Bathymetry Estimation of Taiwan Bank Using MODIS Image

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Abstract

Taiwan bank is a relatively shallow and flat surface, which locates near the middle line Taiwan Strait. The area of Taiwan bank is estimated to be more than 10,000 km2. Applying shipborne acoustic survey technology in this area would be time consuming and financially infeasible. In this study, we employed a MODIS image acquired in summer, when the water turbidity is lower than other seasons. The bathymetry of Taiwan bank is estimated by band ratio technique.

Introduction

Bathymetry estimation using remote sensing images has been conducted for decades. It is most cost efficient for remote ocean (Leu, 2004; Roman et al., 2007). In this study, we follow the procedure reported by Roman et al. (2007), who has successfully generated the bathymetry of Golf of Lion using MODIS, and apply the same procedure to Taiwan Bank, which is near the middle line of Taiwan Strait and rarely visited ships due to it shallow depth.

Material and Methods

Satellite image

We inspected the MODIS image depository held at SeaDAS website (http://seadas.gsfc.nasa.gov/) and found that cloud cover prevents complete image coverage of Taiwan bank in most of the images. Also, it is found that the Kuroshio current passing through Taiwan Strait from south to north all year round affects water turbidity. The water turbidity is worst in winter and spring, when the Kuroshio current is at its apex. Thus, MODIS images collected in summer is more suitable for bathymetry estimation. Thus, we choose the image with ID A2006177053000 acquired by MODIS/Aqua on 26 June 2006 which is shown in Figure 1.

Level 2 product of remote sensing reflectance in the visible range is extracted by

SeaDAS 4.9. The spatial resolution is 1 km

Ground truth

An acoustic survey was provided by Ocean Data Bank (ODB), National Center for Ocean Research of Taiwan. In addition, a bathymetry map with a spatial resolution of 500 m, which is compiled using a decadal acoustic survey, is also provided by ODB. The acoustic survey was conducted on 29 June 2006 and includes 53,781 data points. The ship route is indicated by the red line in Figure 1.

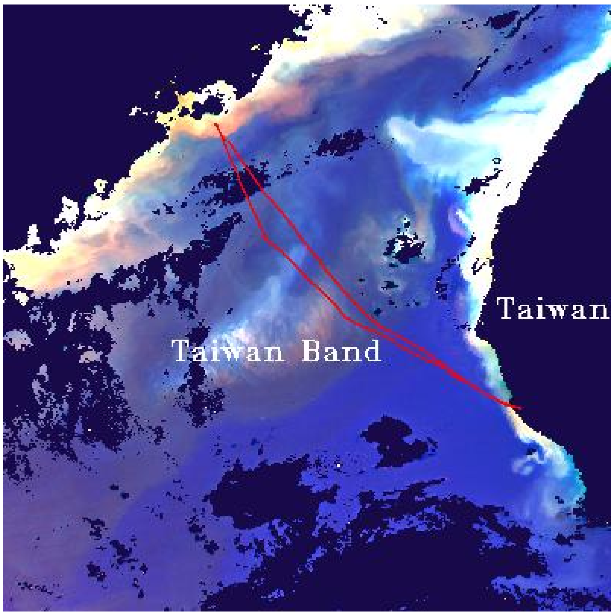

Figure 1. MODIS image A2006177053000 (Color composite: red – 667 nm; green – 551 nm; blue – 488 nm). A ship route of the acoustic survey is denoted by the red line.

Methodology

The reflectance of each pixel is consisted of the radiances contributed from water column and seabed. Following the method provided by Roman et al. (2007), the water surface reflectance is shown in Equation (1)

$$\rho_s(\lambda) = [\rho_b(\lambda) - \rho_w(\lambda)]e^{-2k(\lambda)z} + \rho_w(\lambda) \qquad (1)$$

where

ρ_s is surface reflectance;

ρ_b is seabed reflectance;

ρ_w is deep-water reflectance;

k is diffuse attenuation coefficient;

z is water depth.

Green and red bands are reported to be the most appropriate bands for bathytmetry estimation. Thus, by re-arranging Equation (1) for green and red bands, a set of X and Y can be obtained:

$$\begin{aligned} X &= \ln[\rho_s(\lambda_g) - \rho_w(\lambda_g)] \\ &= \ln[\rho_b(\lambda_g) - \rho_w(\lambda_g)] - 2k(\lambda_g)z \\ Y &= \ln[\rho_s(\lambda_r) - \rho_w(\lambda_r)] \\ &= \ln[\rho_b(\lambda_r) - \rho_w(\lambda_r)] - 2k(\lambda_r)z \end{aligned} \qquad (2)$$

where the subscribe of *g* and *r* denotes green and red bands, respectively. The regression slope in the Y - X plot can be is equal to the ratio of the diffusion attenuation coefficients of red and green band, $k(\lambda_r)/k(\lambda_g)$.

A spectral rotation angel θ can be found by taking arc tangent of $k(\lambda_r)/k(\lambda_g)$. After applying the rotation on the Y – X plot, the water depth can be estimated on the z axis of the new coordinate system (Z, R) shown in Figure 3. And the mathematical form of z is shown in Equation (3).

