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ANALISIS DATA OSEANOGRAFI MARINE COPERNICUS: STUDI PERBANDINGAN DENGAN PENGUKURAN BUOY RAMA

MARINE COPERNICUS OCEANOGRAPHIC DATA ANALYSIS: A COMPARATIVE STUDY WITH BUOY RAMA MEASUREMENTS

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ABSTRAK

Data oseanografi seperti Suhu Permukaan Laut (SPL), salinitas, dan *Sea Surface Height* (SSH) memiliki peran yang penting dalam penelitian terkait laut, seperti perikanan dan biologi laut. Penelitian ini menganalisis akurasi dari data Marine Copernicus dengan cara membandingkan data dari *buoy* RAMA yang berada di Samudera Hindia. Hasil penelitian menunjukkan korelasi yang kuat untuk SPL (r=0.988, R2=0.976, bias -0.020, RMSE 0.110) dan salinitas (r=0.960, R2=0.921, bias -0.001, RMSE 0.119). Untuk SSH, setelah dilakukan koreksi mendapati korelasi yang tinggi dengan nilai bias yang rendah (r=0.934, R2=0.872, bias -0.000, RSME 0.032). Analisis pola musiman juga menunjukkan hubungan kuat dengan bias yang rendah (r=0.934, R2=0.872, bias -0.000, RSME 0.032). Analisis ini menunjukkan puncak nilai SPL pada periode April-Mei dan turun paling rendah pada Bulan September. Untuk data salinitas mengalami kenaikan pada periode April ke Juli-Agustus sebelum menurun kembali. Nilai SSH naik pada periode Januari-Juni, dan menurun setelahnya. Hasil ini menunjukkan data Marine Copernicus memberikan data yang dapat diandalkan untuk perkiraan nilai SPL, salinitas, dan SSH.

Kata Kunci: Suhu Permukaan Laut, Salinitas, Buoy RAMA, Marine Copernicus

ABSTRACT

Oceanographic data such as Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and Sea Surface Height (SSH) have a significant role in understanding ocean related studies, such as fisheries and ocean biology. This study analyzed the accuracy of Marine Copernicus datasets by comparing with data from buoy RAMA in the Indian Ocean. The results show a strong correlation for SST (r=0.988, R2=0.976, bias -0.020, RMSE 0.110) and SSS (r=0.960, R2=0.921, bias -0.001, RMSE 0.119). For SSH, after correction also has strong correlation with lower bias (r=0.934, R2=0.872, bias -0.000, RSME 0.032). The seasonal trend analysis shows SST peaks in April-May and declines to its lowest in September, while salinity increases from April to July-August before decreasing. SSH has a rising trend from January to June and declines afterward. These findings suggest that Marine Copernicus data provide reliable SST, SSS, and SSH estimates.

Keywords: ***Sea Surface Temperatures, Salinity, Sea Surface Heights, Buoy RAMA, Marine Copernicus***

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PENDAHULUAN

In recent decades, remote sensing technology and spatial modeling have enabled global monitoring of ocean conditions with high temporal and spatial resolution. With many nations contribute in developing the system and models, it remarkably promoted the development of ocean observing technologies (Lin & Yang, 2020). Oceanographic data such as Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and Sea Surface Height (SSH) are among the key parameters used in marine studies (Meyssignac et al., 2017), particularly in supporting research related to fisheries, marine biology, and climate change. These data not only provide information about the physical conditions of the ocean but also play a crucial role in modeling and predicting habitats, such as for skipjack tuna, which highly depends on oceanic environmental conditions (Syah et al., 2022; Zainuddin et al., 2023).

Marine Copernicus is one of the widely used data sources for various analyses related to marine and fisheries studies (von Schuckmann et al., 2021). The data produced are model-based, derived from multiple sources such as data from satellites and in-situ observations (Anais P, 2024). Relatively has high resolution both spatial and temporal makes this data source to be one of the main sources for ocean-related research. While the models still actively developed, as model-based data, validation is necessary using in-situ data, one of which is obtained from buoy measurements (Byrne et al., 2023).

