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Case study

Sensitivity of a third generation wave model to wind and boundary condition sources and model physics: A case study from the South Atlantic Ocean off Brazil coast

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ABSTRACT

Three different packages describing the white capping dissipation process, and the corresponding energy input from wind to wave were used to study the surface wave dynamics in South Atlantic Ocean, close to the Brazilian coast. A host of statistical parameters were computed to evaluate the performance of wave model in terms of simulated bulk wave parameters. Wave measurements from a buoy deployed off Santa Catarina Island, Southern Brazil and data along the tracks of Synthetic Aperture Radars were compared with simulated bulk wave parameters; especially significant wave height, for skill assessment of different packages. It has been shown that using a single parameter representing the performance of source and sink terms in the wave model, or relying on data from only one period of simulations for model validation and skill assessment would be misleading. The model sensitivity to input parameters such as time step and grid size were addressed using multiple datasets. The wind data used for the simulation were obtained from two different sources, and provided the opportunity to evaluate the importance of input data quality. The wind speed extracted from remote sensing satellites was compared to wind datasets used for wave modeling. The simulation results showed that the wind quality and its spatial resolution is highly correlated to the quality of model output. Two different sources of wave information along the open boundaries of the model domain were used for skill assessment of a high resolution wave model for the study area. It has been shown, based on the sensitivity analysis, that the effect of using different boundary conditions would decrease as the distance from the open boundary increases; however, the difference were still noticeable at the buoy location which was located 200–300 km away from the model boundaries; but restricted to the narrow band of the low frequency wave spectrum.

1. Introduction

All third generation wave models are based on the wave action balance equation to simulate the directional wave spectrum. In these models, the wave spectrum at each time step is determined according to the following equation:

$$\frac{DN}{Dt} \equiv \frac{S}{\sigma} \tag{1}$$

in which D/Dt represents the total time derivative (includes local rate, as well as spatial and spectral derivatives), and Srepresents all energy sources and sinks terms. The energy transfer from wind to the waves, quadruplet nonlinear wave interaction, and white capping dissipation are the three main mechanisms controlling the wave growth and decay in deep waters. Among these three source/sink mechanisms, the white capping dissipation is the least understood term, and several formulations have been proposed to include it in a more realistic form in the third generation wave models (Cavaleri et al., 2007).

In this study, an unstructured flexible mesh was employed to study the surface wave dynamics in the South Atlantic Ocean close to the Brazilian coast, during several months in 2002 and 2003. The uncertainties in model forecasts and its sensitivity to the formulations used for simulating the physics associated with white capping were addressed by comparing the model outputs, especially significant wave height, using different model configurations with *in situ* measurements from an offshore buoy location. Moreover, significant wave height and wind speed measurements from satellite altimeters were employed for validation of model inputs and outputs.

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2. Method

2.1. Study area and model setup

The wave hindcasting using different parameterization for white capping and wind input terms were performed for South Atlantic Ocean off the coast of Brazil (see Fig. 1). The unstructured computational grid, covering the south-central Brazil coast and offshore, was produced using SMS software (Aquaveo, 2010), and the required bathymetry data were obtained from Nautical Charts of Brazilian Department of Hydrography and Navigation (DHN). The flexible mesh grid composed of 8608 triangles and 4481 vertices, with mesh element size varied from approximately 10 km along the deep water open boundaries, which was located mostly beyond the continental shelf, to less than 2 km close to the buoy location (off the Santa Catarina Island, see Fig. 1) and in shallow waters.

The third generation wave model SWAN (Simulating Waves Nearshore), version 41.01 was used for wave modeling (SWAN TEAM, 2014). Simulations were performed with full spectral formulation using frequency band ranging from 0.039 to 0.619 Hz, and 36 directional bins. Linear wave growth, in response to wind forcing, was activated using formulations proposed by (Cavaleri and Rizzoli, 1981). Exponential wave growth and white capping terms were computed from three different packages: WAM Cycle 3 (denoted by KOM hereafter), WAM Cycle 4 (denoted by JAN hereafter) and the formulation presented by (van der Westhuysen et al., 2007) (denoted by WST hereafter). KOM formulation employs the pulse-based quasi-linear model of (Hasselmann, 1974) for white capping term, and a rescaled version of energy transfer from wind to wave as proposed by (Snyder et al., 1981). In order to accommodate the underestimation of wave period by KOM formulation, (Rogers et al., 2003) suggested to use a second order dependence of white capping dissipation on wavenumber; instead of linear relationship as earlier suggested by (Hasselmann, 1974). This modification became part of SWAN model suite since version 41.01.

