MEASUREMENTS OF THE ELECTRIC FIELD GRADIENT IN A BLIZZARD

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ABSTRACT

In the transport of heavy particulates by wind, as in blizzards and sand storms, much of the particulate flux occurs very near the surface by a process called saltation. A buildup of electrostatic charge usually accompanies this phenomenon. To date, the force due to this electrification has not been included in equations predicting particle transport by saltation. Consideration of electrostatic force on particle saltation trajectories requires knowledge of the electric field strength very near the snow surface. Such measurements have been lacking. This paper reports measurements of the electric field gradient in a blowing snow storm. Given this newly measured electric field gradient and previously measured charge-to-mass ratios for saltating snow particles, the modified equations of motion predict substantial changes in saltation lengths in agreement with experimental observations.

INTRODUCTION

Saltation is a transport mechanism by which solid particles hop along a surface in a fluid undergoing shear flow. Whether it be snow or sand particles in air, sediment in a river bed, or sand in a density current on the ocean floor, the equations that describe this motion are of similar form. The bounce of a particle, rebounding from elastic impact with the surface, is stretched into a long, low trajectory responding to forces of fluid drag and gravitation. Equations of motion currently used to describe the trajectories of these saltating particles are inconsistent with observed trajectories. The vertical deacceleration of assinding particles and aceleration of decending particles are both greater then the gravitational acceleration which indicate the presence of a negative lift force. Lift forces develop if the particle spins (White and Schultz, 1977) but spin rates needed to produce the necessary lift forces are large. Another force that could produce a lift force on the particles is an electrostatic force.

Many observers have reported electrification of natural blowing snow dating back to Simpson (1921). All observers note a considerable increase in the positive electric field gradient normal to the earth's surface, during blowing snow events. Large charge-to-mass ratios have also been measured for blowing snow particles (Whishart, 1968, and Latham and Montagne, 1970). When an electrically charged particle moves through an electric field, it is subject to a force which has a magnitude equil to the particles charge times the magnitude of the electric field. In blizzards, snow particles (carrying a substantial charge) move through electric fields of large magnitude. To date, the electrostatic force on these charged snow particles has not been included in the equations of motion describing particle trajectories, nor has the effects this force has on snow and ice formations been considered. Snow drifts and ice on roadways pose a major obstacle to winter travel. Cornice developments on ridge tops are a dangerous source of avalanche triggers. These avalanches often affect highway travel and ski area operations as well as posing a threat to domestic structures in mountain communities. If electrostatic forces play a part in the formation of these hazards, a better understanding of the force and the physical basis for its generation should lead to better prediction and possible control of these phenomena.

ELECTRIC FIELDS IN BLOWING SNOW

The problem with including the electrostatic force in the equations of motion for blowing snow has been lack of electric field data in the saltation region 0-10 cm above the snow surface. Latham and Montagne (1970) measured the field in the region 30-400 cm above the surface and found it varied significantly with height. Schmidt and Dent (1993) proposed a theoretical model based on Latham and Montagne's (1970) data at distances far from the surface and the electric field due to a bed of charged ice spheres for the near-surface field.

Electric field Model

Based on measurements of surface particle charge, made in a wind tunnel (Maeno et al.,1985), Schmidt and Dent (1993) assumed that ice spheres, making up a bed surface, have a charge-to-mass ratio equal in magnitude but opposite in sign to that measured for blowing snow particles. The electric field above this bed of ice spheres, made up of rings of spheres arranged in closest packing, was computed as a function of height above the bed by treating each sphere as a point charge. Contributions to the field decrease rapidly as the radius of these rings increases, so that little was contributed beyond 10 rings, or the area covered by 61 bed spheres.
This model predicted changes in saltation trajectory lengths as great as 24% for charged particles compared to uncharged particles. These changes in trajectory lengths were consistent with observed trajectories (Kobayashi, 1972).

Verification of the model proposed by Schmidt and Dent (1993) requires a measuring device that can be placed close to the snow surface in a blowing snow storm with minimal effect on the electric field. In the past it was not possible to measure closer then 30 cm to the surface without significantly disrupting the field (Hence Latham and Montagne's 1970 measurements). Recent technologic advancements have resulted in an electric field meter capable of making the needed near-field measurements. This meter was developed by the Jet Propulsion Laboratory (JPL) at the California Institute of Technology. The DC electric field probe is described in detail by Kirkam and Johnston (1988). The following is a brief description of the physics involved.