The RAMA (Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction) buoy array is an in-situ measuring instrument deployed in the Indian Ocean with high temporal resolution (M. J. McPhaden et al., 2018). This device is equipped with various sensors that measure oceanographic parameters, including surface temperature, salinity, sea surface height, wind speed, water pressure, and more. Data from the RAMA buoy have been available since the year 2003 (varying by deployment year), making them suitable for temporal analysis of oceanographic data (NOAA, 2025b). However, due to their limited number of buoys, this system lacks of spatial coverage compared to the Marine Copernicus datasets.

While Marine Copernicus datasets offer global coverage and continuous data, the performance especially in tropical oceanic regions still need to be reviewed to measure its performance (Hart-Davis et al., 2021). Weather conditions such as cloud cover, sensor issues, and algorithmic assumptions can be the sources of value deviation. In the other hands, buoy devices provide direct in-situ observations which relatively has more accurate value of the oceanographic data (Vogelzang & Stoffelen, 2022).

The SSH dataset has high correlation when compared to tide gauge (Lumban-Gaol et al., 2021). Since it compared with tide gauge located near shore, it may result differently when compared with in-situ observation in the ocean. The evaluation of SSS data model derived from Soil Moisture and Ocean Salinity (SMOS) satellite also conducted using RAMA buoys and Argo floats (Ratheesh et al., 2013) with result of RMSE at 0.36 and 0.34 psu respectively. It shown that the RAMA buoys can be used to validate remote sensing or model data.

This study aims to analyze the accuracy of Marine Copernicus data by comparing them with RAMA buoy data in the Indian Ocean. The research focuses on three parameters: SST, SSS, and SSH.

Understanding the accuracy of Marine Copernicus datasets has significant effect for researchers since the data models can be the primary sources alongside in-situ observation such as buoy. Furthermore, the research contributes to continuous monitoring of sustainable fisheries management with high availability and reliabity of the data.

MATERIAL AND METHODS

The research focuses on Eastern Indian Ocean (Figure 1) and carried out in November 2024 – March 2025. The Marine Copernicus datasets downloaded from data.marine.copernicus.eu and the buoy RAMA (Table 1) downloaded from www.pmel.noaa.gov. Both data use data from 2014-2023. Data processing and analysis were conducted at Laboratory of Remote Sensing and Marine Technology, Faculty of Fisheries and Marine Science, IPB University.

Table 1. Position of 6 buoys RAMA.

Buoy name	Locations
a	E 80.50 and N 00
b	E 80.50 and S -40
c	E 80.50 and S -80
d	E 90.00 and N 40
e	E 90.00 and N 00
f	E 95.00 and S -50

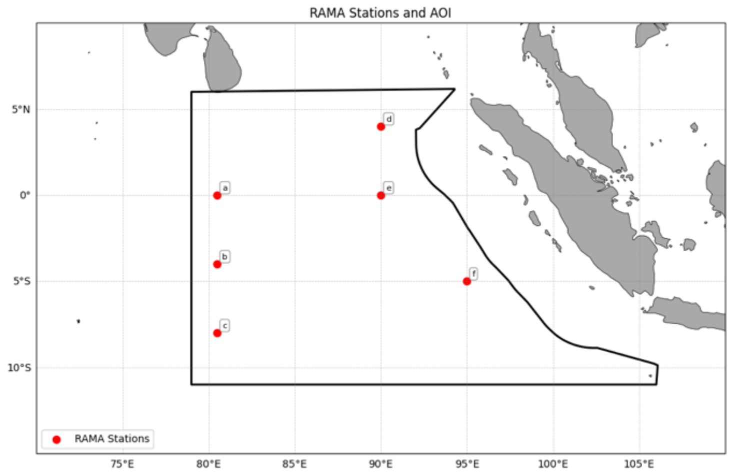

Figure 1. Map showing the location of RAMA buoys (red dot) and the AOI of this research (black line)

This research uses two primary datasets:

1. Marine Copernicus Dataset (Global Ocean Physics Reanalysis, GLORYS12V1)
    a. Resolution: 0.083° x 0.083°
    b. Parameters: SST, SSS, SSH
    c. Temporal Coverage: 2014-2023
2. Buoy RAMA in-situ Observations
    a. Resolution: in-situ measurements
    b. Parameters: SST, SSS, SSH
    c. Temporal Coverage: 2014-2023

The data processed uses Python 3.9 for the flexibility of our needs.

The workflow splitted into 3 steps:

1. data collection and preprocessing,
2. data comparison and validation, and
3. data visualization and analysis.

