THE SIGN OF ELECTROSTATIC CHARGE ON DRIFTING SNOW

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ABSTRACT

A review of the mechanics by which drifting snow develops electrostatic charge shows the sign of the charge is expected to be negative. A corresponding positive charge is expected at the snow surface. These theoretical expectations are confirmed by most measurements, but this paper shows that erosion of surface particles may cause charge sign fluctuations. When surface particles are eroded by wind gusts, these positively charged particles become mixed with moving particles that have developed negative charge. The measured sign of charge on a mass of particles trapped from the drift may swing from negative to positive during strong wind gusts.

INTRODUCTION

Many observers have reported electrification of natural blowing snow. Simpson (1921), Sheppard (1937), Schaefer (1947), Pierce and Currie (1949), Barré (1953), and Magono and Sakurai (1963) all observed a considerable increase in the positive electric field gradient normal to the earth's surface, during blowing snow events. Measurements in Antarctica by Wishart and Radok (1967) and Wishart (1968) showed that blowing snow particles develop negative charges. Latham and Montagne (1970) also showed negatively charged snow particles, moving in a positive electric field that increased as the roof of a snow cornice was approached. Maeno _et al_.(1985) showed that negative charge also develops on snow particles saltating in a wind tunnel. Based on a review of the mechanics by which charge separation develops in drifting snow, it seems likely that during stronger wind gusts, eroded surface particles with positive charge mix with negatively charged saltating particles that have moved over greater distances. If eroded particles dominate the mixture, this should lead to a reversal in the sign of charging current generated by accumulating drift particles in a suitable measuring trap. This paper describes an experiment to detect such reversals and shows that the average sign of the charge on drifting snow particles can indeed change from negative to positive during periods of strong wind gusts. The authors suggest that this new evidence strongly supports past findings indicating that blowing snow particles acquire negative charges while surface particles become positively charged.

ELECTRIFICATION OF BLIZZARDS

From laboratory experiments on the electrification of wind-blown snow, Latham and Stow (1967) suggested three processes for charge separation, all involving

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a process termed the thermoelectric effect. Hobbs (1974 p. 179) reviews the theory of this mechanism, which states that charge will separate in the presence of a temperature gradient across an ice specimen. In their discussion, Latham and Stow (1967) suggest the processes that produce the required temperature gradient are (1) crystal fragmentation, (2) asymmetric rubbing, and (3) transient contact of blown particles with the surface. Each is described below.

Process (1), crystal fragmentation, separates charge when a temperature gradient exists across the crystal. Such a gradient might exist when the temperature of the wind differs from the snow temperature below the surface. If the wind is warmer, the most exposed projections on the surface are warmed, and become negatively charged. If such a fragment breaks from the surface, it carries a net negative charge.

Asymmetric rubbing, process (2), refers to a difference in contact areas when two ice pieces rub together. If a small ice crystal slides along a larger ice surface, the contact area of the crystal remains small, while the area contacted on the surface increases with time. Greater frictional heating of the crystal results, and the warmer crystal gains a negative charge. Henry (1953) described charging of insulators by asymmetric rubbing, which was demonstrated with ice by Reynolds et al. (1957), and Latham (1963).

By process (3), if a temperature gradient exists over the areas of contact, charge will be transferred during the transient contact of a blown particle with the surface. If air flow is warmer than the surface, particles receive negative charge during contact, since surface particles have negatively charged extremities, as in process (1). Net charge on the surface becomes opposite in sign. The signs are reversed if colder air creates saltation across a warmer surface.

These processes indicate that blowing snow particles usually acquire a negative charge, opposite the sign of charge on stationary particles making up the snow surface. This paper tests the hypothesis that wind gusts which erode the snow surface mix particles of opposite sign, reducing the net charge on the drifting particles.