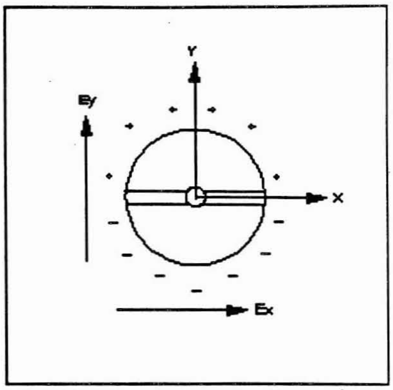

FIGURE 1: End view of electric field probe in electric field.

A cylinder rotates in a two dimensional electric field (E = Ex + Ey) with the axis of the cylinder perpendicular to the field. The cylinder is cut in half length-wise and the two halves separated by a dielectric. The electric field induces a charge on the surface of the cylinder (Figure 1). This induced charge is proportional to the field. There are two electrodes, mounted 180 degrees from each other, on the cylinder's surface. As the cylinder rotates the charge on its surface remains fixed with respect to the electric field thereby inducing a current between the electrodes. This current is converted to optical pulses by a light emitting diode and input into a optical fiber were they are transmitted to a receiver system and converted into an electric field output.

ELECTRIC FIELD MEASUREMENTS

Harold Kirkam made a generous loan of the instrument to Montana State Univ. for the winter of '93-94 in order that it's operation could be tested in harsh blizzard environments. The probe worked exceptionally well in winter conditions and in January '94 measurements were made of the electric field in the region .002-4 m above the snow surface.

On 6 January 1994, a mobile laboratory was moved to a location just south of the Cooper Cove interchange of Interstate Highway 80, 50 km west of Laramie, Wyoming, at 41°31' N, 106°05'W, 2360 m elevation. Consistent west wind during drifting, over nearly level terrain with short-grass vegetation, make the site ideal for such measurements. These conditions exist for approximately 1 km upwind of the measuring location. 10 cm of new snow fall provided light drifting due to moderate winds. At 2458 hours the wind increased, ranging from 4 m/s to 10 m/s on up to 22 m/s.

Instruments

Measurements included average wind speed and air temperature at a 1 m height. Anemometers (19 cm diameter, 3-cup plastic rotors) produced signals with frequencies proportional to wind speed. A thermistor shielded with a plastic pipe 'T' connector produced voltages proportional to air temperatures. Relative humidity at 2 m height was measured in an enclosure mounted on the side of the mobile lab. The inclosure was screened with polyester filter fabric. The electric field probe was mounted on a tripod equipped with a ten-turn potentiometer. Once calibrated, the potentiometer produced voltages proportional to the height of the probe above the snow surface. The electric field probe was connected by 15-m fiber-optic cables to the receiver unit, housed in the mobile laboratory.

Procedure

Computers in the mobile lab recorded data from runs of 1-hour duration for storage on magnetic disks. Measurements of average windspeed, temperature, and humidity, as well as probe height and horizontal and vertical electric field components were recorded every minute. The procedure was to set the probe at a given height for a period of 15 min. Each time the probe height was changed, a manual measurement was taken and compared with the height reading given by the potentiometer to insure accuracy in the electronic reading. A series of vertical profiles for the electric field above the snow surface was measured in the period 0100-h to 0630-h.

Results

Measurements of electric field were averaged at each height interval. A comparison of the measured electric field as a function of height to the model electric field theorized by Schmidt and Dent (1993) is shown in Figure 2.