The data from Marine Copernicus comes in NetCDF format. Meanwhile, the data from RAMA portal downloaded in ASCII format. Both were converted to CSV for easier processing. Resampling into monthly basis was performed to match the temporal resolutions.

The research uses statistical and graphical methods to compare the data. Some metrics were used such as:

1. Correlation analysis: determines the strength of the relationship between data.
2. Coefficient of determination (R2): determines how well a regression model fits the data.
3. Bias calculation: Measures systematic differences between datasets.
4. Root Mean Square Error (RMSE): Evaluates prediction accuracy.
5. Seasonal trend analysis: Examines long-term variability in SST, SSS, and SSH

To visualize the metrics, the research uses scatter plots and regression analysis. Both were used to observe deviations between Marine Copernicus datasets and buoy RAMA data. Time series plots also used to analyze seasonal and interannual trends.

The data obtained in this research were analyzed quantitatively to assess the accuracy and reliability of Marine Copernicus datasets compared to buoy RAMA data. Several statistical methods were used:

1. Correlation Analysis

To evaluate the strength of the relationship between Marine Copernicus and buoy RAMA datasets, a Pearson correlation coefficient (r) was calculated for SST, SSS, and SSH. A higher r value indicates a stronger correlation between the two datasets.

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}}$$

where:
Xi = Marine Copernicus data values
Yi = buoy RAMA data values
X, Y = mean values of each dataset

2. Coefficient of Determination Analysis

To evaluate the performance of regression model between Marine Cocpernicus and buoy RAMA datasets, a coefficient of determination(R2) was calculated for SST, SSS, and SSH. The value interpreted where 1 means a perfect fit and zero values indicate the model performs worse than simply predicting the mean.

$$R^2 = \left(\frac{\sum(\mathrm{X_i} - \bar{\mathrm{X}})(\mathrm{Y_i} - \bar{\mathrm{Y}})}{\sqrt{\sum(\mathrm{X_i} - \bar{\mathrm{X}})^2 \sum(\mathrm{Y_i} - \bar{\mathrm{Y}})^2}}\right)^2$$

where:
Xi = Marine Copernicus data values
Yi = buoy RAMA data values
X, Y = mean values of each dataset

3. Bias Calculation

Bias represents the systematic difference between Marine Copernicus and buoy RAMA datasets. It was computed as:

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)$$

where:
Xi = Marine Copernicus data values
Yi = buoy RAMA data values
N = total number of data points

A positive bias indicates an overestimation by Marine Copernicus, while a negative bias suggests an underestimation.

4. Root Mean Square Error (RMSE)

RMSE was used to quantify the average deviation between Marine Copernicus and buoy RAMA measurements:

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2}$$

A lower RMSE value suggests better agreement between the two datasets.

5. Seasonal Trend Analysis

To analyze seasonal variations in SST, SSS, and SSH, a moving average smoothing technique was applied to the datasets. Monthly averages were computed to observe seasonal peaks and troughs.

The overall workflow of this research can be seen in Figure 2.

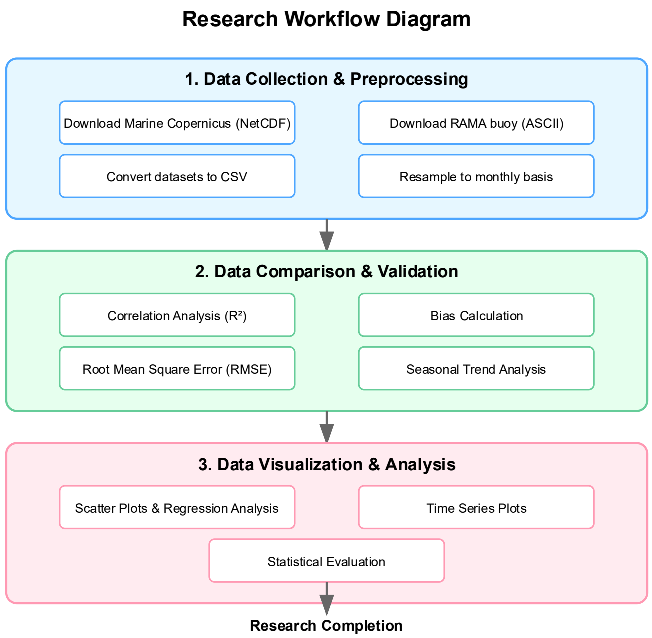

Figure 2. The workflow of the data analysis process

RESULTS

To evaluate the reliability of Marine Copernicus data, we compared SST, SSS, and SSH against in-situ buoy RAMA observations.

