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The geomorphological significance of airflow patterns in transverse dune interdunes

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Abstract

The interdunes between aeolian dunes have been relatively ignored when compared with the research attention on the morphodynamics of the dune bodies themselves. This neglect is in spite of the possible significance of interdune dynamics for the geomorphology of the sand dune system as a whole, especially with regard to dune spacing. This paper considers the mean airflow within four relatively simple transverse dune interdunes. The study locations were chosen in order to sample interdunes with different size and surface characteristics, the dynamics of which were investigated for when incident flow was normal to the upwind crest. The findings confirm existing models of flow reattachment length and recovery for aeolian dune lee-side flow, and show a consistent pattern of increasing near-surface velocity downwind of reattachment that supports a mechanism for interdunes as sand-free features. Flow dynamics are characterised for the different types of interdune observed, where two groups are recognised. The flow patterns in relatively short interdunes (where dunes are closely-spaced) with a sandy surface were accordant with those of the flow response model. In 'extended' interdunes, where bounding dunes were spaced with a length well over that for flow separation, evidence at the downwind edge of the interdunes suggested that flow reacted to the subsequent dune. For the case of these 'extended' interdunes, a new descriptive model is presented to characterise their dynamics. In this model, the variation in near-surface flow allowed process zones to be identified through the interdune. The geomorphological significance of the processes dominating each zone is discussed, and comparisons are made between the flow response case and the new interdune model from this study. In a discussion on the controls of spacing between dunes, where reattachment length exerts a fundamental control, the role of sediment availability is also highlighted as a significant factor. The presence of a sandy bed can, in some circumstances, determine whether dune development, and therefore spacing, is controlled primarily by elements of flow response.

Keywords: Sand dune; Interdune; Aeolian processes; Bedform spacing; Flow reattachment; Flow recovery

1. Introduction

In the work towards an improved understanding of aeolian sand dune dynamics, the interdune spaces within dune areas have been largely ignored. The spatial extent and form of interdunes can vary with dune type, with mean values of 60% and 10%, respectively, for the proportion of linear and transverse dune areas that are

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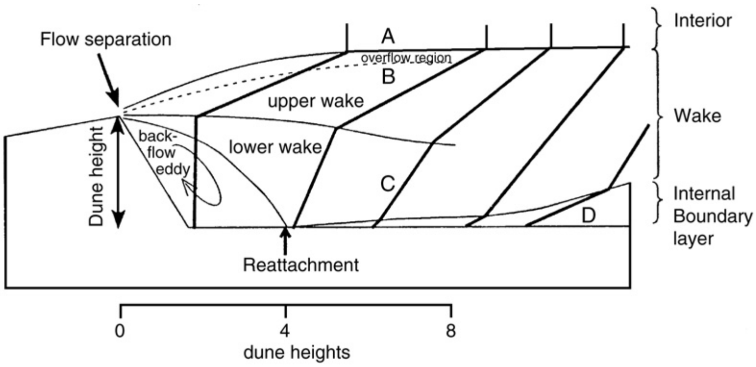

Fig. 1. The generalised pattern of flow in the lee of dunes under perpendicular incident flow. Letters refer to identifiable flow layers. A) Interior B) Upper wake C) Lower wake D) Internal boundary layer (from Frank and Kocurek, 1996b).

made up by interdunes in parts of the Namib Sand Sea (Lancaster and Teller, 1988).

Studies of the effect of dune bodies on flow have considerably increased our knowledge of aeolian dune morphodynamics, and have led to an appreciation of the interaction between flow and form as the primary control on variations in sand transport. These patterns of differential transport, in turn, control dune form and behaviour, and this understanding now exists for all the main types of dune. For transverse dunes, which make up around 40% of the global desert dune extent (Breed and Grow, 1979), the majority of work has been undertaken on the windward slope of dunes (Lancaster, 1985; Tsoar, 1985; Frank and Kocurek, 1996a; Lancaster et al., 1996; Wiggs et al., 1996; McKenna Neuman et al., 1997, 2000). Research attention into the lee-side flow over dunes saw early studies consider the controversial nature of the lee eddy (e.g. Cooper, 1958; Hoyt, 1966). More recently, focus has returned to the lee side of transverse dunes and there have been notable successes in obtaining a detailed insight into the secondary flow patterns (Sweet and Kocurek, 1990; Frank and Kocurek, 1996b; see also Walker and Nickling, 2002) and the associated sediment transport patterns (Walker, 1999). Particular difficulties exist where investigations are undertaken in the lee side of dunes. Here, complex wind patterns affected by the upwind dune result in non-log-linear vertical velocity profiles (Walker and Nickling, 2002, 2003). Such disruption of the log-linear nature of the velocity profile excludes the use of the commonly applied 'law-of-the-wall' to determine local shear velocities and hence sediment transport (Wiggs, 2001).

The majority of previous empirical dune studies have concentrated on the flow over isolated dunes. Most dunes however do not exist in isolation, but in a repeated form. Despite this, the enquiries that have reported any data on the properties of flow in the entire space between successive dunes are relatively few (e.g. Livingstone, 1986; Lancaster, 1989; Sweet and Kocurek, 1990; Ha et al., 1999). Interdunes have often been considered simply as extensions of the lee side of the upwind dune and only recently has the interdune begun to be treated as a feature in its own right, especially in terms of monitoring its flow dynamics.

For transverse dunes, the flow between closely-spaced reversing dunes has been measured through paired studies in the field (Walker, 1999) and wind tunnel (Walker and Nickling, 2003), the latter containing measurements of surface stress. In their key work on the structure of lee-side airflow, Frank and Kocurek (1996b) also examined the development of the wake through the interdunes downwind of transverse dunes (Fig. 1).

The investigation by Frank and Kocurek (1996b) was the first to relate the structure of lee-side airflow for aeolian dunes to that already incorporated in a detailed model for the development of sub-aqueous bedforms (McLean and Smith, 1986). This '*flow response*'-based model accounted for the distribution of boundary shear stress in the lee of bedforms over which flow becomes separated. It proposed that downwind of reattachment, the shear stress exerted at the surface is controlled by the interaction between the wake and the internal boundary layer (IBL) growing beneath it (Fig. 1). Initially, the flow is dominated by an increase in velocity and surface shear stress as the IBL adjusts to momentum received from the turbulent wake above. With increasing distance downwind, the flow adjusts to the effect of the growing boundary layer thickness and a point is reached where surface stress no longer increases.

Downwind of the point where maximum surface stress is established, the flow-response model suggests that deposition is possible, so allowing for the initiation