Instantaneous Height of Sea Surface: A Comparison Between Local Field Observation and The Simulated Level from Global Models

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Abstract— **This paper explores the usability of a global database containing sea surface height. We look at simulated heights of the sea surface at a certain area and compare them with field observation from three stationary stations and one from an ocean cruise. Mean Sea Surface data from the global model and Mean Sea Level (MSL) data from the field observation must be referenced to the same height system. For this reason, a height system in the form of a global ellipsoid model, namely the World Geodetic System 1984 (WGS84) was chosen as the height reference. After being referenced in the same height system, then the MSS and MSL are compared by looking for the difference between the MSS of the ellipsoid (h_{MSS}) and the MSL of the ellipsoid (h_{MSL}) and the average of these differences. The results show that the differences are in the order of < 1 m. The simulated tidal waves from the global model is incapable to describe the actual sea level variations, although it is able to capture the general trend. It should be noted that the field observation is incomplete and subject to various uncertainties. Bearing in mind the limitation of the models and uncertainties of the observation, our study confirms that such an order discrepancy in a global sense is tolerable.**

Keywords—sea level height, mean sea surface, mean sea level

I. INTRODUCTION

Height is a one-dimensional coordinate system used to determine the metric distance of a particular reference plane to a point along its vertical line [1]. For various positioning applications, such as mapping and navigation, it is common to describe height by referring to either orthometric or geodetic systems. The orthometric height (H) system is described by geometric distance measured along the plumb (gravity) line between geoid to a point [1][2][3][4]. Geoid is the shape that the ocean surface without wind and tide would take under the influence of the gravity and rotation of Earth[1][2][3][4][5]. On the other hand, height from ellipsoid (h) is obtained without having to do with the gravity of the earth. It is the distance of a straight line along the normal ellipsoid plane to a certain point [1][2][3]. Height from ellipsoid becomes more valuable and convenient particularly with the presence of satellite for mobile positioning.

An illustration of orthometric height (H) and ellipsoid height (h) can be seen in Fig. 1. The separation between geoid and ellipsoid is called geoid undulation (*N*) [6]. It relates one height refers to the other. As geoid undulation (*N*) relates the height of a point on earth surface having two different references, one may have a sense of interoperability between the two height systems. This implies that, if one can refer the MSL to ellipsoid by means of Global Navigation Satellite System (GNSS) then practically one can materialize the concept of height system into a realization with the help of physical observation.

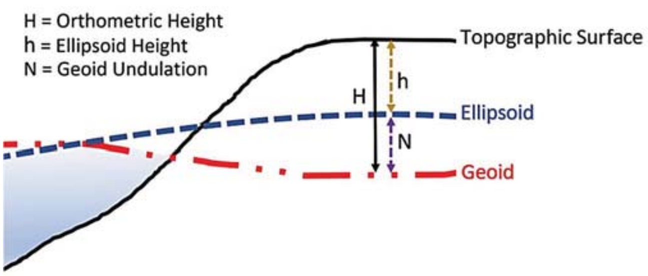

Fig. 1. Vertical position of topographic surface as defined by orthometric and ellipsoid height referring to respectively geoid and ellipsoid.

In this study, we discuss how results from physical observation may fit the conceptual height system. The

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purpose of the study presented here is to assemble sea level data in the nearshore area along the northwest of Java coastal area represented by stations located in Jakarta, Patimban (Subang), and Cirebon. Data from local observation of sea level is collected from the three stations, with additional data taken from field observation using temporary mobile tools (GNSS Positioning) in the sea area of the northeast of Patimban and temporary tide station in Patimban Port. Results from local observation of sea surface are compared with global sea surface models. From the comparison, we expect to spot how sea surface model fit the local observations.

II. Related work

The study of Poerbandono, et al [7] discusses the possibility of Global Navigation Satellite System (GNSS) technology to carry out the shore-based tidal survey function in hydrographic surveys. However, it is necessary to have a Hydrographic Separation Model (HSM) to define the separation of the height datum used in the hydrographic survey. This study uses the global data, namely the global sea surface model from TPXO 7 and the sea surface model from the Indonesian Geospatial Information Agency (BIG) data and compared with the geodetic height observation data on the shipping route between Ancol (Jakarta) and Pramuka Island (Kepulauan Seribu). The results show that this study produces a deviation level in the order of several tens of centimeters in this study concludes that BIG sea surface data has the potential to be developed into HSM.

