

EVALUATION OF NEAR-SURFACE POTENTIAL TEMPERATURE (GLORYS12V1) AGAINST IN SITU OBSERVATIONS IN THE VIET NAM EAST SEA

Tran Thi My Hong⁽¹⁾, Le Duc Quyen⁽²⁾

⁽¹⁾Faculty of Civil Engineering, Ho Chi Minh City University of Technology, Vietnam National University - Ho Chi Minh City

⁽²⁾Institute of Meteorology, Hydrology, Environment and Marine Sciences;

Received: 7 July 2026; Accepted: 21 September 2026

Abstract: This study evaluates the performance of the GLORYS12V1 ocean reanalysis data against in situ near-surface seawater temperature observations at eight hydrographic stations in Vietnamese coastal and offshore waters during 2003-2022. The evaluated GLORYS12V1 field is seawater potential temperature at the uppermost standard level, approximately 0.494 m depth. Monthly matched observation-reanalysis pairs were assessed using the Pearson correlation coefficient, Nash-Sutcliffe efficiency coefficient, mean absolute error, mean bias, and root-mean-square error. The analysis also examined characteristic monthly and annual mean temperature values, trends during 2003-2022, and ENSO-stratified deseasonalized anomaly errors. The results indicate that GLORYS12V1 reproduced the observed monthly temperature variability and seasonal cycle reasonably well at the eight evaluated stations, with correlation coefficients ranging from 0.869 to 0.984 and NSE values from 0.738 to 0.954. Performance varied among stations, with larger absolute errors at some Northern and North-central coastal stations and generally smaller errors at Southern and offshore stations. The regional annual mean near-surface temperature fields showed a persistent North-South thermal contrast and an increasing tendency during 2003-2022. ENSO-stratified analysis indicated differences in deseasonalized anomaly errors among La Niña, neutral, and El Niño conditions. Overall, the results provide a station-based assessment of GLORYS12V1 uppermost-level seawater potential temperature and support its use as a near-surface SST proxy at the evaluated locations, while highlighting the need for caution in coastal areas with strong seasonal and local variability.

Keywords: Sea surface temperature, hydrographic stations, Viet Nam East Sea, GLORYS12V1, ENSO.

1. Introduction

Sea surface temperature (SST) is a key indicator of upper-ocean thermal conditions and air-sea interaction. In Viet Nam East Sea, SST variability is strongly influenced by monsoonal forcing, surface heat fluxes, ocean circulation, coastal upwelling, and mesoscale processes [1-6]. Large-scale climate variability, particularly ENSO, can further modify regional SST anomalies through changes in atmospheric forcing and surface heat exchange.

Ocean reanalysis products provide spatially and temporally continuous information where

long-term in situ observations are limited. However, their performance can be affected by model resolution, atmospheric forcing, parameterization, data assimilation, and spatial mismatch between gridded products and point observations [7], [9], [10]. These limitations are particularly important in coastal and island environments, where shallow-water processes, complex coastlines, river influence, and strong thermal gradients may not be fully resolved by coarse-resolution products. Previous studies in Vietnamese waters have also shown that the accuracy of gridded ocean products can vary among stations and hydrographic regions [9]. Therefore, evaluation against local observations remains necessary before reanalysis data

Corresponding author: Tran Thi My Hong
E-mail: tranthimyhong@hcmut.edu.vn

is applied to regional marine-climate and oceanographic studies.

This study evaluates GLORYS12V1 uppermost-level seawater potential temperature (~0.494 m), used as a proxy for near-surface SST, against in situ observations from eight coastal and offshore hydrographic stations during 2003-2022. The study aims to quantify monthly agreement using standard performance metrics, distinguish seasonal-cycle skill from deseasonalized interannual-anomaly skill, assess the statistical significance of temperature trends, and examine ENSO-stratified error characteristics. The results are intended to clarify the strengths, limitations, and practical applicability of GLORYS12V1 across different hydrographic environments in Vietnamese waters.