ELECTRIC FIELD MODEL

The significance of the hypothesis arises in efforts to estimate changes in saltation trajectories that result from electrostatic forces (Schmidt and Dent, in press). The electrostatic force on the particle is directly related to the charge on the particle and the strength of the surrounding electric field. Electric field measurements in the saltation region, within the few centimeters nearest the surface are lacking. The following model estimates this field. Based on wind tunnel experiments by Maeno et al. (1985), the charge-to-mass ratio of surface particles was assumed equal in magnitude, but opposite in sign, to that measured on saltating particles. Consider a charged ice sphere saltating over a uniform bed of similar spheres (Figure 1a). The electric field above the bed can be calculated by treating each particle as a point charge and summing contributions to the field surrounding the moving particle. Such computations are simplified by adding rings of six spheres (hexagonal packing), equidistant from the bed particle closest to the moving particle (Figure 1b). Contributions to the field decrease rapidly as the radius of these rings increases, so that little is contributed beyond 10 rings, or the area covered by 61 bed spheres.

As an example, such calculations were made for spheres with 400 µm diameter, the average equivalent diameter in experiments by Latham and Montagne (1970). Two values of particle charge-to-mass ratio were used: (1) -10 µC/kg (Latham and Montagne 1970), and (2) -50 µC/kg (Wishart 1968, data for 9 January 1968).

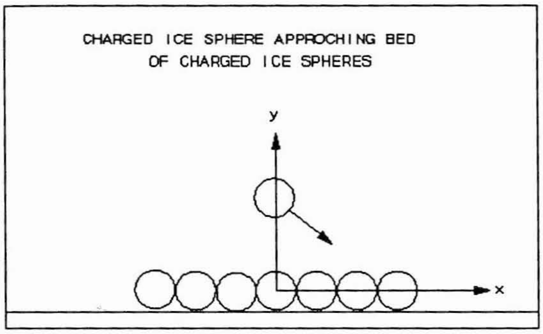

Figure 1a: Snow particle approaching bed of ice spheres.

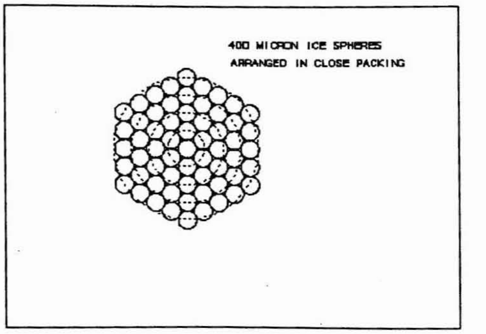

Figure 1b: Bed of ice spheres arranged in closest (hexagonal) packing.

Latham and Montagne (1970) also measured the electric field above three cornices where they found the E-field varied significantly with distance from the surface of the snow. A comparison of the electric field computed for an incoming saltation particle above an ice-sphere bed, to the field extrapolated from Latham and Montagne's (1970) field measurements is shown in Figure 2. Points on the line labeled "combined" were chosen to join the cornice data at distances far from the saltation surface with the computed electric field close to the surface. The regression line through these points represents our best estimate of electric field as a function of height above the saltation surface.

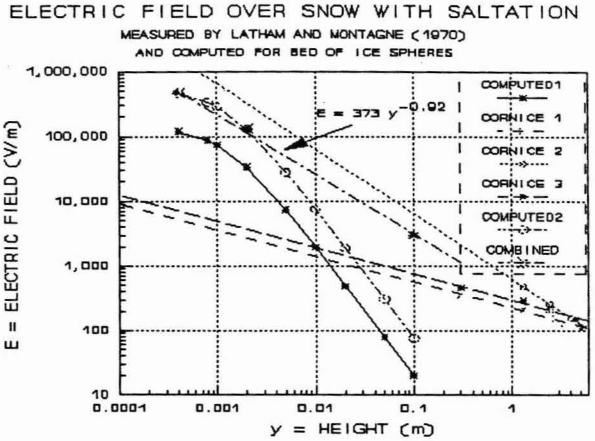

Figure 2: Comparison of measured electric field over three cornices to estimated electric field using Latham and Montagne (1970) and Wishart (1968) field data (after Schmidt and Dent, in press).

THE EXPERIMENT

Measurements in a blizzard in southeastern Wyoming, on 9 and 10 January 1988, provide data for an initial test of the hypothesis. The location is just south of the Cooper Cove interchange of Interstate Highway 80, 50 km west of Laramie, Wyoming, at 41°31′ N, 106°05′W, 2360m elevation. Consistent west wind during drifting over nearly level terrain with short-grass vegetation make the site nearly ideal for such measurements. These conditions exist for approximately 1 km upwind of the measuring location, beyond which terrain becomes more rolling for about 3 km, to the foot of the Medicine Bow Mountains.

