Ocean Engineering 164 (2018) 298–321

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Inter-comparison of WAM and WAVEWATCH-III in the North Indian Ocean using ERA-40 and QuikSCAT/NCEP blended winds

P.A. Umesh[a,b,*], J. Swain[a], A.N. Balchand[c]

[a] Naval Physical and Oceanographic Laboratory, Thrikkakara P.O., Kochi 682 021, Kerala, India
[b] Department of Ocean Engineering & Naval Architecture, Indian Institute of Technology Kharagpur, Kharagpur 721 302, West Bengal, India
[c] Department of Physical Oceanography, Cochin University of Science and Technology, Kochi 682 016, Kerala, India

ARTICLE INFO

Keywords:
WAM
WWIII
Sea-state prediction
Wave model inter-comparisons
ERA-40
Blended winds

ABSTRACT

In this work we present the inter-comparison of wave hindcasts using third generation models WAM and WAVEWATCH (WWIII) for the North Indian Ocean at a 1° × 1° (lat × long) grid resolutions and we show a first assessment of their relative performance by inter-comparing the model results to observational data at selected points in the Arabian Sea and Bay of Bengal. WAM and WWIII inter-comparison studies are carried out for the year 2000 and for the period June 2008 to June 2009. Overall, the inter-comparison shows that both wave models are rather skillful in predicting the integral wave parameters; with lesser PE of the range 8.9–26.7% using WAM than WWIII. It is also quite evident that the WWIII model has a tendency to overestimate mean wave periods, while the opposite is true for WAM model. Further, the validation results using altimeter measurements are quite promising in the Arabian Sea and Bay of Bengal. The study further suggests that, it would be wise to use long-term measurements both in deep and coastal waters of North Indian Ocean to validate and inter-compare WAM and WWIII further, and they may also be coupled with SWAN for the nearshore waters.

1. Introduction

The wind-induced surface gravity waves in the ocean are important in the air-sea interaction process of the coupled ocean-atmosphere system. The knowledge of the ocean waves and their temporal and spatial variabilities are essential for various defence as well as civilian applications (Swain, 1997; Richard et al., 2002; Umesh et al., 2007). The ocean as such is a dynamic system where there are a number of processes which take place simultaneously so that it becomes too complex to predict them. However our understanding of the ocean environment is constantly improving, which enables us to predict its variability well in advance. Forecasting surface waves in the ocean is a problem of great practical interest, as the sea-state conditions influence virtually all most all aspects of naval operations at sea, as well as a variety of commercial and maritime activities. For example, accurate ocean wave forecasting is a key prerequisite for enabling optimum tracking of ship routes and ensuring the safety of lives and property at sea onboard various fixed and floating platforms. Thus, ocean wave forecasting has been a priority for all research and maritime organizations, those who have pioneered the application of operational ocean wave models, dating all the way back to the 1960s.

Considering the variety of applications of sea-state as mentioned above, accurate and extended wave information, including waves of extreme weather events is very essential for a wide range of research and engineering applications. Wave statistics derived from point measurements were considered for obtaining reliable local wave climate in the past. However, these measurements are not sufficient to describe the regional wave patterns over a long period of time. This emphasizes the need to work on wave models driven by wind fields obtained from satellites measurements or/and models. The present day third-generation wave models are capable of predicting the waves reasonably well, and their accuracies can be still improved with appropriate representation of extremely complex physical processes of wind generated waves (Vledder, 2001; Polnikov et al., 2007). The scientific community has developed a series of models called as Third Generation wave models such as WAM (WAve Modeling: WAMDI Group, 1988), WAVEWATCH III (WWIII: Tolman, 2009; Tolman et al., 2002) and SWAN model (Simulating Waves Nearshore: Booij et al., 1999 and Ris et al., 1999) which are being widely applied for global as well as regional ocean state forecasts up to the nearshore zone. The components of source function are used without any prior restrictions on the spectral shape (Tolman and Chalikov, 1996). The shallow water or

* Corresponding author. Department of Ocean Engineering & Naval Architecture, Indian Institute of Technology Kharagpur, Kharagpur 721 302, West Bengal, India.
E-mail addresses: umeshpa.nair@gmail.com, umesh@naval.iitkgp.ernet.in (P.A. Umesh).

https://doi.org/10.1016/j.oceaneng.2018.06.053
Received 30 August 2016; Received in revised form 26 May 2018; Accepted 20 June 2018
0029-8018/

nearshore wave model SWAN (SWAMP, 1985) has been designed specifically for coastal wave prediction, and it is utilized at several coastal regions around the world.

The state of the art and the prospects for improvement of wave models can be found in Holthuijsen (2007), the WISE Group (2007) and Komen et al. (1994). Like many other geophysical phenomena, waves can be studied on very different space and temporal time scales (Lavrenov, 2003). Sea-state belongs to large scales and it is mainly related to the processes of wind momentum transfer, nonlinear transfer, current refraction and turbulent dissipation of energy. As the waves move toward shoreline, other physical processes become important, viz. refraction induced by sudden variations in depth (or by coastal currents) and shoaling. Since the forcing become increasingly dependent on regional currents and local variations in bathymetry, the scale of the problem becomes smaller. In most situations, the two types of waves can still be analyzed within the framework of the same theory. As a result, a third generation wave model like WAM, which efficiently solves the kinetic equation and the source functions in order to give global and regional forecasts, can be combined with other nearshore wave models like SWAN that are more oriented towards propagation on the coastal scale. We refer to Komen et al. (1994) and Janssen (2008) for a complete description of WAM, and to Booij et al. (1999) and the SWAN Team (2011) for information on SWAN. Recent advances in the availability of computer power, it has become feasible to use chains of numerical models in order to connect the wave propagation from the large to the regional/coastal scales. The resulting system might provide not only large-scale wave forecasts based on synoptic-scale wind and satellite data assimilation, but also a realistic ongoing description of the coastal waves in smaller regional areas.

