A NEW DEVICE FOR SAMPLING MASS FLUX OF BLOWING SNOW

BY

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INTRODUCTION

For fifty years, members of this conference have concerned themselves with the measurement of snow. The need to predict water supplies has understandably led to emphasis on measurement of snowpack variables. Only gradually have we become aware of how much our predictions must be adjusted to reflect evaporation from the snowpack (Peak, 1969), and from wind-transported snow (Schmidt, 1972; Tabler, 1975). Measurements of snow, whether it be as precipitation, snowpack, or snow transported by wind, are fraught with errors, so the search continues for more accurate instruments, methods, and techniques. This paper describes a new device that provided very useful measurements of blowing snow in experiments at Diamond Lake, Wyoming, during January and February 1982.

Transport rate (Q) is a fundamental measure of blowing snow. This mass flux is usually expressed as grams of snow passing through an area normal to the wind, one meter wide and extending from the surface to some height above which the flux is negligible. The mass concentration of blowing snow decreases so rapidly with height that the question of the upper limit is not as important as the shape of the concentration profile in the first 10 cm above the surface. Methods of measuring Q can be divided into point and height-integrated sampling.

MEASUREMENT TECHNIQUES

Point Samples.

If point samples of mass concentration are obtained at several heights, Q can be estimated by assuming the particles at each height are moving at the local wind speed, and integrating with respect to height. The main difficulty with this technique is obtaining measurements near the surface, so that the extrapolation to the lowest few centimeters accurately depicts flux in the region of greatest transport. Few techniques are suited to low-level measurement, and those that are cause some obstruction to flow, which can produce substantial errors in calculating flux near the surface.

Considering the conditions in a blizzard, it is remarkable that any such measurements exist. One of the best and most intensive data sets resulted from efforts by Dr. Uwe Radok and his colleagues to estimate mass transport of snow in Antarctica (Budd, Dingle and Radok, 1966). Point samples were obtained using rocket-shaped snow traps (Mellor, 1960) at eight levels, with spacing that increased geometrically between 3.125 cm and 4 m. The profile was integrated between a lower limit of 1 mm and an upper limit of 300 m to obtain estimates of Q. For any given wind speed, these transport rate estimates are larger than all others reported.

Tabler and Jairell (1971) developed a method of recording a continuous point sample. An enlargement of Mellor's trap design gave a sample large enough to be weighed on a recording precipitation gage installed below ground level. The entire trap, including the gage, rotated to aline with the wind direction. Jairell (1975) improved this device with a turntable assembly that allowed the gage to remain stationary while only the trap oriented to the wind, thus eliminating much of the "noise" in recording. Because only a single height (usually 0.5 m) is sampled, such a device cannot provide accurate estimates for transport rate. However, mean hourly fluxes from this instrument provided a weighting index for characterizing weather conditions during drifting (Tabler and Schmidt, 1973).

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Schmidt (in press) reports concentration profiles measured at six levels in the first meter above the surface, by photoelectric particle counters (Schmidt, 1977), with the lowest sensor at 5 cm height. By extrapolating these profiles to a height of 1 mm using a power-law function, the drift estimated in the layer below the lowest measurement level averaged 86% of the total transport rate (Q) calculated to a 1 m height.

Height-Integrated Samples.

A device that samples all drifting between the surface and some specified level automatically integrates the mass flux profile over the sampled height range, thus eliminating the problem of extrapolating a point-sampled profile. Usually this is at the expense of details in the vertical mass concentration profile. Takeuchi (1980) reported measurements in blowing snow with a stack of contiguous rectangular frames supporting porous fabric bags that filtered particles from the wind stream. While working with Dr. Takeuchi during the 1979-80 winter, the authors were impressed with the rapid cohesion of drift particles trapped in the bags, a feature that suggested the feasibility of the design reported here.

A disadvantage of the traps used by Takeuchi is the frequent weighing required. Sampling times from 30 to 60 s are the rule, making it very tedious and extremely demanding to continue such sampling during even moderate blizzards. Further, the accumulation of snow in the bags reduces air flow through the traps, thereby reducing their "aerodynamic efficiency," (the ratio of airflow through the trap to flow through the same normal area without the trap). Some method of recording drift flux over longer periods seemed essential to obtain data that sufficiently characterize such a variable phenomenon, but this brought up questions of what to do with the large volumes of snow that accumulate. The next section describes a solution to this problem.