On 5 January 1988, a mobile laboratory was moved to the site. Electric power is available from a stub line that approaches from the northwest. Light snowfall with light north winds, during the evening of 5 January and all day on the 6th, added 10-15 cm of snow to old, hard snow dunes and drift features formed from a 60-cm snowfall approximately 10 days earlier. Wind speed increased and drifting began about 1200 h on 7 January. Light snowfall and drifting continued throughout 8 January, during preparations for the electrostatic measurements. Interstate 80 was closed from Laramie west to Walcott Junction at 0950 h on 9 January, because of blowing and drifting snow. Measurements from two periods, 2100 h on the 9th to 0020 h on the 10th, and 0800 h to 1030 h on the 10th, are used in this paper. Between the two periods, the observer (the second author) slept (sic).

Instruments

Measurements included vertical profiles of average wind speed and temperature from 10 levels on a 10-m mast. A 2-m high pipe mast supported a wind vane and fast-response sensors of drift particle frequency, wind speed, and electric current generated by accumulating drift particles (Fig. 3). An electronic barometer measured atmospheric pressure in the mobile laboratory. Relative humidity at 2-m height was sensed in an enclosure mounted on the side of the mobile lab, and screened with polyester filter fabric.

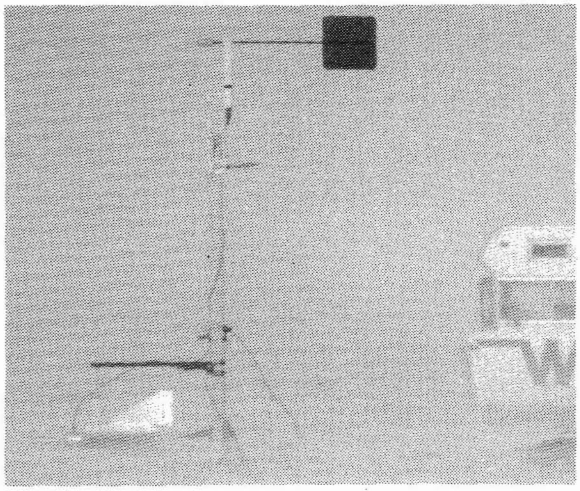

Figure 3: The 2-m mast with sensors. A mobile laboratory (background) housed the computers for data acquisition.

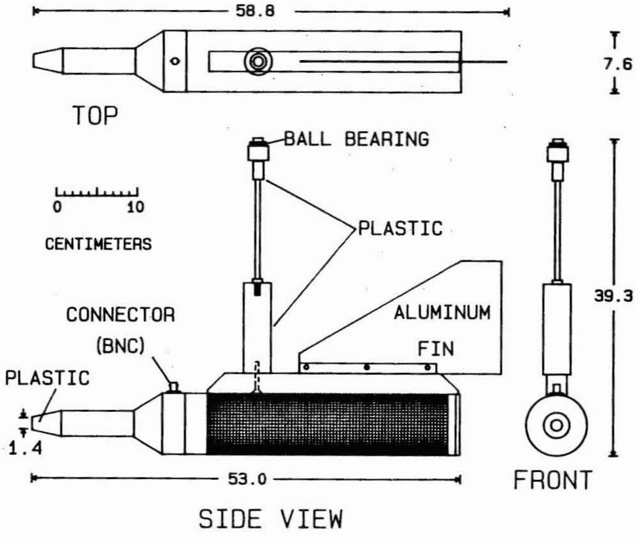

Figure 4: Dimensions of the portable Faraday Cage.

Anemometers with 19-cm diameter, 3-cup plastic rotors produced signals with frequency proportional to wind speed, for the 10-m profile. Two-thermistor networks shielded with plastic pipe 'T' connectors produced voltages proportional to air temperatures at each level on that tower. Tabler (1980) gives details of the vertical profiling system.

A heated-thermistor anemometer (Kurz Mdl 1440M-4*) provided a fast-response voltage proportional to wind speed near 18 cm above the surface at the 2-m mast. Although this sensor iced over in heavy drifting during the last runs on 9 January, readings for most of the experiment compared well with averages from the wind profile.

