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Study of wind waves using satellite altimetry in the coast of south-western Caspian Sea (Gilan Province)

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Waves are an important phenomena in the sea but in view of complicated nature are difficult to study. This research, with the aim of showing a primary research on satellite altimetry, studied significant wave height in offshore waters near Gilan province in the south-east of Caspian region during 2014. So wave's data including significant wave height and wind speed were obtained in a time interval from satellite. The significant wave height data were verified with buoy significant wave height data and their graphs generated. Using wave data and SPM method, the significant wave height and wave period obtained. The contour figure of significant wave height was depicted. The comparison of satellite significant wave height data and result of SPM method by buoy data showed that the satellite data has less error than SPM method result. The result of this research has shown that the effective parameters on wind waves are formation of high and low pressure atmospheric system. The maximum value of mean altimetry significant wave height is 0.70 m in November and 0.80 m in December. The maximum of significant wave height occurs in north portion of study region. The dominate direction of waves is north-western in coasts of Gilan province.

[Keywords: Significant wave height; Satellite altimetry; Wind waves; Caspian Sea; Gilan province]

Introduction

Nowadays, for maritime scientists, satellite altimetry has given new insights into global investigations. Surface elevation (including lands and oceans) is the main satellite altimeters observation along the satellite orbital motion[1]. Variation of radar wave due to the rough sea surface can derive other geophysical information from returned data. The shape and the strength of returned signal can estimate significant wave height and wind speed, respectively, while sea surface and the winds close to it have direct connection. Therefore, it is necessary to find the relation between the strength of sent signals by altimeter radar and their strength after scattering which are received by the altimeter[2]. Electromagnetic radiations sent toward the sea surface are weakened by atmosphere, then some part of these radiations are absorbed by the sea and some others are refracted by the rough sea surface in an expand range and different directions. In addition, the strength of signals reflected to altimeter extremely decreases again by atmosphere[2].

Therefore, the signal strength which is measured by radar depends on refraction properties, radar system parameters and atmospheric bilateral weakening. Straight relation between the sea surface roughness and wave shape and height results in received pulse by satellite and initial pulse properties variation. Consequently, the wave parameters are calculated by making relation between returned pulse and significant wave height. To determine the sea surface height at observation zones these is a need to correct the measured height by considering the systematic errors.

The necessary corrections for omitting the errors include: Wet troposphere, dry troposphere, ionosphere, inverse barometer effects bias, electromagnetic bias (sea state), the changes of altimeter antenna mass centre, and polar tide corrections. Due to changes in the ground shape of observation zones because of the earth rotation, this correction is applied. Atmosphere and ionosphere reduce the speed of radio pulse; there is a ratio between the amount of this reduction with total mass of atmosphere (dry troposphere penetration), the mass of water vapour in atmosphere (wet troposphere penetration) and the amount of free electrons in ionosphere (ionosphere penetration).

Sea state's bias correction is applied for the sea level unrests. The inverse barometer effects bias correction is necessary for momentarily pressure changes at nadir point. Mass centre changes of altimeter antenna correction are applied for solar radiation intensity. Changes in ground shape at observation zones caused by the earth rotation are the reason for polar tide correction. Significant wave height and wind speed data are obtained from satellite Jason-1, which follows satellite TOPEX/Poseidon missions successfully (Fig. 1).

The main purpose of this study was sea surface topography measurements, presenting extended chronological series of ocean topography with a high accuracy that can be important in better understanding ocean circulations and its role in the earth climate. Jason-1 was launched on 7 December 2001 and Jason-2 Satellite on 20 June 2008[1,3]. Figure 2 shows the satellite crossing over Caspian Sea[4].

Materials and Methods

Wind waves are created by energy flux from atmosphere over the sea. The wave generation is a complex process. First, during the wind-wave interaction there is an energy transfer from the wind to smaller waves, and then at wave-wave interaction, the transition of energy occurs from smaller waves to larger waves[6].

