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An assessment on the impact of wind forcing on simulation and validation of wave spectra at coastal Puducherry, east coast of India

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ABSTRACT

In context to application of numerical ocean wave prediction, the validation of ocean wave spectra is a research topic of active interest. This study summarizes the results of validation performed with wave spectra using SWAN model off coastal Puducherry, located in the east coast of India. The impact of wind forcing from ECMWF ERA Interim winds and QuikSCAT-NCEP blended winds on resultant wave spectra has also been studied. The study signifies a good correlation between model wave spectra and *in-situ* observations. Impact of using the two wind field products in predicting extreme wave events was analyzed considering a storm case of November 2008. The numerical results revealed that the blended winds are more suitable in comparison with the ECMWF ERA Interim winds for modeling both normal and extreme events in the coastal Puducherry location. The results also show that wave model output is critically sensitive to the choice of the wind field product, such that the quality of the wind fields is reflected in the quality of the wave predictions. Based on model simulations it is concluded that blended winds generate more realistic wave fields in coastal location and can reproduce the growth and decay of waves in the real-time.

1. Introduction

The exchange of momentum across the air-sea interface is an important phenomenon of ocean surface waves. Today, the topics of great interest for oceanographic research communities and operational centres are Regional Ocean modeling of coastal waters, continental shelves, and marginal seas. Rapid increase of human populations along coastal areas and their dependence on the sea are the main reasons why these topics require attention. The other reasons that can be attributed towards this are the shift in naval interest for littoral (nearshore) operations and improvements in coastal ocean observational networks. With advancements in computational science, the coastal environment can be modeled with very high resolution. The accuracy of regional ocean models simulating the shallower regions can be improved with the proper boundary conditions. To provide surface boundary conditions for ocean models, Numerical Weather Prediction (NWP) products are used. In addition, the wind fields must capture the energetic smaller-scale temporal and spatial variability characteristic prevailing in these regions for better results. The high-resolution NWP products is considered (Morey et al., 2005) as the best option for many ocean modeling related activities and as the only option for ocean forecasting. In situ measurements from ocean observing networks are used for the ocean hindcasting/nowcasting. The wind fields which captures high-frequency (synoptic and shorter scales) atmospheric events can be more accurate and better than NWP data; but it lacks the spatial variability, which highlights the circulation features in smaller scale (Hilburn et al., 2003). Limited availability of in situ data (or none of sufficient quality) and high-resolution regional NWP products for inaccessible regions of the world ocean is a major concern while studying these regions of scientific or strategic interest.

It is significant to understand the wave conditions for all marine related activities such as shipping, fishing, offshore, coastal structures, and naval operations. The development of third generation wave models (Komen et al., 1994) marks the satisfactory level of wave modeling for practical applications. Advancements in weather forecasting (Bidlot et al., 2002) and remote sensing of winds over the oceans has been a major contribution for many wave models – especially atmospheric models computes the wave field from surface winds. In research and operational forecasting, the performance of wave model simulations mainly depends on the quality of the driving wind fields. In one of his research works, Cavaleri (1994) clearly showed the significant wave height (H_s) has direct dependence on wind

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speed with the help of an empirical relation for a fully developed sea. Past study conducted for the Indian Ocean by Kumar et al. (2000) confirmed that precision of the wind forcing used to drive the model plays a major role in predicting wave height and wave period. Kumar et al. (2000) also concluded that the error in the wave hindcast/forecast increases with decreasing frequency of wind forcing. The impact of wind forcing on a global wind-wave model has been studied by Feng et al. (2006). The results of their detailed study suggest that the model output and the choice of wind field product are critically dependent. Similarly, Remya et al. (2014) has studied the impact of three different wind products on the spectral wave model MIKE 21 SW for the Indian Ocean region.

In coastal regions of India, it is quite common to have extreme weather conditions during the southwest monsoon and northeast monsoon seasons. The Northern Indian Ocean which is also the west coast of India experiences rough seas during the southwest monsoon season; but it is relatively calm during rest of the year. On the contrary, the east coast experiences higher wave activity during both monsoon periods. Apart from these monsoon periods, sea is calm and the coastal region is dominated by swells and by locally generated waves to some extent. Sabique et al. (2012) studied the contribution of swells in the Southern Indian Ocean towards the wave climate over the North Indian Ocean. They reported that southern ocean swells are the important factors determining waves over the Northern Indian Ocean and highlighted that this effect has huge impact particularly during southwest monsoon. In a swell dominated system, peaks at high frequencies represents the local wind-waves decay (waves losing energy), wherein the spectral peak at low frequencies represents swell field. The secondary peak in the system usually represents the energy from local wind waves. In a wind-dominated system having multi-peaked spectra, the total energy in the system is a combination of both wind seas and swells co-existing together. The third-generation spectral wave models such as WAM (WAMDIG, 1988), WAVEWATCH III (Tolman, 1991) and SWAN (Booij et al., 1999) represents the wind seas and swell better. Out of these three models, WAVEWATCH III (Tolman, 2009) and WAM model (Nayak et al., 2013a) are widely used (Rajesh et al., 2009) to study the wave processes in oceans (Kumar and Stone, 2007). However, these models have their own disadvantage; the untransformed data at grid points in deep water provides poor estimates of wave characteristics in nearshore region. Hence, the SWAN model (Booij et al., 1996) can simulate the propagation of random, short-crested, wind-generated waves in coastal regions and in inland shallow waters as well. Even the complex wave transformations from bathymetry, wind, and other factors can be dealt using this model.

