University Centre in Svalbard

AT – 301

"Infrastructure in a changing climate"

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Physics of Snow drift

Personal report by

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Introduction

This personal report for the graduate course AT-301 "Infrastructure in a changing climate" gives an introduction to the basic physical principles of snow drift. The understanding of snow drift is important to take the effects of blowing snow into account during the design of new infrastructure like buildings and roads and for improvement of existing drifting snow problems. The effects of snow drift are often underestimated even by professionals, which might be caused by the complexity of the subject. This can be seen for example in the inappropriate placing (related to snow drift) of the entrance to the new UNIS building in Longyearbyen and several recent rescue operations in spring 2009 on Svalbard where an unexpected extremly rapid build up of snow caused serious problems.

This report tries to give a short survey in the involved physical backgrounds, which is needed to get a profound understanding of the involved mechanisms

Wind

The first and probably most important factor to deal with is of course the wind itself. Without wind there is no lateral transportation of snow. For that reason an evaluation of the local wind profiles is the first thing to do when dealing with snow drift problems in a certain area.

Wind directions

The greatest problems will mostly occur within the direction of the prevailing winds on a location. But local meteorology might have a special effect on winds during snow drift events. Snow drift is related to wind which exceeds a threshold velocity of minimum about 5 m/s (moderate breeze, 4 on the beaufort scale). For that reason it is not only interesting to investigate the total distribution of wind directions, but the distribution of wind directions where a certain wind speed is exceeded. As solid precipitation (snow) plays the other key role it is also important to have a look at the wind direction's distribution during events with precipitation. In many areas this data is delivered by meteorological stations. Especially in the arctic where there is no such good coverage with meteorological information this data should be added by on site observations. For example the investigation of existing snow drifts or reconstruction of winter snow distribution out of a biological survey.

Wind speed profile

As wind is no homogenous phenomenon, wind speeds vary a lot in the first meters above ground. Hydrodynamic friction caused by the ground slows down the wind. Wind velocity $u(z)$ can be described by a logarithmic rule depending on the height z above the surface:

$$u(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right) \approx 2{,}5\, u_*\, \ln\left(\frac{z}{z_0}\right)$$

where u_* is the friction velocity given by $u_* = \sqrt{\tau/\rho_{air}}$ and z_0 is the roughness length of the surface with values ranging from $z_0 = 2 \cdot 10^{-3} m$ for a natural snow cover to $z_0 = 3 \cdot 10^{-6} m$ for plane ice. k is the von Karman constant with a value of $k = 0{,}41$.

This leads to a wind profile with zero wind speed at the surface (exact one roughness length above the surface) with increasing speeds with increasing height

If no snow falls as precipitation during a snow drift event, snow from the snowpack is displaced by wind. For transportation, the shear stress of the snow particles in the snow pack has to be exceeded to release them into the free air flow. The shear stress on the snowpack is given by $\tau = \rho_a \cdot |\partial u/\partial z|^2 \lambda^2$ where λ is the mixing length. If the shear stress exceeds the shear strength of the snow pack, snow particles on the surface will start to drift.

This shows, that threshold velocities for snow drift are very much dependant on the mechanical properties of the snow pack (surface roughness and shear strength) and the profile of the wind speeds.

Modes of snow transportation

Snowdrift is the transportation of small granular particles due to wind. This resembles very much the mechanisms of sand drift phenomena in desert areas. The threshold velocities may vary a lot because of the different surface properties and conditions.

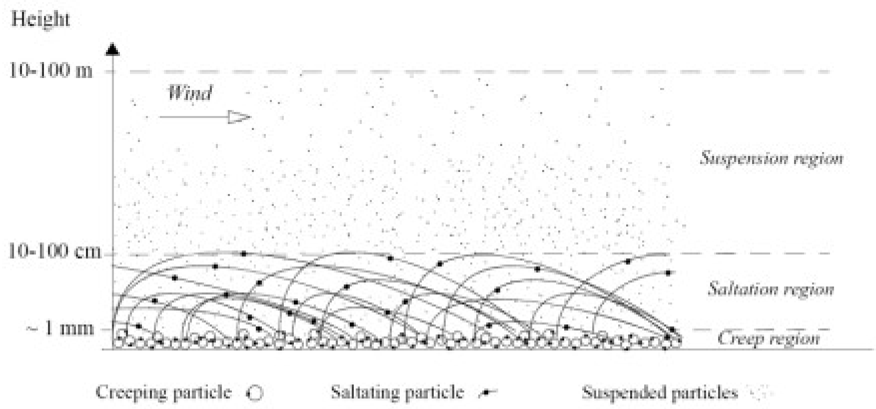

Fig 1: The three modes of transportation in a drifting event (Sundsbø)

Creep

At low wind speeds between 5 and 10 m/s some of the uppermost snow particles on the surface start to roll along the surface in the wind direction. Typical formations related to creeping snow particles are snow waves or snowdunes migrating downwind. On low windspeeds up to one fourth of the transported snow mass can be held by creeping particles but as the total amount is minor and creeping particles are easily stopped by small topographic features the creeping process is mostly not taken into account for numerical analysis of problematic snow drift formations. But however, even snow transported by creep can under certain circumstances build up huge snow drifts in short time.

