Validation of a CROCO configuration for the South African West Coast: SA-West

Model hind-cast validation against in-situ data within the domain ranging 2009-2013

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Abstract

This report describes the evaluation of a high-resolution downscale hindcast model called SA-West a CROCO (Coastal and Regional Ocean Community model) configuration for the South African Western Coast region. The hindcast aims to refine the model configuration for future forecasting and serve as a research tool to investigate oceanographic processes and climate variations. This hindcast is evaluated over the 5 year period 2009-2013. The bathymetry data for the model comes from the South African Navy Hydrographic Office (SANHO). GLORYS 12v1 reanalysis data from Copernicus Marine Environment Monitoring Service (CMEMS) is applied at the open boundaries. The ERA5 reanalysis data from ECMWF and the higher resolution WASA3 from the climate systems analysis group (CSAG) are both used for atmospheric forcing to create two different runs that are helpful to quantify the atmospheric impact on the model solution. In situ temperatures are detected using a wide array of Underwater Temperature Recorders (UTR) from various organisations who shared their records for this assessment. Notwithstanding some differences observed during specific months; the SA-West model runs climatology closely follows the in situ observations and often appears to do better than the GLORYS in terms of bias, RMSD and correlation with the various testing in-situ station data. This is particularly true in coastal region of Betty's Bay, Saldanah Bay and parts of False Bay.

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Introduction

A hindcast model configuration has been developed for the shelf region off the west coast of South Africa. The hindcast is developed for purposes of aiding future operational forecasts, as hindcast can be more readily validated. Two runs of the high resolution SA-West hindcast CROCO model have been developed for the region as shown in (Figure 2.2). This model is based on a curvilinear grid and is validated against the in situ stations located on various coastal moorings. This region is described as the southern Benguela upwelling system. The region is characterized by a wide range of oceanographic processes, including strong coastal upwelling, offshore mesoscale variability, and complex, near-shore circulation associated with embayments. The hindcast serves two overarching goals; the first as a test case to refine the model configuration and forcing for a future forecast model. Evaluating the accuracy of a forecast model is extremely difficult, as there is a lack of real-time in-situ data in the area. Therefore, instead, the accuracy of the model is validated using historical datasets. This allows for the best possible configuration to be created and then deployed in forecast mode. Secondly, the hindcast will serve as research tool as it provides high resolution data for an extended period, the data can be used to investigate various oceanographic processes as well as possible trends and climate-scale variations.

The in-situ data stations used are shown in (Figure 2.1). The data at these stations are collected by different institutions and have been brought together for evaluation work in this region. The validation work done in this region is two pronged; the CROCO_SA-West ERA5 and WASA3 runs are validated against the in-situ data and they are also compared to the performance of the GLORYS global model to determine the effectiveness of the downscaling effort. Comparisons are made on the basis of deterministic statistics. Various stations appear to show an improvement in performance when comparing the CROCO_SA-West runs with GLORYS, and they generally predict the region at a satisfactory level.

2

Materials and methods

2.1. In-situ data

In-situ observations are vital to validating the ability of numerical models to represent local ocean dynamics. In-situ temperature and current observations from numerous different sources were used.

2.1.1. Underwater Temperature Recorders (UTR)

Coastal UTR

The Underwater Temperature Recorder (UTR) data is collected using bottom encored instruments. The stations spanning vast array of the west-coast is the (Smit et al., 2013) AJSMIT data which AJSMIT maintained for the department of Fisheries Forestry the Environment (DFFE) obtainable through the Marine Information Management System (MIMS) repository. The Acoustic Tracking Array Platform (ATAP) from South African Institute of Aquatic Biodiversity (SAIAB) was also essential in the validation work.

GPITCHER SHB Stations

The data provided by Pitcher et al. (2014), is refered to as GPITCHER SHB Stations in this report are also UTRs situated in the Saint Helena Bay region. These are much deeper lying stations compared to the rest used in this report as they are found at depths of 20 and 70 meters. This provides a valuable opportunity for the model to be evaluated down the water column.

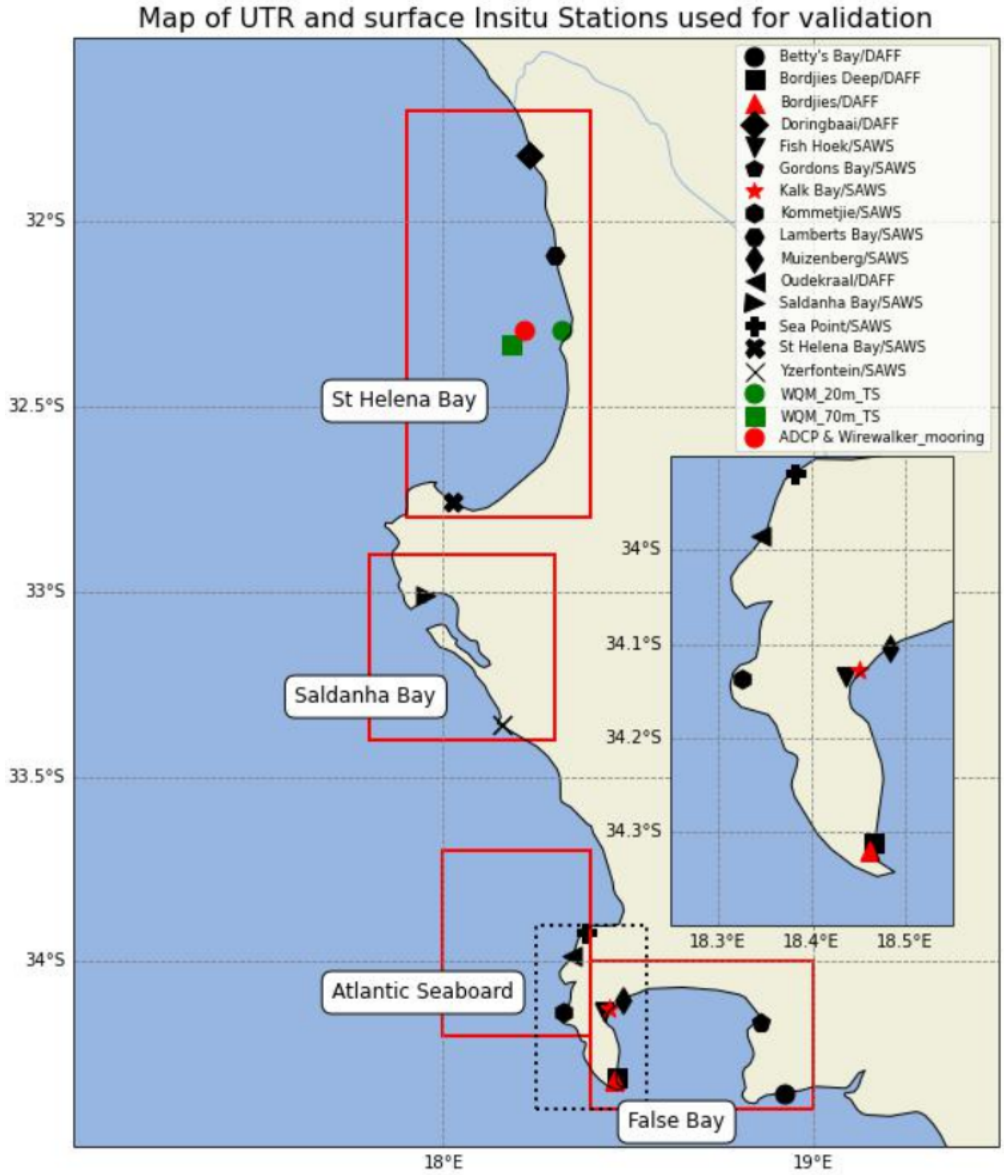


Figure 2.1: The in situ stations used for ocean modelling evaluation.

2.1.2. The Wire-walker and ADCP data

The wire-walker is a wave propelled instrument that walks down the mounted mooring based on the wave oscillation. It pops back to the surface when it reaches the bottom, transmits the data to the satellite, and restarts the process all over again from the surface down, collecting physical properties such as salinity, fluorescence, and temperature down the water column. The Acoustic Doppler Current Profiler (ADCP), on the other hand, is a device that uses sound waves to measure the speed and direction of currents throughout the water column. It is moored to the bottom or mounted on the vessel. This data acquisition for this region is described in the Lucas et al. (2014) paper. The application and effectiveness of these data are well reflected in Fearon et al. (2023) paper.

2.2. Model Description (ERA5 and WASA3 run)

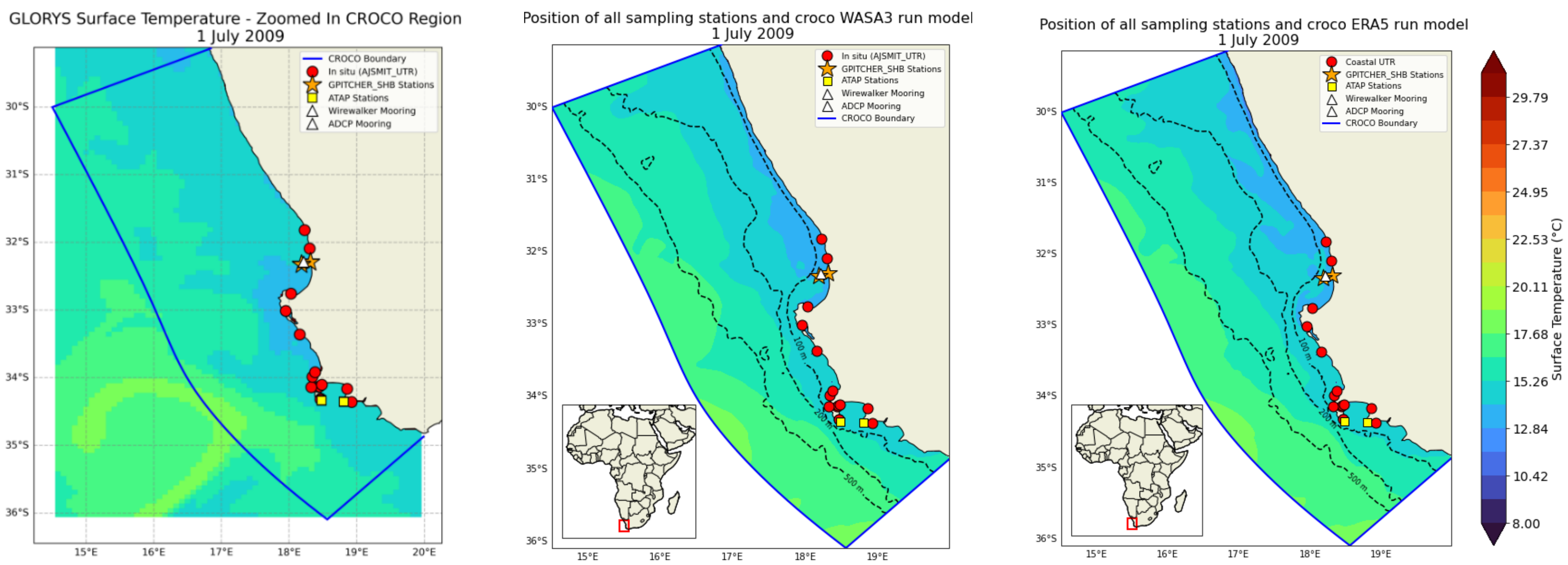
The ocean model used for downscaling the global reanalysis products to high resolution over SA-West is the V1.3.1 official release of the Coastal and Regional Ocean COmmunity model (CROCO), an ocean modelling system built upon ROMS AGRIF (Shchepetkin and McWilliams, 2005). CROCO is a free-surface, terrain-following coordinate oceanic model which solves the primitive equations by invoking the Boussinesq and hydrostatic approximations. The model solves equations governing the conservation of horizontal momentum, hydrostatic balance, incompressibility and the conservation of tracers (temperature and salinity). A curvilinear Arakawa C-grid is used for the discretisation of the horizontal plane, while the vertical grid is discretised using a terrain-following (σ) coordinate reference system. Vertical turbulent viscosity and diffusivity are parametrised in this study using the k-ε turbulent closure scheme within the Generic Length-Scale (GLS) formulation (Umlauf and Burchard, 2003). Horizontal dissipation in the model is included through dissipation associated with a third-order upstream biased horizontal advection scheme. A nonlinear equation of state adapted from Jackett and Mcdougall (1995) is used for the computation of density.

2.3. Model Configuration

The curvilinear computational grid adopted for this study was developed using the Delft3D-RGFGRID package (De Goede, 2020) and is shown in (Figure 2.2 b and c panes). The grid has variable resolution ranging from ~ 3 km at the lateral offshore boundaries to ~ 500 m within SA-West model domain which spans from 29°:36° South and 14°:20° East (Figure 2.2). 30 σ-layers are used to define the vertical grid. The model is integrated in time from January 2009 to December 2013 (a 5 year period selected based on the availability of in-situ observations and model forcing products) using baroclinic and barotropic timesteps of 40 s and 1 s, respectively. The model output is comprised of 6 hourly averaged output at each grid point, hourly output for the surface layer of the model, and hourly output throughout the water column at each location where observation data are available.

The depths assigned to the model grid points are interpolated from digital versions of the most detailed available navigation charts for the region, as provided by the Hydrographer of the South African Navy. The interpolated bathymetry is smoothed to maintain a slope parameter ($r = \frac{\nabla H}{H}$) of less than 0.2 everywhere in the domain in an attempt to circumvent the well-known horizontal pressure gradient errors associated with σ-coordinate models with steep slopes. A minimum depth of 5 m is enforced to avoid vertical advection errors associated with thin vertical layers in shallow water. A hyperbolic tangent function is used over the sponge layer of the grid (10 grid cells wide) to gradually ramp up the model bathymetry to the 30-arc second GEBCO2 dataset at the open boundaries of the model. In so doing, the bathymetry at the model boundaries matches that of the global reanalysis products providing lateral boundary forcing conditions to the model. Surface boundary conditions for momentum (i.e. wind stress) and surface heat fluxes are computed from the respective atmospheric forcing product data using bulk parameterisation (Brunke et al., 2003). Bottom boundary conditions for momentum are computed from the von K´arm´an quadratic bottom stress formulation using a spatially constant bottom roughness length scale of 0.01 m. Open boundary conditions for the model are interpolated from daily surface elevation (η), temperature (T), salinity (S), and horizontal velocity components (u, v) obtained from the respective global reanalysis products. The model solution is 'nudged' to the specified boundary values using relaxation times 1 day and 1 year for inward and outward radiation, respectively (Marchesiello et al., 2001). Nudging is applied within the sponge layer of the model (10 grid cells wide) using a gradual decrease (cosine profile) from the open boundary to the inner border of the sponge layer.

The model is forced at the boundaries by the global model, GLORYS 12v1 reanalysis which is produced by Copernicus Marine Environment Monitoring Service (CMEMS). GLORYS has a horizontal resolution of 1/12 $^{\circ}$ and 50 z-levels. The atmospheric forcing used is the ERA5 reanalysis produced by ECMWF. The horizontal resolution is 30km. Surface boundary conditions for momentum (i.e. wind stress) and surface heat fluxes are computed from the respective atmospheric forcing product data using bulk parametrisation (Fairall et al., 1996; Fairall et al., 2003). The WASA3 winds on the other hand are 3km resolution, 10 times higher than the ERA5, therefore they are expected to make a difference in the model's ability to resolve features better.



(a) GLORYS low resolution global model

(b) WASA-3 surface wind forced model

(c) ERA-5 surface wind forced model

Figure 2.2: Stations map highlighting in-situ datasets and the CROCO day average in a selected day (1 July 2009) for visual comparison of features captured by the models. GLORYS is captured within the CROCO_SA_West domain to show a visual comparison during the same time period.

3

Results

3.1. Atlantic Seaboard region validation

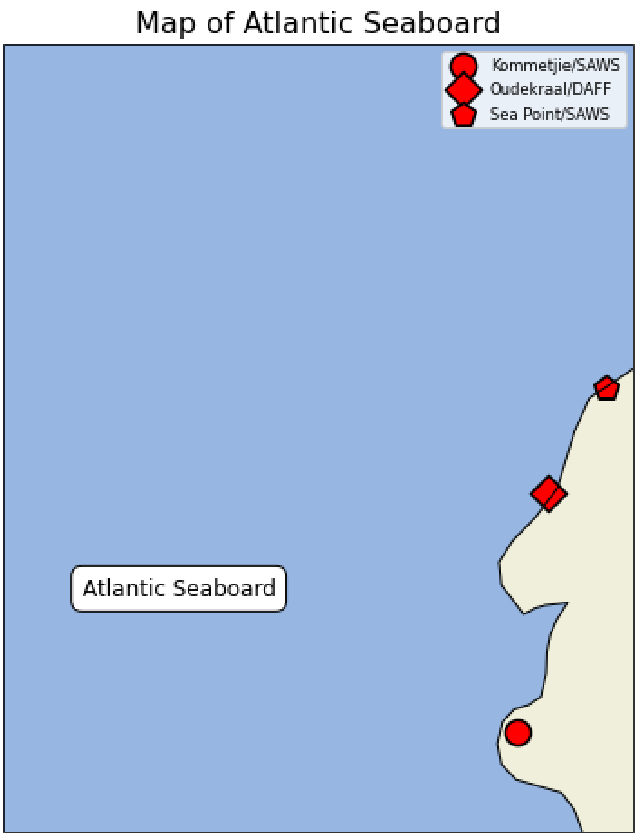


Figure 3.1: Insitu stations at Atlantic Seaboard used for CROCO validation and a comparison with GLORYS.

Validation of sea surface temperature (SST) in Kommetjie, Oudekraal, and Sea Point provides critical information on the comparative performance of the ERA5-run, WASA3-run, and GLORYS models on the West Coast of South Africa (Figures 3.2, 3.3 and 3.4). Although the three stations are relatively geographically close, the performance of the models varies, reflecting localized environmental influences and the dynamics of the model.

Time Series Comparison

In Kommetjie, both the ERA5 run and the WASA3 run show high correlation coefficients (r = 0.6 and r = 0.64, respectively), which are comparable to the values seen at Oudekraal (r = 0.72 and r = 0.74) and Sea Point (r = 0.57 and r = 0.56). However, the GLORYS model consistently under performs compared to the croco model running. Its correlation with in situ data is consistently lower than the ERA5 and WASA3 runs (r=0.41,r=0.14,r=0.38 at Kommetjie, Oudekraal and Sea Point, respectively) (Figure 3.4 (a)). The root mean square error (RMSE) in all stations further highlights the strengths of the ERA5 and WASA3 runs relative to GLORYS. In Kommetjie, the ERA5 run and the WASA3 run show RMSE values of 1.66°C and 1.53°C, while GLORYS exhibits a much higher error (2.42°C) (Figure 3.2 (a)). Similarly, at Oudekraal, ERA5-run (1.27°C) and WASA3-run (1.23°C) produce lower errors than GLORYS, which has a significantly larger RMSE of 3.33°C (Figure 3.3 (a)). At Sea Point, while the errors for the ERA5 run and the WASA3 run remain higher (1.49 ° C and 1.59 ° C), GLORYS also maintains a larger error of 2.27 ° C (Figure 3.4 (a)). Across the stations, a consistent pattern emerges: the croco model runs (ERA5-run and WASA3-run) perform more reliably in capturing the time-series variability of SST, while GLORYS struggles, particularly at Oudekraal, where it shows an abnormally high RMSE and extremely low correlation.

Anomaly Series and Bias Correction

The anomaly series (Figures 3.2 (b), 3.3 (b), 3.4 (b)) further illustrate the differences in model performance once biases and seasonal effects are removed. Although the correlation strength slightly decreases for ERA5-run and WASA3-run across all stations, their RMSE values improve, indicating reduced systematic errors. In Kommetjie, the anomaly correlations for the ERA5 and WASA3 runs are 0.61 and 0.62, respectively, with RMSE values reduced to 1.44 ° C and 1.34 ° C. Similar results are observed in Oudekraal, where the anomaly correlations for the ERA5 run and the WASA3 run are slightly lower at 0.6 and 0.64, but the RMSEs drop to 1.23 ° C and 1.16 ° C (Figure 3.3 (b)). At Sea Point, the anomaly correlations remain moderate at 0.54 (ERA5 run) and 0.55 (WASA3 run), but the RMSE values improve slightly, with the ERA5 run showing 1.42 ° C and the WASA3 run showing 1.38 ° C (Figure 3.4 (b)). GLORYS, however, consistently shows weaker performance even after bias correction. The anomaly correlation values for GLORYS remain modest in Kommetjie ($r = 0.49$) and Sea Point ($r = 0.38$), and are particularly poor in Oudekraal ($r = 0.28$). Despite some improvement in RMSE (for example 1.52 ° C at Sea Point), anomaly analysis reinforces that GLORYS is less capable of resolving SST variations as accurately as the croco model runs, particularly during high-bias periods such as the summer months.

Climatology and Seasonal Performance

The climatology plots (Figures 3.2 (c), 3.3 (c), 3.4 (c)) provide an overview of the models' ability to represent seasonal SST trends. Both the ERA5-run and WASA3-run perform well at capturing the general seasonality at all stations, although a persistent positive bias exists during summer, particularly at Kommetjie and Oudekraal, where the models show a bias of up to 2°C. GLORYS, however, shows much larger biases, especially at Oudekraal, where it reaches up to 3°C during the summer months (Figure 3.3 (c)). Regionally, the croco model runs generally outperform GLORYS, with the ERA5-run consistently showing the best performance in capturing seasonal patterns and minimizing bias across all stations. At Sea Point, ERA5-run is particularly strong in reducing bias and aligning with in-situ data (Figure 3.4 (c)), while GLORYS, though performing marginally better than at other stations, still shows a considerable bias and lower correlation.

