THREE-WAY ERROR ANALYSIS OF SEA SURFACE TEMPERATURE (SST) BETWEEN HIMAWARI-8, BUOY, AND MUR SST IN SAVU SEA

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Abstract. Variance errors of Himawari-8, buoy, and Multi-scale Ultra-high Resolution (MUR) SST in Savu Sea have been investigated. This research used level 3 Himawari-8 hourly SST, in situ measurement of buoy, and daily MUR SST in the period of December 2016 to July 2017. The data were separated into day time data and night time. Skin temperature of Himawari-8 and subskin tempertaure of MUR SST were corrected with the value of ΔT_{dept} before compared with buoy data. Hourly SST of Himawari-8 and buoy data were converted to daily format by averaging process before collocated with MUR SST data. The number of 2,264 matchup data are obtained. Differences average between Himawari-8, buoy and MUR SST were calculated to get the value of variance *(V_{ij})*. Using three-way error analysis, variance errors of each observation type can be known. From the analysis results can be seen that the variance error of Himawari-8, buoy and MUR SST are 2.5 °C, 0.28°C and 1.21°C respectively. The accuracy of buoy data was better than the other. With a small variance errors, thus buoy data can be used as a reference data for validation of SST from different observation type.

Keywords: *Sea surface temperature (SST), Himawari-8, Buoy data, MUR SST, Validation*

1 INTRODUCTION

Savu Sea is located in the eastern part of Indonesia, close to the Banda Sea. It is the outlet of Indonesian Through Flow (ITF) that flows the water masses from the Pacific Ocean to the Indian Ocean, so it has unique characteristics. El Niño Southern Oscillation also affects Sea Surface Temperature (SST) of Savu Sea (Potemra *et al.* 2003). A detailed explanation of the Savu Sea has been studied previously by measuring the surface geostrophic velocity variation. Savu Sea is one of major passages of ITF that flows water masses from internal sea of Indonesia to Indian Ocean (Chong *et al.* 2000). The South Java Current (SJC) that flows eastward also affects the characteristics of Savu Sea (Hautala *et al.* 2001). Driven by Kelvin Waves, SJC flows eastward at surface layer from the Indian ocean to the Savu Sea. A deeper current also flows eastward through the Savu Sea to the Ombai Strait called South Java Under Current (SJUC). The mechanism of SJC is caused by intra-seasonal and semi-annual winds in the equatorial Indian Ocean. Local wind and SJC in Savu Sea cause sea surface temperature front (Sprintal *et al.* 2008).

One of important parameter to have a better understanding of Savu Sea characteristic is SST. Therefore SST variability need to be analysed. The SST dataset derived from satellite for oceanographic observation has several advantages because of its ability to record sea surface with better spatial resolution than in situ data. SST data has been widely used in various research and analysis. SST data is used to analyze the effect of El Niño Southern Oscillation (ENSO) on the characteristics of the rainfall region of Indonesia through the ITF mechanism. Local sea-

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air interaction process is also analysed by using correlation between SST and rainfall cycle (Aldrian and Susanto 2003). The ENSO index is compiled by using SST dataset in the equatorial Pacific Ocean (D'Arrigo and Wilson 2008). SST analysis can also be used to identify the presence of water mass movement associated with the occurrence of El Niño and La Niña (Hartoko 2009). Furthermore, the use of SST data in the field of fisheries are also very important. Alabia *et al.* (2016), use SST dataset to predict the potential habitat distribution of squid in the sea of Japan. Sartimbul *et al.* (2010) also analyse the variability of SST and its impact on Catch per Unit of Effort (CPUE) of S*ardinella lemuru* in Bali Strait and its corelation with El Niño and Indian Ocean Dipole (IOD).

Various satellites have been launched to provide SST dataset. The recently launched satellite to monitor SST is the Himawari-8 satellite. Himawari-8 has been launched on October 7th 2014. This satellite carries an Advanced Himawari-8 Imager sensor (AHI). The sensor has a capability of recording at visible, Near Infra Red (NIR), and Infra Red (IR) wavelengths with 16 channels (3 visible bands, 3 NIR bands, and 10 IR bands) (Bessho *et al.* 2016).

