A Comparison of Tidal Zoning Model for the Depth Reduction

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Abstract: Bathymetric information is essential for navigational purpose. The depth in navigational charts has to be referred to a vertical datum with the intention of ships can navigate safely. Tide plays important rule in a depth reduction in order to provide bathymetric information. Tidal characteristics are unique for any different places. The tidal phase and amplitude propagation may cause difficulties in predicting water levels. The research utilized Tidal Constituent and Residual Interpolation methods to estimate the tide propagation and to achieve a smooth tidal zoning. Tidal constituents at each of observation point are calculated using the least squares method and interpolated based on Laplace formula. The tidal zoning model that has been developed then was compared to the Finite Element Solution 2014 Global Tide Model. The results show that the correlation coefficient between those models is 0.78. Based on the research, the tidal zoning model can be used to improve the global tide model.

1 INTRODUCTION

Seafloor information is important for supporting marine activities (safety of navigation, demersal fishing, offshore oil exploration and drilling, cable and pipeline laying maintenance, and underwater warfare). A depth measurement is the main activity to determine the topography of the seabed. The measured depth must be corrected by the tides so that it refers to a chart datum. Corrected depths are the basic information to generate a nautical chart. The chart can also be utilized for a shipping safety and construction of docks purposes. Due to the importance of a chart datum in reducing depth, the determination of the vertical datum must be conducted accurately and precisely (Hellequin, et.al, 2003). The accuracy of a chart datum in a certain area depends on the tide observation process and the determination of tidal characteristics. The range between tidal stations or between tidal station and survey area may also affects the accuracy as it creates a tide zonation. The determination of the tide zonation can improve the accuracy of the tide correction for the depth reductions.

The study discussed the simulation of a tidal zoning using the TCARI (Tidal Constituent and Residual Interpolation) approach. TCARI uses an interpolation method from tide data at several tide stations. The method applies Laplace equation to simulate the tide on a weighted grid area model (Cisternelli and Gill, 2005). Each point on grid has a unique tide phase and amplitude which can be used to predict the water level at a certain position and time. The advantage of this approach is that the discontinuities of the tide observation which occur in the transition zone can be eliminated. The method can separate the calculation of water level due to tidal and non-tidal effects (weather and river discharge) and can also display model uncertainty due to tidal datum, astronomic, and water level uncertainty errors (Cisternelli, et.al, 20017).

The research also examined the results of the tide model from TCARI and the Finite Element Solution 2014 global tide model (FES2014). FES2014 represents tidal cycles across the globe. This model is derived from several altimetry satellite missions (Cancet, et.al, 2017). Based on the comparison between these models, it is expected that tide model from TCARI can improve the accuracy and the resolution of the global tide model FES2014 especially on the coastal area.

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2 METHODS

The research is located in Makassar Strait, the strait between Kalimantan and Sulawesi which is connected to Pacific Ocean in the north and adjacent with Java Sea in the southern part. The geographical location of the research area stretches from 115°25'03.7"E to 120°00'34.8"E of the longitude and from 05°30'04.8"S to 00°57'52.36"N of the latitude (red line in Fig. 1).

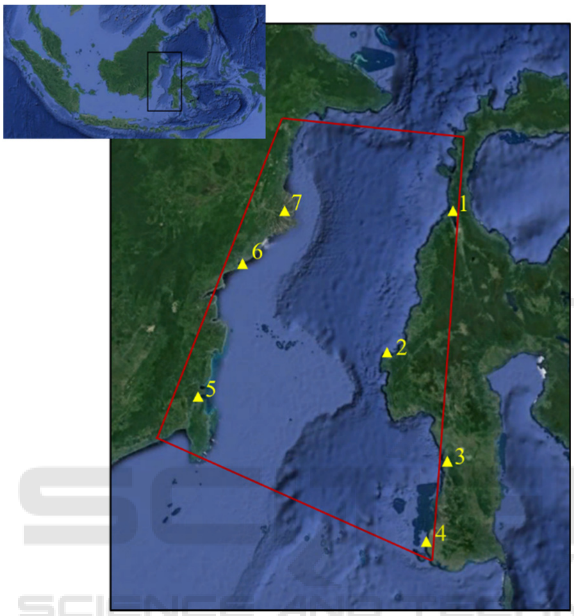

Figure 1: The research area located in Makassar Strait

The research used 7 tide stations in the proximity of the area of interest (yellow triangles in Fig. 1). The tide observations data from these stations are provided by Indonesia Geospatial Information Agency (2017). The data is then processed based on 10 minutes to obtain tide constituents at each tide stations. The geographical coordinates of the tide stations can be seen in Table 1.

