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The effect of wind variability and domain size in the Persian Gulf on predicting nearshore wave energy near Doha, Qatar

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ABSTRACT

Wind-wave generation and propagation processes in the Persian Gulf during October and November 2010 were simulated with a third-generation numerical wave model. Several different numerical configurations were used, with output at an instrument pier near the Doha, Qatar coast used to examine the efficacy of these approaches. Three wind sources were used: two sets of wind hindcasts which span the extent of the Gulf; and 15-min averaged winds measured at the pier and distributed as a spatially constant wind field for the model. Domain size, and its nearshore effect, was examined by using three domains of varying sizes and resolutions. Boundary conditions from nesting between larger and smaller domains were also varied to determine how incoming wave conditions from larger domains located further offshore can affect nearshore wave conditions. The effect of wind field, boundary conditions and domain size were quantified by examining the histograms, correlation coefficient, and root-means-square differences, of various parameters (significant wave height, wave height due to swells, peak period, and mean approach direction) for each wave condition at the site. It is determined that significant wave heights at the pier are strongly dependent on the wind fields used and also have some dependence on the use of boundary conditions, while nearshore peak periods are very dependent on the use of boundary conditions. Furthermore, the distribution of wave mean angles tends to be narrower for cases in which hindcast winds and boundary conditions were used. These results are consistent with the sporadic appearance of a strong, unidirectional wind field over the Persian Gulf basin.

1. Introduction

The Persian Gulf is a large body of water located bordered by Iran, Kuwait, Iraq, Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates. It is connected to the Indian Ocean by the Strait of Hormuz. The Gulf holds a significant proportion of the world's oil reserves, and the Strait of Hormuz is considered a critical chokepoint for energy security; it is estimated that as many as 17 million barrels of crude oil per day passed through the straits in 2011 [1]. A major component of the meteorological environment in this area is the shamal, a strong northwesterly wind caused by cold fronts passing over the mountains of eastern Turkey and northern Iraq. It is a seasonal wind event occurring primarily during summer and winter. The winter shamal season generally lasts from November to February with an average speed of 5 (m/s), while the summer shamal season lasts from June to September with a slightly weaker average speed of 3 (m/s) [2]. Sustained winds of these magnitudes can result in energetic wind seas, which would hamper marine traffic. Fig. 1 shows the area of interest.

There have been relatively few studies of wind wave processes in the Gulf, particularly with respect to the shamal. Attention has been primarily focused on the hydrodynamics of the area [3,4]. [5] performed a numerical study of the area using a coupled system comprised of the wind wave model WAM [6] and the hydrodynamic model RMA-10 to compile a climatological database of conditions in the Gulf; they determined that the maximum significant waveheight in the Gulf was approximately 5.5 m and that the maximum tidal range was more than 4 m. [7] also used the WAM model to examine extreme waveheight statistics near Kuwait, determining that the 100 year wave condition has a significant waveheight of no more than 3.1 m and a mean period of no more than 6.1 s.

However, it is not clear at present whether the WAM model is generally the most suitable model for this region. The SWAN model ("Simulating WAves Nearshore"; [8]), while closely related to the WAM model, incorporates source terms which have more relevance to shallow water processes (e.g. depth limited breaking); [9] show that the SWAN model outperforms the WAM model for when compared to coastal measurements along Norway. The SWAN model also uses numerical schemes which are less diffusive than those in WAM [10]. While useful in terms of greater accuracy, diffusion reduction can lead to disintegration of the directional spectra for swell into individual spikes; this is known as the "Garden

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Fig. 1. Maps of the Persian Gulf, Qatar, and the instrument location.

Sprinkler Effect" (GSE) and is a result of discretization of the swell bands in direction. Numerical treatments which introduce diffusion back into the directional propagation schemes [11,12] have been introduced into the SWAN model to alleviate this problem. In the Gulf, [13] used SWAN to perform extreme wave analysis for coastal areas in Iran, showing that the 50 year waveheight is nearly 2.8 m. While important, the numerical grid used was relatively coarse (roughly 8 km over the entire Persian Gulf); it is not clear what the effect of such resolution would be on the results.

One practical consideration of wave modeling in a large, yet confined, area such as the Persian Gulf includes the treatment of the wind forcing, particularly when different sources are used. Measurements of winds generally provide relatively high temporal resolution (less than one hour between successive measurements) but are coarsely resolved in space, and are mostly located in coastal areas. In contrast, wind information from most available databases generated by model hindcasts replicate the spatial variability of windfields but often have relatively coarse output temporal resolution. For example, the Fleet Numerical Meteorology and Oceanography Command (FNMOC) will provide forecasts of winds over regional domains out to 48 h at three hour intervals; these forecast sets are provided every 12 h. However, the initial wind field for each 12 h forecast set (the so-called "analysis" field) is the most reliable and used for wave hindcasting exercises, but only available every 12 h. There are thus consequences to the selection and processing of wind information for model input.

Another consideration is the configuration of the numerical grids and the implementation of boundary conditions. This becomes a concern when determining nesting configurations for models in order to propagate swell generated from remote weather events to the nearshore. Recent work [14] has shown that multiple nests are needed to reliably capture swell fields in the Southern California Bight, as outer swells are brought into the inner domain by ensuing nested grids. The SWAN model includes utilities in the code which greatly facilitates grid nesting, thus allowing for high resolution only in areas where it is warranted (coastal areas, for example) without using curvilinear or finite element grids (which typically require additional gridding software). While swell may be an important consideration for areas bordering the Pacific Ocean [14], it is not evident how important swell might be for a confined area such as the Persian Gulf.

In this study, we use the SWAN model to investigate wind and swell waves around the coast of Qatar during October and November 2010, in an effort to determine the importance of various modeling procedures and physical processes on nearshore wave energy. In particular, we wish to determine the following:

- The importance of the characteristics (spatial, temporal) of the wind forcing on the nearshore wave environment.
- The importance of remotely-generated swell and wind sea on the nearshore waves.

A multi-level grid setup is used for the model, in which a succession of nested grids are used to propagate waves from their generation in the larger Gulf area to the coast of Qatar. A variety of wind fields are used, from hindcast fields from the COAMPS model [15] and NCEP [16] to local observations from both the airport at Doha, Qatar and those from a weather station located at the end of a maintenance pier. We use the winds to force waves and determine the effect of various grid configurations, nesting options and source of winds on the wave statistics at the maintenance pier. The end result is the establishment of a modeling methodology for prediction of the nearshore wave environment which accounts for the relevant processes affecting wind wave generation for the area.

In Section 2.1, we discuss the study area and the experiment pier. In Section 2.2, the three wind sources used for hindcasting, COAMPS [15], NCEP [16] and the wind observations from the pier, are also introduced, as well as pre-processing of the measured wind data to cover data gaps. In Section 3.1 the SWAN wave model is described in detail. In Section 3.2, we will detail the configurations of numerical cases. By varying the possible combinations of important model factors, such as domain size, wind sources, and swell