Study of Wind and Wave Patterns by Empirical Orthogonal Functions in South Caspian Sea using Quickscat (Ascat) Satellite and Synoptic Stations Data

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Abstract: Having knowledge of wind wave and followed by possible changes in next time especially significant wave height is required in all land and offshore engineering projects and port design engineering and design of coastal structures which is resistant to these changes and to estimate sediment transport and amount of erosion. Estimating the wave height that is too close to the accurate amount could prevent non-economic plan or destruction of structures. In this study, the methods of EOF which is one of the new methods in the analysis of spatial data and time were used to analyze wind data preferentially followed by the wave for the south Caspian Sea. These data were analyzed using MATLAB programming and spatial mode and principal component values are calculated. These interpolated data with high accuracy have been calculated which corresponds to a three-year period with an interval of one day. Therefore, among 14411 spread terrestrial data and three hours satellite data, about 9111 time steps with the same scale have been studied. The most dominant data rate mode on a 78.45% is for EOF1. For wave height, five basic dominant mode were formed and its most dominant amount for EOF1 was obtained 92.43%. To predict wave height data, with time output for mentioned data, for 5, 15, 30 and 45 days forecasts have been achieved. The number of selected points in the South Caspian Sea was 22 cases which considered four spots for around the Babolsar, Ramsar, Anzali and Astara cities and six points was considered as points of control. Of the four regions, wave field data prediction at Ramsar region among all four stations of the region were most accurate and more favorable results than other regions. This is due to better data aggregation from ground stations and regular data registration and also better satellite coverage and recording of data in this area as well as better interpolation of these regular data.
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1. Introduction

Having knowledge of wind wave and followed by possible changes in next time especially significant wave height is required in all land and offshore engineering projects and port design engineering and design of coastal structures which is resistant to these changes and to estimate sediment transport and amount of erosion. Estimating the wave height that is too close to the accurate amount could prevent non-economic plan or destruction of structures. Using empirical orthogonal functions and wind pattern in the Caspian Sea, wave pattern were evaluated and purposes such as determination of influencing factors on wind patterns in the South Caspian Sea, spatial and time changes of wind patterns, determination the pattern of winds and waves in the South Caspian were considered. This study is based on empirical orthogonal functions and the integration of two kinds of data in order to enhance data accuracy, for the first time carried out in the south Caspian Sea. This wind pattern after controlling quality, can be a major source of modeling used for pre-selection and wave forecasting. Also, obtaining temporal and spatial variations of wind patterns have a vital role in precise implementation of waves. Caspian Sea are mainly divided into three northern, central and southern sections (Fig. 1). The northern part of the Caspian Sea has the lowest depth which is 5 meters by average and a maximum depth of it is 20 meters and contains 27 percent of the Caspian Sea area and 0.6 percent of total volume the Caspian Sea.

