

Simulation study on detecting shallow bathymetry via wavelength

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Abstract. Nearshore bathymetry is of vital significance to coastal environment and ocean engineering. Remotely sensing technologies are feasible and economical to detect nearshore bathymetry. Wave Spectrum Bathymetry (WSB) method based on the linear theory takes advantages of the remote sensing to obtain wavelength and leads to bathymetry. A simulation with FUNWAVE model over a plane slope and an elliptical shoal shows the WSB method can do well in different topographies. The mean relative error is less than 8% in the 5-12m depth range.

1. Introduction

In nearshore region of the ocean, bathymetry is one of the significant factors to the marine environment. An accurate nearshore bathymetry can be applied in ocean engineering, disaster protection, navigation and fishing. The conventional method of qualifying nearshore bathymetry is mainly based on the measurements of ship navigation by sonar, multi-beam scanner and other sounding equipment over the area of interest. However, the in-situ measurement method remains costly in terms of time and labor. The existence of small obstacles and strong currents makes the in-situ measurements hazardous and difficult. By comparison, the remote sensing technologies may be a good alternative for nearshore bathymetry with large coverage, fine resolutions and without time or labor consuming. Various methods of detecting nearshore bathymetry via remotely sensing have been developed. One prominent method is the optical bathymetry method, which is based on the visible light transmission in water column in shallow waters [1, 2, 3]. The main drawback of this method is difficult in detecting bathymetry of the waters with high turbidity and also needs to be calibrated [4]. Other method to deriving nearshore bathymetry makes use of surface wave information in remotely sensing imagery [5, 6, 7, 8]. This method mostly relies on the relation between wavelength, period and water depths.

When ocean waves propagate near shore, wavelengths decrease with the water depths. The wavelength can be directly obtained from the remotely sensing imagery using wavenumber spectrum analysis and lead to the determination of nearshore bathymetry without any other environmental information. The Wave Spectrum Bathymetry (WSB) method has been applied to SPOT satellite image and good bathymetry results have been found in the west of Taiwan [7].

However, few research has been discussed on the proper depth ranges for WSB method with good agreement. The goal of this study is to test the WSB method by numerical simulation. Can accurate bathymetry inversions be performed in different topographies such as plane slope and elliptical shoal? In Section 2, we present the based theory and the WSB method. The next we show applications of this



method using FUNWAVE model and discussions on numerical simulation results in Section 3. Section 4 is conclusion.

2. Theory and methodology

Considering the linear theory, the wave period is assumed to be uniform as the waves propagate from deep water to shallow water. The wavelength, period and depths meet the dispersion relation for surface gravity waves in this process

$$\lambda = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi}{\lambda} h\right) \quad (1)$$

Where λ is the wavelength, T is the wave period and h are the water depth,

In deep water (i.e., $h / \lambda \geq 1 / 2$), this equation reduces to $\lambda = gT^2 / 2\pi$, noting that the wavelength is not a function of the water depth. In shallow water (i.e., $h / \lambda \leq 1 / 20$), $\lambda = \sqrt{gh}T$ such that the water depth is depended on wavelength and period. From deep to shallow water, the wavelength becomes shorter and the ratio of wavelength and depths becomes greater, which is illustrated in figure 1. The most obvious change occurs within 10m. Compared with the waves of different periods, the ratio of long-period wave is greater than that of short-period wave. According to the above analysis, we can see that in the shallow water depth, the wavelength is more sensitive to water depth changes. Therefore, it is feasible to rely on the remotely sensing wavelength to derive water depths in intermediate and shallow waters.

