Sediment erosion and coherent flow structures in the nearshore zone of coastal environments

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Introduction:

This experimental project aims to develop new understanding of the role of coherent flow structures in sand transport in the nearshore zone of coastal environments. This new understanding will be gained by addressing the following question: What is the effect of ripple morphology on the size and dynamics of coherent motions, and on their role in sand transport?

Ripples, typically 0.01–0.1 m high and 0.1–1.0 m long, are common bed form features across the coastal nearshore region (e.g. Williams et al., 2003). Above rippled beds, water movement and the associated sand dynamics in the near-bed layer are dominated by coherent motions. These motions are arranged in alternating high and low-speed streaks that evolve into characteristic vortical structures, sweeps (injection of high-speed fluid toward the bed), and bursts (low-speed ejections from the bed). Sand transport is known to be strongly correlated with these motions, particularly with the process of vortex formation in the stoss- and lee-side of ripples (van der Werf et al., 2007). However, the influence of ripple morphology on the size and dynamics of these different coherent motions and on their relative role in sand transport has yet to be considered in great detail. Focusing on these links is key to advancing predictive models of patterns and rates of sand transport in the nearshore, as well in developing further understanding of the wider role that coherent flow structures play in processes such as seabed morphological evolution and the transport of pollutants and nutrients.

Project Summary:

Objectives

Using detailed measurements of flow and sediment processes in a laboratory flume, the project will achieve the following objectives:

- Characterising the dynamics of coherent flow structures present in the near-bed region over ripples in oscillatory flow
- Understanding the effects of ripple morphology on the size and dynamics of these flow structures under a range of wave conditions (water depth and wave period and amplitude)
- Quantifying the relevant role of different flow structures on sand transport, and how this role relates to ripple morphology
- Linking the geometrical and dynamic properties of the flow structures to sand particle concentrations to develop new parameterisations of ripple regime sand transport

The new dataset collected from the experiments will be invaluable for the advancement of state-of-the-art 3D modelling approaches, as it will provide essential high-resolution data and simultaneous measurements in the wave boundary layer. Thus providing a unique source for model calibrations, helping to inform the direction of future model formulation.

Methods

The project will involve an extensive set of controlled laboratory experiments in the Liverpool Coastal Flow Channel. The channel generates oscillatory flows with periods and amplitudes equivalent to full-scale wave flows and therefore enables wave-generated processes to be studied under controlled conditions. The student will use Liverpool's new state-of-the-art Particle Image and Particle Tracking Velocimetry (PIV-PTV) system to simultaneously measure the flow field and sediment transport. The system involves using a laser and high-speed cameras to image the movement of buoyant particles and sediment within the flow. The PIV-PTV system will allow the student to identify vortex events and the role these events have on the movement of sediment. Continuous, co-located measurements of bed geometry will also be taken using compact cameras and structure-from-motion photogrammetric algorithms developed at Liverpool to provide sub-mm resolution DEMs. The laboratory programme will provide an unprecedented dataset for exploring the link between coherent flow structures, bed morphology and sediment erosion.

Work plan

- Formulation of key research questions based on critical review of literature, state-of-the-art knowledge, and existing datasets
- Research training: in particular, familiarisation with laboratory flume experimentation, PIV and PTV, structure-from-motion photogrammetry, and data analysis techniques (time series analysis, spatial correlation analysis, double-averaging)
- Laboratory work: running a series of flume experiments to explore the effects of bed morphology, flow depth and wave period and amplitude (as per rise and fall of the tide) on the interaction between sediment erosion and coherent flow structure dynamics
- Data analysis: analysis of PIV, PTV and topography data, development of parameterisations that link the properties of flow structures to particle entrainment and transport
- Outputs and dissemination: presentations at national and international conferences, writing reports and papers, PhD thesis

Image 1: Understanding nearshore processes is important because the majority of the world's coastlines are eroding

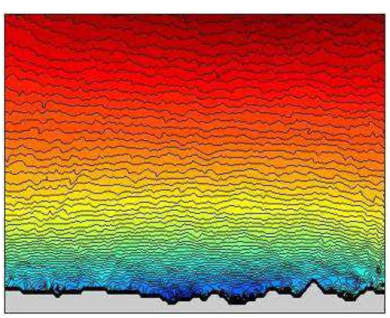

Image 2: PIV measurements of the turbulent flow field over a sediment bed

References

van der Werf, J. J., J. S. Doucette, T. O'Donoghue, and J. S. Ribberink (2007), Detailed measurements of velocities and suspended sand concentrations over full-scale ripples in regular oscillatory flow, J. Geophys. Res., 112, F02012, doi:10.1029/2006JF000614.

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