Investigation and Prediction of Caspian Sea Significant Wave Height Using Chaos Theory

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ABSTRACT

Significant wave height is mean of one third of the largest wave heights in a certain marine condition. Investigation and prediction of the significant wave height have been recently considered in marine system analysis including loadings over marine structures and sediment transport for designing, operation and marine researches. The capability of chaos theory in engineering particularly marine engineering has been gaining considerable interest in recent times. In this research, dynamic characteristics of the significant wave height time series in Caspian Sea at Anzali entrance are considered and the prediction has been performed using ideas gained from chaos theory. To reconstruct phase space, the time delay and embedding dimension are needed and for this purpose, autocorrelation function and algorithm of false nearest neighbors are used. Correlation dimension method is applied for investigating chaotic behavior of the significant wave height, which is the resultant of correlation dimensions, expresses chaotic behavior in the time series. Local prediction algorithm is used for time series prediction and results illustrate good and acceptable accuracy of chaos theory in quantitative prediction of seas significant wave height.

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1- INTRODUCTION

Sea level determines the hydrological regime of some coastal rivers and groundwater table depth in low-lying coastal areas, impacts the planning and construction of coastal and offshore structures, as well as the implementation of ocean-based alternative energy technologies. Understanding the nature of the underlying dynamics of sea level is of fundamental importance for several reasons. Forecasting the behaviour of future sea level heights in the near-shore environment is necessary for protection of coastal and low-lying regions' residents, as well for monitoring and prediction of changes in fishery and marine ecosystems. Different methods including time series analysis, artificial neural networks, fuzzy logic, Neuro fuzzy, genetic programming and, more recently, chaos theory have been used for water level prediction [1-4].

The apparently irregular and unpredictable behaviour of the sea level can be investigated in the framework of stochastic dynamics due to random variations. However chaotic processes are, a special class of deterministic dynamical systems is able to produce similar irregular variation in the absence of randomness. Chaotic dynamics evolve on a complicated structure in the phase space, called the attractor. Small distances between two close states increase exponentially on the attractor. Such a feature is a fingerprint typical of chaotic processes only, and provides a robust method of discrimination from a stochastic dynamics [5,6].

During the past two decades, chaos theory showed its applicability in solving a wide class of problems in many areas of natural sciences and, in particular, of civil engineering and water-related applications. These studies are devoted to model and forecast natural phenomena and require, in each case, a deeper comprehension of the underlying dynamics.

2- METHODOLOGY

In this research, dynamic characteristics of the significant wave height time series in the Caspian Sea at Anzali entrance are considered and the prediction has been performed using ideas gained from chaos theory. To reconstruct phase space, the time delay and embedding dimension are needed and for this purpose, the autocorrelation function and algorithm of false nearest neighbors are used. The correlation dimension method is applied for investigating the chaotic behavior of the significant wave height, which is the resultant of correlation dimensions, expresses chaotic behavior in the time series. The local prediction algorithm is used for time series prediction and results illustrate good and acceptable accuracy of the chaos theory in quantitative prediction of the seas significant wave height. Statistical properties of significant wave height values are available in Table.1.

TABLE 1
PROBABILISTIC PROPERTIES OF SIGNIFICANT WAVE HEIGHT OF CASPIAN SEA

Statistical Characteristics	significant wave height
No. of records	8773
Mean	0.68
Standard deviation	0.52
Max.	4.12
Min.	0.0001
Skewness	1.98
Kurtosis	5.56

The first step to reconstruct the phase-space is estimation of parameters of delay time (τ) and embedding dimension (*m*). Significant wave height's series of one year is divided into two portions. The first eleven months are utilized for creation of phase-space (estimating delay time, embedding dimension) and significant wave heights of the last month are devoted to the estimation process.

Delay time is calculated by the average mutual information, and the first relative minimum is considered as the most proper delay time.

The second parameter of the phase-space is the embedding dimension, which has been determined by the False Nearest Neighbor (FNN) method

The correlation dimension method is used for assessment of chaos and fractal geometry determination. The correlation function corresponding to delay time and embedding dimension is calculated and. In order to determine the correlation dimension and chaos analysis of the data, values of the curves' slopes by the minimum square method in the interval of -1.2 to -0.2 from log(r) and also for all values of r (on the y axis) in the interval of -4.5 to -0.2 from logC(r) is calculated. the chosen qualified correlation dimension for significant wave heights is D2=2.63. Saturation of the correlation dimension is also an indication of chaos in changes of significant wave height of the Caspian Sea [7,8].

For the forecasting process, the local forecasting algorithm has been used and all stages of calculations for the last month have been performed as the test period. The correlation index and root mean square of errors for recorded and calculated values of horary significant wave height for the last month are 0.9909 and 0.0335, respectively. Diagrams of recorded and calculated values are available in Figs. 1. As it is obvious in Fig. 1, recorded and calculated values of wave heights are so close to each other (except in the maximums), that this closeness is a proof for accuracy and qualification of this theory in forecasting and applicability of calculated parameters.
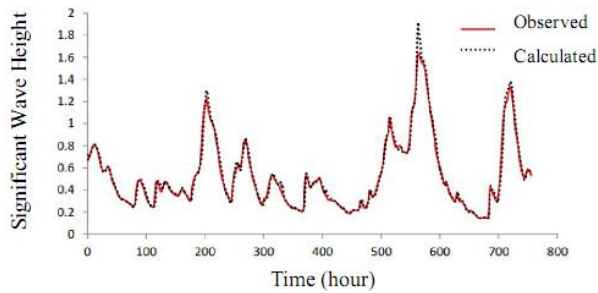
Fig. 1: Comparison between calculated and observed horary values of significant wave height

3- CONCLUSION

The presented paper assesses the applicability of chaos theory for modeling horary significant wave heights in the entrance zone of Anzali Port for a statistical year.

Utilizing the auto correlation function and false nearest neighbor, values of delay time $\tau = 63$ and embedding dimension $m = 17$ are achieved for reconstruction of phase-space for analyzing dynamic behavior of hourly wave height. Results obtained by the correlation dimension were used for distinguishing between chaotic and stochastic behavior. Performed local forecasting, except in maximums, has revealed reliable results. Also, in points of maximums, calculated values are more than the observed ones and this can be considered as a safety margin in the results. This matter, i.e. applicability and reliability of chaos theory in studying fluctuations of seas water level has also been proven in works done by Zaldivar et al.(1998) [8].

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