In JAN formulation, two-way interaction of wave and wind were taken into account in wind term, using formulation presented by (Janssen, 1991). Moreover, a combination of linear and quadratic terms are used to realistically include the wave dissipation by white capping process in high frequency end of the spectrum. Both WAM formulations (KOM and JAN) suffer from erroneous over-prediction of wind-sea (chops) in the presence of swell waves because of the dependence of dissipation term on mean wavenumber and wave steepness (Ardhuin et al., 2010; Young and Babanin, 2006). In WST formulation, a nonlinear saturated-base white capping equation is presented to solve this over-prediction problem (van der Westhuysen et al., 2007). Also, the wind input term from (Yan, 1987) was used, instead of the formulation presented by (Snyder et al., 1981), to improve the results during high wind speed events.

It is worth to note that in version 41.01, SWAN employs updated coefficients for frequency tail of power spectrum compared to the original formulations presented in (Komen et al., 1984); which is critical in defining nonlinear interaction term, and have impacts on wave growth. Moreover, new drag coefficient formulation was used in wind input term to avoid unrealistically large values for drag coefficient associated with high wind velocities (SWAN TEAM, 2014).

In all simulations presented in this study, the Discrete Interaction Approximation (DIA) method was employed for quadruplet wave-wave interaction term, due to its computational efficiency (Hasselmann and Hasselmann, 1985). Shallow water terms such as triad wave–wave interaction and the spectral form of the bore model for depth-induced wave breaking were also included in the computations (Eldeberky, 1997). We would not expect any influence from these latter terms, which were meant for wave transformations in shallow water, on the model data presented here because all the measurements used for model skill-assessments were in deep water. The empirical formulation of JONSWAP (Hasselmann et al., 1973) was included in the model setup to take into account wave dissipation due to bottom friction. The constant value of 0.038 $m^2\ s^{-3}$ was used as bottom friction coefficient for entire study area, as suggested by (Zijlema et al., 2012)

Note that Eq. (1) is solved on discrete frequencies in SWAN, and therefore the minimum and maximum frequencies used in the computations needs to be set by the user. Due to the shape of normal wind-induced wave spectrum, not much energy is retained in frequencies lower than 0.05 Hz (wave period of 20 s). Therefore, the minimum frequency is usually set within the range of 0.03–0.05 Hz (Janssen, 2008). On the other hand, the wave energy decays slowly in high frequency part of the spectrum. SWAN Team recommended 1 Hz for high frequency cut-off but (Siadatmousavi et al., 2012) showed that the modeling would be more successful in reproducing the wave spectrum and bulk wave parameters in oceanic scales if the high frequency cut-off were set to some values close to 0.5 Hz, as used in other deep water wave models (Janssen, 2008). Therefore the value of 0.6 Hz was used for high frequency cut-off in this study.

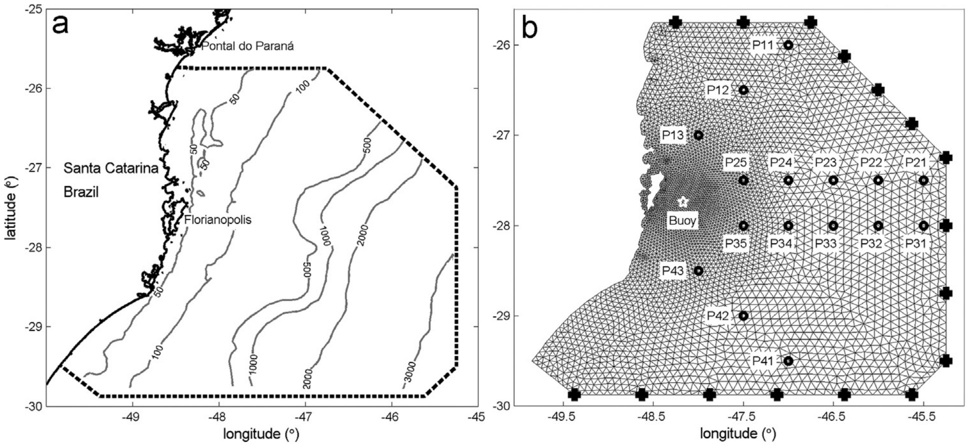

Fig. 1. (a) The study area and (b) the unstructured mesh used for simulations. The gray contours are isobaths. The locations of provided open boundary data marked by the black plus marks, and the location of buoy used for verification of the models was shown by a white pentagram mark. The wave spectrum at points $_{Pi}$ were used to assess the model sensitivity to the boundary conditions.