2. Data and Methodology

2.1. Study data

The in situ dataset consisted of monthly mean near-surface seawater temperature observations from eight hydrographic stations: Bai Chay, Hon Dau, Sam Son, Con Co, Truong Sa, Phu Quy, Con Dao, and Tho Chu. The data were obtained from the Viet Nam Institute of Meteorology, Hydrology and Climate Change and covered the period from January 2003 to December 2022. The stations represent Northern, central, Southern, and offshore

hydrographic environments in Vietnamese waters (Figure 1). The records were available directly as monthly mean temperature values and were checked for missing, non-finite, and abnormal data before analysis. Each station contained 236-240 valid monthly observations, corresponding to a data completeness of approximately 98.3-100% (Table 1).

The seawater potential temperature reanalysis data was obtained from the Copernicus Marine Service (CMEMS). This study used the seawater potential temperature field from the GLORYS12V1 product (Product ID: GLOBAL_MULTIYEAR_PHY_001_030) over the spatial domain of 100°E - 120°E and 0° -25°N. GLORYS12V1 is a global ocean physical reanalysis product with a horizontal resolution of approximately 1/12°, equivalent to about 8 - 10 km depending on latitude, and has been available from 1993 onward [7]. In this study, values from GLORYS12V1 were interpolated to the locations of the hydrographic stations and then aggregated into monthly means to match the temporal scale of the station observations. The analysis period was defined as 1 January 2003 to 31 December 2022, depending on the availability and completeness of the observation records at each station.

Table 1. Locations and characteristics of the eight hydrographic stations. (*According to Circular No. 08/2020/TT-BTNMT on technical regulations for marine hydrological observation methods, issued by the Ministry of Natural Resources and Environment of Viet Nam on 11 September 2020)

No.	Stations	Region	Longitude (°E)	Latitude (°N)	Completeness percentage	N	Measurement depth
1	Bai Chay	Northern coastal waters	107.07	20.867	98.3	236	Near-surface (~0.5 m below sea surface)*
2	Hon Dau	Gulf of Tonkin	106.80	20.569	100	240	
3	Sam Son	North-central coastal waters	105.90	19.657	100	240	
4	Con Co	Central coastal waters	107.33	17.079	98.3	236	
5	Truong Sa	Offshore Southern East Sea	111.93	8.4956	98.3	236	
6	Phu Quy	South-central coastal waters	108.94	10.433	100	240	
7	Con Dao	Southeastern waters	106.60	8.6334	98.3	236	
8	Tho Chu	Southwestern waters	103.14	9.2288	100	240	



Figure 1. Locations of the hydrographic stations (red circles) in the Viet Nam East Sea

2.2. Methodology

The methodology was designed to evaluate the agreement between in situ near-surface seawater temperature observations and GLORYS12V1 uppermost-level seawater potential temperature (~ 0.494 m), used as a proxy for near-surface SST.

The coordinates of the eight hydrographic stations were used to collocate the in situ observations with GLORYS12V1. At each station, the uppermost-level seawater potential temperature was estimated using bilinear interpolation from the surrounding valid ocean grid cells. Grid cells located on land or containing missing values were excluded from the interpolation, and the nearest valid ocean grid cell(s) were used when necessary. The resulting GLORYS12V1 values were then matched with the monthly in situ observations for statistical analysis.

Only months with valid values in both datasets were retained, ensuring that all statistical metrics at each station were calculated from the same paired sample set. The in situ observations were treated as the reference data, whereas GLORYS12V1 was treated as the evaluated dataset. The paired time series were assessed using time-series comparisons, scatter plots, and statistical performance metrics. Let (O_i)

denote the observed temperature at time (i), (S_i) the corresponding GLORYS12V1 temperature, ($\bar{O}$) and ($\bar{S}$) their respective means, and (n) the number of valid paired observations.

2.2.1. Pearson correlation coefficient

The Pearson correlation coefficient, (R), was used to evaluate the strength of the linear association between observed and GLORYS12V1 temperature data. The value of R ranges from -1 to 1 [11]. A value close to 1 indicates a strong positive linear relationship between the two series, a value close to 0 indicates a weak linear relationship, and a negative value indicates an inverse relationship. The Pearson correlation coefficient was calculated as follows:

$$R = \frac{\sum_{i=1}^n (O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (S_i - \bar{S})^2}} \quad (1)$$

(R) were used to assess the ability of reanalysis data to reproduce the temporal variability of SST at each station [12]. A higher R value indicates that the GLORYS12V1 temperature data better represent the linear variability of the observed SST series.

