

Evaluating The Accuracy of Gridded Sea Surface Temperature Datasets in Central Java

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Abstract

This study evaluates the accuracy of three gridded sea surface temperature (SST) products, OSTIA, RAMSSA, and GAMSSA, against in-situ observations from the in-situ SST Quality Monitor (iQuam) in the waters of Central Java, Indonesia, for the period 2008–2024. Validation is performed for three spatial aggregations: a combined domain (Northern + Southern waters), the Northern Sea, and the Southern Sea. Performance is assessed using standard error metrics (bias, MAE, MAPE, RMSE), scatterplots, annual cycle patterns, and Taylor diagrams to synthesize correlation, variability, and centered RMSE. Results show that OSTIA and RAMSSA consistently outperform GAMSSA across all zones, with the strongest agreement in the Southern Sea, where correlations are highest, and errors are lowest in the Taylor diagram summary. The annual-cycle analysis indicates that all products reproduce the timing of the seasonal SST evolution, including the pronounced cool season in the Southern Sea during the southeast monsoon. However, variability is generally damped in gridded products, particularly in nearshore/complex waters of the Northern Sea. These findings support the operational use of OSTIA and RAMSSA for regional marine monitoring and climate services in Central Java, including anomaly-based advisories and early warning information for ocean-related climate hazards.

Keywords : Sea Surface Temperature, iQuam, OSTIA, RAMSSA, GAMSSA

INTRODUCTION

Anthropogenic climate change has significantly altered global ocean conditions, leading to warming seas, changing circulation patterns, and shifts in marine ecosystems (WMO, 2024; Marcott & Shakun, 2021). Sea Surface Temperature (SST) plays a pivotal role in ocean–atmosphere interactions, affecting extreme events such as El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), which strongly influence rainfall and temperature variability in Indonesia (Bronkhorst & Bhandari, 2021; Dunn *et al.*, 2022).

In Central Java, SST variability impacts monsoonal dynamics and coastal socio-ecological systems, including fisheries and aquaculture. Despite the importance of SST, direct observational networks like buoys and ship-based measurements provide limited spatial coverage (Zhao *et al.*, 2024). Conversely, satellite and reanalysis SST datasets such as the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA), the Regional Australian Multi-Sensor Sea Surface Temperature Analysis (RAMSSA), and the Global Area Coverage Multi-Sensor Sea Surface Temperature Analysis (GAMSSA) offer wide coverage but are subject to retrieval errors and model bias (Tresnawati *et al.*, 2022; Mao *et al.*, 2024).

Previous global and regional validations confirmed that OSTIA exhibits minimal bias and RMSE below 0.5°C globally (McLaren *et al.*, 2019; Tresnawati *et al.*, 2022). RAMSSA achieved comparable accuracy (Beggs *et al.*, 2019), while GAMSSA showed reliable results for large-scale monitoring but with higher errors in complex coastal environments (Wick *et al.*, 2023). However, few studies have specifically assessed the accuracy of SST datasets in Central Java waters.

Although numerous validation studies of satellite-derived SST products have been conducted globally and regionally, most of them focus on large ocean basins or the wider Indonesian seas (McLaren *et al.*, 2019; Tresnawati *et al.*, 2022). However, there is still a lack of detailed assessment in the Central Java region,

where the northern coastal waters are strongly influenced by riverine discharge and anthropogenic pressure. In contrast, the southern waters are dominated by open-ocean processes and monsoonal variability. This contrasting setting provides a unique natural laboratory to examine the performance of gridded SST datasets across tropical coastal-ocean-open ocean transitions. Therefore, this study offers novel insights by providing a focused comparison of OSTIA, RAMSSA, and GAMSSA products with in-situ SST Quality Monitor (iQuam) observations (Xu & Ignatov, 2014) in Central Java, Indonesia, to better understand their applicability for local climate services, fisheries management, and disaster risk reduction. These three products were selected because they are widely used multi-sensor gridded SST analyses for operational monitoring and climate applications, provide consistent long-term coverage from 2008 to 2024, and represent contrasting spatial resolutions (0.05 to 0.25°). This selection enables an explicit assessment of how resolution and analysis smoothing affect SST accuracy across a coastal-to-open-ocean setting in Central Java.

This study addresses this gap by evaluating OSTIA, RAMSSA, and GAMSSA against iQuam observations from 2008 to 2024, providing critical insights into the reliability of these datasets for regional climate monitoring and applications.