- **Sea Surface Temperature (SST)**

The regression model of SST between Marine Copernicus and Buoy RAMA has a strong relationship (r = 0.988, R^2=0.976, n =366), which indicating high agreement between both datasets in terms of detecting SST value. The bias value was quite low at -0.020^{0}C, suggesting that Marine Copernicus slightly underestimates SST value but in small margin. The RMSE value at 0.110 overall indicated the error margin is small. The comparison analysis for each site listed in Table 2 and Figure 3.

Table 2. Result of SST comparison

Site	RMSE	MAE	R²	Bias	r
All	0.110	0.085	0.976	-0.020	0.988
a	0.086	0.071	0.974	0.005	0.987
b	0.100	0.079	0.971	-0.040	0.985
c	0.125	0.097	0.974	-0.038	0.987
d	0.130	0.102	0.961	-0.061	0.980
e	0.092	0.077	0.970	-0.015	0.985
f	0.122	0.092	0.968	0.000	0.984

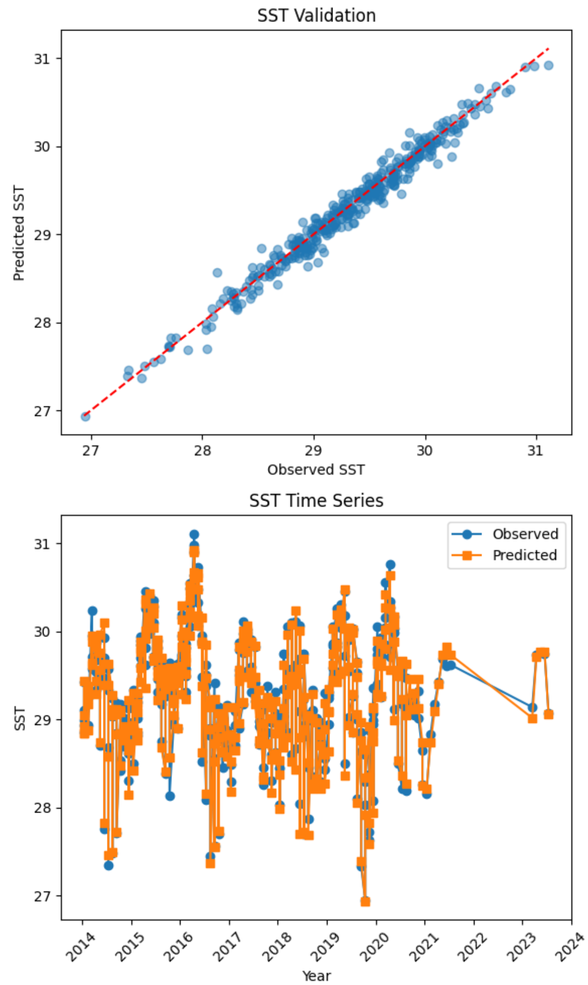

Figure 3. Comparison between SST buoy data (observed) and model data (predicted)

- **Sea Surface Salinity (SSS)**

The correlation between the SSS Marine Copernicus and RAMA buoys is relatively high (r = 0.960), with an R^2 value of 0.921 (n = 333). The bias was -0.001 PSU which indicated the model can predict the salinity value in small margin compared to the buoy data. The RMSE was 0.21 PSU, meaning Marine Copernicus slightly underestimates salinity levels compared to buoy RAMA but still in very good margin. The comparison analysis for each site listed in Table 3 and Figure 4.