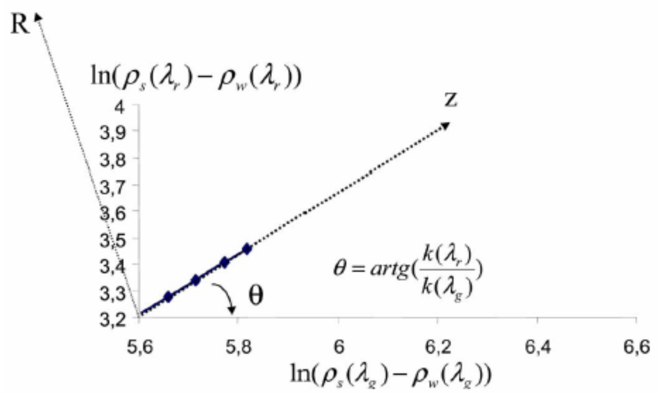

Figure 3. Spectral rotation for bathymetry estimation (adapted from Roman et al., 2007). See text for detail of variables.

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$$Z = a\left[\ln\left[\rho_s(\lambda_g) - \rho_w(\lambda_g)\right] + \frac{k(\lambda_r)}{k(\lambda_g)}\ln\left[\rho_s(\lambda_r) - \rho_w(\lambda_r)\right]\right] + b \qquad (3)$$

For the above mentioned values, ρ_s is obtained from each single pixel of the MODIS image, ρ_w is obtained by averaging a group of pixel representing deep water, and $k(\lambda_r)/k(\lambda_g)$ is estimated by linear regression in Y- X plot. The coefficients of *a* and *b* in Equation (3) requires ground truth for calibration.

Result and Discussion

Regression coefficients

MODIS band 4 (667 nm) and band 5 (551 nm) are chosen for the representation of red and green bands in Equation (3), respectively. A region of interest (ROI) is selected for the representation of deep water shown as red region in Figure 4a. Figure 4b shows the regression result for the ratio of diffuse attenuation coefficient of two wavelengths, $k(\lambda_r)/k(\lambda_g)$, obtained using the deep water ROI is 0.84, where the coefficient of determination R^2 is 0.8.

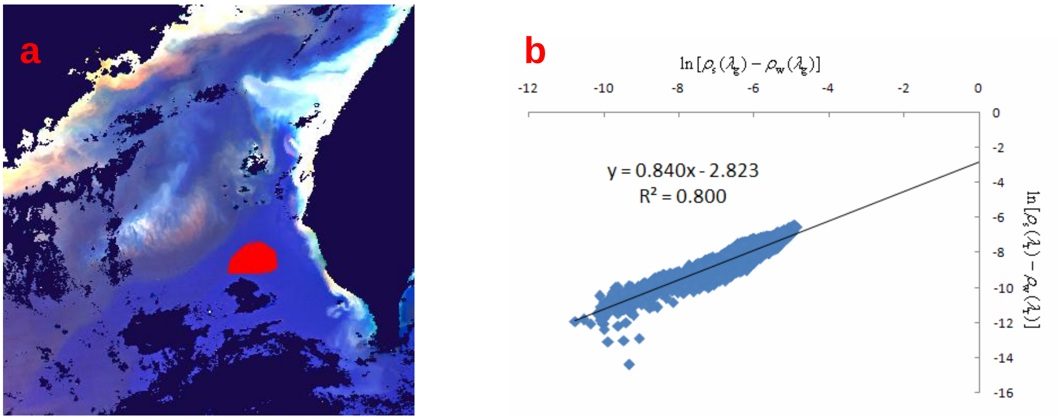

Figure 4. (a) The red region indicated the deep water ROI. (b) Regression result for the ratio of diffuse attenuation coefficient of two wavelengths, $k(\lambda_r)/k(\lambda_g)$, obtained using the deep water ROI in (a).

The acoustic data are divided into two subsets, track 1 and track 2 shown in Figure 5. Because the sampling interval of acoustic survey is much smaller than the spatial resolution of MODIS image, the acoustic data enclosed by a MODIS pixel are averaged as the representative depth. Thus, a total of 178 and 169 depth values are obtained for tack 1 and track 2, respectively.

Four test studies are conducted in order to verify the bathymetry estimation accuracy as follows.

Case 1: Use data from track 1 as training pixels and those from track 2 for verification.

Case 2: Use data from track 2 as training pixels and those from track 1 for verification.

Case 3: Randomly select 30 pixels from track 1 and track 2 as training, and use data from track 1 for verification.

Case 4: Randomly select 30 pixels from track 1 and track 2 as training, and use data from track 2 for verification.

The comparisons of acoustic survey and bathymetry estimation from MODIS image for all the above mentioned cases are shown in Figure 6. Although the overall trend of the acoustic survey and bathymetry from MODIS are similar, there are differences in details, which merit further inspection in future study.