The Himawari-8 satellite is located at 140.7^{o}E and observes the Earth from 80^{o}E-160^{o}W between 60^{o}N-60^{o}S. SST from Himawari-8 satellite is processed from IR band centered on wavelength 3.9, 8.6, 10.4, 11.2, and 12.4 µm with spatial resolution of 2 km. Skin temperature is calculated from wavelength 10.4 11.2, and 8.6 µm (Kurihara *et al.* 2016).

Skin SST is a temperature measured by a radiometer at a wavelength below 5µm on a top layer with a very thin depth of about 550µm, while bulk SST is the temperature measured on the layer beneath the skin SST where the layer is still dominated by heat transfer process using a sensor mounted on the buoy, profiler or ships (Donlon *et al.* 2002)

SST from IR wavelength needs to be evaluated using in-situ measurement such as buoy data (Emery and Baldwin 2001). Comparisons between IR data from Himawari-8, Visible Infrared Imaging Radiometer Suite (VIIRS), and Moderate Resolution Imaging Spectroradiometer (MODIS) have been done by Liang *et al.* (2016). However it is important to validate the accuracy of Himawari-8 SST especially in Savu Sea. One of the validating method using satellite dataset and in-situ data is three-way error analysis. This method is performed by analyzing the standard deviation of error of three kind of dataset derived from satellite and in-situ measurement (O'Carroll *et al.* 2008). Xu and Ignatov (2010), used a three way error analysis method to calibrate and validate satellite data using insitu data, while Tu *et al.* (2015), Using a 3 way method to validate The NAVO S-NPP VIIRS SST using in situ data from the National Oceanic and Atmospheric Administration insitu Quality Monitor (iQuam). In this study we use SST from Himawari-8, Multi-scale Ultra-high Resolution (MUR) SST, and buoy data.

The Indonesian buoy was deployed and operated by Institute for Marine Research and Observation (IMRO), Ministry of Marine Affairs and Fisheries of Indonesia. Ten sets of buoy were deployed in December 2016 and measuring in-situ data of Indonesian water including SST. There are two locations of IMRO buoy that deployed in the Savu Sea. It is located at 121.60°E, 8.84°S and 123.56°E, 10.06°S as shown in Figure 2-2. The sensor on IMRO buoy measures SST every 15 minutes and sent to the database server (IMRO 2016).

MUR SST data has been widely used for various applications and research, i.e. to identify upwelling phenomenon (Vazcuez *et al.* 2013; Xu *et al.* 2016; Gentemann *et al.* 2017). The use of MUR SST for identification of tidal mixing signatures is done by Ray and Susanto (2016).

MUR SST is a very good data that was developed with blending many different satellite data with different resolution and specification, provide clear cloud timeseries SST dataset with high spatial resolution up to 1 km with high accuracy. MUR SST was developed by *National Aeronautics and Space Administration* (NASA) Interim Sea Surface Temperature Science Team by blending many satellite dataset of IR wavelength of *Advanced Very High Resolution Radiometer* (AVHRR), MODIS, *Advanced Along-Track Scanning Radiometer* (AATSR), Geostationary Operational Environmental Satellite (GOES) Imager, Spinning Enhanced Visible and Infrared Imager (SEVIRI), and microwave wavelength (MW) such as Advanced Microwave Scanning Radiometer (AMSR)-E, TMI (Chin *et al.* 2013).

This paper is focused on validation of SST from Himawari-8, buoy, and MUR SST in Indonesian waters, especially Savu Sea by using three-way error analysis. This validation procces is important to be done as a previous step for further applications of SST, such as the prediction of potential fishing zone and other application.

2 MATERIALS AND METHODOLOGY

2.1 Himawari-8 SST

We use level 3 Himawari-8 hourly skin SST data in the period of December 2016 to July 2017. Skin SST of Himawari-8 was calculated based on Kurihara *et al.* (2016). Himawari-8 SST in Savu Sea has a 2 km spatial resolution as shown in Figure 2-1. SST Himawari-8 dataset which is near-simultaneous to buoy data were obtained. This data was provided by Japan Aerospace Exploration Agency on the website *http://www.eorc.jaxa.jp/ptree/*.