There are different methods to identify the wave characteristics. The first method is called SPM; with regard to wind fetch, the significant wave height, H_m and wave period, T_p, are obtained by this method[7]. Finally, H_m and T_p are calculated by equation,

$$\begin{cases} \dfrac{gH_{m0}}{U_A^2} = 0.0016\left(\dfrac{gF}{U_A^2}\right)^{1/2} \\ \dfrac{gT_p}{U_A} = 0.2857\left(\dfrac{gF}{U_A^2}\right)^{1/3} \end{cases}$$

According to mentioned equation and SPM method, wind speed data transform to the significant wave height and period, and then linear contour plot of the significant wave height drawn by comparison with the significant wave height data received from satellite and applying Surfer software. Another method is the usage of wave fetch data or the significant wave height data. Gilan Province coast is the considered area for this investigation. The Caspian Sea is the largest one in the world which has a surface area of 393000 km^2 and a volume of 78000 km^3. Latitude and longitude of Gilan provinces are 36.8 to 38.2 and 49 to 51, respectively Fig. 3[8, 9].

The 2014 satellite data and buoy data were considered and set daily and monthly. The satellite and buoy data, were calibrated and a linear relation was obtained between them which resulted in satellite data correction. According to new data, linear contour plot of the significant wave height was drawn by Surfer.

Regarding to all corrections, satellite data of wind speed were measured over the sea, and were placed in SPM formulas to obtain the new significant wave height and period and then compared with the buoy and satellite significant wave heights. U_A placed in SPM formula at considering area that was corrected in previous investigations, is $U_A = 0.8U_{10m}^{1.25}$.

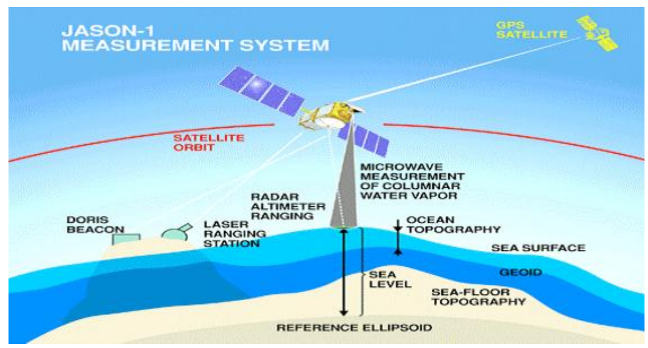

Fig. 1 — Jason – 1 measurement system[4]

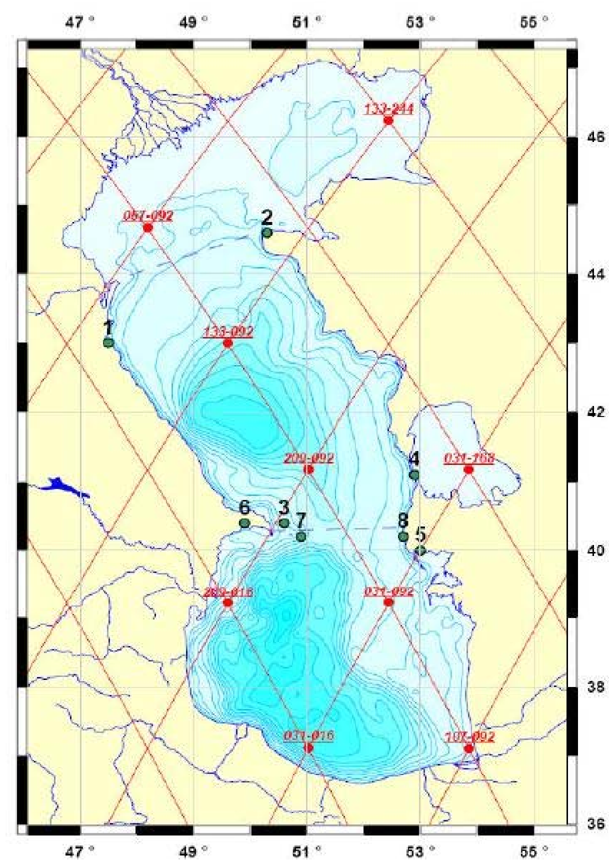

Fig. 2 — Satellite crossover the Caspian Sea[5]