Table 3. Result of SSS comparison

Site	RMSE	MAE	R^2	Bias	r
All	0.119	0.087	0.921	-0.001	0.960
a	0.102	0.077	0.926	0.040	0.962
b	0.091	0.069	0.952	-0.030	0.976
c	0.087	0.066	0.951	0.005	0.975
d	0.191	0.158	0.816	-0.106	0.903
e	0.144	0.101	0.869	-0.000	0.932
f	0.132	0.101	0.768	0.017	0.876

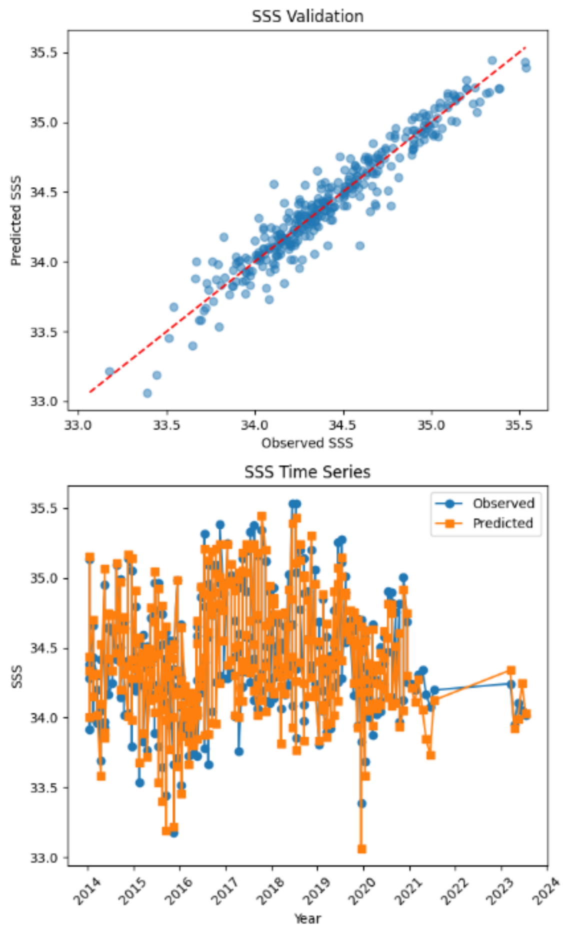

Figure 4. Comparison between SSS buoy data (observed) and model data (predicted)

- **Sea Surface Height (SSH)**

The correlation coefficient between SSH Copernicus and RAMA data is 0.934, indicating a high correlation, and the R^2 value is 0.872 with a bias of -0.724, as shown in Table 4. It indicated the model data can represented the buoy data but with offset (high bias) as seen in Figure 5.

Table 4. Initial result of SSH comparison

Site	RMSE	MAE	R^2	Bias	r
All	0.725	0.724	0.872	-0.724	0.934
a	0.730	0.729	0.675	-0.729	0.822
b	0.725	0.725	0.757	-0.725	0.870
c	0.714	0.712	0.898	-0.712	0.947
d	0.714	0.713	0.849	-0.713	0.921
e	0.734	0.733	0.904	-0.733	0.951
f	0.732	0.732	0.854	-0.732	0.924

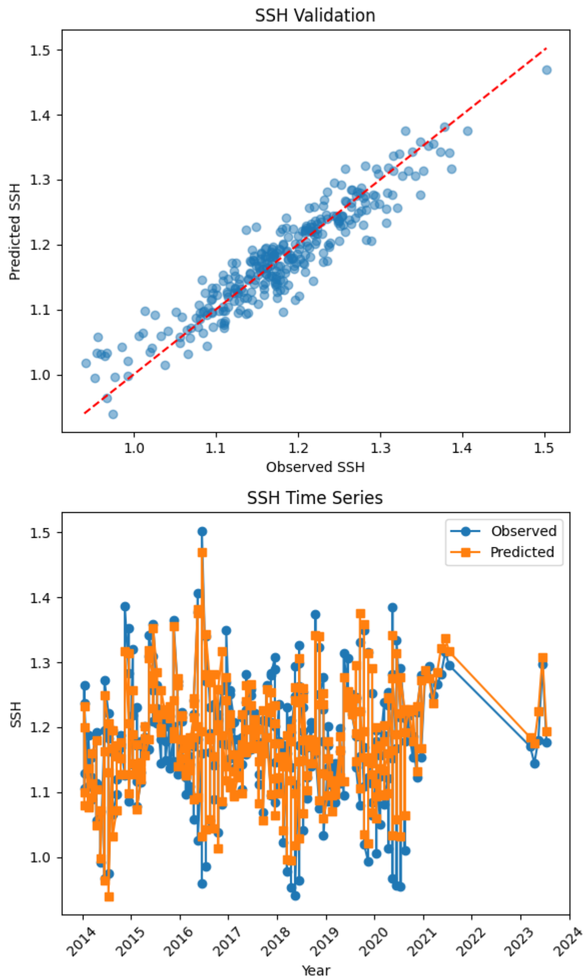

Figure 5. Initial comparison between SSS buoy data (observed) and model data (predicted

