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## SALTATION AND SUSPENSION OF SNOW BY WIND: A GENERAL THEORY

### (Abstract)

by

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Although the blowing of snow by wind has been quantified repeatedly and fully in both experimental and natural settings, no general theory currently exists which makes it possible for us to describe the full range of particle behavior and to predict the values of parameters of interest to Man in his efforts to deal with a snowy environment. The phenomena of snow saltation and suspension have previously been treated separately and by the use of a variety of different formulae, yet there is no fundamental physical difference between the processes involved. A full simulation of snow transport is presented that includes as its end-members both saltation and suspension, and that therefore addresses not only the role of turbulent fluctuations in altering grain trajectories but also the interaction of energetic grains with the granular snow surface and the modification of the wind profile by these grains.

Saltation trajectories begin to be modified by turbulent fluctuations of the wind once the saltation time, $\tau_s$, which is roughly proportional to the lift-off velocity (and can be expressed by the equation $\tau_s = V_0^2/2g$ where $V_0$ is the initial vertical velocity of the particle, and $g$ the acceleration due to gravity), becomes significantly greater than the response time, $\tau_r$, of the particle to air velocity changes, which is proportional to the square of the particle diameter ($\tau_r = \rho_p D^2/18\rho_a \nu$, where $\rho_p$ and $\rho_a$ are the particle and air densities, respectively, $D$ the particle diameter, and $\nu$ the kinematic viscosity of air).

Because of the low density of snow, modified saltation trajectories become important for relatively smaller particle diameters than is the case for blowing sand. Grain trajectories calculated with proper account being taken of the random turbulent velocity fluctuations within the boundary layer, themselves scaled by a height-dependent standard deviation of vertical velocity, $\sigma_w$, and energy dissipation, $\varepsilon$, display increasingly irregular paths as particle diameter decreases. Large grains at low lift-off velocities trace essentially pre-determined paths. These are the familiar saltations (for which a given set of lift-off conditions the standard deviation of hop lengths, $\sigma_\lambda \approx 0$). Intermediate combinations of grain-size and lift-off velocity yield modified saltation trajectories characterized by $\sigma_\lambda \approx 0(\lambda)$, where $\lambda$ is the mean hop length. Very small grains trace irregular suspension trajectories that are essentially independent of the initial conditions (hence for these grains $\sigma_\lambda >> \bar{\lambda}$).

The full simulation is based upon an iterative scheme in which, at each time-step, (1) the number of aerodynamically entrained grains $N_a(V_0)$ is calculated, and taken to be proportional to the excess shear stress; (2) the resulting grain trajectories are calculated with allowances made for the effects of profiles of concentration $c$, mass flux $q_m$, kinetic energy flux $q_{ke}$, and horizontal force on the wind due to the acceleration of the grains $F_x$; and (3) the numbers of grains impinging on the bed in each of ten impact-velocity increments $N(V_{im})$, are used as input into a "splash function", which returns a new set of impact-ejected grains $N_s(V_0)$ distributed between ten lift-off velocity increments. Between time-steps, the wind-velocity profile is modified via a feed-back loop, which reflects the force imposed upon it by the previous set of saltation trajectories. This provides the new shear stress at the bed to be used in the subsequent calculation of the number of aerodynamically entrained grains.

The transport process is initiated aerodynamically, with all saltation trajectories assumed to occupy the lowest lift-off-velocity increment. The impact of particles in these initial trajectories leads to the ejection of more grains from the snow surface and these have a broader distribution of lift-off velocities than was previously observed. The process cascades at an essentially exponential rate until the wind profile becomes substantially modified by the extraction of momentum by the many saltating grains, a process which eventually curtails further growth of the saltating population. The resulting predictions of steady-state quantities such as the concentration, mass flux and wind velocity profiles, and the distribution of hop lengths, are checked against experimentally derived data sets.

Coupling between multiple grain-sizes occurs at the bed throughout the impact process. Importantly, it is this process that determines the reference level concentration needed in the closure of the earlier analytical suspension theory. The splash function for the two grain-size case will be based upon numerical simulations of the impact process, using a grain-dynamics code, and upon physical experiments performed with bimodal sands.

Simulation of profile quantities such as concentration and mass flux due to both modified saltation and suspension requires averaging not only over the range of initial velocities but also over many presentations of the trajectory process for each condition. For the smaller particles likely to be in suspension such calculations result in concentration profiles that fall off as power laws with height, in agreement with the impressive data sets at Byrd Station, Antarctica, two decades ago, and with available analytical theory which treats suspension as a two-phase flow.

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