MATERIALS AND METHODS

The reference dataset is provided by the iQuam system from NOAA (NOAA, 2025), consisting of buoy and ship-based SST observations from 2008–2024 across the Java Sea (northern sea) and Indian Ocean sector (southern sea) of Central Java. SST evaluated gridded datasets are OSTIA, RAMSSA, and GAMSSA (Table 1). The datasets have spatial resolutions ranging from 0.05° to 0.25°. They are sourced from official data repositories such as the Copernicus Marine Environment Monitoring Service (CMEMS) and the Bureau of Meteorology (BoM), and distributed via NASA PODAAC.

In addition to source and spatial resolution, we summarize key product characteristics (product type, temporal resolution, general input characteristics, and spatial coverage) to clarify methodological differences among datasets. This information supports interpretation of performance differences, particularly those associated with resolution and analysis smoothing in coastal versus open-ocean conditions. The SST study area was evaluated based on iQuam observations in the North and South Seas of Central Java. Images of distribution are presented in Figure 1.

Grid data were adjusted to station coordinates using the bilinear interpolation method, as illustrated by Figure 2. This technique calculates a value's location as a weighted function from the four nearest grids based on their spatial distance (Zhang *et al.*, 2023). This method provides continuous data and prevents unreasonable increases in values between grids (Kim *et al.*, 2019).

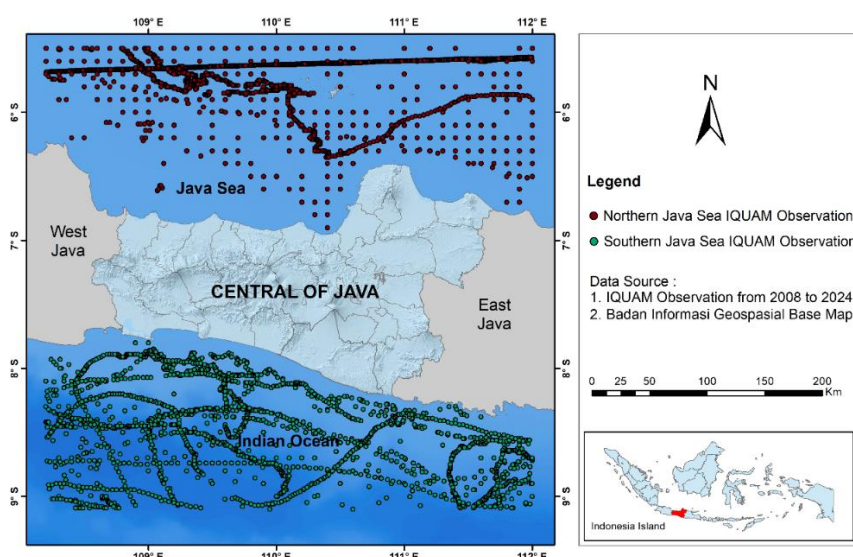


Figure 1. Spatial distribution of iQuam in situ SST observation points in the northern (Java Sea sector) and southern (Indian Ocean sector) waters of Central Java from 2008 to 2024

Table 1. Gridded Dataset Attribute

Dataset	Source	Spatial Resolution	Temporal Resolution	Product Type	Coverage	Characteristics
iQuam	https://www.star.nesdis.noaa.gov	In Situ (point)	Daily matchup (2008 to 2024)	QC in situ system	Global	QC in situ reference
OSTIA	https://marine.copernicus.eu	0.05°	Daily (2008 to 2024)	L4 gridded analysis	Global	L4 multi-sensor, high-res
RAMSSA	https://podaac.jpl.nasa.gov	0.083°	Daily (2008 to 2024)	L4 gridded analysis	Regional	L4 multi-sensor, regional
GAMSSA	https://podaac.jpl.nasa.gov	0.25°	Daily (2008 to 2024)	L4 gridded analysis	Global	L4 multi-sensor, coarse/smoothed

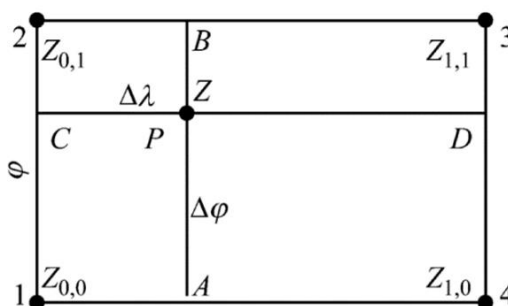


Figure 2. Interpolation of 4 points around (Zhang *et al.*, 2023)

