Wave Hindcast Study of the Caspian Sea

Aliasghar Golshani, Ali Nakhaee, Soheila Taebi, Vahid Chegini and Majid Jandaghi Alaee[1]

1-Iranian National Center for Oceanography (INCO)

Abstract

The significant effect of waves on coastal and marine activities urges the precise identification of wave characteristics using field measurements, theoretical studies, physical modeling or numerical simulations. In order to study thoroughly the wave climate in the Caspian Sea, a wave modeling and hindcast project was performed by Iranian National Center for Oceanography. In this study, one of the latest versions of numerical wave models (3rd generation) was employed for long-term simulation of waves in the Caspian Sea using wind data. The wind field was obtained from ECMWF global operational model after a few local modifications were made. For calibrating the model, in-situ measurements and available satellite data were used. Extreme value analysis was the next stage in which for different return periods the wave characteristics were calculated. Finally, a user-friendly software was developed with the aim of presenting the results of the project.

Keywords: Wave modeling, Wave hindcast study, the Caspian Sea

Introduction

Wave, is one of the most significant maritime phenomenon that due to its complicated and stochastic behavior is known as one of the most difficult case studies for engineering practice. The effect of waves on coastal and marine activities urges the identification of wave characteristics using field measurements, theoretical studies, physical modeling, and numerical simulations. Coastal and harbor engineers generally use these methods to identify wave climate and the highest probable wave characteristics, as well as annual attribute of waves.

For this reason, countries which take the advantage of contiguity to seas or great lakes have developed a regular plan for studying waves and other marine phenomena. The first attempt for studying the wave characteristics of the southern part of the Caspian Sea began by deploying some wave measurement stations in deep waters in the vicinity of Amirabad, Anzali, and Neka ports. Together with this basic data, other data sources such as different short period measurements of wave parameters, satellite data, and results of large scale numerical simulations enable us to pursue a hindcast study in the Caspian Sea.

The main goal of this study is to identify wave climate in the southern part of the Caspian Sea using the results of wave simulations. This study was performed by employing the latest versions of wave numerical models (3rd generation) together with in-situ measurements and available satellite data for calibrating the model and verifying the results. The results of the study present the required wave parameters for different applications in harbor engineering and coastal works.

[DOR: 20.1001.1.17357608.1383.1.2.5.7]

Input Data

In order to simulate the wave characteristics of an area, the bathymetry of that area is needed. Bathymetry data used in this study was extracted from the latest electronic sea charts using MIKE C-Map software from DHI. This dataset was used for presenting the bathymetry and also the boundary of the Caspian Sea. Fig.1 shows the final bathymetry used for the Caspian Sea.

