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A Coupled Numerical and Artificial Neural Network Model for Improving Location Specific Wave Forecast

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ABSTRACT

As more than a quarter of India's population resides along the coastlines, it is of utmost importance to predict the significant wave height as accurately as possible to cater the needs of safe and secure life. Presently Indian National Centre for Ocean Information Services (INCOIS) provides wave height forecasts on regional as well as local level ranging from 3 hours to 7 days ahead using numerical models. It is evident from numerical model forecasts at specific locations that the significant wave heights are not predicted very accurately. The obvious reason behind this is the 'wind' used in these models as a forcing function is itself forecasted wind (ECMWF wind (European Centre for Medium-range Weather Forecasting)) and hence many times the forecasts, differ very largely from the actual observations. These models work on larger grid size making it as major impediment in employing them particularly for location specific forecasts even though they work reasonably well for regional level. Present work aims in reducing the error in numerical wave forecast made by INCOIS at four stations along Indian coastline. For this 'error' between forecasted and observed wave height at current and previous time steps was used as input to predict the error 24 hr ahead in advance using ANN since it has been effectively used for wave forecasting (univariate time series forecasting in general) since last two decades or so. This predicted error was then added or subtracted from numerical wave forecast to improve the prediction accuracy. It is observed that numerical model forecast improved considerably when the predicted error was added or subtracted from it. This hybrid approach will add to the usefulness of the wave forecasts given by INCOIS to its stake holders. The performance of improved wave heights is judged by correlation coefficient and other error measures like RMSE, MAE and CE.

1. Introduction

Earth System Science Organization – Indian National Centre for Ocean Information Services (ESSO-INCOIS), Hyderabad delivers quantitative ocean state forecast (OSF) to the Indian coast, from the year 2008 onwards by issuing forecasts of vital ocean parameters like significant wave height, remotely generated waves (swells) and ocean surface winds, seven days in advance and at 3-hourly interval with daily updates. Additionally ESSO-INCOIS is issuing high wave alerts under extreme events, as forecasted by numerical models. These alerts give information about significant wave height, swell wave height, wave period, wave direction and ocean surface winds. High wave alerts are issued in English as well as local languages so that the users can easily understand and start the preparedness. Most of the users utilize these forecasts as guidance for their daily operational activities and to ensure safe navigation at sea [3]. Apart from this the forecast is being sent to the Non-Governmental Organizations (NGOs) in the coastal areas who perform the dissemination through FM Radio and Village Information Centres [41]. Being the sole operational ocean state forecast agency for the north Indian Ocean, ESSO-INCOIS gives high-wave alerts/warnings during high wave conditions.

The numerical models require exogenous data inputs and work on larger gird size making it as major impediment in employing them particularly for location specific forecasts even though they work reasonably well for regional level. It can be observed from Fig. 1 that the forecast given by numerical models are not very

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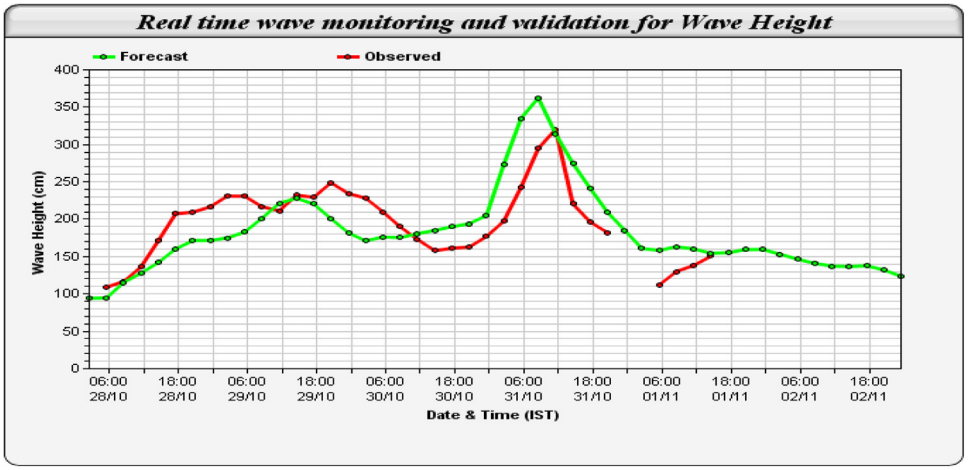

