MASS FLUX AND VISIBILITY OBSERVED BY SNOW PARTICLE COUNTER

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Abstract: Mass flux of blowing snow was observed with real-time processing using the Snow Particle Counter (SPC) which could measure the number and size of snow particles. Mass flux derived from SPC was in good agreement with the result obtained by a snow trap. The comparison of the real-time mass flux observed by SPC and the visual range obtained by transmissometer showed a reasonable correlation. The existence of snow particles whose velocities were faster than the instantaneous maximum wind speed in the field was confirmed.

1. Introduction

Real-time and continuous observation of mass flux is important to search for the mechanism of blowing snow and accumulation process of snow drift. So far in measurements of mass flux by mechanical devices such as rocket shaped snow traps, precise real-time mass flux could not be measured because of the variation of aerodynamic efficiency related to the meteorological condition, difficulty of continuously weighing mass flux for a long period and time lag in the case of melting.

SCHMIDT (1977) designed the Snow Particle Counter (SPC) which could measure the number, velocity and size of blowing snow particles. We show that the SPC can be used as a real-time high-response mass flux gauge over a long period from the comparison of the mass flux derived from the SPC with that from a snow trap set at the same level.

Horizontal velocity of each snow particle below 5 cm (saltation layer) was observed photoelectrically by ARAOKA and MAENO (1981) in a cold wind tunnel. They reported that velocities of the descending particles were larger than wind speeds at each height and most of descending particles maintained their large horizontal velocities. However, those results have not been confirmed in fields and at higher levels than 5 cm above the snow surface. In the present study the interaction between snow particle motion and wind was studied in fields from measurement of horizontal velocity of drifting snow particles compared with instantaneous wind speed measured by ultrasonic anemometer.

2. Measurement

A snow trap and a transmissometer were set at the same level as the SPC over the snow surface at Ishikari Observatory near Sapporo (Figs. 1 and 2). As shown

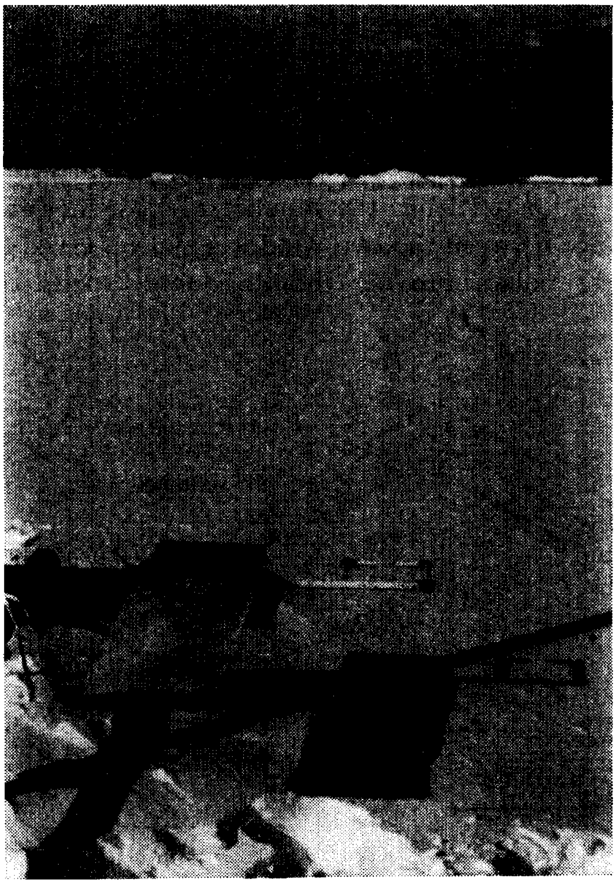

Fig. 1. Snow trap with a porous fabric bag and the SPC set at the same level above the snow surface.