With the increasing demand for modernization, there is equally an increasing demand to forecast ocean waves (Rusu, 2011) in open sea and coastal areas to aid marine applications. Many users and the scientific community depend on nowcasts and ocean state forecasts for marine related operations (Balakrishnan Nair et al., 2013, 2014; and Sandhya et al., 2014). Wave modeling studies for the North Indian ocean using WAM, WWIII and SWAN have been carried by several researchers such as Sabique et al. (2012), Nayak et al. (2013), Amrutha et al. (2016). Wave model inter-comparison studies have been reported across the globe by various researchers till date (Tolman et al., 2002; Padilla-Hernandez et al., 2007; Ortiz-Royero and Mercado-Irizarry, 2008; Hanson et al., 2009; Korres et al., 2011). A systematic inter-comparison of WAM Cycle-4 and WWIII wave model results has been reported for the Mediterranean region by Korres et al. (2011). The inter-comparison of the two wave models over the whole Mediterranean basin showed that noticeable differences in terms of significant wave height (Hs) and periods (significant wave height RMS differences of 0.5–0.7 m and wave period RMS differences of 1.5–2.0s) was seen along the track of the main cyclones over the basin, where the swell contribution to the wave field was important. In the geographic areas of the Mediterranean Sea where wind-seas dominate, the two models exhibit almost the same performance. Inter-comparison of SWAN and WWIII with buoy observations was carried out by Ortiz-Royero and Mercado-Irizarry (2008). The study tested the applicability of the SWAN model at oceanic scales. Although comparison between buoy observations and model outputs tend to favor WWIII over SWAN in deep waters, it was stressed that the ease of using SWAN, together with the simplification offered by just having to learn to use one model, makes the SWAN model a good option for simulations all the way from deep waters up to the nearshore.

Hanson et al. (2009) evaluated the performance of three numerical wave models (WAM Cycle-4.5, WWIII and WAVAD) in the Pacific basin. The three models exhibited varied performance in the depiction of wind sea and young swells in their physical attributes. WWIII hindcasts exhibited consistently higher performance scores than those from WAM and WAVAD. The prediction of mature swells in the winter months, with elevated height errors in all three models was a noteworthy problem. In another study, three state-of-the-art operational forecast wave models, WAM, WWIII and SWAN were compared through simulations (Padilla-Hernandez et al., 2007) of two severe winter storms in the northwest Atlantic. Model performances were also evaluated through comparisons/validations with field measurements. The results revealed that, although the models are comparable in terms of their overall performance and skill, it was found that WWIII provides (Padilla-Hernandez et al., 2007) a better statistical fit to the observed wave data compared with the other models, and that SWAN gives slightly better results if nested within WWIII, rather than within WAM. Tolman et al. (2002) reported that for Japan, the Gulf of Mexico, and the NW Atlantic, NWW3 (NOAA WW3) appears to be significantly better than WAM, primarily based on the regression slopes. For the NE pacific and Atlantic, NWW3 has much better correlation coefficients and smaller standard deviations and rms errors than WAM. However, NWW3 overestimates the slope of the regression line by 16%, whereas WAM underestimates the slope by a much smaller region.

A long-term inter-comparison of model computed wave parameters for the North Indian Ocean region is however missing. The novelty of this work is the inter-comparison of two modeling systems viz; WAM and WWIII to suggest the suitability and capabilities for their future utilization and exploitation in predicting the sea state information required for various practical applications. In an operational scenario, to verify the efficiency of model computed parameters, systematic validation studies with long-term observational data is an essential prerequisite to improve the prediction capability and enhancement of wave model performances. The inter-companion study gives reasonably good results with low RMS error and high correlation coefficients. The present study is going to be the first, but initial attempt to inter-compare each of the models such as WAM C4.5.3 and WWIII V3.14 for the North Indian Ocean (NIO) region by conducting a few carefully chosen case studies for selected years to project its usefulness on sea state information.

2. Composition of the modeling system

The state-of-the art third generation wave prediction models evolved initially with the development of WAM followed by WWIII, and coastal wave model SWAN. However, the modeling system architecture employed here is comprised of WAM and WWIII. Both these models are used in many operational centers worldwide for routine sea-state forecasts.

2.1. WAM Cycle 4.5.3

The WAM model solves the spectral energy balance equation describing the two-dimensional wave spectrum in the following way:

$$\frac{\partial F}{\partial t} + \nabla\cdot(C_g F) = S_{in} + S_{nl} + S_{ds} \tag{1}$$

where $F\ (f,\vec{\theta};\vec{x},t)$ is the spectral energy density, depending on wave frequency, f, wave direction, θ, position, $\vec{x}$, and time, t, and deep-water group velocity, $C_g = C_g\ (f,\theta)$. Equation (1) describes the loss, gain and shifting of energy and the equation is valid for deep water with no refraction and no significant current. The so called source functions on the right hand side in Equation (1), describe the wind input, S_{in}, nonlinear transfer S_{nl}, and dissipation due to white-capping, S_{ds}.

WAM Cycle 4.5 is an update of the WAM Cycle 4 wave model, which is described in Komen et al. (1994) and Gunther et al. (1992). The basic physics and numerical approaches are kept in the new release. The source function integration scheme adopted by Hersbach and Janssen (1999) and the its updates (Bidlot et al., 2005) have been incorporated. A number of additional options are also added in the new model release of WAM Cycle 4.5.3 (Gunther and Behrens, 2011). The new method in WAM 4.5.3 is semi implicit and it is based on the developments at ECMWF (Janssen, personal communication):