The study of Poerbandono, et al [8] discusses the suitability of sea level height observed from geodetic heigths data with the global Mean Sea Surface (MSS) model, which was produced from Gravity Recovery and Climate Experiment (GRACE) Gravity Model (GGM) and Mean Dynamic Ocean Topography (MDOT). These models are then compared with geodetic heights data with Wide Area Differential (WA D) and RTPPP GNSS in the west of the Java Sea, Indonesia. The results show that the vertical offset of the geodetic height of sea level and MSS observed by WA DGNSS is 7.5 cm (away tracking), while those observed by RTPPP GNSS is 39.5 cm (away tracking) and 36.0 cm (return tracking) with the condition that the tide the model used here does not fit the sea level from the geodetic height data. In this study, the MSS data from the model is compared not only with geodetic height from field observation (temporary mobile) data but also from MSL obtained from tide stations.

III. System Model

A. Methods

This research is conducted by determining the value of Mean Sea Surface (MSS) and Mean Sea Level values from observational data both from tide station data (fixed station and temporary station) and temporary mobile data. The MSS value and the MSL value from the observation data are then referenced to a certain height reference field. In this case, the World Geodetic System 1984 (WGS84) ellipsoid model with the International Terrestrial Reference Frame 2014 (ITRF2014) as the reference frame is used.

MSS data from ellipsoid reference can be obtained from the earth's gravity model and Mean Dynamic Ocean Topography (MDOT) [9] as can be seen in (1).

$$MSS = N + MDOT \tag{1}$$

Where:
N = geoid undulation
$MDOT$ = mean dynamic ocean topography

MSL data from observation data consists of temporary mobile data and tide station data (fixed station and temporary station). MSL value from temporary mobile data is obtained by averaging sea level values during field observations taking place with MSL values that have been ellipsoid-referenced because the temporary mobile tools are using GNSS, whereas MSL values from tidal stations are MSL values from tidal observations at stations the tide with a reference height of 0 tide pole, so that reference to the WGS84 ellipsoid is still needed. This height reference change is done by finding the height difference value of the tide pole to the Tidal Benchmark that has known for its geodetic height.

An analysis of temporary mobile data is conducted by looking at the standard deviation value to find out the dispersion of the temporary mobile data by using an (2) [10]:

$$\sigma = \frac{\sum (x_i - \bar{x})^2}{n-1} \tag{2}$$

Where:
σ = standard deviation
x_i = observation data
$\bar{x}$ = mean
n = data size

Then the Mean Sea Level value from ellipsoid (h_{MSL}) from the observation data, and tide station are compared with MSS data from ellipsoid (h_{MSS}). Under ideal conditions, h_{MSS} and h_{MSL} have the same values as those listed in (3). However, there are differences between the two data which are most likely due to the resolution and accuracy of the data used to obtain the value of MSS so there is a difference between h_{MSS} and h_{MSL}. Then the comparison between the Mean Sea Surface and the Mean Sea Level is carried out using (4):

$$h_{MSS} = H_{SL(x,y,t)Mean} \tag{3}$$

$$S = h_{MSS} - H_{SL(x,y,t)Mean} \tag{4}$$

Where:
h_{MSS} = Mean Sea Surface BIG data from ellipsoids
$h_{SL(x,y,t)\ Mean}$ = Mean water level value of observation data from ellipsoids.
S = The difference between MSS with Mean Sea Level values from the observation data.

Meanwhile, the difference between MSS with Mean Sea Level (MSL) values from the observation data is analyzed with Mean Absolute Error (MAE) for measure of errors between paired observations expressing the same phenomenon [11] with (5):

$$MAE = \frac{\sum_{i=1}^{n}|y_i - x_i|}{n} \tag{5}$$

Where:

x_i = observation data

y_i = prediction/model data

B. Data

The summary of data used in this study can be seen in Table 1. We collect primary data of sea level from 4 tidal stations: Jakarta (2 stations), Patimban Port, and Cirebon. Sea level data is also collected using temporary mobile along 327.5 km sailing track in the northeast of Patimban with help of Global Navigation Satellite System device with Real-Time Precise Point Positioning method (GNSS-RTPPP). Models of global sea surface are obtained from Geospatial Information Agency (BIG) official data.

