Correlation Analysis of Underwater Bottom Topography and Its SAR Images

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Abstract

Processes of underwater bottom topography (water depth) being imaged by SAR includes some complicated interaction processes. The main imaging mechanism of underwater bottom topography is well known. SAR image of underwater bottom topography is correlative to tidal current in SAR imaging time. Three scenes of ERS SAR images and in situ measurement water depth of three profiles of Taiwan Shoal were used to analyze the correlation of underwater bottom topography and its SAR images obtained in different times. SAR images of the same underwater bottom topography obtained in different times are different through SAR influences of magnitude and direction of tidal current to SAR images was learned by correlation analysis. Qualitative relation between underwater bottom topography and its SAR images was established by correlation analysis.

1. Introduction

SAR image includes many kinds of information about ocean. One important application of SAR in ocean is to detect underwater bottom topography. Since America launched Seasat in 1978, many scholars began to study underwater bottom detection by SAR. De Loor firstly found underwater bottom topography in one image of real aperture radar in 1978. Alpers and Hennings(1) firstly presented a theory of SAR imaging of underwater bottom topography. From then on many theories and models of SAR imaging were put up. In these theories, the main reason why underwater bottom topography can be observed by SAR is that tidal current flowing over underwater bottom topography modulates roughness of ocean surface. So SAR images of the same underwater bottom topography in different times are different. Tidal current influences the detection of underwater bottom topography by SAR.

Relationships between tidal current and SAR image of underwater bottom topography are complicated. One should know influence of varieties of tidal current to SAR image of underwater bottom topography. Alpers and Hennings thought gray values of SAR image are correlated with the slope of the depth profile divided by the square of the depth. In this paper, three scenes of ERS-2 SAR image of Taiwan Shoal and in situ measurement of water depth in three profiles are used to study correlation of underwater bottom topography and its SAR image.

Fig.1. Schematic figure of research area

2 DATA OF RESEARCH AREA

2.1 Research Area
Research area is Taiwan Shoal. It lies in southern part of Taiwan Strait. Taiwan Shoal is a mesa which is surrounded by steep slopes, and there are hundreds of sandbanks in Taiwan Shoal. Water depth of Taiwan Shoal is about several decades meters. Fig.1 is schematic figure of research area where small rectangle is the area of in situ measurement of water depth and large is SAR covering area.

2.2 In Situ Data of Water Depth
Water depth of three profiles along latitude was measured by sounding instrument aboard ship on 11th September 2005. Three profiles lie in 118.6°E (Profile 1), 118.63°E (Profile 2) and 118.68°E (Profile 3), respectively. Fig.2 is water depth after tidal correction of three profiles.

![Fig.2. Water depth in three profiles of Taiwan Shoal](image)

2.3 SAR Images
Three scenes of ERS-2 SAR images (fig.3) are used in this study. They were acquired in 31st October 1999, 9th January 2000 and 6th June 2004, respectively. Tab.1 is the basic information of these SAR images.

![Fig.3. Three ERS-2 SAR images of Taiwan Shoal (©ESA 1999, 2000, 2004)](image)

<table>
<thead>
<tr>
<th>No.</th>
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<th>Center Longitude/Latitude</th>
<th>Resolution</th>
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3  ANALYSIS OF TIDAL CURRENT

Tide and tidal current of Taiwan Strait was numerically simulated with Princeton Ocean Model (POM) and data of tide table. We can know tidal current in the research area is alternating current and varieties of velocity of flow is small in whole research area from analysis of simulation results integrated with others’ research results. The main tide component of Taiwan Shoal is semidiurnal tide. According to SAR imaging time of three SAR images, we can know that the directions of tidal current in SAR imaging time of three SAR images were northwest, north and northeast, respectively. They are showed in fig.5 by white arrows. Left figure of fig.4 is tidal current field in some time obtained by POM. Middle[2] and right[3] figures are the others’ study results.

![Fig.4. Tidal current of Taiwan Strait](image)

4  CORRELATION ANALYSIS

We calculate backscatter cross section of three SAR images. Three sub-profiles are selected to study correlation between underwater bottom topography and its SAR image. Fig.5 is the map of backscatter cross sections of three SAR images. Red line is profile 1. Blue line is profile 2. Green line is profile 3. Fig.6 is distribution of backscatter cross section of three profiles in three SAR images.
In order to analyze correlation between underwater bottom topography and its SAR image, we define correlation coefficient between underwater bottom topography and backscatter cross section or its slope of its SAR image. Correlation coefficient is:

\[ R = \frac{S_{h\sigma}^2}{S_{hh} S_{\sigma\sigma}} \]  

(1)

Where,

\[ S_{hh}^2 = \sum_{i=1}^{m} \left[ h(i) - \bar{h} \right]^2 / m \]  

(2)

\[ S_{\sigma\sigma}^2 = \sum_{i=1}^{m} \left[ \sigma(i) - \bar{\sigma} \right]^2 / m \]  

(3)

\[ S_{h\sigma}^2 = \sum_{i=1}^{m} \left[ h(i) - \bar{h} \right] \left[ \sigma(i) - \bar{\sigma} \right] / m \]  

(4)

\( h(i)(i=1,2,...,m) \) is water depth in some profile, and \( \bar{h} \) is its average. \( \sigma(i)(i=1,2,...,m) \) is backscattering cross section
of SAR image or its slope in some profile, and \( \sigma \) is its average.

Calculate correlation coefficients between underwater bottom topography and backscattering cross section and correlation coefficients between underwater bottom topography and slope of backscattering cross section in three sub-profiles of three SAR images, and analyze results combined with tidal current in SAR imaging time.

Fig. 6. Comparison of water depth and the slope of backscatter cross section

Calculate correlation coefficients between underwater bottom topography and backscattering cross section and correlation coefficients between underwater bottom topography and slope of backscattering cross section in three sub-profiles of three SAR images by Eq. 1, and analyze results combined with tidal current in SAR imaging time.

Results show that Correlation between underwater bottom topography and slope of backscattering cross section of SAR image is better than that between underwater bottom topography and backscattering cross section. In sub-profile 1, slope of water depth is small and angle between direction of tidal current and direction of slope of water depth is large. Correlation between underwater bottom topography and backscattering cross section is not so well. So the stripes of topography in three SAR images are different because angles between direction of tidal current and direction of slope of water depth are different. In sub-profile 2, sandbanks are typical and its slope is large enough that the stripes of topography in three SAR images are clearly. But varieties of backscattering cross section are not corresponding to varieties of its underwater topography because velocities of tidal current are different in three SAR images. In sub-profile 3, sandbanks are also typical and its slope is smaller than in sub-profile 2. So stripes of topography in three SAR images are different and the stripes in the first and third SAR images are not clearly.

5 CONCLUSION

Based on the study above we can know:
(i) Position of stripes of underwater bottom topography in SAR image changes with tidal current, and it is not always corresponding to position of underwater bottom topography. Varieties of velocity of tidal current cause the varieties of
position of stripes in SAR image, and position of stripes is before the position of real topography in direction of tidal current.

(ii) In conditions of the same tidal current and water depth, underwater bottom topography which can be observed by SAR has the minimal slope of water depth.

(iii) Slope of backscattering cross section in SAR image increases with the velocity of tidal current. Varieties of underwater bottom topography are corresponding to varieties of slope of backscatter cross section in SAR image.

ACKNOWLEDGEMENT

This research was supported by the Dragon Programme through id 2566.

REFERENCES