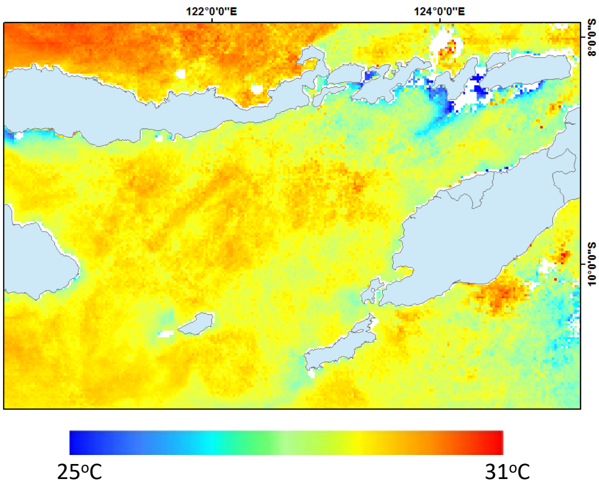


Figure 2-1: SST derived from Himawari-8 satellite in Mei 1st, 2017

Based on Figure 2-1. the selected SST data that collocated with buoy data then extracted into digital value at a location corresponding to the buoy location. According to cloud cover in the Savu Sea that often occurs, extracted digital data will be filtered to get cloud-free SST data. Filtering was done using threshold values. The SST in Indonesian water range between 25°C – 30.5 °C (Aldrian and Susanto 2003, Sprintal *et al.* 2008). In this paper we use threshold value at 25°C – 30.5 °C, so the value below threshold will be discarded or considered as cloud-covered data, while value above threshold will be discarged or considered as outliers value. A total number of 5,832 scene of Himawari-8 SST were available and leaving 1,745 scene after discarged as cloud-covered data in collocation area within buoy location.

Himawari-8 SST has been validated and bias corrected by comparing to drifting and tropical moored buoy data. Root mean square differences (RMSD) and the bias of the analysis results are found around 0.59K and 0.16K respectively. Data quality control (QC) has been performed to reduce systematic errors caused by non linearity in physical processes. The validation process has also considered the atmospheric profile component by using numerical weather prediction data. Cloud screening has also been applied to define the threshold of cloud probabilities. Solar zenith angle was calculated for day time data to obtain bias along the viewing boundaries (Kurihara *et al.* 2016).

2.2 Buoy data

IMRO buoy deployment is aimed to get the environmental data as the basis of oceanographic prediction and coastal dynamics monitoring. On the other hand, buoy data can also be used to perform satellite data validation including SST data. As the tropical region is always cloud-covered, the recording of SST satellite data is severely affected (IMRO 2016). Therefore, it is necessary to use in-situ data as a comparison to improve its accuracy. Location of IMRO buoy in Savu sea can be seen in Figure 2-2.

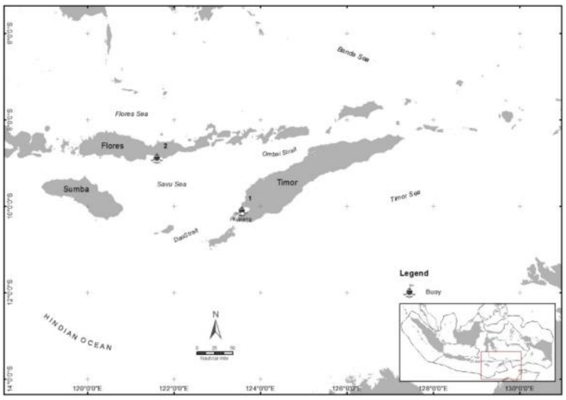
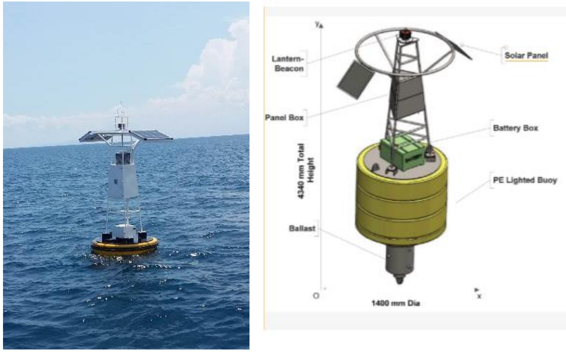


Figure 2-2: Savu Sea and the location of buoy

The specifications of IMRO buoy can be seen in Figure 2-3.