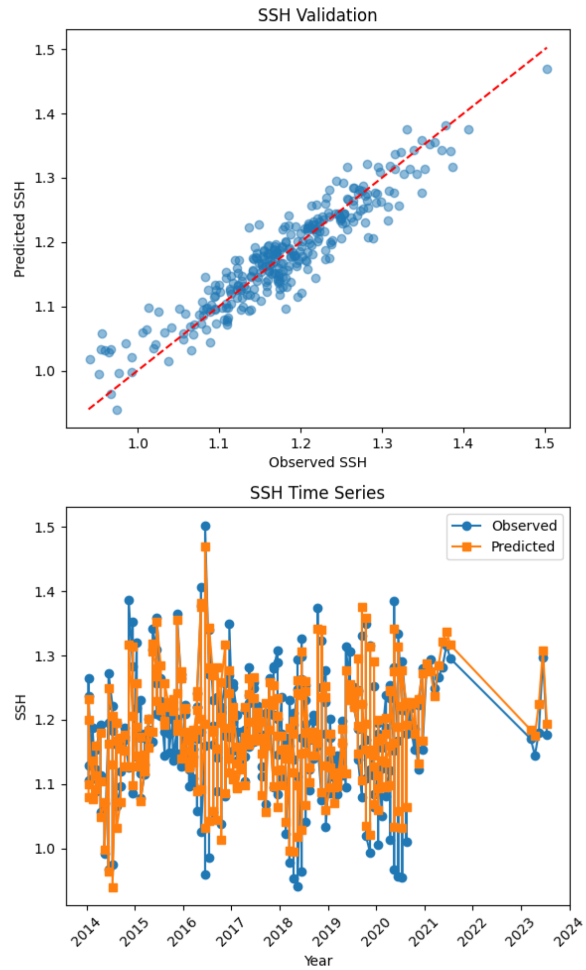

Figure 6. Comparison between SSH buoy data (observed) and model data (predicted)

Table 5. Result of SSH-corrected comparison

Site	RMSE	MAE	R^2	Bias	r
All	0.032	0.025	0.872	-0.000	0.934
a	0.030	0.024	0.675	-0.005	0.822
b	0.026	0.020	0.757	-0.001	0.870
c	0.043	0.035	0.898	0.012	0.947
d	0.038	0.031	0.849	0.011	0.921
e	0.026	0.021	0.904	-0.009	0.951
f	0.029	0.024	0.854	-0.008	0.924

The seasonal analysis highlights the impact of monsoon patterns on SST, SSS, and SSH fluctuations. The peak SST found in March-May, then decreased until the lowest point at September-October (Figure 7). SST hits the peak when in transition from wet to dry monsoon and vice versa. It shown that the SST value affected by monsoon pattern. In monthly basis, it shown that both data have similar pattern with different variance. It caused by the model data uses all the data inside the AOI instead of average of points like RAMA buoys.

In interannual analysis, it shown that SST affected by Indian Ocean Dipole (IOD). When the IOD is negative, it got higher peak SST as shown in 2016, 2019, and 2020. In the opposite, when the IOD is positive, the SST relatively has lower value.

