SIMULATION STUDY ON THE EFFECT OF SAND DIGGING AND HEAPING ON SAR IMAGING IN THE PEARL RIVER ESTUARY

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ABSTRACT:

There are frequent sand digging and heaping activities in shoal in the Pearl River Estuary (PRE). Water depth has changed in patches, which can be imaged by synthetic aperture radar (SAR). According to SAR imaging mechanism of underwater bathymetry, a 3-D hydrodynamic model is used to demonstrate the temporal variations of the shoal topography changes due to sand digging and heaping. A microwave radar imaging of oceanic surface's program is used to simulate the variation of normalized radar cross section (NRCS) induced by the ocean surface current. The simulation is carried out to study the digging-heaping shape, water depth changes on SAR imaging of shoal bathymetry. Results indicate several points as followings. 1. Circle-shaped sand digging and heaping are imaged clearer by SAR than other shapes. 2. Sand heaping has a greater effect on SAR imaging than sand digging. 3. Bigger depth change induces bigger NRCS variation.

1. INTRODUCTION

Since the 1980s, with the economic booming in China, there has been great demand of sand for the infrastructure. A large amount of sand is being minded across most rivers in China regions with the largest scale of such activity in the middle and lower reaches of the Yangtze River, the Pearl River Delta, and the adjacent estuarine areas (Jia et al, 2007). Illegal and disordered sand dredging has induced a lot of problems such as fall of water level, serious riverbed deformation as well as turbulent currents in waterways, and then the security of flood control and stabilization of river regime is badly influenced (Xie, 2007; Han et al., 2005). Also, the deterioration of ecological environment in these estuarine areas has something to do with the frequent sand excavation activities (Liu et al., 2006). Thus, the sand excavation has been the focal points of the academic research since the 1990s.

With the rapid population growth and economic development, the Pearl River Delta is the area with the highest urbanization development level. The Pearl River Estuary (PRE), located at the middle south of Guangdong Province, is a bell-shaped estuary with a north-south direction. The shoal alternates with the deep trough within the bay. From west to east, there are the west shoal, the Lingding Channel, the middle shoal (Fanshi shoal), the Fanshi Channel and the east shoal (Chen et al., 2011). There are plenty of sand resources in channels and shoals in the PRE, which can supply raw materials for construction. The sand excavation has a long history in the PRE. There are two kinds of large-scale dredging activities, one is reclamation for construction, and the other is channel dredging (Liu et al., 2005).

Water depth has changed in patches in the shoals of PRE, which can be imaged by synthetic aperture radar (SAR). Fanshi shoal, the important dredging area, also the mud dumping area of Lingding Channel, has tremendous sand digging and heaping activities. So this paper takes the Fanshi shoal as a case to simulate the sand excavation including sand digging and sand heaping by using hydrodynamic model and SAR remote sensing methods.

2 STUDY AREA AND DATA

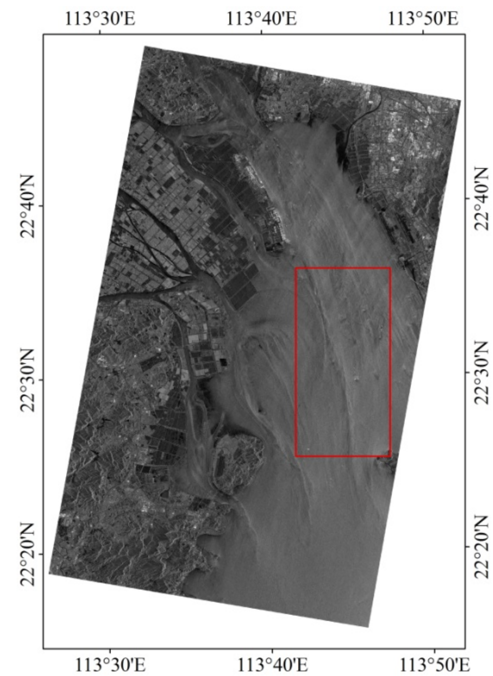

Figure.1 SAR image and study area (in red rectangle)

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surface can cause signatures in radar images via hydrodynamic and aerodynamic modulation of the surface wave spectrum. (Romeiser, 2005)

3.2.1 Parameters in the 3-D hydrodynamic model: The simulation time of current of the PRE is the same as the acquisition time of the Terra SAR-X image used in this paper. The input water depth is the field data obtained in 2012.

3.2.2 Parameters in M4S programs: in the computation of spatially varying wave spectra, a limited quadratic source function, the RA surface wave spectrum (Romeiser & Alperse, 1997) and Plant relaxation rate (Plant, 1982) had been chosen. Based on the parameters of the Terra SAR-X images used in this study, the other parameters input in the computation of radar signatures are as follow: the incident angle is 21.3° , the radar frequency is 9.65 GHz, the radar polarization is VV, the platform altitude is 514.8km, and the platform velocity is 7km/s. The composite surface model was chosen as the radar cross section mode (Romeiser & Alpers, 1997)

3.3 The simulation scheme

The simulation is carried out to study the digging-heaping shape, water depth changes on SAR imaging of shoal bathymetry.