To sense drift rate, a photoelectric device called a snow particle counter (SPC) generated pulses from shadows of drift particles breaking a light beam. The sensing window is approximately 25 mm long and 3 mm high, normal to the wind. Height of this sensor was near 18 cm throughout the experiment. Electronics in the mobile lab produced a voltage proportional to a 5-s running average of the frequency of these pulses. Schmidt (1977) details this system.

The device constructed to measure the charging current produced by drifting snow particles is a portable Faraday Cage (Fig. 4), similar in principle to the design reported by Wishart and Radok (1967). Two cylinders of brass screen are held concentric by insulating plastic. Polyester filter fabric (50-micron mesh) covers each cylinder. Particles arrive at the inner cylinder through a copper tube insulated from the outer stainless steel support tube by plastic. Lifting the plastic swivel from its socket in the support arm and disconnecting the outer cylinder at the threaded coupling allows weighing of the trap and accumulated snow. A ball-bearing in the support swivel aids the fin in orienting the trap into the wind.

The outer cylinder is electrically grounded by the shield of a 50-ohm coaxial cable with center conductor connected to the inner cylinder. The cable connects to an electrometer (Keithley Mdl 617*) that measures the current conducted through a high resistance shunt between the two cylinders. The system ground was a copper ground rod driven at the rear of the mobile lab, approximately 4 m from the ground at the electric power pole.

Procedure

Computers in the mobile lab accumulated data from runs of 5-min duration for storage on magnetic disks. Wind profiles were plotted between runs. The system multimeter (Hewlett Packard Mdl 3455A*) sampled signal voltages routed by a multiplexer. Fast response data were sampled each 0.75 s, yielding 397 readings of wind speed, drift frequency, and charging current during a 5-min run. To test the portable Faraday Cage, the trap was plugged during some runs, and during two runs it was disconnected, to measure signal noise generated by the cable. Weighing snow in the trap on an electronic balance (Mettler Mdl PK36*) after periods of several runs provided estimates of drift flux. During the night of 9 January, the trap sampled drift at 2-3 cm height. On the 10th, sampling was at 16 cm. Shining a spotlight windward at night permitted new snowfall to be detected as bright crystals amid the duller, rounded drift particles.

RESULTS

Least-squares fits of the logarithmic wind profile equation (e.g., Schmidt, 1982) provided estimates of profile parameters u_*, the friction velocity, and z_0, the roughness parameter. Table 1 lists these parameters for each run, together with temperature, humidity, and averages for the fast-response wind speed, drift rate, and charging current. Plotting reveals several pertinent changes in conditions (Fig. 5). During run 10917, wind direction became more westerly by 25-30°, relative humidity increased about 10%, and wind speed increased, with a corresponding increase in drift particle frequency. Fields notes indicate new precipitation was observed in the spotlight beam during runs 12 and 13.

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*Names of manufacturers are given to aid the reader and do not represent endorsement by the authors' institutions to the exclusion of others that may offer suitable devices.

Table 1.--Average conditions during 5-min runs on 9-10 January 1988.