2.2.2. Nash-Sutcliffe efficiency coefficient

The Nash Sutcliffe efficiency coefficient (NSE), was used to evaluate the overall agreement between the reanalysis and observed data time series. NSE compares the squared error between simulated and observed values with the natural variance of the observed series. This index was proposed by Nash and Sutcliffe (1970) and has been widely used in environmental and hydrological model evaluation [13]. When NSE equals 1, the reanalysis data perfectly match the observations. When NSE equals 0, the model performance is equivalent to using the observed mean as a predictor. When NSE is less than 0, the reanalysis data perform worse than the observed mean.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (2)$$

Where, *NSE* was used as an integrated performance index to evaluate the ability of reanalysis to reproduce the monthly mean SST time series at each station.

2.2.3. MAE, and mean bias

In addition to correlation based statistics, error metrics were used to quantify the absolute differences between reanalysis data and station observations. The mean absolute error (MAE), was calculated as:

$$MAE = \frac{1}{n} \sum_{i=1}^n |S_i - O_i| \quad (3)$$

MAE represents the mean absolute difference between reanalysis and observations. Willmott and Matsuura (2005) suggested that *MAE* is a more direct and clear measure for evaluating the mean error of a model [14].

Mean bias was used to determine whether reanalysis data tend to overestimate or underestimate SST relative to the observations.

$$Bias = \frac{1}{n} \sum_{i=1}^n (S_i - O_i) \quad (4)$$

A positive bias indicates that GLORYS12V1

temperature data tend to overestimate SST compared with the observations, whereas a negative bias indicates that reanalysis data tend to underestimate SST.

2.2.4. Root Mean Square Error (RMSE)

The root mean square error (RMSE) was used to quantify the overall magnitude of the differences between reanalysis and observed temperature values. Unlike MAE, RMSE gives greater weight to large errors because the individual differences are squared before averaging. RMSE was calculated as:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (S_i - O_i)^2} \quad (5)$$

RMSE is expressed in °C, and a lower *RMSE* indicates better agreement between the reanalysis and observations.

2.2.5. Mann-Kendall method and Sen's slope

The non-parametric Mann-Kendall test was applied to assess the statistical significance of monotonic trends in annual mean temperature during 2003-2022, following the approach used in previous studies of sea surface temperature and salinity trends in Vietnamese coastal waters [5]. Statistical significance was evaluated at the 95% confidence level ($p < 0.05$). Sen's slope estimator was used to quantify the magnitude and direction of the trend, with positive and negative values indicating increasing and decreasing temperature, respectively.

3. Results and Discussion

3.1. Spatial and temporal characteristics of GLORYS12V1 near-surface potential temperature

GLORYS12V1 shows a persistent North-South thermal contrast during 2003-2022 (Figure 2): cooler annual conditions occur in the Gulf of Tonkin and Northern waters, while the Southern and offshore domain is warmer and more spatially homogeneous. This large-scale structure is physically consistent with latitude and monsoon-driven winter cooling and provides the regional background against which

station-scale errors should be interpreted.

Selected annual fields also show year-to-year changes in the extent of warm and cool water, but the present evaluation focuses on station-based skill rather than attributing basin-wide variability to individual mechanisms.

The gridded domain-mean series in Figure

2 shows a positive linear tendency ($\sim 0.33^\circ\text{C}$ decade $^{-1}$). Because GLORYS12V1 assimilates observations and the station trends are not spatially uniform, this regional signal is interpreted as a reanalysis feature during 2003–2022 rather than independent evidence of basin-wide warming.