A NEW DRIFT FLUX TRAP

Design.

Better drift flux measurements are needed in scale-model studies (Tabler and Jairell, 1980), where efficiency of drift control is determined experimentally. These model studies are being carried out on a frozen lake, which provides a smooth, horizontal surface. To characterize wind conditions during these experiments, vertical profiles of wind speed and temperature are measured with a computer-controlled system, over intervals typically 5 min in length. Our design objective was to produce a height-integrated measurement of drift flux that could be recorded with each wind/temperature profile. To provide dynamic similitude of the models, wind speeds must be within a few meters per second of the threshold speed for drifting. At these speeds, all published data indicate negligible mass flux above 50 cm, so a 50-cm height was chosen for the trap.

The trap's across-wind dimension was chosen with two conflicting objectives in mind. Although a wide frame was considered desirable to minimize effects of the trap edges, a narrow aperature is needed to keep the sample storage volume manageable. Based on our experience with Takeuchi's traps, which sample 15 cm across the wind, and with two earlier designs, which had corresponding dimensions of 0.2 and 1.0 cm, a width of 5 cm seemed to provide a reasonable compromise. Although wind speeds, and therefore drift transport, are light to moderate during scale-model experiments, other plans required a device that could measure transport rates up to 1000 g/m·s. Mass of snow accumulated during a 5-min run in such intense drifting through a trap 5 cm in across-wind dimension would amount to 15000 g. Assuming 100% efficiency in trapping drift and 200 kg/m^3 bulk density of snow deposited in the trap, storage for at least 0.075 m^3 would be required.

With a design storage volume determined, mechanical methods were explored for removing the trapped snow, including use of a screw conveyor. This experience suggested that such a refinement in design presented so many additional problems that at this stage of development it would be best to empty the trap manually, at intervals determined by drift transport rate. This decision necessitated the design of a tank that would provide room for a weighing device and snow container, to be installed below the ice surface.

Selection of a weighing mechanism was based on (1) resolution to 1 g, (2) capacity of at least 15 kg, and (3) computer interface capability. Because the scale would be located at least 75 m from the computer, a data transfer method using few wires was desirable. Some moderation of temperature in the tank by heat from the surrounding water could be expected, but it was anticipated the scale would operate in ambient temperatures below 0°C. Although no manufacturers were located who specified a weighing device that met all requirements, a Mettler model PK 36 [3/] with CL data interface was selected to attempt this measurement. Because data transfer was done by current loops (ASCII format, 2400 baud, full duplex), only four lines were required.

Once the dimensions of both the balance and the container needed to hold the design snow volume were known, a tank diameter could be selected; 0.915 m (3.0 ft) was the closest standard size available (in the local junk yard). The tank had to be at least 90 cm deep in order to accommodate the balance and container, including allowance for approximately 10 cm of extra space under the balance to keep it above fugitive snow and any melt-water that might accumulate in the bottom of the tank. Because the buoyant force (equal to the weight of the volume of water displaced by the tank) exceeded the tank weight, space also had to be provided for steel ballast plates used to submerge the tank partially so that its top would be flush with the ice surface. With the unit-weight of the steel and other materials known, it was a simple matter to compute the required tank depth of 100 cm. The calculated buoyant force on the tank was 558 kg and the empty weight of the tank was 167 kg, so that approximately 391 kg of ballast was required for neutral buoyancy.

A 13-cm-wide flange around the top of the tank was designed to provide support under the added weight of the collected snow. To eliminate any tendency for the tank to melt into the ice, it seemed desirable to maintain a small net buoyant force with the collecting bucket empty. Field experience later proved this precaution unnecessary because the flange in contact with the ice was well insulated and solar heating of the tank was negligible.

Cohesion of wind-blown snow particles can make sampling very difficult, as we had learned in previous attempts at height-integrated measurements. By using a porous bag that had sufficient freedom to shake in the wind, we took advantage of this cohesion to transfer the particles from the wind stream into the container. The idea was to use a porous polyester fabric fashioned as a bonnet, attached to a frame of sharpened blades facing the wind, and open along its lower edge, or "neck," to the container beneath the ice. Particles striking the fabric would cohere, and the aggregate would gain mass until it fell into the storage container. A turntable assembly, similar to that reported by Jairell (1975) allowed the flux trap to orient into the wind, driven by a wind vane above the "flapping bag."