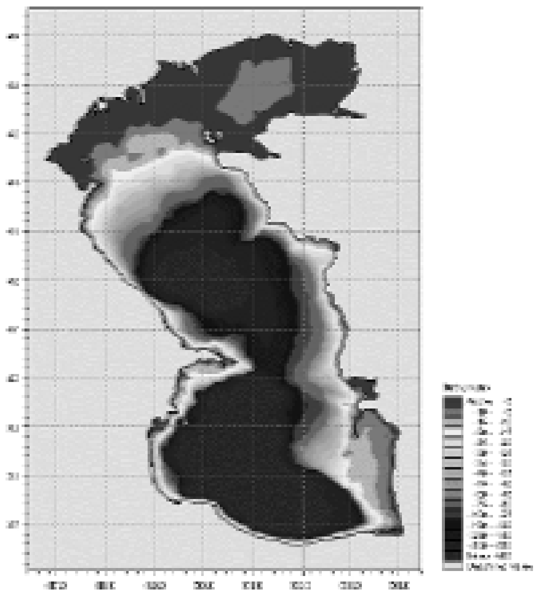

Fig. 1 - Caspian Sea bathymetry

The wind field over the area as the main source of the energy is the most important input for wave modeling and should be exactly known. As field measurements obtained from synoptic stations or buoys represent the meteorological condition of a limited region, these kinds of data cannot be employed directly as model input. Therefore, the wind fields generated by meteorological models which normally involve the wind components over a regular grid are used alternatively. The following wind data sets were compared for simulating the wind waves: ECMWF ERA-40 model wind field dataset with a grid spacing of 1.125 degrees, and ECMWF operational wind field dataset with a grid spacing of 0.56 degrees, both with time resolution of 6 hours. For example, fig.2 shows the ECMWF operational wind field in one time step of the numerical simulation. Test runs and local comparisons with field wind data showed that the operational model output is the most appropriate wind input data for the wave generating model.

For evaluating the wind field, several synoptic stations, mostly along Iranian coastline, as well as wind data collected by Anzali and Amirabad buoys and non-directional wind data of Topex-Poseidon satellite were used. The location of wind synoptic stations and buoy locations are shown in Fig.3. The comparisons of these wind data sources indicated that the wind field should be slightly modified, especially in coastal area where the ECMWF model cannot generate the wind field correctly due to the unrealistic high surface roughness of coastal area in the ECMWF model. The modification process consisted of copying the wind of some offshore grid points to nearshore grid points and applying some local correction factors to the wind field.

Two sets of wave measurements which were carried out by Ports & Shipping Organization in Anzali and Amirabad harbors were used for model calibration. Also meteorological buoy data in Neka were used for verification of the model results. The quality of these data was controlled by comparisons with other available data sources. For example, the data of Anzali buoy were checked by a simultaneous one-month ADCP record, which showed a very good agreement between two sets of data.

[DOR: 20.1001.1.17357608.1383.1.2.5.7]

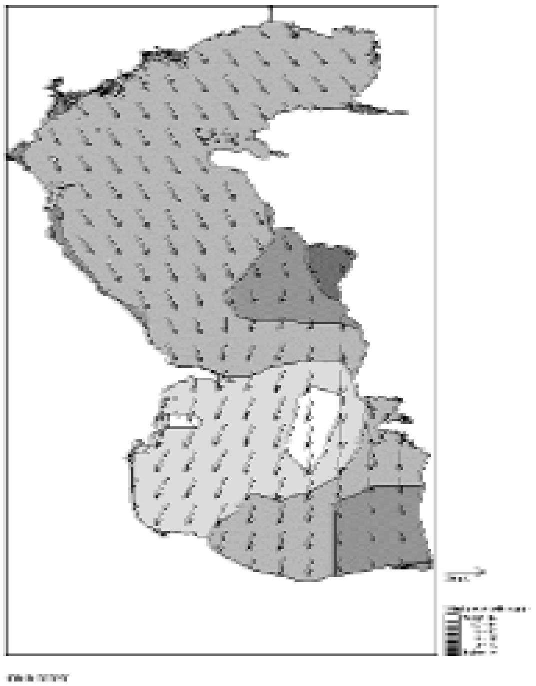

Fig. 2 - ECMWF Operational wind field

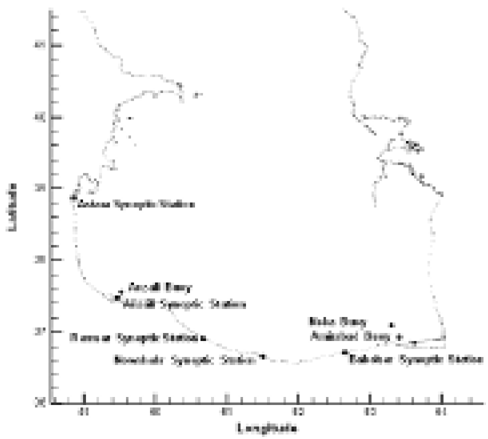

Fig. 3- Location of wind and wave measurement stations

Although the buoy data were accurate enough for calibration of the model in the vicinity of the buoy, the satellite data were also used to control the results of the model, especially in the offshore zones. The employed satellite data consisted of the data of RA (Radar Altimeter) and scatterometer instrument from Topex/Poseidon for the period of 1992-2000. The data were collected along four different tracks with a distance of 200 kilometers from each other with time resolution of about ten days. Thirty to sixty points are located on each track with a distance of 0.06 geographical degrees. The location of satellite tracks in the Caspian Sea is shown in fig.4.

