August 27-31, 2023
FLORENCE - ITALY
ICWE 16
16th International
Conference on
Wind Engineering

CFD simulations of snow saltation on flat terrain

Tiange Zhang[1], Xuanyi Zhou[1]

[1] State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University, Shanghai, China, lovelysf@tongji.edu.cn

SUMMARY:
Drifting snow on flat terrain would develop downwind from the starting point. It is necessary to conduct an in-depth study on the development of snow saltation, so as to enhance the unsaturated snow transport in engineering. In this study, an Eulerian-Lagrangian snow drifting model was built to simulate the development of snow saltation on flat terrain. Airflow turbulence is simulated using the high-efficient Reynolds-averaged Navier-Stokes equations (RANS). The movement of snow particles includes four sub-processes: aerodynamic entrainment, particle trajectory, splash process and wind field modification. Six study cases with different friction velocities are set in this study. The characteristics of snow concentration and snow transport rate are discussed. The results show that the snow concentration decreases along the height, while it increases along fetch until reaching the equilibrium. Snow transport rate increases rapidly along fetch within the distance of 20 m, and then it increases slowly until reaching the equilibrium.

Keywords: Snow transport, snow saltation development, Eulerian-Lagrangian method

1. GENERAL INSTRUCTIONS

Drifting snow on flat terrain would develop downwind from the starting point, as illustrated in Fig. 1. The snow transport rate Q increases along fetch until it reaches a saturated value, which is related to the wind velocity and the particle properties. When the snow transport rate remains stable, the snow drifting reaches the saturated or fully-developed state. There exist many researches on saturated snow drifting, including discussions of the relationship between the saturated transport rate and the wind velocity and studies on the motion mechanism of snow particles. However, there are few studies on the development of snow drifting on the ground. Therefore, it is necessary to conduct an in-depth study on the development of drifting snow on flat terrain, so as to enhance the understanding of the unsaturated snow transport in engineering.

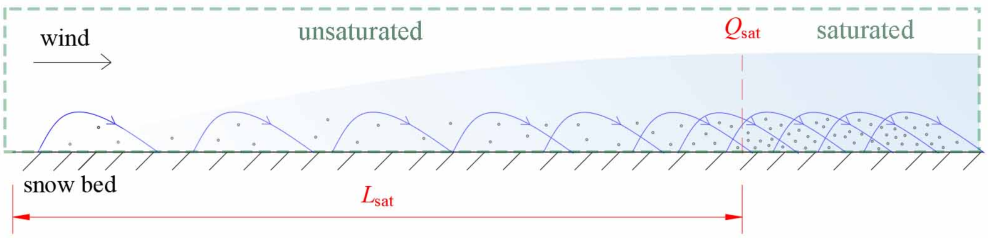

Figure 1. Development of drifting snow.

2. NUMERICAL METHOD

In this study, an Eulerian-Lagrangian model is established to simulate the development of snow saltation on flat terrain. Airflow turbulence is simulated using the high-efficient Reynolds-averaged Navier-Stokes equations (RANS). The Lagrangian snow drifting model includes four sub-processes: aerodynamic entrainment, particle trajectory, splash process and wind field modification (Anderson and Haff, 1991).

Particle trajectory is calculated by the equation of particle motion, namely (Liu et al., 2022)

$$m_p \frac{du_{pi}}{dt} = \frac{1}{2}\rho_a C_D A_p |U_r| U_{ri} + \delta_{i3} m_p g \tag{1}$$

where m_p is the mass of the particle; u_p is the particle velocity; ρ_a is the air density; C_D is the drag coefficient; A_p is the cross-sectional area of the particle; U_r is the relative speed between particle and air; δ_{i3} is the Kronecker symbol.

When the friction velocity acting on the snow surface is larger than the threshold one, snow particles would be entrained into the computational domain, which is denoted as the aerodynamic entrainment. The aerodynamic entrainment rate N_{ae} can be calculated by (Anderson and Haff, 1991)

$$N_{ae} = \eta_{ae} \rho_a (u_*^2 - u_{*t}^2) \tag{2}$$

where η_{ae} is the coefficient; u_* is the friction velocity; u_{*t} is the threshold friction velocity.

The initial velocity and the initial angle of aerodynamically entrained particles follow the lognormal distribution. The splash function used in this study is obtained by Sugiura and Maeno (2000) based on the wind tunnel test. In the splash function, the vertical restitution coefficients e_v (i.e. the ratio of the vertical velocity component of ejected particles to that of impact particles) follows the Gamma distribution; the horizontal restitution coefficients e_h (i.e. the ratio of the horizontal velocity component of ejected particles to that of impact particles) follows the normal distribution; and the ejected particle number n_e follows the binomial distribution. In addition, a source term representing the drag force of snow particles is added to modify the wind field (Huang and Wang, 2016).

3. RESEARCH OBJECT

A two-dimensional full-scale model is used to simulate snow saltation on flat terrain with high efficiency. The computational domain is 1 m × 400 m, as shown in Fig. 2. Both ends of the computational domain (i.e. X = -100 - 0 m and X = 100 - 300 m) are filled with hard snow, where snow saltation would not occur. While the middle region (i.e. X = 0 - 100 m) is filled with loose snow, where snow saltation develops from the starting point (X = 0 m). Six study cases with different friction velocities are set, as shown in Table 1.