Regional Statistical Summary

Across the region, ERA5-run and WASA3-run emerge as the more reliable models for nearshore SST, both in terms of correlation, RMSE and seasonal signal. The validation statistics show that both croco models (ERA5 and WASA3) consistently achieve higher correlation coefficients and lower RMSE values than GLORYS, especially in capturing the time series and seasonal variations. The anomaly and climatology analyses further solidify this trend, demonstrating that the croco models, while not without biases (particularly during summer), offer a much more accurate representation of the in-situ data. GLORYS, on the other hand, consistently under performs, particularly at Oudekraal, where the model exhibits very high RMSE values and low correlations, raising concerns about its suitability for this region. While GLORYS may capture some general trends, its substantial bias, particularly during warmer months, suggests that it is less suited for SST validation in this region compared to the croco models.

3.1.1. Kommetjie

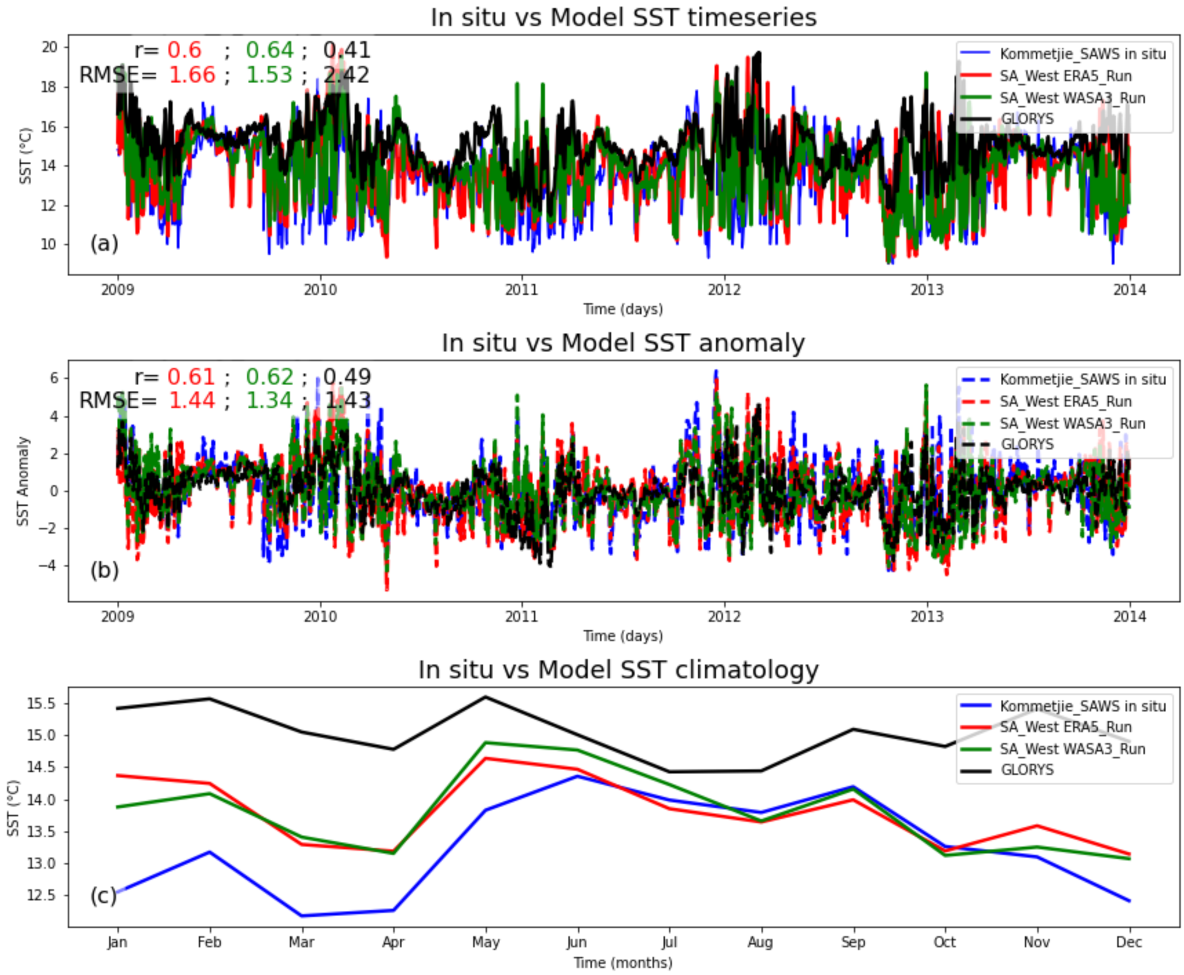


Figure 3.2: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Kommetjie SAWS station located at (-34.137: 18.327), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.1.2. Oudekraal

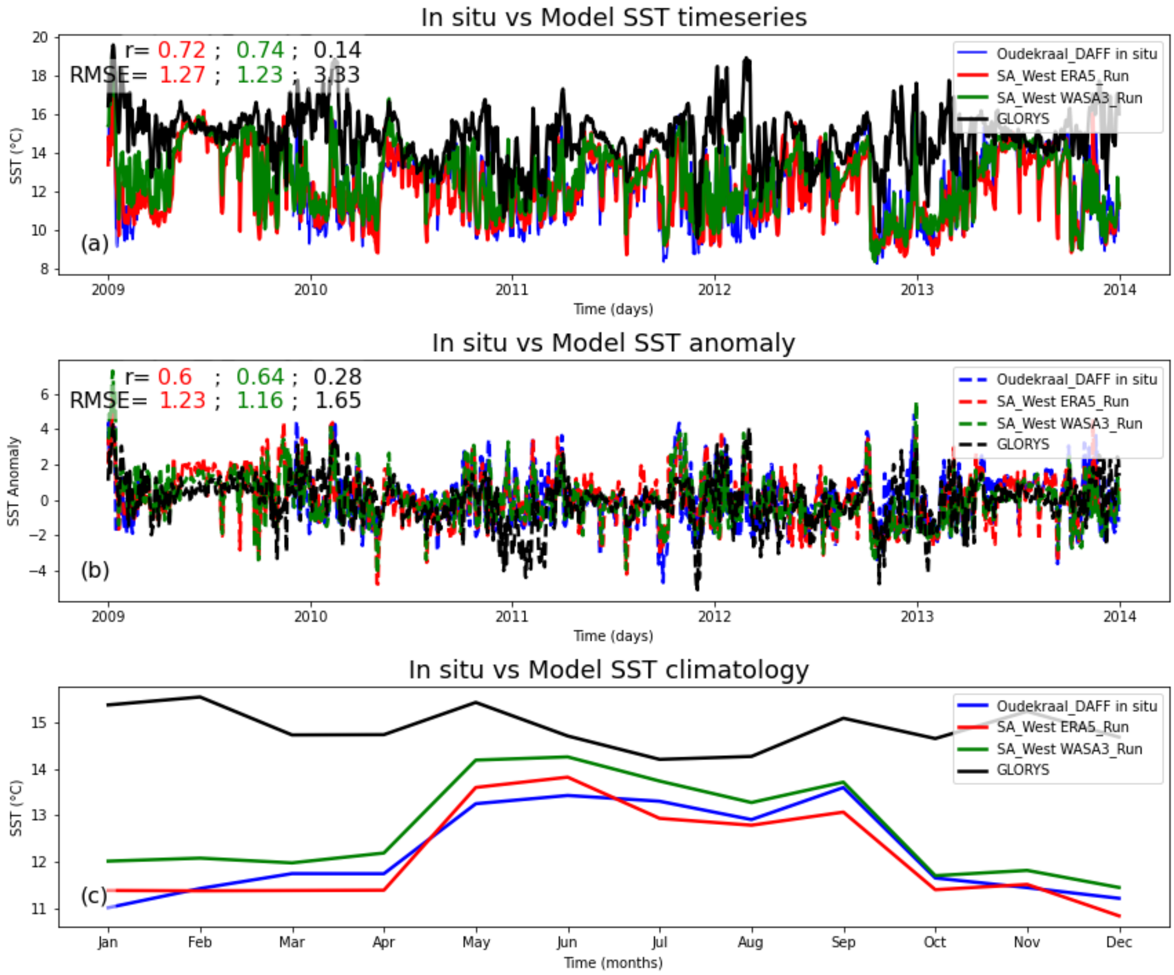


Figure 3.3: Temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Oudekraal DAFF station located at (-33.985: 18.346), depth = -9 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.1.3. Sea Point

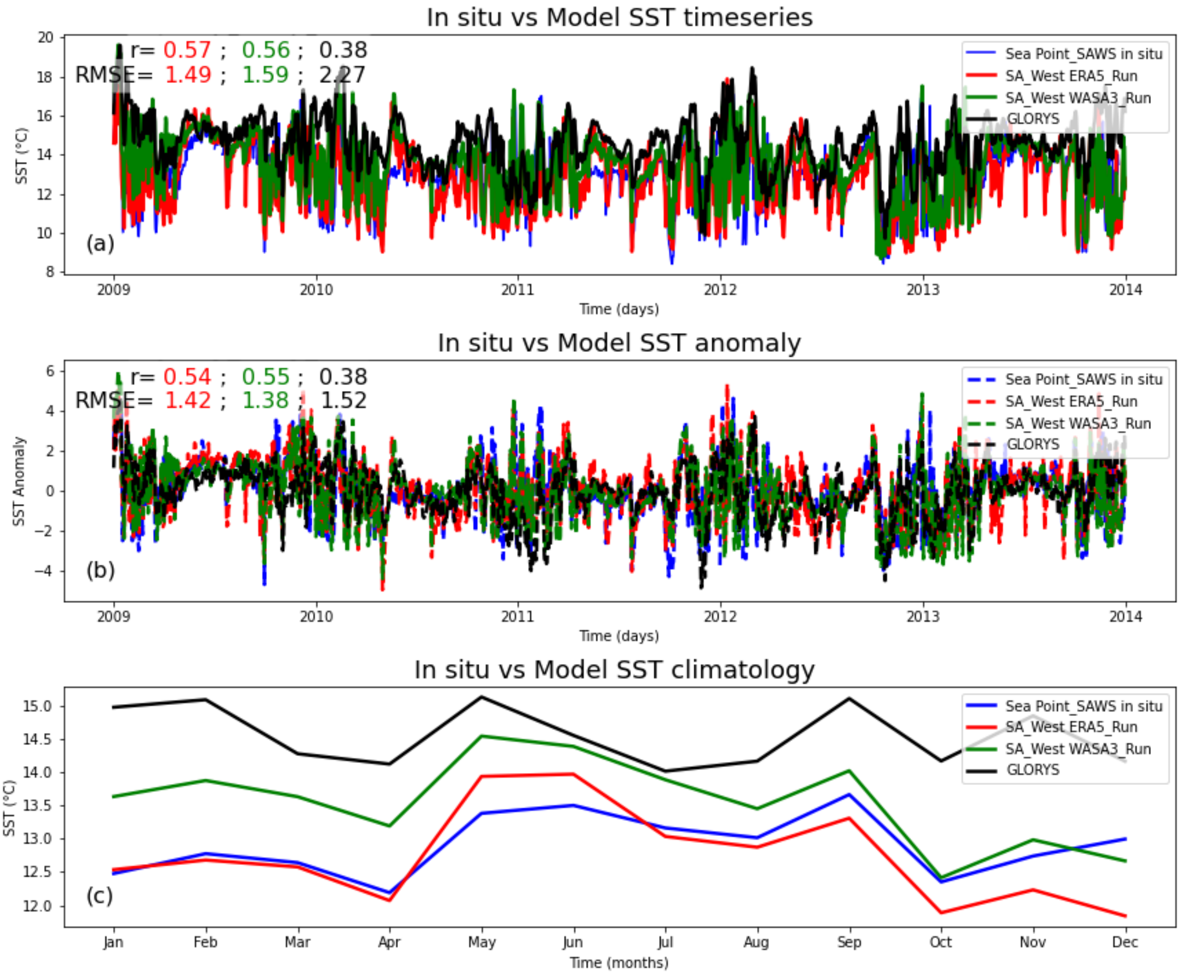


Figure 3.4: Sea temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Sea Point SAWS station located at (-33.918: 18.382), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ sst vs the model outputs.

In conclusion, ERA5-run and WASA3-run should be favored for future SST validations in this region, with ERA5-run showing slightly better overall performance, particularly in reducing bias and aligning with seasonal climatology. The consistent under-performance of GLORYS, especially at Oudekraal, suggests that this model requires further tuning or may be unsuitable for SST studies in this specific coastal environment.

3.2. Saldanha Bay region validation

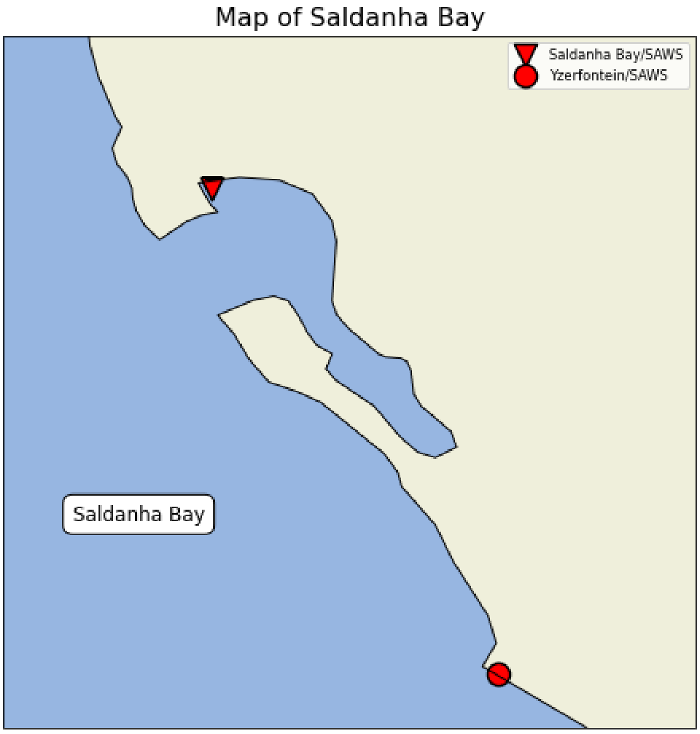


Figure 3.5: Insitu stations at Saldanha Bay used for CROCO validation and a comparison with GLORYS.

The validation of sea surface temperature (SST) at Saldanha Bay and Yzerfontein, using the ERA5-run, WASA3-run, and GLORYS models, provides further insight into model performance across the West Coast of South Africa (Figures 3.6 and 3.7). Although these two stations are situated along the same coast, the model results vary between them, reflecting local environmental influences.

Time Series Comparison

At Saldanha Bay, both the ERA5-run and WASA3-run display high correlation coefficients (r = 0.87 and r = 0.9, respectively), indicating a strong agreement with in-situ observations. By contrast, GLORYS shows a significantly lower correlation (r = 0.27) (Figure 3.6 (a)). The root mean square error (RMSE) further reinforces this pattern, with ERA5-run and WASA3-run showing relatively low RMSE values of 1.09°C and 1.06°C, respectively, while GLORYS exhibits a much higher RMSE of 2.31°C. Similarly, at Yzerfontein (Figure 3.7 (a)), the correlation coefficients for ERA5-run and WASA3-run are more moderate (r = 0.51 and r = 0.47), while GLORYS performs comparably with a correlation of r = 0.47. The RMSE values reflect this, with ERA5-run and WASA3-run showing errors of 1.29°C and 1.65°C, while GLORYS has an error of 2.02°C. Across both stations, it is evident that the croco model runs (ERA5-run and WASA3-run) consistently outperform GLORYS, particularly at Saldanha Bay, where the models show exceptionally high correlations. However, at Yzerfontein, the performance gap between the croco model runs and GLORYS narrows slightly, although GLORYS continues to exhibit higher error values overall.

Anomaly Series and Bias Correction

The anomaly series for both stations (Figures 3.6 (b) and 3.7 (b)) demonstrate how the models perform once biases and seasonal effects are removed. At Saldanha Bay, ERA5-run and WASA3-run still maintain moderate correlations (r = 0.53 and r = 0.56, respectively), though slightly lower than the original time series. GLORYS, on the other hand, shows a significant drop in performance, with an anomaly correlation of just r = 0.12 (Figure 3.6 (b)). Similarly, at Yzerfontein, the anomaly correlations for ERA5-run and WASA3-run are moderate (r = 0.53 and r = 0.54), and GLORYS performs comparably with r = 0.48 (Figure 3.7 (b)). The RMSE values improve in the anomaly series across both stations, indicating that the models capture the underlying trends more effectively once biases are removed. At Saldanha Bay, ERA5-run and WASA3-run have RMSE values of 0.97°C and 0.94°C, while GLORYS, although improving slightly, still shows a much higher RMSE of 1.56°C. At Yzerfontein, the RMSE values for the models are 1.14°C for ERA5-run, 1.18°C for WASA3-run, and 1.29°C for GLORYS.

Climatology and Seasonal Performance

The climatology plots (Figures 3.6 (c) and 3.7 (c)) provide an overview of the models' ability to represent seasonal SST variations. At both stations, ERA5-run and WASA3-run effectively capture the general seasonality but exhibit a low bias according t. GLORYS, in comparison, shows a larger bias, particularly at Saldanha Bay, where it reaches up to 3°C during the summer months (Figure 3.6 (c)). At Yzerfontein, the croco models perform reasonably well in representing seasonal temperature variations, though the summer bias persists. GLORYS, while improving slightly compared to its performance at Saldanha Bay, still shows significant deviation from the in-situ data, justifying the need for further downscaling efforts in this region (Figure 3.7 (c)).

Regional Statistical Summary

Overall, both ERA5-run and WASA3-run emerge as the more reliable models across both Saldanha Bay and Yzerfontein. At Saldanha Bay, the models demonstrate high correlation coefficients and low RMSE values, outperforming GLORYS by a substantial margin. The anomaly analysis further solidifies this trend, as both croco models show improved RMSE values once biases are removed. At Yzerfontein, while the performance gap between the models narrows slightly, ERA5-run and WASA3-run still show better overall performance than GLORYS. GLORYS continues to exhibit larger biases and higher RMSE values, particularly at Saldanha Bay, where its performance is notably poor. The consistent bias and error in GLORYS across both stations, especially during the summer months, indicate that it is less suited for accurate SST validation in this region compared to the croco models.

3.2.1. Saldanha Bay

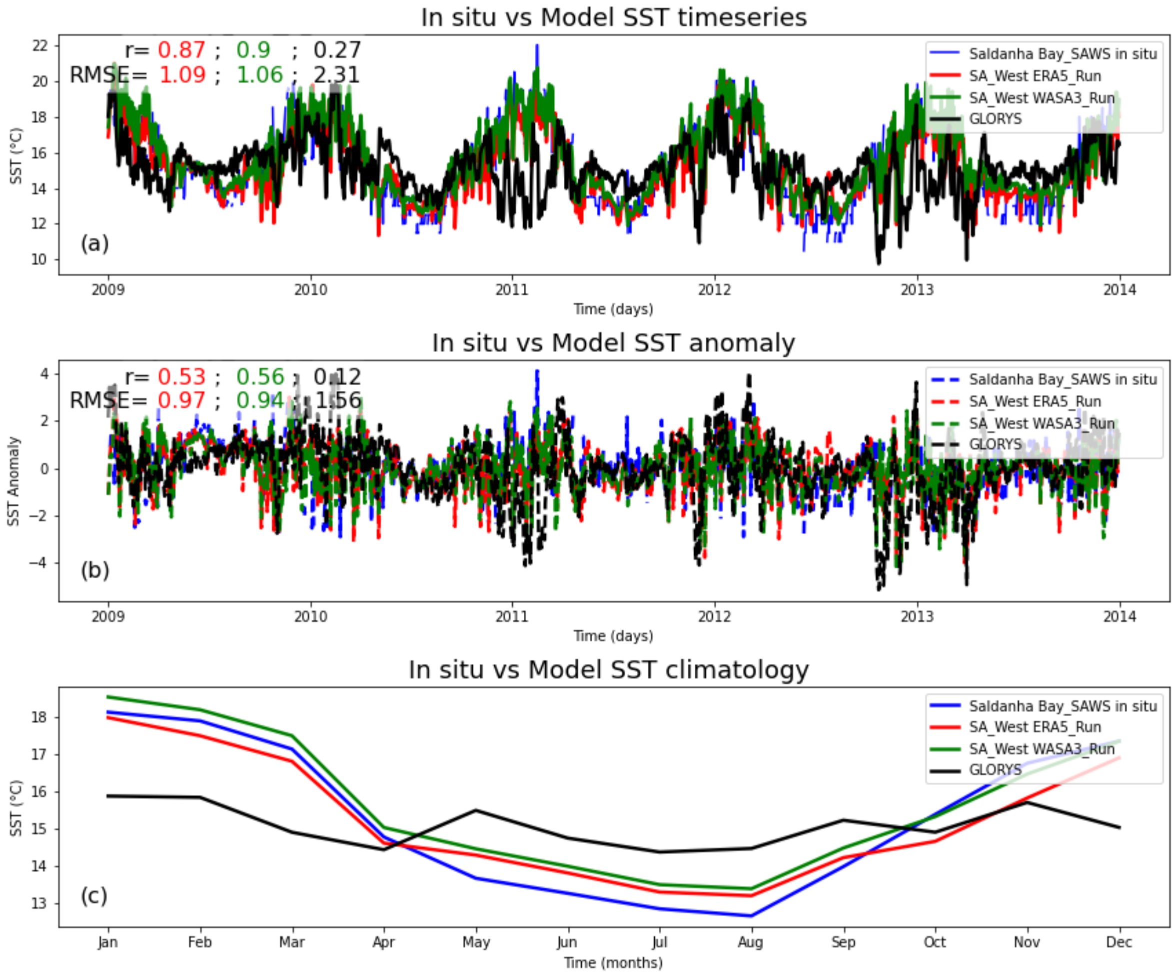


Figure 3.6: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Saldanha Bay SAWS station located at (-33.011: 7.951), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows sst time series, (b) shows anomaly series and (c) shows the climatology of the in situ sst vs the model outputs.