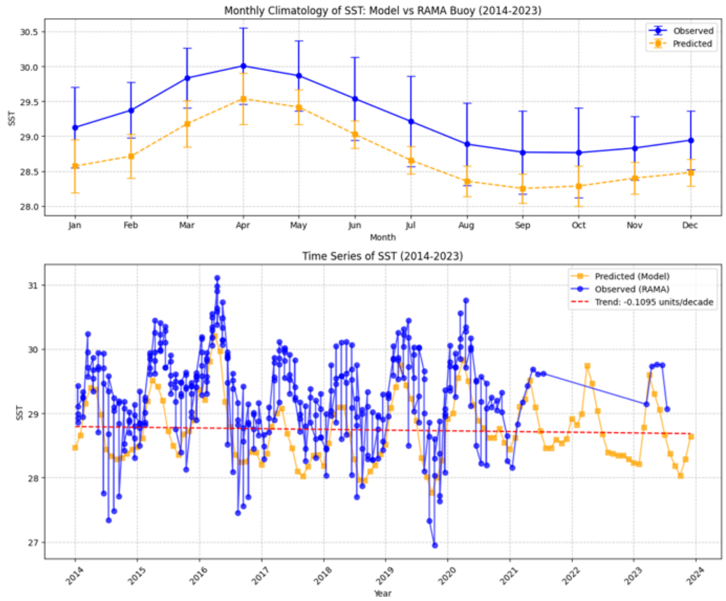

Figure 5. SST seasonal pattern in monthly (above) and time series (below) from 2014-2023

SSS increases from April to August, and peaking in July-August before gradually declining until the lowest point at December (Figure 8). Compared to SST, it has lower variance between month. The average values from model data relatively higher compared to the RAMA buoys. The gap created because the AOI also contained more data which leads to lower average salinity value. As presented in Figure 8, the buoy has more variance compared to the model data. Both monthly and interannual data shown the buoy retrieved more variance.

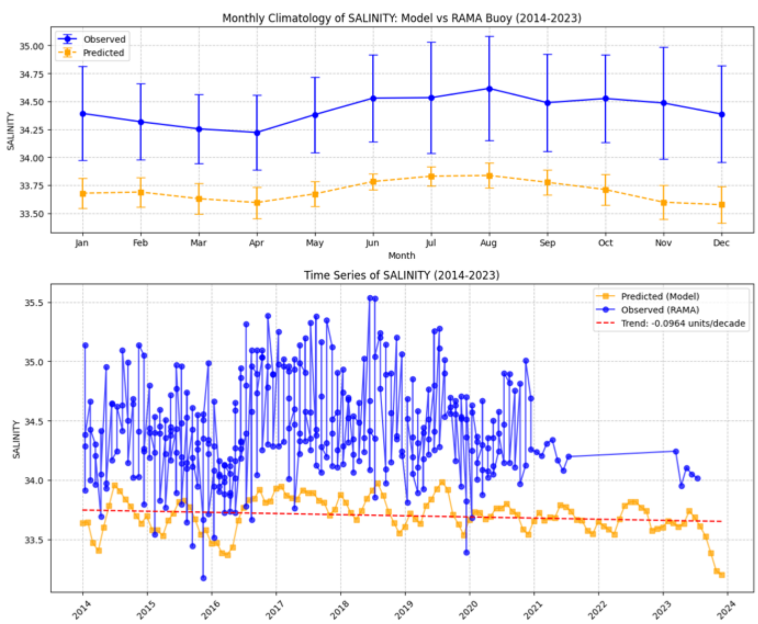

Figure 6. SSS seasonal pattern in monthly (above) and time series (below) from 2014-2023

SSH rises from January to June, and reaching the peak in June-July, before gradually decreasing. Both data have similar pattern in monthly basis (Figure 9). Since the buoys only records in specific places, it considerably has higher variance both in monthly and interannual basis.

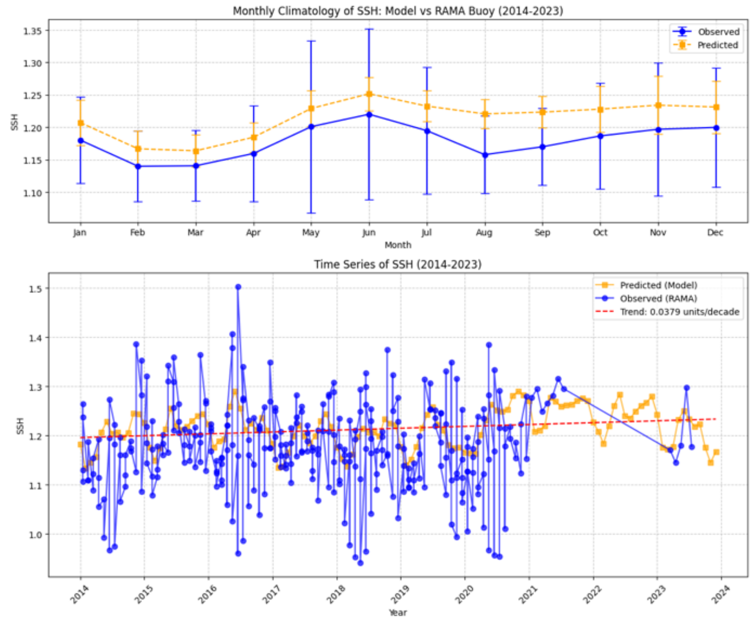

Figure 7. SSH seasonal pattern in monthly (above) and time series (below) from 2014-2023