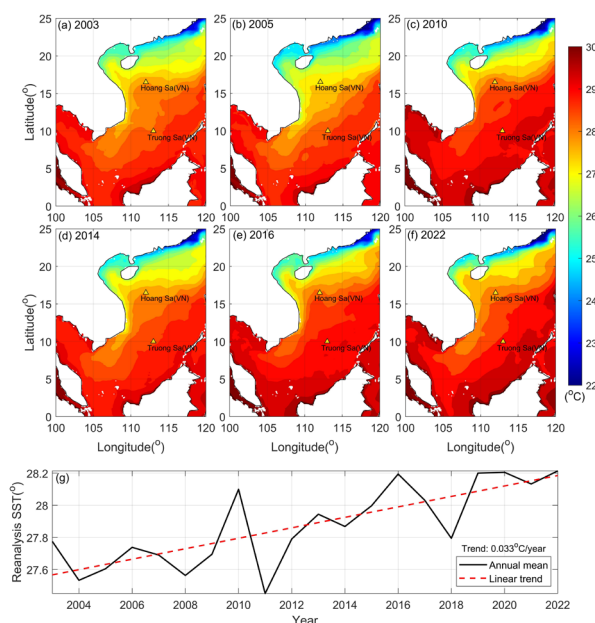


Figure 2. Selected annual GLORYS12V1 uppermost-level thetao fields and domain-mean time series during 2003–2022. Panels (a)–(f) show annual mean thetao for six representative years (2003, 2007, 2011, 2015, 2019, and 2022) over 100–120°E and 0–25°N. Annual means were calculated from monthly mean thetao fields at valid ocean grid cells. Panel (g) shows the domain-averaged annual mean temperature and its linear tendency during 2003–2022

3.2. Evaluation of GLORYS12V1 near-surface potential temperature against observations

Raw monthly comparisons indicate strong agreement between GLORYS12V1 and the observations at all eight stations ($R = 0.869$ – 0.984 ; $NSE = 0.738$ – 0.954 ; Table 2; Figure 3), although error magnitude varies considerably among locations. Bai Chay and Sam Son show the largest MAE (1.278 and 1.664°C) and RMSE (2.344 and 2.077°C), whereas Truong Sa, Phu Quy, Con Dao, and Tho Chu have much smaller MAE values ($\leq 0.456^\circ\text{C}$). The largest positive bias occurs at Sam Son ($+1.283^\circ\text{C}$), while the largest negative bias is found at Hon Dau (-0.469°C).

The deseasonalized analysis provides a different perspective on model skill (Table 3).

Anomaly correlations decrease markedly at Bai Chay ($R = 0.191$) and Sam Son ($R = 0.267$), whereas higher values are retained at Phu Quy ($R = 0.813$) and Con Co ($R = 0.800$). A similar spatial contrast is evident in anomaly RMSE, which reaches 2.276°C at Bai Chay and 1.471°C at Sam Son but remains about 0.36 – 0.48°C at several central, Southern, and offshore stations. These results demonstrate that the high correlations obtained from raw monthly temperatures partly reflect the common seasonal cycle, while the ability of GLORYS12V1 to reproduce interannual anomalies is substantially more station dependent.

The relatively weak anomaly performance at Bai Chay and Sam Son highlights an important

coastal limitation of the reanalysis. Strong winter cooling and large seasonal amplitudes, together with shallow-water processes, complex coastline geometry, possible riverine influence, and unresolved sub-grid variability, may produce local temperature fluctuations that are smoothed by

the 1/12° GLORYS12V1 grid. These mechanisms are considered plausible explanations rather than directly tested causal factors. In contrast, Southern and offshore stations are more strongly influenced by broader-scale oceanic conditions that are better represented by the reanalysis.

