The role of surface cohesion in wind-driven snow transport

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Wind-driven snow transport

Mountain terrain

Polar regions

Relevance:

- Snow redistribution in mountain terrain
- Formation of snow cornices and wind crusts
- Slab avalanche formation
- Erosion and sublimation of snow in polar regions

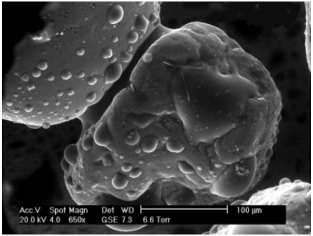
Saltation process

Modified after Sundsbø(1998)

- Saltation is initiated by aerodynamic entrainment of surface grains when the wind friction velocity u_* exceeds the fluid threshold $u_{*,ft}$
- Accelerated by the wind, grains hop along the surface and splash other grains upon impact with the surface
- Saltation can be sustained through granular splash in absence of aerodynamic entrainment
- To minimum friction velocity that can sustain saltation through granular splash is known as impact threshold $u_{*,it}$

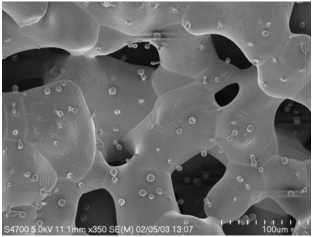
Snow cohesion

Water menisci



Modified after Lourenço (2012)

Ice sintering



Modified after Blackford (2007)

What we already know

- Cohesion limits particle entrainment from the surface

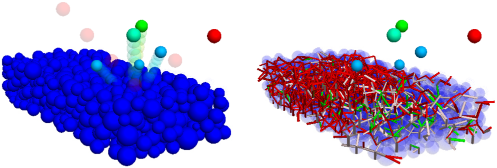
What we want to find out

- What is the effect of cohesion on the impact threshold $u_{*,it}$?
- What is the effect of cohesion on the length scale required to saturate saltation?

How we do it

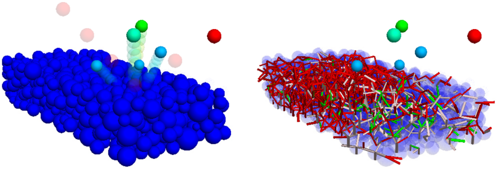
- We run discrete element simulations of granular splash and saltation in presence of cohesion

Granular splash simulations

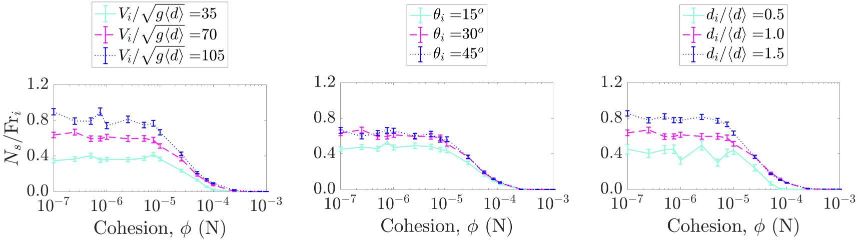


- We generate a bed of poly-disperse spherical snow grains
- We generate cohesive bonds among neighbouring grains
- We assign the diameter, velocity, and angle of the impactor
- We run impact simulations for different values of cohesion (bond tensile and shear strengths)
- We track the rebound velocity, number and mean velocity of splashed grains

Granular splash simulations

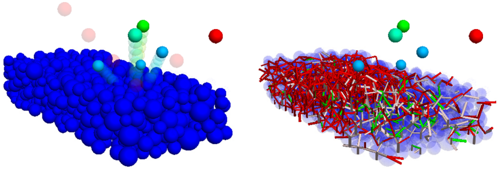


The number of splashed grains N_s decreases with cohesion

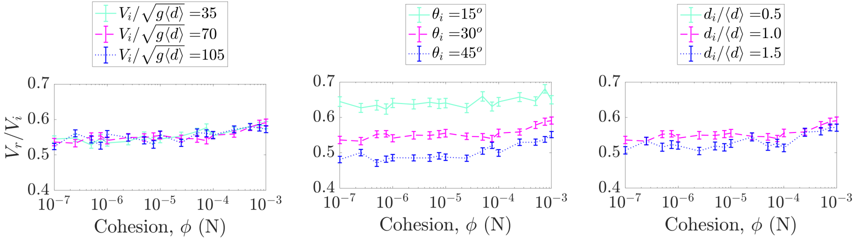


Comola, F., Gaume, J., Kok, J.F. and Lehning, M., 2019. Cohesion-induced enhancement of aeolian saltation. Geophysical Research Letters, 46(10), pp.5566-5574. click here to see

Granular splash simulations



The velocity of the rebounding grain V_r shows a minor increase with cohesion



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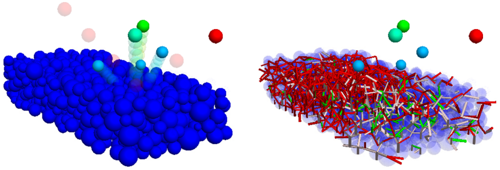
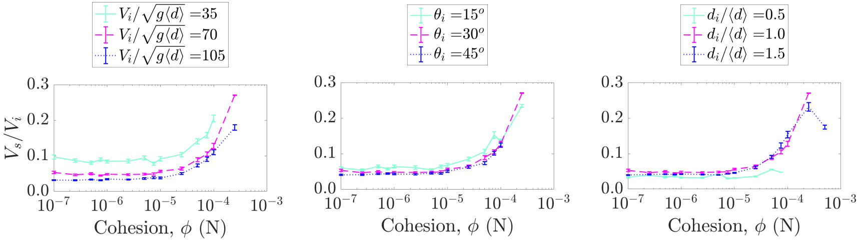
Granular splash simulations