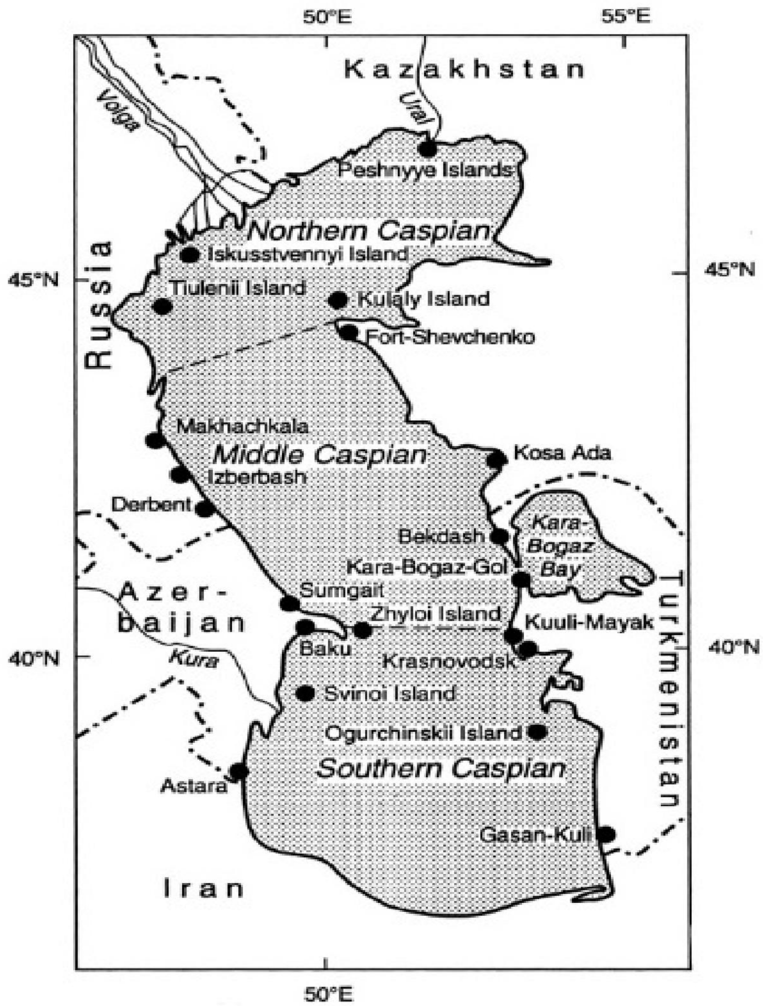

Figure 1: Division of the Caspian Sea to the north, middle and south (Rodionov, 1994)

One of the most important economic characteristics of the Caspian Sea is huge oil and gas resources. In addition, Caspian Sea is one of the world's suitable water environment for living and growth of the world's caviar and 90 percent of the world's caviar obtain from Caspian Sea. The Caspian Sea, due to the impact of climate of its neighboring regions and having islands, lagoons, bays and different estuaries become a unique habitat and has great ecological importance. In recent decades, the pollution of the Caspian Sea has become one of the most serious problems of this vast sea, so that with the arrival of thousands of tons of pollutants annually from the Caspian Sea littoral states, especially pollution from oil exploration and extraction operations, Caspian Sea became polluted and many kind of species are in serious danger.

Advantages and disadvantages of orthogonal functions

Advantages:

- Achieving an accurate way to explain the dominant mode of spatial data;
- Providing a summary of the data with maintain total data conditions;
- Achieving and display an indication of the time series shows the highest available diversity;
- EOF patterns and time series are used as independent linear in equations;
- A combination of satellite and synoptic data with EOF can be used as a single set of data;
- Due to linear properties of EOF patterns, gap of terrestrial and satellite data covered by each other.

Disadvantages:

- Sensitive restriction in selection of spatial location and time period;

- EOF patterns may be noisy, which must be checked;
- EOF cannot simultaneously examine the association between the dominant modes;
- Selected eigenvalues should not be closed to each other and degree of freedom of data in time series should not be too small. (Making Problem).

Literature review:

Zoning and study of geographical precipitation pattern has special importance because of its wide relationship with various sectors of farming activity in the region. Analysis of empirical orthogonal functions which are known as a principal component analysis, is one of the most efficient methods of extracting information from large data sets, respectively. The main advantage of analysis of empirical orthogonal functions is providing compression, spatial and temporal variability of the data series in terms of orthogonal functions or statistical methods.

According to this research, first to eighth component of EOF, which explained a total of 90.74 percent of the total variance of original data, is considered as the main components of EOF and precipitation of them were used for delimiting areas (Samadi, 2010).

Esmaeili (2011) was used OSW model in Chabahar to study parameters of sea waves. In his study, wind waves in the maritime zone of Chabahar were calculated using OSW numerical modeling and data were analyzed.

Taleghani (2011) had investigated the implementation of the local wave climate in Amir Abad Port using Mike21-sw and semi-empirical methods. In this study, wave characteristics in the waters off the coast of AmirAbad were calculated using semi-SMB, SPM, CEM, JONSWAP and then compared with the data of Amirabad buoy and Neka buoys.