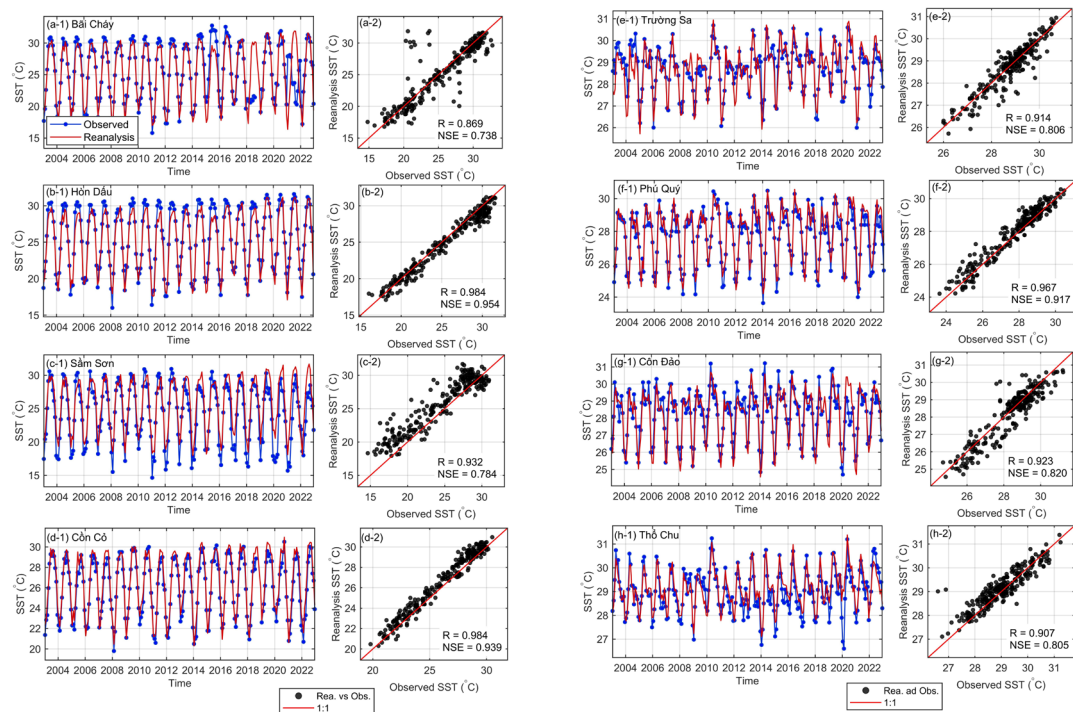


Figure 3. Comparison between observed and reanalysis monthly mean SST at eight hydrographic stations during 2003-2022. For each station, the left panel, labeled “-1”, shows the monthly SST time series from station observations and reanalysis data, while the right panel, labeled “-2”, shows the scatter comparison between observed and reanalysis SST. The black line represents the 1:1 reference line. The statistical indicators shown in each scatter panel include the Pearson correlation coefficient (*R*) and Nash-Sutcliffe efficiency coefficient (*NSE*)

Table 2. Statistical performance metrics between observed and reanalysis SST data at eight coastal and island stations in the Viet Nam East Sea. The metrics include the correlation coefficient (*R*), Nash-Sutcliffe efficiency coefficient (*NSE*), mean absolute error (*MAE*), and mean bias (*Bias*), and root mean square error (*RMSE*)

Station	N	R	NSE	MAE (°C)	Bias (°C)	RMSE (°C)
Bai Chay	236	0.869	0.738	1.278	-0.195	2.344
Hon Dau	240	0.984	0.954	0.734	-0.469	0.937
Sam Son	240	0.932	0.784	1.664	1.282	2.077
Con Co	236	0.984	0.939	0.585	0.475	0.707
Truong Sa	236	0.914	0.806	0.304	-0.059	0.441
Phu Quy	240	0.967	0.917	0.368	0.208	0.462
Con Dao	236	0.923	0.820	0.455	-0.140	0.600
Tho Chu	240	0.907	0.805	0.294	0.116	0.399

Table 3. Performance of GLORYS12V1 in reproducing deseasonalized near-surface temperature anomalies at the eight stations during 2003-2022

Station	N	R_Anomaly	MAE_Anomaly (°C)	Bias_Anomaly (°C)	RMSE_Anomaly (°C)
Bai Chay	236	0.191	1.319	0.000	2.276
Hon Dau	240	0.756	0.520	0.000	0.656
Sam Son	240	0.267	1.111	0.000	1.471
Con Co	236	0.800	0.383	0.000	0.480
Truong Sa	236	0.684	0.301	0.000	0.418
Phu Quy	240	0.813	0.294	0.000	0.362
Con Dao	236	0.691	0.328	0.000	0.455
Tho Chu	240	0.648	0.264	0.000	0.361

Table 4. Mann-Kendall trend test and Sen's slope estimates for annual mean GLORYS12V1 near-surface temperature at the eight stations during 2003-2022.

