CHAPTER IV. SIMULATION OF WAVE CLIMATE

IV.1 INTRODUCTION

Simulation is the process of designing a model of the real system, conducting experiments for the purpose of understanding the system behavior, and evaluating various strategies within the boundary conditions that are imposed for executing the modelled system. In fact, real world systems are often complex and composed of several subsystems and their interactive components. The same is the case with the evolution of wind-induced surface gravity waves in the ocean. In this study, a well established wave model has been adopted. Although the model represents the physics of the wave evolution in accordance with our knowledge today, there can be a number of potentially important effects which are not included in this model. Air-sea temperature differences, particularly under highly stable situations modify the energy input from the wind (Cardone, 1969). The effect of rain may be significant in certain circumstances. The most trivial effect is the attenuation produced in a heavy downpour resulting in the disappearance of short gravity waves. The attenuation coefficient is the product of rain fall rate and the wave number (Phillips, 1987). In addition, rain may also modify the effective mean wind profile. These are some of the examples which are to be considered in the wave prediction models used for operational wave forecasting purposes. In the present study the above mentioned effects seem to be less important as we are dealing with the problem of wave climate simulation based on the mean climatic year of winds derived using long-term historical data. Here the main interest is to estimate monthly and seasonal variability of the sea-state for the region of interest.

The following sections will summarize: i) the details of wave model implementation, ii) the various strategies that are adopted in specifying inputs to the model and evaluation of simulated results within the specified boundary conditions, and iii) compilation of simulated outputs.

IV.2 WAVE MODEL IMPLEMENTATION

The presently used wave model 3g-WAM was originally developed at Max-Plank-Institut fur Meteorologie in Hamburg, Germany by S. Hasselmann with the help of P. Janssen, G. Komen, L. Zambreski and H. Gunther (Gunther et al., 1992). The model has been installed at about 35 institutions world
wide. Naval Physical and Oceanographic Laboratory (NPOL) is one of the users of this model. The model code designed for the CRAY supercomputer with UNICOS operating system is suitably modified by the author at NPOL for DOS & WINDOWS platforms. Incidentally, this is the first attempt to implement 3g-WAM for the Indian Seas (Swain et al., 1995).

IV.2.1 Regional grid system

In the present study, 3g-WAM has been implemented for wave climate simulation for the Indian Seas (0-25°N, 50-100°E). The regional grid system for this region is shown in Fig.9. The land grids are indicated with solid squares. It may be noted that the regional grid system as shown in Fig.9 has only one open sea boundary to its south (0° Latitude) and there are a few sea grids to its west. Most of the wave energy that may propagate out or into the area under study is only across the southern boundary. However, both the southern and western boundaries of the grid system are extended up to 10°S and 40°E respectively to take care of advection. The sea grids and the open sea boundary grids are indicated with plus (+) and cross (x) symbols respectively. The grids which are indicated with symbols other than "+" and "x" (plus with circle around, hollow plus, and stars) also represent open sea grids. There are 915 open sea grids out of which 570 grids belong to the Arabian Sea and the rest 345 belong to the Bay of Bengal. The total number of grids between 40° and 100°E, and 10°S and 25°N is 1540 as there are 625 additional open sea boundary grids considered outside the regional grid system.

IV.2.2 Input and output specifications

The input data which are supplied to the wave model are the estimated mean climatic year of winds and the mean monthly surface currents as discussed in Chapter-III. Fig.3A-C and 5A-C show the mean monthly wind and surface current fields only for the region between 0° and 25°N latitudes and 50° and 100°E longitudes, data are also available for the open sea boundary grids shown in Fig.9. The mean monthly surface current data are supplied to the wave model at each grid point for all the model grids only once for a representative month. However, the estimated mean climatic year of winds are provided at each input time step for all the grid points of the regional grid system but the open sea boundary grids are provided with only the sixty-year mean monthly values (H&L, 1911-70).
Fig. 9  Model grid system for Indian Seas.
All the gridded outputs of the model as given in Chapter-II are stored at the end of each input time step while the spectral outputs are stored only for selected grids. The central grids of each \(5^\circ \times 5^\circ\) square boxes in the regional grid system are indicated in Fig.9 with the plus symbols (+) enclosed in a circle. These grids are the open sea spectral output grids. Spectral outputs are also stored for all the sea grids along the west and east coasts of India (shown with hollow plus symbols and stars respectively). There are a total of 90 spectral output grids, 35 in the open sea, 28 along the west coast, and 27 along the east coast of India (Fig.9).

IV.3 WAVE MODEL EXECUTION

The present simulation experiment is carried out for deep waters with current refraction. The main idea being the establishment of the climatic wave fields in terms of monthly and seasonal distributions, the mean monthly surface currents are considered as inputs which do not change during model execution for a given month. Similarly, mean monthly winds are used as inputs for the open sea boundary grids to cater for wave propagation across the open sea boundaries. It may be noted that for the above wind inputs, waves propagating into the regional grid system will be able to attain fully developed condition within the open sea boundary region which extends for about 1000 km bordering the southern and the western boundaries. These are important aspects essentially required in the gross specification of associated problems while dealing with the simulation over a regional grid system from a climatic point of view. However, the above boundary conditions assumed in the present study do not appear to be limiting factors for simulation of wave climate based on mean climatic year of winds.

