Numerical modelling of wave-current interaction in the Agulhas Current towards better sea-state estimation

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Ocean currents such as the powerful Agulhas Current have a direct influence on the wavefield propagation. Southwesterly swells formed by strong westerly winds, approach the Southwest Indian Ocean in a direction opposing the flow of the Agulhas Current. The interaction between swell waves and currents alter wavefield propagation and result in cross-seas which ultimately can cause rogue waves. These extreme events are known to be too hazardous for ships navigating around the main current systems. Thus, the principal aim of this study is to investigate the interactions between waves and currents along the South African east coast, thereby improving the sea state monitoring and forecasting. In this study, WaveWatch III (WWIII) numerical wave model has been used to quantify the wave-current interactions along the Agulhas Current region. WWIII simulations with and without the surface currents have been conducted. Preliminary results show there are eminent changes in the significant wave height induced by surface currents. Model results were validated against buoy observations, except for the peak period and wave direction, the significant wave height agrees well with the available wave measurements along the South African coast. However, the model still represents lower wave heights poorly.

1. Introduction

Ocean waves which are generally referred to as wind-generated waves are regarded as an important factor of sea-state. They have an impact on a wide range of activities such as shipping, fisheries, and offshore operations (e.g., oils platforms/rigs) (Quilfen et al., 2018; Chen, 2018). They can disrupt harbor traffic and cause problems for ship routes as well as endanger offshore operations or make it difficult to install offshore marine structures (e.g., Wave Energy Converters). A good understanding of open and coastal ocean wave fields and its evolution in time and space is thus of vital importance. Numerical modeling provides a better way of understanding the variability of ocean surface properties (e.g., surface winds, waves, and other essential variables) (Babanin et al., 2017).

The Agulhas Current flows along South African eastern shores and has a direct influence on the wave field propagation (Ardhuin et al, 2017). The south-westerly swells which approach the south-west Indian Ocean in a direction opposite to the Agulhas Current, alter the wavefield and result in wave steepness and crossing seas which can lead to extreme wave conditions (e.g., Rogue waves). To the authors' knowledge, there are few wave models that account for the influence of the ocean currents on the wavefield (e.g., Meteo France Wave Model). Thus, in this study, we aim to investigate the effect of the Agulhas Current and the Agulhas Return Current on the properties of wave fields. High resolution numerical wave model WWIII forced with the reanalysis wind and current products are used to quantify the effects of strong surface currents. Two cases are considered, simulations with and without surface currents.

2. Data and method

Numerical wave model, WWIII version 6.07 (Tolman, 2019) 10 km by 10 km was implemented in this study over gridded bathymetry for both global and regional domains. GEBCO gridded data was used to construct the bathymetry map. The global model was executed to generate boundary conditions for the regional model. Accurate wind field forcing is needed to provide better wave predictions and forecasts. In this study, the global reanalysis winds from the European Centre for Medium-Range Weather Forecasts (ECMWF) with a spatial resolution of 0.125° x 0.125° and temporal resolution of 6 hours have been used to force the numerical wave model. Glorys surface currents with the spatial resolution 0.083° x 0.083° was used to couple the model with currents. The regional model domain covers 14.50° to 34.0117° E and 27.13247° to 42.94180° S, with a spatial resolution of 0.0278° x 0.0278° and temporal resolution of 3 hours.

The *in-situ* observations from 5 locations along the South African coastline have been used in this study to validate the WWIII model results. Skill metrics such as correlation coefficient, root mean square error and standard deviation was used to assess the model performance.