Station	Z	p-value	Sen's Slope (°C decade ⁻¹)
Bai Chay	1.784	0.0743	0.2818
Hon Dau	2.174	0.0297	0.4202
Sam Son	2.498	0.0125	0.3755
Con Co	1.071	0.2843	0.1985
Truong Sa	2.239	0.0252	0.3325
Phu Quy	2.303	0.0212	0.3097
Con Dao	1.719	0.0855	0.2289
Tho Chu	2.498	0.0125	0.2387

Because GLORYS12V1 assimilates satellite and in situ observations, the agreement reported here should be interpreted as an assessment of local representativeness rather than a fully independent validation of predictive skill. Trend analysis further shows that significant increasing trends occur at Hon Dau, Sam Son, Truong Sa, Phu Quy, and Tho Chu ($p < 0.05$), with Sen's slopes of 0.239-0.420 °C decade⁻¹, whereas the positive trends at Bai Chay, Con Co, and Con Dao are not statistically significant (Table 4). This distinction is important because it prevents positive slopes from being interpreted as robust warming signals when statistical support is insufficient.

3.3. Comparison of Characteristic SST Values between Observations and Reanalysis

Table 5 summarizes the mean, maximum and minimum of the monthly-mean and annual-mean temperature series; these are not instantaneous temperature extremes. Values were calculated from the same paired samples used in Table 2 so that mean differences are consistent with the bias.

GLORYS12V1 reproduces mean conditions well at most Southern and offshore stations but smooths some Northern cold conditions. The monthly-mean minimum differs most at Bai Chay and Sam Son, where GLORYS12V1 is warmer than observations by about 1.6 and 3.3 °C, respectively. This is consistent with the large

anomaly errors at these stations and indicates that quantitative use near the Northern coast requires greater caution.

At the annual-mean scale, differences are generally smaller, although Bai Chay and Sam

Son retain notable discrepancies. The scientific implication is that GLORYS12V1 is more robust for mean thermal conditions and broad seasonal evolution than for station-scale cold anomalies in strongly variable coastal waters.

Table 5. Characteristic monthly and annual mean SST values derived from observations and reanalysis data

No.	Stations	Values	Monthly mean SST (°C)		Annual mean SST (°C)	
			Observed	Reanalysis	Observed	Reanalysis
1	Bai Chay	Maximum	32.8	31.9	28.0	26.3
		Mean	25.5	25.3	25.4	25.3
		Minimum	14.8	16.4	21.1	24.0
2	Hon Dau	Maximum	31.6	31.2	26.6	26.3
		Mean	25.6	25.2	25.6	25.2
		Minimum	16.0	17.1	24.7	23.8
3	Sam Son	Maximum	31.0	31.7	25.2	26.7
		Mean	24.4	25.6	24.4	25.6
		Minimum	14.6	17.9	22.9	24.2
4	Con Co	Maximum	30.5	31.0	26.7	27.4
		Mean	26.1	26.6	26.1	26.6
		Minimum	19.8	20.3	25.2	25.7
5	Truong Sa	Maximum	30.7	30.9	29.2	29.1
		Mean	28.7	28.7	28.7	28.7
		Minimum	26.0	25.7	28.1	28.2
6	Phu Quy	Maximum	30.5	30.6	28.5	28.6
		Mean	27.7	27.9	27.7	27.9
		Minimum	23.6	24.2	27.3	27.3
7	Con Dao	Maximum	31.2	30.7	28.9	28.8
		Mean	28.3	28.2	28.3	28.2
		Minimum	24.7	24.6	27.5	27.6
8	Tho Chu	Maximum	31.2	31.4	29.7	29.8
		Mean	29.0	29.1	29.0	29.1
		Minimum	26.6	27.1	28.6	28.7

3.4. Variation of Reanalysis SST Errors under Different ENSO Phases

ENSO classification used the NOAA/CPC ONI based on ERSSTv5 [15], [16]. For stations with complete records, the phase samples were 71 La Niña, 113 neutral, and 56 El Niño months (Figure 4). Bai Chay, Con Co, and Con Dao had 71/113/52 valid months, and Truong

Sa had 70/113/53, reflecting the four missing observation months at those stations.

Pooled anomaly MAE was 0.612 °C during La Niña, 0.537 °C during neutral conditions, and 0.562 °C during El Niño. Twelve-month moving-block bootstrap 95% confidence intervals were 0.478-0.769, 0.460-0.659, and 0.434-0.673 °C, respectively. Pairwise bootstrap intervals for MAE differences all included zero, so the between-phase

differences are not statistically distinguishable at the 95% level and are interpreted descriptively rather than as evidence of a causal ENSO influence.