(a) (b)

Figure 2-3: IMRO buoy in Savu sea *(a)* and the buoy specifications *(b)*. (IMRO, 2016)

The materials used to construct buoys were polyethylene rotomold, with galvanized steel pipes, and finished with marine spec paintings. Equipped with solar panels, the buoy can automatically charge the battery. The sensor used in this buoy is Hydrolab DS 5X multiparameter, measuring parameters at a depth of 3m consisting of temperature, conductivity, dissolved oxygen, turbidity, and chlorophyll (IMRO 2016). Real time data from buoy is very important for use on various fields especially for application in internal sea of Indonesia. IMRO buoy measure in-situ data of SST every 15 minute. The accuracy of sensor used in the buoy is 0.05^{o}C.

After SST is recorded by sensor, the data is transmitted directly to the data server as presented in Figure 2-4. A total number of data in the same period with Himawari-8 data were collected.

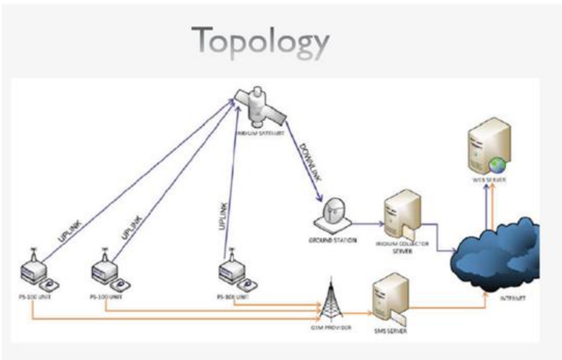


Figure 2-4: Topology of buoy data management (IMRO, 2016)

Based on Xu and Ignatov (2014), the QC of bouy data is performed to check the quality of in situ measured data. There are two main purpose of in situ data QC, which are self consistency and cross consistency with other data. In general QC data buoy consists of prescreening, plausability, internal consistency, mutual consistency and external consistency.

In this study, in situ measurement of SST is obtained from moored buoy, therefore the QC performed consists of the ID check to ensure that the data used was matches with the buoy ID number at the correct location. Geolocation check is performed to ensure that the measurement of SST should not be overland and buoy are located in the area of their deployment location. Extreme value are filtered or considered as outlier by by using threshold value between 25 °C - 30.5 °C.

2.3 MUR SST

Development of MUR SST was done by applying the algorithm based on theoretical algorithm Basis Document Version 1.3 (Chin *et al.* 2013) where the algorithm produces SST with spatial resolution of 1-2 km. The data of MUR SST is available daily by Group of High Resolution Sea Surface Temperature (GHRSST) datasets L2 as shown in Figure 2-5.

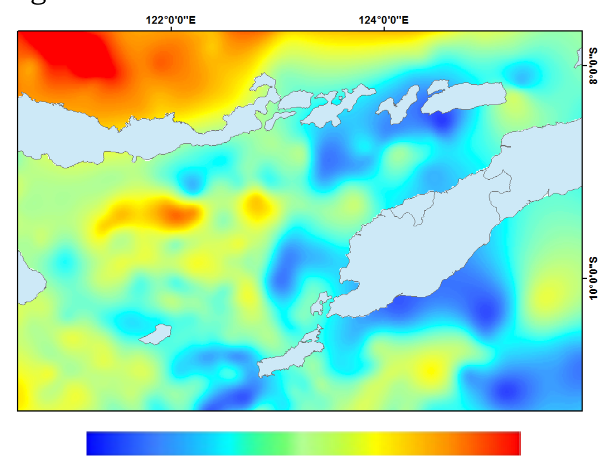


Figure 2-5: MUR SST in Mei 1st, 2017

Figure 2-5 shows the spatial distribution of SST in Mei 1st, 2017. The blending process of SST data from IR and MW sensors provides an advantage where the data has high spatial resolution up to 1 km and is free of cloud cover. MUR SST data is available in daily basis. With cloud-free images and high spatial resolution then this data is appropriate for use as a comparator in the validation process, (*https://coastwatch.pfeg.noaa.gov/erddap/index.html*).