Statistical Evaluation

The precision of the gridded dataset relative to observations is evaluated using four statistical metrics: Bias, Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and Root Mean Square Error (RMSE) (Frakusya *et al.*, 2022).

$$\begin{aligned}
 \text{Bias} &= \frac{1}{n} \sum_{i=1}^n (\text{Data Grid-Observation}) \\
 \text{MAE} &= \frac{1}{n} \sum_{i=1}^n |\text{Data Grid-Observation}| \\
 \text{MAPE} &= \frac{1}{n} \sum_{t=1}^n \left| \frac{y_t - \hat{y}_t}{y_t} \right| \times 100 \\
 \text{RMSE} &= \sqrt{\frac{1}{n} \sum_{i=1}^n (\text{Data Grid-Observation})^2}
 \end{aligned}$$

Bias measures the systematic tendency of estimates to differ from observations; MAE describes the average magnitude of absolute errors; MAPE expresses errors as a percentage of the observed value; and RMSE is sensitive to large errors because it uses the square of the difference. Referring to the classification developed by Moreno (Moreno *et al.*, 2013) in Table 2, the MAPE value can be interpreted in Table 2.

Visual Diagnostic Analysis

Visual diagnostics were used to complement summary error statistics and to interpret dataset behaviour across zones. Scatterplots (gridded SST vs iQuam) with an identity line reference line were used to examine agreement, systematic bias (offset from identity), dispersion (random error), and outliers. Monthly climatology (annual cycle) was analyzed to evaluate each product’s ability to reproduce the timing

(phase) and magnitude (amplitude) of seasonal SST variability in each zone. Taylor diagrams were then applied to summarize correlation, relative (normalized) standard deviation, and centered RMSE simultaneously, providing an integrated comparison of pattern similarity and variability representation across datasets (Taylor, 2001).

RESULT AND DISCUSSION

Figure 3 shows scatterplots for the Combined, Northern Sea, and Southern Sea zones. All zones show a clear linear relationship between gridded SST and iQuam, but performance varies by zone. The Southern Sea displays the tightest clustering along the identity line, indicating greater agreement and lower random error. In contrast, the Northern Sea shows greater scatter due to stronger coastal variability and unresolved nearshore gradients. Overall, OSTIA and RAMSSA match iQuam more closely than GAMSSA, which shows a stronger cold bias and wider dispersion, particularly in the Northern Sea, likely linked to resolution, smoothing, and coastal representativeness effects.

In the combined domain, RAMSSA yields the lowest MAE (0.285°C) and MAPE (0.951%), while OSTIA shows the bias closest to zero (-0.069°C), indicating minimal systematic error, and the lowest RMSE (0.454°C). GAMSSA exhibits a stronger cold bias (-0.300°C) and the largest errors (MAE 0.358°C; MAPE 1.194%; RMSE 0.556°C) (Table 3). Overall, OSTIA and RAMSSA provide more reliable SST estimates over the study region than GAMSSA.

A clear coastal–open-ocean contrast emerges from the zonal validation: performance degrades in the Northern Sea compared with the Southern Sea. In the Northern Sea, RMSE ranges from 0.531 - 0.633°C with MAE of 0.331 - 0.404°C and MAPE of 1.099 - 1.338%, whereas errors in the Southern Sea are substantially lower (RMSE 0.246–0.366°C; MAE 0.162 - 0.271°C; MAPE 0.552 - 0.920%) (Table 3). The reduced performance in the Northern Sea likely reflects stronger nearshore gradients, riverine influence, and higher sub-grid variability, which increase representativeness mismatch between point observations and grid-cell means (Zhao *et al.*, 2024; Wick *et al.*, 2023).

The higher errors observed in the northern coastal waters are consistent with previous findings that satellite-derived SST products tend to be less accurate in estuarine and river-influenced regions due to the strong influence of freshwater inflows and high turbidity (Zhao *et al.*, 2024). In Central Java, particularly along the Semarang–Demak and Pekalongan routes, river discharge and coastal sedimentation are known to alter near-surface thermal conditions, which may explain the reduced performance of GAMSSA in this region. Conversely, the Southern Sea shows improved accuracy across all datasets, consistent with global studies reporting better performance in open-ocean conditions with reduced anthropogenic disturbance (Wick *et al.*, 2023). These results indicate that the relative stability of the southern waters enhances the consistency of OSTIA and RAMSSA retrievals.