Khoshravan (2010) in a thesis research work tried to determine the range of breaking wave using wave model and the Caspian Sea wave (CASWAC) and sedimentary morphodynamic features of Anzali and Amirabad coasts. In this research, one of the changes in the wave e.g. breaking wave were studied and determination the range of breaking of waves in Anzali and Amirabad e area, located on the southern shores of the Caspian Sea is discussed.

Other methods like SMB in the Caspian Sea and around Babolsar were done and with this method, wave height in Babolsar area were evaluated (Haj Babaei, 2003).

Hosseini (2010) conducted a research to evaluate the spatial-temporal pattern of the Caspian Sea surface temperature using empirical orthogonal functions. In this study, it was considered to determine spatial-temporal pattern of surface temperature of the Caspian Sea and influencing factors on it to be determined. For this purpose water level data of the Caspian Sea were examined over a period of 19 years using empirical orthogonal functions.

The other group, using empirical orthogonal functions tried to analyze the data of Caspian Sea's surface temperatures nad by help of Fourier analysis, sea surface temperatures predicted for the coming year (Torabi Azad, 2009).

Lorenz using statistical prediction methods and also using empirical orthogonal functions have predicted the pressure on the sea level (Lorenz, 1956).

Takashi (1981) using empirical orthogonal functions to predict the cycles of tropical storms. He collected 25-year period of data for the North-West Pacific and evaluate all of them. Results indicate empirical orthogonal functions prediction with error less than one. (Takashi, 1981).

Ebruchi et al. (2002) evaluated Quicksat vectors which picked up by satellites using data buoys in the Pacific Ocean and the Atlantic Ocean and concluded that wind speed and wind direction of Quickscat buoy is in line with observations in that area. Also, accuracy of wind direction of Quickscat satellite, in the range of weak winds is less than medium and strong winds (Ebruchi et al., 2002).

In another study by Ardhuin, wind vectors picked up by Jason and Quickscat satellites and numerical models like ECMWF with the wind from the west of Mediterranean Sea were compared and came to the conclusion that Quickscat wind in west of the Mediterranean Sea is higher rather than wind is numerical method.

Material and Methods:

Analysis of empirical orthogonal functions is known as a way of principal component analysis and also is one of the most efficient methods of extracting information from large data sets, respectively. The main advantage of analysis of empirical orthogonal functions is providing compression, spatial and temporal variability of the data series in terms of orthogonal functions or statistical methods.

Since our prediction is based on time, so the uncertainty of our prediction in combination with nonlinear dynamics system will create a dynamic clutter, and noise should be removed. One of the major important issues in climate research is temporal and classified information. This information has been produced to be adapted with a variety of time and spatial conditions, the process of assimilation and output models of raw observations. So, several ways can be used, most notably are analysis of empirical orthogonal functions or EOF, analysis of temporal and spatial of principal oscillation pattern or POP and spatio-temporal Canonical Correlation Analysis or

CCA. In this study, empirical orthogonal functions was used.

Example of a time series can be seen in the following:

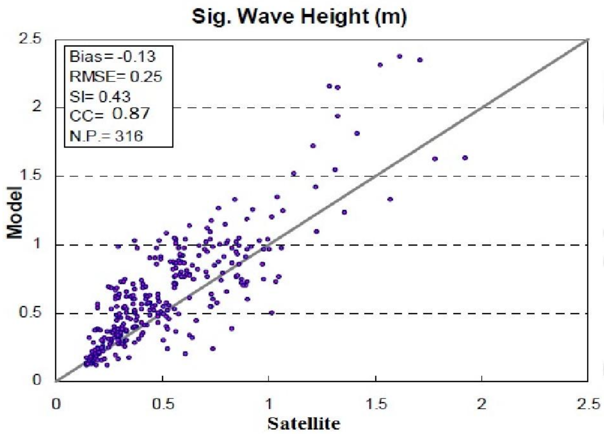

Fig. 2: An example of a time series model, the change in wave height and the distribution of data compared with satellite data on the two-month period of March and April 2013

Discussion:

Waves are created by transfer of energy from the wind into the sea. The rate of energy transfer depends on the wind speed and the distance that the water level in the interplay with the wind. Waves due to a mass of water that moved relative to mean sea level carry potential energy and due to water particle velocity carry kinetic energy. Stored energy would be lost through friction and turbulence and with an intensity that depends on the characteristics of waves and water depth. Big waves in deep water lose their energy very slowly, so waves systems are very complex and often originate from local winds and the storms that occurred days before and in long distance.