The tide constituents from the tide stations are interpolated using TCARI method. The Pydro (Python and Hydrography) software was utilized to generate the tidal zoning in TCARI method.

Table 1: Tide Station Coordinate

Number	Station Name	Easting (dec deg)	Northing (dec deg)
1	Pantoloan	119.857E	-0.712S
2	Mamuju	118.893E	-2.667S
3	Pare-pare	119.620E	-4.014S
4	Makassar	119.417E	-5.112S
5	Kota Baru	116.146E	-3.291S
6	Balikpapan	116.806E	-1.272S
7	Mahakam	117.399E	-0.553S

The boundary for the model is derived from the medium resolution of GSHHG. The GSHHG is a high-resolution geography data set, amalgamated from World Vector Shorelines (WVS) and CIA World Data Bank II (WDBII) (Wessel and Smith, 1996). The data contains coastline and islands in shp format. The model boundary for the model is a closed polygon. The open ocean boundary for the model is delineated from the area which is adjacent with Pacific Ocean and Java Sea. In Fig. 2 shows the coastal boundary is represented by green line and the open ocean boundary is represented in blue line.

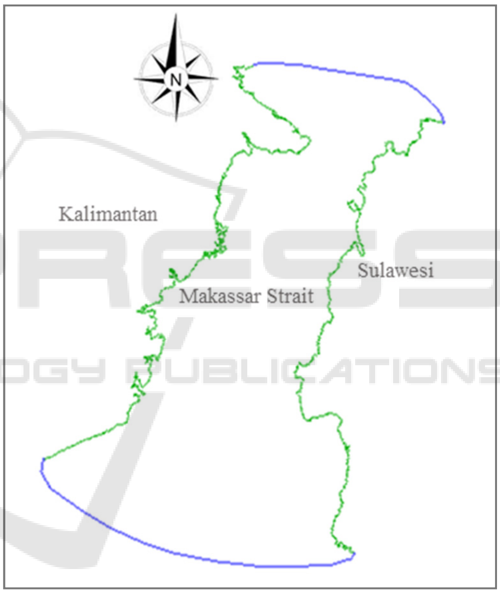

Figure 2: The boundary of the model

Tidal constituents at each tide station are arranged in a .txt file in a format that can be read in Pydro. The file also includes additional information such as the results of vertical datum calculations (MHHW, MHW, MLW, MLLW, and MSL). In this case MSL (Mean Sea Level) was used as a vertical reference for each tide stations. Note that amplitude and phase formats follow the format from NOAA and for constituents with 0 value will not be modeled. This research used 11 tidal constituents; K1, O1, P1, M4, MS4, MF, MM, M2, S2, K2, and N2.

There are several tide stations located not exactly at the shoreline, due to the shoreline resolution. Thus, the position of the station is shifted so that it intersects to the shoreline. This used an assumption that the shifting positions have the same tide regime with the tide actual stations.

The model used TIN (Triangular Irregular Network) with 9900 nodes and approximately 255268.763 square kilometers of model domain. The distribution of nodes is organized so that areas close to the shoreline and islands' boundaries have denser distribution than other areas. The nodes distribution for the model can be seen in Fig. 3. The nodes distribution considers geometry of the beach, bay, and headland which affect local effects such as wind and currents which indirectly influence the hydrodynamic characteristics in the research area.

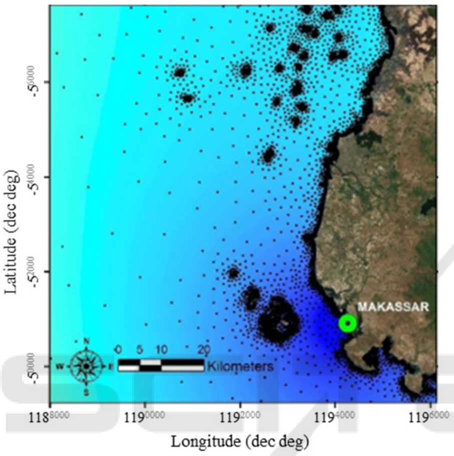

Figure 3: The distribution of nodes used in the model

The tidal amplitude and phase from each tidal station are interpolated and iterated using Laplace formula. The calculation process was performed for each node. To speed up the iteration and effectiveness of storage space (memory), the formula is simplified as follows (Cisternelli, et.al, 2007):

$$G(x,y) = \sum_{m=1}^{M} g(x,y,m)\, G_m^0 \tag{1}$$

$$\frac{\partial g}{\partial y^2} + \frac{\partial g}{\partial y^2} = 0 \tag{2}$$