TABLE 1. Details of data

No.	Types of Data	Location and Source	Description
1	***Mean sea level - Observation***	***Jakarta – station***	***Sunda Kelapa Station Lon= 106.810 Lat= -6.125 h_{MSL}= 19.05 m Kolinlamil Station Lon= 106.883 Lat= -6.107 h_{MSL}= 19.17 m***
		Patimban – temporary station	***Lon= 107.903 Lat= -6.244 h_{MSL}= 22.50 m***
		Patimban – temporary mobile (sailing)	***Day 1 Start: 20/09/2016 12:04:41 AM End: 20/09/2016 1:20:38 PM Day 2 Start: 20/09/2016 10:04:34 PM End: 21/09/2016 6:18:30 AM Day 3 Start: 21/09/2016 7:54:33 PM End: 22/09/2016 12:40:39 PM***
		Cirebon – station	***Lon= 108.581 Lat= -6.734 h_{MSL}= 22.42 m***
2	***Mean sea surface - Model***	***Geospatial Information Agency (BIG) [12]***	***Geoid undulation and MDOT data from the sea of Jakarta to Cirebon***

Observation data from Jakarta station is BIG tide station data consisting of 2 tide stations, including Sunda Kelapa and Kolinlamil. At Sunda Kelapa, tide station has a h_{MSL} value of 19.05 m while in Kolinlamil has an h_{MSL} value of 19.17 m.

The next data is observation data in the Patimban area which consists of Patimban Port tide station (temporary station) and temporary mobile data from field observation. The difference between these two data is the temporary tide station data are tidal data located in coastal areas while the temporary mobile data are water level data obtained in the high seas in the north of Patimban. The h_{MSL} value at Patimban temporary station is 22.50 m, while the temporary mobile data are water level observation data with GNSS tools for 3 days survey with the survey location illustrated in Fig 2.

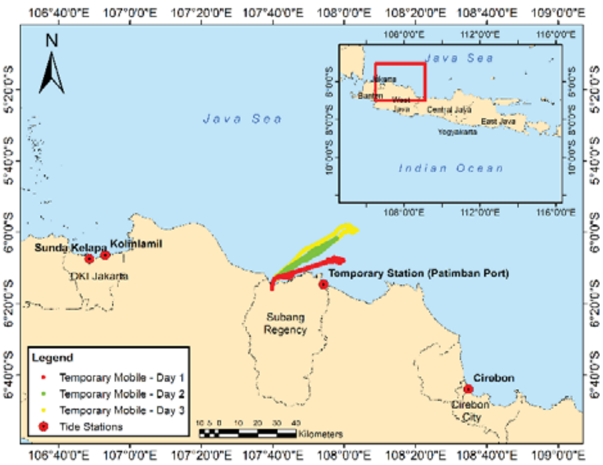

Fig. 2. Map of study location.

The last observation data is Cirebon tide station data. We conducted GNSS observations to determine the height of the tidal benchmark from ellipsoids and then combined with BIG's tidal datum data to obtain h_{MSL} values at Cirebon station. The h_{MSL} value in the Cirebon region is 22.42 m.

Observation data at the Jakarta tide station, Patimban, and Cirebon require information of tide station metadata. The metadata required is the tidal datum in the survey area and the height difference between the tide station and the Tidal Benchmark that has been referred to the ellipsoid. Illustration of tide station metadata can be seen in Fig. 3.

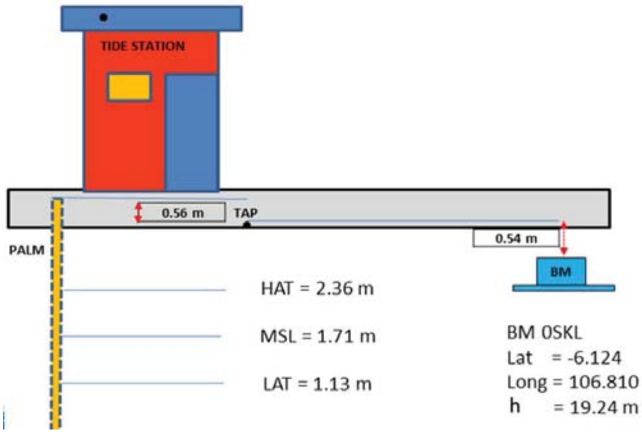

Fig. 3. Illustration of tide station metadata [13].

The next data used is the geoid undulation and Mean Dynamic Ocean Topography (MDOT) data. This data is obtained from the Geospatial Information Agency (BIG) where the data is generated from the assimilation of BIG tidal stations and data from altimetry satellites with a 0.6 minute geoid undulation resolution and 2.5 minutes MDOT resolution. Both of these data are taken from the waters of Jakarta to Cirebon from longitude 106.500° - 108.750°. Then, the MSS value is calculated using (1).