Wave modeling with SWAN (Ris et al., 1994) model for different geographical regions is reported by several researchers. Mazaheri et al. (2013) discussed the use of SWAN model for wave modeling in the Iranian seas. Nayak et al. (2013b), Sandhya et al. (2014) and Umesh (2015) have reported the use of SWAN model for wave modeling in Bay of Bengal. Similarly, Chabahar Zone (Saket et al., 2013) and the Persian Gulf (Moeini et al., 2012) has been modeled. An unstructured-grid procedure for SWAN has been presented by Zijlema (2010). The other application of the SWAN model to study the wave field in the Bohai Sea regions has been explained by Wang et al. (2004) and Yang and Zhang (2013). Akpınar et al. (2012) carried out the implementation of the SWAN model forced by the ECMWF ERA Interim dataset reanalyzed 10 m winds over the Black Sea, which was used to study the wind-wave climate and wave energy potential in the region, and its verification. The SWAN model results were compared with directional buoy measurements and agreement between simulated and observed wave parameters was satisfactory. The study concluded the possible reason for the lower estimates of wave parameters as due to too low wind speeds in the applied ECMWF wind fields, which is probably caused by orographic effects and due to the relatively coarse resolution in time and space of the ECMWF (ERA-Interim) wind fields for the Black Sea. Similarly, a recent study by Akpınar et al. (2016) also reported the long-term spatial changes and inter-annual variability of winds and waves in the Black Sea covering a substantial historical time period of 31 years by using the calibrated SWAN model forced with the CFSR winds. Nekouee et al. (2015) investigated the wave regime in lakes under different lake and coastal geometries and wind regimes using SWAN model. This study gives necessary knowledge to coastal engineers to makes a rational judgment when there is not complete data on coastal geometry and wind regime. Another recent study of wind-wave predictions in Lake Michigan by Nekouee et al. (2016) dictates that the uncertainty of wave numerical models is due to input uncertainties and model principals that should be taken into account for design risk factors. Nayak et al. (2013a) coupled SWAN with WAM to study the interaction of distant long-period swells with the local wind-seas in the south-western Bay of Bengal and found it to be non-linear. Yin et al. (2005) introduced a coefficient improved associated with the variation of friction velocity to improve the linear growth term of wave growth source function in SWAN. Further, the use of this coefficient improved Halcyon's white capping. Later, this modified model has been used to investigate the wave characteristics and the wave parameters, which are in the Bohai Sea between 1985 and 2004. Montoya et al. (2013) realized that simulation of important wave parameters and directional spectrum in hurricane conditions can generate good results when realistic blended wind forcing and a high resolution WWIII model are used. Sanil Kumar et al. (2013), Glejin et al. (2013a) and Sandhya et al. (2014) reports wave spectral studies performed in the coastal Puducherry region of India. Sandhya et al. (2014) concluded that integrating the two modeling systems WWIII and SWAN produces high-resolution forecast for Puducherry region. Amrutha et al. (2016) performed sensitivity analysis of the integrated model in the regions where wind-seas and swells coexist in the eastern Arabian Sea.

The uniqueness of this study is the application of a multi-scale modeling approach using two state-of-art-numerical models like WAM Cycle 4.5.3 (Gunther and Behrens, 2011) and SWAN (SWAN Team, 2012). Apart from numerical modeling, experiments have been performed to simulate the nearshore wave conditions. Later, the wave spectra obtained from simulation and experiments have been validated for the coastal location of Puducherry as shown in Fig. 1 (Domain D_3).

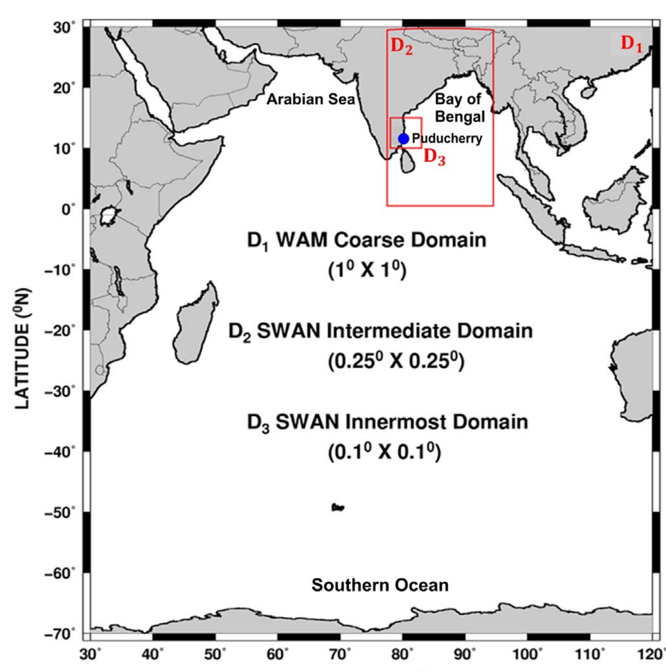

Fig. 1. Multi-scale domains for the numerical experiment (D_1-Coarse grid WAM domain; D_2-intermediate SWAN domain; and D_3-innermost SWAN domain).

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