Construction Details.

Figure 1 shows the device before installation; dimensions are given in Figures 2 and 3. Watertight welds attached the bottom and flange to the tank. A steel pipe with inside diameter large enough to pass the power and signal cable connectors was welded into the top of the tank as a cable port. The entire tank was painted white. A 20-mm-thick redwood ring insulated the tank flange, and 3-mm white plastic covered the wood, forming the top surface which was installed flush with the ice.

The trap assembly, built on an aluminum base plate 6.4 mm thick and 600 mm in diameter, latched to the turntable. Fabric for the bag was precisely woven polyester with 0.105-mm-square openings. Silicone rubber proved an excellent adhesive for securing the fabric to the aluminum blades. As an additional measure, thread passing through small holes in the blades tied the cloth at 2-cm intervals. A flat, double-stitched seam extended from the blades back along the top of the bonnet, ending in a reinforced corner that was attached to the supporting frame by a pipe cleaner, with 2-3 cm slack, which allowed the bag to be shaken by the wind. The cloth "neck" passed through a 5- by 30-cm opening in the base plate, where a thin aluminum angle held it in place. Two brass rods, 3.2 mm in diameter, were necessary to maintain the 5-cm dimension between blades during strong winds.

[3/] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

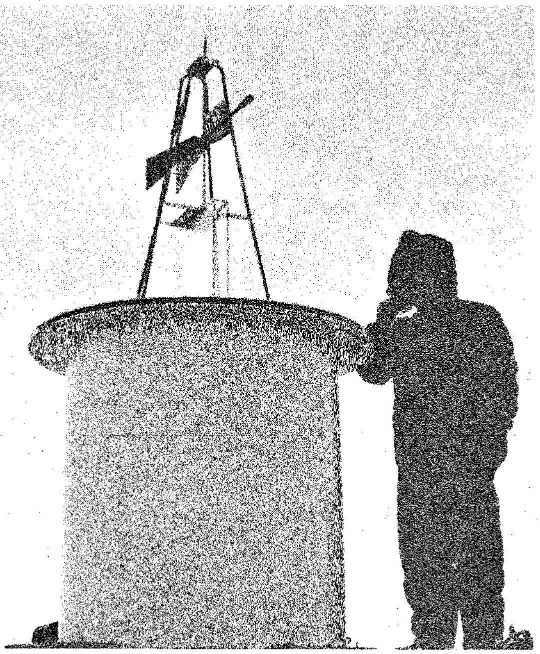

Figure 1.

The drift trap ready for installation in the ice.

Installation.

Ice thickness was 30 cm at the time of installation (15 cm was considered a safe minimum). The procedure began with site selection on sound ice, free of large cracks and surface irregularities. A circular groove was chiseled in the ice to receive the tank flange, before the hole was cut with a chain saw along the inside circumference of this groove. Sectioning the ice core allowed the pieces to be pushed back under the surrounding ice. The tank, with turntable in place, was skidded to a position near the hole and then lifted into the hole to avoid the possibility of it jamming at a list. Once the tank was in the water, a person climbed into it to place the ballast plates, which were cut in semicircles to facilitate handling (Figure 4).

The design called for enough buoyancy to provide several centimeters of freeboard, eliminating any load downward on the ice under the flange. Ice screws and brackets held the tank level at the proper height during freeze-in. The tank became solidly frozen in the ice overnight. Finishing the ice surface surrounding the trap consisted of filling cracks and chips with a snow-and-water grout, then scraping the surface with a square-nosed shovel, giving special attention to the quadrant of drifting winds. The finished installation (Figure 5) had a very smooth transition from ice to trap, as shown by the streamlines of drifting snow.

Operation In Blizzards.

During a 5-min run, the computer requested the weight of snow entering the trap at 15-s intervals. After each run, approximately 4.5 min was required to automatically record, analyze, and plot results. This procedure allowed anomalies and equipment problems to be spotted and corrected between runs. To observe and evaluate the performance of this new drift flux recorder, at least one observer was on the ice during most of the blizzards sampled this season. Experimenters on the ice and in the van that housed the computer, communicated by radio.

A foam-covered wooden cap, attached to the trap opening, served to divert drift around the trap during intervals between runs, if drifting was heavy enough to necessitate emptying the trap frequently. Just before a run, this cap was removed by the observer. It was replaced when a computer-controlled light at the trap signaled the end of the run. To remove trapped snow, the observer unlatched and moved the trap assembly to a position on the ice where it was retained by an arrangement of ice screws (Figure 6).

