A Self-Organization Model for Multi-Scale Bedforms in Tidal Inlets and Bedform-Induced Roughness

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ABSTRACT: Bedforms are predicted with a self-organization model. The model predicts realistic features and their dynamics. Predicted features are compared with bedforms from field experiments and from the literature. One goal of this work is to estimate roughness based on predicted bedforms.

1. INTRODUCTION

Bedforms are ubiquitous in unconsolidated sediments. They range in size from small orbital ripples (□□ ~5-50 cm) to megaripples (□□~1-5 m) to large dunes (□□~10s-100s m). Bedforms are important because they affect sediment transport, flow energy dissipation, and larger-scale hydro- and morpho-dynamics. Bedforms in different environments (eg, deserts, rivers and oceans) are thought to be dynamically similar, therefore modeling approaches from one environment can be used to predicted features in another (Gallagher 2011). Here, a self-organization model is used to simulate the formation and development of bedforms in the combined flows of the surf zone, tidal inlets and river mouths. Sediment flux is determined from combined wave and current flows using different formulations, but, interestingly, the transport formulation has little effect on model results. Random bed irregularities, either imposed or resulting from small variations in the flow representing turbulence, are seeds for bedform development. Feedback between the bed and the flow in the form of a shadow zone downstream of a bedform and increasing flow velocity with elevation over bedform crests alter the transport such that organized bedforms emerge. The model has been used to predict surf zone megaripples and bedforms in tidal inlets and river mouths.

Many observations report multiple scales of bedforms existing simultaneously in tidal inlets and in rivers (Barnard et al. 2006, Bauijsman and Ridderinkof 2008, Parsons et al. 2005, Ernstsen et al. 2005, Lefebvre et al. 2011). Large-scale features take longer to adapt to changing flows, simply because there is more sand to move, thus they will maintain their orientation or equilibrium (like under flow direction changes in a tidal inlet). Whereas superimposed smaller-scale features can change shape more quickly and change direction. A recent study by Lefevbre et al. (2013) found that the boundary layer thickness and resulting bedform-induced roughness was different for single and multiple bedform fields. During one phase of the tide large features induced flow separation and generated increased flow roughness. When the tide turned these large features no longer induced separation and only smaller-scale features, which changed their orientation, generated flow roughness.

2. PRELIMINARY RESULTS

The present model predicts multiple bedform scales and is being used to examine the development and the temporal evolution of primary and secondary bedforms as a function of flow characteristics and water depth (the two factors that Sterlini et al. 2009 said were most important). The present model does not accurately represent the vertical flow profile above the bedforms. However, using the modeled bedforms shape, inferences about the time-history of the drag over changeable bedforms can be made. Following the observations of Lefebvre et al. (2013), if a bedform is asymetric in the downstream direction, with a steep lee slipface, then it will cause flow separation and it will generate more drag on the flow, thus the bedform-induced roughness will increase dramatically (an order of magnitude). If a bedform is not oriented with the flow and/or its slopes are gentler (less than 10-15 degrees, Paarlberg et al. 2009), then they do not induce separation and they appear smoother to the flow.

Observations from the New River Inlet (Fig 1) come from Peter Traykovski, (pers. comm., https://vimeo.com/44806773) and show dramatic bed changes over a tidal cycle. There are bedforms of 1-3 m lengths that exist most of the time. But they change orientation with the tide, they sometimes have superimposed, smaller-scale bedforms, and they are sometimes smoothed or even wiped out. In contrast to Lefebvre et al. (2013), these observations are from shallow water and there are no permanent bedforms with fixed orientation. However, these features will generate their own roughness time series, including increased roughness owing to secondary bedforms and reduced roughness when features are reorienting and there is no lee slip face and separation. Figure 2 shows modeled results that are similar to those in Fig 1. The four sets of panels illustrate changes in bedforms from one slack period to the next. Near slack tide (t=19200s, top panels in Fig 2) the model predicts a bed where large bedforms (oriented to the left) have been smoothed by the waning water velocities just before slack. This is similar to the third panel in Fig 1, which is just before slack tide. As the tidal flow begins to pick up strength in the opposing direction, the existing bedforms begin to reverse direction and secondary features start to build (t=19320s, second panel, Fig 2, similar to left panel in Fig 1). In the third panel (t=19450s in Fig 2), the larger bedforms are still visible, but the strong flows have helped to build the secondary features (similar to second panel in Fig 1). (Note that the model makes bedforms too tall and peaky when flows are strong. This is owing to anomalously large transport gradients at the bedform crests, because there is no sediment suspension and bypassing in the present simplistic model.) As the tidal flows wane again the large features are smoothed and the underlying bedforms again are visible. This series of images is similar to what is observed in the natural tidal inlet (Fig 1).