3.2.2. Yzerfontein

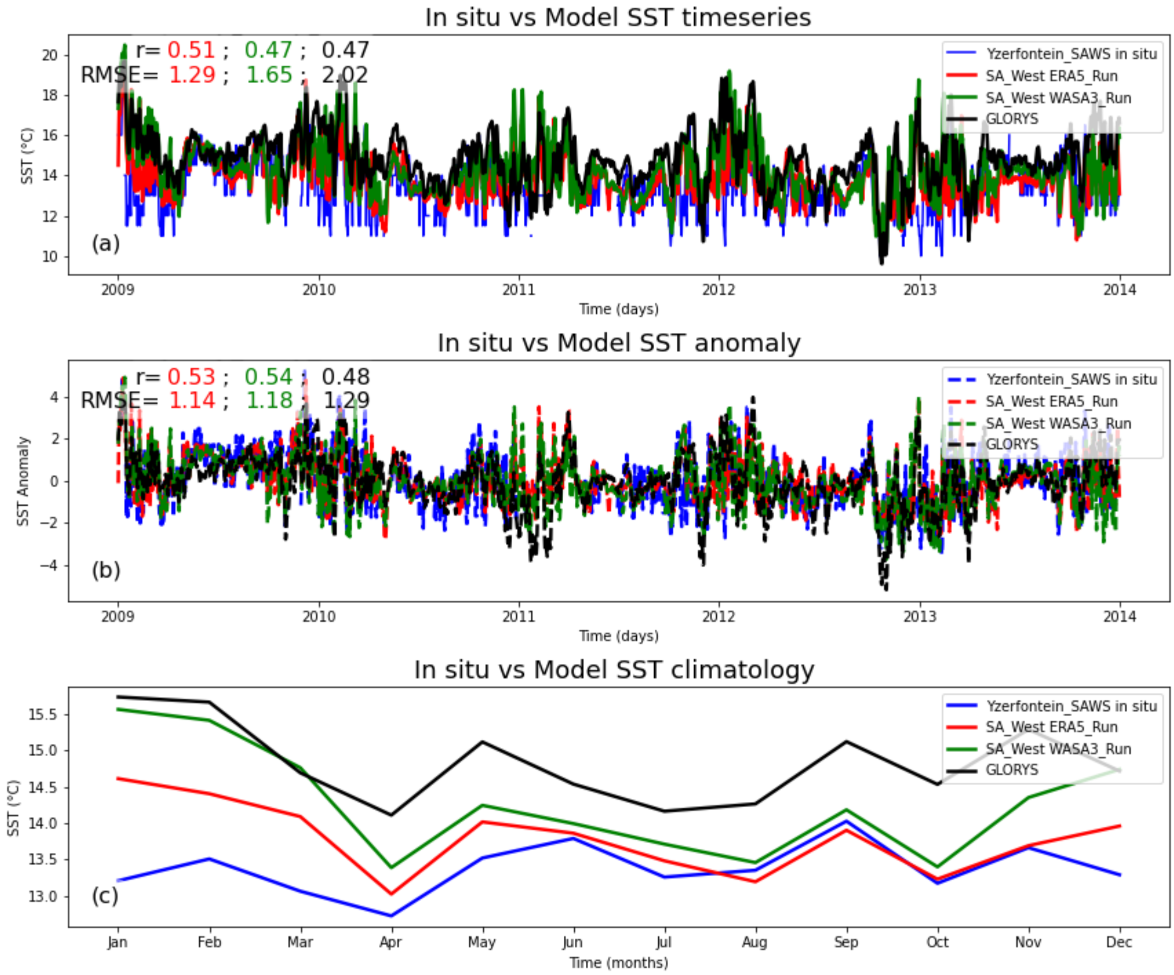


Figure 3.7: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Yzerfontein SAWS station located at (-33.361: 18.157), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

In conclusion, ERA5-run and WASA3-run provide better alignment with in-situ SST data, particularly at Saldanha Bay, where their performance is exceptional. GLORYS, though improving slightly at Yzerfontein, remains problematic due to its persistent bias and higher errors. These results highlight the need for downscaling efforts and suggest that the croco models are better suited for future SST validation in this coastal region.

3.3. False Bay region validation

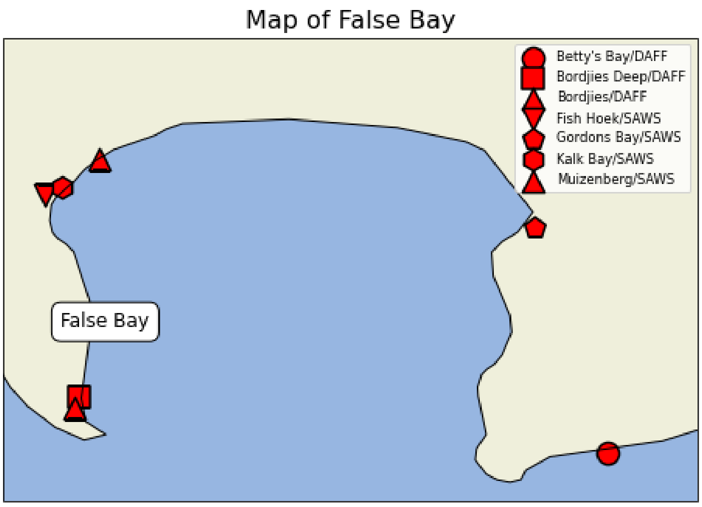


Figure 3.8: Insitu stations at False bay used for CROCO validation and a comparison with GLORYS.

The validation of sea surface temperature (SST) across seven key stations—Betty's Bay, Bordjies Deep, Bordjies Shallow, Fish Hoek, Gordons Bay, Kalk Bay, and Muizenberg—provides detailed insight into the performance of the ERA5-run, WASA3-run, and GLORYS models in the South African West Coast region. Figures 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, and 3.15 present the results of these validations. Across these stations, the croco model runs (ERA5-run and WASA3-run) generally perform well, while GLORYS exhibits some notable biases, especially during the summer months.

Time Series Comparison

At Betty's Bay (Figure 3.9 (a)), the ERA5-run, WASA3-run, and GLORYS all exhibit high correlation coefficients (r = 0.80), with RMSE values of 1.13°C and 1.1°C for the croco models, while GLORYS has a higher RMSE of 1.7°C. Similarly, at Bordjies Deep (Figure 3.10 (a)), the croco models show strong correlations (r = 0.68 for ERA5-run and r = 0.75 for WASA3-run), with RMSE values of 1.68°C and 1.48°C, respectively. GLORYS performs slightly better here, with an RMSE of 1.34°C. At Bordjies Shallow (Figure 3.11 (a)), the models perform even better, with correlation coefficients of r = 0.7 (ERA5-run), r = 0.77 (WASA3-run), and r = 0.77 (GLORYS). The RMSE values for ERA5-run and WASA3-run are 1.68°C and 1.45°C, while GLORYS performs comparably with an RMSE of 1.27°C. Fish Hoek (Figure 3.12 (a)) presents a similar pattern, with all models achieving high correlations (r = 0.68 for ERA5-run, r = 0.75

for WASA3-run, and r = 0.73 for GLORYS). In contrast, Gordons Bay (Figure 3.13 (a)) shows higher errors, with RMSE values of 5.39°C and 3.55°C for ERA5-run and WASA3-run, respectively, while GLORYS has a slightly lower RMSE of 4.03°C. Finally, at Kalk Bay (Figure 3.14 (a)), the croco models continue to perform well, with RMSE values of 3.53°C (ERA5-run) and 3.37°C (WASA3-run), while GLORYS shows an RMSE of 3.93°C. At Muizenberg (Figure 3.15 (a)), the ERA5-run and WASA3-run models achieve high correlations (r = 0.88 and r = 0.91, respectively), with RMSE values of 1.69°C and 1.91°C. GLORYS performs similarly well, with a correlation of r = 0.85 and an RMSE of 1.95°C.

Anomaly Series and Bias Correction

The anomaly analysis (Figures 3.9 (b), 3.10 (b), 3.11 (b), 3.12 (b), 3.13 (b), 3.14 (b), and 3.15 (b)) provides further insight into model performance after removing biases and seasonal effects. At Betty's Bay, the correlations for the ERA5-run and WASA3-run remain high (r = 0.78 and r = 0.80), while GLORYS shows a slightly lower correlation of r = 0.77. The RMSE values for ERA5-run and WASA3-run are 1.1°C and 0.96°C, with GLORYS also showing a low RMSE of 0.98°C. At Bordjies Deep, the anomaly correlations decrease slightly for all models, with ERA5-run (r = 0.5), WASA3-run (r = 0.63), and GLORYS (r = 0.6). The RMSE values improve, with ERA5-run at 1.41°C, WASA3-run at 1.23°C, and GLORYS at 1.26°C. Bordjies Shallow also shows a reduction in anomaly correlations, with r = 0.47 for ERA5-run, r = 0.63 for WASA3-run, and r = 0.62 for GLORYS. The RMSE values similarly decrease to 1.39°C, 1.19°C, and 1.19°C, respectively. At Fish Hoek, the anomaly correlations follow the same trend, with moderate-to-high correlations for the croco models and GLORYS. The RMSE values also improve to 1.41°C, 1.23°C, and 1.26°C, respectively. Gordons Bay sees a notable improvement in RMSE values when considering anomalies, with ERA5-run improving to 1.79°C, WASA3-run to 1.66°C, and GLORYS to 1.58°C. At Kalk Bay, the anomaly correlations drop (r = 0.34 for both croco models), with GLORYS performing slightly worse (r = 0.26). However, the RMSE values improve to 1.38°C (ERA5-run), 1.33°C (WASA3-run), and 1.43°C (GLORYS). Lastly, at Muizenberg, the anomaly correlations decrease to r = 0.41 (ERA5-run), r = 0.44 (WASA3-run), and r = 0.43 (GLORYS), while the RMSE values improve to 1.23°C, 1.14°C, and 1.14°C, respectively.

Climatology and Seasonal Performance

The climatology plots (Figures 3.9 (c), 3.10 (c), 3.11 (c), 3.12 (c), 3.13 (c), 3.14 (c), and 3.15 (c)) offer insights into the models' seasonal performance. At all stations, the ERA5-run and WASA3-run models generally capture the seasonal variability well, although they tend to exhibit some bias during the summer months. At Betty's Bay, the croco models perform well but show some underestimation in early summer and overestimation in other parts of the year. GLORYS, however, shows a general positive bias of around 1.5°C, which is a concern. At Bordjies Deep and Bordjies Shallow, the croco models show a similar pattern, with GLORYS exhibiting a smaller bias of around 1°C at both stations. Fish Hoek shows similar results, with the croco models generally aligning with the in-situ data, while GLORYS continues to exhibit a positive bias. Gordons Bay shows more significant issues with model performance, particularly in summer, where ERA5-run and WASA3-run show a positive bias of around 3°C and 1°C, respectively. GLORYS also exhibits a large positive bias and fails to capture the seasonal trends effectively. At Kalk Bay and Muizenberg, the croco models perform better, but GLORYS continues to show some bias, particularly during the summer months.

Regional Statistical Summary

Overall, the ERA5-run and WASA3-run models perform reliably across most of the stations, showing high correlation coefficients and relatively low RMSE values. At stations like Betty's Bay, Bordjies Deep, and Muizenberg, the croco models consistently demonstrate their ability to capture SST variability. However, they exhibit some bias during the summer, particularly at Gordons Bay and Kalk Bay, where the errors are more pronounced. GLORYS, while performing reasonably well at some stations like Bordjies Shallow and Muizenberg, generally shows higher biases and larger errors, especially during the summer months. The positive bias seen in the GLORYS model raises concerns about its suitability for capturing accurate seasonal variations along the South African West Coast. In conclusion, the croco models (ERA5-run and WASA3-run) should be favored for SST validation across this region, with WASA3-run generally outperforming ERA5-run in terms of RMSE. GLORYS, though capable in some instances, exhibits a persistent bias and higher error, particularly at Gordons Bay, suggesting that it may not be the most reliable model for this region's SST analysis.

3.3.1. Betty's Bay

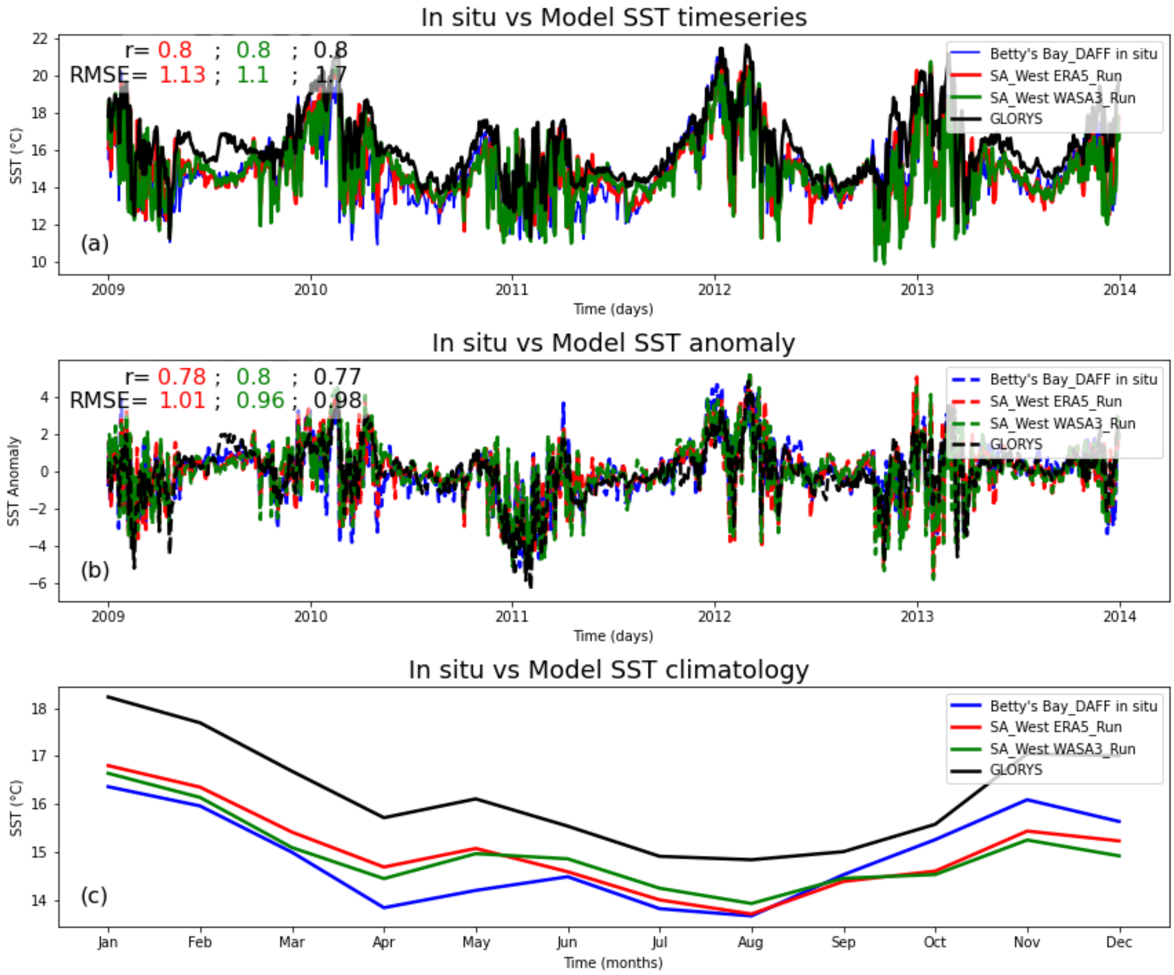


Figure 3.9: Temperature validation of the SA West Model, ERA5 and WASA3 wind forced configurations at Betty's Bay DAFF station located at (-34.359: 18.922), depth = 5 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.3.2. Bordjies Deep

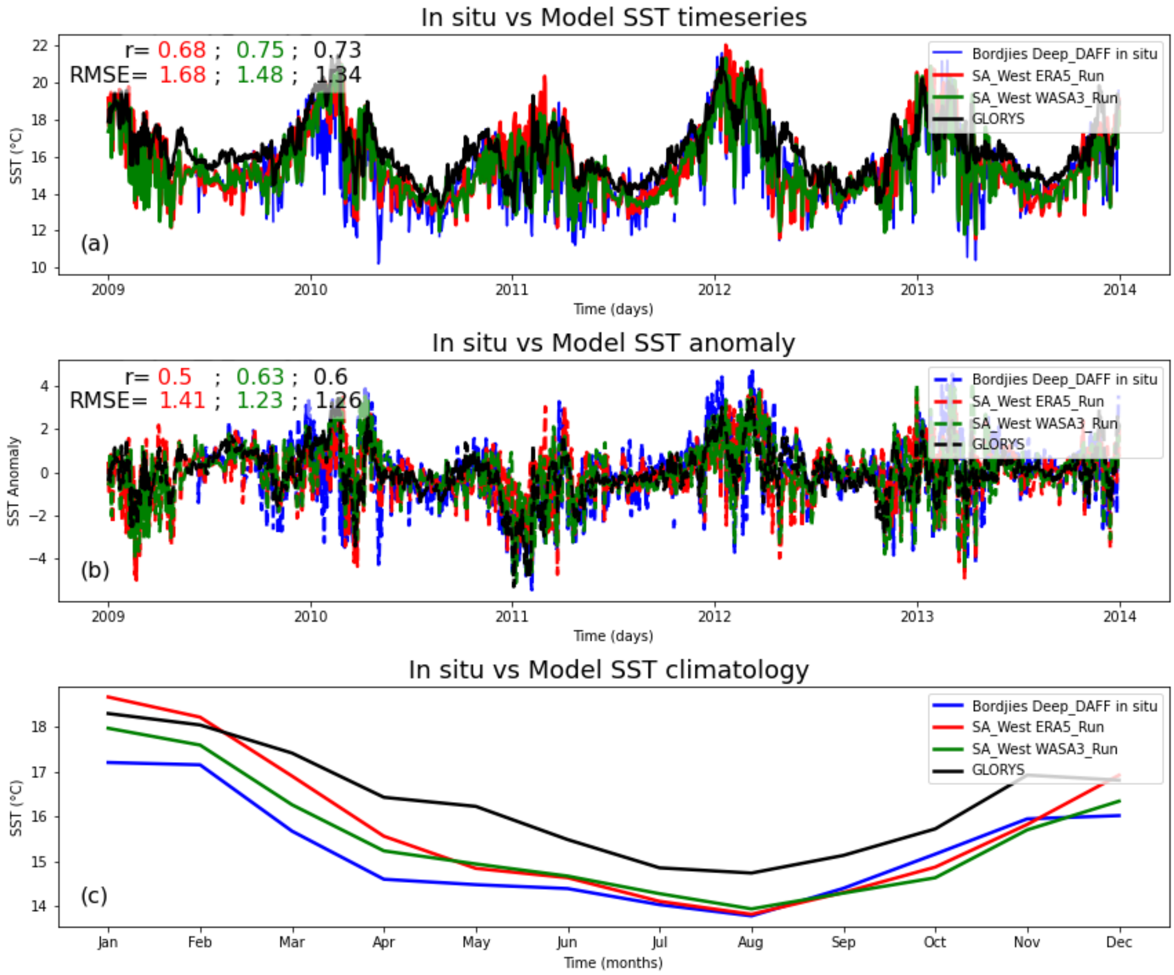


Figure 3.10: Temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Bordjies Deep DAFF station located at (-34.31: 18.465), depth = 9 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.3.3. Bordjies Shallow

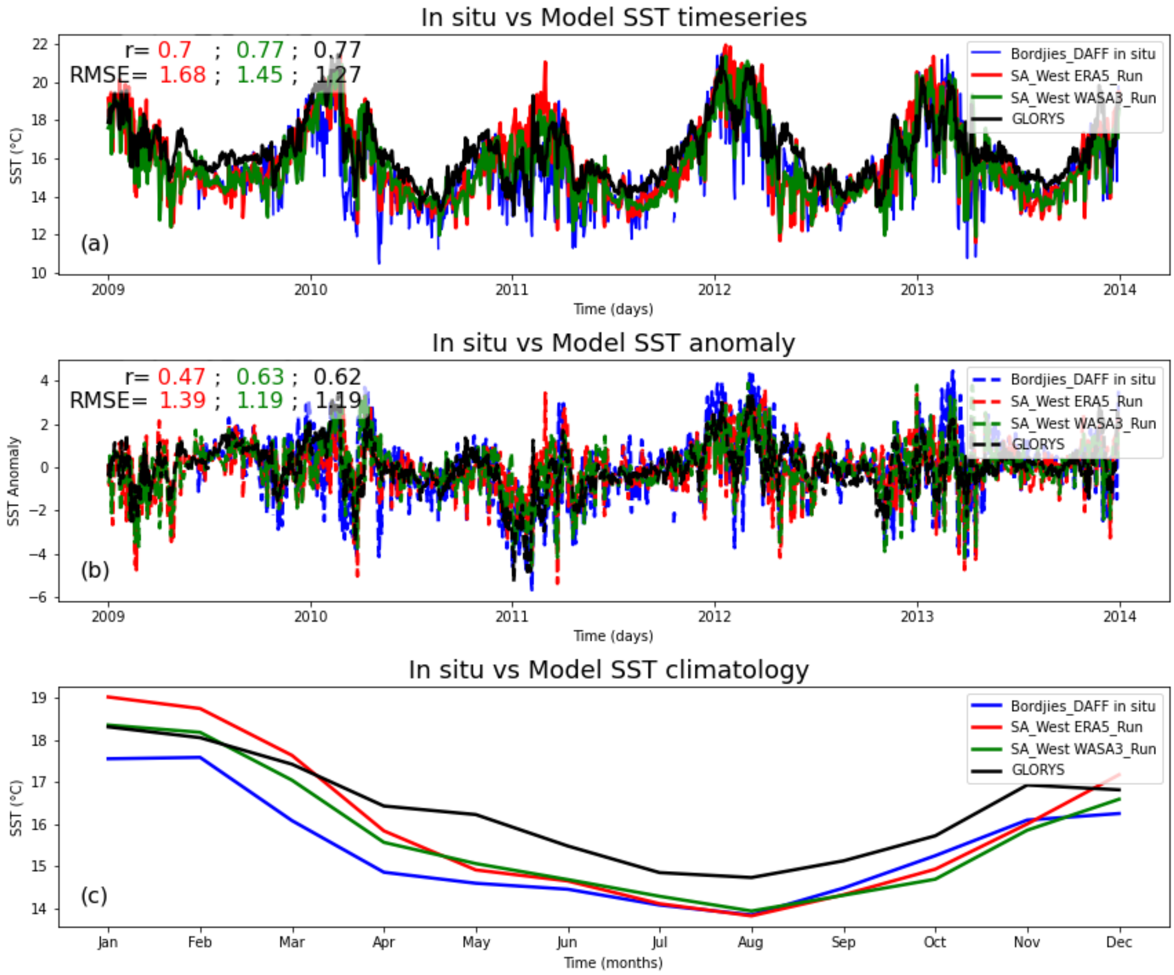


Figure 3.11: Temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Bordjies Shallow station located at (-34.32: 18.462), depth = 4 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.3.4. Fish Hoek