SST data from IR sensor records SST on the skin layer with very thin depth of about 550μm, While SST from MW sensor record subskin SST which is integrated dept from surface up to about 1 mm. MUR SST was produced by applying strict quality control. The optimum interpolation process between multiple data sources with different spatial resolution was performed by applying the weight computation data method. The bias correction is performed on sensors error, so that the data obtained are bias adjusted. By using diurnal phase screening method, MUR SST can be produced using both day time and night time data (Chin *et al.* 2013).

2.4 Collocation criteria

Varians error analysis are conducted by using collocation between Himawari-8, MUR SST and buoy data. Himawari-8 data at the same location as the buoy within radius of 2 km (spatial resolution of Himawari-8) were selected, while MUR SST will be collocated with buoy within radius of 1 km (spatial resolution of MUR SST).

The data from Himawari-8 used in this study is level 3 hourly skin SST. The data is then collocated with the closest buoy data within 15 minute period. Dataset of cloud free Himawari-8 SST were match up with buoy and MUR SST.

Since MUR SST data used in this study is daily data, then Himawari-8 data and buoy data should be calculated in daily average.

The buoy data used in this analysis is the SST at a depth of 3 meters, while Himawari-8 data used is skin SST. Based on Donlon *et al.* (2002), there is a difference between skin SST with bulk SST (ΔT_{dept})as follows:

$$\Delta T_{dept} = SST_{skin} - SST_{depth} \qquad (2\text{-}1)$$

In this study, the corresponding data between the SST of Himawari-8 and buoy is separated into day time data and night time data, so the ΔT_{dept} of Himawari-8 and buoy will also be separated into day time and night time. When data is recorded between 06.00 – 17.00 local time then set to daytime data, while if recorded between 18.00 - 05.00 local time then set to be night time data. Therefore in this study skin SST of Himawari-8 will be corrected with the value of ΔT_{dept} before compared with buoy data and MUR SST. Himawari-8 SST both day time and night time are used in three-way error analysis.

Since MUR SST represents subskin SST which is lays only about 1mm below surface, so in this study, the data of MUR SST should be corrected with the value of ΔT_{dept} before compared with buoy data and Himawari-8. ΔT_{dept} of MUR SST and buoy were obtained from differences of MUR SST data with daily average of buoy data.

2.5 Three-way error analysis

Three-way error analysis method based on O'Carroll *et al* (2008). The error variance is describe as follows:

$$\sigma_1^2 = 0.5\,(V_{12} + V_{31} - V_{23}) + (r_{12}\sigma_1\sigma_2 + r_{31}\sigma_3\sigma_1 - r_{23}\sigma_2\sigma_3)$$
$$\sigma_2^2 = 0.5(V_{23} + V_{12} - V_{31}) + (r_{23}\sigma_2\sigma_3 + r_{12}\sigma_1\sigma_2 - r_{31}\sigma_3\sigma_1)$$
$$\sigma_3^2 = 0.5(V_{31} + V_{23} - V_{12}) + (r_{31}\sigma_3\sigma_1 + r_{23}\sigma_2\sigma_3 - r_{12}\sigma_1\sigma_2) \qquad (2\text{-}2)$$

σ_i^2 are error variance of observation type i. (i = 1, 2 and 3), V_{ij} is the variance of the difference between observation type i and$j$, and r_{ij} is the correllation of error between observation type i and$j$.

If the random errors of σ are assumed to be uncorrellated (explanation of this assumption is based on O'Carroll *et al* (2008), in appendix A) , and observation type 1, 2, and 3 are Himawari-8 Satellite (*H*), Buoy (*B*), and

MUR SST (*M*) respectively, then the equation of three-way error analysis can be derived as follows:

$$\sigma_H = \sqrt{0.5(V_{HB} + V_{HM} - V_{BM})}$$
$$\sigma_B = \sqrt{0.5(V_{HB} + V_{BM} - V_{HM})}$$
$$\sigma_M = \sqrt{0.5(V_{HM} + V_{BM} - V_{HB})} \qquad (2\text{-}3)$$

Since MURSST data is available in daily data format, then Himawari-8 data and buoy of data should be averaged to daily format before three way error analysis was performed.