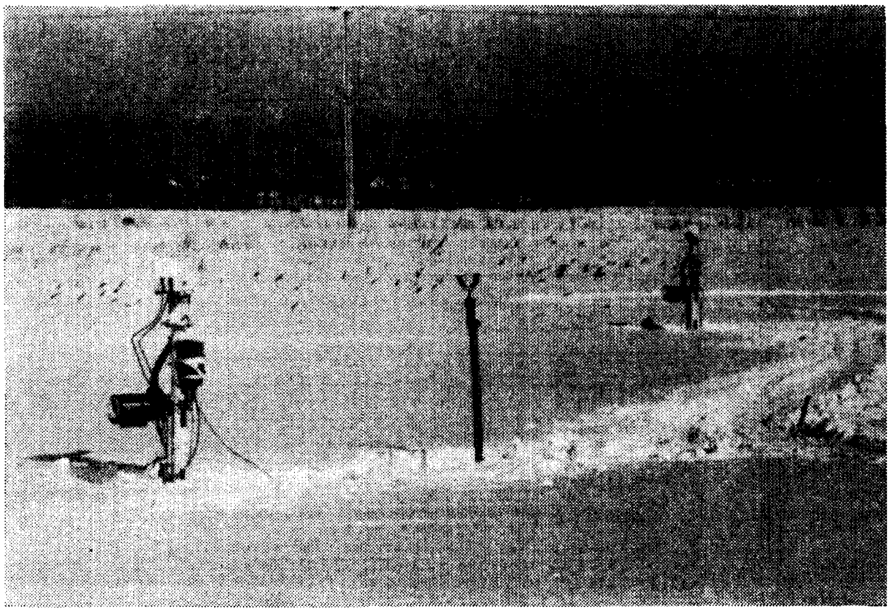

Fig. 2. Transmissometer installed above the snow surface with 30 m light path.

in Fig. 3, the SPC produces two light beams exposed to the wind stream across a 25 mm light path. The two phototransistors detect the shadow of any obstacle as it crosses these beams. The amplifier installed in the arm of the SPC connects the two phototransistors in such a way that a particle passing through the first light beam produces a positive pulse and a negative pulse at the second window. The frequency of snow particles is estimated from the number of positive (or negative) pulses per unit time. The distance between the two windows and observed time interval between positive and negative pulses provide the horizontal speed of the particle. The