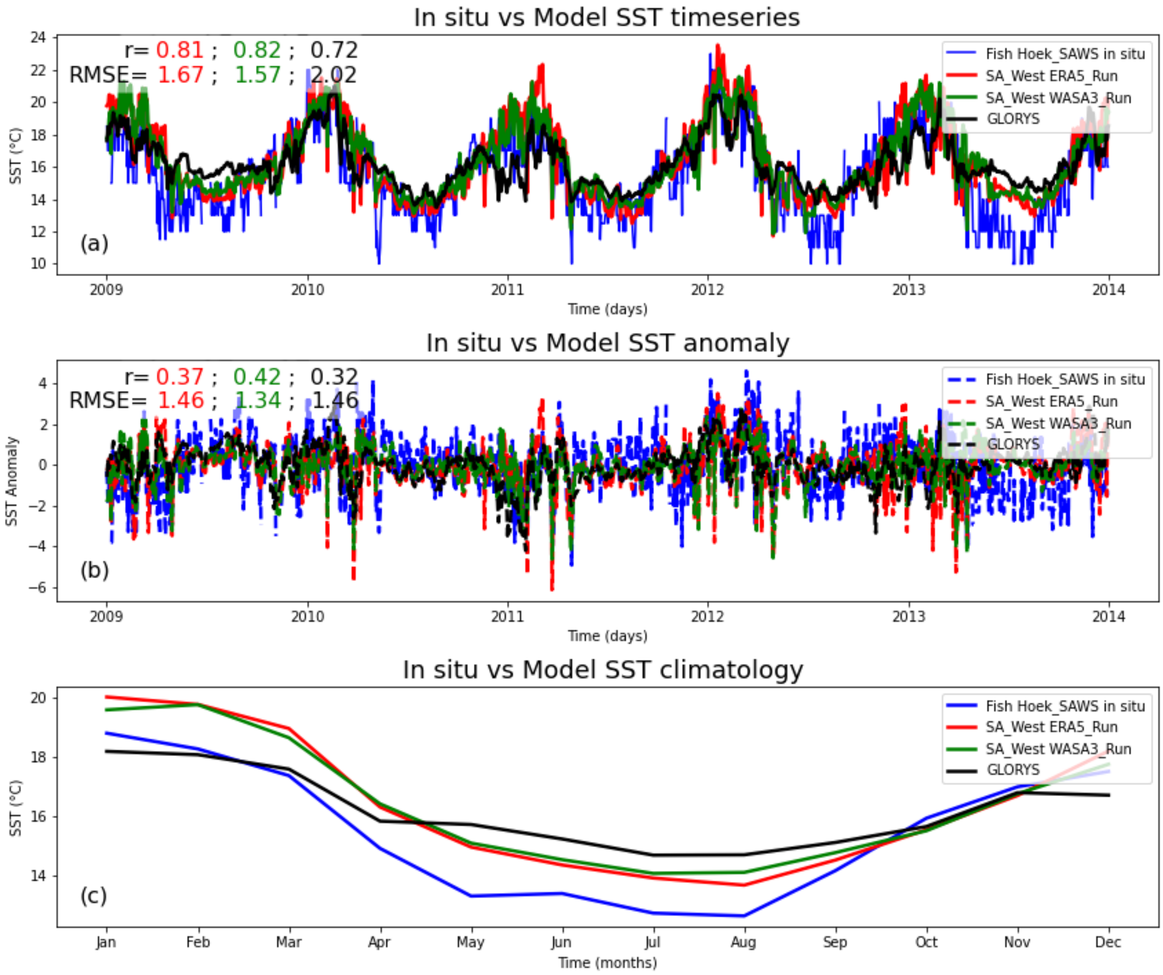


Figure 3.12: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Fish Hoek SAWS station located at (-34.135: 18.436), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.3.5. Gordons Bay

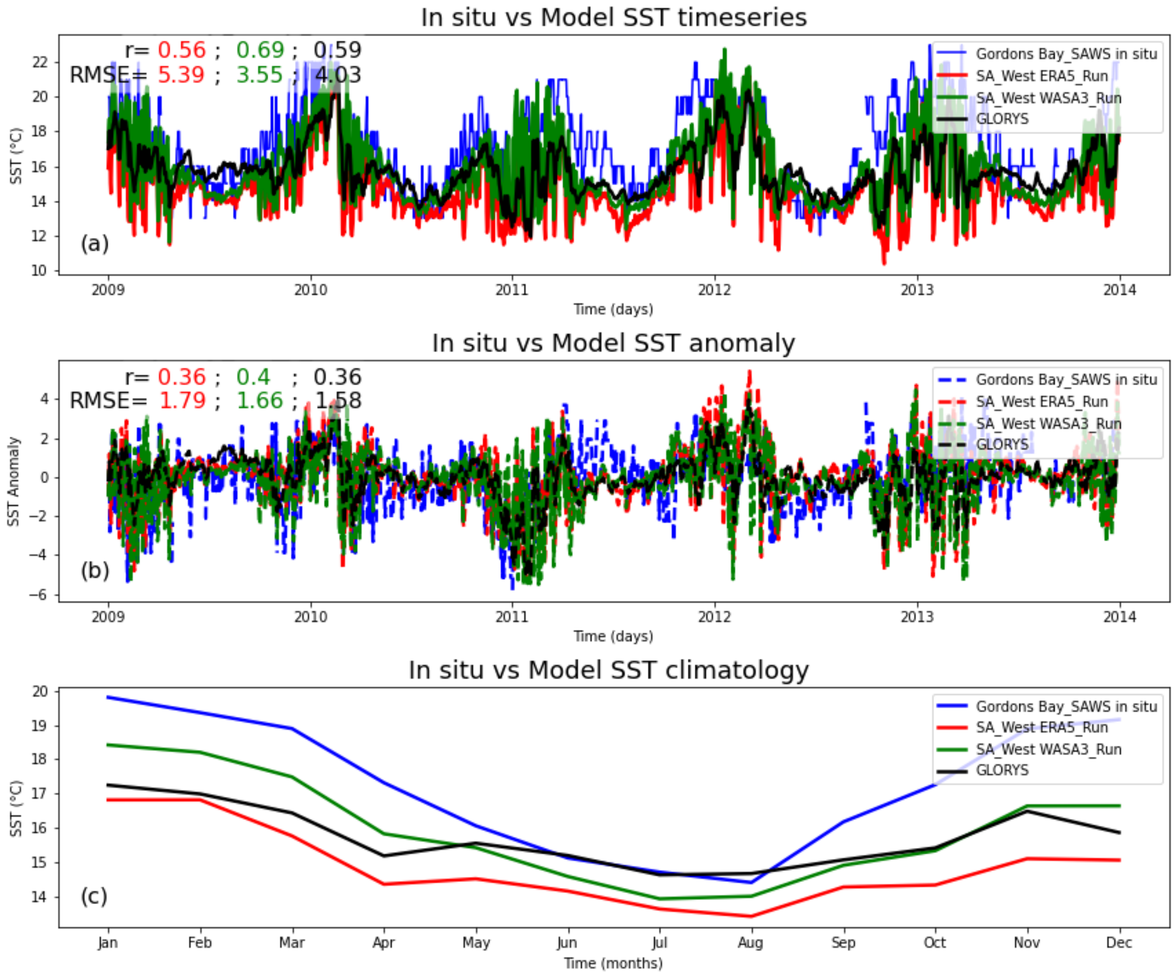


Figure 3.13: : SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Gordons Bay SAWS station located at (-34.163: 18.859), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.3.6. Kalk Bay

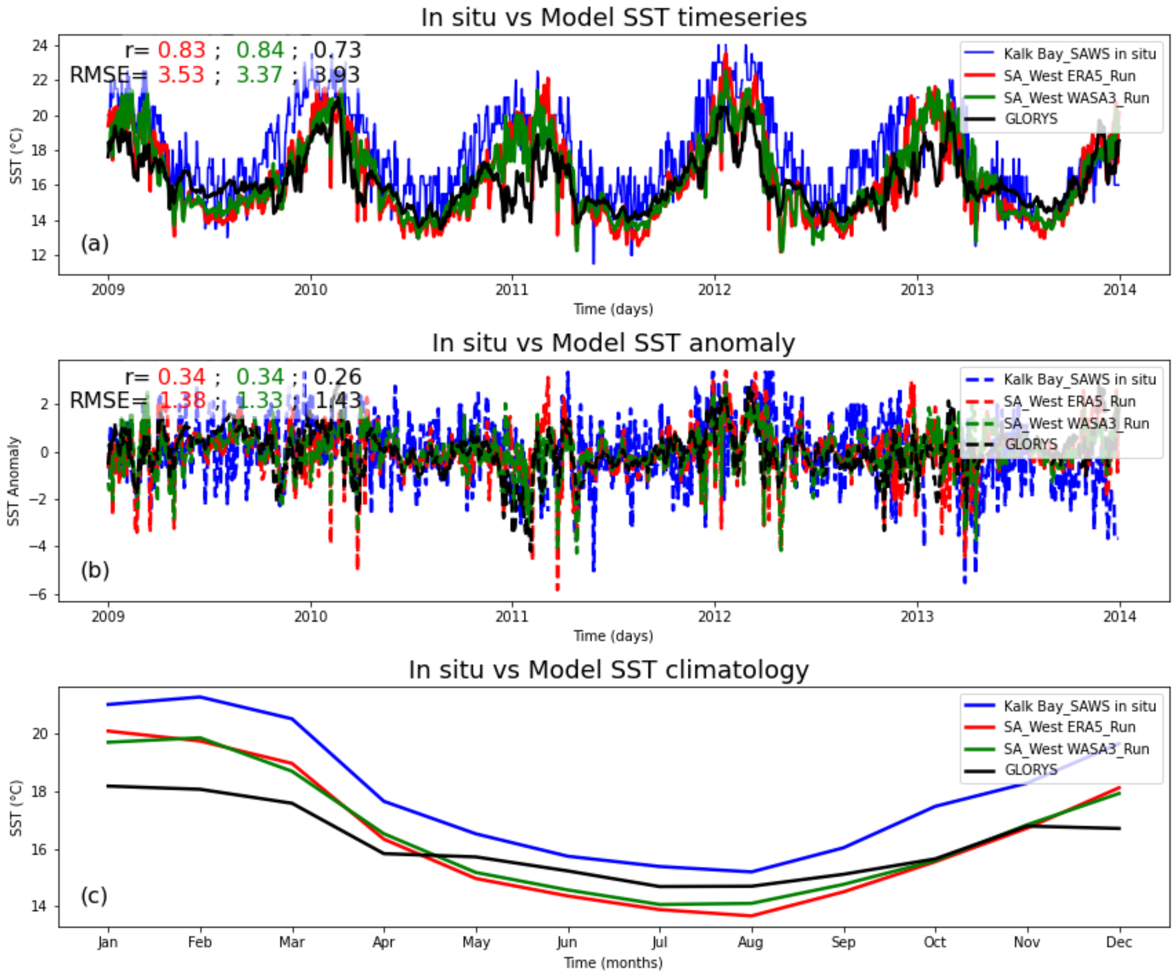


Figure 3.14: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Kalk Bay SAWS station located at (-34.128: 18.451), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.3.7. Muizenberg

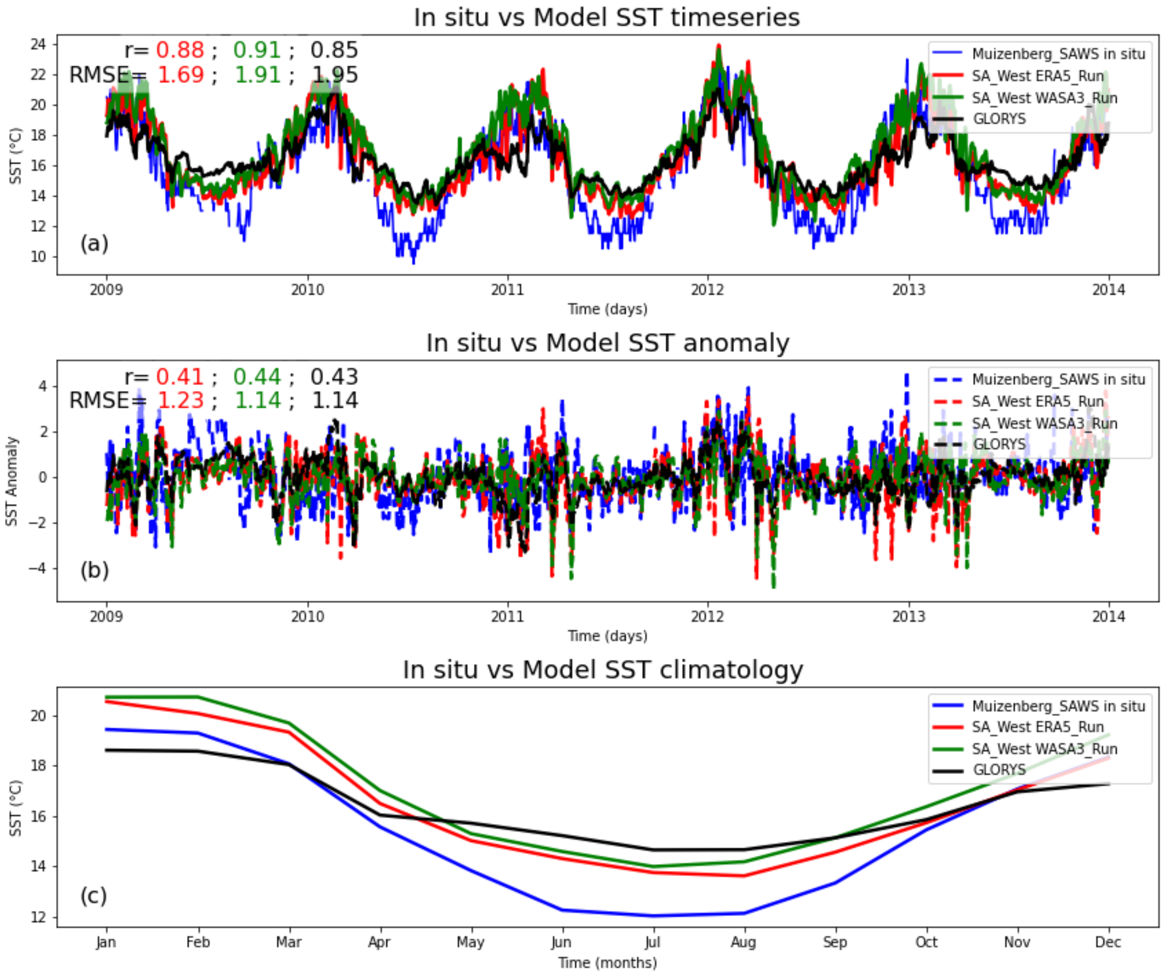


Figure 3.15: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Muizenberg SAWS station located at (-34.104: 18.484), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.4. Southern St Helena Bay region validation

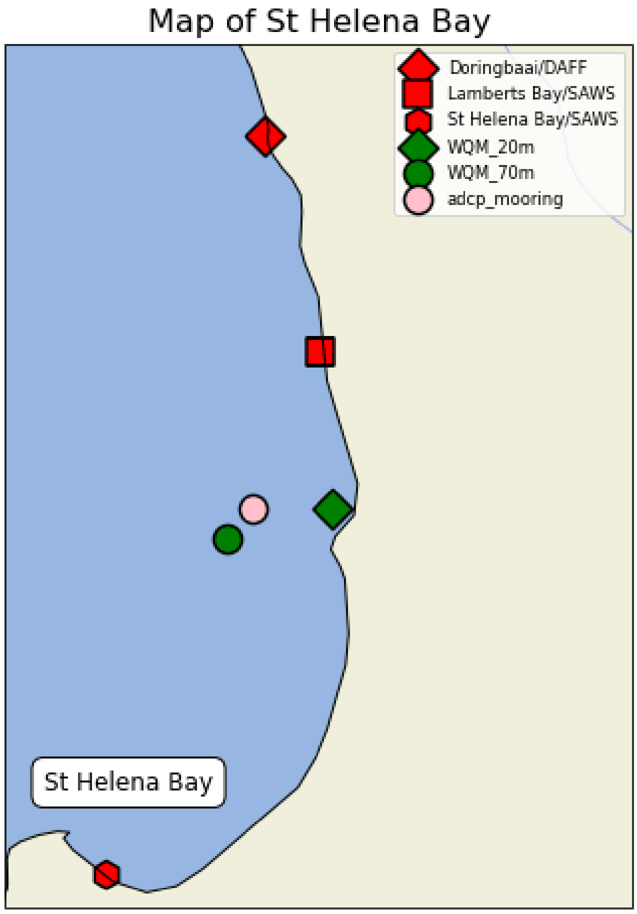


Figure 3.16: Insitu stations at St Helena Bay used for CROCO validation and a comparison with GLORYS.

The validation of the St Helena Bay region includes temperature observations at five key stations Doringbaai, Lamberts Bay, St Helena Bay, WQM 20 m, and WQM 70 m as well as curents at an ADCP mooring. Figures 3.17, 3.18, 3.19, 3.20, and 3.30 present the results for these stations, highlighting the comparative model performance.

Time Series Comparison

At Doringbaai (Figure 3.17 (a)), the croco models show strong correlation coefficients, with r = 0.76 for ERA5-run and r = 0.82 for WASA3-run. GLORYS, by contrast, performs poorly with a correlation of r = 0.25. The RMSE values for ERA5-run and WASA3-run are 1.65°C and 1.09°C, respectively, while GLORYS shows a much higher RMSE of 2.43°C. Similarly, at Lamberts Bay (Figure 3.18 (a)), ERA5-run and WASA3-run perform moderately well (r = 0.63

and r = 0.71, respectively), while GLORYS again shows a lower correlation of r = 0.34. The RMSE values for ERA5-run and WASA3-run are 1.39°C and 1.28°C, while GLORYS shows a higher RMSE of 2.01°C. At St Helena Bay (Figure 3.19 (a)), the performance of all models decreases, with ERA5-run showing r = 0.5, WASA3-run at r = 0.45, and GLORYS at r = 0.36. The RMSE values remain relatively high, with ERA5-run at 1.57°C, WASA3-run at 1.33°C, and GLORYS at 1.52°C. The WQM 20 m station (Figure 3.20 (a)) sees stronger correlations, with ERA5-run (r = 0.82), WASA3-run (r = 0.83), and GLORYS (r = 0.26). The RMSE values for the croco models are below 1°C, with ERA5-run at 0.91°C and WASA3-run at 0.87°C, while GLORYS shows a higher RMSE of 1.53°C. At the deeper WQM 70 m station (Figure 3.30 (a)), the ERA5-run and WASA3-run show very high correlations, with r = 0.89 and r = 0.92, respectively. GLORYS, on the other hand, performs poorly with a correlation of r = 0.46. The RMSE values for the croco models are remarkably low, with ERA5-run at 0.46°C and WASA3-run at 0.27°C, while GLORYS shows a higher RMSE of 0.87°C.

Anomaly Series and Bias Correction

The anomaly series analysis (Figures 3.17 (b), 3.18 (b), 3.19 (b), 3.20 (b), and 3.30 (b)) further illustrates the models' performance after biases and seasonal effects are removed. At Doringbaai, the croco models maintain high anomaly correlations (r = 0.74 for ERA5-run and r = 0.76 for WASA3-run), while GLORYS improves slightly to r = 0.36. The RMSE values also improve to 1.05°C and 1.00°C for the croco models, while GLORYS shows an improved RMSE of 1.7°C. At Lamberts Bay, the anomaly correlations remain similar, with ERA5-run and WASA3-run showing r = 0.63 and r = 0.72, respectively, while GLORYS drops to r = 0.27. The RMSE values improve across the models, with ERA5-run at 1.26°C, WASA3-run at 1.09°C, and GLORYS at 1.65°C. St Helena Bay shows further degradation, with the anomaly correlations dropping to r = 0.48 for ERA5-run, r = 0.42 for WASA3-run, and r = 0.32 for GLORYS. The RMSE values, however, improve slightly, with ERA5-run at 1.22°C, WASA3-run at 1.3°C, and GLORYS at 1.43°C. At WQM 20 m, the anomaly correlations remain moderate to high, with ERA5-run and WASA3-run showing r = 0.62 and r = 0.63, respectively. GLORYS, however, remains weak, with a correlation of r = 0.16. The RMSE values improve for all models, with ERA5-run at 0.6°C, WASA3-run at 0.53°C, and GLORYS at 0.81°C. At WQM 70 m, the anomaly correlations remain high for the croco models, with r = 0.62 for ERA5-run and r =

0.63 for WASA3-run. GLORYS continues to struggle with r = 0.16. The RMSE values improve further, with ERA5-run at 0.6°C, WASA3-run at 0.53°C, and GLORYS at 0.81°C.