Using SPSS, data histogram of including minimum, maximum and average points were drawn; and monthly minimum and maximum of the significant wave height were defined. Monthly and annual graphs of significant wave height were drawn through either methods and compared with wave fetch data graph. The buoy data measure the significant wave height and other marine parameters hourly, while satellite data do these measurements 3 or 4 times per 10 days approximately in a month. Consequently, the satellite data and buoy data can be compared during 37 days in a year, in significant day and hour and the closest longitude and latitude to the area.

So in an Excel spread sheet, columns were allocated to date, the time of data recording, the significant wave height from satellite data and the last column for the significant wave height from buoy measurements. After data comparison, Figure 4 was drawn, and the correlation coefficient between the significant wave height from satellite and buoy data was calculated.

By confirming goodness of fit between satellite and buoy data, linear equation was obtained as:

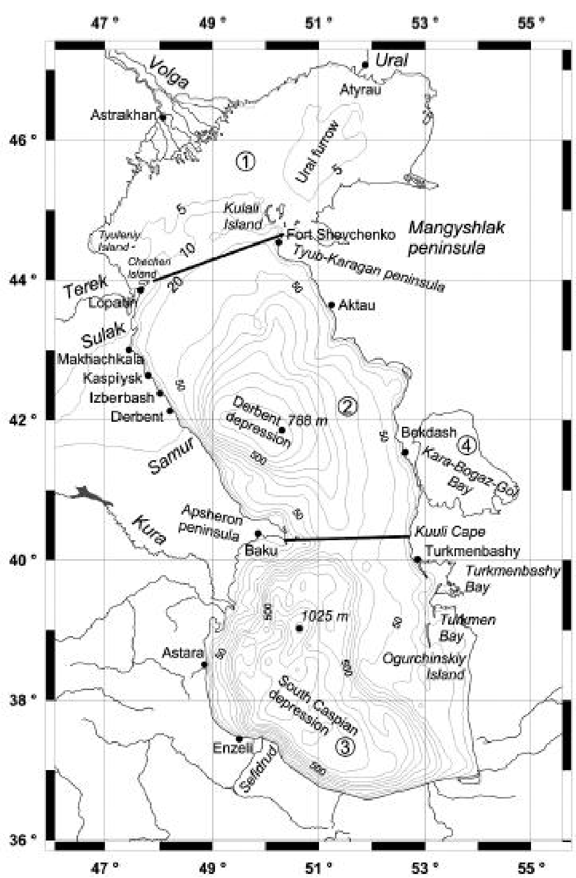

Fig. 3 — The Caspian Sea distribution and topography map[10]

Y=0.618X+0.099

Correlation coefficient between the significant wave height from satellite and buoy data was calculated as 0.744. According to regression relation, all the satellite data were corrected and used at continuance.

Results and Discussion

A total of 74 linear contour plots of the significant wave height were drawn via Surfer. Out of these, 37 plots were drawn from the significant wave height data and 37 plots were based on the significant wave height data received via placing wind speed in SPM formula. Among numerous plots, two plots associated with the method of using the satellite data and two plots by using SPM method are shown in this investigation; the horizontal and vertical axes indicating longitude and latitude of Gilan Province, respectively. (Fig. 5-8)