IV. Results and Discussion

Based on the results of the temporary mobile data in Patimban Sea, it shows that the water level in the survey area changes over time. This is because during the survey there is also a tidal phenomenon so that the position of the water level changes. Observation data has a mean sea level value of 21.49 m with a standard deviation value on day 1 is 0.39, on day 2 is 0.34 and on the day 3 is 0.50. The results of this standard deviation indicate that the value of the water level from the survey field has sufficient distribution of the mean water level value. This is most likely due to the frequency of field data recording which caused other high frequency waves to be recorded, causing the data deviation to become larger.

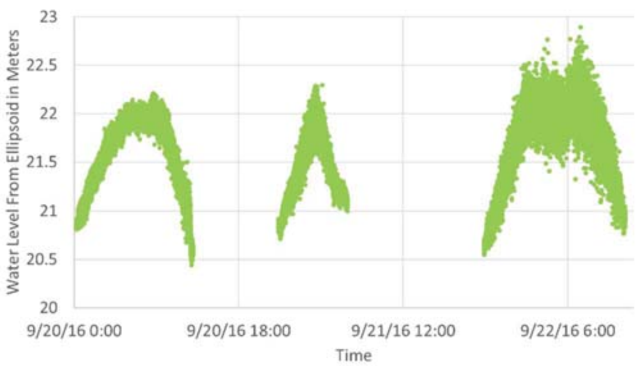

Fig. 4. Plot of water level from field observation on Patimban waters.

The MSL value from Ellipsoid (h_{MSL}) from the observation data (fixed tide stations in Jakarta and Cirebon, temporary station in Patimban, and temporary mobile data in Patimban Sea) is compared with the h_{MSS} from the BIG as can be seen in Fig. 5 and Table II.

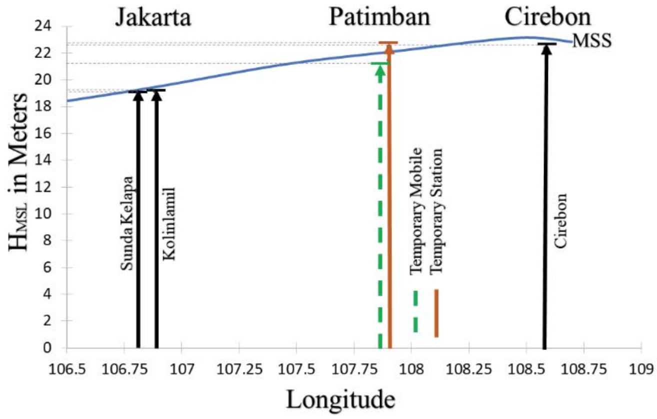

Fig. 5. Comparison of h_{MSL} and h_{MSS}.

TABLE 2. THE DIFFERENCE BETWEEN H_{MSS} WITH H_{MSL} VALUES FROM THE OBSERVATION DATA.

No	Location	h_{MSL} (m)	h_{MSS} (m)	S (m)	Tidal Range (m)
1	Tide Station Sunda Kelapa	19.05	19.28	0.23	1.24
2	Tide Station Kolinlamil	19.17	19.52	0.34	1.14
3	Temporary Mobile - Patimban Sea	21.49	21.97	0.48	-
4	Temporary Station - Patimban Port	22.50	21.98	-0.52	1.09
5	Tide Station Cirebon	22.42	22.83	0.41	1.23
Maximum Value of S				0.48 m	
Minimum Value of S				-0.52 m	
Mean of *S*				0.19 m	
Mean Absolute Error				0.40 m	

Based on Fig. 5 and Table 2 it can be seen that the h_{MSL} from Jakarta to Cirebon has varying heights so is the h_{MSS} value. Both h_{MSL} and h_{MSS} experienced an increase from the west to east and then declined in the Cirebon region. The results of the h_{MSL} from the temporary mobile data still have a reasonable value with vertical offset within 1 m from the h_{MSL} of temporary station in Patimban Port considering that temporary mobile data has a standard deviation within 0.5 m. In addition, other factors that cause these offsets can be caused by vertical uncertainty during the field observation as explained in Poerbandono, et.al [8] that the vertical uncertainty is not only caused by the equipment used but most probably can also be caused by vessel attitude which causes the water level observation data to have noise. Another thing that causes noise is due to the installation of tools and the presence of other waves recorded by the water level data using GNSS-RTPPP.