$$g(x_i, y_i, m) = \delta m \tag{3}$$

Where m is the index of the tidal stations, G is the value of the amplitude and phase at a node and x, y is the position of the node in cartesian coordinates system which will be calculated its magnitude. A weighted parameter was applied to improve the equation. The weighted parameter was generated based on the boundary configuration. The following formula shows the weighted parameter applied in Laplace formula:

$$\frac{\partial g}{\partial \varsigma} = 0 \tag{4}$$

$$\frac{\partial g}{\partial \varsigma} = \alpha \frac{\hat{g}}{\partial \varsigma} \tag{5}$$

$$0 \le \alpha \le 1$$

Formula 4 was applied at points located on the coastline where the interpolated value is known. Formula 5 was applied at points where interpolation values want to be determined.   is the direction of a node with respect to a shoreline. α is a constant which affects the contour. The weighted parameter ranges from 0 to 1. The farther from the tide station, the weighted value will be close to 1. This means the predictive data is more accurate when the radius of the place to the tide observation point gets closer. Thus, this range can be a representation of the uncertainty level of the tide model. Fig. 4 shows the weighted distribution of the model.

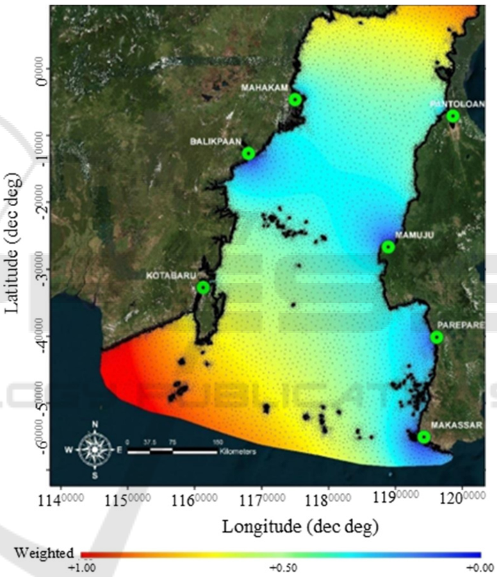

Figure 4: Weighted distribution of the model

The step after a computation using Laplace formula is extracting the co-amplitude and co-phase of the tide using TCARI. The co-amplitude and co phase of every tidal constituents are computed using interpolation method. Fig. 5 is one of the example of the co-amplitude and co-phase from K1 constituent. This co-tidal chart of K1 constituent is created using TCARI method. The co-amplitude is represented with colors gradation and the co-phase is represented by white lines. Other tide constituents are extracted using the same technique used to develop the K1 co-tidal chart.

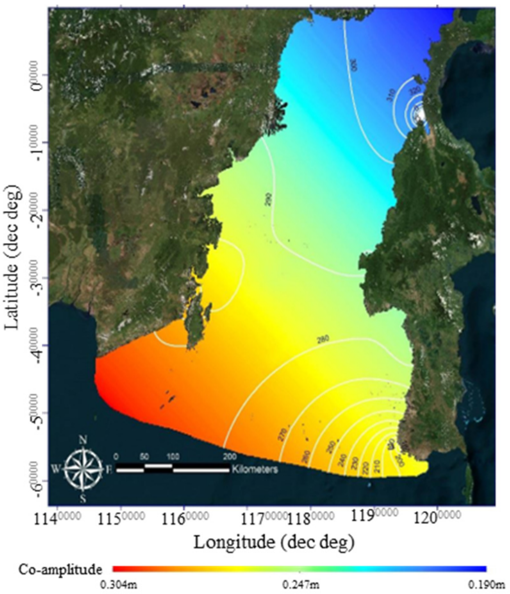

Figure 5: Co-amplitude and co-phase of K1

3 RESULT AND DISCUSSION

The research compared the tide model from TCARI to the FES2014 model. The comparation is performed to analyze the co-tidal chart pattern of each model. This process aims to test the quality of the TCARI tide model. FES2014 is developed from tide observation data collected using satellite altimetry whereas TCARI is generated by interpolating in-situ data. Both models should show the same tide pattern in the research area. However, these methods have weaknesses and strengths which can be seen in Table 2.

Table 2. Comparation between FES2014 and TCARI

Parameter	FES2014	TCARI
Observation Time Interval	Depend on cycle period of satellite altimetry mission	Up to 1 hour
Quality base on characteristic area	Good in *off-shore*, not really good in *near-shore.*	Good in *near-shore* and not really good in *off-shore.*
Observation Continuity	Consistent (for along years)	Inconsistent (depends on tide gauge accuration)
Scale	Global	Local to Global

The difference in Table 2 causes inconsistent variations in TCARI and FES2014 tide constituent values, depending on the position of the points compared. Correlation values were obtained from 32 Independent Check Points that had been spread evenly in the study area as in Fig. 6.