Compared with broader evaluations across Indonesian waters (Tresnawati *et al.*, 2022), the present study highlights that regional-scale differences within Central Java can significantly influence dataset reliability. These results underscore the importance of localized validation, as applying global or national-level performance metrics may mask critical coastal-to-open-ocean contrasts that are essential for climate monitoring and early warning systems in densely populated regions.

In the Southern Sea, precision improves across all datasets. OSTIA achieves an MAE of 0.162°C, a MAPE of 0.552%, and an RMSE of 0.246°C, while RAMSSA and GAMSSA also show relatively small errors (RMSE 0.284°C and 0.366°C, respectively). This enhanced consistency is likely attributable to more stable open-ocean conditions with minimal freshwater influence and reduced anthropogenic disturbance, thereby improving the reliability of gridded SST analyses in the southern waters.

Table 2. Interpretation of typical MAPE values

MAPE	Interpretation
< 10	Highly accurate forecasting
10-20	Good forecasting
20-50	Reasonable forecasting
>50	Inaccurate forecasting

Annual Cycle Pattern Analysis

Figure 4 shows the monthly climatology (annual cycle) for the three zones. The monthly climatology highlights distinct seasonal SST behavior across zones. The Combined and Northern Sea zones show a moderate annual cycle, with SST generally increasing toward late boreal winter–early boreal spring and decreasing during mid-year. The Southern Sea presents the strongest seasonality, characterized by a pronounced cooling during the southeast monsoon (approximately June–October), which is widely associated with wind-driven coastal upwelling along the southern Java–Sumatra margin (Susanto *et al.*, 2001). All gridded products reproduce the timing of the seasonal evolution, indicating skill in capturing large-scale monsoon-driven SST variability. However, compared with iQuam, gridded products tend to have slight month-to-month variability, particularly in the Northern Sea, where coastal complexity and stronger sub-grid variability can lead to larger representativeness errors between point observations and grid-cell averages. In the Southern Sea, agreement among datasets is generally higher, consistent with the Taylor diagram synthesis, suggesting that open-ocean conditions and more coherent seasonal forcing favor better performance of gridded analyses.

Taylor Diagram Analysis

Figure 5 synthesizes performance using Taylor diagrams and provides an integrated view of correlation, relative variability, and centered RMSE for each zone. The Southern Sea shows the strongest overall performance, with OSTIA and RAMSSA closest to the reference point (iQuam), indicating higher correlation and lower centered RMSE than in the Combined and Northern Sea zones. In the Combined domain, all products show moderate. At the same time, the Northern Sea displays the largest departure from the reference, consistent with the increased scatter and reduced agreement noted in Figure 3. Across zones, GAMSSA tends to exhibit lower correlation and/or larger centered RMSE than OSTIA and RAMSSA, reflecting the compounded effects of coarser spatial resolution and stronger smoothing that can reduce the representation of observed variability (normalized standard deviation typically below the reference). Overall, the Taylor-diagram synthesis reinforces the conclusion that OSTIA and RAMSSA are more suitable for operational and applied SST monitoring in Central Java waters, with the Southern Sea being the most reliably represented among the evaluated zones.