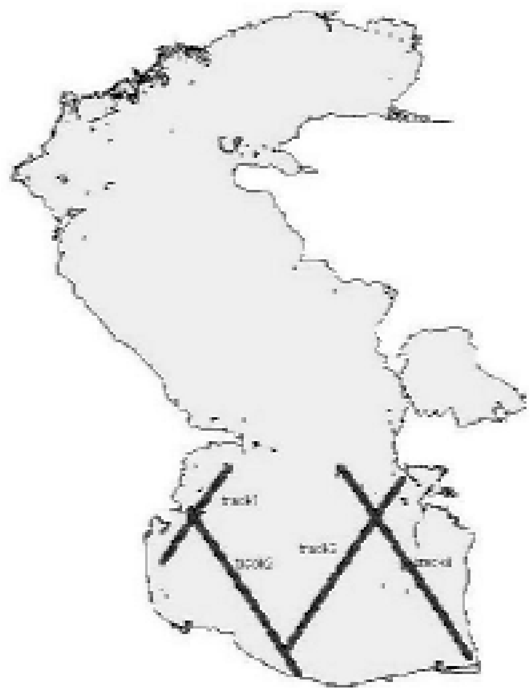

Fig. 4 - Location of satellite measurement Tracks in the Caspian Sea

The water level variation along the simulation period was considered by employing an average level. Two sets of water level data collected in Anzali and Noshahr harbors during 1950-2002 were used for correcting the datum level, which was used for preparation of the bathymetry files.

SW Model

MIKE 21 SW which was used in this study for wave simulation, is used for the assessment of wave climates in offshore and coastal areas - in hindcast and forecast mode. It includes a new generation spectral wind-wave model based on unstructured meshes.

The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. It includes the following physical phenomena: wave growth by action of wind, non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, refraction and shoaling due to depth variations, wave-current interaction, effect of time-varying water depth and flooding and drying. Diffraction and reflection is not considered in this module.

Setup of the Caspian Sea Model

Set-up of the model was the next step of this study. In this step, the input data files were prepared. The following activities were performed in this step:

1) Preparing bathymetry and mesh files including 8132 unstructured elements and 4176 nodes.
2) Determining the time step of the model run according to courant number criterion which was led to a time interval of 600 seconds as the most appropriate and 900 seconds as practically accepted time step.
3) Determining 25 frequencies and 16 directions for frequency-directional discretization.
4) Comparing the ERA-40 and operational sets of wind data from ECMWF which yields to make the decision about the modification and selection of the appropriate wind field data, i.e. the operational wind field with modification in the coastal areas.

Calibration of the Caspian Sea Model

The next step of wave modeling in the Caspian Sea was the model calibration. Following procedure was pursued for the model calibration:

1) Selecting the appropriate set of data for calibrating the model. The data from Anzali and Amirabad buoys were selected for this purpose.
2) Selecting the period of calibration. Four periods including considerable storm events were selected for calibration of the model, named as A, B, C & E periods.
3) Selecting the calibration parameters based on the behavior of the model at the location of each buoy, including the white-capping, wave breaking factor, and bed roughness parameters. According to the calibration results, the values of these parameters were defined 2, 0.8, and 0.002, respectively. A comparison between modeled and measured data for the final calibration setup have been presented in Fig. 5 and Fig. 6 which are related to calibration periods A and B for Anzali and Amirabad, respectively.

