CHAPTER 1

INTRODUCTION
Chapter 1: Introduction

1.1 Preamble

Since the historic past, humans realize water as an essential commodity for their survival. About 71% of earth’s surface is covered by oceans and seas, which contain about 97% of water (mainly salt or saline water) on the earth. Historically, 4 oceans are considered on the earth, namely Arctic Ocean, Atlantic Ocean, Indian Ocean and Pacific Ocean. (Ref.: http://water.usgs.gov/edu/earthhowmuch.html and http://www.noaa.gov/ocean.html)

Knowledge of sea waves, sea water levels and their variations is essential for a variety of maritime activities; including planning, operation, and maintenance, safety and efficiency of activities such as construction of jetties and harbors in the coastal and offshore locations, grounding of ships, navigation of the vessels with deep draft, installation of platforms, loading and unloading in the high tide zones, etc. For the safety of the vessels and for the analysis of dynamic action of the forces exerted by waves on the marine (coastal and offshore) structures such as seawalls, jetties, piles, oil drilling platforms/ rigs, etc.; accurate peak wave height predictions are required.

Sea level fluctuations causing large variations in the waterfront distances in low lying areas, small islands, and the lands with gentle slope are critical for the safety of infrastructure (properties) and human lives. Working and safety of ocean based nonconventional energy power plants also depends on such fluctuations. A significant increase in the hydro-metrological events such as rise of the sea water levels, frequency of occurrence of cyclones and their severity is experienced in the recent past all over the globe. This highlights reliable and accurate prediction of sea water levels as one of the major challenges for the researchers. Variations of the sea levels are due to complex processes involving a combination of forces of attraction of the Moon and the Sun on the Earth, bathymetric characteristics as well as meteorological parameters like wind, atmospheric pressure, air temperature, water temperature, ocean currents, etc.

The above discussed factors underline the necessity and significance of predicting oceanic parameters such as wave heights and sea water levels as accurately as possible, especially the peaks.
1.2 Oceanic Parameters and their Measurement

Generation, growth and propagation of ocean waves are complex phenomena and their exact nature still eludes the researchers. Continuous changes in the temperature over the earth produce changes in the atmospheric pressure all over it. The wind produced by these gradients blows with different energies at different places and at different times. Relatively higher energies possessed by the wind are transferred to the calm water through the components of pressure force acting perpendicular (normal component) and tangential (shear component) to the ocean surface.

In the past, many investigators attempted to explain the process of wind energy transfer through factors such as pressure gradient across the wake, resonance of turbulent eddies in the atmosphere, shear forces based on the logarithmic wind profile, resonant interactions between various wave components, etc. The consequent formation and growth of surface waves is influenced by the wind pressure, its speed, fetch (the distance over which the wind, blowing over the sea surface, remains the same), wind duration (the time for which the storm prevails), and the depth of water at the particular site or station. The wind-generated waves in oceans are divided into three categories for convenience as sea, swell, and surf. The term sea refers to waves under the direct influence of generating winds, swell means waves that have left the generating area and are subject to decay in regions of weak winds or calms. The breakers resulting from the waves moving from deep to shallow water comprise surf.

In the initial stages of wave generation, high frequency and short length waves are formed. These break and supply energies to the lower frequency waves due to instability. This process continues till a 'fully developed sea' is formed, where all wave component reach a saturation stage (Brebbia and Walker, 1979). As the wave height and period increases, waves start moving faster and faster. The transfer of wind energy ceases and the growth of waves stop as soon as the wave speed matches speed of the generating wind.

The physics behind surface waves can be simplified as: wind force pushes the water, creates disturbance in the form of waves and tries to increase the wave height if it flows over a sufficient period of time; while the gravitational pull tries
to subside it. Therefore time series of wind velocity is an essential model input for wave height predictions.

Significant Wave Height \((H_s)\) is the most important oceanic parameter. The concept and definition of significant wave height was an outcome of the work by a genius oceanographer Walter Munk during World War-II (Sverdrup and Munk, 1947). In physical oceanography, it is determined directly from a wave record in a number of ways, but the most commonly used approach in the wave-by-wave analysis is to rank the waves in the wave record and choosing the highest one-third waves. The average of the chosen (highest one-third) waves gives the significant wave height as

\[
H_s = \frac{1}{3} \sum_{i=1}^{N} H_i
\]

Huge waves are sometimes produced in the seas due to extreme events such as hurricanes (also known as typhoons or cyclones) under peculiar meteorological conditions. Possibly the largest known (measured or recorded) significant wave has a magnitude of about 17 m in the Gulf of Mexico due to hurricane Catarina in the year 2004. It should be noted that maximum wave height is about two times the significant wave height.