Station-specific errors remain more informative than the modest phase differences: Bai Chay and Sam Son have the largest MAE

under all three phases, whereas Truong Sa, Phu Quy, Con Dao, and Tho Chu generally remain below $\sim 0.4^{\circ}\text{C}$ (Figure 4c). This spatial consistency supports the interpretation that local coastal representativeness is a stronger limitation than ENSO phase for the evaluated record.

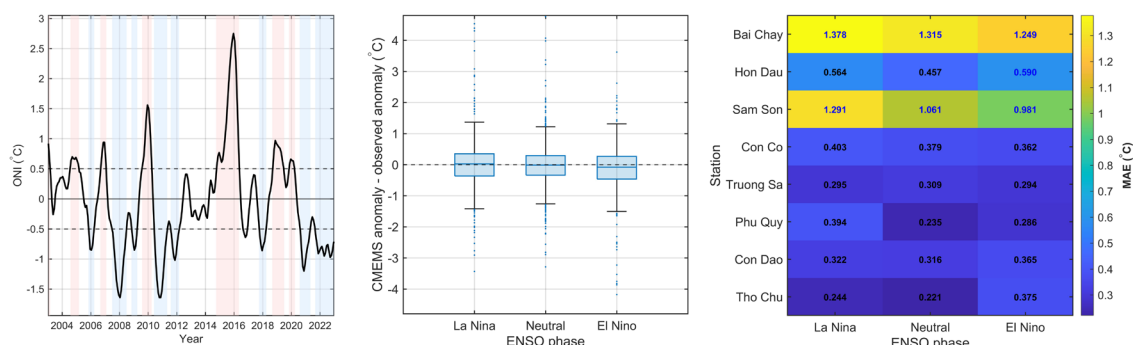


Figure 4. ENSO-phase dependence of deseasonalized SST errors between CMEMS and in situ observations during 2003-2022

4. Conclusions

This study evaluated GLORYS12V1 uppermost-level sea water potential temperature (~ 0.494 m), used as a near-surface SST proxy, against eight Vietnamese hydrographic stations during 2003-2022. A consistent paired-sample audit showed strong agreement for raw monthly temperature ($R = 0.869$ - 0.984 ; $NSE = 0.738$ - 0.954), but substantially weaker and more spatially variable skill for deseasonalized anomalies ($R = 0.191$ - 0.813). This separation of seasonal-cycle and interannual-anomaly skill is a central contribution of the study.

The largest errors occur at Bai Chay and Sam Son, where strong coastal variability and winter cooling are not fully represented by the gridded reanalysis. Central, Southern, and offshore

stations generally show smaller anomaly errors. Mann-Kendall/Sen analysis identifies significant positive GLORYS12V1 trends at five stations during 2003-2022, but the trend signal is not spatially uniform. ENSO-stratified MAE differs modestly among phases, yet block-bootstrap confidence intervals show that these phase differences are not statistically distinguishable at the 95% level.

Overall, GLORYS12V1 provides a useful representation of near-surface thermal conditions at the evaluated stations, particularly for mean conditions and seasonal variability. However, quantitative applications in strongly variable coastal environments should account for local bias, limited anomaly skill, and unresolved small-scale processes.

Author Contributions: Conceptualization: Tran Thi My Hong, Le Duc Quyen; Data curation and analysis: Tran Thi My Hong, Le Duc Quyen; Methodology: Tran Thi My Hong, Le Duc Quyen; Writing - original draft: Tran Thi My Hong, Le Duc Quyen.

Declaration: The authors declare that this manuscript is their original work and has not been published previously. The manuscript does not contain any form of plagiarism or unauthorized reproduction of published materials. The authors further declare that there are no conflicts of interest among the authors regarding the publication of this work.