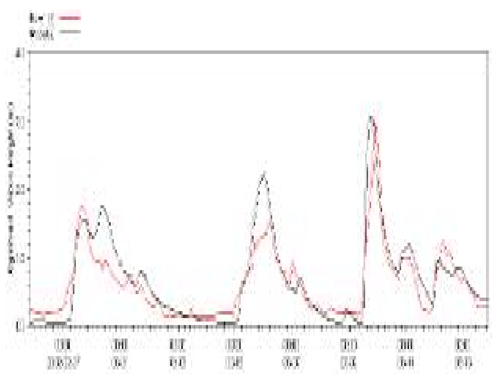

Fig. 5 - Comparison results for calibration period A in Anzali

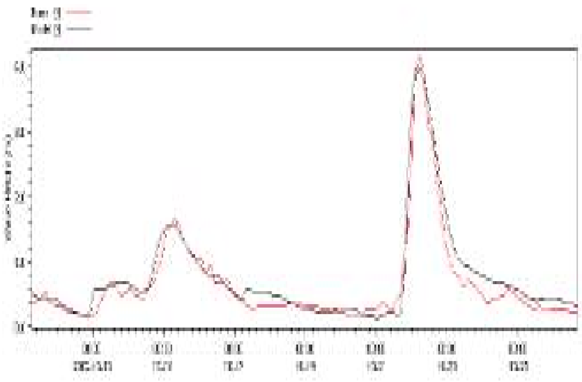

Fig. 6 - Comparison results for calibration period B in Amirabad

Running the Caspian Sea model

The long term modeling of the wind waves in the Caspian Sea was performed for a period of approximately 12 years from 1992 to the middle of 2003 using Mike21 SW model developed by DHI Water and Environment. The following physical phenomena are included in the SW module of Mike21 software: wave growth by action of the winds, non-linear wave-wave interaction, dissipation due to white-capping, bottom friction, and depth-induced wave breaking, refraction and shoaling due to depth variation, wave-current interaction, and effect of time varying water depth. In order to reduce the risk of missing data during running the model, the whole simulation period was divided into several 3-month runs with two days overlap, which had been found from different test runs to be a suitable time for model warm-up. The output of the model cover the parameters related to the total waves, seas and swells and the frequency-directional wave spectrum for the region below the latitude 38.5 degree with a grid spacing of 0.125 degrees and for the region above the latitude 38.5 degree with grid spacing of 0.25 degrees.

Verification of the 12-year simulations

The final results were compared with the field data and in this way the accuracy of the results was checked. Mapping the maximum values of various parameters resulted from the 12 year run assured that no unrealistic storm event or numerically made high waves were resulted during the simulations. The results were also compared with the buoy and satellite data again in order to re-evaluate the quality of the wave simulation results.

Extreme value analysis

The extreme value analysis was carried out using EVA software developed by DHI Water and Environment. This stage of the work was finalized after performing various tests. On this basis, the optimum attributes of input data and appropriate distributions for wind and waves were selected. Scientific references (Goda, 1985) mention that Gumble and Weibul statistical distributions are the best distributions for wind and wave. However, test runs and related investigation of statistical parameters such as correlation coefficient (CC) showed that the most appropriate statistical distribution for both wind and wave is Truncated Gumble (TG) which results in less standard deviation and a smoother spatial pattern of extreme values.

The final EVA analysis results on wave data are shown in fig. 7 for the upper part of the Caspian Sea and in Fig. 8 for the lower part of this lake.

Furthermore, the relationship between the significant wave height (Hs) and the corresponding period (To2) for the extreme events was investigated. The relationship for two points has been shown in Figs. (9) and (10).