RUN NO	TIME (hhmm)	WIND AZ (deg)	u_* (cm/s)	z_0 (cm)	RH (%)	TEMP (C)	DRIFT (no/s)	CURRENT (Na)	WIND (cm/s)
10902	2021	302	46.9	0.064	84	No disk file, program error			
10903	2044	305	55.4	0.108	93	-7.4	628	0.006	1244
10904	2104	301	59.0	0.085	93	-7.4	851	0.007	1144
10905	2112	300	56.1	0.061	93	-7.5	525	0.003	977
10906	2119	299	63.0	0.080	93	-7.5	757	0.006	1185
10907	2125	302	60.1	0.064	93	-7.5	638	0.009	1165
10908	2131	301	59.3	0.087	89	-7.5	473	0.007	1054
10909	2137	301	60.2	0.075	85	-7.5	690	0.010	1150
10910	2144	301	53.2	0.057	80	-7.5	339	0.006	1013
10911	2155	308	51.8	0.054	75	-7.5	205	0.002	977
10912	2202	308	60.0	0.057	78	-7.4	325	0.004	1149
10913	2208	308	60.4	0.058	74	-7.3	217	0.001	1148
10914	2215	310	57.9	0.061	76	-7.4	186	0.001	1089
10915	2223	311	56.3	0.057	77	-7.4	291	0.004	1049
10916	2233	301	58.5	0.088	74	-7.5	350	0.000	1081
10917	2243	291	69.8	0.111	81	-7.8	921	0.035	1762
10918	2251	282	81.7	0.137	87	-7.8	1365	-0.067	1383
10919	2256	280	77.7	0.130	89	-7.8	1494	0.035	1331
10920	2302	280	81.6	0.124	90	-7.8	1485	0.123	1338
10921	2307	280	91.0	0.174	89	-7.7	1743	0.114	1421
10922	2321	284	75.4	0.114	83	-7.7	1181	0.081	1467
10923	2327	283	86.1	0.129	87	-7.7	1606	0.061	2510
10924	2332	280	79.1	0.110	88	--------Disk Full Error-----			
10925	2339	278	86.2	0.111	90	0.0	0	0.000	0
11001	4	283	84.1	0.112	91	0.0	0	0.000	0
11002	15	284	80.4	0.132	88	0.0	0	0.000	0
-----------------------Observer sleeping (sic)----------------------------									
11003	751	285	82.0	0.195	74	-3.4	419	-0.204	205
11004	853	282	82.8	0.236	74	-2.2	410	-0.263	930
11005	900	279	83.1	0.158	77	-2.2	574	-0.262	958
11006	905	283	85.1	0.236	76	-2.2	416	-0.275	927
11007	911	281	83.8	0.169	78	-2.2	563	-0.241	997
11008	916	281	87.7	0.181	77	-2.1	626	-0.226	1038
11009	922	278	84.5	0.171	80	-2.1	674	-0.219	1012
11010	947	282	83.1	0.185	79	-1.7	674	-0.237	1016
11011	1027	279	87.9	0.383	75	-1.4	398	-0.001	1145

It is likely that light snowfall occurred with the drifting during runs on 9 January, and unlikely during the period on 10 January. Figure 5 also indicates the status of the Faraday Cage (open, closed, or disconnected) during the experiment.

By historical convention, the sign of electric current is defined as positive in the direction toward lower voltage potential. Negative current through the electrometer corresponds to a negative potential on the inner cylinder of the trap, with respect to the outer cylinder (system ground). Actual flow of electrons is from negative potential to ground. The plot of average drift charging current (Fig. 5) shows a small, positive current during the light drifting through run 10915, indicating a net positive charge on the drift particles. The trap was disconnected for weighing during run 16, and connected but closed (intentionally plugged) during runs 10917 and 18. Stronger positive current was recorded with the trap open during runs 10919-23. In contrast, the sign of the charging current was negative, and consistently stronger during drifting on the 10th, reflecting net negative charge on the incoming particles. The drift trap was open during runs 11004-8.

Measured current during runs when the trap was opened or closed partway through the run show current fluctuations as large, but more frequent and less correlated with drift rate, when the trap was closed. The average current shifted in the sign direction of other runs within the period, when the trap was opened.

Figure 6 is an example plot of both vertical profile and fast response data, for run 14 on 9 January. All vertical temperature profiles showed about 1 °C colder air at 18 cm than at 10 m, indicating a slightly stable stratification. This was true of both data periods, even though temperatures were warmer during runs on the 10th.

Scatter plots (Fig. 7) of charging current against drift frequency show positive correlation during slower drifting (runs 10903-15). This correlation supports the hypothesis that stronger gusts carry greater net positive charge. Figure 7a shows the plot for run 10914. The correlation becomes insignificant during the stronger drifting in runs 10919-11011.