Concept of all types of waves based on the wave period is shown in Fig.1.1, including the primary cause (disturbing forces) of waves.

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Fig. 1.1 Types of Ocean waves: Based on Time (Wave) Periods
(Ref.: http://tidesandcurrents.noaa.gov/levelhow.html)
Measurement of wave heights is done using the moored wave rider or drifting buoys, the measuring principle being the relationship between the wave height and vertical acceleration and/or vertical displacement of the buoy that floats on the water surface (wave). The chief agency that collects the data for Indian stations is National Institute of Ocean Technology (NIOT), an autonomous body under the Ministry of Earth Sciences, Government of India. Data measured every three hours at the Indian stations are available. For the USA, the chief agency is National Data Buoy Center (NDBC), Center of Excellence in Marine Technology of the National Oceanic and Atmospheric Administration (NOAA), United States Department of Commerce. Data measured at the NDBC buoys along the USA coastline is available free of cost on their website (www.ndbc.noaa.gov). Fig. 1.2 shows photographs of some buoys.

![Photographs of some buoys](image)

(a)The NIOT (DISCUS) Buoys

(a)The NDBC (NOMAD and DISCUS) Buoys

**Fig. 1.2 Types of NIOT and NDBC Buoys**

Tides are long period waves (e.g. 12 h 25 min for semidiurnal tide and 24 h 50 min for diurnal tide), while the common ocean waves have short periods ranging from about 1 s to 30 s. Sea levels are measured by the tide gauges located at the tidal stations. The tidal and meteorological data is available free of cost on the
NOAA website (http://tidesandcurrents.noaa.gov) for the tidal stations along the USA coastline owned and maintained by the NDBC. Data related to oceanic wave heights, harmonic tides, sea water levels and meteorological parameters measured every hour are available. Fig. 1.3 shows a typical tidal station.

![Typical Tidal Station](image)

**Fig. 1.3 A Typical Tidal Station**

Main three types of tides (viz. Diurnal, Semidiurnal and Mixed tides) are shown in Fig.1.4

![Types of Tides](image)

**Fig. 1.4 Types of Tides**
Tides are produced by gravitational attraction of the Sun and the Moon on the Earth. The latter ones are wind generated waves, also called as gravity waves in which the disturbing force on the ocean surface is the wind shear while the restoring force is the Earth’s gravitational attraction. The water level difference may be small, moderate or huge depending on many parameters. The tides on Earth are strongly influenced by other factors apart from the astronomical factors such as meteorological parameters like winds, barometric pressure fluctuations, as well as by the sizes, boundaries, and depths of ocean basins and inlets, etc.

1.3 Types of Predictions

Based on the time at which the value of a parameter or parameters is determined by model, prediction of oceanic parameters can be of 3 types. First, prediction of a parameter is made at the same (present or current) time, is termed as estimation. Second is hindcasting – the prediction of historic values of parameters (values from the past). Third type is forecasting, which means prediction of a parameter at some time in the future i.e. few steps ahead of the present time.

Hindcasting is useful for filling the data gaps or for determining the missing data, while forecasting is required to get the futuristic values for planning, designing and management activities. The utility of the accurate forecast of parameters with sufficient lead time are evident by its use by the ocean engineers, designers, administrators, fishermen, military officials, etc. for their efficient and effective use in their planning, duties and activities.

Modelling may be categorized based on the variables used as the model inputs and the model output. Temporal modelling employs time series of only one parameter (univariate time series) or many parameters (multivariate time series) of the present and the past times as model inputs to obtain an output. In cause-effect modelling, the output parameter is predicted using causal parameters as model inputs. Hence cause-effect modelling may also be of univariate or multivariate temporal modelling. Another category is spatial modelling, in which the input parameters at one or more stations are utilized to predict output parameter at other station or stations.
1.4 Traditional Prediction Techniques

Most of the theoretical work necessary for understanding and numerical descriptions of ocean waves was laid in the 1950s and 1960s. It was realized for forecasting purpose that the random nature of the sea state could be best described by a spectral decomposition in which the wave energies were attributed to as many wave trains as necessary, each having a specific direction and period. This approach allowed combined forecasts of wind seas and swells. The first numerical model based on the spectral decomposition of the sea state was probably operated by the French Weather Service focused on the North Atlantic in 1956. The first operational, hemispheric wave model – the Spectral Wave Ocean Model (SWOM) was developed in the 1970s at the Fleet Numerical Oceanography Center. Regression and regression-based statistical models such as ARMA (Auto-Regressive Moving Average), ARIMA (Auto-Regressive Integrated Moving Average) models of Box and Jenkins (1976) have also been tried out for wave parameter predictions.

