Reattachment zone characterization under offshore winds blowing over a complex foredune topography using three-dimensional modelling and high resolution field investigations

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Predictions of sediment supply to the foredunes often exclude the role played by offshore wind events and hinders explanation of the existence of extensive aeolian dunes on coasts where the dominant wind direction is offshore (leeside coasts). However, recent findings from wind tunnel studies, desert environments and a few coastal sites suggest that airflow separation, lee-side eddies and secondary flows play an essential role on the formation and maintenance of sand dunes. Under offshore winds the flow surface layer detaches from the ground downstream from the dune crest and generates an area characterised by turbulent eddies on the dune lee slope. At some distance downstream from the dune crest, flow separates into a reversed component directed toward the dune toe and an offshore "re-attached" component (Walker and Nickling, 2002). This study examines the temporal evolution of the reattachment zone (RZ) in relation to changing wind speed and direction and evaluates its implications for aeolian sediment transport and beach-dune interaction.

Field data was collected during an experiment carried out at Magilligan Strand, Co. Derry, Northern Ireland. The strand is oriented NW-SE and is approximately 6 km long. The beach is up to 100 m wide during low tides and displays a dissipative, planar topography due to the effect of high energy Atlantic swell waves. The coast is microtidal with a tidal range of approximately 1.6m. Beach sediment consists predominantly of very well sorted quartz sand with a mean grain diameter of 0.17mm. The foredune ranges in height from 6 to 11m and it is covered by *Ammophila arenaria* of approximately 1.5m height. Prevailing

winds from the SW (offshore) dominate the aeolian system and previous studies have reported significant secondary airflow effects where the foredune is of sufficient height. The experimental site was thus located at a section of the beach-dune system where the foredune crest reaches its highest (11m). At this location the foredune is largely linear and unbroken and approximates idealized transverse ridges (Lynch et al., 2010).

Wind parameters were measured over a profile extending from the dune crest towards the beach, covering a total distance of 65 m cross-shore. Data were collected using an array of nine ultrasonic anemometers (3D Gill HS-50 model) deployed in April-May 2010, as part of a larger experiment to capture airflow data under a range of incident wind velocities and offshore directions. Ultrasonic anemometers (UAs) were located along the profile (5m tower spacing) over the beach, which allowed a detailed examination of the RZ with empirical data. Sensor locations (35 to 65 m from the dune crest) were based on a preliminary CFD run indicating the extent of different turbulent areas. U, V, W output was sampled at 25Hz and used to calculate wind speed and direction, Reynolds stresses and quadrant analysis. Numerical modelling using Computational Fluid Dynamics (CFD) software was also conducted with input data from anemometer field measurements. Simulations were carried out using the open-source CFD software OpenFOAM which solves the system of partial differential equations representing the fluid dynamics on a three-dimensional computational grid. The one-equation eddy (k) Large Eddy Simulations (LES) were conducted due to their ability to resolve turbulence wind flow characteristic, and included a constant aerodynamic roughness length to account for terrain roughness (Beyers et al., 2010). The mesh of the dune and beach surface was created using LiDAR and DGPS suvery data. The LiDAR survey was completed using a LADS MKII LiDAR in June 2008 and covered the entire Magilligan foreland. The spatial resolution of the spot data was every 4 m using the spheroid ETRF89 and projection UTM, zone 29N, CM 9°W. Topographic LiDAR mapping was supplemented with a detailed DGPS survey of the beach and foredune crest within the study site which extended approximately 150m (longshore) x 250m (cross-shore). This was undertaken during September 2009 and April 2010 using a Trimble 4800 RTK at a point sampling resolution of 1m x 1m. In addition, DGPS data points were gathered along the main frontal foredune ridge crest at a resolution of 0.2m x 0.2m to examine topographic detail on the crestal region.

Results demonstrate the existence of flow separation under offshore winds with wind speeds over a minimum threshold of approximately 5-6m/s. Under relatively low winds the wind streamlines reflected the underlying topography but as wind speed increased over the threshold a flow reversal area was quickly formed, with a RZ reaching maximum distances of approximately 3.5 dune heights (h). The maximum extent of the RZ increased up to 4.5h with stronger wind speeds of 8-10m/s and remained relatively constant as wind speed further increased. This suggests that the spatial extent of the RZ is largely independent of incident wind speed and is located between 4-5h. Airflow steering and reverse flow directions appeared to be dependent on incident wind direction at the crest with maximum reversal under near perpendicular offshore winds. As the incident wind became more oblique offshore the flow steered rather than reversed. The potential for onshore sediment transport under offshore winds was apparent across the foredune toe and back beach area and contained flow that was above threshold for aeolian sediment entrainment. The magnitude of the maximum extent of the RZ was similar to that simulated using CFD, which also showed a RZ located at approximately 4h from the dune crest. Comparisons between CFD results with field data suggest the potential of numerical simulations using OpenFOAM and illustrate how the methodology may provide valuable insights into coastal dune dynamics. These findings are consistent with previous studies conducted in desert dunes and wind tunnel simulations for offshore winds blowing over tall and sharp-crested dunes.

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