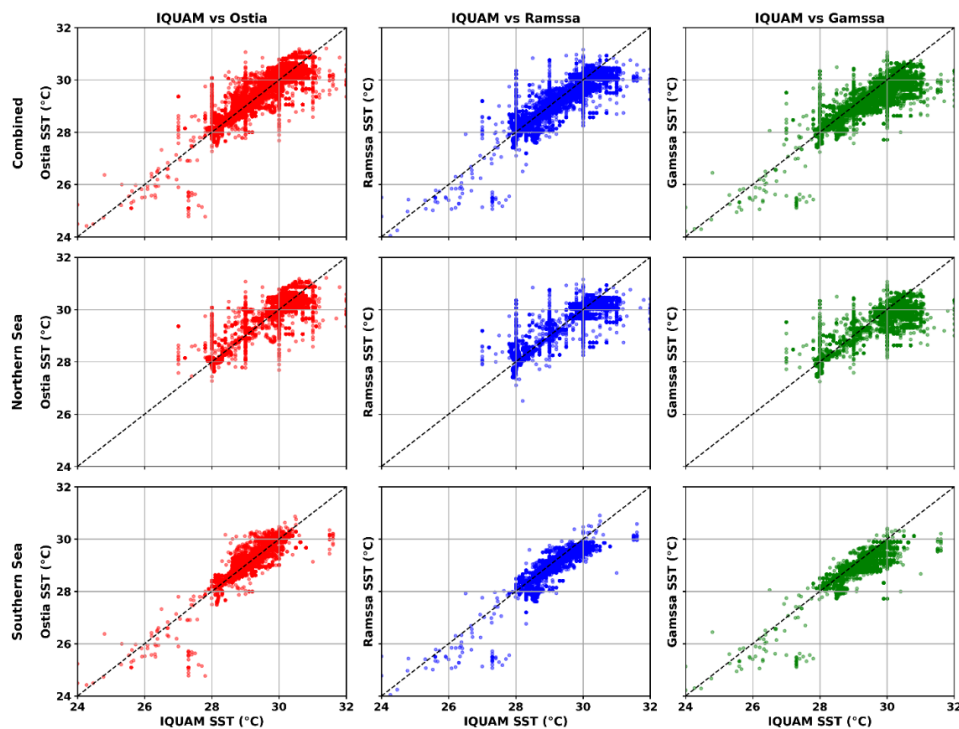


Figure 3. Scatter Plot of Datagrid SST against iQuam

Performance and Implication for Climate Services

As an SST product in the Southern Ocean area of this study, the OSTIA has generally shown rather excellent accuracy and consistency. With minimal absolute errors, the RAMSSA appears to be a reasonable substitute; however, the GAMSSA should be used with caution due to its tendency to produce greater deviations, particularly in the northern coastal area. These results underscore the need to select the appropriate SST datasets for tropical climate monitoring and regional oceanographic uses. These findings align with previous global validation studies confirming OSTIA as the most accurate SST dataset for tropical oceans (McLaren *et al.*, 2019; Tresnawati *et al.*, 2022). RAMSSA remains a reliable alternative, while GAMSSA should be used cautiously in coastal monitoring. The results emphasize the importance of dataset selection in climate services, fisheries management, and disaster preparedness in Indonesia.

Table 3. Evaluation of SST Datagrid Statistics against iQuam

Zone	Datagrid	Bias	MAE	MAPE	RMSE
Combine Sea	OSTIA	-0.069	0.293	0.985	0.454
	RAMSSA	-0.203	0.285	0.951	0.482
	GAMSSA	-0.300	0.358	1.194	0.556
Northern Sea	OSTIA	-0.109	0.362	1.211	0.531
	RAMSSA	-0.233	0.331	1.099	0.559
	GAMSSA	-0.337	0.404	1.338	0.633
Southern Sea	OSTIA	0.008	0.162	0.552	0.246
	RAMSSA	-0.147	0.196	0.667	0.284
	GAMSSA	-0.231	0.271	0.920	0.366