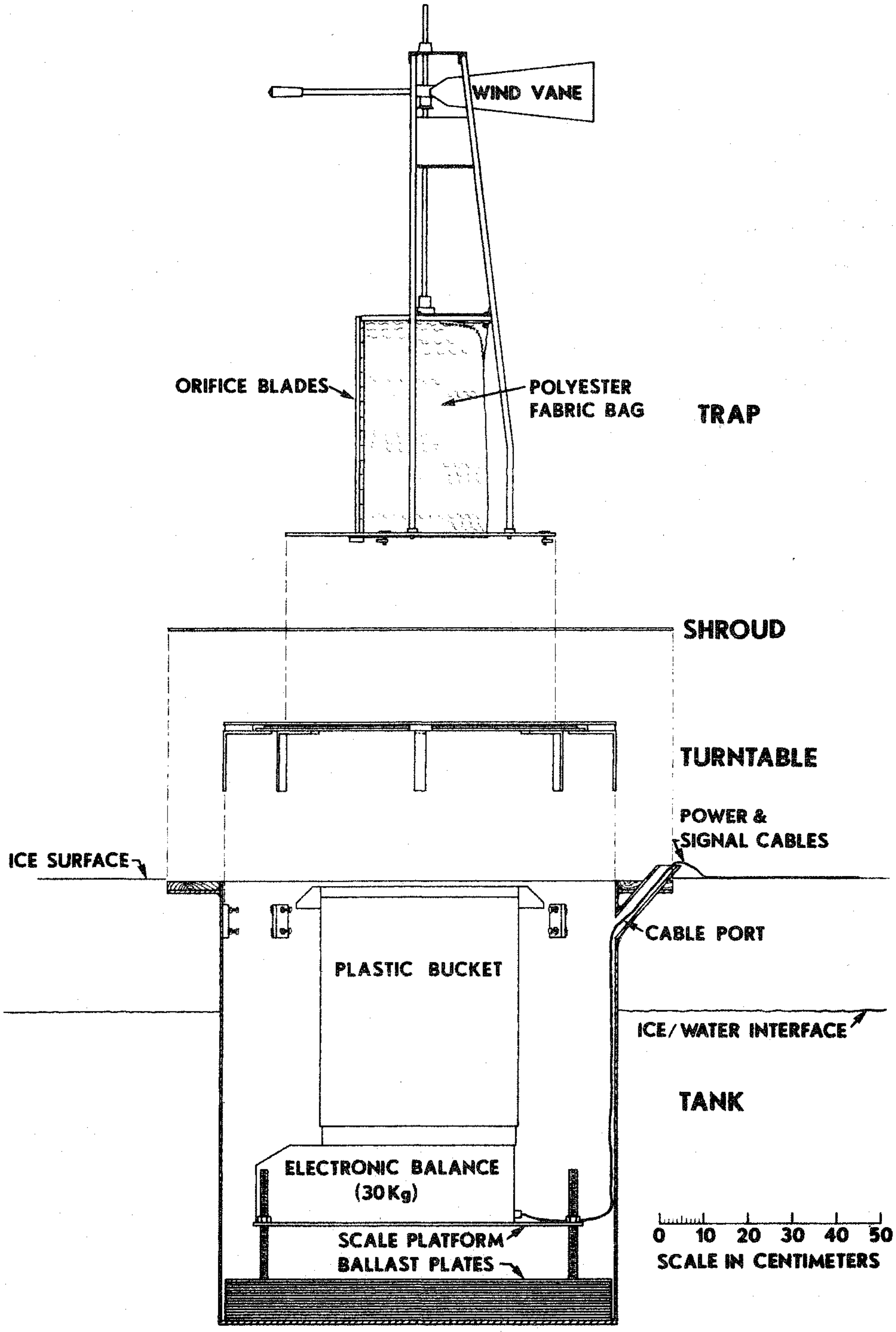

Figure 2. Exploded cross section of the drift flux trap.