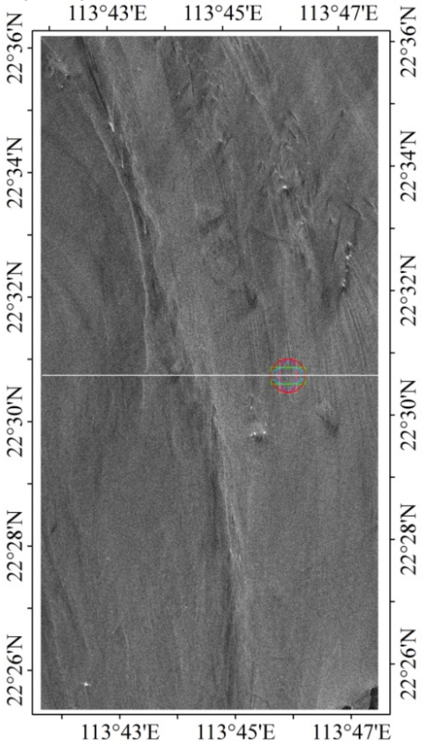

Figure.4 Sand digging and heaping area (the color-labeled place)

3.3.1 Simulation of different shapes: five different shapes are considered in the simulation: circle, ellipse in two directions (N-S direction and W-E direction) and rectangle in two directions (N-S direction and W-E direction). According to the real sand excavation activities in location A (see Fig.1 b), the parameters of the five shapes are set as follows: the diameter of the circle is 1km, the major axis and minor axis of both ellipses are 1km and 0.5 km separately, and the length and width of both rectangles are 1 km and 0.5 km separately. The average depth in the excavation area is about 5m. So the depth of sand excavation in these five shapes is set as 9m, namely this simulation is actually under the case of sand digging.

3.3.2 Simulation of different depths: The depth of sand digging is defined between 6 m to 11 m with a change interval of every meter while that of sand stacking is defined between 3m to 5.5m with a change interval of every half meter.

4 RESULTS AND DISCUSSION

A relative normalized radar backscattering cross section (NRCS) has been defined as $\Delta\sigma_0 = |\sigma_0 - \sigma_0^0|$, σ_0 is the SAR NRCS of underwater bathymetry, while σ_0^0 is the SAR NRCS in the ambient field without current filed modulation. $\Delta\sigma_0$ can demonstrate the clarity of the dark and bright streaks in the SAR imaging of underwater bathymetry. S_{BD} (dB) is the absolute value of the difference value of the dark and bright streaks which can reflect the imaging capability of SAR underwater bathymetry (Fan et al, 2007).

Fig.4 shows that the $\Delta\sigma_0$ of circle-shaped sand digging is bigger than others, while there is no significant difference between ellipse-shaped and rectangle-shaped sand digging. Also, with the same shape, the $\Delta\sigma_0$ in W-E direction is bigger than that of N-S direction, we suppose this has something to do with the current direction in this area, which is N-S direction in the acquisition time of the Terra SAR-X used in our study .

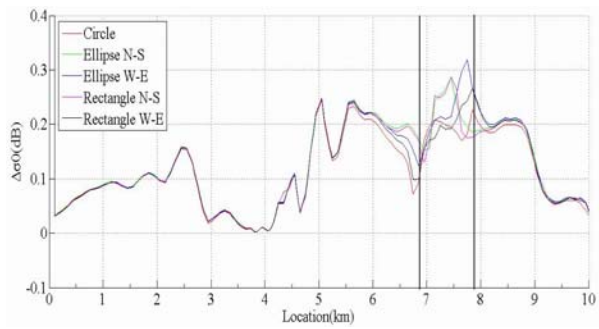

Figure.5 The relative NRCS of sand digging under different shapes along the white solid line in Fig.4, the profiles of sand digging area are between two black solid line.

A circle-shaped sand heaping with a depth of 3m has been carried out, to compare with the circle-shaped sand digging, as mentioned before, whose depth is 9m. The result shows that, when the depth changes 2m (from 5m to 3m), the S_{BD} of sand heaping is 0.6dB, which is equivalent to a average variation of 0.3 dB per meter; when the depth changes 6m (from 5m to 11m), the S_{BD} of sand digging is 0.2 dB, which is equivalent to a average variation of 1/30 dB per meter. Namely, the S_{BD} of sand heaping is bigger than that of sand digging, which means sand heaping has a greater imaging effect by SAR than sand digging. The light streak appears in the left of the sand heaping area, while the dark streak appears in the right, which is contrary to the case of the sand digging (see Fig.6).