3 RESULTS AND DISCUSSION

3.1 Initial comparison between Himawari-8, MUR SST and buoy SST

Variability of SST in Savu sea during December 2016 to July 2017 was displayed in Figure 3-1.

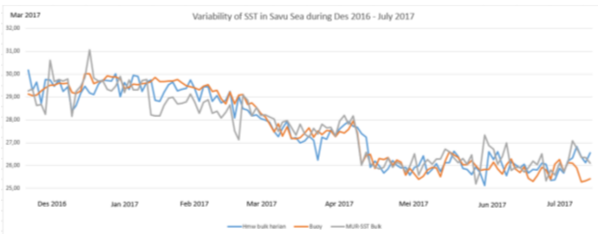


Figure 3-1: Variability of SST in Savu sea during December – July 2017

Figure 3-2 shows SST in Savu sea derived from Himawari-8, MUR SST and buoy. Generaly SST in Savu sea experienced monthly fluctuations. During December to February, SST is relatively high with a range of 28°C to 31°C, then decreased in March. The lowest SST was found in June-July with a range of 25°C to 27°C.

Spatial distribution of SST from Himawari8 and MUR SST can be seen in Figure 3-2.

Based on Figure3-2, it can be seen that the SST of Savu sea in June 2017 was relatively cold ranged from 25°C to 27°C. The spatial distribution of SST from the himawari indicates a cold SST around 124°E – 8°S, this is slightly different from the MUR SST which shows the distribution of cold SST that spread from 8°S to 10°S

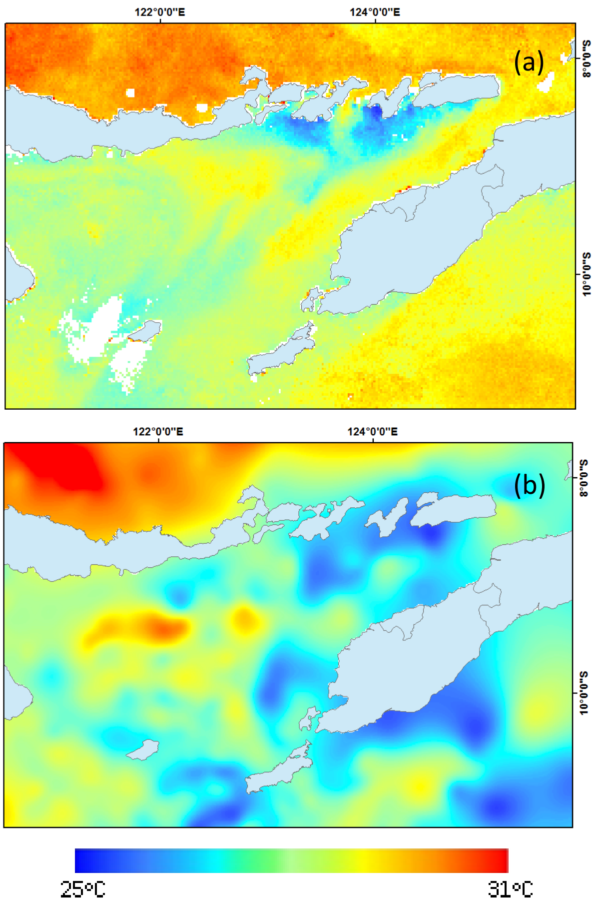


Figure 3-2: Spatial distribution of SST in June 2017 derived from Himawari-8 (a) and MUR SST (b)

To analyze accuracy of Himawari-8, buoy, and MUR SST by using three-way error analysis, we need to know standard deviation and correlation between different observation types of SST. In this analysis, the comparison is performed using Pearson Correlation and calculation of standard deviation. Values of R^2 from Comparison between different observations can be seen in Figure 3-3.