[DOR: 20.1001.1.17357608.1383.1.2.5.7]

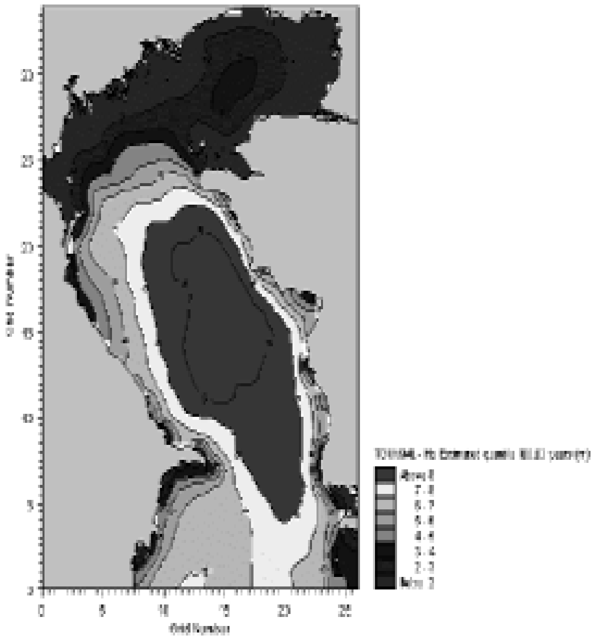

Fig. 7 - EVA analysis results of wave height for the upper part of the Caspian Sea

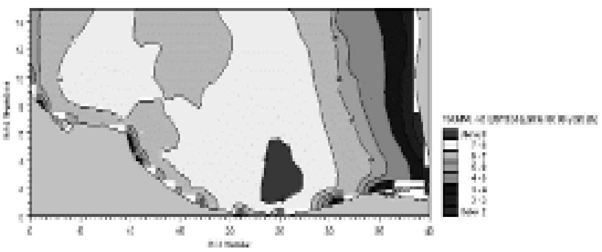

Fig. 8 - EVA analysis results of wave height for the lower part of the Caspian Sea

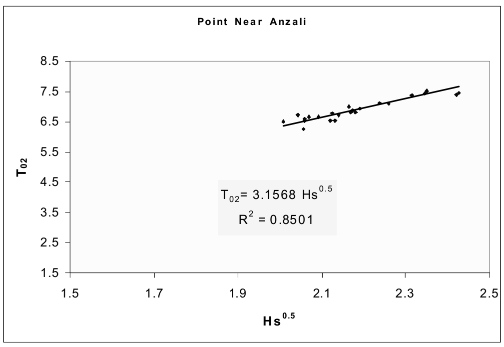

Fig. 9 - Relationship between Hs (extreme events) and T02 for a point near Anzali

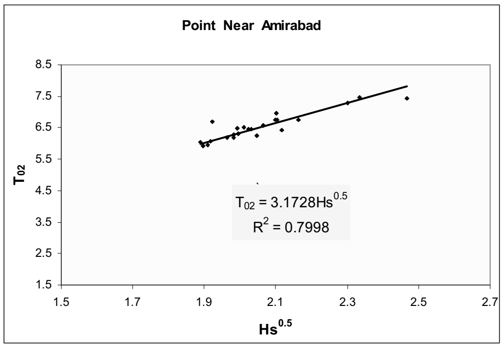

Fig.10 - Relationship between Hs (extreme events) and T02 for a point near Amirabad

Regarding the wind data, an extreme value analysis for some synoptic data, from stations near the Caspian Sea coasts was performed and the results were compared with a similar analysis for corresponding points of ECMWF wind data set. This comparison also showed reasonable agreement between the predicted wind speeds from both sources.

Some points adjacent to the coast with unrealistic predicted values from EVA were investigated and it was found that the main reason for these unrealistic values were due to the effect of land interpolation for calculation of wave height at the points, which were thus removed from the results.

Finally, a comparison of extreme winds and waves between model results and satellite measurements for 1/4 lower part of the Caspian sea showed a good agreement between these two sets of data.