Saltation

When the wind speed exceeds around 9 m/s starts another mode of transportation. Snow crystals cannot resist the lifting forces of the wind and are vertically lifted into the air due to the vertical gradient in velocity. Once in the air, they follow ballistic trajectories ruled by wind- and gravitational forces. The height of this saltation layer is limited to the first decimeters above the surface and the length of these saltation-jumps does not exceed one meter. The impact of landing snow particles releases more saltating particles like in a chain reaction. The total amount of snow transported by saltation on high wind speeds is only about 10% of the total flux. Nevertheless saltating snow particles can cause immense problems for the visibility for example in narrow street cuttings.

The average height of the saltation layer is given by $z_{salt} = C\frac{u_*^2}{2g}$ with the constant C describing the properties of the snowpack. This height of the saltation layer has also an influence to the surface roughness and through that to the windfield. Saltating particles can easily be trapped by a physical obstacle or can the other way round be the source of snow streams over snow free terrain.

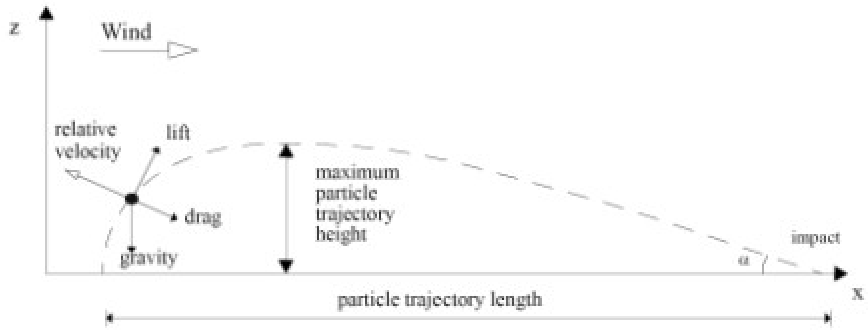

Fig 2: Trajectory of a saltating particle and the forces on it (Sundsbø)

Fig 3: Snow streams of saltating particles on a street in Longyearbyen

Suspension

When the wind speed increases further to more than 12 m/s, the airflow in the atmospheric boundary layer becomes more and more turbulent. Then the shear stress of the airflow equals the weight of the snow particle and it can be lifted up by turbulent wind eddies and transported by the horizontal component of the wind. Even though snow particles can be lifted up to several hundred meters by that process, 90% of the transported snow blows in the first 2 meters above the ground. For that reason the total snow transport is often described by the total flux in the first 5 meters above ground. When local wind is slowing down, the particle follows the gravitation and settles on the ground. Another possibility for settling of snow is an overload of snow in the airflow due to deflecting structures.

Snow crystals under wind transportation

Wind transported snow crystals are smaller than fresh fallen snowflakes. During snow drift they become continuously smaller and more rounded due to abrasion, physical stresses and evaporation. The particle size ranges below 0,5mm and smaller particles are carried higher up into the boundary layer whereas bigger particles are transported in the lower parts.

Drift Snow Flux

Pickup

The above mentioned mechanisms of snow transportation by wind are not able to pick up all their capacity at once. It needs up to roughly 60 seconds for snow particles to gain a reasonable height by suspension and wind has to blow a certain distance above snow until the full bearing capacity is achieved. Distances of 150 to 300 m are required before an equilibrium transport rate is reached and the blowing snow profile in the first 5 m will not be fully developed before 500m of blowing about a even snow covered surface.

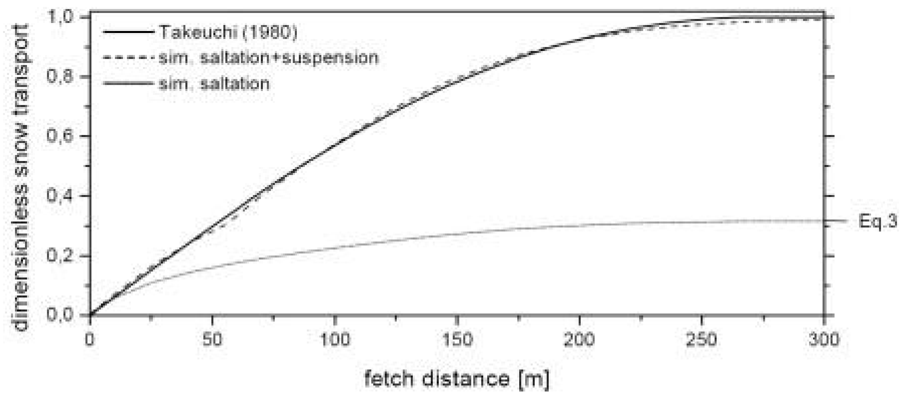

Fig 4: Snow Pickup along a snow surface (Sundsbø). Only after 250m the full transport capacity is reached.

