The role of surface cohesion in wind-driven snow transport

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Wind-driven snow transport

**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 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 $u_{*,it}$. 

Saltation process

Modified after Sundsbø(1998)
Snow cohesion

Introduction

Water menisci

[Image of water menisci]

Ice sintering

[Image of ice sintering]

Modified after Lourenço (2012)
Modified after Blackford (2007)

Research questions

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

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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

Granular splash simulations

The velocity of the rebounding grain $V_r$ shows a minor increase 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](francesco.comola@gmail.com)
Granular splash simulations

The mean velocity of splashed grains $V_s$ significantly increases 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](francesco.comola@gmail.com)

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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).
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 $u_{*i}$).
- 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 \((u_\ast \text{ assigned})\)
- 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

- 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 $\mathcal{O}(10^{-1})$ for all tested cohesions.


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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
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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