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

Engineering Department Petra Christian University, Surabaya, Indonesia Email: shermawan **@petra.ac.id Abstract** 18

The need of renewable energy in Indonesia has increased constantly

in order to generate electricity, **reduce** the **over** depended **on fossil fuel** and **meet energy demand.** 2

Tidal sea current energy is one of technology which offers a huge and expected energy resource. But, the lack of measurements data in remote areas has identified as a major problem since many years. This resource can be determined by an application of the numeric mathematical model of the marine current flow which illustrates the physical process of domain area. At this paper, the assessment utilized

2-dimensional numerical models **of** sea **tidal current velocities** 5

in the vicinity of Galang Island, Riau Archipelago Province, Indonesia

and from this numerical model, the theoretical tidal current resource was identified. 2

Simulations were carried out by applying the open source of Delft3D modelling system which was fully integrated with modelling framework for the simulation, among others of flow and waves. In this paper, the domain decomposition technique was used as a technique which divided the model into several smaller model domains and confirmed modeling flexibility, accuracy as well as efficiency. To assess the results of hydrodynamic flow models due to the criteria of sea current energy device development, this result demonstrates information at a high spatial grid resolution of 44 m to 52 m and 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. Keywords: Indonesia, numerical modeling, renewable sea current energy, site selection, Galang Island. 1.0 INTRODUCTION The

contribution of renewable energy in Indonesia **is expected to be at 17% of the total** national **primary energy in** 8

2015 (Indonesia's Centre

for Data and Information on Energy and Mineral Resources, 2006). The need **of** renewable **energy** in **Indonesia** 7

has increased constantly

in order to generate electricity, **reduce** the **over** depended **on fossil fuel** and **meet energy demand.** 2

In fact, Indonesia is still using oil as an energy source and the problems are even worsened by the recent raise of oil price which forces almost all provinces in Indonesia to familiar with electricity blackout (Indonesia's Centre

for Data and Information on Energy and Mineral Resources, 7

2008). On the other hand, practical experiences in the commercial application of marine renewable energy, including tidal energy have proven that in the long term, these technologies can compete with conventional power plants (Zhang et al. 2014). As the largest archipelagic country, Indonesia has a huge potential for development of sea current energy sites with respect 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** 12

as well as always available (Rourke et al. 2010, Wang et al. 2011). 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 successful of 3

sea current energy devices (Wang et al. 2011, Rourke et al. 2010).

Gross energy content of sea currents within a certain zone can be determined by modelling the sea current flow. 3

But, the lack of measurements data in remote areas has identified as a major problem since many years. This resource 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 the suite location of marine current energy devices within the area of interest, in this manuscript is able to determine of 2-dimensional hydrodynamic numerical models with a high resolution of sea tidal current velocities in the vicinity of Galang Island, Riau Archipelago Province. 2.0 METHODOLOGY 2.1 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 km2. It is located in the southern part of the Malacca Strait,

in the southern part of the South China Sea, 36

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 km2. Only 36 islands are populated. About 14,600 inhabitants live in Galang Island (Act no. 25, 2002). 2.2 Model Solver Flow

models were developed to simulate water levels and 28

current velocities.

Simulations were carried out with the two-dimensional depth-integrated 13

model

developed by Delft Hydraulics in Netherlands 13

(WL|DELFT HYDRAULICS, 2009) 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** 33

for the simulation of

water motion due to tidal and meteorological forcing by solving the unsteady shallow water equation for **the** 11

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** 1

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

(Lesser et al. 2004; Roelvink and Banning, 1994). 32

2.3 Domain Decomposition Domain decomposition was used in the development of the regional models. The

approach implemented in open source **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** 1

(WL|DELFT HYDRAULICS, 2009). The

advantages of a multi-domain modeling **approach for flow and transport problems** 1

are

an efficient iterative method which **has been used for solving the discretised equations over the domains,** 1

modeling flexibility and accuracy. The information of astronomical input of segment A for Galang Island model can be seen in Table 1. 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** 17

astronomical constituents to execute the model. They are located on the northwest, north, east, as well as southeast. In Fig. 1a, the larger scale model with grid size ranging from 194 m to 1941 m and 136,240 grid cells (261 cells x 525 cells) is shown. Figure 1b shows the intermediate grid model with grid size from 185 m to 347 m and 122,475 grid cells (356 cells x 346 cells). Finally, in Figure 1c the local model of Galang Island with grid size varying from 44 m to 52 m, with 207,000 grid cells (451 cells x 461 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** 27

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). Table 1: Astronomical constituent input for Galang Island Model A1 A2 Beginning with the first segment End of 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 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 2.4. Physical and Numerical Parameters Table 2 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/s2, water **density** 35

1023 kg/m3. Manning roughness represents the resistance of the seafloor to the flow of water in it is set to 0.02 m1/2/s. A measure of the resistance of sea water fluid which is being deformed by shear stress or tensile stress as well as described as eddy viscosity is computed with 1 m2/s. Wind-based on NCEP wind data,

a measure of **the change of the water level as a function of time with** an **as characteristic** 1 amplitude known as threshold depth is set to 0.1 m. The

threshold depth above which a grid cell is considered to be wet 1

(WL|DELFT HYDRAULICS, 2009). Marginal depth

for the water level at the velocity points as default the mean value as -999.99 **is used.** 1