DISCUSSION

The findings in this research show a strong correlation between Marine Copernicus dataset and buoy RAMA data in the Indian Ocean. The statistical and time series analysis for SST, SSS, and SSH indicate Marine Copernicus model can provide a reliable oceanographic data with minimal bias and acceptable R2 which important to evaluate model (Chicco et al., 2021).

For SST, the data model showed a high correlation (r = 0.988) with the buoy data, suggesting that the model can represent the real-world measurement quite accurate because 97.6 % variation in the SST buoy that is predicted by the statistical model (R2=0.975). It also has a low bias (-0.020) indicated the model can predict the value relatively close with the buoy data. With RMSE at 0.110, the variance of the model data also acceptable. This result similar with other research which shown that the SST model can predicted quite similar with the in-situ observation data (Moteki, 2022; Yang et al., 2021).

The correlation of SSS model data with buoy data showed a high value (R2=0.921) and low bias at -0.001 PSU. The model has a very good performance to predict the value since it relatively very closes with small bias. According to (Boutin et al., 2021), the model data tends to have lower value and expected to have lower variance which it proved on Figure 8.

The initial comparisons of SSH data model with buoy data showed a high bias. at -0.724 compared to SSS and SST. But the correlation value showed the data actually has a very good relationship in terms of pattern. When the data corrected using the bias value, the bias improved at 0.000 with RMSE of 0.032 cm. This suggests that while the model data contains some systematic bias, the high correlation indicated the data model can be corrected. In (Ballarotta et al., 2023) also showed the data corrected with constant bias to ensure the continuity of the data. The differences in how height is calculated may be a source of bias. In the data model, height is derived from the difference between the satellite altitude and the altimeter range, using an ellipsoid as the reference surface (CLS, 2025). Whereas, the SSH from buoys was calculated by integrating the specific volume anomaly of the sea water between the sea surface and 500 m depth (NOAA, 2025).

The SST data comparison has the highest correlation and the SSH has the lowest. The differences of sensitivity from buoy sensor compared to model data affected the correlation result since it leads more variance in buoy data. Compared to the SST data, SSS has lower R2 caused by more points has more bias shown in Figure 4. Compared between sites, not all sites have similar performance, such as site d and e have lower R2 compared to the rest.

The comparison between buoy data and whole model data in the AOI showed the mean value of model data relatively lower than the buoy data. It because the model data contains more variance since it covers more area.

The seasonal trend analysis revealed both data have similar pattern to detect peak and dip for monthly basis and interannual pattern. Both SST data peaked in April-

May and declined in September. The seasonal trend matches with research conducted by (Lumban-Gaol et al., 2021). The SSS data increased from April to August before it starts to decrease. The IOD events affected the interannual pattern of SSS (Sun et al., 2022). SSH showed a rising trend from January to June, then followed by a decline. In interannual SSH variations, it related to the monsoon season and IOD, which indicated the significance of IOD and monsoon season (Zhang & Mochizuki, 2022).

There was a strong agreement between Marine Copernicus and buoy RAMA data. However, some notes need to be addressed before using the model data. The model data covers more area than the buoy data, so it possible to have a strong correlation between data but in other area the model data can predict both underestimate or overestimate values (de Souza et al., 2021). Additionally, proximity to land can introduce bias also can makes some bias as the buoys are positioned relatively far from the coast, whereas the oceanographic parameters affected by land-ocean interaction (Ramesh et al., 2015).

CONCLUSION

This research confirms that the Marine Copernicus model provides reliable SST, SSS, and SSH estimates with a strong correlation to buoy RAMA data. SST showed the highest correlation, followed by SSS and SSH. Seasonal trend analysis also showed both data can capture the pattern quite similar, making the model can be used to be the primary data for future research. However, the bias exist which can make the model predict the values both underestimate or overestimate. Especially for the the area near shore, it can be refined with other in-situ data sources.

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