The simulation experiment is supposed to be carried out for the full climatic year of winds by executing the model for the inputs covering the twelve calendar months of the year or 365 days. However, computer time can be saved significantly by reducing the duration of wind input appropriately. In doing so, care has been taken to achieve the desired level of accuracy for the simulated outputs. Instead of a 31 days model run, say, for the month of January, the model is executed only for 72 hours of wind input. This is done by reducing the time axis from 31 days to 72 hours keeping the wind inputs the same. This means that the winds that are shown in Fig.8A for one particular grid in the month of January are
considered as the winds that have varied for 72 hours duration, with each wind stick representing the mean over 30 minutes.

A three-days model run representing a month is found to be very appropriate in this simulation experiment which reduces computation times by a factor of ten. First of all, the estimated mean climatic year of winds which are to be used as inputs to the wave model will allow the waves to grow and decay in four phases so that it can satisfy the most general patterns of wind and wave variabilities often encountered in the field. During the first 18 hours, with the increase of wind speed, waves will grow from either zero sea-state (cold start) or the equivalent of the initial wind field. The waves will start to decay during the second phase as the winds gradually decrease for the next 18 hours. Towards the end of the decay phase, the winds again increase gradually for the next 18 hours (Phase-III) resulting in further growth of waves. During the last 18 hours, waves will again decay gradually with the withdrawal of wind. These are the four stages through which growth and decay of waves have been taken care of in this study. It may be noted that the growth of waves during the simulation continues for the period of 36 hours in two phases. Therefore, even for a wind speed of 20 m/s the waves will be able to attain the fully developed stage within a period of 18 hours since fetch is not a limiting factor. Similarly, the swell waves of 9 to 25s period either in the Arabian Sea or Bay of Bengal can propagate from one end of the of the regional grid system to the other in 72 hours. Moreover, a wave of 5s period can also propagate over 2000 km. Hence, a minimum of 72 hours model run representing a month does also satisfy the propagation of waves from the other generating areas within the Arabian Sea and Bay of Bengal.

Model execution is carried out for 72 hours of wind input at steps of 6 hours (total 12 model runs) for each of the twelve calendar months. The initial wave field was set to the fully developed sea following Phillip's spectrum. Normally, the initial winds are of low magnitudes. Therefore, the parameters of the wave spectrum are chosen accordingly to compute initial wave energy. The wind input, source integration, and propagation (spherical co-ordinates) time steps are set to 1800, 600, and 1800s respectively. The output time step for the integrated wave parameters for total sea and swell are set as 1800s. The spectra of total sea and swell were stored for every 3 hours. All the user inputs are given in Appendix-D (Input Files: *.DAT). Since these are self explanatory, further discussions on the same are avoided here.
Fig. 10 shows the evolution of the simulated wave spectrum for 72 hour of model run for one particular grid during the month of July. It is just an example and it is quite interesting to note that the spectra gradually grow for the initial 18 hours and decay for the next 18 hours. The same sequence is followed for the subsequent 36 hours. The peak of the spectrum gradually becomes sharper and the energy slowly shifts to the lower frequencies. During the decrease in winds, a secondary peak develops at the high frequency region although it is not very significant for this representative grid. By and large, Fig.10 reveals that the simulation results are in close agreement with the input winds specified to the wave model as discussed in Chapter-III.

IV.4 COMPILATION OF MODEL OUTPUTS

All the integrated wave parameters (Chapter-II) namely the significant wave height, mean wave direction, mean wave frequency, friction wind speed, friction wind direction, peak wave frequency, sea-state dependent drag coefficient, normalized wave stress, swell wave height, mean swell direction, mean sea direction, and mean swell frequency are stored for all the grids of the regional grid system for every 30 minutes interval. Thus there would be 144 output fields in a month. A complete analysis of all these parameters would not be practical in this study. Therefore, out of the twelve output parameters, only six of them namely significant wave height, significant wave period (inverse of peak wave frequency), windsea direction (mean sea direction), swell wave height, swell wave period (inverse of mean swell frequency), and swell direction (mean swell direction) are compiled and the monthly mean fields are estimated. Moreover, seasonal mean fields are obtained only for the significant parameters. The bivariate and cumulative distributions of significant wave height and period are also computed for both the rough weather (May-September) and fair weather (October-April) seasons in the Arabian Sea and Bay of Bengal. Lastly, the average wave spectra for a selected grid in the Arabian Sea are computed for the rough and fair weather seasons. Analysis of the model outputs will be presented in Chapter-VI.
Fig. 10  Evolution of wave spectrum for 72 hours of model run using estimated mean climatic wind fields for the month of July.