References

- [1] Y. Yu, H. R. Zhang, J. Jin, and Y. Wang, "Trends of sea surface temperature and sea surface temperature fronts in the South China Sea during 2003-2017," *Acta Oceanologica Sinica*, vol. 38,

- no. 4, pp. 106-115, 2019, doi: 10.1007/s13131-019-1416-4.
- [2] S.-P. Xie, Q. Xie, D. Wang, and W. T. Liu, "Summer upwelling in the South China Sea and its role in regional climate variations," *Journal of Geophysical Research: Oceans*, vol. 108, no. C8, Art. no. 3261, 2003, doi: 10.1029/2003JC001867.
 - [3] M. Herrmann, T. To Duy, and C. Estournel, "Intraseasonal variability of the South Vietnam upwelling, South China Sea: Influence of atmospheric forcing and ocean intrinsic variability," *Ocean Science*, vol. 19, pp. 453-467, 2023, doi: 10.5194/os-19-453-2023.
 - [4] V. H. Đang, N. M. Huan, N. B. Thuy, and Đ. N. Thực, "Characteristics of sea surface temperature variability in the South Central Vietnam Sea during 2002-2018," *Journal of Hydro-Meteorology*, no. EME2, pp. 139-145, 2019 (in Vietnamese).
 - [5] T. M. H. Tran and D. Q. Le, "Application of non-parametric statistical methods for analyzing sea surface temperature and salinity trends in the Southern Coast of Viet Nam," *Journal of Climate Change Science*, no. 35, pp. 3-17, 2025.
 - [6] T. D. Thai, T. B. Ngoc, and B. H. Long, "The role of water circulation and eddy currents in the variability of upwelling in the South Central Vietnam Sea," *Journal of Hydro-Meteorology*, no. 758, pp. 11-22, 2024 (in Vietnamese).
 - [7] Copernicus Marine Service, "GLORYS12V1," Product ID: GLOBAL_MULTIYEAR_PHY_001_030. [Online]. Available: <https://doi.org/10.48670/moi-00021>
 - [8] W. Tan, X. Wang, W. Wang, C. Wang, and J. Zuo, "Different responses of sea surface temperature in the South China Sea to various El Niño events during boreal autumn," *Journal of Climate*, vol. 29, no. 3, pp. 1127-1142, 2016, doi: 10.1175/JCLI-D-15-0338.1.
 - [9] N. Q. Trinh, N. M. Huan, P. Q. Nam, N. Q. Vinh, D. T. T. Ha, and N. Q. Thanh, "Assessment of sea surface temperature in the Vietnamese waters during 2000-2022 using HYCOM model data," *Journal of Hydro-Meteorology*, no. 761, pp. 70-81, 2024 (in Vietnamese).
 - [10] D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith, "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations," *Transactions of the ASABE*, vol. 50, no. 3, pp. 885-900, 2007, doi: 10.13031/2013.23153.
 - [11] R. Taylor, "Interpretation of the correlation coefficient: A basic review," *Journal of Diagnostic Medical Sonography*, vol. 6, no. 1, pp. 35-39, 1990, doi: 10.1177/875647939000600106.
 - [12] J. L. Rodgers and W. A. Nicewander, "Thirteen ways to look at the correlation coefficient," *The American Statistician*, vol. 42, no. 1, pp. 59-66, 1988, doi: 10.1080/00031305.1988.10475539.
 - [13] J. E. Nash and J. V. Sutcliffe, "River flow forecasting through conceptual models. Part I: A discussion of principles," *Journal of Hydrology*, vol. 10, no. 3, pp. 282-290, 1970, doi: 10.1016/0022-1694(70)90255-6.
 - [14] C. J. Willmott and K. Matsuura, "Advantages of the mean absolute error over the root mean square error in assessing average model performance," *Climate Research*, vol. 30, pp. 79-82, 2005, doi: 10.3354/cr030079.
 - [15] B. Huang, P. W. Thorne, V. F. Banzon, T. Boyer, G. Chepurin, J. H. Lawrimore, M. J. Menne, T. M. Smith, R. S. Vose, and H.-M. Zhang, "Extended reconstructed sea surface temperature, version 5 (ERSSTv5): Upgrades, validations, and intercomparisons," *Journal of Climate*, vol. 30, no. 20, pp. 8179-8205, 2017, doi: 10.1175/JCLI-D-16-0836.1.
 - [16] National Oceanic and Atmospheric Administration, "Oceanic Niño Index (ONI), version 5." [Online]. Available: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso/oni/v5/ [Accessed: Sep. 22, 2026].