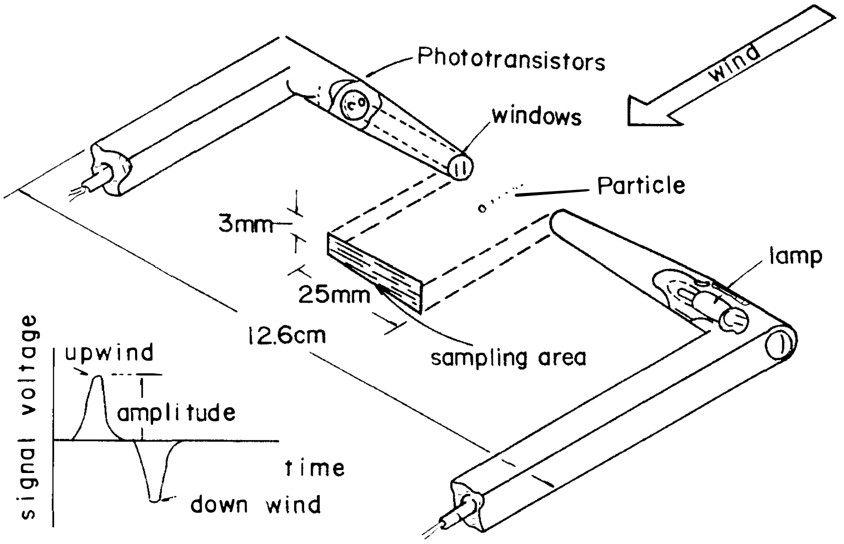

Fig. 3. Sensing elements of the SPC (quoted from the report of Schmidt, *1977).*

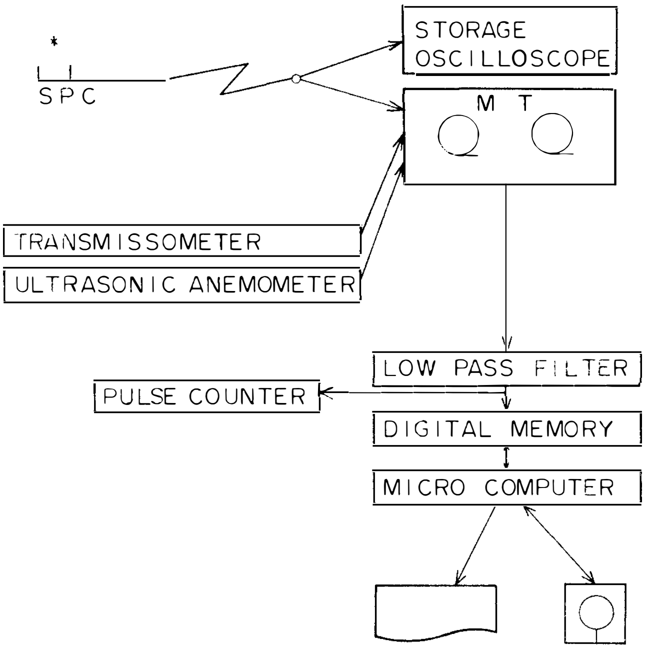

Fig. 4. Block diagram of data processing.

amplitude of the pulse depends on the size of the shadow which corresponds to the particle size.

The block diagram of data processing is shown in Fig. 4. Analog data from the SPC, transmissometer and ultrasonic anemometer were recorded on magnetic tapes, which were also monitored with a storage oscilloscope in the field. At the same time, snow particles were captured directly on glass slides, covered with cedar oil and melted. Microphotographs of them were taken to derive size distributions of blowing snow particles. Pulse levels of the SPC provide size distributions through a microcomputer shown in Fig. 4. Those results were compared with each other to confirm the reliability of the SPC. Frequencies of pulses above trigger level (0.12V) in each minute were counted with a pulse counter.

Mass flux was calculated from the number and size distribution of particles measured by the SPC. Its total was compared with that estimated from a snow trap with a porous fabric bag.

3. Results and Discussion

3.1. *Size distribution of snow particles*

Using a microphotographic analysis, the accuracy of snow particle size distributions from the SPC was verified. Glass slides with cedar oil exposed three times in 11 min at 25 cm above the snow surface (1038–1049, no precipitation February 15,

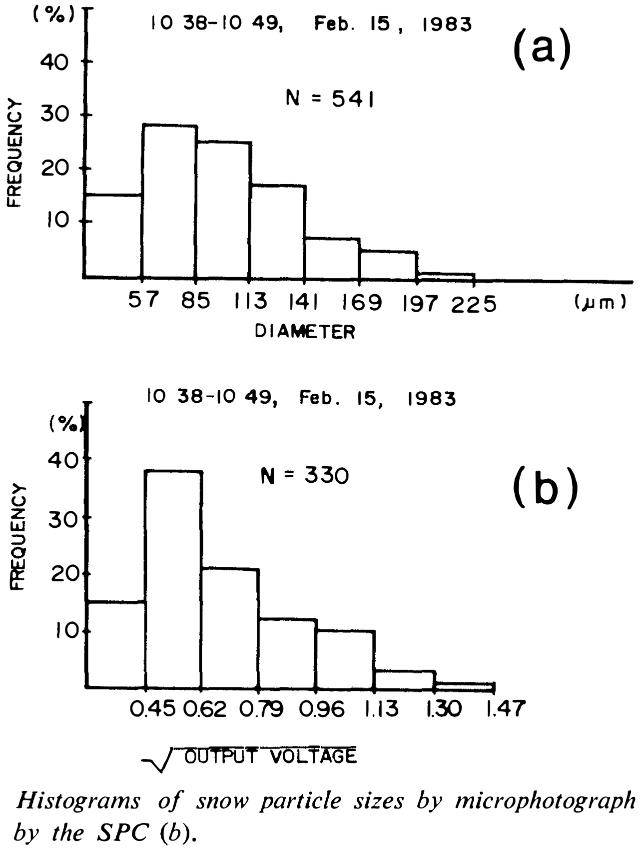

Fig. 5. Histograms of snow particle sizes by microphotograph (a) and by the SPC (b).

1983). Each exposure time was about 2–3 s. Snow particles were captured and melted on the slides. Figure 5a shows the frequency histogram of snow particles from photographs.

The amplitude of pulses (V) measured by the SPC is related to the cross sectional area (πr^2) of a snow particle by;

$$V \propto \pi r^2, \qquad 2r = A\sqrt{V}, \qquad (1)$$

A: constant.

The square root of a pulse amplitude corresponds to the diameter ($2r$) of the snow particle. A histogram of the square roots of pulse levels is shown in Fig. 5b.