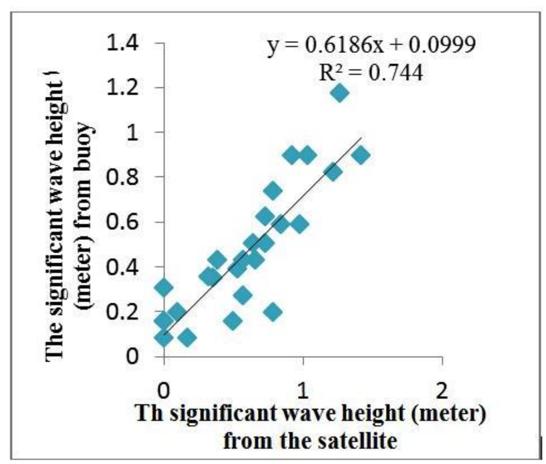

Fig. 4 — Goodness of fit confirmation graph the satellite data

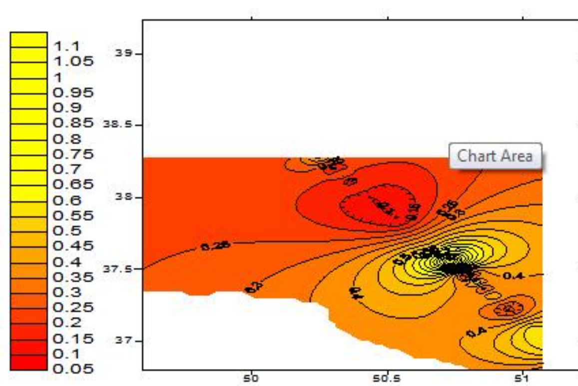

Fig. 5 — Linear contour plot of the significant wave height (m) on February 3, 2014C

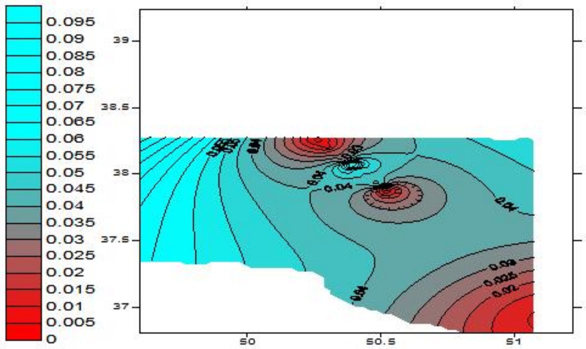

Fig. 6 — Linear contour plot of the significant wave height (from assessed wind by satellite, replacing in SPM) on February 3, 2014

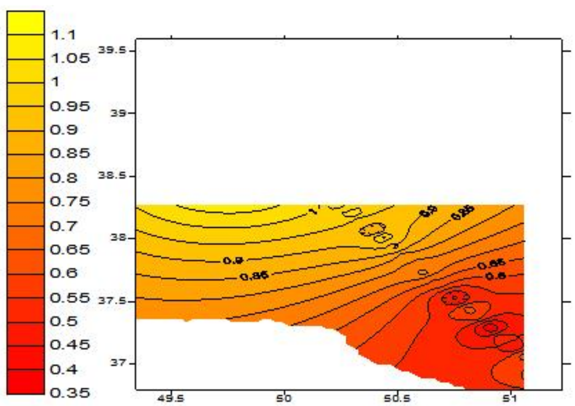

Fig. 7 — Linear contour plot of the significant wave height (m) on August 10, 2014

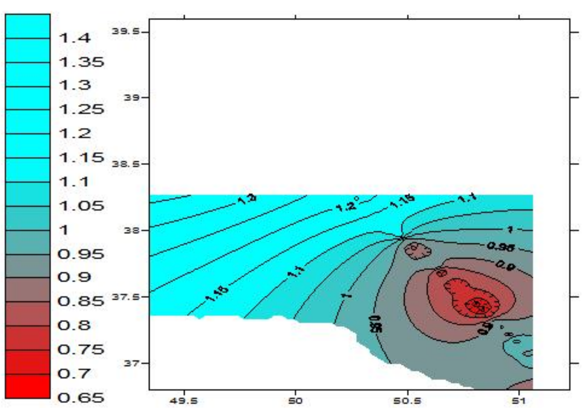

Fig. 8 — Linear contour plot of the significant wave height (from assessed wind by satellite, replacing in SPM) on August 10, 2014

Once the graphs were drawn by the significant wave height data after their goodness of fit confirmation with buoy data, then they were drawn by the significant wave height data from the satellite wind speed data placing in SPM. Now the graphs these analysed by minding effective features such as the sea surface roughness, friction of the bottom, fetch length, blowing wind duration, weather temperature, region climate, and influences of low pressure and high pressure systems on the sea surface. Direct relationship of the sea surface roughness and both shape and height of the wave causes difference between received pulses properties by the satellite and the primary pulses properties; the significant wave height obtained by minding the relation of returned pulses by satellite. So the sea surface roughness was considered by the satellite and applied on data.

