Geophysical Research Abstracts
Vol. 21, EGU2019-391, 2019
EGU General Assembly 2019

Particle image velocimetry measurements of the flow structure associated with interacting barchan dunes in a refractive index matched flume

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Barchan dunes typically occur in fields with significant heterogeneity in dune size and migration rate. In this situation, the interaction between barchans of different sizes produces complex processes such as collisions, amalgamation and breeding. While the morphology of barchan dunes has been widely studied, the interaction between turbulent flows and barchans is limited to a few recent studies. "Minimal" models without an adequate simulation of the wake flow structure induced by dunes struggle to accurately predict the morphodynamics of barchans when they come in close proximity, including dune–dune collisions. Further experimental work is needed to elucidate the role of unsteady turbulence in barchan morphodynamics.

In the present work, we study the flow field both in the wake of an isolated barchan and in the interdune space of interacting barchans using a combination of low and high frame-rate measurements with both two-component planar PIV and three-component stereo-PIV. The low frame-rate measurements are made in all three spatial planes independently, while high frame-rate measurements were limited to the cross-plane. Several different configurations of models are investigated, including a baseline isolated case and a series of dune–dune collision configurations where the upstream and downstream barchans are laterally offset from each other. Access to the flow field around these geometrically complex dunes is achieved using a refractive index matching (RIM) approach. This method facilitates unimpeded data collection around the entire bedform configuration. The RIM approach also minimizes reflections of the laser sheet off the model and floor surfaces, allowing for higher accuracy measurements in these critical regions.

Calculations of length scales in the flow are made by computing the spatially inhomogeneous two-point correlation function of the streamwise fluctuating velocity fields. Calculations thus made at each grid point allows for contour maps of length scales, aspect ratios, and orientation angles of the large scale turbulent flow structures to be analyzed for the entire field of view, in each measurement plane, revealing several key features of the flow.

Application of Taylor's frozen field hypothesis to high frame-rate measurements in the cross-plane allows for 3D reconstruction of the flow field. While rapid dissipation of turbulence in the wake requires careful treatment of this application of Taylor's hypothesis, such reconstructions are at least valid within an integral length scale, which from the previous results in shown to be on the order of several barchan heights.

Such results demonstrate the utility of the refractive index matching approach for the measurement of flow around complex geometries such as the barchan dune. The ability to capture the entire flow field, particularly close to the model surfaces, allows analysis of first order flow features as well as higher order turbulent statistics of dominant length scales in the flow.