Climatology and Seasonal Performance

The climatology plots (Figures 3.17 (c), 3.18 (c), 3.19 (c), 3.20 (c), and 3.30 (c)) provide further insights into the models' seasonal performance. At Doringbaai, the ERA5-run slightly underestimates the temperature during the summer months, while the WASA3-run tends to overestimate it. GLORYS shows a persistent positive bias of around 1°C and struggles to capture the seasonal trend accurately. At Lamberts Bay, the WASA3-run show a positive bias during summer up to $\tilde{2}$.5°C, whereas the ERA5-run exhibits negative biasduring the summer periods. During winter time both models do well while GLORYS shows constant positive bias. St Helena Bay presents a different picture, where all models fail to resolve the finer features of the climatology, although they appear to capture trends relative to each other. The croco models tend to underapproximate the temperature, while GLORYS overapproximates it. At WQM 20 m and WQM 70 m, the croco models perform bad in capturing the seasonal trends, particularly at the deeper 70 m station. Both models poorly align with the in-situ climatology and a general positive bias of around 2°C persists during the summer and gets exhaggerated in winter in the WQM 70 m station. GLORYS, shows a strong positive bias at both depths.

Regional Statistical Summary

Across these stations, the ERA5-run and WASA3-run models demonstrate better overall performance compared to GLORYS. At the surface-level stations (Doringbaai, Lamberts Bay, and St Helena Bay), the croco models consistently show higher correlation coefficients and lower RMSE values, though they exhibit some bias during the summer months. GLORYS, while improving slightly in the anomaly analysis, remains the weakest model across all locations. At the deeper WQM 20 m and WQM 70 m stations, the croco models perform exceptionally well, particularly at the 70 m depth, where they show very low RMSE values and high correlations. GLORYS, however, continues to struggle with higher errors and biases, suggesting that it is less suited for deep-water validation in this region. In conclusion, the croco models (ERA5-run and WASA3-run) provide the most reliable SST and temperature validation across the surface and deeper stations. WASA3-run tends to outperform ERA5-run in terms of RMSE, particularly at deeper locations. GLORYS, while occasionally showing some capability, is consistently hindered by higher biases and errors, especially during the summer months. These results suggest that further refinement and downscaling efforts are necessary for GLORYS to achieve similar levels of performance in the South African coastal region.

3.4.1. Doringbaai

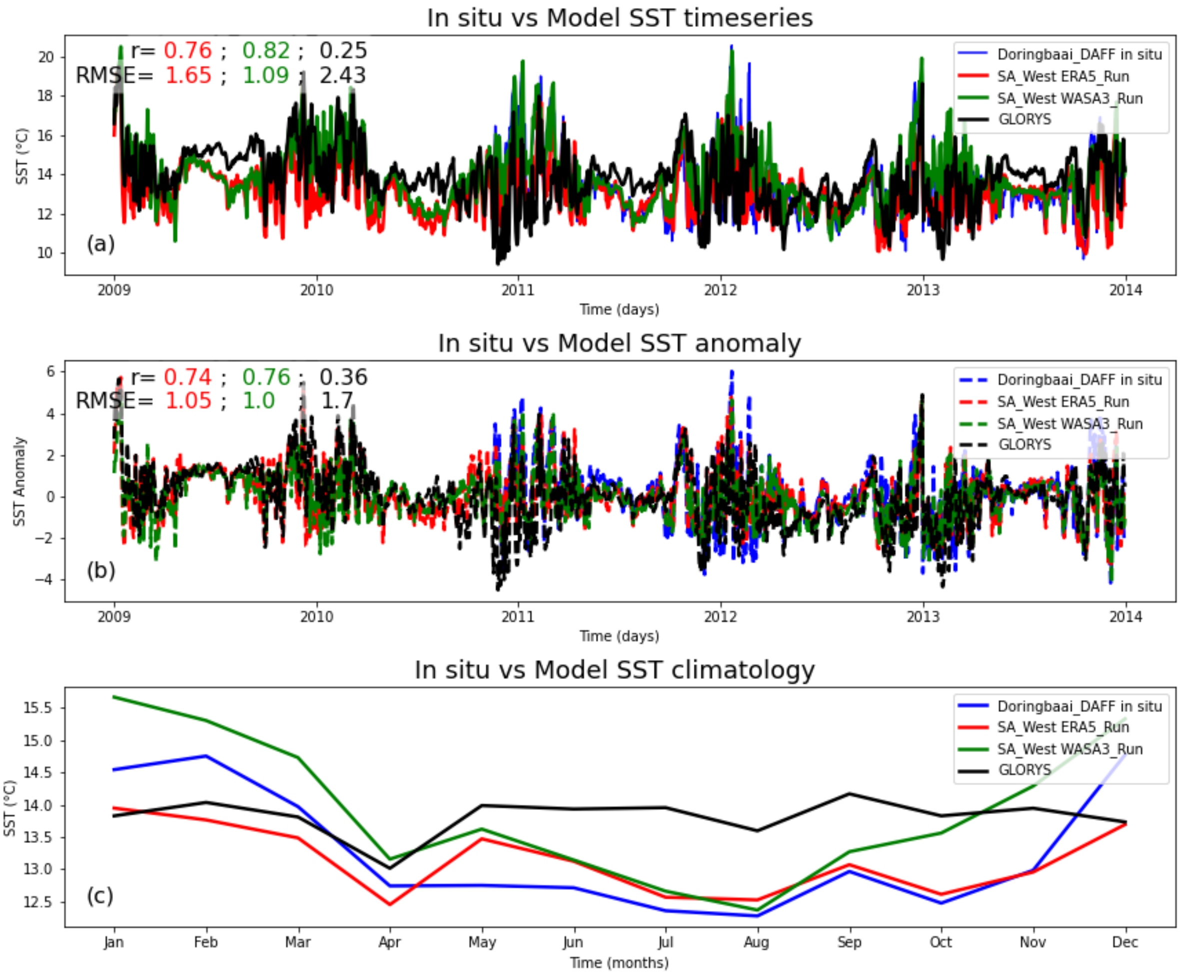


Figure 3.17: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Doringbaai DAFF station located at (-31.817: 18.231), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.4.2. Lamberts Bay

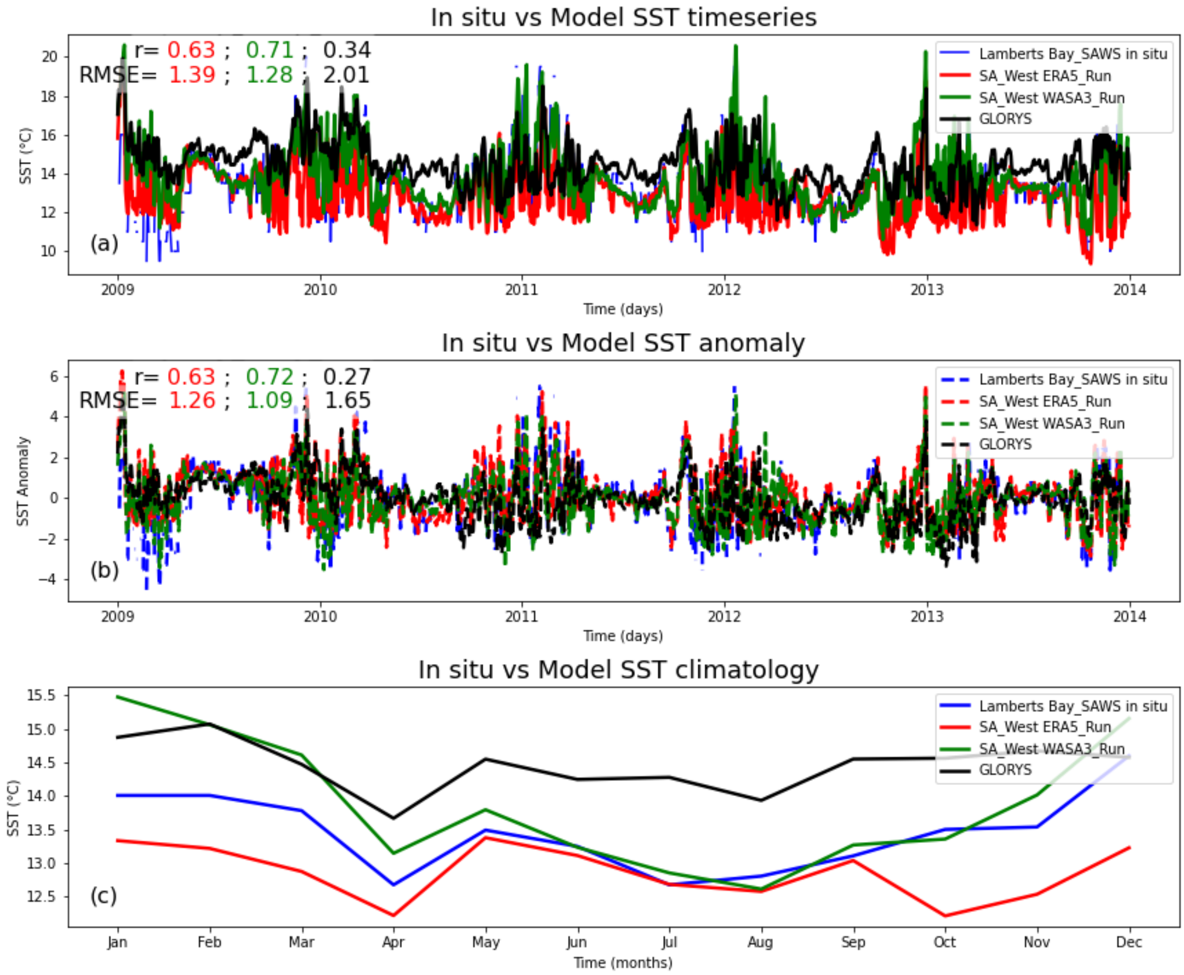


Figure 3.18: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at Lamberts Bay SAWS station located at (-32.092: 18.303), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.4.3. St Helena Bay

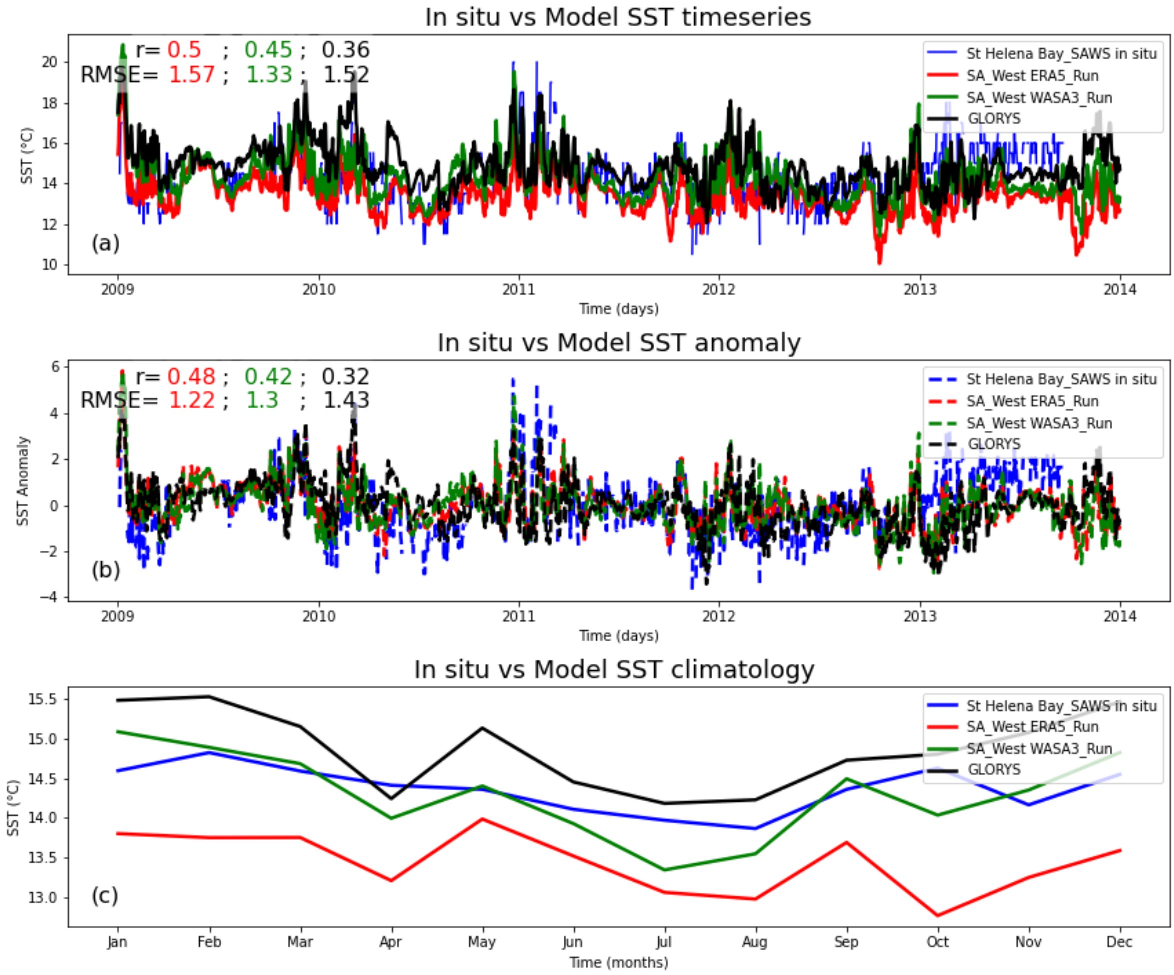


Figure 3.19: SST validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at St Helena Bay SAWS station located at (-32.758: 18.028), depth = 0 m and a comparison with GLORYS global model. Subplot (a) shows SST time series, (b) shows anomaly series and (c) shows the climatology of the in situ SST vs the model outputs.

3.4.4. WQM 20 m

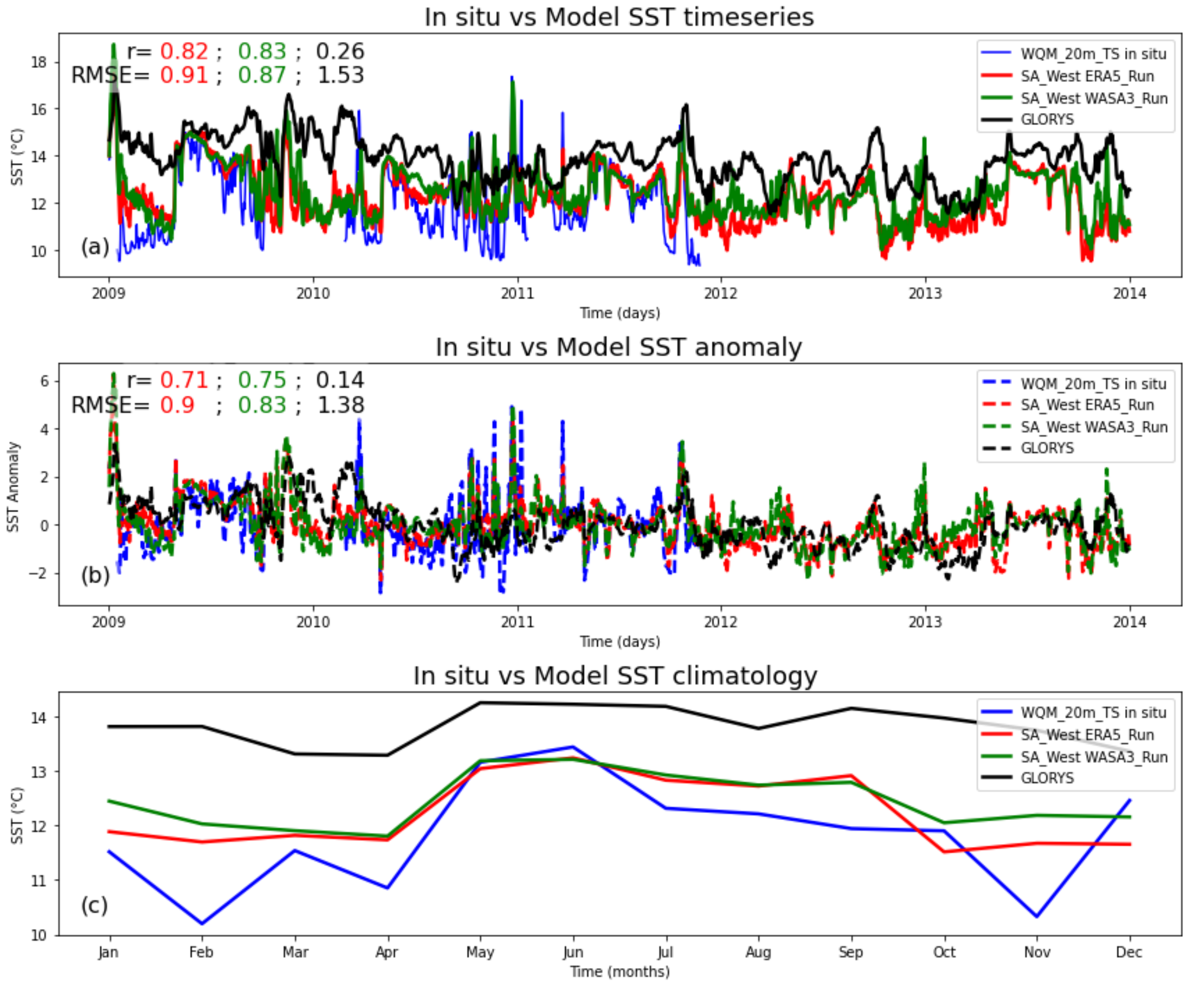


Figure 3.20: Temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at WQM 20m TS station located at (-32.292: 18.318), depth = 20 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.4.5. WQM 70 m

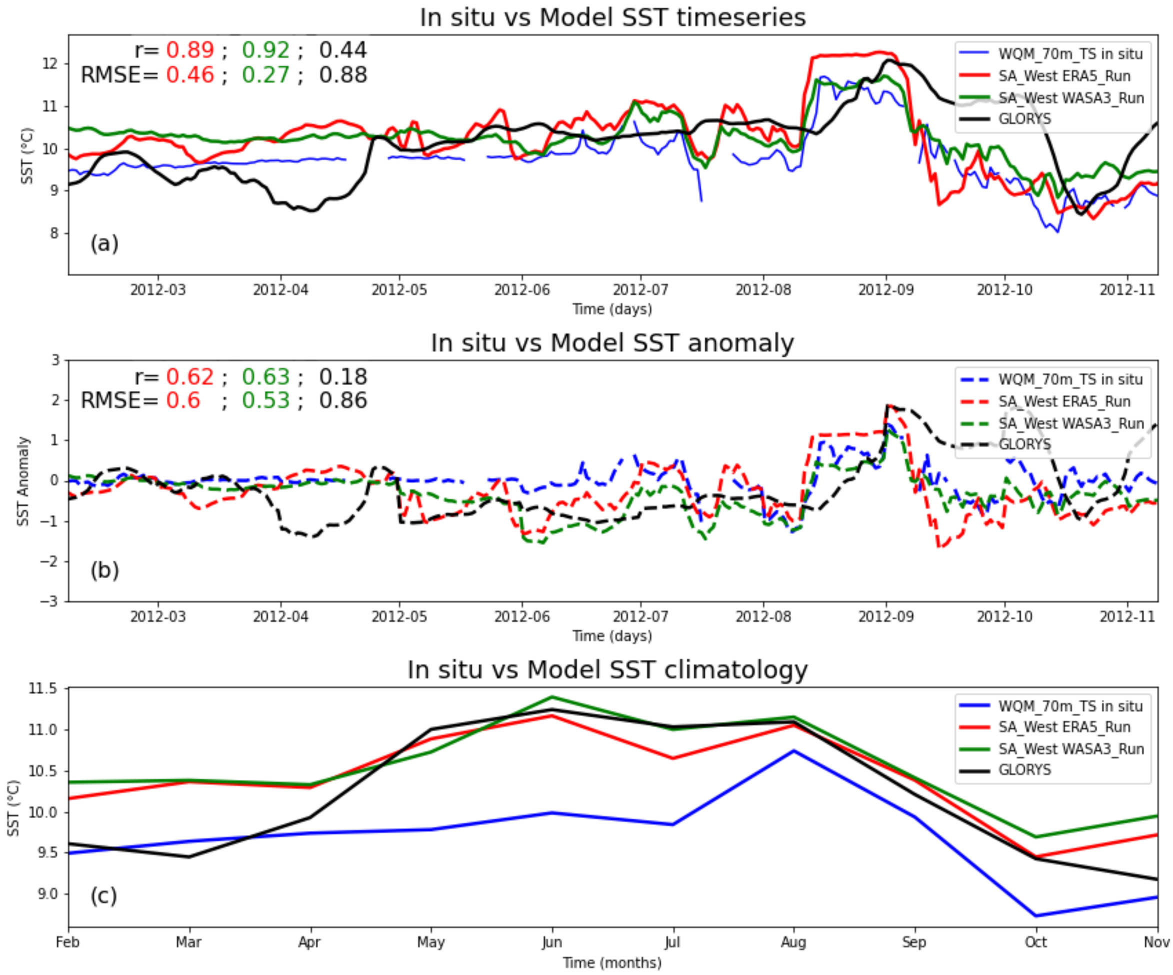


Figure 3.21: Temperature validation of the SA West Model, both the ERA5 and WASA3 wind forced configurations at WQM 70m TS station located at (-32.292: 18.318), depth = 70 m and a comparison with GLORYS global model. Subplot (a) shows temperature time series, (b) shows anomaly series and (c) shows the climatology of the in situ bottom temperature vs the model outputs.

3.4.6. Wirewalker (Water column temperature evaluation)

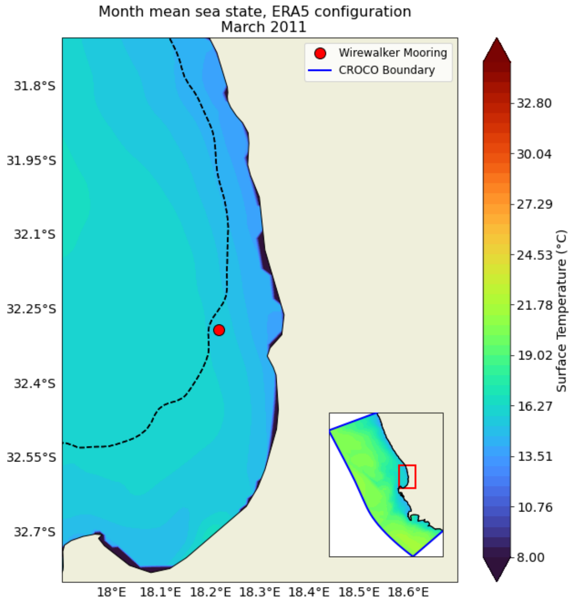


Figure 3.22: Insitu wirewalker station at St Helena Bay used for CROCO validation and a comparison with GLORYS.

