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Three-Dimensional Dune Morphodynamics Using Dune Skeleton Model

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Sand dunes, which are the largest granular objects on the Earth, form the large scale of dune networks and the distinct patterns such as barchan, transverse, linear, star-shaped, dome-shaped, and parabolic dunes also formed. These patterns are determined by two dominant factors; the steadiness of wind direction and the amount of available sand in each dune field. For example, unidirectional steady wind generates barchans or transverse dunes. The former are crescentic shaped dunes, and are formed in dune fields with small amounts of available sand, whereas transverse dunes which extend perpendicular to the wind direction, are formed in dune fields with the larger amounts of available sand than the barchan-rich field. As a characteristic property, barchans move keeping their shape with two horns directing leeward at their lateral edges, additionally, their velocity is kept constant roughly inverse proportional to the height.

One of remarkable aspects of recent dune studies is that quantitative analysis of dune morphodynamics has largely progressed. In particular, rescaled water tank experiments and computer models have successfully reproduced qualitative properties of large scale of desert barchans[1][2]. However, the theoretical methodology explaining the mechanism for the complex morphodynamics of dunes beyond the numerical reproduction of their formation process is yet to be developed. We propose a *Dune skeleton model* consists of coupled ordinary differential equations each of which represents the dynamics of two-dimensional cross sections (hereafter, 2D-CSs). Using the model, we study the morphodynamics of dunes; i) the stability of the shape of transverse dunes, ii) the deformation form transverse dunes to barchan, iii) the condition for the formation of steady barchans and the scaling law with respect to their shape.

First, laterally arraying wind directional 2D-CSs of a 3D transverse dune or a barchan are set as an elements of the present *dune skeleton model*. Hence, we consider the migration process of each 2D-CS and the interaction between laterally neighboring them. The dune migration occurs by the sand flow along the surface is divided two types; (a) intra 2D-CS flow and (b) inter 2D-CS flow. This model simply describes the essential dynamics of 3D dunes as a system of coupled ordinary differential equations.

Dune skeleton model reproduced 3 typical shapes of dunes; straight transverse dune, wavy dune, and barchan, depending on the amount of available sand and wind strength. Also, the present model shows that the increase in the amount of available sand and the inter 2D-CS flow enhances the stability of the shape of transverse dune, whereas the decrease in the amount of available sand and the increase in the intra 2D-CS flow destabilizes its shape to enforce the deformation to a barchan. Additionally, the linear stability analysis of two 2D-CSs system obtained the stability condition of the straight and wavy transverse dune[3].

Moreover, we simulate the stability condition of barchan under 2 different types of sand influx condition from the upwind boundary; i) spatially uniform supply and ii) local supply. It was found that; i) under the uniform supply, steadily maintained barchans are formed within a narrow range of the amount of supply and their size is almost uniquely determined independent of the amount of supply. ii) under the local supply around the central axis of a barchan, steadily maintained barchan is formed and its size varies according to the amount of supply. Moreover, the scaling relations with respect to their shape and dynamics are found that correspond to the observation and the experimental fact.

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