A PIV study of flow over interacting barchan dunes

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1. Introduction

Barchan dunes are common features on the Earth’s surface, are characterized by their crescentic planform shape and are formed under the presence of a unidirectional flow and a starved sediment supply (Bagnold, 1941). In deserts, barchan dunes often occur within wind regimes that have a directional variability of less than 15°. When a barchan dune is subjected to oblique flows, its horns become asymmetrical, and with sufficient variability in flow direction more complex barchan dune morphologies may emerge. Barchan dunes are found in many aeolian environments on Earth but have also been documented on the continental shelves, as well as in the wind-blown environments of Mars. The simplest type of barchan, the isolated barchan, appears to form under the presence of a restricted sediment supply, and often forms fields of dunes whose individual members may interact with each other. Although the flow field over isolated flow-transverse dunes is fairly well known (Best, 2005), there has been much less attention devoted to the interactions between barchan dunes, despite the fact that most barchans occur in dune fields where such interactions are the norm.

2. Experiments

This study uses high-resolution particle-image velocimetry (PIV) experiments using fixed-bed models to examine the effects of barchan dune interaction upon the flow field structure. The barchan dune models were based upon an idealized contour map, the shape and dimensions of which were based upon previous empirical studies of dune morphology. The experimental setup comprised two, co-axially aligned barchan dune models that were spaced at different distances apart. The models were rapid prototyped using a 3D powder-deposition printer. In this paper, two volumetric ratios (Vr; upstream barchan dune: downstream barchan dune) of 1.0 and 0.175 were examined. Models were placed in an Eiffel-type, open-circuit wind tunnel and flow quantification was achieved using PIV at 0.5Hz using a 4k × 2.7k-pixel 12-bit frame-straddle CCD camera and two, 200mJ/pulse Nd:YAG lasers (Figure 1). PIV measurements of the mean and turbulent flow field were made in the streamwise–wall-normal plane, along the centerline of the barchans(s), at an average Reynolds number of 59,000. The dune surfaces were treated with Rhodamine 6G and B fluorescent dyes and a band-pass filter was employed upstream of the CCD camera, thus allowing only the scattered light from the tracer particles to be imaged while protecting the CCD from fixed laser reflections from the dune surfaces.

3. Results

The presence of an upstream barchan dune of equal volume to the downstream barchan dune (Vr = 1) induces a ‘sheltering effect’ on the flow, manifested by a significantly shorter separation bubble and both reduced streamwise velocity and turbulence intensity in the downstream barchans dune leeside, as compared to an isolated barchan. The volumetric ratio Vr = 0.175 shows enhanced turbulence production over the downstream barchan dune leeside, that is proposed to be caused by interacting shear layers from the up- and down- stream dunes. The influence of the upstream dune is greater for a larger volumetric ratio due to the sheltering effect of the upstream bedform. Proper orthogonal decomposition (POD) analysis shows that the distribution of turbulent kinetic energy is shifted to higher modes (i.e. smaller spatial scales) over interacting barchan dunes, which also reflects the role of the leeside free shear layer in dominating the flow field by generation, or redistribution, of TKE to higher modes.

References