The mean velocity of splashed grains V_s significantly increases with cohesion



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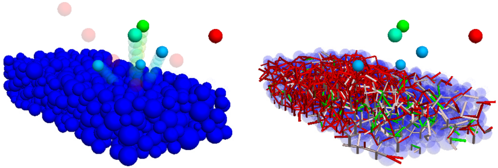
Granular splash simulations

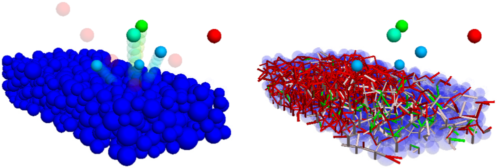


Why does the mean velocity of splashed grains V_s increase with cohesion?

- Think of two bonded grains as two players in a tug of war.

- The thickness of the rope represents the strength of the cohesive bond
- When tugged, a thin rope snaps easily (several splashed grains) and players will not experience a strong recoil (low splash velocity).
- Conversely, a thick rope is tough to snap (few splashed grains) and players will experience a strong recoil (high splash velocity).

Granular splash simulations

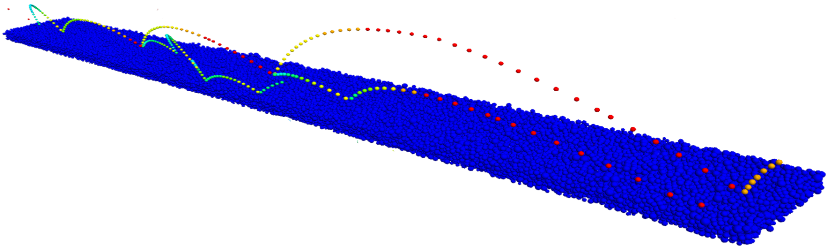


What are the implications for the wind speed required to sustain saltation?

- Saltation is sustained when the mean replacement capacity equals unity, that is, when every impact produces on average one splash or rebound
- Because of the lower entrainment rate, saltation over cohesive surface was thought to require high wind speeds (high $u_{*,it}$)
- However, the increase in splash velocity can potentially enhance particle speed and reduce the wind speed required to sustain saltation

Saltation over cohesive beds may therefore require a lower wind speed than previously thought!

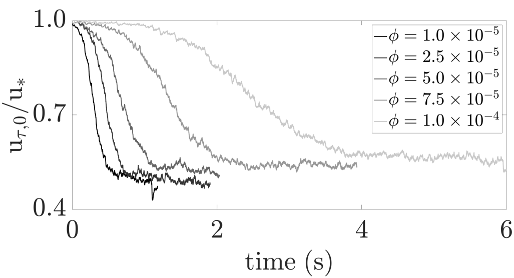
Saltation simulations



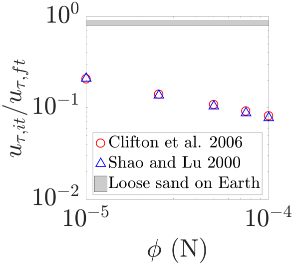
- We impose an initial logarithmic wind speed profile (u_* assigned)
- We trigger saltation with a single particle impact at the inlet section
- We impose periodic boundary conditions at the later walls
- We simulate saltation until steady state for different values of cohesion
- We track surface shear velocity $u_{\tau,0}(t)$ and mass flux $Q(t)$

Saltation simulations

Surface shear velocity



Impact and fluid thresholds



- The surface shear velocity converges to similar stationary values (impact threshold) for all tested cohesions
- The time required to reach stationary shear velocity increases with cohesion
- The ratio between impact and fluid threshold is $\mathcal{O}\left(10^{-1}\right)$ for all tested cohesions

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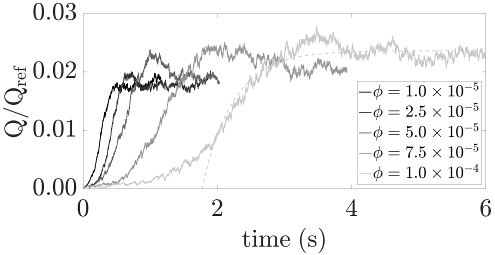
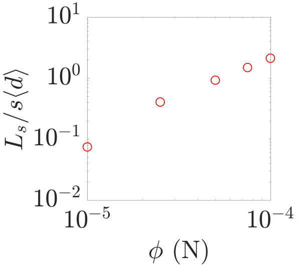
Saltation simulations

Mass flux time series



Saturation length



- Cohesion increases saturated mass flux, due to the high speed of saltating grains
- Cohesion increases the time- and length-scale required to saturate the mass flux
- The saturation length scales with cohesion like a power law

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Conclusions

Summary:

- Cohesion is known to increase the wind speed required to initiate saltation (fluid threshold)
- We showed that cohesion reduces the number of splashed grains but increases their mean splash velocity
- We showed that the increase in splash velocity can sustain saltation over cohesive beds at low wind speed
- We showed that saltation over cohesive beds requires much longer time and distance to saturate

Implications:

- Saltation hysteresis, whereby the occurrence of saltation depends on the history of the wind speed
- The size of the smallest stable bedforms (surface ripples) may increase with cohesion
- Snow erosion and sublimation in Antarctica may occur even at low wind speeds and over compact snow surfaces

Thank you for your attention

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