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Large eddy simulation of dune evolution by wind erosion, sand transport and deposition

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Abstract

Sand dune deformation is a dynamic process resulting from complex interactions between the atmospheric boundary layer, aeolian particle transport, sand erosion and dune deformation. This work undertakes these problems by conducting three-dimensional numerical simulations of solid particle transport over a deformable sand dune. A turbulent boundary layer flow is computed by Large-eddy simulation (LES). A complete model has been developed for sand particle transport from saltation initiation to particle-surface interactions. Simulation of a time evolving dune, corresponding to the experiments of Ferreira et al. (2012), is performed. Numerical results match with the experimental ones. A consistent small-scale tool for predicting particle transport and wind erosion of a deforming dune is constructed and validated in this work.

Introduction

By wind erosion, large areas of cultivated land loose their top soil nutrients, resulting in higher production costs and an increasing use of fertilizers. Understanding, modeling and predicting wind erosion is crucial for reducing land degradation and improving landscape planning. Most studies focused on the understanding and modeling of dune dynamics without accounting for turbulence effects on particle transport (Wiggs 2001). Large scale, global models need reliable parametrization of small-scale particle transport and pickup. Hence, the broad objective of the present study is to develop a consistent small-scale tool for predicting particle transport and wind erosion around a deforming dune.

Numerical Method and Transport Models

The turbulent boundary layer flow is resolved by Large-eddy simulations (LES) with the atmospheric code ARPS (Xue 1995). The complete model with particle transport has already been used by our team to study saltation within a flat turbulent boundary layer, over gaussian hills (Huang 2018) or above square obstacles with varying separation (Le Ribault et al. 2021). An immersed boundary method (IBM) is used here to account for dune deformation.

To initiate saltation, a particle entrainment model based on the forces acting on individual particles within the bed has been developed according to Huang et al. (2019). The advantage of this model is that it relies on instantaneous quantities provided by the LES. It therefore avoids the use of averaged and global flow characteristics such as the friction velocity. When the instantaneous impulse is greater than a threshold value, particles take-off. Another threshold crite-

riion is imposed for rolling or sliding. Particles in the air or rolling on the wall are tracked using a Lagrangian method. Considered forces, exerted on particles are gravity and drag. Particle-surface interactions and particle deposition are also accounted for. Due to gravity, particles fall and may either deposit, rebound or eject new particles by splashing. Here, the rebound model proposed by (Kok and Reno 2009) and the splash model given by (Beladjine et al. 2007) are applied. An avalanche model that reduces the dune slope when locally it exceeds the angle of repose is also used. The dune shape is computed in function of the instantaneous and local deposition and erosion rates.

Results and Discussion

Very few laboratory experiments of deforming dunes in air exist in literature. Ferreira et al. (2012) measured the deformation of a small sand dune during 12 minutes in a wind tunnel. Initially, the dune height is $H = 6\text{cm}$ and the fluid velocity 9m/s . Dune shapes are given at 2, 4, 6, 8 and 12 minutes.

Simulations of particle transport over this deformable dune are carried out to validate our model. Initially, the dune is sinusoidal. The incident turbulent boundary layer has a Reynolds number based on the average velocity and dune height $Re_H = 36400$. The considered domain spans $53H \times 6H \times 8.5H$, respectively in the streamwise, spanwise and vertical directions. The corresponding number of nodes is $1063 \times 63 \times 100$. Parallel computations are performed on 128 MPI nodes. However, simulations are computationally expensive and last two months since dune evolution up to 12 minutes is achieved.

Figure 1 presents the dune, flow-laden sand particle posi-

tions and streamwise flow velocity isovalues at 2 minutes. At this time, a small recirculation zone is present after the dune playing an important role in dune erosion and particle deposition. Particles with positive and negative vertical velocities are driven by the flow just after the dune crest.

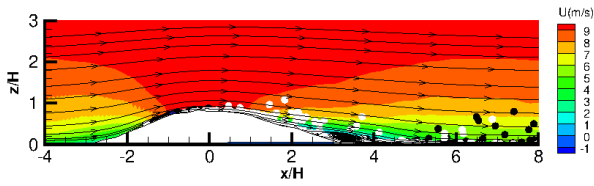


Figure 1: Sand particle positions, dune shape and instantaneous streamwise fluid velocity isovalues. Black (white) particles move away from (towards) the wall.