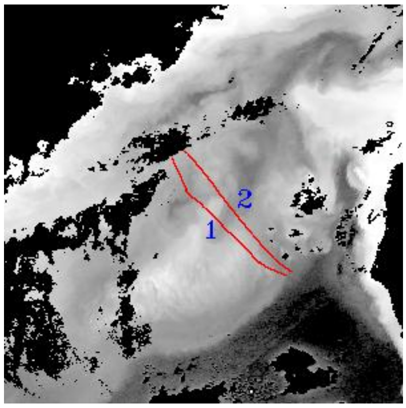

Figure 5. Track 1 and track 2.

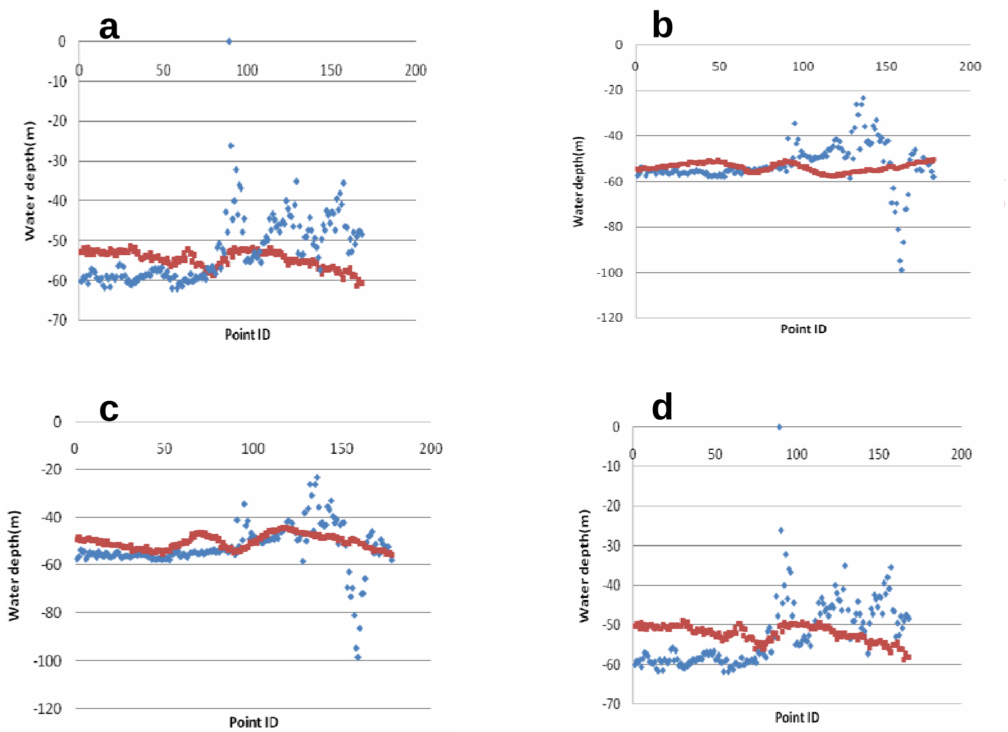

Figure 6. Comparisons of acoustic survey (blue dots) and bathymetry estimation (red dots) from MODIS: (a) case 1; (b) case 2; (c) case 3; (d)case 4.

Comparison of bathymetry estimation from MODIS and bathymetry map from ODB is shown in Figure 7. The water depth of Taiwan Bank is shallower in both maps, however, the detailed bathymetric variation are different. Postulations include the effect of variations of water optical properties within and near the region Taiwan Bank and choices of training pixels fro the calibration of *a* and *b* coefficients in Equation (3).

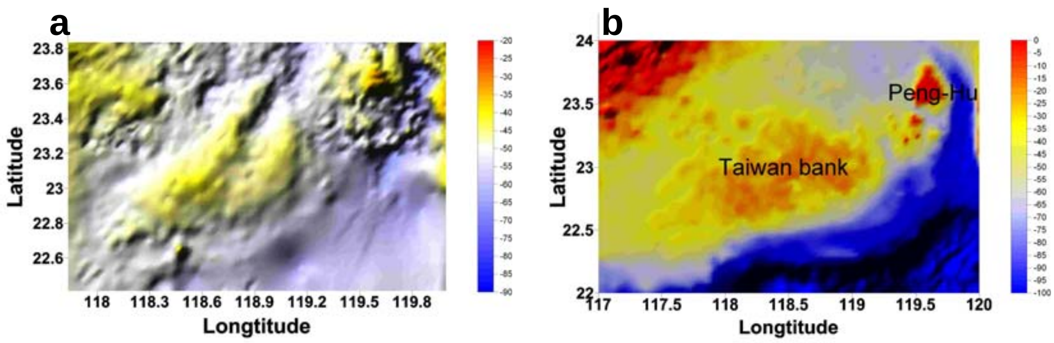

Figure 7. (a) Bathymetry estimation from MODIS. (b) Bathymetry map from ODB.

Conclusion

Bathymetry estimation using band ratio technique is demonstrated in this study. Although it has been successfully applied to many sea waters, it does not merit trivial applications. The choices of deep water pixels in Equation (2) and training pixels for Equation (3) are essential for a good bathymetry result.

References

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