Numerical Simulation of the Formation of Linear Dunes

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Abstract

Three dimensional flow above a sand dune has been studied numerically by using Large-Eddy Simulation (LES) method. The movement of the sand which is formed by converging wind directions has been investigated. The numerical method employed in this study can be divided into three parts: (i) calculation of the air flow above the sand dune using MAC method with a generalized coordinate system; (ii) estimation of the sand transfer caused by the flow through the friction; (iii) determination of the shape of the sand surface. Since the computational area has been changed due to step (iii), (i)-(iii) are repeated. The simulated dune, which has initially elliptic cross section, extending at the converging direction which is known as linear dunes.

Keyword: Simulation of Linear Dunes

1. Introduction

Various sand dunes are found in a desert which have typical configurations e.g. the barchan sand dune [1] and linear dunes (Fig.1). It is considered that the formation of these typical shapes depends on the mass of the sand supply, the power of the wind and the steadiness of the wind direction [2]. However, it is difficult to find out these effects on the formation and the movement of the typical sand dunes by observation or experiment because of the large spatial scale of the sand dunes and the long time scale of these formations. On the other hand, using high speed computer, numerical methods seem to be powerful to investigate these phenomena. In this study, the formation of linear dunes is simulated.

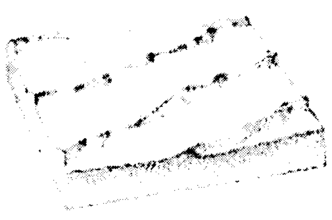
Fig. 1. Linear dunes

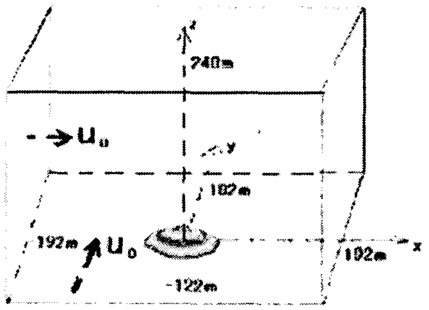
Fig. 2. Computational domain

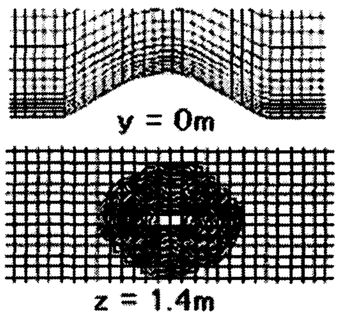

Fig. 3. Computation grid

2. Numerical methods

The numerical method employed in this study consists of the following three parts:
i) Calculation of the air flow above the sand dune.
ii) Estimation of the sand transfer caused by the flow through the friction.
iii) Determination of the shape of the sand dune.
Because the shape of the sand surface is changed. (i)-(iii) are repeated until prescribed times.

2.1 Calculation of the Air Flow

The Reynolds number of the flow over the sand surface is high enough that LES method is used. Standard MAC method is employed to solve 3 dimensional Navier-stokes equations. As is shown in Fig.2, the initial sand dune has elliptic cross section parallel to the x-y plane and parabolic cross section parallel to both the x-z and y-z planes. In x-z and y-z planes cyclic boundary conditions are

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imposed for velocity and pressure. The height of the dune is 25m and lengthes of major and minor axes of the base are 80m and 50m. The number of grid points is $85 \times 77 \times 26$.

2.2 Estimation of the Sand Transfer

According to the study of Bagnold and others, sand transfer equation is given by

$$q = c\frac{\rho}{g}u_*^3 \tag{1}$$

where u_* is the friction velocity, ρ is the density of the air and q is the mass transfer of the sand. c is the constant which is determined by the experiments. The friction velocity is given by

$$|u_*| = \sqrt{\upsilon\frac{d|U|}{dz}}, \quad u_* // U \tag{2}$$

where U is the velocity parallel to the sand surface.

2.3 Determination of the Shape of the Sand Dune

The sand dune will change its shape by the sand transfer estimated by the equation (1). Consider the local coordinate system along the sand surface, equation (1) becomes

$$\rho_s\frac{dh}{dt} = -\frac{dq_1}{dX} - \frac{dq_2}{dY} \tag{3}$$

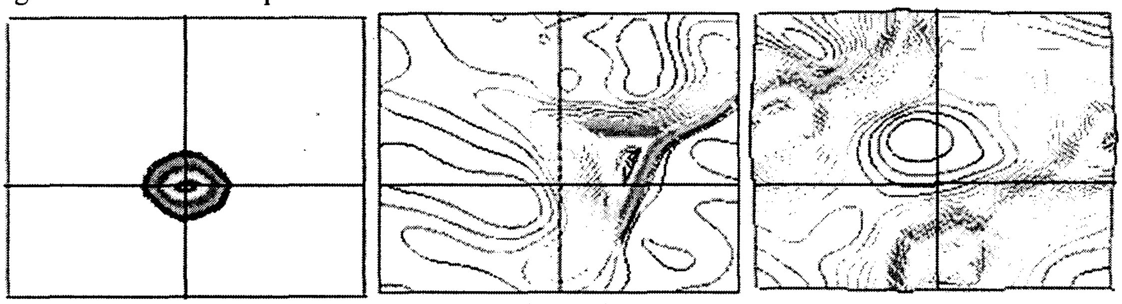
Where h is the normal distance from the base plane parallel to the sand surface, ρ_s is the density of the sand and q_1, q_2 are the X, Y components of the vector q.

If the slope of the sand exceeds the maximum angle--30^0, the height of the sand at the grid point is changed artificially both to keep the maximum value and to satisfy the conservation of the sand.

3. Results and Discussion

We calculate the flow field over the fixed sand dune without the movement during the first 2000 steps in order to obtain the initial conditions. By using this initial condition, we repeat three steps mentioned in section 2 and compute the change of the shape of the sand dune.

Fig.4 is the time development of sand surface contours.



t=0d t=4.4d t=23d

Fig. 4. Surface contours at various time

4. Concluding Remarks

In this study, we proposed one method to simulate the sand movement by the wind, investigate the flow over linear dunes and make clear the mechanism of the formation of linear dunes.

The remaining problems which are not solved in this study are: To investigate the effect of the wind direction above the dune; To make clear the effect of the vegetation on the sand dune.

References

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