In this section, we evaluate the CROCO ERA5 and CROCO WASA3 model runs with temperature profiles obtained from the wire-walker station in St Helena Bay (3.22). The observations are made hourly and are compared with hourly outputs. Note that GLORYS dataset is not included in this assessment as it is only available as daily outputs. The profiles shown in Figure (3.23) shows that the in-situ data recorded a much more intense temperature within the top 5-10 meters something that all the models failed to capture accurately as they all seem to under-approximate the temperature intensity in that depth region, although not always and they also stratification does not seem well represented in the model which also appears to have a deeper mixed layer when compared with the in-situ record shown in Figure 3.23 (a). The models however seem to capture the warm pool events accurately across time with the surface of the in-situ record. This signals that there would be strong surface temperature correlations between the in-situ data the models shown in Figure 3.23 (b), (c) and (d). The hourly in situ data compared with hourly model runs on the other shows a well captured WASA3 run stratification within the 5-10 meter band inline with in-situ data as shown in Figure 3.24 (a) and (c). The ERA5 hourly run also captures the temperature events across time very well but poorly resolves stratification as shown in Figure 3.24 (a). To perfectly sum this strong temporal signal the statistical analysis is performed on all levels and shows a strong correlation on the surface which quickly dies down through the water column as the models mostly poorly resolve the mixed layer depth given their deep thermocline, the exception is the WASA3 daily runs which maintains the good correlation and RMSE in atleast the top 20 meters and maintains bias of below 2 throughout the water column Figure 3.25 (a) (b) and (c) shows this phenomenon.

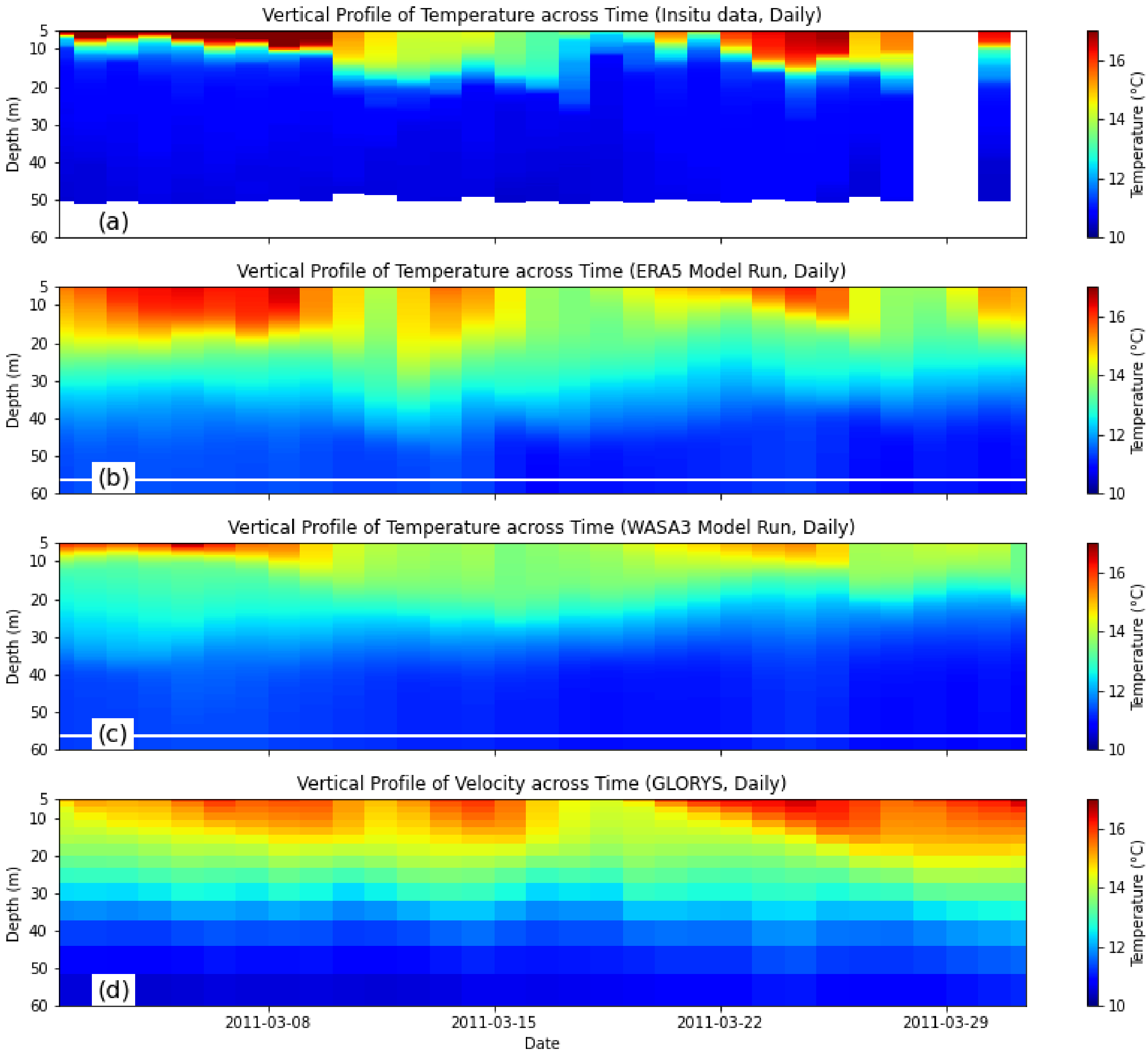


Figure 3.23: Daily Temperature validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay Wirewalker station (located on the adcp mooring) and comparison with GLORYS (global model). Subplot (a) shows insitu temperature, (b) shows ERA5 run, (c) shows WASA3 run and (d) shows the GLORYS Temperature on the station across the water column.

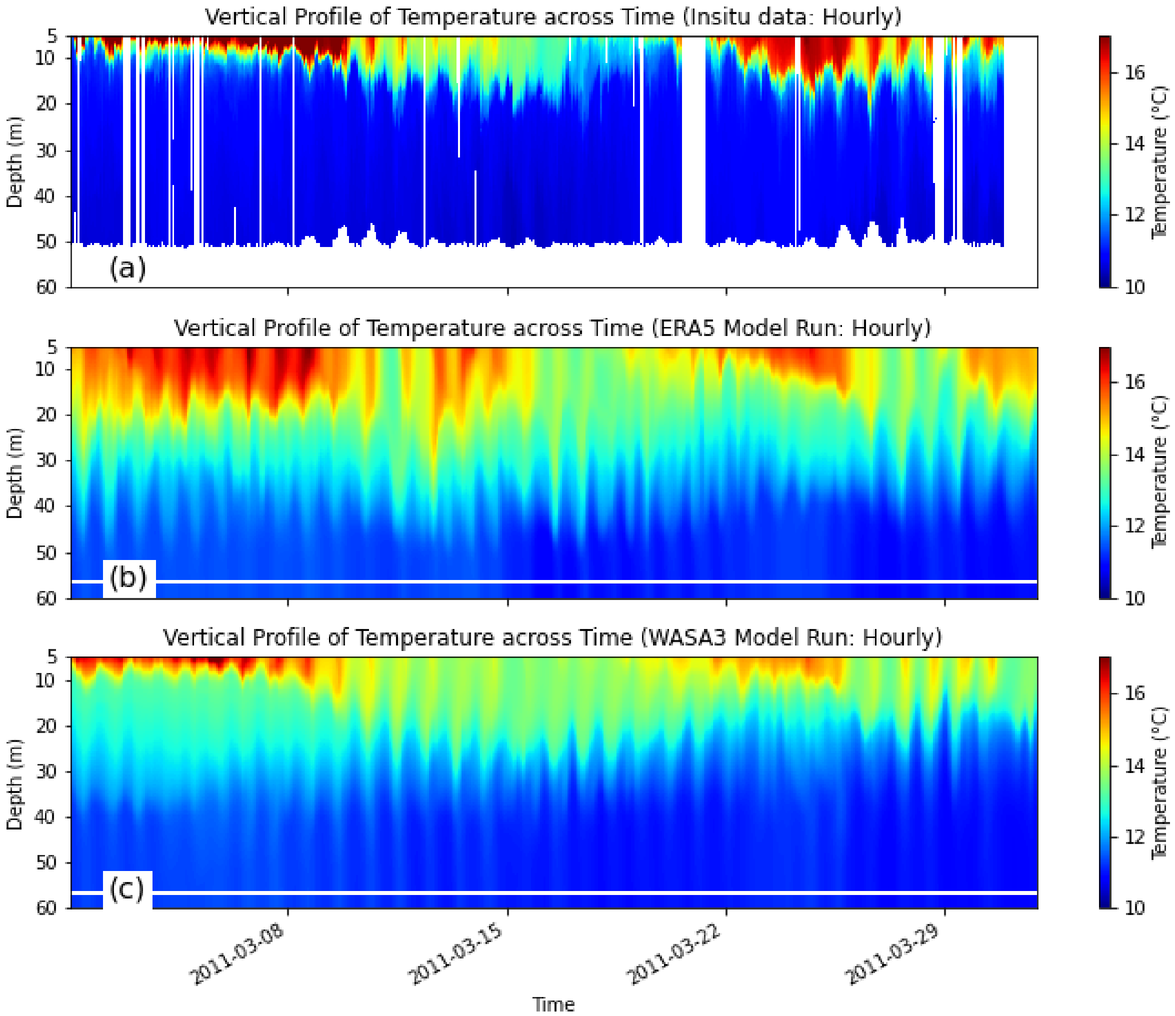


Figure 3.24: Hourly Temperature validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay Wirewalker station (located on the adcp mooring) and comparison with GLORYS (global model). Subplot (a) shows insitu temperature, (b) shows ERA5 run and (c) shows WASA3 run on the station across the water column.

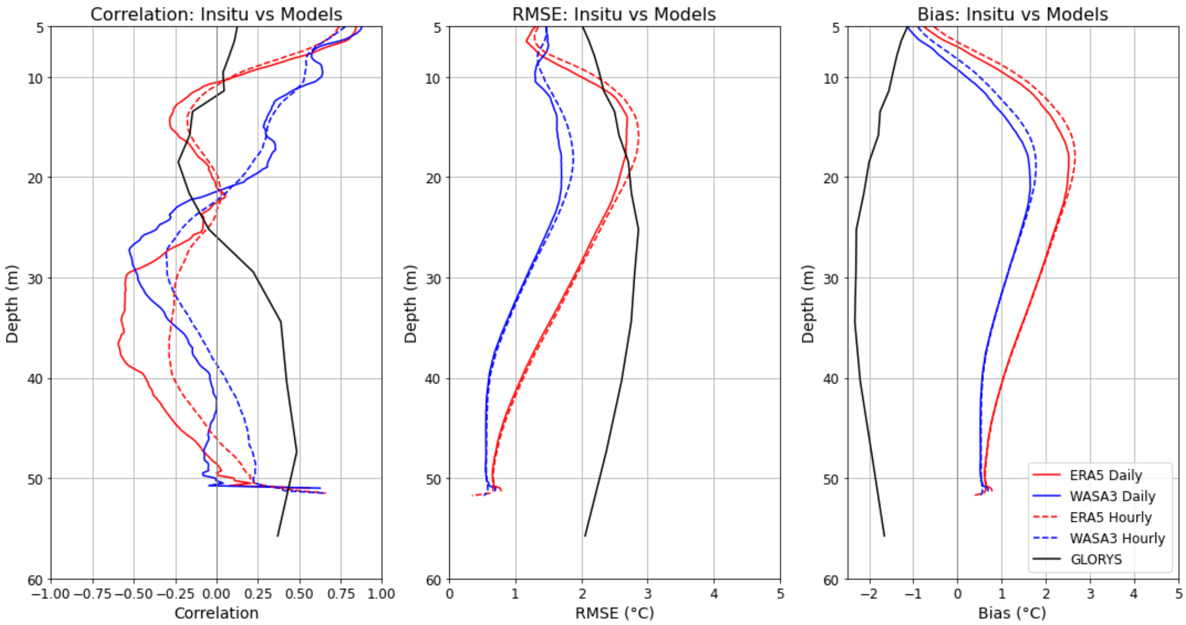


Figure 3.25: Temperature statistical validation of the SA-West Model, ERA5 and WASA3 wind forced configurations daily and hourly runs vs GLORYS. The statistics shown are correlation (left pane), RMSE (middle pane) and the total bias (right pane).

3.4.7. ADCP (Water column current evaluation)

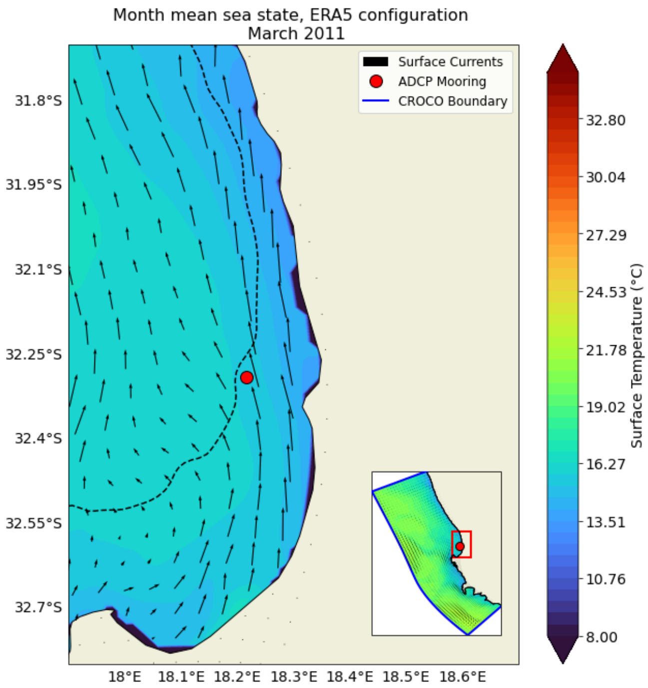


Figure 3.26: Insitu adcp station at St Helena Bay used for CROCO validation and a comparison with GLORYS.

The ADCP provides current profiles u and v at the station shown in Figure 3.25. The components are first assessed separately to validate against the model configurations. Figure 3.27 shows this comparison„ where Figures 3.27 (b), (c), & (d) are SA-West ERA5, WASA3 configurations and the GLORYS model all at dailyfrequency,y, respectively. Figures 3.27 (a) shows the u-component at the same frequency. GLORYS is not able to, however that is still not a very good resolve fine scale variability of the current field in this location as shown in shown in Figures 3.27 (d). When it comes to the ERA5, WASA3 configurations shown in Figures 3.27 (b), (c), The u component of the current field tends to be not on phase with the observations in the upper 20 m, with a west ward-flow dominating in the near surface in the models at daily scales. The v component on the other hand on the daily runs below 20 m the zonal currents in the model appear to be more in phase with observations, albeit much weaker as shown in Figures 3.28 (a), (b), (c). GLORYS again is unable to capture fine scale variability.

The current rose plots for the hourly frequency shows

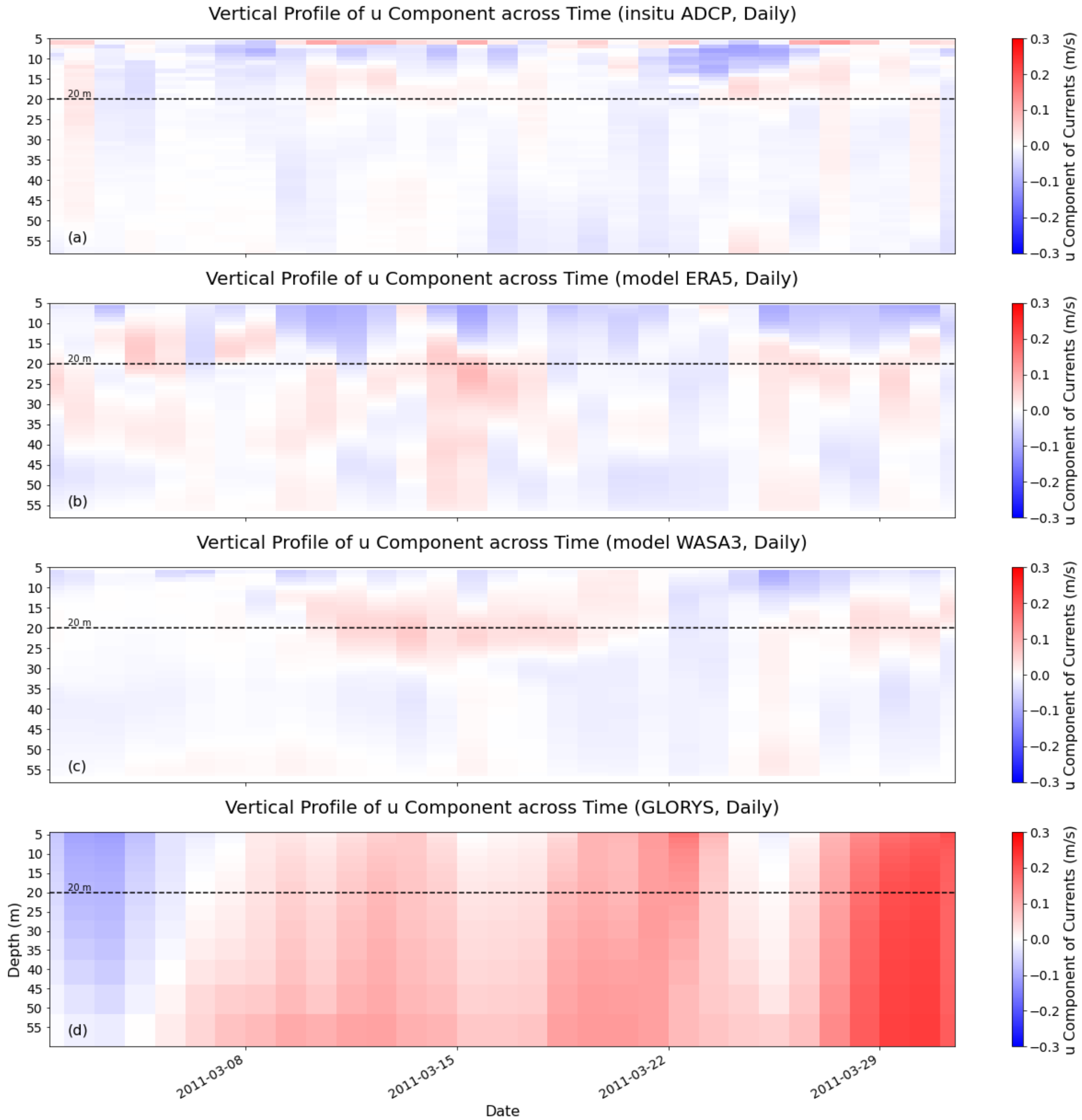


Figure 3.27: Daily current u-component validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay adcp mooring station and comparison with GLORYS (global model). Subplot (a) shows insitu, (b) shows ERA5 run, (c) shows WASA3 run and (d) shows the GLORYS u-component on the station across the water column.

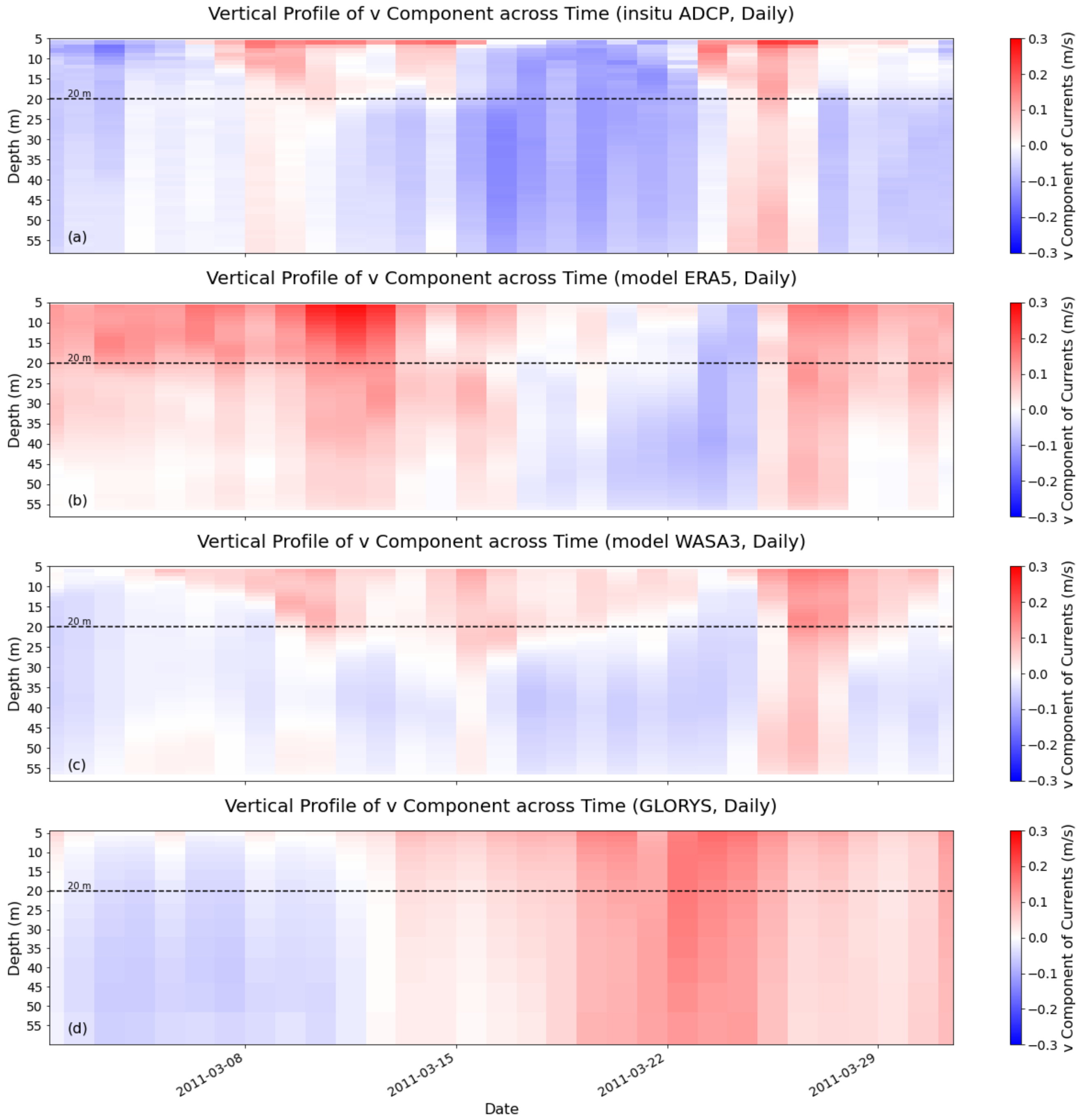


Figure 3.28: Daily current v-component validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay adcp mooring station and comparison with GLORYS (global model). Subplot (a) shows insitu, (b) shows ERA5 run, (c) shows WASA3 run and (d) shows the GLORYS v-component on the station across the water column.