3. Results

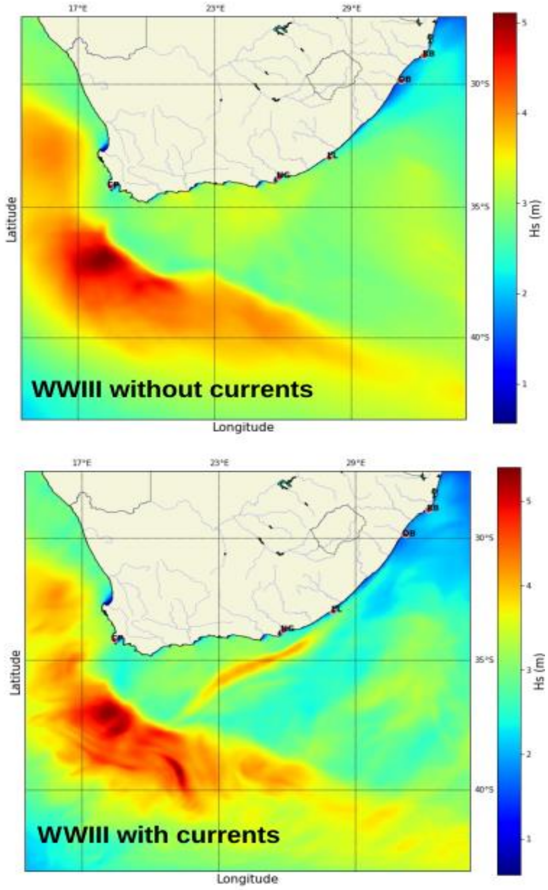

Figure 1: The spatial distribution of the significant wave height with and without surface currents along the South African coast for 2017 - 01 – 24 at 18:00 UTC.

In this study, the impact of surface currents on the wavefield characteristics is investigated using the numerical model WWIII. Two cases are considered, simulations with and without the surface currents to quantify the effects of the surface currents. For the purpose of the analysis, we have considered 2017 monthly simulations. Figure 1 shows the spatial variability of the significant wave height with and without the surface current. The influence by the surface current along Agulhas Current region is quite eminent, especial along the Agulhas Bank, retroflection and return regions as shown by Figure 2. This is caused by the wave-current interactions, where these cases oppose each other.

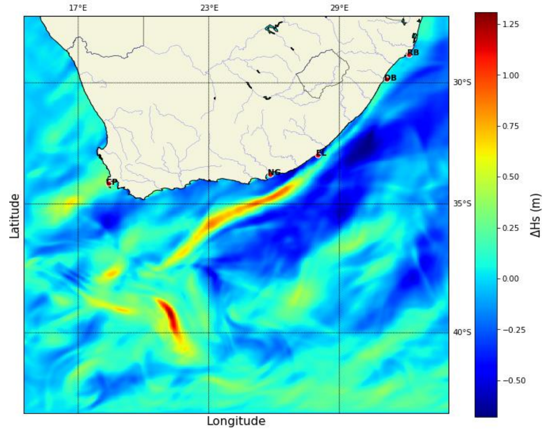

Figure 2: The spatial distribution of the significant wave height differences with and without current along the South African coast for 2017 - 01 – 24 at 18:00 UTC.

Figure 2 indicates that the wave-current interactions are not limited locally (not far from East London and Ngqura regions) but extends further away from where the interaction occurred. This is illustrated by the Agulhas Retroflection and the Agulhas Return Current regions. These areas show a large difference in wave height which is attributed to the relative direction between incoming waves and surface currents. It can also be noticed that there is a reduction in wave height between East London and Durban stations (Natal Valley). This is due to the wave refraction induced by bottom topography in that region. It is quite clear that surface current intensity has a major impact on wavefield propagation.

The model results showed a lot of biases compared to observations as illustrated in Figure 3. Most of the buoys along the South African coast are in sheltered areas and coastal topography tends to affect the quality of simulated wind fields, as a result, affect the wavefield simulations (Christakos et al., 2020). A study conducted by Ardhuin et al., (2007), showed that the quality of wind input degrades when approaching the coastal and semi-enclosed areas, especially areas with orographic effects. Due to such reasons, we can assume that the model performance is different in the open seas and coastal areas.

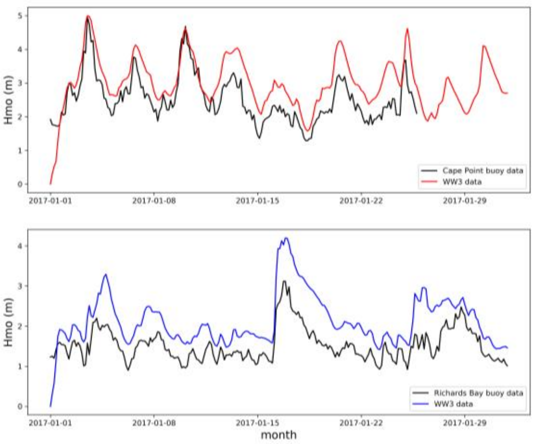

Figure 3: Significant wave height time series comparison againts buoy observations at Cape Point and Richards Bay stations.

3. Conclusion

The model needs to be further calibrated to buoys data. Also improving the wind forcing for the model should improve the agreement of the model results against observations. This will help to provide a reliable wave prediction and early warning of extreme events that often occur along South African coasts.

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