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Study on the free oscillations in the Yellow Sea

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Abstract : The free oscillations in the Yellow Sea triggered by atmospheric forcing had been revealed from the tidal record. The period of free oscillation is estimated to be about 22 hours by power spectrum via maximum entropy method. The phase delays among the free oscillations at selected three tidal stations show that the free oscillation propagates from north to south along the west coast of the Yellow Sea. The numerical modeling gives almost the same results.

Key words : *free oscillations, Yellow Sea, period*

1. Introduction

In the Yellow Sea, there should be free oscillations triggered by atmospheric process; their period are estimated by the geometry of the Yellow Sea, using J. R. MERIAN's fromula (SVERDRUP, 1946) as follows.

For enclosed rectangle bay:

$$T = \frac{2l}{\sqrt{gh}}.$$

For semienclosed rectangle bay:

$$T = \frac{4l}{\sqrt{gh}}.$$

Here T is period of free oscillation, l and h are the length and the average depth of the bay respectively, and g is the gravity acceleration. For the Yellow Sea, the west–eastward length is about 500 km, the south–northward length is also about 500 km, and the average depth is about 50 m. By using above formulae and parameters, the period of the free oscillations occurring in the Yellow Sea is estimated to be about 12.55 hours and 25.1 hours. These periods are nearly equal to the semidiurnal and diurnal tidal periods. However their phases should be different from the astronomic tides, because the free oscillations are generated by storms at a random time. Therefore these free oscillations should be extracted from the tidal record in order to estimate their period.

To determine the existence of free oscillation in the Yellow Sea and to calulate its period, in this paper, the free oscillation components are derived from tidal records and their periods are estimated by power spectrum. In order to examine the driving mechanism of observed free oscillations, the numerical modeling was also done.

2. Observational results in the Yellow Sea

To extract the free oscillation components from tidal records, firstly the astronomic tides are calculated by using the harmonic constants obtained from tidal records by harmonic analysis method, secondly the astronomic tides are wiped off from tidal records. The remains containing free oscillation components are analyzed by intrinsic mode function (IMF) method (HUANG, 1998), this method is also called EMD (Empirical Mode Decomposition) and used to decompose a numerical signal series into several modes; as a result, the free oscillation systems can be found in the data series of some modes of IMF.

The tidal records measured at Lianyungang, Qingdao and Rushan during 1981 to 1985 had been analyzed by the method described above. The positions of the three tide gauge stations are shown in Fig. 1. From the above results, four typical free oscillation components are selected and shown in Fig. 2 to Fig. 9. Figures 2, 4, 6, and 8 show the free oscillation at the three stations, Figures 3, 5, 7, and 9 show the water elevations from which the free oscillation had

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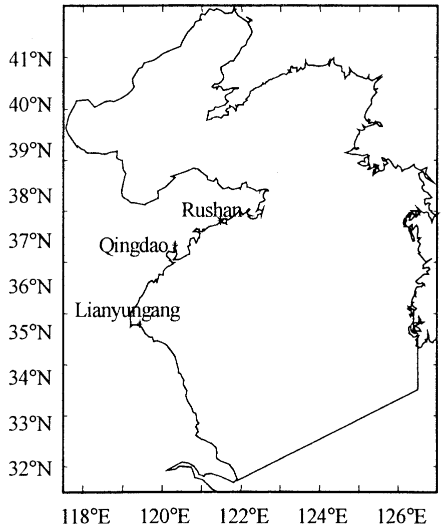

Fig. 1. The tide gauge stations and calculating field

been extracted.