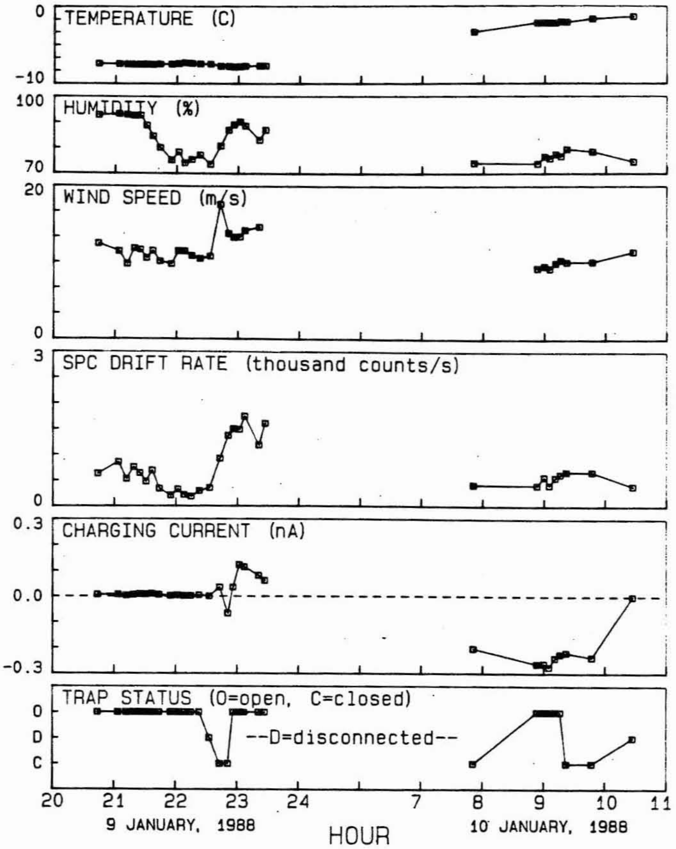

Figure 5: Average values during 5-min runs show changes for the two data collection periods during the 9-10 January, 1988 blizzard.

DISCUSSION

The experiment clearly shows extended periods of positive and negative charge on the inner cylinder of the portable Faraday Cage (Fig. 5). Charge reversal corresponding to wind gusts and bursts of drift particles are also evident (Fig. 6 and 7). However, several shortcomings of this experiment make a test of the hypothesis less than satisfactory. The difference in temperature, and difference in sample height of the Faraday Cage, between runs on the 9th, with positive current, and runs with negative current on the 10th, confound the test. Lack of data during the 8 h between the periods also frustrates us, since there is no way to know if the change in sign was gradual or rapid. Occurrence of snowfall during the first period added complication. Finally, the noise generated by the cage when closed makes one question whether a test is even possible with this apparatus.