Figure 2 presents the dune shape at different times available by the experiment. The height of the dune decreases with time and the dune spreads in the streamwise direction. Particles deposit on the lee side. This is enhanced by the presence of the back flow at the beginning in the recirculation region mentioned above. The simulated dune shape at 6min differs slightly from the experimental one. Experiments show an upwind shift of the dune crest as the dune becomes asymmetric. This asymmetry is less pronounced in the LES. At 8 and 12min, the experiments predict high erosion after the dune crest starting from $x/H = -1$. Our simulations give higher erosion before $x/H = 0$ and higher deposition after, leading to a more flattened shape.

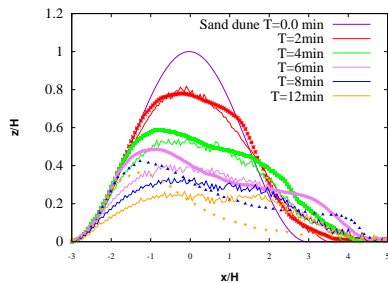


Figure 2: Dune shape at different times. Lines - our LES. Points - experiments by Ferreira et al. (2012).

Figure 3 presents the total dune mass evolution with time. Numerical results are compared to experiments. As expected, the dune mass decreases both in the simulations and in the experiments. This decrease comes from sand particles that take off and do not deposit on the dune but are transported by the mean flow. An overall satisfying agreement is achieved for the time evolution of the total dune mass between our LES and the experiments leading to a global validation of the presented model.

Conclusion

A consistent small-scale tool for predicting particle transport and wind erosion around a deforming surface is presented.

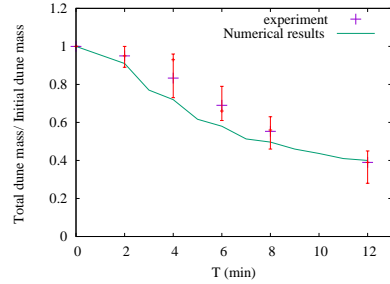


Figure 3: Time evolution of total dune mass. Line - our LES. Points - experiments by Ferreira et al. (2012).

LES is used for the flow and a complete physical model has been developed for particle transport. The model is validated by comparison with the experimental dune evolution of Ferreira et al. (2012). An overall agreement between experimental and computational results is obtained. Further insight on particle transport in the vicinity of a deforming dune will be given by analyzing the results of our simulations.

Acknowledgments

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References

- Ferreira, A.D. & Fino, M.R.M. A wind tunnel study of wind erosion and profile reshaping of transverse sand piles in tandem. *Geomorphology*, Vol. 139, pp. 139-241 (2012).
- Wiggs, Giles FS. *Desert dune processes and dynamics* Progress in Physical Geography, Vol. 25, pp. 53-79 (2001).
- Xue, M. and Droegemeier, K.K. & Wong, V. The Advanced Regional Prediction System (ARPS)—A multi-scale nonhydrostatic atmospheric simulation and prediction model. Part I: Model dynamics and verification. *Meteorol. and Atmospheric Physics*, Vol. 75, pp. 161-193 (2000).
- Huang, G., Le Ribault, C., Vinkovic, I. & Simoëns, S. Large eddy simulation of erosion and deposition over multiple two-dimensional Gaussian hills in a turbulent boundary layer. *Boundary Layer Meteorol.*, pp. 193-222 (2019).
- Le Ribault C., Vinkovic I., Simoëns S. Large eddy simulation of particle transport and deposition over multiple 2D square obstacles in a turbulent boundary layer. *J. Geophys. Res. Atmospheres*, (2021)
- Kok, J.F. and Renno, N.O. A comprehensive numerical model of steady state saltation (COMSALT) *J. Geophys. Res.: Atmospheres*, Vol. 114 (2009).
- Beladjine, D. and Ammi, M. and Oger, L. and Valance, A. Collision process between an incident bead and a three-dimensional granular packing *Phys. Rev. E*, Vol. 75, pp. 061305 (2007).