The free oscillation during 17 to 25 August 1985 was triggered by the typhoon named Mamie. The maximum wind speed at the center of Mamie reached 34 m/s; it crossed the Yellow Sea during 17 to 20 August 1985 (Fig. 10 shows Mamie's path), and triggered the free oscillation in the Yellow Sea. Another three during 25 April to 1 May 1983, 12 to 20 November 1983, and 4 to 9 October 1985, were triggered by three extratropical cyclones respectively. The three extatropical cyclones had similar characteristicsl; they moved eastward over the East Asia Continent along the 40°N latitude with a cold front extended southwestward from their centers; before the attack of cold fronts, the Yellow Sea was controlled by southwest wind; when the fronts crossed the Yellow Sea, the northwest wind controlled the Yellow Sea.

All these free oscillations have the amplitude exceeding 10 cm, and their periods are about 20–22 hours extimated by power spectrum via maximum entropy method. The oscillation phases at the three stations have obvious relationship (see figures 2, 4, 6 and 8) from Rushan to Lianyungang with phase delay of about one hour. This result indicates that the free oscillations should propagate from north to south along the west shore of the Yellow Sea.

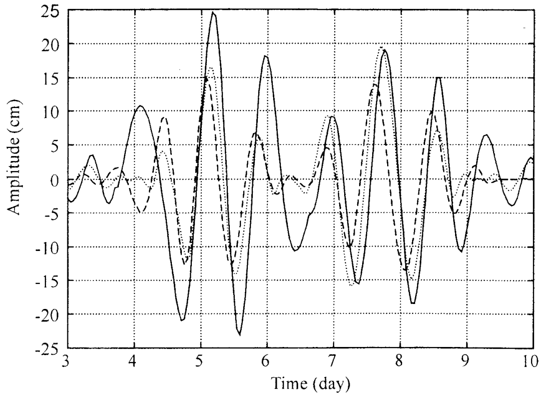

Fig. 2. The free oscillations derived from observation data, 25 April to 1 May 1983 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

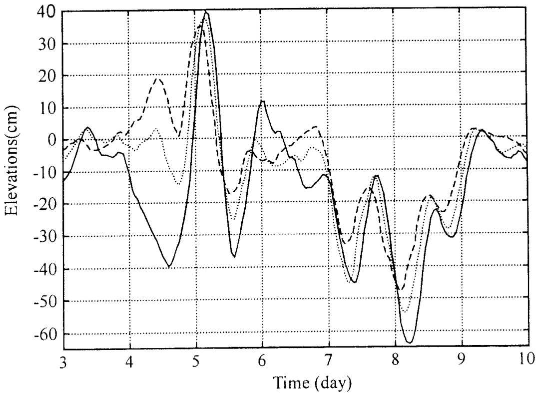

Fig. 3. The water elevations derived from tide data, 25 April to 1 May 1983 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

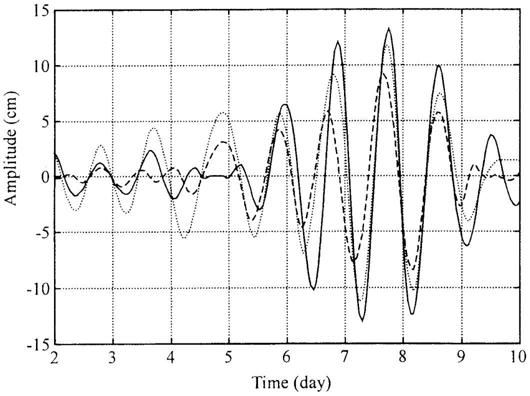

Fig. 4. The free oscillations derived from observation data, 12 to 20 November 1983 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

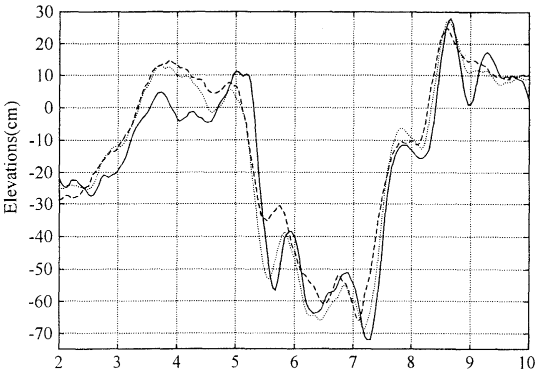

Fig. 5. The water elevations derived from tide data, 12 to 20 November 1983 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