Under restriction of data processing, the frequency of pulse levels was calculated using 0.2% of snow particles which passed through the sampling volume of the SPC. Both histograms in Figs. 5a and 5b were results from partial samples of all snow particles which ideally would be observed. However, as a result of testing the statistical hypothesis, both histograms were recognized as samples from the same population at a significant level of 0.2. Therefore, the frequency of pulse levels derived from SPC can be regarded as the real size distribution of snow particles.

3.2. *Mass flux and visual range*

The mass flux of blowing snow was obtained from snow particle frequencies measured by pulse counter and histogram of snow particle size by the SPC. Mass

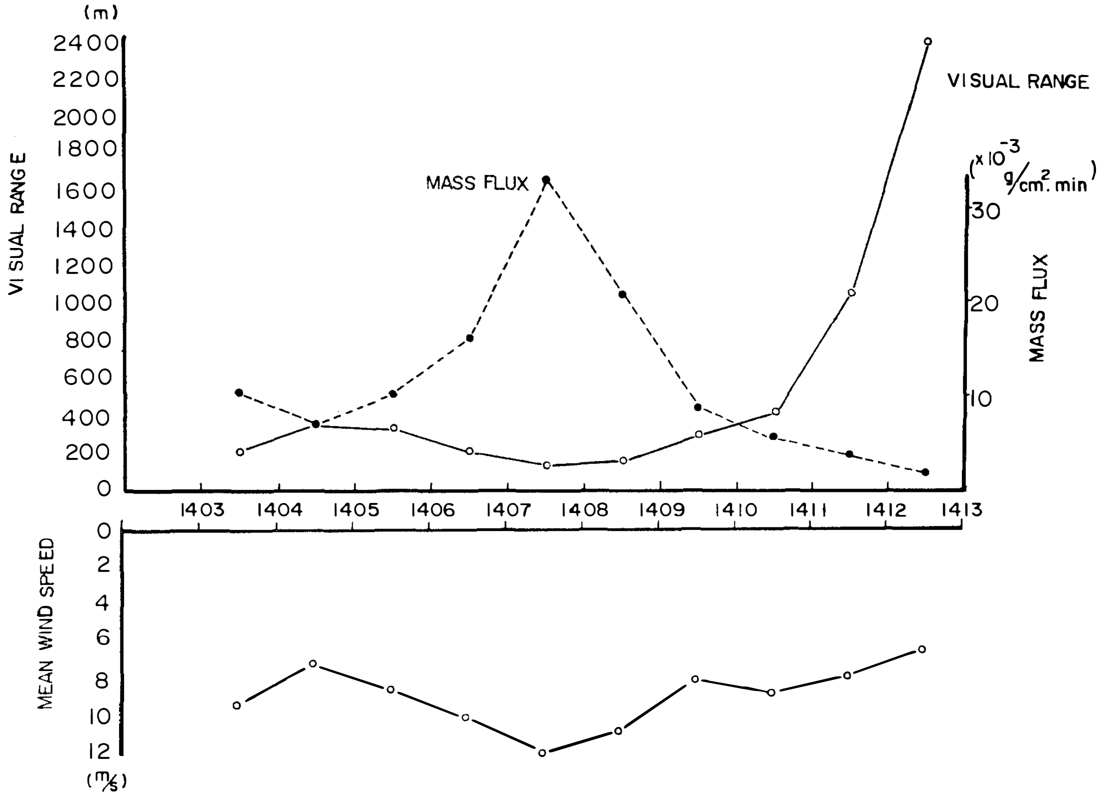

Fig. 6. Transition of wind speed, mass flux and visual range (January 31, 1983).

flux by the SPC was coincident with that by a snow trap within 10% difference.

The visual range (V_r) is derived from transmissivity (T) by using the threshold value (ε) of the eye in differenciating ($\varepsilon=0.05$, as used in highway meteorology). This method was applied to blowing snow by TAKEUCHI (1980) using the theories of KOSCHMIEDER (1924) and MIDDLETON (1952).

$$V_r=\frac{L\log_e 0.05}{\log_e T}, \qquad (2)$$

L: light path of transmissometer (m),
V_r: visual range (m).

Figure 6 shows the mean wind speed, visual range by transmissometer and mass flux by SPC in every 1 min (January 31, 1983). The higher wind speed caused the increase in mass flux and decrease in visibility. The relation between mass flux and visual range by transmissometer is shown in Fig. 7. The result by Budd *et al.* (1966) was averaged value over 30 min (black spots) and that by TAKEUCHI and FUKUZAWA (1976) (crosses) was averaged every few minutes.