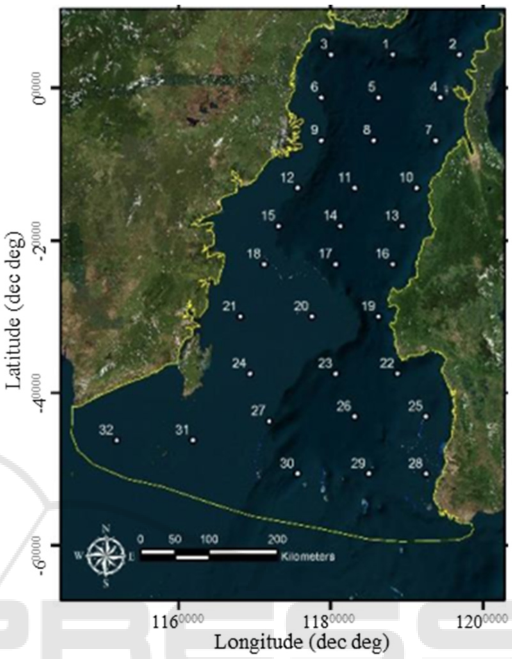

Figure 6: Independent Check Points

Figure 7 shows the average between the FES2014 and TCARI amplitude values for each tidal constituent at 32 ICP points. The correlation coefficient shows a strong relationship to the diurnal and semidiurnal tidal constituents. Whereas for the long period tidal constituents between TCARI and FES2014 have magnitude close to 0 (Fig. 7).

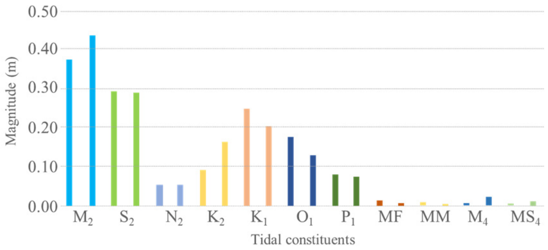

Figure 7: Average of Amplitude Value in Independent Check Points

The small values of the MS4, M4, MF and MM constituents are influenced by Rayleigh criteria. The Rayleigh criteria is if there are two components A and component B can only be separated if the length of the data is more than a certain period called the synodic period. The synodic period can be formulated by the following formula (Hess, 2004):

$$PS = \frac{360}{\omega_A - \omega_B} \qquad (7)$$

PS= Synodic Period (hours)
 = Angular Velocity of A Component (°/hour)
 = Angular Velocity of B Component (°/hour)

Based on the formula 7, the observed period values for distinguishing spectral MS4 and M4 are 4.310 months and for distinguishing MF and MM spectral, a minimum observation time of 27.076 days is required. Thus, because the length of observation used varies at each station, which is only about 3 to 7 months, it is considered less ideal for extracting the M4 and MS4. However, this is ideal for extracting MM and MF. The small MM and MF magnitudes are possibly caused by other factors, for example the influence of the position of the Makassar Strait which is located at the equator. Considering that MM and MF are long-term conditions that are influenced by the declination of the moon, this made MM and MF are minimum at near equator. Based on 11 tidal constituents that have been modelled, the K1 has a strongest correlation between TCARI and FES2014. Fig 8 shows the coefficient correlation between the models. The magnitude of their correlation is 0.976.

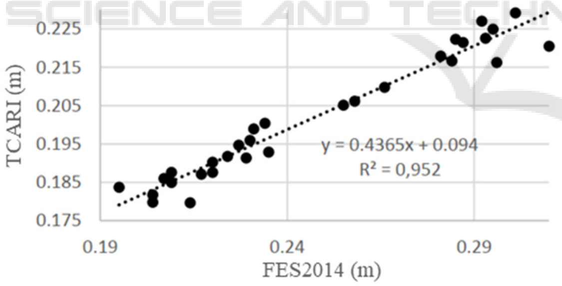

Figure 9: The coefficient correlation between TCARI and FES2014 for K1 constituent

4 CONCLUSION

The tidal zoning model generated using the TCARI method was compared with the global tide model FES2014 to test the accuracy and precision of the model. Based on the correlation test that has been carried out on both models, the tide constituents of S2, N2, K2, K1, O1, P1, and M2, have correlation coefficient of 0.78. The best correlation is shown by the pattern of K1 values with a correlation coefficient of 0.95. The TCARI method can display smoother tide models than the global tide model FES2014. Tidal zoning model developed using TCARI might be used to improve the resolution of global tide models for the future purposes.

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