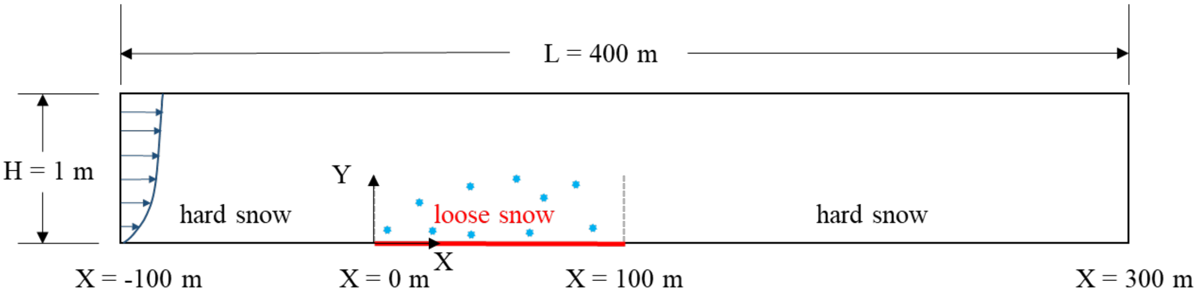

Figure 2. Computational domain.

Table 1. Study cases.

Case	Friction velocity
Case 1	0.23 m/s
Case 2	0.26 m/s
Case 3	0.29 m/s
Case 4	0.32 m/s
Case 5	0.35 m/s
Case 6	0.37 m/s

4. SIMULATED RESULTS

4.1. Snow concentration

The trajectory of each snow particle can be tracked in the Eulerian-Lagrangian method, and thus the snow concentration can be obtained. Fig. 3 shows the near-wall snow concentration along fetch in each case. It is seen that the snow concentration decreases with height, and it gradually increases along fetch until reaching the equilibrium.

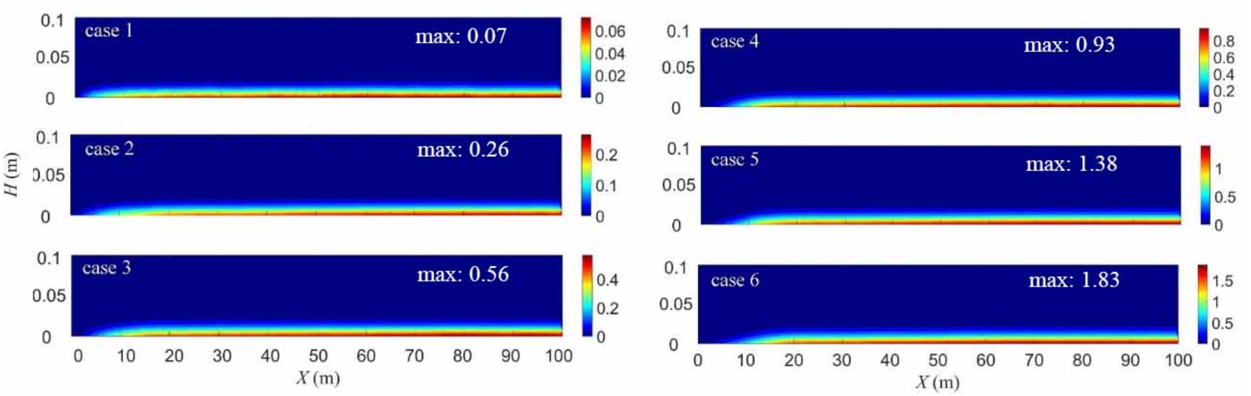

Figure 3. Snow concentration (Unit: kg/m^3).

4.2. Snow transport rate

Snow transport rate is a factor representing the transport capacity. Fig. 4 shows the development of snow transport rate along fetch. Snow transport rate increases rapidly within 20 m, and then it increases slowly until reaching the equilibrium.

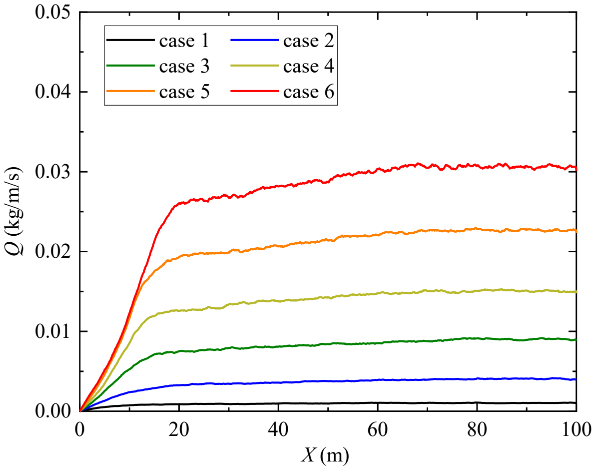

Figure 4. Snow transport rate along fetch.

5. CONCLUSIONS

In this study, an Eulerian-Lagrangian snow drifting model is established to simulate the development of saltation on flat terrain. The characteristics of snow concentration and snow transport rate are discussed. Snow concentration decreases along the height, and it increases along fetch until reaching the equilibrium. Snow transport rate increases rapidly along fetch within the distance of 20 m, and then it increases slowly until reaching the equilibrium.

ACKNOWLEDGEMENTS

This project is supported by the National Natural Science Foundation of China (52078380), which is gratefully acknowledged.

REFERENCES

Anderson, R.S., Haff, P.K., 1991. Wind modification and bed response during saltation of sand in air. Acta Mechanica 1, 21-51.

Huang, N., Wang, Z, 2016. The formation of snow streamers in the turbulent atmosphere boundary layer. Aeolian Research 23, 1-10.

Liu, Z., Zhou, X., Gu, M., 2022. A numerical model for snow drifting simulations on flat roofs using Lagrangian approach. Journal of Wind Engineering and Industrial Aerodynamics 222, 104922.

Sugiura, K., Maeno, N., 2000. Wind-tunnel measurements of restitution coefficients and ejection number of snow particles in drifting snow: Determination of splash functions. Boundary-Layer Meteorology 95(1), 123-143.