As the visibility becomes higher, the blowing snow tends to occur more locally. Thus the error of the visual range estimated by SPC is larger than that by a transmissometer because of the shorter light path. The regression line below 1 km visual range yields the relation between visual range (V_r) and mass flux (M):

$$V_r=10.5M^{-0.73} \qquad (3)$$

M: mass flux (g/cm^2·min).

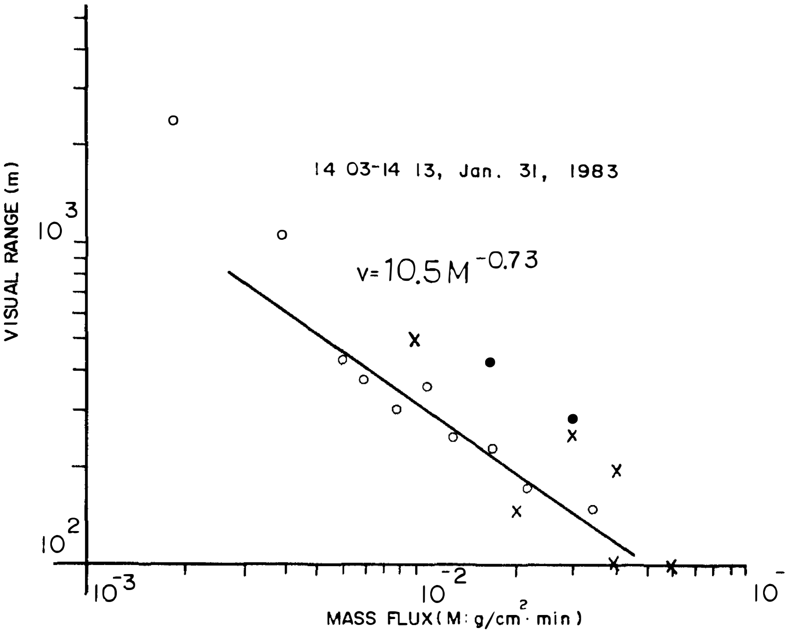

Fig. 7. Mass flux by the SPC and visual range by transmissometer. Closed circle was observed by BUDD *et al. (1966) and cross was observed by* TAKEUCHI *and* FUKUZAWA *(1976).*

3.3. Velocity of snow particle and wind speed

The horizontal wind speed was measured with a three-component ultrasonic anemometer 120 cm above the snow surface, and snow particle velocity with the SPC at the same level as the anemometer. These data were recorded on magnetic tapes and calculated on a micro computer with A/D converter and high-speed (1 μs) digital memory as shown in Fig. 4. The wind direction at 6 m above the snow surface fluctuated within 20° during the blowing snow.

Histograms of wind speed (narrow columns) and snow particle velocity (wide columns) are shown in Fig. 8. It is shown that the average velocities of snow particles are faster compared to the wind speed. Velocities of some particles even exceeded instantaneous maximum wind speed; the mean wind speed was 8.8 m/s (January 31, 1983). In the process of reproducing from magnetic tapes, over and under shooting problems were encountered, which might modify speeds of particles. Consequently higher velocities than real might be calculated sometimes. However, it is probable that velocities of some snow particles are larger than the maximum wind speed. In the saltating layer, ARAOKA and MAENO (1981) reported that horizontal velocities of descending particles were higher than mean wind speeds in cold wind-tunnel experiments. They observed velocities of particles by a photographic technique.

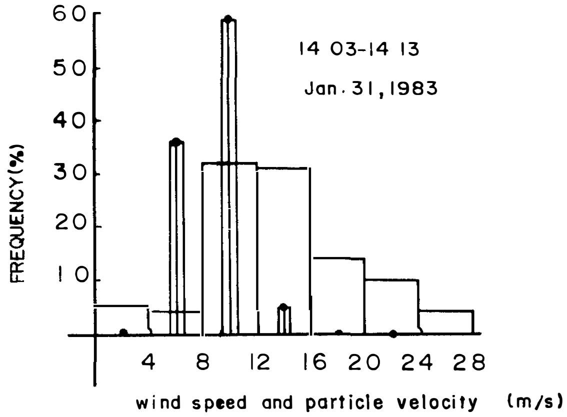

Fig. 8. Histograms of wind speed (narrow column) and velocity of snow particles (wide column).