First generation wave models did not consider nonlinear wave interactions. The second generation models developed in the early 1980s parameterized these interactions. The third generation wave models rely primarily on the energy balance equation, which uses a combination of wind input, wave dissipation and nonlinear wave interactions and explicitly represent all the physics relevant for the development of the sea state in two dimensions. The WAve Modeling project (WAM) led to the refinement of modern wave modeling techniques during the decade 1984-1994 (The WAMDI Group, 1988). WaveWatch III® (Tolman 1990, 1991a 1991b, 1992, and 1996) is a third generation wave model developed at NOAA/NCEP (National Oceanic and Atmospheric Administration/ National Centers for Environmental Prediction of National Weather Service, USA) in the spirit of the WAM model (WAMDIG 1988, Komen et al. 1994). It is an advanced version of the model WaveWatch developed at Delft University of Technology and WaveWatch II developed at NASA (National Aeronautics and Space Administration, USA), Goddard Space Flight Center (e.g., Tolman 1992) which have been used for forecasts over lead times of 3–72 h, over large spatial domains. SWAN (Simulating WAves Nearshore), a third-generation wave model developed at Delft University of Technology, computes random, short-crested wind-
generated waves in coastal regions and inland waters (Booij et al., 1999). In 2D cases, the computations of SWAN are based on approximate equations, which can only be applied to open coast (unlimited supply of water from outside the domain, e.g. nearshore coasts and estuaries) in contrast to closed basin, e.g. lakes, where this option should not be used. SWAN is less efficient on oceanic scales than WaveWatch III and probably also less efficient than WAM. (Ref.: http://www.swan.tudelft.nl). Need of huge exogenous data including bathymetry and other boundary values, large number of computations requiring considerable time for modelling and predictions on large spatial domains are other possible drawbacks of these techniques (Londhe and Panchang, 2006; Kambekar and Deo, 2010, 2012).

With reference to the sea water levels, predictions are traditionally carried out by using harmonics but it is noticed that the predicted and measured water levels. It is reported by Cox et al. (2002), Makarynska and Makarynskyy (2008), Londhe (2011) and others that such an anomaly is caused by meteorological parameters such as winds.

1.5 Need of the Alternate Techniques
Conventional modelling techniques have been physics-based or numerical analysis based in the field of ocean engineering. But research is an ongoing continuous process involving innovations and improvements in the existing systems of various types including the data measurement techniques, tools and techniques of modelling the data and so on.

Often smaller lengths of data are available due to several reasons such as instrument malfunction or damage caused by extreme meteorological conditions such as hurricanes, hardware and software problems, tampering or theft by antisocial elements, paucity of funds, etc. Satisfactory predictions of the oceanic, hydrological and hydraulic parameters using fewer parameters and smaller data lengths of the available quality are perhaps the ideal conditions for employing the alternate techniques.

Additionally, for complex natural phenomena which involve interactions and processes between large numbers of variables, modelling the available data for station specific predictions (i.e. on much smaller spatial scale) with desired
accuracy is a challenging task for the researchers. This has given a scope for further exploring the modelling techniques other than the physics-based modelling.

In the alternate modelling strategies, data-based or data-driven techniques which are aimed at extracting the knowledge hidden in the data are more frequently tried out by researchers, utilizing the latest available computing facilities for faster model development with acceptable accuracy. Soft computing techniques such as Artificial Neural Network (ANN), Genetic Programming (GP) and many others are the choice of many researchers in the recent past.

1.6 Motivation
A significant increase in the number of extreme meteorological events such as hurricanes as well as their severity is witnessed in the recent times. The 2010 Atlantic hurricane season was the third most active season on record, tying with the 2011, and 2012 Atlantic hurricane seasons. There were as many as four Category-4, one Category-3, four Category-2 and three Category-1 Hurricanes on ‘Saffir-Simpson Hurricane Scale’ (Readers are referred to Appendix C for more explanation), apart from 10 tropical storms in the 2010 Atlantic hurricane season.