Conclusions

The 12-year wave hindcast study that was carried out in INCO, has lead to a significantly improved definition of wave climate in the southern part of the Caspian Sea. Excellent agreement was obtained between the model results at the locations of Anzali and Amirabad buoys and buoy measurements for all

[DOR: 20.1001.1.17357608.1383.1.2.5.7]

measurement periods, including calibration periods. A comparison of extreme winds and waves between model results and the satellite measurements for 1/4 lower part of the Caspian Sea showed a good agreement between these two sets of data.

This study showed that the most appropriate statistical distribution for both wind and wave is Truncated Gumble (TG) which results in less standard deviation and a smoother spatial pattern of extreme values. Based on this study, the maximum wave height of 100-year return period for the lower part of the Caspian Sea is about 8 meters, which is quite comparable with the satellite data of about 8.8 meters.

Acknowledgements

This project has been funded by Port and Shipping Organization (PSO) and the authors of this paper wish to thank them for their continuous support.

References:

1- Berek, E.P., V.J. Cardone, and V.R. Swail(2000), "Comparison of Hindcast Results and Extreme Value Estimates for Wave Conditions in the Hibernia Area - Grand Bank of New Zeeland", Proc. 6th International Workshop on Wave Hindcast.
2- Caires. S, J. R. Biodlot, N. Graham, and V. Swail (2002), "Climatological Assessment of Reanalysis Ocean Data", 7th international workshop on wave hindcasting and forecasting, pp. 1-12, Banff, Canada.
3- Caires, S., and A. Strel (2001), "Comparative Assessment of ERA-40 Ocean Wave Data", Global Change Open Science Conference, Amsterdam.
4- Caires, S., A. Strel (2001), "Comparative Assessment of ERA-40 Ocean Wave Product", Proc. of the ECMWF Workshop on Re-Analysis, ERA-40 Project Report Series, No. 3, pp. 353-368, Reading.
5- Cox, A.T., and V.R. Swail (2000), "A Global Wave Hindcast over the Period 1958-1997: Validation and Climate Assessment", Journal of Geophysical Research, Vol. 106, No. C2, pp. 2313-2329.
6- Cox, A. T., V. J. Cardone, and V. R. Swail (1999), "On the Use of In-situ and Satellite Wave Measurements for Evaluation of Wave Hindcasts", CLIMAR 99, WMO Workshop on Advances in Marine Climatology, Vancouver, Canada.
7- Goda, Y., "Random Seas and Design of Maritime Structure", World Scientific, Vol. 15, 1985.
8- Graham, C., V. J. Cardone, E. A. Ceccacci, M. J. Parsons, C. Cooper and J. Stear (2002),"Challenges to Wave Hindcasting in the Caspian Sea", 7th International Workshop on Wave Hindcasting and Forecasting, Banff, Alberta, Canada.
9- Hosking, J. R. M., "Algorithm AS215 (1985) "Maximum-Likelihood Estimation of the Parameters of the Generalized Extreme-Value Distribution", Journal of Applied Statistics, Vol. 34, pp. 301-310
10- Ozhan, E, and Saleh Abdalla (1998), "Wind-Wave Climate of the Black Sea and the Turkish Coasts (Nato Tu-Waves Project)", 5th International Workshop on Wave Hindcasting and Forecasting, Melbourne, Florida, USA.
11- Swail, V. R., V. J. Cardone, and A. T. Cox(1998), "A Long Term North Atlantic Wave Hindcast", 1-5th International Workshop on Wave Hindcasting and Forcasting, Melbourne, Florida.
12- Weisse, R., and G. Gayer (2000), "An Approach Toward a 40-year High-Resolution Wave Hindcast for the Southern North Sea", Proc. 6th International Workshop on Wave Hindcasting and Forecasting, Monterey, USA.
13- Weisse, R., and F. Feser (2003), "Evaluation of a Method to Reduce Uncertainty in Wind Hindcasts Performed with Regional Atmosphere Models", Coastal Engineering Journal, Vol .48, pp. 211-225

[DOR: 20.1001.1.17357608.1383.1.2.5.7]