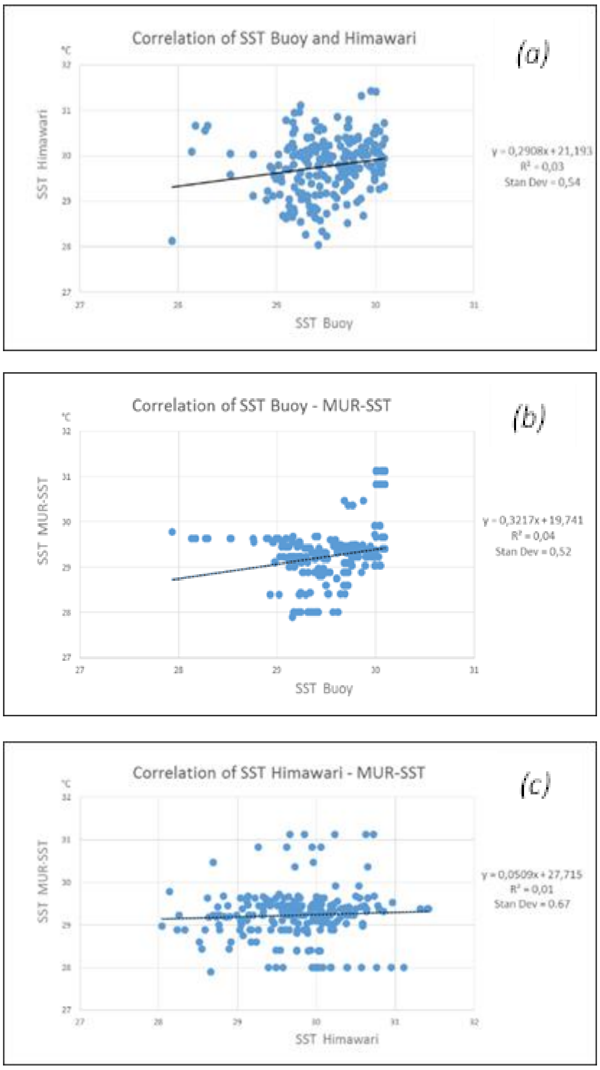


Figure 3-3: Correlation coefficient of buoy and Himawari-8 *(a)*, buoy and MUR SST *(b)*, Himawari-8 and MUR SST *(c)*

Based on Figure 3-3, Corrrellation coefficient between buoy with Himawari-8 SST is relatively low about 0.03. A higher coefficient is indicated by the correlation between buoy with MUR SST about 0.04. The lowest correlation is shown by the SSTof Himawari-8 with MUR SST about 0.01. Generally, it can be said that the correlation between different observations type is relatively very small. This shows that the three types of data do not affect each other and eligible to be analyzed using three way error method.

Standard deviation of SST from buoy, Himawari and MUR-SST can be seen in Table 3-1.

Table 3-1: Standard deviation and Mean of SST for each observation type

No	Type	Std Dev
1	Himawari 8	0.63
2	Buoy	0.39
3	MUR SST	0.61

Table 3-1 shows the the standard deviation of Himawari-8, buoy, and MUR SST respectively. the best standard deviation was provided by SST from buoy with the value of 0.35 while MUR SST and Homawari 8 were 0.61 and 0.63.

Clear cloud data in collocated time and space between Himawari-8 SST with buoy data and MUR SST are selected. The number of 2,264 match up data were obtained. The data were then separated into day time data and night time data.

Analysis of himawari-8 with buoy data shows the ΔT_{dept} of each observation type as presented in Table 3-2.

Table 3-2: ΔT_{dept} of Himawari-8, MUR SST and buoy

No	Type	ΔT_{dept} (°C)
1	Himawari 8 – Buoy 1 (day)	-2.62
2	Himawari 8 – Buoy 1(night)	-2.32
3	Himawari 8 – Buoy 2(day)	-2.53
4	Himawari 8 – Buoy 2(night)	-2.49
5	MUR SST – Buoy	0.50

ΔT_{dept} between day time data of himawari-8 with data buoy in location 1 is -2.62 °C, while during night time ΔT_{dept} in the same location is -2.32 °C. ΔT_{dept} in location 2 during day time and night time were -2.53 °C and -2.49 °C respectively. Skin temperature of Himawari-8 was lower than the temperature data at a depth of 3 meters as measured by the buoy. ΔT_{dept} during day time was higher than that of night time. Analysis of MUR SST with buoy shows ΔT_{dept} of the collocated data. ΔT_{dept} of daily average buoy data with daily MUR SST was 0.5 °C.