About bottom friction, when wave propagate from deep water to shallow water, particles circulation reach to the sea bed, therefore the affection of friction of sea bed becomes important. Bottom friction causes wave height to increase on the shore. Limit duration of wind blowing is a state that takes time shorter than minimum duration of necessary wind blowing. There is no general formula for this situation. SPM has offered limit fetch state formulas for limit duration of wind blowing condition[11].

There is a direct relationship between wind speed and both significant wave height and period in SPM method, which causes a decrease in significant wave height and period by reducing the wind speed in SPM formula. By considering the Caspian Sea synoptic pattern of January for the earth surface, it can be seen the Caspian Sea is affected by low pressure systems from north-west and high pressure systems from east and south-east, as it was positioned at 1025 high pressure area.

From 500 hpa geopotential plots inspecting, it is shown the Caspian Sea is influenced by high altitude systems and there is a ridge over it. So the height of waves increases toward north-west. Atmospheric quantities are continuous and therefore according to growth of atmospheric column the height of waves increase. On February 3rd the height of wave grew by 1.1 m. Regarding to 500 hpa plots, a trough over the Mediterranean Sea and a ridge over the Indian Ocean cause their system extending to north-east of the Caspian Sea. Pressure plots on this day indicate that there are high pressure systems from south-east and low pressure systems from north-west influencing the Caspian Sea. Consequently direction of the waves is toward north and north-west. The correlation coefficient between H_{m0} and H_{m0} from SPM was calculated by drawing correlation graph which confirms correlation between the significant wave height data from satellite and satellite wind speed data[11].

The annual variations related to the significant wave height data were calculated by placing the wind speed in SPM formula and the significant wave height data from satellite, respectively. The maximum amounts of the significant wave height are in November and December. The trends of the significant wave height increasing and decreasing showed by the graphs are in agreement. Differences among data in each month are the result of their 0.79 correlation coefficient.

To compare the parameters distribution in 2007, histogram of data frequency was applied. ΔF is the width of frequency range. When ΔF approaches zero, variances spectrum change to a continuous curve. As much as data frequency gets more, probability becomes more. As the resulted histogram becomes sharper, it indicates that regarded parameter dispersion and its deviation from average is less.

There is a maximum frequency of significant wave height between zero to 0.25 in May from frequency distribution of significant wave height resulted after confirming goodness of fit with buoy data. There is approximately uniform and normal frequency of significant wave height in June from zero to 0.5 m. Frequency of significant wave height in July is not normal and maximum frequency is between 0.25 to 0.38 m. Maximum frequency of significant wave height in August is between 0.38 to 0.63 m. In September, the amount of maximum is between 0.5 to 0.63 m. Maximum frequency of significant wave height in October is between 0.38 m and 0.75 m, and associated histogram is sharp which is showing the data dispersion.

Between 0.5 m and 1 m, there is the maximum frequency of significant wave height in November. Maximum frequency of significant wave height between 0.6 to 1.6 m is in December. In February, the amount of maximum frequency of significant wave height is between 0.31 to 0.56 m. Maximum frequency of significant wave height in March and April with a non-uniform distribution and a sharp histogram is between 0.35 m and 0.5 m. The best normal distribution of significant wave height is in June which indicates a gentle sea without any high waves.

Monthly variation graph of the significant wave height from satellite data and buoy are adapted (Fig 9). The quantities of satellite data are less than buoy data for following reasons:

1. Duration of measurement by buoy is 24 hours every day, while this duration by satellite is averagely per 9 days and 22 hours.

