PREFACE

Knowledge of ocean wave climate is important for several practical applications such as ship routing and deep sea drilling with significant economic importance. This information is vital near shore for design of coastal structures. Ocean wave studies are also important for port and harbor development, coastal zone management strategic operation and for tapping the wave energy.

Wave observations are carried out from a variety of platforms i.e. moored and drifting ocean buoys ships and near shore recorders to provide information in deep as well as shallow waters. However, all these measurements are point specific or sparsely distributed both spatially and temporally. This, therefore, is not quite suitable to provide a full knowledge of wave climatology of a particular region.

Developments in remote sensing of ocean surface have enabled wave-modeling community to collect wind and wave data using space-born active/passive microwave remote sensing instruments. Altimeter is an active microwave sensor, which can be used to obtain highly accurate significant wave height as well as ocean wind information from the space. Though altimeter is nadir looking sensor having very narrow swath, significant coverage of the ocean can be obtained using more number of altimeters in space, periodically looking at the same region. Synthetic Aperture Radar (SAR) is another active microwave radar, which is used to obtain full 2-D wave spectrum. The quality of the data obtained using these sensors have been extensively validated against in-situ observations.

The directional wave spectrum of the ocean surface is a compact way of presenting the important wave parameters like wave height, wave period, and the wave propagation direction. The development in ocean wave modeling using spectral approach started from the concept of the spectral energy balance for the spatially evolving wave system. Several theoretical and observational studies over the last many years have been carried out to understand wave generation, interactions and dissipation, which are later incorporated in the wave models as source terms. In spite of all these theoretical developments, numerical wave predictions are not very accurate due to several numerical limitations of the model. This difficulty is tried to be reduced by developing suitable data
assimilation techniques. Highly reliable wave data obtained from in-situ as well as space-born instruments can be used for improving the ocean wave model physics and satellite data assimilation in order to improve the understanding of wave climate in shallow as well as deep ocean.

In the present study a third generation global wave model WAM-3g has been used to simulate ocean wave climate in the Indian Ocean region. The wave model WAM has been described along with results of some typical high sea state conditions. The analyzed/forecast winds and waves are validated with in-situ observations. In the present study emphasis is given on the satellite data utilization in the wave model to simulate the wave statistics. For this purpose QuikSCAT scatterometer winds have been used for forcing the wave model. The genesis of cyclone occurred during 25th May 2001 was fully/partially captured by the scatterometer and the response of the wave model to these winds has also been studied. The results are quite encouraging. This study also demonstrates the wave evolution in southern ocean and its impact on wave prediction over the Indian Ocean region. The present work also discusses about several satellite data assimilation scheme used to improve the wave analysis and subsequent wave forecast. In particular, the altimeter data obtained from three different satellites have been used simultaneously for assimilation in the wave model.

The dissertation content is presented in five chapters as given below.

Chapter-1

This chapter includes brief introduction about waves, classification of waves on the basis of their generation and wave periods, properties of ocean waves. It discusses about wave estimation using classical techniques like beaufort scale, nomograms etc. and sequential evolution of wave prediction techniques. The importance of remote sensing techniques used to observe ocean surface in modern era has also been discussed here. Working principal of several space-borne sensors like altimeter, synthetic aperture radar (SAR) is discussed in brief. It also discusses about methods of taking in-situ observations by various instruments.
Chapter-2

This chapter discusses about evolution of numerical wave prediction techniques with time and their present form. It also describes the theory of wave growth with winds, different mechanisms like fetch/duration limited growth of wind waves. It also discusses about resonant nonlinear wave-wave interactions and its role in evolution and decay of wave spectrum. The dissipation of the ocean waves due to bottom friction and white caps has also been discussed in this chapter.

Chapter-3

In this chapter experiments using the WAM model are discussed. The basic physics of the WAM model has also been summarized in this chapter. Parameterization of the source terms wind input, non-linear wave-wave interaction, and wave dissipation terms used in the energy balance equation has also been discussed. The major forcing in the wave model is due to the ocean surface winds. To assess the impact of this forcing, sensitivity of wave model against errors in input winds are also illustrated and results are also discussed. Sensitivity experiments show that model is less sensitive to wind input with errors less than 2 m/s but as error in the input winds increases errors in predicted wave heights also increase. Moreover it was also seen that error in model hindcast wave height increases when the wave model is forced by winds at longer temporal interval. A complete validation study using SSM/I derived wind fields was carried out for the year of 1995. These hindcasts were validated against satellite observations. It was observed in these experiments that wave heights show fair consistency against observations but wave periods are not matching with the satellite derived wave periods. This may be due to algorithmic inadequacy to obtain wave period from Topex/Posiedon altimeter. Experiment carried out using Multi-frequency Scanning Microwave Radiometer (MSMR) derived wind fields as well. Experiments have also been conducted using ocean surface winds from scatterometers. It was found that wave model output using scatterometer wind data show excellent consistency with altimeter measurements.
In this chapter sequential assimilation techniques and results of some assimilation experiments are discussed. Among several technique of satellite data assimilation, computationally less expensive techniques of assimilation like rescaling wave spectrum in accordance with observed wave height and advanced technique like optimal interpolation technique of wave height data assimilation are discussed in detail.

Altimeter wave height data is not only useful to validate the model forecast/hindcast but to improve the hindcast capacity of the numerical models. Though wave height is not direct output of wave models, wave height data can be assimilated in order to improve the wave hindcast/forecast. Space-borne altimeters provide wave height data over a limited region of the ocean at a given time. Since wave model computes wave spectrum for each grid point, observed wave height were converted to equivalent wave spectrums using first guess spectrum available from the model. Preliminary experiments on assimilating by direct insertion of along track satellite data into wave model show little improvement in the wave model hindcast. Further extension in the same technique of assimilating data shows remarkable improvement in the wave hindcast, which persists for longer forecast period after assimilation. In other experiment of direct insertion of satellite data, the influence of track data was spread to the near by model grid points by maintaining the model wave height slope. This modification of the assimilation scheme shows greater improvement in the wave hindcast field then just assimilating data along track only.

Before attempting the analyzed wave field, an identical twin experiment was carried out. In this experiment, model wave height field obtained using QuikSCAT wind forcing has been considered as pseudo-observations and used to assimilate in to the wave model, when forced using NCMRWF model analyzed wind fields. This experiment shows high improvement in the model after assimilation. The high sea state conditions observed on the 24th of May was reproduced after assimilating the wave height data. This shows that assimilation of the altimeter data would also show the remarkable improvement if available globally.

Optimal interpolation technique of data assimilation is a statistical technique. In this technique, analyzed wave spectrum is obtained by minimizing
model error covariance in accordance with the observations. Thus new spectrum is considered to be better approximation to actual spectrum.

Chapter-5

In this chapter the detailed conclusions of the study and scope of the future work is described. It has been observed that WAM model physics is reasonably good for the significant wave height predictions over the Indian Ocean. However it shows large biases in the swell component in some regions of the globe especially in the Indian Ocean. The positive impact of satellite-derived winds on the wave simulations has also been observed in this study. The impact of altimeter derived significant wave height data assimilation in high sea state conditions has clearly been observed in our wave model experiments.