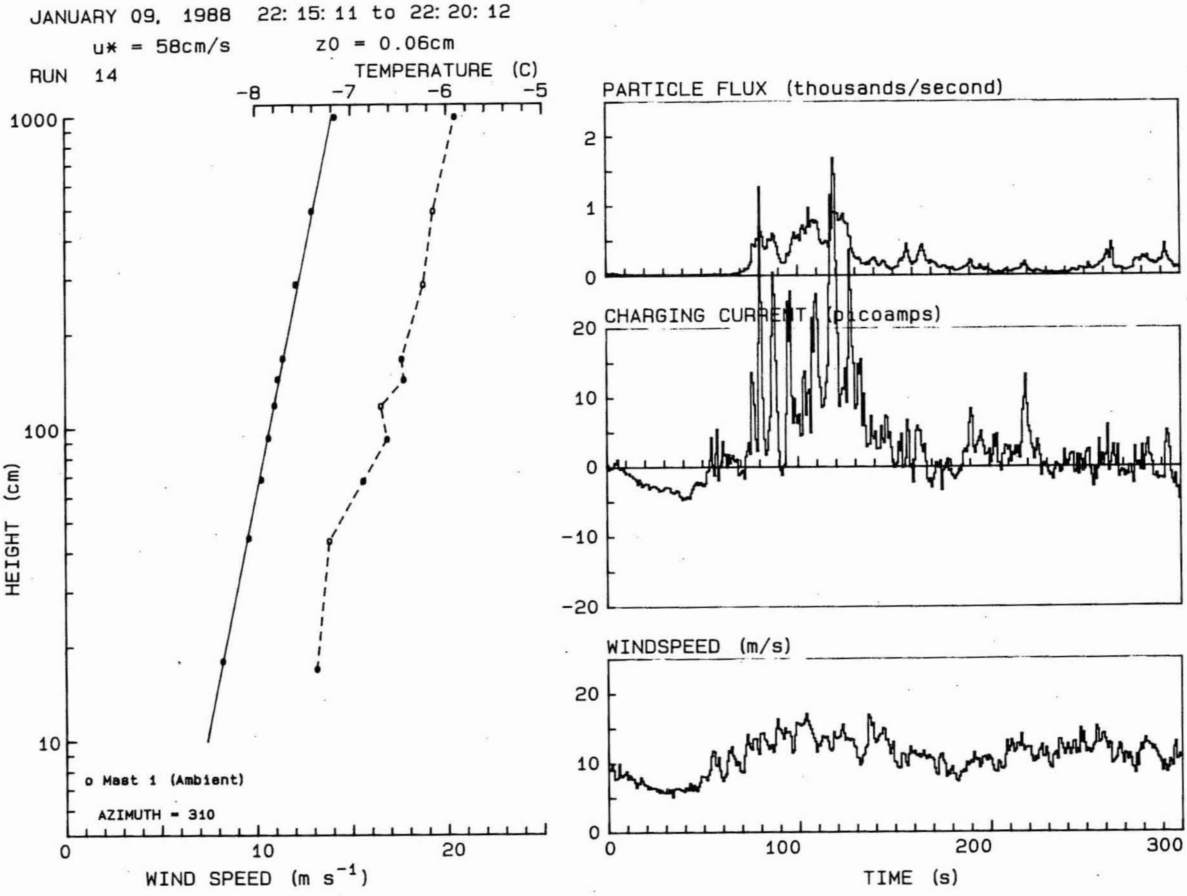

Figure 6: An example plot of data for run 10914, showing the 5-min average vertical profile of wind speed and temperature on the left, and fast-response particle frequency, wind speed, and charging current on the right.

The hypothesis is significant in interpreting charge-to-mass ratios previously reported for drifting snow. If such measures are derived by weighing samples of particles with a mixture of sign, they underestimate the ratios for individual particles. The force that a saltating snow particle experiences depends on the particle's charge-to-mass ratio and the electric field it travels in. The model electric field presented by Schmidt and Dent (in press), based on previously measured charge-to-mass ratios, indicates the electrostatic force on blowing snow particles may change saltation trajectories substantially. If particle charge-to-mass ratios are larger then those previously reported, the force on blowing snow particles would be even larger then predicted by the proposed model.

Experimental support for the hypothesis, while not conclusive, encourages questions on the process of snow cornice formation suggested by Latham and Montagne (1970). It seems likely that the additional cohesion, created between drift particles and surface particles of opposite sign, may be at least as important as cohesion between particles of like sign, forced by a strong electric field.

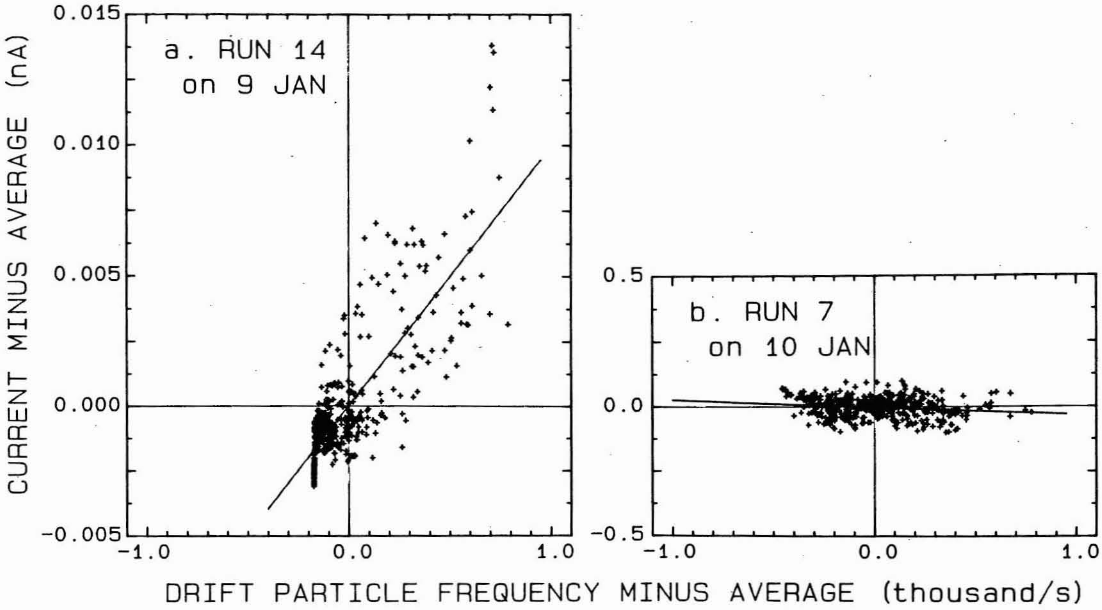

Figure 7: a. Scatter plots of charging current and drift rate show positive charging currents corresponding to particle gusts on 9 January (data in Fig. 6). b. Average charging current during runs on 10 Jan. were negative, and scatter plots of charging current and drift rate show little relationship.