Results like this are encouraging and it is expected with a few model improvements, the correspondence with the observations will be better and our understanding of bedform growth, development, adaptation, sediment transport and roughness will all be informed and improved. Using model results, roughness time series will be constructed and compared with measurements of roughness from velocity profiles. From this understanding, fluid flow models can be improved with predictions of time varying roughness.

3. CONCLUSIONS

Bedforms in a natural tidal inlet are highly dynamic, changing shape and orientation and migrating over the course of a tidal cycle. The roughness induced by these bedforms can also change depending on their characteristics (Lefebvre et al. 2013). A self-organization model is being used to predict bedform characteristics and from that changing roughness regimes. The goal of this work is to inform larger-scale hydro- and morpho-dynamic models.

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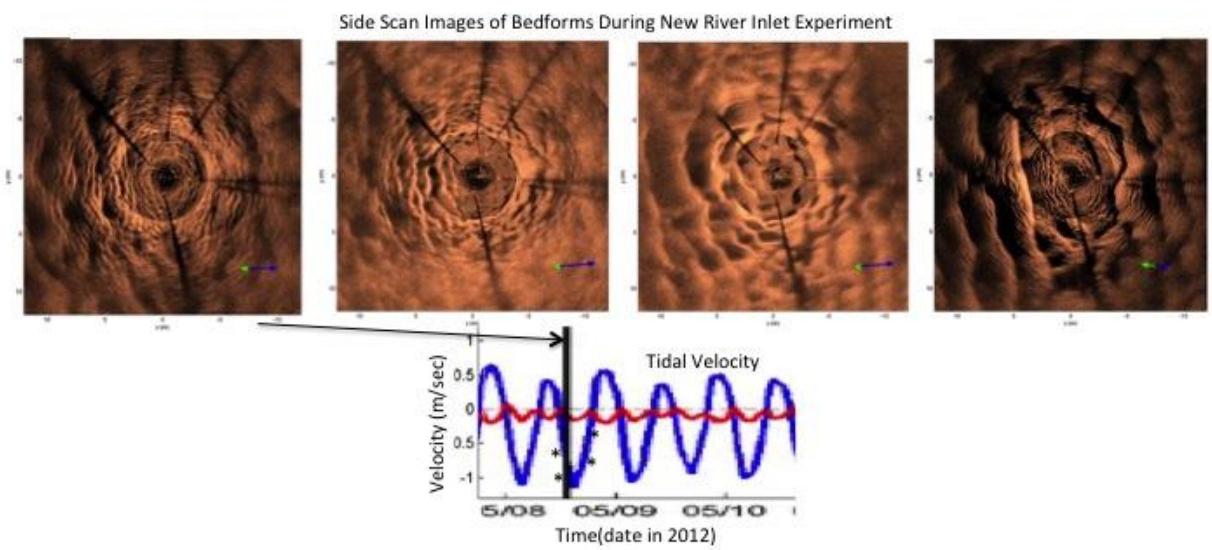

Figure 1. Examples of bedforms from side scan sonar images from the New River Inlet experiment (Traykovski, per.s comm., https://vimeo.com/44806773). The four panels are from a single ebb tide and the time of each image (from left to right) is indicated by an asterisk in the lower velocity panel. This time series of bedforms over an ebb tidal cycle suggests a change in orientation, an increase and then a decrease in bedform roughness. Dark brown color indicates acoustic shadows and lighter colors indicate surfaces sloped toward the sonar. Outward rays are shadows of the sensor platform.