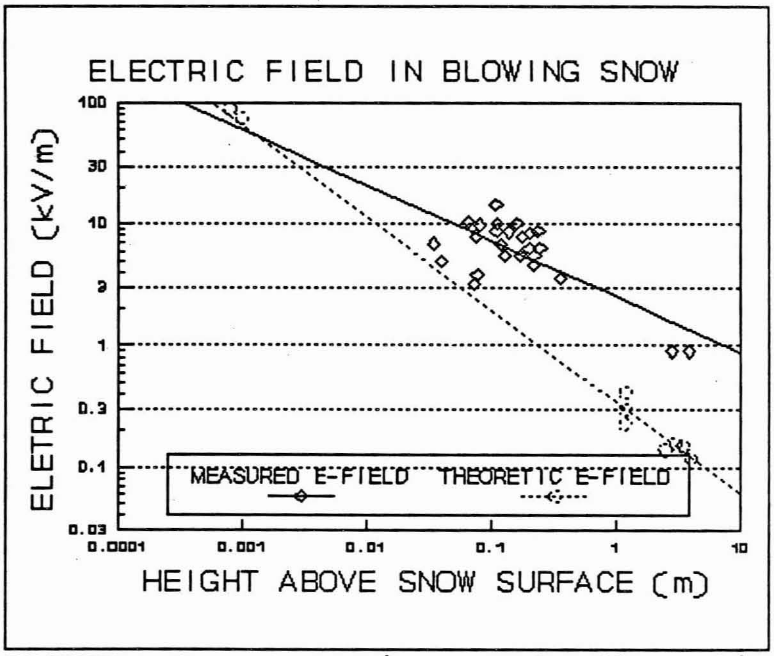

FIGURE 2: Comparison of theoretic electric field proposed by Schmidt and Dent to measured electric field. Power law regression used to fit data.

DISCUSSION

The electric fields measured in this experiment were as great as 30-kV/m at a height of 4-cm as compared to the fair weather electric field of 0.06-kV/m measured at the same height. Electric fields measured in a blowing snow storm compare surprisingly well with the theoretical model developed by Schmidt and Dent (1993). This indicates that the effects of electric fores can not be neglected when describing the motion of saltating snow particles. Based on previously reported charge-to-mass ratios, electric forces can affect snow particle saltation trajectories by as much as 24 % (Schmidt and Dent, 1993). Schmidt and Schmidt (1992) predict that previously measured charge-to-mass ratios for blowing snow are at least an order of magnitude too small. If this is the case, the electrostatic force on a saltating snow particle could be of the same order of magnitude as the gravitational force.

Electrostatic forces calculated by multiplying the electric field measured in this experiment with measured particle charge-to-mass ratios may explain many wind-related snow and ice formations. Wind tunnel experiments (Maeno et.al., 1985) showed saltation surfaces also become charged during blowing snow storms. The magnitude of the charge-to-mass ratio is approximately equal to the charge-to-mass ratio of the saltating particles but the sign of the surface charge can be positive or negative. The sign change appears to coincide with local deposition and erosion areas on the surface. Saltating snow particles carry charge whose sign is predominantly negative but Schmidt and Schmidt (1992) show that this sign fluctuates. The change in sign for the saltating particles seems to be related to the presence of newly fallen snow being transported as opposed to snow that has been on the ground for several days. This change in sign may explain why freshly fallen blowing snow is more apt to form large drift formations, cornices, and icing on roads. A relationship between surface charge, saltation particle charge, and electric field may provide information from which a model predicting, in particular, roadway icing can be developed. Understanding the electrostatic relation should also result in better predictions of drift formation and may lead to an explanation for cornice formation.

As expected from a review of the charging mechanisms for ice particles (Hobbes, 1974) the measured electric field appears to be a strong function of blowing snow particle flux. Temperature and humidity must also play a role in the charging of the blowing snow particles. For the measurements made here temperature and humidity remained constant but if a general model for snow electrification is to be developed, experiments relating particle flux, temperature, and humidity with electric field must be conducted.

CONCLUSION

Ground blizzards transport a great quantity of snow. It has been observed that this transported snow is accompanied by an increase in the electric field normal to the earth's surface. Measurements of electric fields in a blowing snow storm give a quantitative verification indicating that electric fields are enhanced by more then four orders of magnitude. These measurements also indicate that the electric field in a blowing snow storm varies significantly as a function of height above the snow surface as predicted by Schmidt and Dent (1993). The presence of such a large electric field may help to explain snow and ice formations such as dunes, cornices, and roadway icing.

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