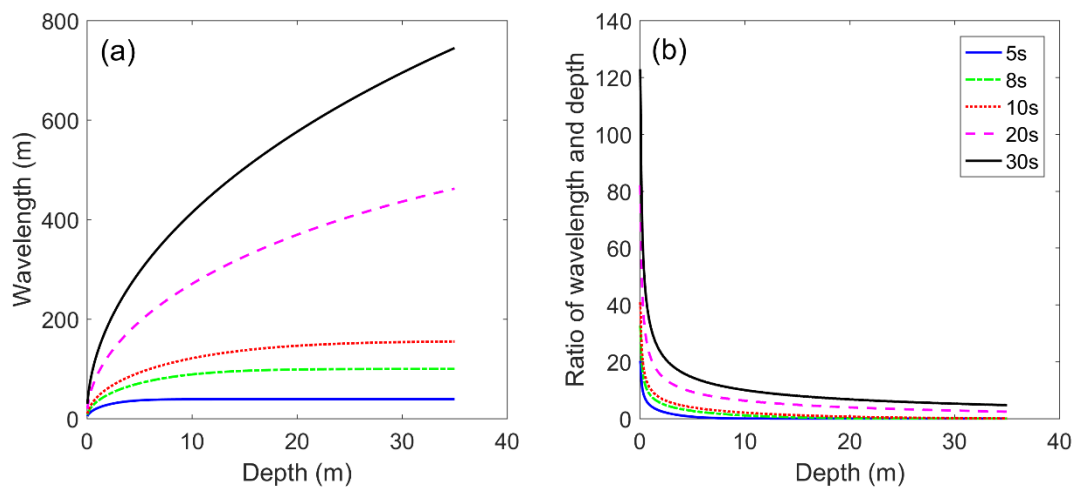


Figure 1. Simulating wavelength (a) and ratio (b) of five different periods [$T=5s$ (blue), $T=8s$ (green), $T=10s$ (red), $T=20s$ (pink), $T=30s$ (black)] waves vary with water depths according to the dispersion relation.

To obtain the wavelength from the remotely sensing imagery, the 2-D Fourier transform is often applied to derive the wavenumber spectrum, which is defined as [9]

$$F(k_x, k_y) = \frac{1}{N^2} \sum_{m_2=0}^{N-1} \left[\sum_{m_1=0}^{N-1} X(m_1, m_2) \cdot e^{-in_x k_0 m_1 \Delta x} \right] \cdot e^{-in_y k_0 m_2 \Delta x} \quad (2)$$

Where N refers to pixels number, ΔX refers to spatial resolution, D refers to the size of subscene of the remotely sensing image defined as $N\Delta X$, k_x and k_y refer to wavenumbers in x direction and y direction defined as $n_x k_0$ and $n_y k_0$, n_x and $n_y=1, 2, 3, \dots, N$. The choice of N is limited to the 2^p ($p=1, 2, 3, \dots, N$) since Fast Fourier Transforms (FFT) is used to compute Formula 2.

The wavenumber spectrum reflects the spectral energy distribution in frequency domain. The wavenumber k_{px} and k_{py} corresponding to the component wavenumbers of the spectral peak in whole subscene can be extracted from the spectrum. Therefore, the wavelength λ and direction θ of the dominant wave:

$$L_p = \frac{2\pi}{\sqrt{(k_{px})^2 + (k_{py})^2}} \quad (3)$$

$$\theta_p = \arctan\left(\frac{k_{py}}{k_{px}}\right) \quad (4)$$

3. Simulation study

To simulate on detecting bathymetry by WSB methods, the Boussinesq model FUNWAVE have been used to obtain the surface elevations over the test topographies. The process of coastal wave propagation can be simulated well with high accuracy [10].

In the first case, the model was run for the regular waves over a 1-D plane slope at an angle of 0.08° with the horizontal range of approximate 15km. Input wave at depth 20m with period 8s, height 1m and spatial resolution 1m was run toward the near shore until it is steady. We divide the elevation data into a series of subscenes size 512×512 pixels. Furthermore, the subscenes are overlapped at the step of 64 pixels in order to improve the spatial resolution of the inversion bathymetries. Then, the dominant wavelength and the water depth can be derived from the wave spectral analysis by means of FFT. Figure.2 shows a good agreement between input bathymetries of the numerical model and inversion bathymetries from WSB method, with the mean relative error of 8.64% within 5m depth, 7.69% in the 5-12 m depth and 11.50% in the 12-20 m range respectively.

In the second case, there is an elliptical shoal on a plane slope at an angle of 0.29° with the horizontal range of about 4 km. The shoal acts as an obstacle that the depths shapely decrease near it. Input wave with period 8s, height 1m and spatial resolution 1m was generated at depth 15 m. This case is also calculated according to the method mentioned above. The average error of the derived water is 15.10% while the mean relative error of 18.31% within 5 m depth, 6.72% in 5-12 m and 11.50% in the 12-20 m range. The wavelength and bathymetry changes near the elliptical shoal have been presented. The good fit has been showed in Figure.3 implies that the WSB method can do well in complex bathymetry.

From the case1 and case2, the accuracy of WSB method tends to be better in the shallower area between 5-12m.