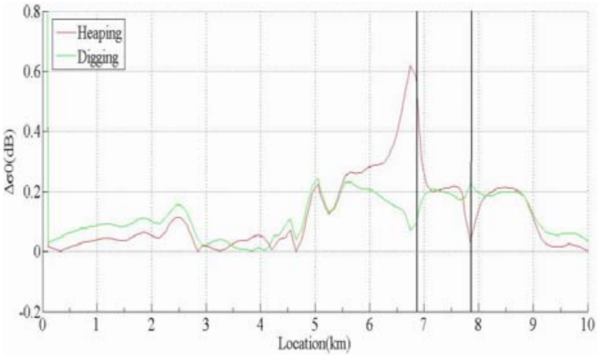

Figure.6 The relative NRCS of sand heaping and digging along the white solid line in Fig.4, the profiles of sand digging and heaping area are between two black solid line.

The simulation images of the real topography and sand digging and heaping show similar results. Changes on underwater topography can be clearly reflected by SAR, there are light and dark streaks around the sand digging and heaping area. For sand heaping, the light streaks are located in the NE-SW direction, while the dark steaks are located NW-SE direction, which is contrary to the case of the sand digging. We suppose the directions of light and dark streaks are also related to the tidal flow direction in the study area (see Fig.7).

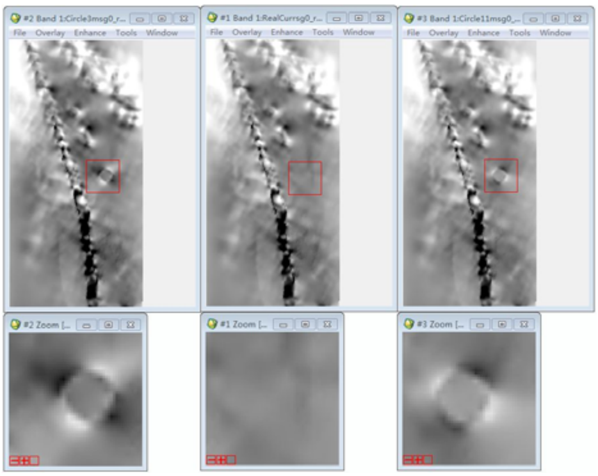

Figure.7 The simulation images of: Left: sand heaping; Mid: real topography; Right: sand digging.

As Fig. 8 shows, the bigger depth change compared with base depth of 5m, the bigger $\Delta\sigma_0$ of sand digging in SAR image, for example, the $\Delta\sigma_0$ of 11m is 0.25 dB, while the $\Delta\sigma_0$ of 6m is less than 0.1 dB. So it is with sand heaping (see Fig.9). That means bigger depth change induces bigger NRCS variation.

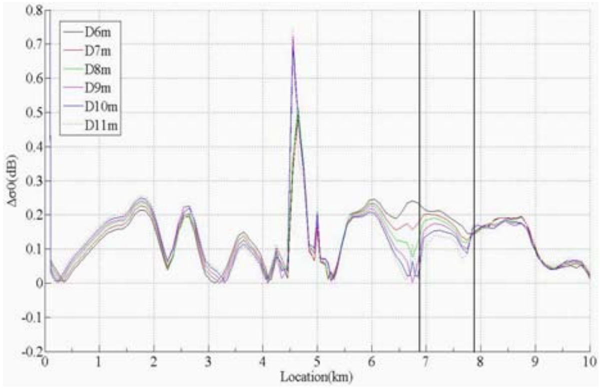

Figure.8 The relative NRCS of sand digging under different depths along the white solid line in Fig.4, the profiles of sand digging area are between two black solid line.

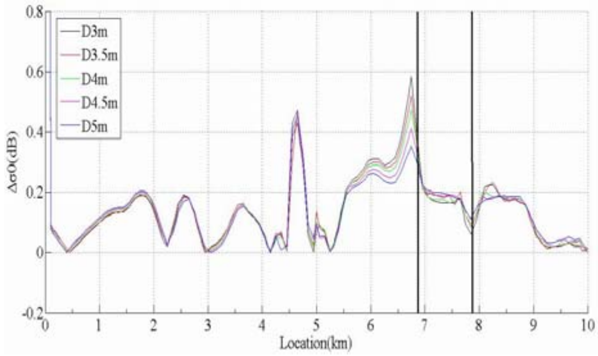

Figure.9 The relative NRCS of sand heaping under different depths along the white solid line in Fig.4, the profiles of sand heaping area are between two black solid line.

5 CONCLUSIONS

Results indicate several points as followings.

(1) Circle-shaped sand digging and heaping are imaged clearer by SAR than other shapes.

(2) Sand heaping has a greater effect on SAR imaging than sand digging. The profile images shows that the light streak appears in the left of the sand heaping area, while the dark streak appears in the right, which is contrary to the case of the sand digging. Similar results are derived from the simulation images. Also, we suppose the directions of light and dark streaks are also related to the tidal flow direction in the study area.

(3) Bigger depth change induces bigger NRCS variation, which is suitable in the cases of both sand heaping and digging.

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