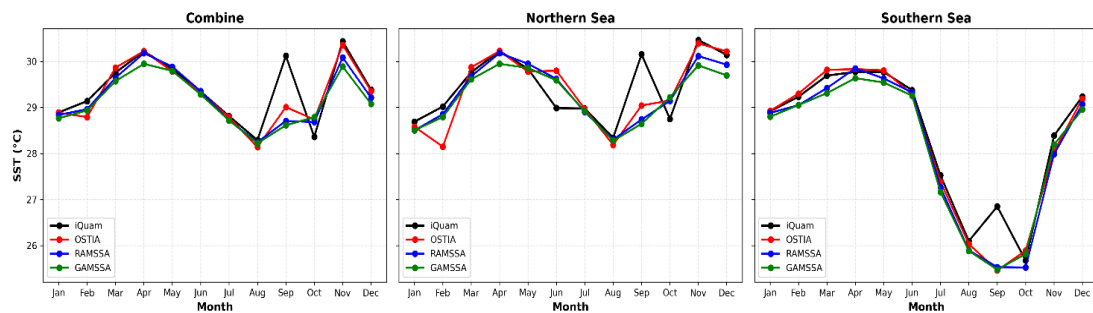


Figure 4. Monthly SST Climatology

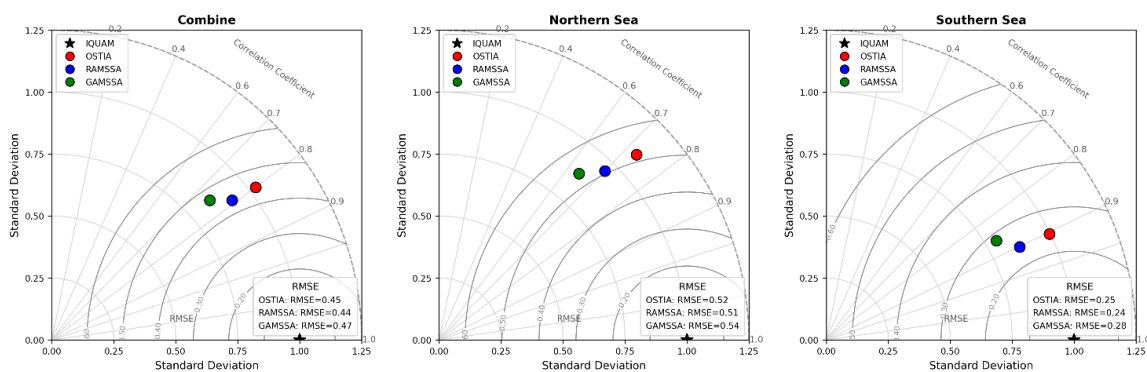


Figure 5. Taylor diagrams summarizing the performance of gridded SST products relative to iQuam for the Combined, Northern Sea, and Southern Sea zones. The diagrams integrate correlation coefficient, normalized standard deviation, and RMSE.

The zone-dependent performance identified in this study has direct relevance for operational ocean–climate services in Central Java. First, the consistently better agreement between OSTIA and RAMSSA, particularly in the Southern Sea, supports their use for routine monitoring of SST variability and anomaly-based products (e.g., monthly anomaly maps and seasonal outlook context) with greater confidence than coarser analyses. Second, the stronger uncertainty in the Northern Sea highlights the need for caution when translating gridded SST into coastal-impact advisories, where nearshore gradients are sharp, bias correction or multi-product blending may be required, and communication should emphasize uncertainty ranges. Third, the ability of gridded products to reproduce the seasonal cooling signal in the Southern Sea indicates utility for tracking monsoon-related upwelling variability, which is relevant to fisheries, aquaculture, and marine ecosystem conditions. Finally, the validated datasets can provide a foundation for marine hazard information services, such as marine heatwave monitoring using standardized definitions and thresholds (Hobday *et al.*, 2016), and for strengthening early-warning communication as part of broader climate-service frameworks (WMO, 2022). Future service development may benefit from combining high-resolution gridded SST with in situ monitoring and adopting routine verification to ensure product reliability over time.

CONCLUSION

This study evaluated the performance of three gridded SST products (OSTIA, RAMSSA, and GAMSSA) against quality-controlled in situ observations from iQuam over Central Java waters for 2008–2024, using three spatial aggregations: Combined, Northern Sea, and Southern Sea. Overall, OSTIA and RAMSSA consistently show better agreement with iQuam than GAMSSA. Quantitatively, errors are lowest in the Southern Sea (RMSE = 0.246 - 0.366 °C) and highest in the Northern Sea (RMSE = 0.531 - 0.633 °C), while the Combined domain exhibits intermediate performance (RMSE = 0.454 - 0.556 °C). Most products display a cold bias, whereas OSTIA shows near-zero bias in the Southern Sea. Visual diagnostics reinforce these findings. Scatterplots indicate tighter clustering around the identity line in the Southern Sea and larger dispersion in the Northern Sea, consistent with stronger coastal heterogeneity and representativeness mismatch between point observations and grid-cell means. Monthly climatology confirms that all products capture the seasonal SST evolution, including the pronounced cool season in the Southern Sea during the southeast monsoon. However, variability is slightly weaker in gridded analyses, especially in nearshore northern waters. Taylor diagrams further summarize this pattern by placing OSTIA and RAMSSA closer to the iQuam reference, particularly in the Southern Sea. These results support the preferential use of OSTIA and RAMSSA for operational SST monitoring and climate services in Central Java (e.g., anomaly-based advisories and marine hazard context). At the same time, GAMSSA and Northern Sea applications should be treated with greater caution. Future work should prioritize bias correction for coastal applications, multi-product ensemble approaches, and sustained verification using expanded in situ observations to improve reliability in complex coastal environments.

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