In Fig. 5 can also be seen that h_{MSL} and h_{MSS} have the same pattern. However, when viewed at the same point, namely at the Sunda Kelapa Tide station, Kolinlamil, Patimban Port, Cirebon and Field Observation there are differences between h_{MSL} and h_{MSS}. The difference ranged from -0.52 m to 0.48 m with a mean of the difference between h_{MSL} and h_{MSS} of 0.19 m and Mean Absolute Error (MAE) of 0.40 as can be seen in Table 2. Considerable differences are found in the field observation data which can be caused by interference with the observational data as explained previously. This result is actually still a considerable result considering that the difference between h_{MSL} and h_{MSS} within 0.5 m and the Mean Absolute Error (MAE) between h_{MSL} and h_{MSS} has a fairly good considering this is seen from the broad scope from Jakarta to Cirebon. The results of this study also confirm the results from Poerbandono, et al [8] that there is a difference in the order of tens of centimeters between the MSS of the model and the sea level values. However, in this paper, the same trend can be found between MSS and MSL.

In addition, when viewed from the tidal range obtained from the Highest Astronomical Tide (HAT) minus the Lowest Astronomical Tide (LAT) obtained at the tide station. HAT and LAT are obtained from tidal harmonic analysis for at least 18.6 years with the highest water level value in that period called HAT and the lowest water level value is called LAT [14]. The comparison results with the tidal range show that the S results are still within the tidal range. The tidal range value at each tidal station varied from 1.09 m to 1.24 m while the S result was <0.5 m, this made the S value still relatively small and tolerable. However, further studies still need to be done to state that the value of h_{MSS} can be used as a substitute for the value of h_{MSL} for more practical needs.

V. Conclusion

Based on the above results it can be concluded that the observation data has the standard deviation value on day 1 is 0.39, on day 2 is 0.34 and on the day 3 is 0.50 which shows that the water level data has a high deviation from the mean sea level value. This is most likely caused by several factors, among others, the water level measured in the survey field is water level data with high frequency intervals so that high-frequency sea wave data is recorded, not only tidal waves. However, when viewed from the h_{MSL} comparison results from Jakarta to Cirebon, the survey field results still have a reasonable value with difference within 0.5 m when compared to the h_{MSS} from BIG data because of the many factors that cause noise in the field observation data and resolution and accuracy issue in geoid undulation and MDOT data to calculate h_{MSS} data.

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References

[1] Featherstone, W. E. and Khun, M.. "Height Systems and Vertical Datums: A Review in The Australian Context" 2006.

[2] Vanícek P. and Krakiwsky E. "Geodesy the concepts (2nd edn)." Elsevier, Amsterdam, 1986.

[3] Hofmann-Wellenhof, B., And Moritz, H. "Physical Geodesy." Vienna: Springer-Verlag Wien, 2006.

[4] Kelompok Keahlian Geodesi ITB. "Geoid Study and Modeling in the Indonesian Area" geodesy.gd.itb.ac.id/2007/01/05/studi-geoid-teliti-dan-pemodelannya-di-daerah-indonesia/

[5] Sideris, Michael G. "Geoid Determination, Theory and Principles". Encyclopedia of Solid Earth Geophysics. Encyclopedia of Earth Sciences Series, 2011.

[6] EGM 2008. "Earth Gravitational Model 2008 (EGM2008)", 2008.

[7] Poerbandono, et al. "Hydrographic datum and GNSS heighting on the SW Java Sea, Indonesia: Comparison between observed and models of Sea Surface". IOP Conf. Ser.: Earth Environ. Sci. 389 012017. 2019.

[8] Poerbandono, et al. "Tracking of geodetic height of sea level in the west of Java Sea, Indonesia: A preliminary assessment." E3S Web of Conferences. 94.01003, 2019.

[9] Chu P.. "Ocean Science" 14 947–957, 2018.

[10] Bland, J.M. and Altman, D.G. "Statistics notes: measurement error". BMJ. 312 (7047): 1654, 1996.

[11] Willmott, Cort J.; Matsuura, Kenji. "Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance". Climate Research. 30: 79–82 2005.

[12] BIG. "Datum Pasut", tides.big.go.id/pasut/index.html

[13] BIG. "Stasiun Pasang Surut", srgi.big.go.id/jkg-active

[14] International Hydrographic Organization, "IHO/C-13 Manual on Hydrography, 1st Edition Chapter 5". May 2005