In the Indian context during past five years, hurricanes Phyan (2009), Giri, Laila and Jal (2010), Nilam (2012), Helen, Madi, Lehar and Phailin (2013), Hudhud and Nilofar (2014) can be quoted. Hurricanes are formed on the ocean surface due to difference in pressure, temperature, and moisture in the atmospheric air; create high velocity winds that produce huge waves and increase in the sea water levels. This poses threat to the lives, properties and infrastructure at the locations near the coastlines.

India has a long coastline of 8118 km with the Indian Ocean on the South, the Bay of Bengal on the East and the Arabian Sea on the West. There are as many as 133 ports along the west coast, 54 along the east coast in the 9 states adjoining the coasts, two Island Territories and two Union Territories (Ref.: Website of Indian Ports Association, http://ipa.nic.in/state_ports.htm).

The population of Coastal States and Union Territories is more than 560 million while that of total 73 Coastal Districts is 171 million (Ref.: http://iomenvis.nic.in, the website of Center for Coastal Zone Management and
Coastal Shelter Belt, hosted by Institute of Ocean Management, Anna University Chennai, sponsored by the Ministry of Environment, Forests & Climate Change, Government of India). As per the Indian Livestock Census 2003, 14.49 million people were engaged in various fisheries related activities. About 25% of the fishermen are engaged in marine fisheries. (Ref.: http://www.cmfri.org.in) One of the most significant characteristics of Indian fisheries sector is its small scale nature and the poor fishermen should be warned and informed about the oceanic conditions sufficiently in advance, say before going in to the sea with their boats or ships. (Ref.: Indian Census Report of the working group on Development and Management of Fisheries and Aquaculture: 12th Five Year Plan 2012-2017; January 2012 by the Planning Commission, Government of India. Website: http://planningcommission.nic.in). Fig. 1.5 shows map of Indian coastal states.

![Fig.1.5 Indian Coastline, Coastal States and Union Territories](image-url)
The poor fishermen would be greatly helped by as accurate forecasts of the oceanic parameters as possible. Also predictions of the oceanic parameters would be very important and useful for Indian Navy for planning and execution of their maritime strategies and operations.

The above stated facts highlight the need of more ocean studies in general and wave heights as well as the sea water levels in particular as important issues for our country in the near future.

Possible drawbacks and limitations of the traditional modelling techniques underline the need for employing the alternate techniques such as artificial neural network and genetic programming (discussed in details in chapters 2 and 3) as well as the Indian scenario described in the preceding paragraphs is the motivation and direction for the present work.

1.7 Research Objectives

Research objectives finalized for this work are listed below.

1. To review existing work on the Soft Computing Techniques of Artificial Neural Network (ANN) and Genetic Programming (GP).
2. To develop Wave forecast model using ANN for at least 48 hours ahead forecasts.
3. To develop Wave forecast model using GP for at least 48 hours ahead forecasts.
4. To develop Water Level forecast model using ANN for at least 48 hours ahead forecasts.
5. To develop Water Level forecast model using GP for at least 48 hours ahead forecasts.
6. To test the developed models in real-time mode.
7. To develop Graphical User Interface (GUI) for web-based forecast system.

1.8 Organization of Thesis

The thesis is organized in six chapters. An overview of the soft computing techniques in general and Artificial Neural Networks (ANNs) and Genetic Programming (GP) in particular is given in chapter 2. Literature review and findings are discussed in chapter 3. Chapter 4 describes the methodology for development of the ANN and GP models for prediction of Significant Wave
Heights (Hs) and the model results with their assessment. Modelling strategy and model development for prediction of Sea Water Levels (SWLs) are explained in chapter 5 along with the model results and their assessment. Graphical User Interface (GUI) developed and real time testing of GUI for obtaining wave height and sea water level forecasts with a lead time of 1-day (24 hours) at one station each are given in chapter 6. Summarized conclusions and scope for the future research are stated in chapter 7.

References are listed after the last chapter. Sample outputs of the ANN models (weight and bias matrices) and GP models (C++ Code generated by the model) are presented in Appendices A and B. An outline of Saffir-Simpson Hurricane wind-scale is given in Appendix C.
CHAPTER 2
SOFT COMPUTING TECHNIQUES EMPLOYED