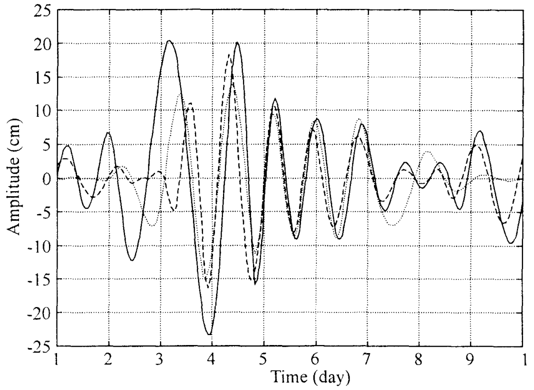

Fig. 6. The free oscillations derived from observation data, 17 to 25 August 1985 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

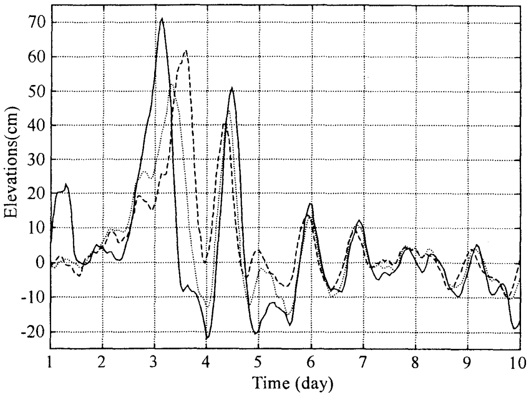

Fig. 7. The water elevations derived from tide data, 17 to 25 August 1985 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

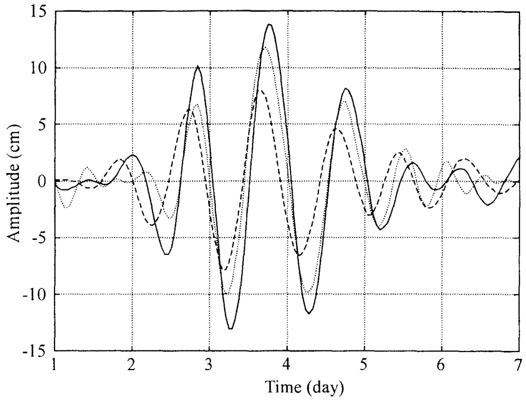

Fig. 8. The free oscillations derived from observation data, 4 to 9 October 1985 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

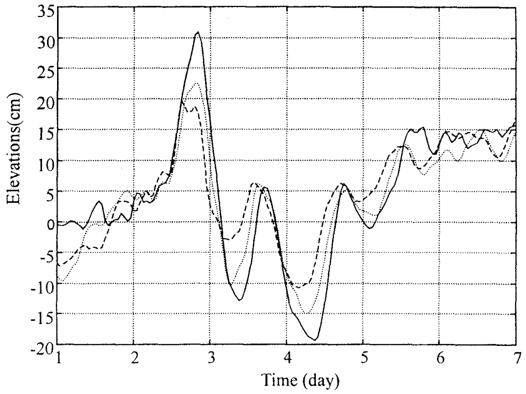

Fig. 9. The water elevations derived from tide data, 4 to 9 October 1985 (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

3. Numerical simulating of free oscillations in the Yellow Sea

The depth integrated two-dimentional long wave equations are employed for simulating the free oscillations in the Yellow Sea. The finite-difference mesh is used. At the land boundaries, the velocity components in the direction perpendicular to the coastline are set to be vanished. At the open boundaries, radiation types of conditions are adopted. The calculating field includes the Yellow Sea and the Bohai Sea (see Fig. 1); the grid spacing is 1/12 degree (longitude and latitude); the time step length is 5 minutes; the bottom friction coefficient is 0.0016 (due to the slightly variation with location and the lack of observation, generally the

