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Prediction of significant wave height using spatial function

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ABSTRACT

Determining the contribution of variables from stations surrounding a pivot station to variables at the pivot station is very important for many purposes. In this regard, a Regional Dependency Function (RDF) among the variables needs to be obtained. RDF can be used to estimate missing data, determine the location and optimum number of measurement stations (station network design), estimate the potential of a variable under consideration and calculate radius of influence. However, conventional geostatistical methods cannot be employed to achieve the above mentioned uses as they have a number of limitations. As a result, a new method called Slope Point Cumulative Semi-Variogram (SPCSV), was developed to obtain RDF and to address all the limitations of the conventional geostatistical methods. SPCSV was developed by using data from 22 wave measurement stations located off the west coast of the United States. The objective of the study was to predict the significant wave height and determining the influence of radius of the pivot station using this method. Also, the SPCSV method was compared with two other geostatistical methods known as Point Cumulative Semi-Variogram (PCSV) and Trigonometric Point Cumulative Semi-Variogram (TPCSV) using the same data set by taking the mean relative error (MRE) as a performance evaluation criterion. The MRE of the SPCSV method was found to be 6%, which is acceptable in engineering applications. The superiority of the SPCSV method in predicting the significant wave height over the PCSV and TPCSV methods is presented both numerically and graphically.

1. Introduction

Prediction of significant wave height values is an important prerequisite for designing coastal and offshore structures (Soares and Scotto, 2001). According to Bidlot and Holt (1999), wave forecasting has become an integral part of operational weather forecasting at several weather forecasting centers. Saetra and Bidlot (2002) indicated that the incorporation of wave models into numerical weather prediction models can improve atmospheric forecasts by allowing the transfer of momentum between the ocean's surface and the atmosphere to be better modeled.

A few techniques have been developed for estimating significant wave height. These techniques range from simple statistical methods to complex polynomial curve fitting models. Roulston et al. (2005) used numerical prediction models to forecast significant wave height probabilities. Altunkaynak and Ozger (2004) developed a technique called Perceptron Kalman Filtering to predict significant wave height from wind speed. Artificial Neural Networks (ANNs) have been successfully used in tracking, retrieval, reconstruction and prediction of waves with the objective of improving the accuracy of numerical models (Makarynskyy, 2005). Paplinska-Swerpel and Paszke (2006) applied the ANN technique to undertake short-term wave forecasts. The neural network model was used to predict significant wave height at a selected location in the Baltic Sea based on wave and/or wind data at 10 points scattered over the sea. Makarynskyy and Makarynska (2007) proposed a site-specific ANN methodology that could serve as a basic tool for predicting both present and future wave parameters in various coastal environments. The methodology was recommended as an alternative way of supplementing data and computational effort to demanding deterministic wave models. ANNs have a number of advantages. One of these advantages is that ANNs require less formal statistical training. They have the ability to implicitly detect complex nonlinear relationships between dependent and independent variables and the ability to detect all possible interactions between predictor variables. They are also known to have multiple training algorithms. However, their “black box” nature, greater computational burden, proneness to over fitting and the empirical nature of the models' development are some of the limitations of ANNs (Tu, 1997). Altunkaynak (2008a) developed a method called Geno–Kalman Filtering by combining genetic algorithm and Kalman Filtering method to estimate wave parameters and uses adaptive calculation to reach the solution. In addition, a method called Geno-Multilayer Perceptron was introduced to predict significant wave height by Altunkaynak (2013).

The above mentioned techniques, however, were developed to forecast site-specific, short or long term significant wave heights and, therefore, they cannot be directly used for spatial analyses. As a result, surfaces, which can be used as basic information to

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perform further spatial analyses need to be generated from available data sources at individual stations. Data required for generating these surfaces are usually collected through field sampling and surveying. Because of the high establishment and operational cost and limitations of other resources, a limited number of stations could be established at selected points and a limited amount of data can be collected as a result. In order to generate a continuous surface of a property (for example: wave energy potential, groundwater table etc…), some kind of interpolation technique has to be used to estimate surface values at those locations where no samples or measurements were taken.

The theory of Regionalized variable (ReV) was first developed by Matheron (1963), (1971) to deal with various aspects of a geospatial variable as an alternative technique. The basic principles of regional predictions are based on the study of Krige (1951), which assumed that the spatial variation of any geological, soil or hydrological property, known as a 'regionalized variable' is statistically homogenous throughout a surface. This means that the same pattern of variation can be observed at all locations taken into consideration. The Kriging method, which is a weighted moving average based method of interpolation (gridding), was later developed and became the most advanced technique among the regional prediction methods. However, this technique does not have the ability to determine the so-called 'radius of influence', which helps to determine the number and spacing of wave power harnessing facilities.