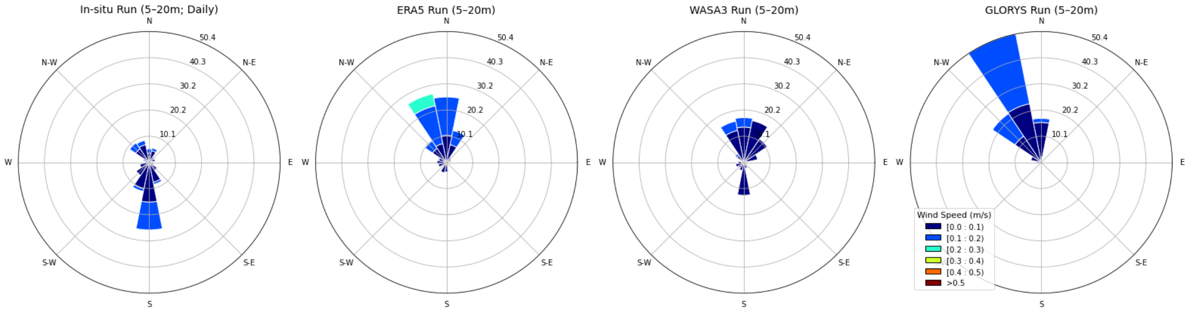


Figure 3.29: Daily current-rose plots for the insitu on the left, ERA5 in the middle and WASA3 run on the right hand side. All are measured at the adcp mooring station averaged on the top 20 meters

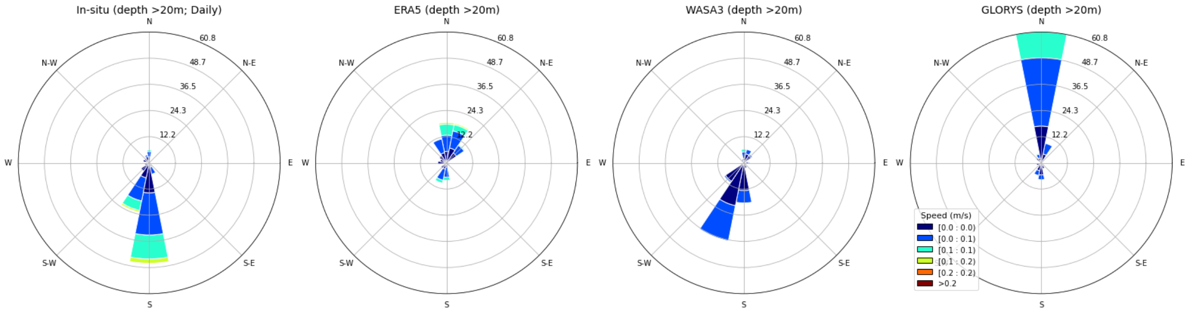


Figure 3.30: Daily current-rose plots for the insitu on the left, ERA5 in the middle and WASA3 run on the right hand side. All are measured at the adcp mooring station averaged at depths deeper than 20 meters

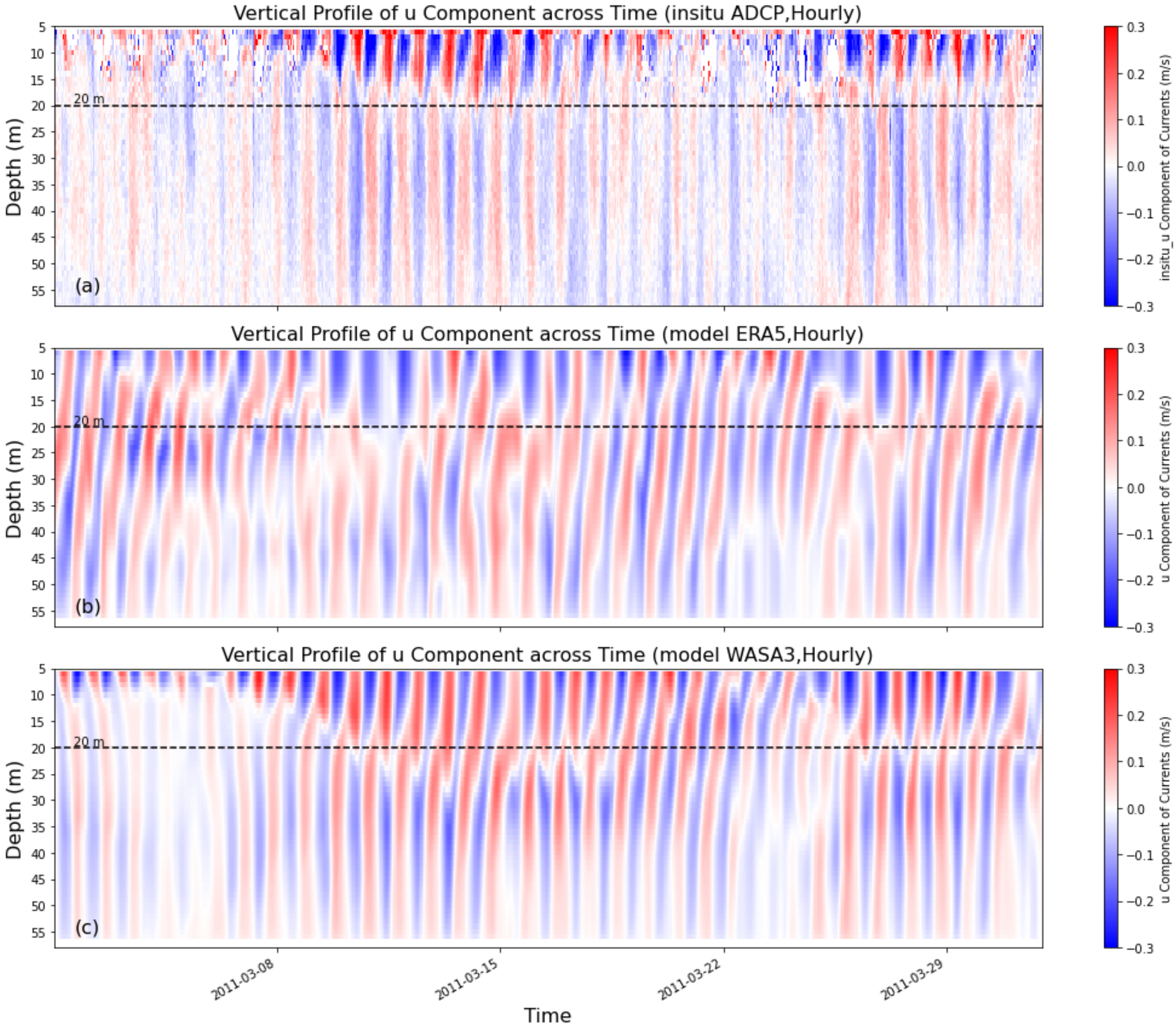


Figure 3.31: Hourly current u-component validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay adcp mooring station and comparison with GLORYS (global model). Subplot (a) shows insitu, (b) shows ERA5 run and (c) shows WASA3 run u-component on the station across the water column.

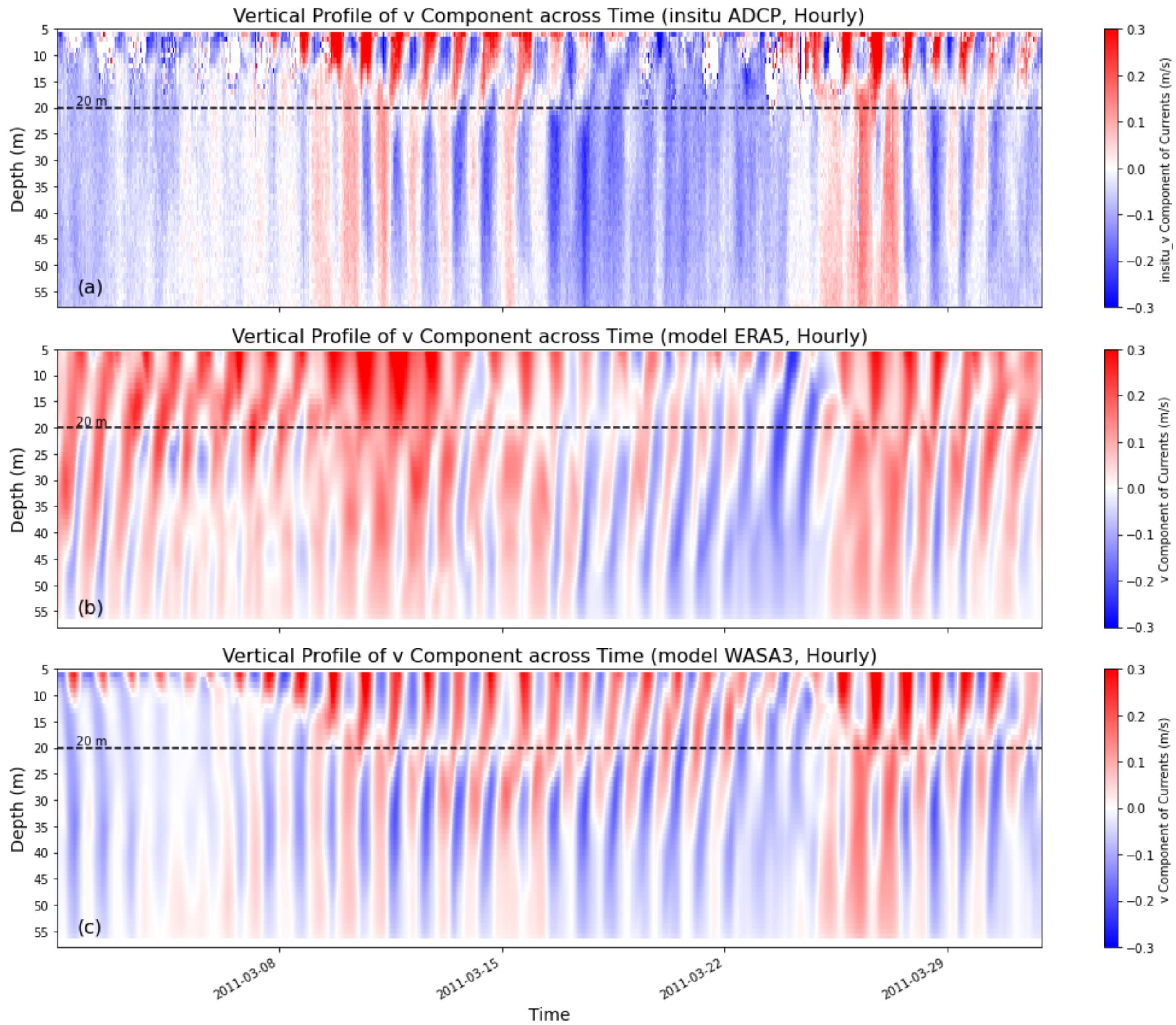


Figure 3.32: Hourly current v-component validation of the SA-West's ERA5 and WASA3 wind forced configurations at St Helena bay adcp mooring station and comparison with GLORYS (global model). Subplot (a) shows insitu, (b) shows ERA5 run and (c) shows WASA3 run v-component on the station across the water column.

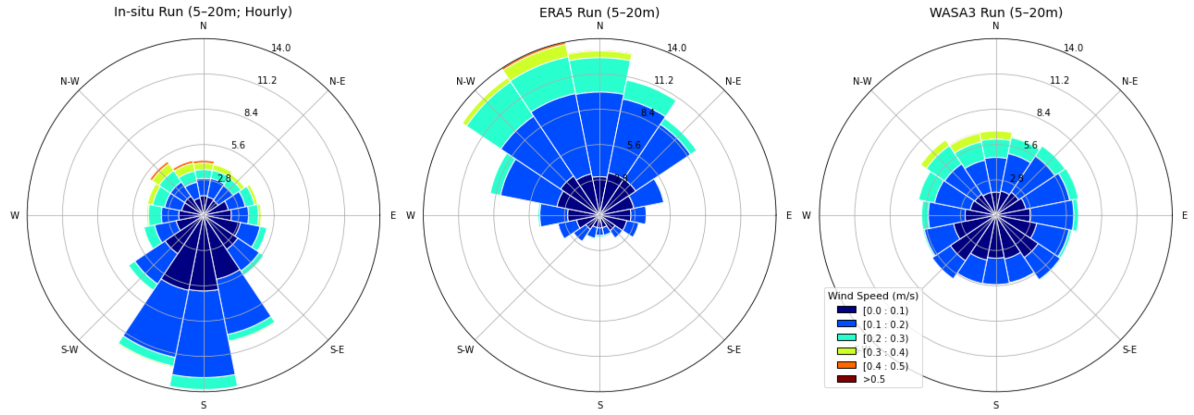


Figure 3.33: Hourly current-rose plots for the insitu on the left, ERA5 in the middle and WASA3 run on the right hand side. All are measured at the adcp mooring station averaged on the top 20 meters

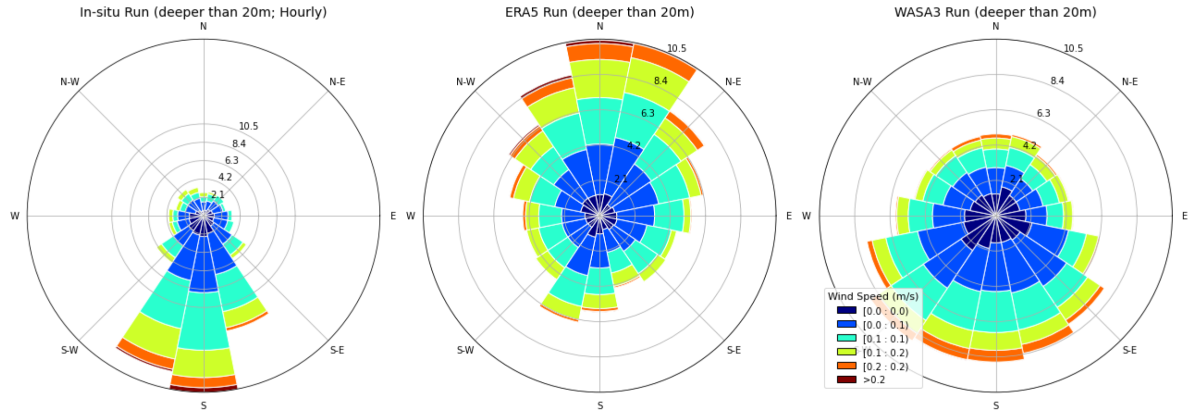


Figure 3.34: Hourly current-rose plots for the insitu on the left, ERA5 in the middle and WASA3 run on the right hand side. All are measured at the adcp mooring station averaged at depths deeper than 20 meters

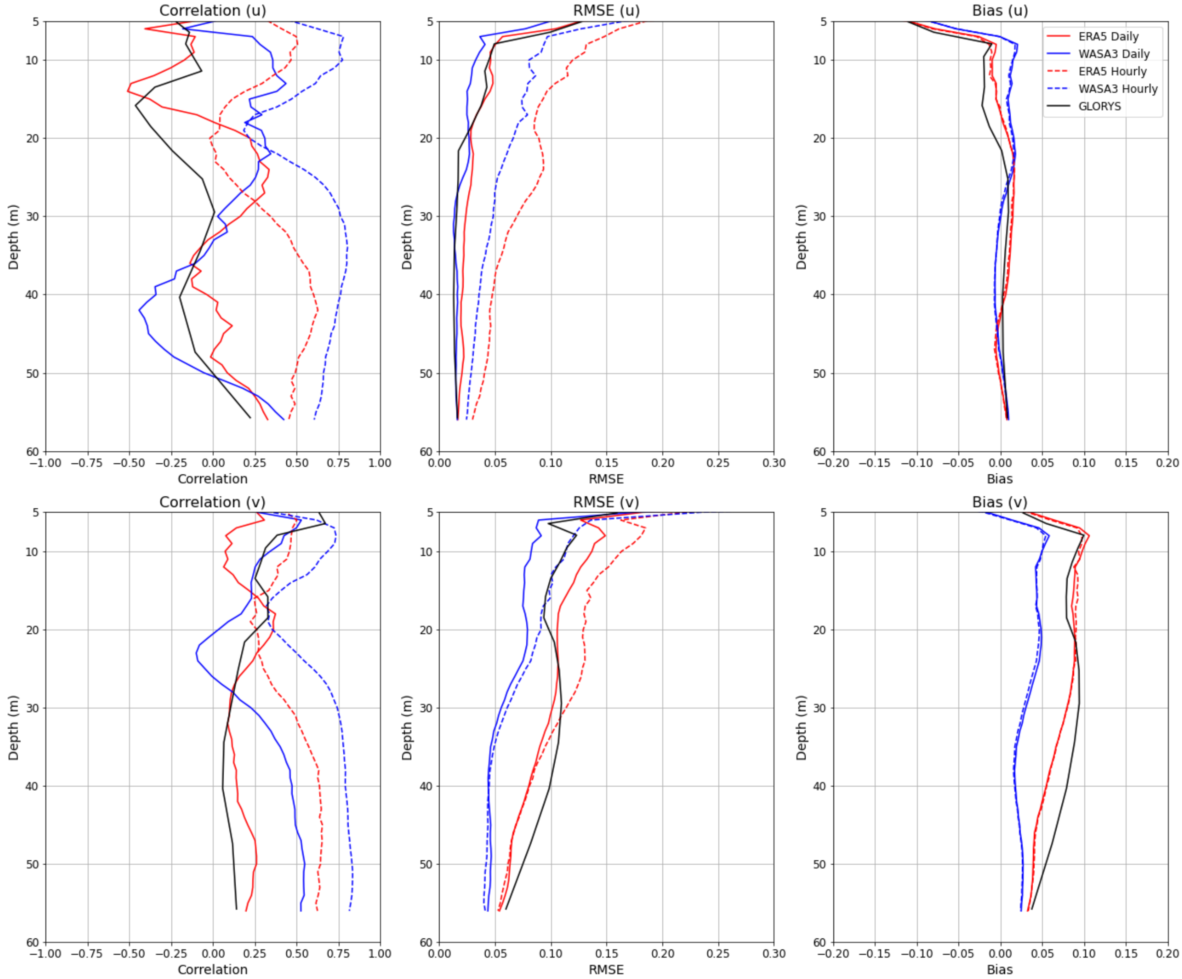


Figure 3.35: The u and v components statistical validation of the SA-West Model, ERA5 and WASA3 wind forced configurations with both their daily and hourly runs vs GLORYS. The statistics shown are correlation (left panes), RMSE (middle panes) and the total bias (right panes).

4

Conclusions

In conclusion, the hindcast evaluation of the CROCO_SA-West both running the ERA5 and the WASA3, performs well in representing the subsurface temperature and closely matches the in-situ observations along the West Coast region. The in situ data from all localities within the CROCO_SA-West domain indicated moderate to very high correlations when evaluated against the nearest model points within the grid. The exception to this positive outcome was the Saint Helena Bay SAWS station, which had unexplained low resolutions on both runs and on GLORYS. In-situ were not well captured in the models and resulted in correlations dropping to (r = 0.5, 0.45 and 0.36) in ER5, WASA3 run and GLORYS respectively while also negatively impacting the RMSE by increasing it to 1.52. This is one of a few similar examples in which modest outcomes were observed as a departure from the high correlation, low RMSE general scores found within the configuration.

Overall, the results were obtained after a two-pronged evaluation strategy to address the challenge posed by the modest resolution bathymetry used on the model grid. The modest bathymetry resolution poses a challenge when working on shallow coastal regions, as the model height might significantly differ from the sea height on the in situ stations. This leads to a problem where the in situ observation can be located at a depth that is deeper than the model height, referred to as (h). This creates cases where the in situ station does not have corresponding z-levels in the model as those z-levels would be below the sea floor. To address this issue, the bottom layer of the model is taken as the level to be compared with the ATAP in situ dataset. This decision is supported by the open knowledge that the ATAP data are bottom anchored. The second prong solution to this bathymetry issue was performed in stations such as Saldanha Bay where instead of taking the bottom most level within the model at the station, the model point was shifted by x number of xi, eta, or both grid points to a location where model sea height is deep. This was mainly applied in the case where the GLORYS did not have a grid cell in a small bay due to its low resolution. The model validation against in situ data at these points also yielded moderate to high statistical validation outcomes. The overall conclusion reached from this evaluation exercise is that the SA-West CROCO model runs resolves the temperatures and their local variability very well and that they are indeed an improvement on the GLORYS model used as a boundary forcing in this configuration as seen through high correlation coefficients in various stations and low RMSE's across the domain. Based on the results presented in this report, it is correct to assert that the downscalling efforts taken up in this region were justified and have yielded results to show further support.