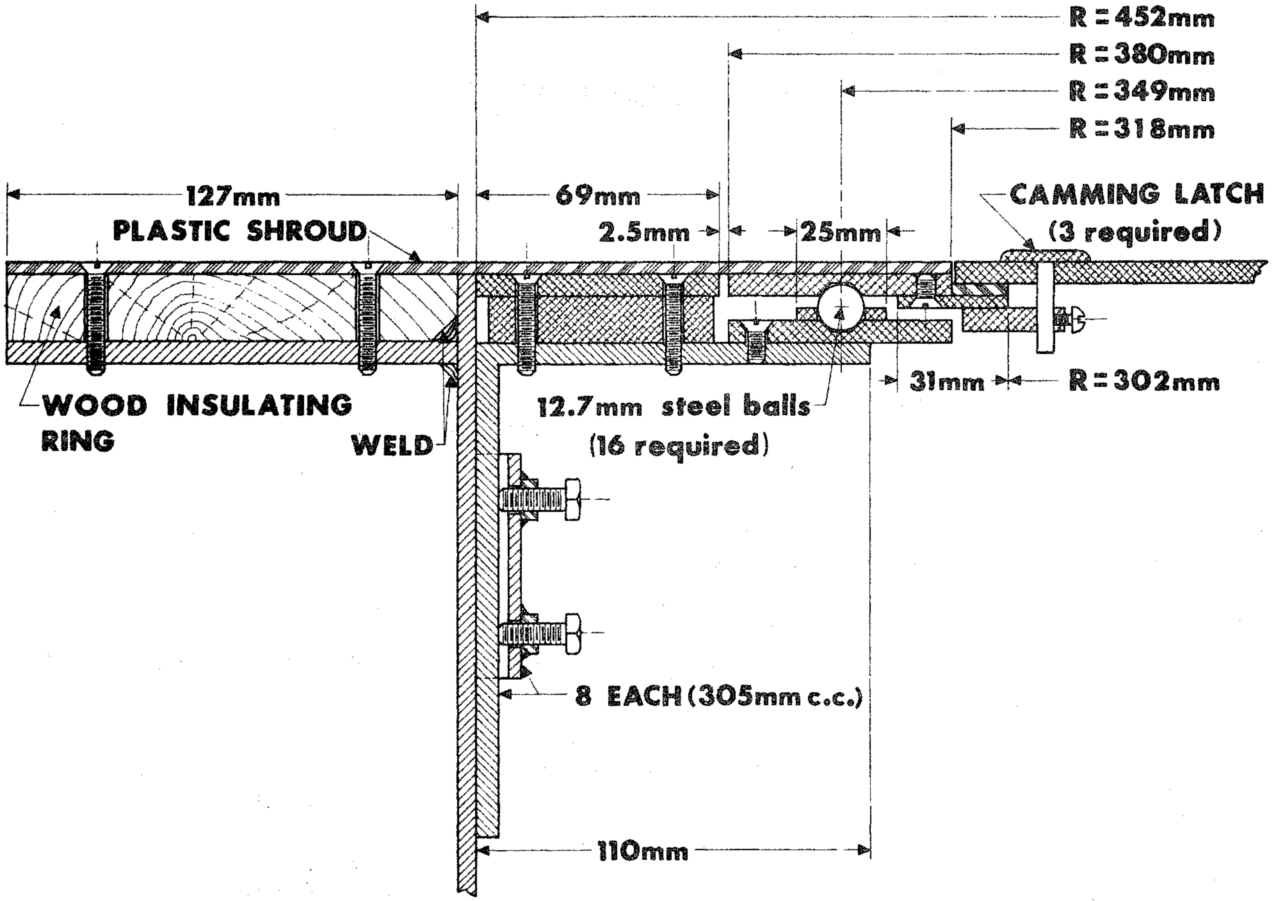

Figure 3. Details of the turntable assembly.

Figure 4.

Installing ballast plates used to achieve neutral buoyancy.

The storage container, a 100-liter plastic barrel, was lifted through the service hatch, and a plywood cover placed over the opening to keep snow from drifting in around the scale. Unless winds were exceptionally strong, the observer dumped the snow at least 20 m downwind, to reduce any tendency for deposition near the trap. The container and then the trap assembly were replaced, and the hatch cover was stored flat on the ice, downwind. After each blizzard, the container, scale, and scale platform were removed, and the tank cleaned of all snow. Usually no more than 1 kg was present on the ballast plates, even after measurements in heavy drifting that lasted more than 24 hours.

TRAP PERFORMANCE.