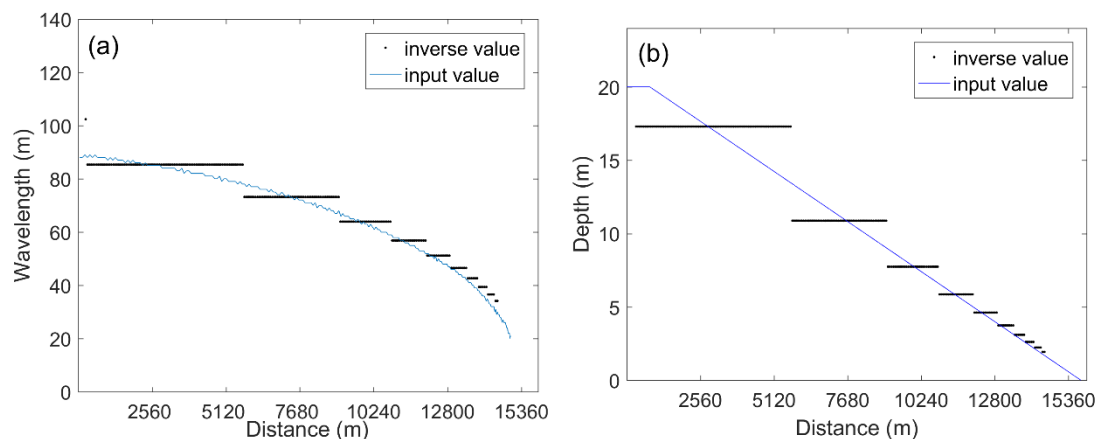


Figure 2. Case 1. Wavelength (a) and depth (b) from deep to shallow water, including input value of FUNWAVE model and inverse value obtained using the WSB method.

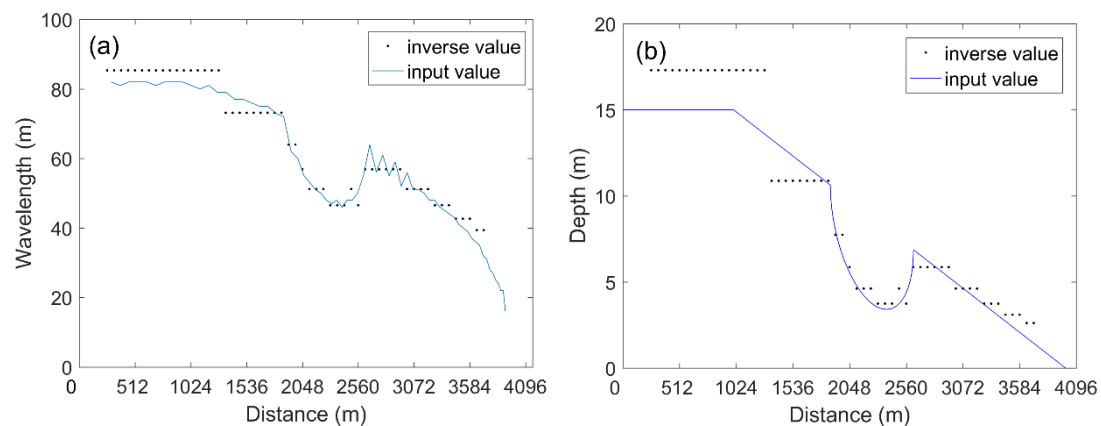


Figure 3. Case 2. Wavelength (a) and depth (b) from deep to shallow water, including input value of FUNWAVE model and inverse value obtained using the WSB method.

4. Conclusion

This study introduces the Wave Spectrum Bathymetry (WSB) method as a feasible way to detect the near shore bathymetry via remotely sensing especially in the regions where ships cannot reach. Some previous work has been done to derive the bathymetry by means of the WSB method, but few tests the method for suitable water ranges and topography. To exam the method, using numerical simulation instead of the remotely sensing imagery can easily control variables (e.g., wave characteristics and sea bottom). Assuming that the wave period without changing when wave propagate from deep to nearshore water, the wavelength is more sensitive to water depth changes, especially within 10m range. Based on the dispersion relation and wave spectral analysis, nearshore bathymetry can be calculated by wavelength and wave period.

The FUNWAVE model is used for surface elevations over a plane slope and an elliptical shoal. The WSB method results show a better agreement between input and inversion bathymetries when the region depth is shallower at the range of 5-12m, with the mean relative error within 8%. Even in relatively complex topography like shoal, the method also does well. However, in regions with abrupt change bottom, the method may be not present the detail for the limit of subscene size or spatial resolution. Further investigations are in need to clarify the above questions.

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