A numerical study of Yellow Sand transport in stably stratified flows over a two-dimensional mountain

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1 Introduction

Numerical modeling plays an important role in understanding the transport mechanism of Yellow Sand. The Long-range transport simulations of Yellow Sand from the continent of Asia to Japan have been executed by many researchers(1). However, there seems to be no short-scale simulation that considers small-scale meteorology and topography in a range from several km to under hundreds km.

Mountain wave is one of the small-scale meteorology phenomena. It occurs on the lee side of a mountain when the atmosphere is stably stratified. It develops strongly as the atmospheric stability increases. Because of mountain wave, flows at high altitude are pulled down behind the mountain. Hence there is a possibility that mountain wave might affect transport of Yellow Sand from 500 meter to 5 km altitude by pulling it down to the ground. The main purpose of this study is therefore to examine our hypothesis for a deposition mechanism of Yellow Sand due to mountain wave by numerical simulation.

2 Numerical methods

Two-dimensional unsteady calculations are executed using commercial CFD software FLUENT. The governing equations are the continuity equation, Navier-Stokes equation, the transport equation of density disturbance, and the transport equation of scalar concentration. Boussinesq approximation(2) is applied to calculate the density stratified flow. The k-ε model is used to compute the eddy diffusivity.

The computational domain is - 45[km] ~ 45[km] in x-direction and up to 27[km] altitude in y-direction (Fig. 1). A bell-shaped mountain which is 900[m] height and 1000[m] half width is set in the middle of computational domain on the ground. The origin of x- and y-axis is set at the center of the mountain on the ground. The number of the grid points are 250×200 in x- and y-direction. To obtain finer resolution, grid points are spaced closely near the mountain and the ground. An impulsive-start is used for the initial condition, which applies a sudden acceleration of flow from rest. The time step is $\Delta t = 1$[s].

The atmospheric stability parameter Froude number $Fr = U / Nh$ is employed, where U is the upstream uniform velocity and N is the buoyancy frequency. The atmosphere becomes more stable as Fr decreases. As the atmospheric model, we employ two different models, one is a one-layer model in which the density gradient is constant in the entire domain. And the other is a two-layer model in which the density gradient changes at 11 km altitude. In the two-layer model, trapped mountain waves are expected to occur.(3)

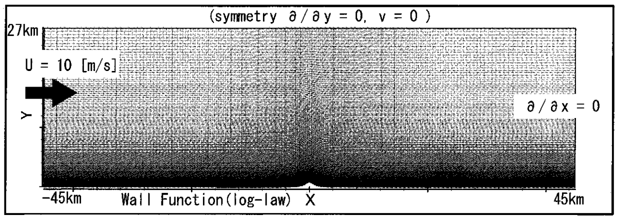

Figure 1 Computational domain and boundary conditions

3 Results

Fig. 2, 3 show the streamlines and the scalar concentration for the one-layer model with $Fr = 0.75$ at t = 2500[s]. The injection point of the scalar concentration is set at 10 [km] upstream from the center

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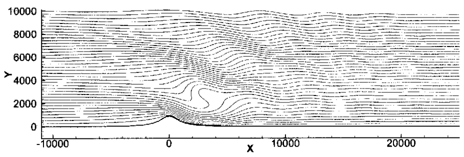

Figure 2 Streamlines with Fr = 0.75 at t = 2500[s]

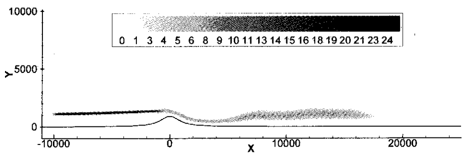

Figure 3 Scalar concentrations with Fr = 0.75 at t = 2500[s]

of the mountain and y = 1000 ~ 1200 [m]. Mountain waves propagate obliquely upward and wave breaking occurs behind the mountain. The scalar concentration is transported along the downslope of the mountain. The height of scalar concentration behind the mountain is pulled lower as the *Fr* decreases, that is, as the atmosphere becomes more stable. Fig. 4 shows the ground scalar concentration. It rises behind the mountain, but the values are 10^{-7} order and still very low.

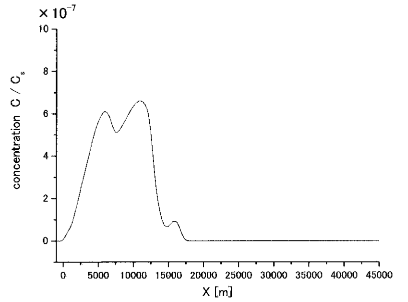

Figure 4 Ground scalar concentration with Fr = 0.75 at t = 2500[s]

Fig. 5, 6, and 7 show the streamlines, the vertical velocity and the scalar concentration for the two-layer model with *Fr* = 0.5 at t = 5000[s]. There are long wave trains and rotors on the ground. Fig. 8 shows the ground scalar concentration. The predicted value is much higher than those by one-layer model and the high concentration region corresponds to the rotor locations. Therefore, the rotor has a strong effect to diffuse scalar concentration.

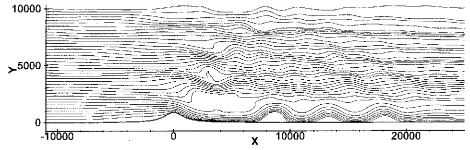

Figure 5 Streamlines with Fr = 0.5 at t = 5000[s]

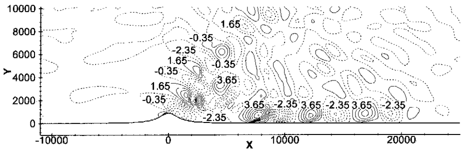

Figure 6 Vertical velocity with Fr = 0.5 at t = 5000[s]

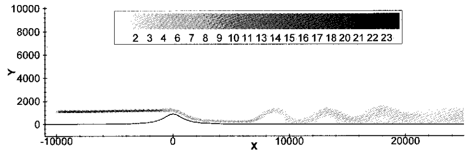

Figure 7 Scalar concentration with Fr = 0.5 at t = 5000[s]

4 Conclusions

We have studied the effect of mountain wave on the transport of Yellow Sand by 2-dimensional simulation. In the one-layer and the two-layer models, mountain wave develops strongly and flows tend to come down toward the ground as the atmospheric stability increases. The ground scalar concentrations of the one-layer model are much smaller compared with those by the two-layer model.

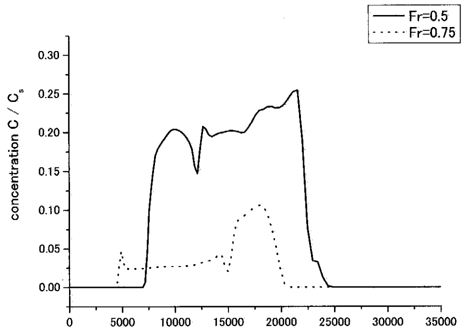

Figure 8 Streamlines with Fr = 0.75 and 0.5 at t = 2500[s]

In the two-layer model, mountain waves reflect at the interface of the two layers and trapped mountain waves and rotors are generated. The ground scalar concentrations take much larger value at the rotor region and become higher with an increase in the atmospheric stability. Therefore, there is a possibility that Yellow Sand at high altitude may be pulled toward the ground at the rotor regions.

References

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