As expected, the environment of the scale was less severe than ambient conditions above the surface. Temperature inside the tank remained close to 0°C even when the outside temperature was -30°C, due primarily to the 0°C temperature of the water under the ice. The scale was placed in a clear plastic bag to prevent snow from blowing into the electronic components when the tank was opened to empty the snow container. Air movement at the level of the balance was so slight that the plastic bag could be tared with the container and any error introduced by this procedure was within the specified accuracy of 1 g (resolution of the balance is 0.1 g). The balance performed without problems during every experiment.

All snowfalls during tests were less than 20 cm deep, so the trap was never covered. During the beginning of new snow drifting, trap performance improved if the observer drew a smooth lath through the snow along both sides of the bag to relieve restrictions to movement. Although the trap distributed snow in the container, it tended to accumulate at the downwind edge (Figure 7), as snow aggregated at the back of the bag.

Tank design proved to be nearly ideal. Insulation of the flange with redwood reduced melting to such an extent that the opposite became the problem. After almost a month, ablation of the ice during dry, windy periods had lowered the ice more than 1 cm below the tank surface. A warm spell freed the tank from the ice, allowing us to deepen the groove and reset the tank.

The white plastic cover over the tank flange provided a very smooth surface that resisted snow deposition, but there was a tendency for snow particles to lodge underneath the shroud. This increased friction and prevented the turntable assembly from orienting properly in light to moderate winds. The problem was of little consequence as long as an observer was on hand to check alinement, but improvements would be needed for unattended operation. A possible solution to this problem would be to eliminate the plastic shroud, leaving the gap between the rotating turntable and the stationary ring exposed; however, this solution would have the disadvantage of allowing more snow to accumulate in the tank, on the outside of the container.

The leakage of snow through the fabric bag was tested by two methods. The addition of a second bag to a single 5- by 15-cm frame from a Takeuchi trap allowed computation of the percentage of mass that leaked through the first bag and was caught by the second. The inner bag was of the same fabric as the trap (0.105-mm openings) while the outer bag had openings half as large. Near the surface, larger particles and low speeds produced leakage less than 1% of the mass trapped during 30- to 60-s samples. Samples at a 50-cm height had less than 3% leakage. In view of the distribution of drift, leakage would be less than 1% of mass trapped in the 5- by 50-cm flux trap. This estimate was confirmed by covering the trap opening with the 0.105-mm fabric, and comparing the mass leaking into the trap with the catch in another trap nearby.

One hypothesis in trap design, as mentioned above, was that measurement errors decreased as the across-wind dimension increased. This was based on an assumption that the orifice blades created edge effects that reduced drift catch. To test the hypothesis, a bag of filter fabric was attached to a square aluminum frame, 50 cm on a side. The bag extended 80 cm downwind from the frame, which rested on the ice, normal to the wind, forming the trap orifice. During eight 5-min samples, the transport rate measured with the 5-cm-wide flux trap averaged 1.6 times the Q estimated from the 50-cm-wide trap. Flux trap measurements ranged from 0.3 to 88.6 g/m·s, and for the three runs with highest Q, the flux trap gave 1.2 to 1.3 times the drift rate estimated from the 50-cm-square trap.

Figure 5.

The drift trap during measurement in light drifting conditions.

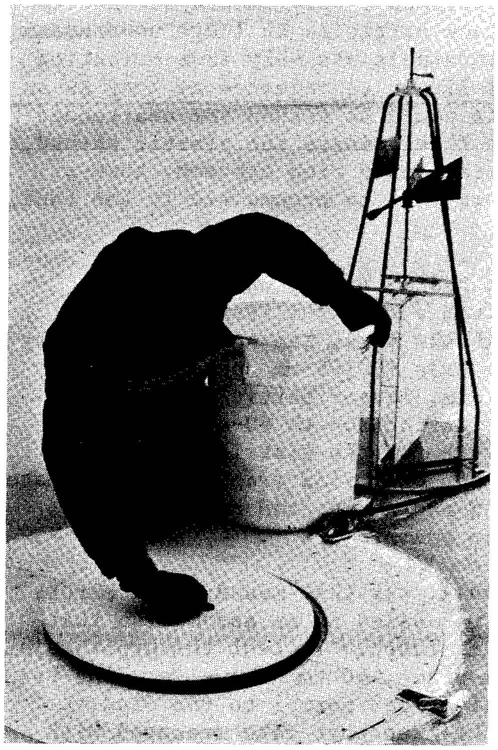

Figure 6. Temporary cover is placed over hatch while emptying container.

