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ScienceDirect

Energy Procedia 137 (2017) 443–451

Energy Procedia

www.elsevier.com/locate/procedia

14th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2017, 18-20 January 2017, Trondheim, Norway

Demonstrating the impact of bidirectional coupling on the performance of an ocean-met model

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Abstract

The mass, momentum and energy fluxes between the atmosphere and ocean surface depend on the state of the ocean surface. The fluxes in turn can significantly alter the nature of the marine boundary layer and the state of the ocean surface. These interactions can be modelled deterministically using a multiphase modelling approach or using a semi-stochastic approach. While the multiphase approach can give better insights (e.g. wave generation), it is computationally too expensive and not suited for modelling ocean waves which are inherently random in nature. It is for this reason that in a forecasting context, semi-stochastic approach is still the workhorse. Furthermore, even in a semi-stochastic approach ocean and atmospheric models can be coupled in either unidirectional way (ocean affecting the atmosphere) or bidirectional way (both ocean and atmosphere affecting each other). Current work compares the performance of these two coupling approaches and validates them using significant wave heights and 10m wind magnitude.

Peer-review under responsibility of SINTEF Energi AS.

Keywords: WAM, HARMONIE; Ocean-Met interactions; Wave Modeling

1. Introduction

The exchange of mass, momentum and energy between atmosphere and ocean surface depend on the state of the surface. For example, young ocean waves typically have a larger roughness compared to older waves and hence bigger mass, momentum and energy flux. The flux in turn can significantly alter the nature of the marine boundary layer (MBL) and the state of ocean surface. Many offshore engineering applications rely on a detailed ocean and atmospheric state at specific locations. Within the marine industry attention to joint met-ocean description was given already three decades ago due to expected economic advantages of using it. It was shown that typically, the environmental forces on marine structures may be reduced from 5% to 40% by accounting for the lack of full correlation

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1876-6102
Peer-review under responsibility of SINTEF Energi AS.
10.1016/j.egypro.2017.10.368

of met-ocean parameters; see e.g. [1]. Gregersen et al [2] suggested that the met-ocean model developed originally for design purpose can also be applied for specification of operational criteria for marine structures in general. Since direct measurements of waves are often constrained by budget that allows only short or intermittent datasets, numerical modeling is becoming more of a norm. Wave models like WAM [3] and SWAN [4], and atmospheric models like HARMONIE [5] are now increasingly used for getting a real time state of ocean and atmosphere. However, most often than not the ocean and atmospheric models are run in isolation. For a better prediction of the ocean-atmospheric state interaction between the two needs to be modeled accurately. The interactions can either be modeled deterministically using a multiphase modeling approach (where a liquid phase represent ocean and gas phase represents atmosphere) or can be modeled using a semi-stochastic approach where stochastic action balance equation is used to model the state of ocean surface and a deterministic approach based on the Navier Stokes equations is used for atmospheric modeling. While a multiphase approach can give better insights into mechanisms of wave generation, white capping, dissipation and diffraction, it is computationally expensive and not suited for modeling ocean waves which are inherently random in nature under realistic meteorological conditions. It is for this reason that in a forecasting context, semi-stochastic approach is still the workhorse. Barbariol in 2013 [6] used coupled wave-ocean model for improving wave energy assessment. To better identify the significant processes affecting coastlines and how those processes create coastal changes COAWST Modeling System, which is comprised of the Model Coupling Toolkit to exchange data fields between the ocean model ROMS, the atmosphere model WRF, the wave model SWAN, and the sediment capabilities of the Community Sediment Transport Model was developed [7]. The coupled modeling system was used to investigate atmosphereoceanwave interactions in November 2009 during Hurricane Ida and its subsequent evolution to NorIda, [8]. There has also been efforts to couple wave models having different resolutions and focus like WAVEWATCH III (WWIII) for wave generation and deep water propagation and SWAN model for wave propagation in intermediate and shallow water [9]. Waves at the surface of the deep ocean can be well predicted with third-generation wave models that are driven by predicted wind fields [10] [3]. Although these recent models are coupled they were mostly unidirectional in nature (only atmosphere affecting the ocean state). In the current work we simulate the ocean atmospheric interactions through both unidirectional and bidirectional coupling of the atmospheric code HARMONIE [5] and the wave modeling code WAM ([3]). It is expected that in bidirectional coupling, atmospheric and wave models will mutually benefit each other through a frequent update of the inter-facial conditions (wind computed by atmospheric model and Charnock parameter computed by wave model) and provide a better prediction of significant wave height and local wind. The atmospheric code HARMONIE solves for the standard governing equations of mass, momentum, energy and humidity using appropriate physical models to simulate the effects of clouds, pollutants, rotation of earth etc. For the state of ocean surface, action balance equation is solved giving wave energy spectrum as a function of location, frequency and direction of the waves. Ocean surface characteristics (like surface roughness, Charnock number) are evaluated using the spectrum. Surface fluxes for momentum, energy and humidity is then computed and passed on to the HARMONIE model as boundary condition at the ocean surface. The HARMONIE model in turn computes wind magnitude and direction at 10 meter height above the average ocean surface and hence provide the source term corresponding to wind generated waves. In the current work uni- and bi-directional coupling effectiveness is evaluated by comparing the predicted results with data from sea-buoy and observation platforms located in offshore locations.

2. Computational Models

In this section we give a brief description of the computational models used. Readers are directed to relevant articles giving more details about the models wherever required.

2.1. Atmospheric Model

The atmospheric component in the coupled system is a mesoscale model named HARMONIE based on the equations governing mass, momentum, energy and species conservation. The model is a non-hydrostatic model, of which the dynamical core is based on a two-time level semi-implicit semi-Lagrangian discretisation of the fully elastic equations, using a hybrid coordinate system in the vertical direction [5]. The simulation domain is shown in Figure 1(b). A horizontal resolution of $2.5km \times 2.5km$ is used. This is the same resolution that is used for weather forecast on a