This calls for the need to develop a technique that is capable of determining the radius of influence. At the same time, the technique should depict the variation of a variable within a region and should be able to develop surface data by interpolation so that missing data could be estimated. The technique could also be developed so that it can be used for calculating the potential of a variable as well. For example, a spatial interpolation technique can be employed to generate the wave energy potential and its variation at various points within a certain domain by using ocean wave data measured at few representative points. In the presence of spatial relationship (spatial dependency), stations located closer to each other show more similarities than those located far apart. This shows that the similarity between the stations and the contribution of a station to a pivot station decreases with the increase in distance between them. Actually, the presence of a spatial structure where observations at stations close to each other are more alike than those from that are far apart (spatial dependency) is a prerequisite to the application of spatial interpolation (Goovaerts, 1999).

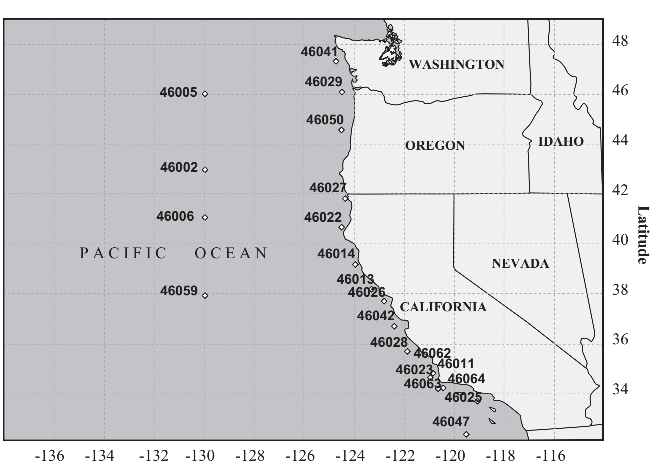

Fig. 1. Map of study area.

As indicated earlier, taking a certain variable into consideration, the same pattern of variation may be observed at all locations on the surface. This spatial variation of a property can be expressed in terms of semi-variograms. A Semi-variogram (a technique proposed by Matheron (1963)) is a graph that shows the variance in measure with distance between all pairs of sampled locations. It is one of the significant functions that indicate spatial correlation in observations taken at sample locations. Despite this advantage, the semi-variogram technique is also known to have some limitations. One of these limitations is the requirement of a uniform distribution of grid points and stationarity in the spatial series. If one does not achieve these requirements, the results will not be valid. In order to deal with the case of irregular distribution of nodal points and non-stationarity, Sen (1989) proposed the Point Cumulative Semi-Variogram (PCSV) method based on point and area relationship. The differences between the point of interest (concern) and the adjacent points are considered in the PCSV technique. These differences are calculated using the variables at each nodal point. Sen and Habib (1998) developed the standard areal dependency approach to make point and spatial estimations of a variable. Later, Altunkaynak and Ozger (2005) used PCSV to predict significant wave height. In the PCSV approach, it is assumed that the highest correlation exists between the pivot station and the closest station to the pivot station, and the lowest correlation exists between the pivot station and the farthest station from the pivot station. Here, it should be noted that this assumption is not necessarily true. The Trigonometric Point Cumulative Semi-Variogram (TPCSV) technique, which was proposed by Sahin and Şen (2004), was applied to deal with wind data. The basic principles of this technique are based on geostatistics. Altunkaynak (2005) then applied the TPCSV technique on wave data. A close investigation of this technique, however, shows that the technique was developed by giving more weight (degree of influence) to the distance between points of measurement than the changes in the regional variables with distance. It is believed that this can affect the performance of the approach. In addition, the TPCSV approach takes into consideration only analytical implications. In other words, the TPCSV technique is used to determine weighting coefficients analytically.

This study was, therefore, undertaken to address the limitations indicated above by developing a technique that has the ability to make geometrical evaluations as well as analytical interpretations by giving more weight to the changes in the regional variables with distance as opposed to the TPCSV method. The technique proposed in this study is called Slope Point Cumulative Semi-Variogram (SPCSV).

2. Materials and methods

2.1. Data used and analysis

In this study, the SPCSV method was developed to predict significant wave heights in January 2003 at 22 stations located in the Pacific Ocean off the west coast of the United States of America (USA) (Fig. 1). The stations are located at depths ranging from 47 m to 4599 m. In the study area, while larger significant wave heights appear in the winter season, relatively smaller waves occur in the summer season. The annual spatial average significant wave height at the study area is 2.31 m. Previously, Altunkaynak (2005) and Altunkaynak and Ozger (2005) applied the TPCSV and PCSV techniques do determine significant wave height using data from the same stations. The same data were used in the method developed in this study, i.e., SPCSV. In addition, the PCSV and TPCSV approaches were applied to determine the significant wave height using the same data with the objective of comparing the performance of these two techniques with the SPCSV method.