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** 1

again. This is done

to prevent drying and flooding in two consecutive time steps. The 1

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** 1

depth. Figure 1: Galang Island Nesting Sequence: Large Scale, Intermediate, and Regional Models Table 2: Physical and numerical parameters of Galang Island Model Parameter Setting Gravity acceleration 9.81 m/s2 Water density 1023 kg/m3 Manning roughness 0.02 m1/2/s Horizontal Eddy Viscosity 1 m2/s Wind NCEP wind data Threshold depth

0.1 m Marginal depth -999. 99 **Smoothing time** 1

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 near shore 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). 15

GEBCO (General Bathymetric Chart of the Oceans) data, issued **by the** 22

British Oceanographic Data Centre, U.K. **(www.gebco.net/data_and_products/gebco_digital_atlas/)** 4

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 (see

Egbert and Erofeeva, 2002). The **data** is obtained **from the** NCEP/NCAR reanalysis **database** 30

(NOAA/OAR/ESRLPSD, 2009)(See Table 3). Figure 2: Bathymetry depth with respect to Indonesian nautical chart no. 42 Figure 3: Galang Island-Local Model bathymetry 2.5. 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. Table 3: List of data supplies in Study Area Description Physical Process Galang Island 1 Minimum water depth 2 Maximum mooring depth 3 Flushing 4 Exposure to currents 5 Exposure to waves 6 Exposure to the wind Tides Remarks: Indonesian Nautical chart number:42 IOC/IHO/BODC. (2003).a Derived from Physical Models Egbert and Erofeeva. (2002)c Derived from Physical Models NOAA/OAR/ESRLPSD. (2009). NCEP/NCAR Reanalysis 2 data b. Derived from Physical Models a

IOC/IHO/BODC. (2003). IOC/IHO/BODC.(2003). 26

General Bathymetric Chart of the Oceans.British Oceanographic Data Centre, Liverpool, U.K. **http://www.gebco.net/data_and_products/gebco_digital_atlas/** 4

Global bathymetric grid at 30 arc- second intervals. 25

b NOAA/OAR/ESRLPSD. (2009).

NCEP/NCAR Reanalysis 2 data. **http://www.cdc.noaa.gov/** 23

Global six hourly reanalysis data with the resolution 1.87 degrees (192 x 94 grids) for wind and sea level pressure c

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EgbertErofeeva_2002. Tide extracted from Total Model Driver 3.0 RESULTS AND DISCUSSION The flow and wave simulation results along with sensitivity analysis of a model simulation of the Galang Island model can be seen from Figure 4 to Figure 8. 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 (October 1st – October 15th, 2007). In a period of 2 weeks we'll cover a neap and spring tide, supposed that we start appropriately with the period of time, then water levels, currents, and waves are presented. 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 executed by applying various inform throughout the model domain. We considered constant bottom roughness coefficients of 0.02, 0.025, and 0.03 for a local model. As can be seen in Figure 4 that the sensitivity analysis result with regards to difference bottom roughness by comparing water level at observation point Galang 1 (G1) which covering selected period is presented (compare to Figure 1c). Then, from the data in Figure 5, we can see that the sensitivity analysis result with regards to difference bottom roughness by comparing the current speed at observation point G1 and G3 for the local model is presented. These figures showed the obvious dependency of the calculated water level and current velocities on the

bottom roughness. Therefore, **bottom roughness is** also **important** to include **in the** 29

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 there was very little difference. Figure 6: Current magnitude during spring-ebb flow for the regional model at Galang Island Figure 7: 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 6). In contrast, as can be seen in Figure 7, 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 needs 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 8 demonstrate 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 8: Predicted Maximum Sea Current Velocities in the vicinity of Galang Island using Delft3D Software and Grid Spacing of 44 m to 52 m 4.0 CONCLUSION Indonesia has great potential for sea/marine current

energy development and **plays an important** task **in the** future **of**	31

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	5

improvement

of a grid with resolution could **increase the accuracy of the numerical model** along with **the**	5

development of a more detailed spatial map of Ireland will enable each site to be assessed accurately	2

(Rourke et al. 2010b). 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**	5

devices. This method seems similar with Rompas and Gouin (2012) which carried out

a numerical model for a **study of marine currents in the Bangka strait, North Sulawesi, Indonesia**	9

using horizontal meshes of 60 side meters;	34

as well as marine currents around Ireland have been modeled used 2 dimension flow model within grid spacing 45 m and 135 m (Rourke et al. 2010); whilst Shaw (2004) used grid spacing of 405 m. There were about 13.95 GW

of tidal current energy technically available in 130 channels in China 19

(Li, 2008; Wang and Lu, 2009). Generally, currents in water channel with a maximum flow velocity of more than 2 m/s are high significance in practical application (Wang et al. 2011). 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** 20

sea current map which shows sea current at this location are higher than 2 m/s (see Figure 8). Whilst, another author revealed that numerous sites were

not economically viable due mainly to current velocity being less than 2 m/s 14

(Rourke et al. 2010). On the other hand, Wang (2009) showed that a prototype a 5 kW could start

at a current **speed of** 0.8 **m/s and the** 24

output about 3 kW at a current

velocity of 1.5 m/s, with a power coefficient **of** 2

28% to 30%. Acknowledgement The Author gratefully acknowledges the support and generosity of The

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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. References

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