The Himawari-8 data and MUR SST should be corrected using the ΔT_{dept} before apply analysis of error. Differences average between Himawari-8, buoy and MUR SST were calculated to get the value of variance as shown in Table 3-3.

Table 3-3: Difference average of Himawari-8, MUR SST and buoy

No	Type	Diff average (°C)
1	Himawari 8 - Buoy	-0.25
2	Buoy – MUR SST	0.48
3	MUR SST – Himawari 8	-0.24

As seen in Table 3-3, the differences average between Himawari-8 and buoy was -0.25 °C, indicate that temperature of Himawari-8 was lower than buoy data. Differences average between buoy and MUR SST was 0.48 °C, while MUR SST and Himawari-8 was -0.24 °C. The differences between Himawari-8, buoy and MUR SST are used to define the variance of each type (V_{ij}) which are then used as input in equation (3).

Variance of different observation type that used to calculate error based on O'Carroll *et al* (2008) are presented in Table 3-4.

Table 3-4: Variance of the difference SST

No	Type	Variance
1	Himawari 8 - Buoy	6.34
2	Buoy – MUR SST	1.53
3	MUR SST – Himawari 8	7.71

From Table 3-4 can be seen that variance of differences between Himawari-8 wirh buoy was 6.34, while variance of differences between buoy with MUR SST was 1.53. The highest variance of differences was presented by Himawari-8 with MUR SST at 7.71.

Table 3-5 shows the error variance of σ_H, σ_B and σ_M for Himawari-8, buoy, and MUR SST respectively.

Table 3-5: Error analysis of each observation type

No	Himawari-8(°C)	Buoy(°C)	MUR SST(°C)
	2.50	0.28	1.21

From the calculation as in Table 3-5, it can be seen that error variance of Himawari-8 SST was 2.50°C, buoy SST was 0.28°C, and MUR SST was 1.21°C.

The calculation results for each type of observation is in accordance with the prediction that the error varians of buoy data has the smallest value. This is because the temperature measured by the buoy is bulk temperature at a depth of 3 meters which is not directly affected by air-sea interaction. Therefore the buoy data can be used as a reference in SST validation of satellite data. The value of buoy error is consistent with Emery and Baldwin (2001), who found RMS error of buoy SST about 0.4°C, while Xu and Ignatov (2010), using three-way error analysis, found that the error of buoy is around 0–0.6°C with median value at 0.26 °C. O'Carroll *et al.* (2008) even got a smaller buoy error value of about 0.23 °C.

The SST of Himawari-8 has the greatest errors or least accurate compared to the buoy and MUR SST. This is corresponded to Liang *et al* (2016), who found that the IR band of Himawari-8 has an error bias between 0.2-0.5°C depend on the wavelength. Meanwhile Kurihara *et al.* (2016), found that the Himawari-8 eror against the buoy was 0.16°C to 0.59°C. To improve the validation of the data Himawari-8, longer timeseries of satellite data and more buoy data are needed.

MUR SST error is better than that of Himawari-8. Chin *et al.* (2013) stated that MUR SST is developed based on Group for High Resolution Sea Surface Temperature (GHRSST) data in both IR and MW wavelengths that have been validated on bias and standard deviation. In addition, SST data from the MW sensor also has the advantage of its ability to penetrate cloud cover, so the errors caused by cloud contamination are relatively small.

4 CONCLUSION

Data of Himawari-8 has significant differences compared to data of buoy. The temperature differences of Himawari-8 data and buoy data were ranges from 2.32°C to 2.62°C while differences of MUR SST and buoy data was about 0.5°C. Error variance of Himawari-8, buoy and MUR SST were 2.5 °C, 0.28 °C and 1.21 °C respectively.

The variance error analysis of Himawari-8, buoy and MUR SST shows that buoy data has the highes accuracy, followed by MUR SST and Himawari-8. MUR SST have the advantage of provide high spatial resolution and free cloud coverage data by combining IR and MW satellite image. While Himawari-8 have the advantage of temporal resolution by providing hourly data.

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