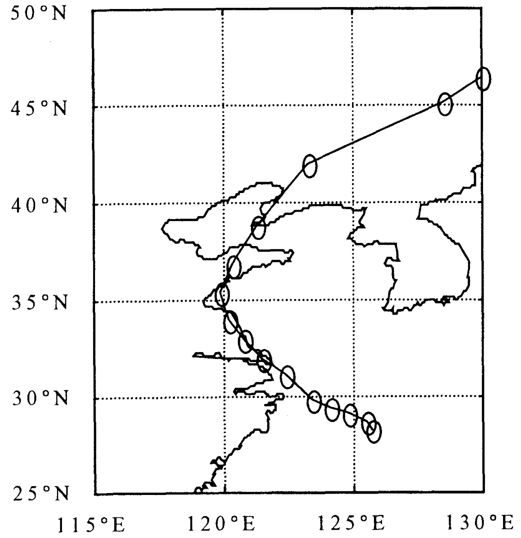

Fig. 10. The path of typoon Mamie (the circles indicate the center positions every 6 hours from 02:00, 17 August 1985)

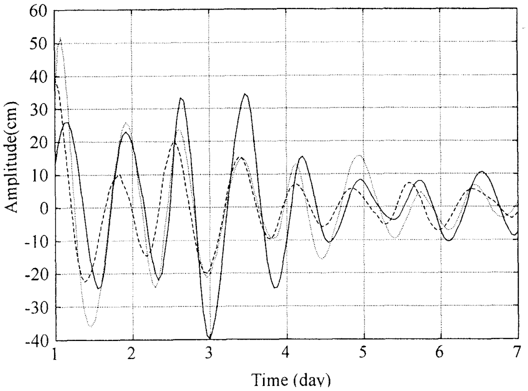

Fig. 11. The free oscillations derived from numerical simulation (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

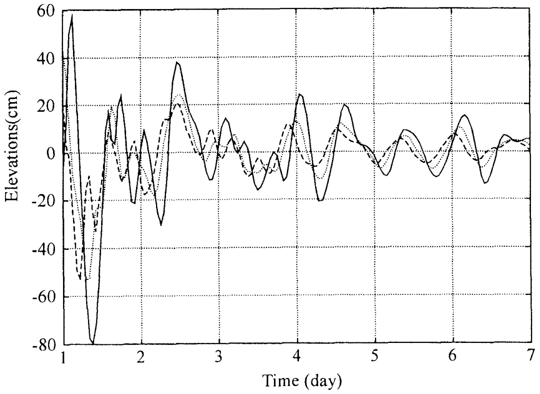

Fig. 12. The water elevations derived from numerical simulation (Dot line: Qingdao, solid line: Lianyungang, dash line: Rushan)

bottomo friction coefficient is selected to be 0.001–0.003 in numerical simulating). The initial conditions for all the calculated points are as follow: the water level increases from 0 cm to 300 cm in south–north direction, in west–east direction the water level is constant; there is no motion of water.

The model runs for 7 days and outputs the water level at the three points Lianyungang, Qingdao and Rushan. The model's results are analyzed by IMF method; the obtained free oscillations (see Fig. 11 and Fig. 12) have the period about 18.5 hours estimated by power spectrum via maximum entropy method.

The results of numerical simulation are little different from those derived from the tidal records due to inadequate selection fo coefficient of bottom friction. If the coefficient of bottom friction is increased from 0.0016 to 0.0026, the period increased to 20.5 hours.

4. Conclusions

In the Yellow Sea, when there is a storm affecting this sea area the free oscillation will be triggered and propagate from north to south along the west shore of the Yellow Sea with the period of about 20–22 hours.

The numerical simulation showed that free oscillation can be generated and it can propagate in the Yellow Sea.

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