Fig. 1. Wave plot showing the observed and forecasted wave heights by INCOIS (www.incois.gov.in).

accurate and there is a scope for improving the forecast. For the current study it was thought of to obtain the error between the observed and forecasted values of the wave heights at particular locations and to predict these errors for the desired future time step. These errors were then added or subtracted to the forecasts made by the numerical models, in an effort toimprove their accuracy particularly for specific locations. The numerical models already take into consideration the physics of the underlying process involved and thus, the authors thought of using soft computing tools for the modeling of these errors. Soft computing techniques which do not require a priori knowledge of the underlying phenomenon and can give meaningful solutions by using the readily available measured data and their antecedent values, can therefore be employed to bridge the gap between these wave forecasts and observed values by developing a wave forecast improving model using the error between the observed and forecasted wave values.

The last two decades of the twentieth century witnessed a surge of publications in the area of modelling hydrodynamics using the soft computing technique of Artificial Neural Networks (ANNs). ANN is now an established technique in the field of Hydraulic Engineering as well as coastal and Ocean Engineering as evident from a plethora of publications in the journals of international repute. Therefore, it is proposed to use Artificial Neural Networks (ANNs) as a modeling tool in the present study.

2. Details of the Tools Used

2.1. MIKE 21 SW model

The ESSO-INCOIS uses operational MIKE21 SW (Spectral Waves) model for significant wave height (SWH) forecasting over the entire Indian coastal region covering the Arabian Sea (AS), Bay of Bengal (BOB) and North Indian Ocean. MIKE21 SW is a third generation spectral wind wave model, based on unstructured meshes, and is developed by Danish Hydraulic Institute. The model simulates growth, decay and transformation of wind generated waves and swells in offshore and coastal areas. The use of unstructured mesh enhances accuracy of the wave model near the complex areas of the coastline. SW model is based on flexible mesh and therefore is particularly applicable for wave analysis both on regional and local scales which is very important in simulating cyclone generated wave fields [39]. Model simulates the wave growth by the action of wind, non-linear wave–wave interaction, dissipation due to white-capping, bottom friction and depth induced wave breaking, refraction and shoaling due to depth variations, wave–current interaction and the effect of time varying water depth. Description of all source functions and the numerical methods used in the model are elaborated in Sørensen et al. [42]. In the present study, SW model domain from 60°S–30°N; 30°–120°E is used. Many recent studies show that swells from the southern Indian Ocean significantly modify the wave climate in north Indian Ocean [39,40]. Hence, the domain was extended up to 60°S so that swells generated at southern ocean were properly simulated by numerical model

For the model runs, the mesh resolution was chosen to be 0.13^0 along the Indian coast, 0.40^0 for the BOB and AS and a coarse resolution of 1^0 for the southern ocean. Bathymetry data from etopo2 (2 min gridded global relief data) and etopo5 (5 min gridded global relief data) were used in this study. Readers are referred to [37], for more information on etopo2 and etopo5.

2.2. Artificial Neural Networks

An artificial neural network (ANN) works like a biological neural network of the human brain and provides mathematical models for cognition [15]. It is a soft computing tool which treats the human brain as its role model and mimics the ability of the human mind to effectively employ modes of reasoning and/or pattern recognition that is approximate rather than exact. The mapping of input and output to the required accuracy is done by using an iterative procedure for minimizing the error between the observed and network predicted variables (outputs). The calibration ('training' as per ANN terminology) is done on a set of data using a training algorithm which minimizes the error and makes the network ready to face the unseen data kept aside for testing the model.

The ANN is now an established technique in modeling water flows and therefore most of readers are well versed with the terminology and working of ANN. Hence detail information of its working is avoided in the current paper. The readers can refer text books like Bose and Liang [5], Wasserman [46] and research papers by The ASCE Task Committee [44], Maier and Dandy [24] and Dawson and Wilby [7] for understanding the preliminary concepts and working of ANN.

3. Literature Review

The technique of ANN has been successfully used since the last two decades for the forecasting of wave heights.The previous attempts to forecast significant wave heights (SWHs) can be divided into various categories. The first category represents temporally univariate models, in which current and previous SWHs are used to forecast the SWHs a few hours to a few days in advance as