Transport Rates

As above mentioned the windfield can be described as a logarithmic function. The total flux of blown snow can be calculated as a sum of the transport by creep, saltation and suspension out of diffusion theory. For the suspended snow density in a height you can get:

which describes an exponential decrease of drifting snow densities with height. The factor is a function of the particle fall velocity and the wind speed. Higher wind speeds result in more transported snow in the upper layers. The total flux in the first five meters above the surface is defined as

With the snow flux . The multiplication of the logarithmic increasing windprofile and the exponential decreasing diffusive drifting snow leads to a flux profile with a broad maximum in the first meter above the ground. Most snow is transported in less than one meter above surface. Therefore the total flux in the first five meters is in nearly all cases taken as the complete flux of drifting snow.

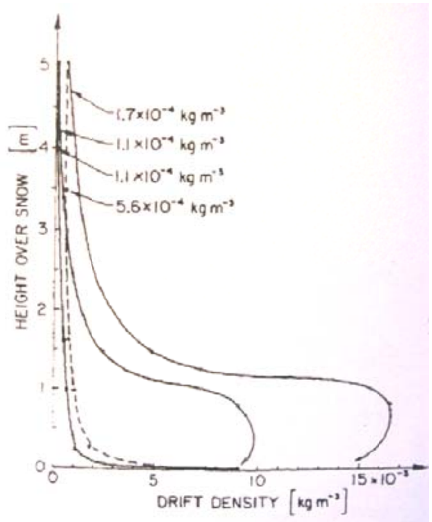

Fig 5: Snow flux distribution with height (Jædicke)

Transport capacity

Very important for the investigation of snow drift is the question how much snow can be carried by winds at a certain wind speed. Regression analysis of field data revealed a more than cubic dependency of the wind speed:

$$Q_{0-5} = \frac{u(10m)^{3,8}}{c}$$

A reduction of the wind speed by 50% will decrease the transport capacity of the snow by 94%. A reduction in wind speed therefore is the most obvious reason to cause snow to accumulate in quite reasonable amounts. This roughly cubic dependency can also be derived from the logarithmic formulation of the wind field and the transport density $c(z)$ as given above. Integration over the first 5m of $\Phi(z) = c(z) \cdot u(z)$ together with some assumptions gives the cubic dependency.

Evaporation

Deposition of transported snow is not the only mechanism to remove snow from the airprofile. Due to the high velocities and small particle sizes evaporation (sublimation) of drifting snow particles plays a major role in the mass balance of snow drift. Snow crystals loose mass by sublimation during the transport. Because of that, the pickup rate has at least to equal the evaporation rate to allow a equilibrium snow drift. This evaporation rate can vary a lot under different circumstances.

Visibility

The visibility during a snow storm is of high interest for the construction of roads and other infrastructure. The transport rates have a maximum in the first meter above the surface and most snow is transported there, which result in the worst visibility conditions in the first meter. At higher wind speeds snow flux at higher levels might also reach a level causing considerable visibility problems.

Fig 6: White-out conditions during a snow storm

Build up of Snow drifts

As seen above, the wind speed plays the major role in the transportation of snow by wind. At high wind speeds the airflow is able to transport much more particles. When the wind speed drops, the wind has no longer the transport capacity for all the snow and will deposit it. It is also possible, that for some reason – e.g. deflection from horizontal obstacles - the density of transported snow exceeds the transport capacity which results in snow deposition even without a decreased or even slightly increased wind speed.

The biggest reason for deposition are eddies behind or in front of a structure, where the wind speed is locally slowing down because of the nonlaminar turbulent flow. The deposition of snow due to eddies in wind flow is not necessary. At high wind speeds, eddies might have a velocity big enough to keep the snow suspended or even erode more snow on their own. This is the reason for almost snow free scoops around many buildings.

Generally all Lee zones are natural deposition areas, where the wind flow is slowing out and snow can be deposited. Sensible Lee zones can be narrow trenches, road cuttings or other structures with a high difference in elevation perpendicular to the wind direction.

Fig 7: Enormous snow deposition around the Northern Lights station (KHO) near Longyearbyen (The building is built on piles with a length up to 2m

Numerical simulations

In Building Design and for an estimation of snowdrift influences for infrastructure it becomes more and more common to use computational simulation programs. These snow drift simulations usually model the wind field using existing hydrodynamic solvers and link the wind field to the different snow transportation rates by the basic transport equations. Feedback containing updating surface models takes the change of the surface due to snow accumulation into account.

Summary

The physical background of Snow drift is based on a few basics but is difficult to predict because many material parameters are changing even during the deposition. Numerical models give a good survey about the possible Problems.

The transport mechanisms of Snow drift are Creep, Saltation and Suspension. Most of the transported snow is held suspended in a layer not higher than 2 meters above ground. The transport capacity is dependent to the wind velocity almost with the fourth power, which explains why slight changes in the wind velocity have a great effect on the snow deposition.

References

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