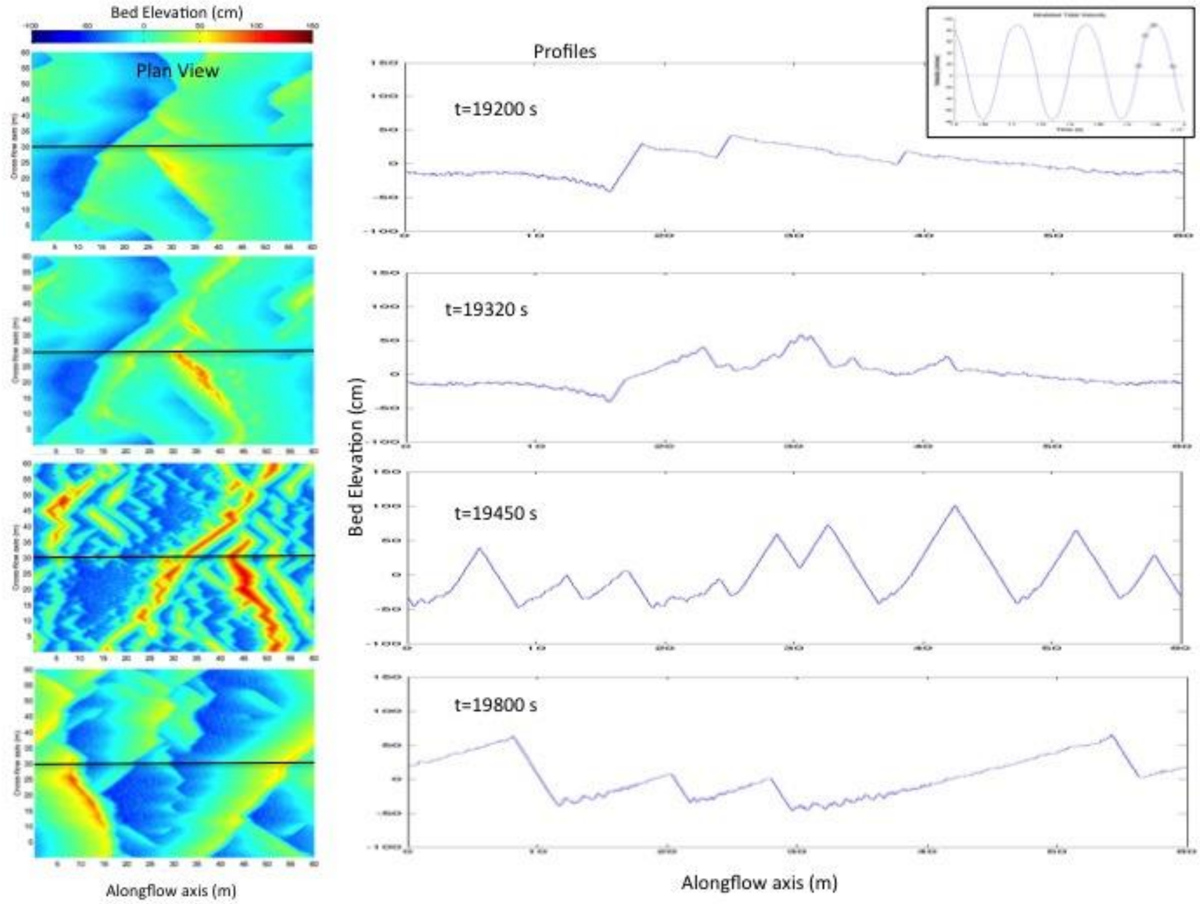

Figure 2. Modeled bedform time series over a single ebb tidal cycle (asterisks in small top panel indicate time in the cycle). Left panels show plan views of beds, right panels show profiles along black line in left panels. Large bedforms with wavelengths of about 15 to 20 m have formed, but are broken down and reformed with each tidal cycle (similar to observations Fig 1). The time series of roughness can be estimated from bedform predictions like these. (Note, peaky bedforms in panel 3 are anomalously high, see text.) Conditions are steady flow, S = 15 cm/sec, oscillatory flow amplitude, A=95 cm/sec, tidal period, P=1200 sec. Positive velocity is from left to right. This model run was for 20000 secs.