Cereal, sand and snow

UNIVERSITY OF CAMBRIDGE

As your cereal tumbled into your bowl this morning, were you daydreaming of sand dunes or snowy mountains? If yes, then don't worry: there is a mathematical excuse.

Left: Nathalie Vriend on her way to the bunker at the test site in Switzerland. It is safer to travel by helicopter as there is a danger of spontaneous avalanches

Right: Josh Caplan in the Qatari desert

Granular flows

Cereal, sand and snow can all be examples of *granular flows*. These occur when a large number of particles move together, and mathematically they are not well understood. Mathematicians here at DAMTP are working to remedy this situation. Their results will help us understand natural processes, such as avalanches in the mountains or the motion of sand dunes across the desert, and also optimise industrial processes involving granular materials, such as coffee or sugar.

Dr Nathalie Vriend, a member of the fluid dynamics research group, is one such mathematician. With her PhD students, Matthew Arran and Josh Caplan, she works in a laboratory underneath the courtyard of the Centre for Mathematical Sciences, but also spends a good amount of time on field trips to the mountains or deserts. The aim of her group is to develop mathematical models of granular flows: sets of equations that describe the behaviour of a flow.

This is a difficult task because such flows combine qualities of solids, liquids and gases all at the same time. For example, snow can form solid boulders that tumble down at the front of an avalanche, but also powder clouds that rise above it. Granular flows are at the interface of different areas of physics – Newtonian physics, statistical mechanics and fluid dynamics – and any model of how a granular flow behaves has to take into account what is happening at many different scales.

The brazil nut effect

One phenomenon Vriend's group is particularly interested in is commonly known as the *brazil nut effect*. You might have observed this yourself when you've shaken your box of muesli – the larger nuts will rise to the top. This is because smaller particles fall through the gaps between grains, gradually making their way downwards, leaving the larger ones on the surface. Counter-intuitively, shaking doesn't induce mixing, but segregates particles into regions of similar sizes. In industrial processes that require a consistent proportion of ingredients the brazil nut effect can be a real problem. In natural processes the effect can give vital clues about the physics involved.

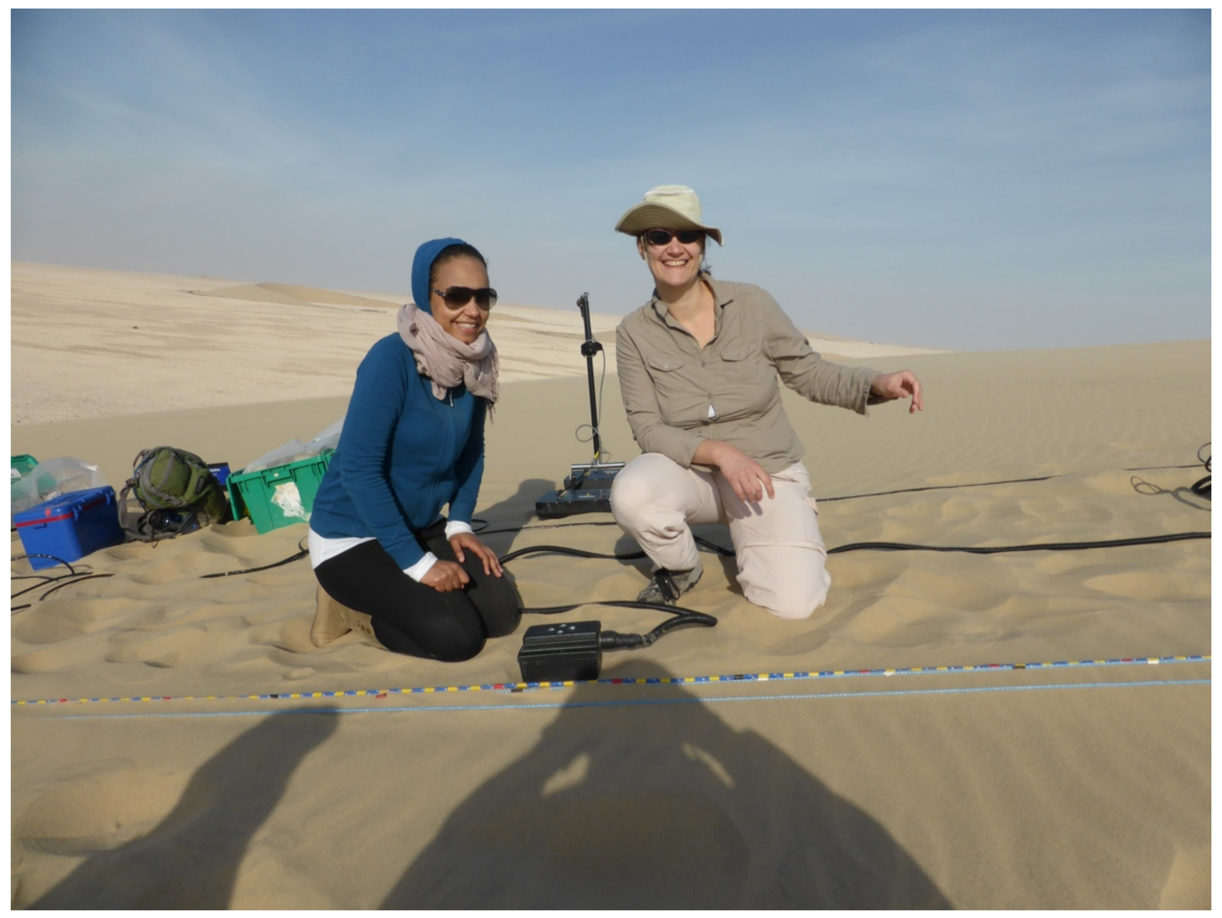
Vriend and her group investigate granular flows in the lab, for example by releasing differently sized balls down slopes or chutes and investigating the external and internal structures of flows using highspeed cameras and MRI scanners. In the field, such as the Alps or the Qatari desert, they observe flows using ground-penetrating radar as well as sampling "slices" of deposits. This might involve sliding down the side of sand dunes to induce avalanches, or releasing full-scale snow avalanches in the mountains and watching from the safety of a snow bunker.

The work has led to some interesting results. For example, studying avalanches has given insight into the surges of fluid gas and rock seen in some volcanic eruptions. A field trip to the desert has confirmed that the brazil nut effect occurs in sand dune avalanches, leading to regular layers all the way through a dune. This affects the flow of rainwater, and can be used to model the transport of oil or gas through sandstone.

The work of Vriend and her group is part of an international collaboration involving scientists from Cornell University, USA, and support from a range of organisations, including the Royal Society, the National Environmental Research Council, and the Weill-Cornell Medical College, Qatar.

Below left: Nathalie Vriend explaining the ground penetrating radar procedure

Below right: Matthew Arran pouring resin into a sand core, to lock it in place and transport it back to Cambridge for further analysis



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