Wave specified by height, wavelength and period. Signal strength, usually expressed in terms of kilowatts per meter that represents the transfer intensity or cross energy in an imaginary line with one meter in length and is parallel to the wave front. Today, there are technologies to create energy from ocean wave, and more than 400 patents in this area has been registered. There are three main ways to use that create energy: truncated cone channel, general motion of ocean waves by a variety of mechanisms and the use of an oscillating water column [Yousefi].

Wave is one of the most important natural phenomena that occur on the surface of the seas and oceans. The waves under normal conditions has average height less than 2 meters. But in times of storm reached to 30 meters high which able to damage and severe damage to the ship, as well as coastal and offshore marine structures and the coastal line. Accordingly, generations of models predicting the properties of sea waves, which are provided and used for their calibration requires knowing the waves in each region. The understanding of sea waves in a geographic area requires having the field information and water level profile changes and weather conditions, speed and wind direction over the years (Ketabdari, M. J., 2006).

Spectral analysis using the Fourier transform is one of the practical tools used in wave's physics. Besides, Fourier spectrum explain the wave's energy at different frequencies. The below figure shows an example of the level of irregular wave surface.

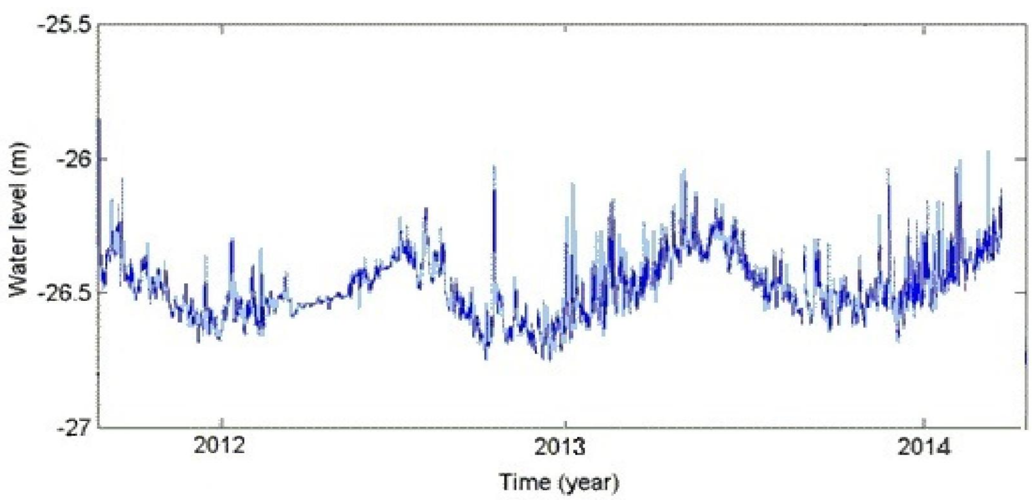

Figure 3: Wave registration in the south of the Caspian- Bandar Anzali region

In some cases, wind speed with a maximum value help researchers to calculate the speed of wind traveled distance or just the average speed achieved in a specified time interval. Likewise, based on figure 4, it is possible to calculate the ratio between wind speeds with desired averaging time.