2. Buoys usually damage and their data goodness of fit is not be confirmed, also their maintenance cost is high.

3. There could be errors in one or more of measurements.

Proportional error is applied to compare the fetch data and satellite data, as it approaches less than 40 per cent. By comparison between fetch and satellites significant wave height the amount of proportional error is obtained 18 per cent. Proportional error of buoy significant wave height and significant wave height calculated by SPM method is 38 per cent.

In 2006, variation of significant wave height from 1992 to 2005 were determined by Lebedev and Kostianoy, the Southern Caspian Sea Crossover point (16-209) is considered[5]. By comparison between graphs of Figure 10 for significant wave height annual variation in 2014 and Figure 11 considering variation of the significant wave height during 13 years at southern coasts; and annual variation graph related to significant wave height data by satellite, they are in

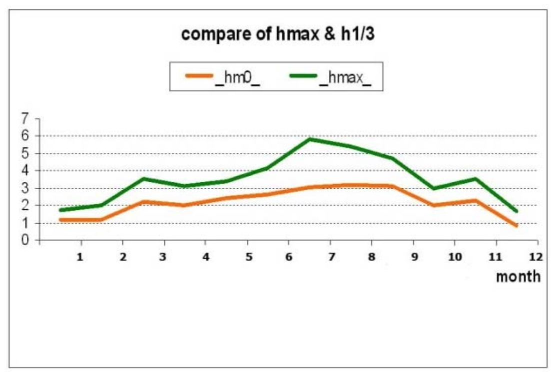

Fig. 9 — Monthly variation graph of significant wave height in 2014

Fig. 10 — Annual variation of the significant wave height in 2014 at Gilan Province shores

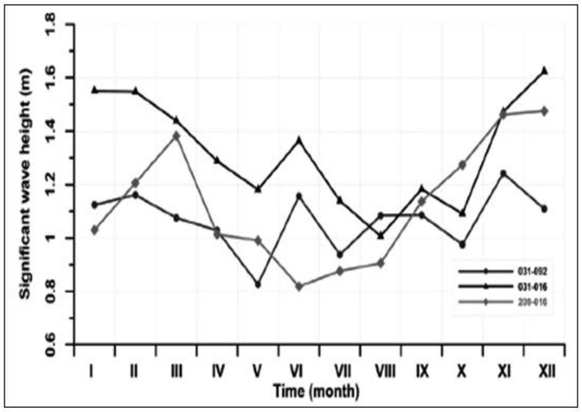

Fig. 11 — The Caspian Sea annual variation of the significant wave height from 2002 to 2015[12]

agreement. As well as the maximum amount of the significant wave height in both graphs in November and December and the minimums in May and June.

Conclusion

By a general reviewing between two sources of considered significant wave height (the significant wave height data from satellite and the significant wave height data from using wind fetch in SPM forecasting method) we reach to the following result are assailed:

- The maximum significant wave height is in November and December, and the minimum is in May and June. The range of significant wave height variation in winter is more than summer.
- The wave direction is toward north and north-west and has conformity with the 2014 annual wind rose direction.
- The amount of proportional error of the significant wave height obtained from satellite data is 18 per cent and proportional error of the significant wave height calculated by replacing wind fetch in SPM forecasting method is 38 per cent.
- The correlation coefficient between the significant wave height from satellite data and buoy data was obtained as 0.74. The correlation coefficient between the significant wave height from satellite data and the significant wave height from replacing wind fetch in SPM method was obtained as 0.79.
- The local variations of the significant wave height are in northern spring, northern and eastern summer, eastern autumn, and north-western winter.
- The best frequency distribution is in June. In this month, the area has a uniform frequency distribution of the significant wave height.
- Comparison between annual variation graph of the satellite significant wave height data and previous studies makes a good agreement. Therefore, the maximum amount of the significant wave height in both graphs is in November and December and the minimums are in May and June.

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