For more detailed analysis of particle velocity and wind speed, the instantaneous maximum wind speed concerning the snow particle velocity under drifting snow condition without precipitation (February 15, 1983) was investigated in our field observation. The SPC was set 25 cm above the snow surface. The instantaneous maximum wind speed 80 cm above the snow surface was 8.8 m/s while the mean (10 min) speed was 5 m/s. There were several snow particles whose velocities exceeded the maximum wind speed without under and over shootings. One of their wave forms was shown in Fig. 9a. The particle velocity was 15.9 m/s, which was faster than the instantaneous maximum wind speed observed simultaneously.

Generally, the heavier (larger) particles with greater inertia may be expected to have higher velocities than the lighter (smaller) particles if the descending particles

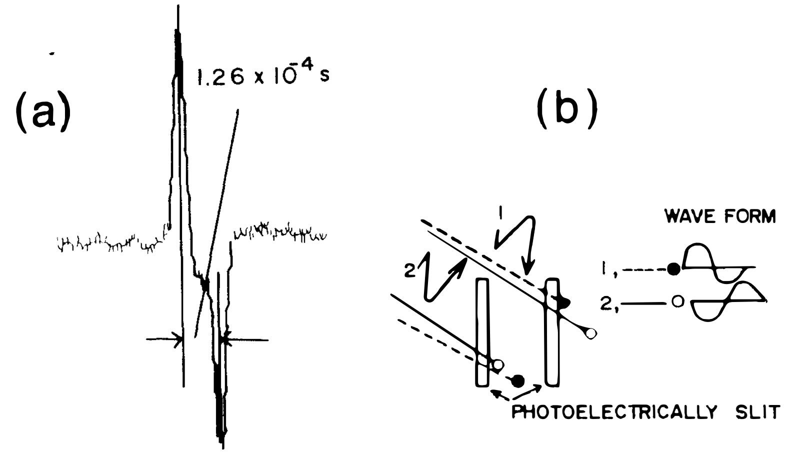

Fig. 9. Wave form a snow particle by the SPC whose velocity was faster than the instantaneous maximum wind speed measured by ultrasonic anemometer (a), and the wave form in the case of two particles existing simultaneously in the sampling volume (b).

maintained their large horizontal velocities. If a snow particle with higher velocity than wind speed descended from the upper layer preserving its speed, it should have descended from 11 m above the surface assuming a log linear wind profile as shown in Fig. 9. Therefore, it is unreasonable that the higher velocity of snow particle is attributed to the descending of particles. The snow particles with faster velocities than the wind speed were relatively small ($<60\,\mu$m). Some force to accelerate snow particles must exist. After size distribution analysis, the weight ratio of the larger particles to the smaller ones was found to be more than 50. Hence, it is probable that relatively small snow particles are accelerated by collision with other particles even if some energy scattering occurs by destruction of snow particles.

The apparent higher than real speed may be observed if two or more particles passed through the sampling volume at the same time; two possible wave forms are shown in Fig. 9b. In wave form 2, the phase is opposite to that of form 1. The occurrence probabilities of the two are equal to each other if several particles exist. Wave form 2 was not found in our observation. Consequently, it was concluded that more than two particles did not exist in the sampling volume simultaneously. However, it is still probable that several particles are observed at the same time even if rarely. SCHMIDT (1977) considered SPC to give reliable single-particle measurements 10 cm above the surface at wind speed up to 15 m/s (measured at 10 m height) using Antarctic drift data by BUDD *et al.* (1966).

4. Concluding Remarks

As results of comparing SPC data to mass flux obtained by a snow trap and size distribution by microphotograph, it is confirmed that the SPC can be used to measure real time mass flux directly using particle frequency and size distribution. There is a possibility to observe continuously the long-period real time mass flux by the SPC which may contribute to mass accumulation in polar regions.

Mass flux obtained by the SPC corresponds to the visual range observed by a transmissometer. The SPC is a more portable and small-sized sensor compared to the usual mass flux gauges and visibility meters. We are going to use the SPC as mass flux gauge and visibility meter installed on a car. Many more observations should be made to ascertain the accuracy of the SPC statistical methods. Some snow particles were found whose velocities were faster than the instantaneous maximum wind speed.

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