Figure 7. Snow distribution in the bucket after several 5-min runs. The conical deposition formed beneath the rear of the bag.

Particle flow divergence around the large trap was clearly visible during the runs, and snow deposited upwind. Any increase in trapping efficiency due to a reduction in edge effect was completely overshadowed by losses from flow divergence. Although the reason for the disproportionately large divergence around the 50- by 50-cm bag is unknown, at least two factors can be suggested. The large volume of air in the tank below the 5-cm wide flux trap may act to reduce back-pressure at the orifice during gusts. Also, since the wind-field disturbance extends upwind in proportion to frontal area, the travel distance over which drag forces operate to overcome particle inertia is significantly greater for the 50- by 50-cm bag.

Because the snow particles exhibit inertia, particle-trapping efficiency is not necessarily the same as aerodynamic efficiency, especially for larger particles near the surface. In spite of the porous fabric, there is undoubtedly divergence of airflow around the 5-cm-wide trap. However, there were several indications that snow flux divergence was negligible. No trap-related deposition was observed upwind unless the trap door was in place. During drifting of new snow, the snow surface extended several centimeters into the trap, with no erosion of the surface at the orifice blades. Particle divergence was clearly visible with the cover on the orifice, but without the cover divergence was noticeable only if the wind veered sharply and the blades were momentarily oblique to the wind.

A primary use for this device is to study the relationship of snow transport to wind speed. This subject continues to be a focus for research because neither theoretical nor empirical expressions satisfactorily describe this relationship for all surface and boundary layer conditions. As an example, Figure 8 compares transport rates measured by the new flux trap with some relationships reported in the literature.

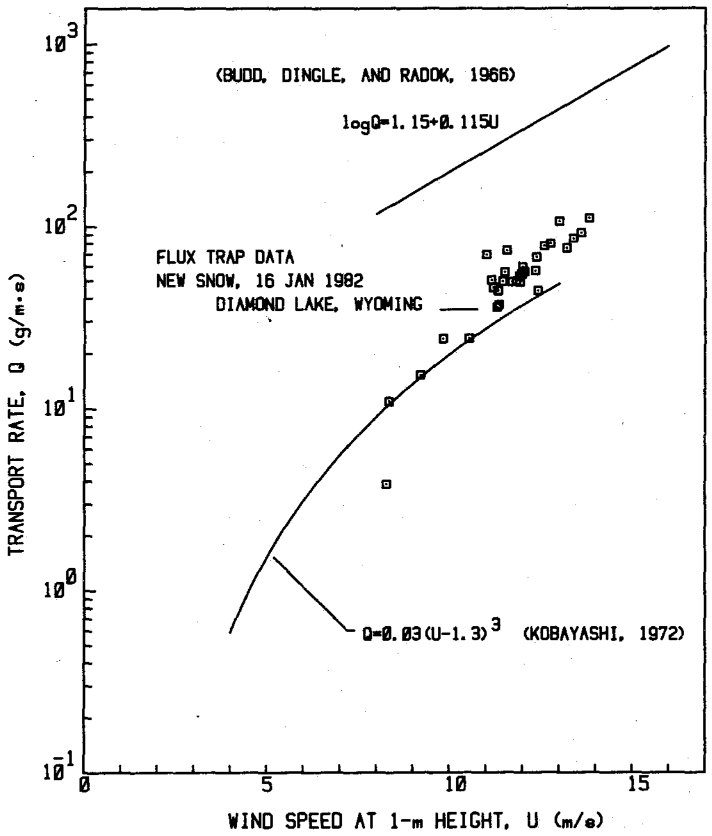

Figure 8. Transport rate as a function of wind speed, comparing measurements by the new flux trap with some reported in the literature.

CONCLUSIONS

1. A drifting snow trap with below-surface weighing, as reported by Tabler and Jairell (1971), is feasible even on a frozen lake.
2. The "flapping bag" design that uses particle cohesion to remove snow from the filter fabric works well up to transport rates of 300 g/m•s, the maximum encountered during these tests.
3. Electronic scales that interface with data acquisition systems greatly expand the potential of height-integrated drift flux samples, by eliminating manual weighing of the samples under blizzard conditions.
4. The design reported here provides the best measure of blowing snow transport rate of those we have tested.

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