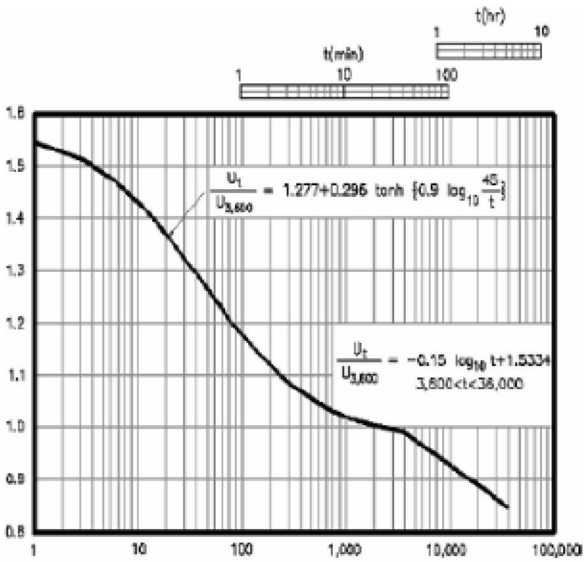

Figure 4: duration of the fastest wind that travels one mile distance (Edward, 1956)

Conclusion:

According to the final data which obtained by a combination of synoptic stations data and satellite data and thus covered temporal and spatial gap data, it is possible to interpolate these data with high accuracy which corresponds to a three-year period with an interval of one day, so among 14560 scattered terrestrial data and three hours satellite, about 9,000 steps were studied with the same time scale.

By obtaining wind field through the Mike software which previously described, separation and sorting data on wind speed and wind direction were studied.

According to the EOF analysis results for wind and wave fields' data and among all dominant modes of data about wind speed, 48 modes were chosen that amounts of EOF and Periodogram were evaluated. Then, they were predicted based on artificial intelligence algorithms, ANN coding, Fourier series and parallel ANN. Specification of each of them is as follows:

1. Out of 48 selected modes, the dominant mode for wind speed with a period of fifteen days is 78.45%.
2. To evaluate wave height, five basic modes of it were considered, which is equal to 92.43 percent of first dominant mode for EOF1.
3. In 2012, in May and July and especially in October, wind speed was more than the other months and its maximum value reached to 12 meters per second. The wind speed in January and June and August of 2013 and 2014 reached to peak of itself and this may be due to high temperatures and seasonal changes and in September the wind speed reaches to its minimum among these months. Some days the wind speed of 15 meters per second is in January. Since the wave field and the network of wave height has direct relationship with wind field, it is possible to have economic and scientific predictions based on this direct relationship and linear change between these two factors.
4. Prediction the wave field data in Ramsar in all four stations had more favorable results than other regions and this is due to better data collections of regular ground stations and data records, as well as better satellite coverage and recording of data in this area as well as better interpolation of regular data.
5. The results of wind field conversion to wave field with direct relationship provided more precise information to predict wave height. The standard deviation of about 0.1 obtained from comparison of wave field data shows that these high accuracy data can be used.
6. One of the advantages of this research is three-dimensional prediction of wave height. This means that the amount of data used in the project is enormous and neural network algorithm using MATLAB and Parallel ANN position PCA and the algorithm of wave heights is studied in three directions and that's why the network predicted collection point's waves after reconstruction is one of the dimensions of the coordinate system. This means that even height of the waves could be predicted. This feature can be useful for prediction of advance and retreat waves.
7. The results show that the correlation coefficients for the first five days to predict can be more acceptable rather than other days. The number of day's predictable increases, the standard deviation become higher. On the fifth day, about 90% of the wave height predicted.
8. Having more number of selected points for predicting the wave height led to better wave height, interpolation and regression of established networks prediction. In this case, the area covered by waves and elevation changes obtained, the more areas can be considered to predict. For example, it is done for Ramsar.

Suggestions:

1. The use of multi-year statistical data of wind field in evaluation and using empirical orthogonal functions;
2. Using continuous and regular data with low observational gap in short time intervals;
3. Using long period data for wind and wave fields to forecast data used in the Fourier series;
4. Comparison of this method with other wave height prediction methods;
5. Use of simultaneous satellite and field data to compare parallel and higher accuracy.

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