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A

Appendix

A.1. Kommetjie

Table A.1: Kommetjie model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.602	0.643	0.407
3	RMSE		1.66 °C	1.53 °C	2.42 °C
4	Total bias		1.20 °C	1.16 °C	1.95 °C
5	Std.	1.734 °C	1.785 °C	1.639 °C	1.253 °C
6	Mean	13.27 °C	13.81 °C	13.82 °C	15.02 °C
7	Min	9.00 °C	9.08 °C	9.08 °C	11.45 °C
8	Max	18.80 °C	20.12 °C	19.11 °C	19.62 °C
9	**Summer Correlation**		0.59	0.67	0.58
10	**Summer RMSE**		2.19 °C	1.86 °C	1.84 °C
11	**Summer Bias**		1.90 °C	1.59 °C	2.76 °C
12	**Summer Std.**	2.07 °C	2.47 °C	2.26 °C	1.89 °C
13	**Summer Mean**	12.69 °C	13.94 °C	13.68 °C	15.29 °C
14	**Winter Correlation**		0.74	0.67	0.46
15	**Winter RMSE**		1.14 °C	1.10 °C	1.20 °C
16	**Winter Bias**		0.69 °C	0.75 °C	0.98 °C
17	**Winter Std.**	1.26 °C	1.16 °C	0.97 °C	0.75 °C
18	**Winter Mean**	14.04 °C	14.00 °C	14.22 °C	14.63 °C

A.2. Oudekraal

Table A.2: Oudekraal model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-9 m	-9 m	-9 m	-9.6 m
2	Correlation		0.716	0.743	0.511
3	RMSE		1.27 °C	1.23 °C	2.24 °C
4	Total bias		0.98 °C	0.93 °C	1.80 °C
5	Std.	1.699 °C	1.567 °C	1.602 °C	1.610 °C
6	Mean	12.17 °C	11.90 °C	12.48 °C	13.70 °C
7	Min	8.26 °C	8.64 °C	8.37 °C	7.84 °C
8	Max	16.08 °C	16.87 °C	19.03 °C	19.21 °C
9	**Summer Correlation**		0.56	0.59	0.33
10	**Summer RMSE**		1.83 °C	1.58 °C	2.07 °C
11	**Summer Bias**		1.09 °C	1.20 °C	2.28 °C
12	**Summer Std.**	1.61 °C	1.32 °C	1.52 °C	1.88 °C
13	**Summer Mean**	11.21 °C	11.11 °C	11.73 °C	13.06 °C
14	**Winter Correlation**		0.61	0.62	0.37
15	**Winter RMSE**		1.43 °C	0.81 °C	1.04 °C
16	**Winter Bias**		0.75 °C	0.60 °C	1.18 °C
17	**Winter Std.**	0.92 °C	1.18 °C	0.82 °C	0.92 °C
18	**Winter Mean**	13.21 °C	12.89 °C	13.53 °C	14.24 °C

A.3. Sea Point

Table A.3: Sea Point model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.568	0.557	0.379
3	RMSE		1.49 °C	1.59 °C	2.27 °C
4	Total bias		1.10 °C	1.22 °C	1.83 °C
5	Std.	1.497 °C	1.667 °C	1.603 °C	1.372 °C
6	Mean	12.92 °C	12.73 °C	13.54 °C	14.53 °C
7	Min	8.40 °C	8.82 °C	8.66 °C	9.70 °C
8	Max	17.10 °C	17.88 °C	18.58 °C	18.55 °C
9	**Summer Correlation**		0.41	0.41	0.29
10	**Summer RMSE**		2.91 °C	2.43 °C	2.28 °C
11	**Summer Bias**		1.64 °C	1.77 °C	2.43 °C
12	**Summer Std.**	1.83 °C	1.86 °C	2.02 °C	1.87 °C
13	**Summer Mean**	12.75 °C	12.28 °C	13.30 °C	14.63 °C
14	**Winter Correlation**		0.77	0.80	0.59
15	**Winter RMSE**		0.99 °C	0.63 °C	0.87 °C
16	**Winter Bias**		0.59 °C	0.73 °C	1.07 °C
17	**Winter Std.**	1.03 °C	1.28 °C	0.88 °C	0.88 °C
18	**Winter Mean**	13.22 °C	13.24 °C	13.87 °C	14.22 °C

A.4. Saldanha Bay

Table A.4: Saldanha Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.873	0.896	0.27
3	RMSE		1.09 °C	1.06 °C	2.31 °C
4	Total bias		0.86 °C	0.83 °C	1.84 °C
5	Std.	2.234 °C	1.862 °C	2.017 °C	1.398 °C
6	Mean	15.30 °C	15.23 °C	15.68 °C	15.07 °C
7	Min	10.50 °C	11.21 °C	11.90 °C	9.77 °C
8	Max	22.00 °C	20.98 °C	20.93 °C	19.82 °C
9	**Summer Correlation**		0.59	0.56	0.14
10	**Summer RMSE**		1.89 °C	1.52 °C	5.34 °C
11	**Summer Bias**		1.04 °C	1.01 °C	2.61 °C
12	**Summer Std.**	1.39 °C	1.29 °C	1.34 °C	1.91 °C
13	**Summer Mean**	17.83 °C	17.42 °C	18.02 °C	15.56 °C
14	**Winter Correlation**		0.59	0.72	0.48
15	**Winter RMSE**		0.80 °C	0.65 °C	0.85 °C
16	**Winter Bias**		0.71 °C	0.79 °C	1.62 °C
17	**Winter Std.**	0.93 °C	0.74 °C	0.73 °C	0.69 °C
18	**Winter Mean**	12.92 °C	13.43 °C	13.62 °C	14.51 °C

A.5. Yzerfontein

Table A.5: model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.512	0.468	0.466
3	RMSE		1.29 °C	1.65 °C	2.02 °C
4	Total bias		0.96 °C	1.23 °C	1.63 °C
5	Std.	1.291 °C	1.186 °C	1.391 °C	1.405 °C
6	Mean	13.38 °C	13.79 °C	14.28 °C	14.84 °C
7	Min	10.00 °C	10.79 °C	10.49 °C	9.61 °C
8	Max	18.50 °C	19.49 °C	20.47 °C	19.67 °C
9	**Summer Correlation**		0.51	0.49	0.49
10	**Summer RMSE**		1.54 °C	1.64 °C	1.70 °C
11	**Summer Bias**		1.36 °C	2.05 °C	2.30 °C
12	**Summer Std.**	1.53 °C	1.47 °C	1.71 °C	1.79 °C
13	**Summer Mean**	13.33 °C	14.29 °C	15.20 °C	15.45 °C
14	**Winter Correlation**		0.66	0.68	0.60
15	**Winter RMSE**		0.94 °C	0.82 °C	0.83 °C
16	**Winter Bias**		0.63 °C	0.64 °C	0.98 °C
17	**Winter Std.**	1.00 °C	0.76 °C	0.77 °C	0.79 °C
18	**Winter Mean**	13.44 °C	13.51 °C	13.72 °C	14.31 °C

A.6. Betty's Bay

Table A.6: Betty's Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-5 m	-5 m	-5 m	-5.1 m
2	Correlation		0.796	0.798	0.797
3	RMSE		1.13 °C	1.10 °C	1.45 °C
4	Total bias		0.82 °C	0.82 °C	1.19 °C
5	Std.	1.719 °C	1.794 °C	1.725 °C	1.730 °C
6	Mean	14.90 °C	15.03 °C	14.96 °C	15.86 °C
7	Min	10.94 °C	10.28 °C	9.91 °C	10.68 °C
8	Max	21.02 °C	20.66 °C	20.77 °C	21.22 °C
9	**Summer Correlation**		0.83	0.86	0.83
10	**Summer RMSE**		1.69 °C	1.70 °C	1.46 °C
11	**Summer Bias**		1.08 °C	1.02 °C	1.35 °C
12	**Summer Std.**	2.27 °C	2.51 °C	2.49 °C	2.40 °C
13	**Summer Mean**	15.99 °C	16.12 °C	15.89 °C	16.89 °C
14	**Winter Correlation**		0.76	0.68	0.76
15	**Winter RMSE**		0.57 °C	0.58 °C	0.55 °C
16	**Winter Bias**		0.40 °C	0.52 °C	1.10 °C
17	**Winter Std.**	0.76 °C	0.63 °C	0.58 °C	0.82 °C
18	**Winter Mean**	13.99 °C	14.12 °C	14.36 °C	15.08 °C

A.7. Bordjies Deep

Table A.7: Bordjies Deep model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-9 m	-9 m	-9 m	-9.6 m
2	Correlation		0.683	0.752	0.639
3	RMSE		1.62 °C	1.33 °C	1.53 °C
4	Total bias		1.14 °C	0.99 °C	1.21 °C
5	Std.	1.894 °C	1.992 °C	1.799 °C	1.419 °C
6	Mean	15.18 °C	15.67 °C	15.46 °C	15.60 °C
7	Min	10.21 °C	11.56 °C	11.80 °C	12.01 °C
8	Max	21.61 °C	22.04 °C	21.33 °C	20.93 °C
9	**Summer Correlation**		0.49	0.68	0.69
10	**Summer RMSE**		2.05 °C	1.79 °C	2.49 °C
11	**Summer Bias**		1.84 °C	1.35 °C	1.37 °C
12	**Summer Std.**	2.15 °C	1.66 °C	1.85 °C	2.08 °C
13	**Summer Mean**	16.73 °C	17.99 °C	17.33 °C	16.25 °C
14	**Winter Correlation**		0.63	0.57	0.62
15	**Winter RMSE**		0.84 °C	0.85 °C	0.73 °C
16	**Winter Bias**		0.54 °C	0.60 °C	1.01 °C
17	**Winter Std.**	0.90 °C	0.75 °C	0.69 °C	0.74 °C
18	**Winter Mean**	14.06 °C	14.17 °C	14.28 °C	15.03 °C

A.8. Bordjies Shallow

Table A.8: Bordjies Shallow model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-4 m	-4 m	-4 m	-3.8 m
2	Correlation		0.702	0.771	0.767
3	RMSE		1.63 °C	1.32 °C	1.46 °C
4	Total bias		1.14 °C	0.98 °C	1.12 °C
5	Std.	1.922 °C	2.076 °C	1.869 °C	1.578 °C
6	Mean	15.36 °C	15.85 °C	15.67 °C	16.14 °C
7	Min	10.46 °C	11.57 °C	11.89 °C	12.98 °C
8	Max	21.50 °C	21.97 °C	21.38 °C	21.38 °C
9	**Summer Correlation**		0.51	0.71	0.75
10	**Summer RMSE**		1.97 °C	1.64 °C	1.64 °C
11	**Summer Bias**		1.80 °C	1.30 °C	1.14 °C
12	**Summer Std.**	2.11 °C	1.58 °C	1.75 °C	1.93 °C
13	**Summer Mean**	17.05 °C	18.32 °C	17.71 °C	17.43 °C
14	**Winter Correlation**		0.64	0.58	0.63
15	**Winter RMSE**		0.85 °C	0.85 °C	0.71 °C
16	**Winter Bias**		0.53 °C	0.58 °C	0.95 °C
17	**Winter Std.**	0.88 °C	0.75 °C	0.69 °C	0.71 °C
18	**Winter Mean**	14.12 °C	14.18 °C	14.29 °C	15.02 °C

A.9. Fish Hoek

Table A.9: Fish Hoek model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.806	0.818	0.725
3	RMSE		1.85 °C	1.78 °C	1.96 °C
4	Total bias		1.45 °C	1.40 °C	1.57 °C
5	Std.	2.603 °C	2.498 °C	2.222 °C	1.553 °C
6	Mean	15.50 °C	16.45 °C	16.45 °C	16.21 °C
7	Min	10.00 °C	11.71 °C	11.86 °C	13.46 °C
8	Max	23.00 °C	23.54 °C	22.09 °C	20.99 °C
9	**Summer Correlation**		0.41	0.48	0.55
10	**Summer RMSE**		1.74 °C	1.62 °C	2.33 °C
11	**Summer Bias**		1.64 °C	1.40 °C	1.25 °C
12	**Summer Std.**	1.56 °C	1.49 °C	1.39 °C	1.55 °C
13	**Summer Mean**	18.21 °C	19.35 °C	19.04 °C	17.65 °C
14	**Winter Correlation**		0.27	0.35	0.24
15	**Winter RMSE**		1.25 °C	1.17 °C	1.26 °C
16	**Winter Bias**		1.25 °C	1.42 °C	1.96 °C
17	**Winter Std.**	1.24 °C	0.64 °C	0.58 °C	0.67 °C
18	**Winter Mean**	12.92 °C	13.97 °C	14.23 °C	14.85 °C

A.10. Gordons Bay

Table A.10: Gordons Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.563	0.691	0.585
3	RMSE		3.19 °C	2.24 °C	2.51 °C
4	Total bias		2.55 °C	1.72 °C	1.97 °C
5	Std.	2.429 °C	1.921 °C	2.066 °C	1.460 °C
6	Mean	17.25 °C	14.83 °C	15.91 °C	15.70 °C
7	Min	12.00 °C	10.35 °C	11.84 °C	11.93 °C
8	Max	23.00 °C	21.49 °C	22.76 °C	21.06 °C
9	**Summer Correlation**		0.52	0.53	0.53
10	**Summer RMSE**		7.06 °C	4.45 °C	6.00 °C
11	**Summer Bias**		3.40 °C	2.18 °C	2.90 °C
12	**Summer Std.**	1.88 °C	2.56 °C	2.29 °C	1.97 °C
13	**Summer Mean**	19.45 °C	16.16 °C	17.68 °C	16.65 °C
14	**Winter Correlation**		0.22	0.43	0.34
15	**Winter RMSE**		2.56 °C	1.84 °C	1.40 °C
16	**Winter Bias**		1.24 °C	0.93 °C	0.89 °C
17	**Winter Std.**	1.15 °C	0.66 °C	0.52 °C	0.69 °C
18	**Winter Mean**	14.76 °C	13.74 °C	14.17 °C	14.81 °C

A.11. Kalk Bay

Table A.11: Kalk Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.832	0.835	0.729
3	RMSE		2.06 °C	1.97 °C	2.36 °C
4	Total bias		1.73 °C	1.66 °C	1.90 °C
5	Std.	2.464 °C	2.363 °C	2.135 °C	1.520 °C
6	Mean	17.75 °C	16.24 °C	16.32 °C	16.12 °C
7	Min	11.50 °C	12.17 °C	12.20 °C	13.46 °C
8	Max	24.00 °C	23.50 °C	22.54 °C	20.99 °C
9	**Summer Correlation**		0.41	0.49	0.50
10	**Summer RMSE**		3.57 °C	3.73 °C	6.13 °C
11	**Summer Bias**		1.78 °C	1.86 °C	3.02 °C
12	**Summer Std.**	1.64 °C	1.52 °C	1.36 °C	1.61 °C
13	**Summer Mean**	20.59 °C	19.24 °C	19.05 °C	17.70 °C
14	**Winter Correlation**		0.36	0.41	0.26
15	**Winter RMSE**		3.19 °C	2.72 °C	1.96 °C
16	**Winter Bias**		1.55 °C	1.33 °C	1.02 °C
17	**Winter Std.**	1.08 °C	0.64 °C	0.58 °C	0.68 °C
18	**Winter Mean**	15.46 °C	13.99 °C	14.25 °C	14.87 °C

A.12. Lamberts Bay

Table A.12: Lamberts Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.632	0.714	0.336
3	RMSE		1.39 °C	1.28 °C	2.01 °C
4	Total bias		0.98 °C	0.91 °C	1.61 °C
5	Std.	1.673 °C	1.311 °C	1.464 °C	1.126 °C
6	Mean	13.40 °C	12.95 °C	13.84 °C	14.52 °C
7	Min	9.50 °C	9.35 °C	10.84 °C	11.72 °C
8	Max	20.00 °C	19.13 °C	20.62 °C	19.54 °C
9	**Summer Correlation**		0.52	0.63	-0.00
10	**Summer RMSE**		3.07 °C	1.84 °C	3.05 °C
11	**Summer Bias**		1.63 °C	1.70 °C	2.42 °C
12	**Summer Std.**	2.24 °C	1.75 °C	1.62 °C	1.43 °C
13	**Summer Mean**	14.18 °C	13.48 °C	15.33 °C	15.11 °C
14	**Winter Correlation**		0.81	0.79	0.65
15	**Winter RMSE**		0.70 °C	0.68 °C	0.68 °C
16	**Winter Bias**		0.41 °C	0.43 °C	1.27 °C
17	**Winter Std.**	0.89 °C	0.76 °C	0.75 °C	0.65 °C
18	**Winter Mean**	12.91 °C	12.86 °C	12.94 °C	14.17 °C

A.13. Muizenberg model

Table A.13: Muizenberg model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.885	0.911	0.85
3	RMSE		1.69 °C	1.91 °C	1.95 °C
4	Total bias		1.41 °C	1.63 °C	1.59 °C
5	Std.	2.988 °C	2.644 °C	2.620 °C	1.688 °C
6	Mean	15.63 °C	16.59 °C	17.08 °C	16.40 °C
7	Min	9.50 °C	12.52 °C	12.05 °C	13.38 °C
8	Max	23.00 °C	23.93 °C	23.63 °C	21.16 °C
9	**Summer Correlation**		0.45	0.44	0.45
10	**Summer RMSE**		1.83 °C	1.43 °C	2.61 °C
11	**Summer Bias**		1.42 °C	1.52 °C	1.31 °C
12	**Summer Std.**	1.40 °C	1.67 °C	1.23 °C	1.36 °C
13	**Summer Mean**	19.02 °C	19.59 °C	20.21 °C	18.15 °C
14	**Winter Correlation**		0.52	0.56	0.63
15	**Winter RMSE**		0.89 °C	0.86 °C	0.81 °C
16	**Winter Bias**		1.75 °C	2.08 °C	2.64 °C
17	**Winter Std.**	1.04 °C	0.65 °C	0.58 °C	0.64 °C
18	**Winter Mean**	12.13 °C	13.84 °C	14.20 °C	14.76 °C

A.14. St Helena Bay

Table A.14: St Helena Bay model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	0 m	0 m	0 m	-0.5 m
2	Correlation		0.498	0.448	0.361
3	RMSE		1.57 °C	1.33 °C	1.52 °C
4	Total bias		1.24 °C	1.06 °C	1.19 °C
5	Std.	1.404 °C	0.928 °C	1.056 °C	1.157 °C
6	Mean	14.36 °C	13.40 °C	14.23 °C	14.76 °C
7	Min	10.50 °C	10.23 °C	11.89 °C	12.24 °C
8	Max	20.00 °C	18.50 °C	20.23 °C	19.65 °C
9	**Summer Correlation**		0.45	0.45	0.28
10	**Summer RMSE**		2.85 °C	1.92 °C	2.14 °C
11	**Summer Bias**		1.42 °C	1.30 °C	1.73 °C
12	**Summer Std.**	1.66 °C	1.17 °C	1.29 °C	1.50 °C
13	**Summer Mean**	14.68 °C	13.70 °C	14.88 °C	15.43 °C
14	**Winter Correlation**		0.54	0.43	0.41
15	**Winter RMSE**		2.24 °C	1.76 °C	1.24 °C
16	**Winter Bias**		1.10 °C	0.92 °C	0.85 °C
17	**Winter Std.**	1.15 °C	0.51 °C	0.46 °C	0.58 °C
18	**Winter Mean**	13.97 °C	13.05 °C	13.47 °C	14.17 °C

A.15. WQM 20 m

Table A.15: WQM 20 m model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-20 m	-20 m	-20 m	-18.5 m
2	Correlation		0.824	0.832	0.264
3	RMSE		1.13 °C	1.14 °C	2.63 °C
4	Total bias		0.91 °C	0.91 °C	2.26 °C
5	Std.	1.511 °C	1.016 °C	1.071 °C	0.843 °C
6	Mean	11.98 °C	12.69 °C	12.74 °C	14.13 °C
7	Min	9.34 °C	10.51 °C	10.44 °C	11.72 °C
8	Max	17.36 °C	15.98 °C	17.13 °C	16.73 °C
9	**Summer Correlation**		0.76	0.72	-0.30
10	**Summer RMSE**		1.44 °C	1.40 °C	2.42 °C
11	**Summer Bias**		1.52 °C	1.66 °C	3.15 °C
12	**Summer Std.**	1.93 °C	1.00 °C	1.22 °C	0.90 °C
13	**Summer Mean**	11.41 °C	12.41 °C	12.70 °C	14.06 °C
14	**Winter Correlation**		0.79	0.78	0.54
15	**Winter RMSE**		0.66 °C	0.69 °C	0.89 °C
16	**Winter Bias**		0.58 °C	0.67 °C	1.66 °C
17	**Winter Std.**	1.06 °C	0.84 °C	0.72 °C	0.56 °C
18	**Winter Mean**	12.65 °C	13.11 °C	13.21 °C	14.31 °C

A.16. WQM 70 m

Table A.16: WQM 70 m model comparison table of statistics

	Statistic	In situ	ERA5 Run	WASA3 Run	GLORYS
1	Depth	-70 m	-70 m	-70 m	-65.8 m
2	Correlation		0.888	0.919	0.441
3	RMSE		0.64 °C	0.57 °C	0.90 °C
4	Total bias		0.55 °C	0.51 °C	0.70 °C
5	Std.	0.670 °C	0.920 °C	0.573 °C	0.845 °C
6	Mean	9.75 °C	10.20 °C	10.24 °C	10.12 °C
7	Min	8.02 °C	8.34 °C	8.84 °C	8.44 °C
8	Max	11.69 °C	12.26 °C	11.70 °C	12.07 °C
9	**Summer Correlation**				
10	**Summer RMSE**				
11	**Summer Bias**				
12	**Summer Std.**				
13	**Summer Mean**				
14	**Winter Correlation**		0.92	0.92	0.58
15	**Winter RMSE**		0.31 °C	0.26 °C	0.58 °C
16	**Winter Bias**		0.70 °C	0.36 °C	0.55 °C
17	**Winter Std.**	0.67 °C	0.78 °C	0.60 °C	0.39 °C
18	**Winter Mean**	10.22 °C	10.92 °C	10.56 °C	10.58 °C