CONCLUSION

The thermoelectric and asymmetric rubbing mechanisms are expected to produce negative charge on snow particles saltating in blizzards, with a corresponding positive charge on the stationary surface particles being bombarded. If this is true, then wind gusts which erode surface particles would mix particles of positive sign with negatively charged drift particles, producing a decrease, and perhaps a reversal in the sign of current resulting from the accumulation of these particles in a suitable drift trap. An experiment that measured such data in a blizzard supports this hypothesis, although several shortcomings of the data leave the test less than conclusive. However, if further work confirms these suggestions, then reported charge-to-mass ratios of drifting snow particles, measured by accumulating particles in a trap, should be considered underestimates. Methods other than trapping drift particles are required to obtain accurate charge-to-mass ratios for individual particles.

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REFERENCES

Barré, M. 1953. Propriété électriques du blizzard. Ann. Geoph. 9 (2), 164-166.

Henry, P.S.H. 1953. The role of asymmetric rubbing in the generation of static electricity. Brit. J. Appl. Phy., Supp., 2, S31-S36.

Hobbs, P.V. 1974, Ice Physics. Oxford. Clarendon Press, 837p.

Latham, J. 1963 Electrification produced by the asymmetric rubbing of ice on ice. Brit. J. App. Phys.,14(8), 488-490.

Latham, J. and Montagne, J. 1970. The possible importance of electrical forces in the development of cornices. J. Glaciol., 9(57), 375-384.

Latham, J. and Stow, C. D. 1967. A laboratory investigation of the electrification of snowstorms. Quart. J. R. Met. Soc., 93, 55-68.

Maeno, N., Naruse, R., Nishimura, K., Takei, I., Ebinuma, T., Kobayashi, S., Nishimura, H., Kaneda, Y., and Ishida, T., 1985. Wind-tunnel experiments on blowing snow. Annals of Glaciology 6, 63-67.

Magono, C. and Sakurai, K. 1963. On the electric charge of drifting snow pellets. J. Met. Soc. Japan, 41, 211-217.

Pearce, P. C. and Currie, B. W. 1949. Some qualitative results on the electrification of snow. Canad. J. Res., 27A(1), 1-8.

Reynolds, S.E., Brooks, M. and Gourley, M.F. 1957. Thunderstorm charge separation. J. Met., 14, 426-436.

Schaefer, V. J. 1947. Properties of particles of snow and the electrical effects they produce in storms. Trans. Amer. Geophys. Un., 28(4), 587-592.

Schmidt, R. A., 1977. A system that measures blowing snow. USDA Forest Service Research Paper RM-194, 80 p.

Schmidt, D. S., and Dent, J. (in press). A theoretical prediction of the effects of electrostatic forces on saltating particles. In: Proceedings of the September, 1992 International Glaciological Society symposium in Nagaroka, Japan. Annals of Glaciology.

Sheppard, P. A. 1937. British Polar Year Expedition, Fort Rae, 1932-1933, discussion of results, Vol. 1:Atmospheric electricity. Roy. Soc., London, p.319.

Simpson, G. C. 1921. British Antarctic Expedition, 1910-1913. Vol. 1, London, Harrison and Sons.

Tabler, R. D., 1980. Self-similarity of wind profiles in blowing snow allows outdoor modeling. J. Glaciology 26(94):421-433.

Wishart, E. R. and Radok, U. 1967. Electrostatic charging of aerial wires during Antarctic blizzards. Polar Meteorology, Techn. Note, No. 87, WMO-No. 211.TP.111, p. 492-529.

Wishart, E. R. 1968. Electrification of Antarctic drifting snow. Proc. Int. Symposium Antarctic Glaciological Exploration, Sept. 3-7, 1968, Hanover, NH, USA. IASH Pub. No. 86, 1970, p. 316-324.