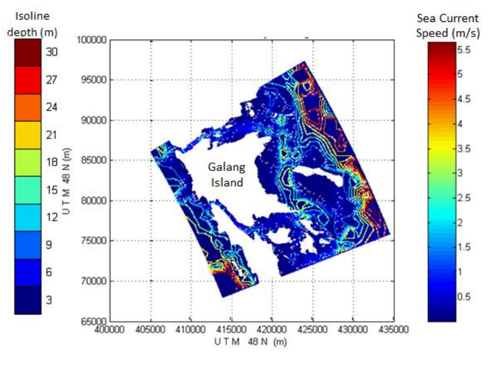

Figure 6: Predicted Maximum Sea Current Velocities in the vicinity of Galang Island using Delft3D Software and Grid Spacing of 44 m to 52 m

IV. Discussion

Indonesia has great potential for sea/marine current energy development and plays an important task in the future of energy supply because this resource characteristic is predictable. The main topic with respect to the exploitation of renewable energy was availability as well as these technologies offered an indigenous non-polluting energy source. The improvement of a grid with resolution could increase the accuracy of the numerical model along with the development of a more detailed spatial map of Ireland will enable each site to be assessed accurately [15].

Currently, the source maps available are characterized by low resolution and variability [16]. Thus, making it hard to develop a cost-effective technology. The MARS2D model is used to estimate France tidal current energy resource using 250 m embedded grid for the smallest resolution [17]. Also, SWAN and WAVEWATCH III models have been used to hindcast a 31-year wave data in Australia with a 500 m spatial grid resolution [18]. Since the resolutions are mostly low, it is hard to determine specifically the potential harnessable amount of energy in the sea.

Most of the result of source maps being discussed show an inaccuracy upon determining high wave and insensitivity to high wind speeds from 60 km offshore to the shoreline. The inaccuracy is mostly affected by the low spatial resolution of the global atmospheric model and errors associated with the sea-land boundary and the insensitivity to high wind speeds is due to underestimation from CFSR reanalysis of the wind force. Then, simply increasing the resolution of our hydrodynamic modeling will not affect much of the data gained [19]. Both increasing also the spatial resolution of the global atmospheric model and improving the frequency of wind variability by increasing wind data frequency are also needed.

This paper shows that the difference results of current speed characteristic are founded between regional models (low resolution of 477 m to 1923 m) and local models (high resolution of 40 m to 52 m). The utilization of hydrodynamic numerical model analysis of the local model is used to determine the suitable site for the development of marine current energy devices. This method seems similar with Rompas and Gouin [20] which carried out a numerical model for a study of marine currents in the Bangka Strait, North Sulawesi, Indonesia using horizontal meshes of 60 side meters; as well as marine currents around Ireland have been modeled using 2 dimensions' flow model within grid spacing 45 m and 135 m [4].

There were about 13.95 GW of tidal current energy technically available in 130 channels in China [21-22]. Generally, currents in water channel with a maximum flow velocity of more than 2 m/s are high significance in practical application [5]. At this manuscript, we can see that there are a lot of sites in the vicinity of Galang Island potential for future development of marine current energy devices. It is indicated by the color of the blue, red and green color of the sea current map which shows sea current at this location are higher than 2 m/s (see Figure 6). Whilst, another author revealed that numerous sites were not economically viable due mainly to current velocity being less than 2 m/s [4]. On the other hand, Wang [22] showed that a prototype a 5 kW could start at a current speed of 0.8 m/s and the output about 3 kW at current velocity of 1.5 m/s, with a power coefficient of 28% to 30%.

V. CONCLUSION

This paper presents the assessment utilized 2-dimensional numerical models of sea tidal current velocities in the vicinity of Galang Island, Riau Archipelago Province, Indonesia. Simulations were carried out by applying an open source model, Delft3D modeling system. To assess hydrodynamic flow models results in accordance with the standards of sea current energy device development. This result demonstrates information at a high spatial grid resolution of 44 m to 52 m and a sequential resolution for the suitability assessment within the area of interest. It performs that the potential areas of sea current energy generation possibilities in the vicinity of Galang Island have a current speed greater 2.5 m/s. Thus, in the future, this area in the vicinity of Galang Island has great potential for sea/marine current energy development in Indonesia.

ACKNOWLEDGEMENT

The Author gratefully acknowledges the support and generosity of The Centre for International Migration and Development (**CIM**), and the Deutsche Gesellschaft für Internationale Zusammenarbeit (**GIZ**). This study was supported by the Directorate General of Higher Education, Ministry of Education and Culture of Indonesia (DGHE), the German Academic Exchange Service or Deutsche Akademische Austauschdienst (DAAD), the Research and Technology Center Büsum / Forschungs-und Technologie Zentrum Westküste (FTZ)–Büsum and the International Center, Career Center of Christian-Albrechts-University in Kiel.

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