Surface Sampling of a Snowstorm by a 2D-C Probe with and without Aspiration

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ABSTRACT

A 2D-C probe was mounted on the front of a truck for operation in a horizontal orientation, as on an aircraft, and also in a vertical orientation using an aspirator. A snowstorm with calm conditions was sampled by alternatively driving the truck through the snow, using a calibrated anemometer to control the strobe rate, and then sampling with an aspirator while parked. The concentration measurements using an aspirator were about 2.4 times larger than those using the standard aircraft orientation mode. There was little size dependence in this factor for the dendrite/aggregate snow sampled. It is not yet known what causes the aspirator concentration measurements to be larger than those from other techniques.

1. Introduction

The use of an aspirator for surface measurements of airborne snow particles with a Particle Measuring Systems (PMS) 2D-C optical array probe has been described by Humphries (1985). In private discussions with Humphries and with Roger Berger of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), we have all had the suspicion that concentration measurements using an aspirator may give different values from measurements using other sampling techniques. Our other references are typically sedimentation slides using photographic or replication methods for sample preservation. Sedimentation analysis requires estimation of terminal velocities for each particle, based on size and habit, to assign a sample volume to each particle. Analysis of sedimentation samples is laborious and subject to large errors for the smallest particles, few of which ever settle on the slide. Consequently, we tend to be reluctant to quote our sedimentation calculations. Our discussions suggested that the use of an aspirated 2D-C results in concentration values larger than those from sedimentation samples by factors ranging up to an order of magnitude. This experiment was an attempt to begin a proper quantification of possible sample distortions by an aspirator on a 2D-C. Independent measurements by other techniques in the next winter season by Deshler et al. (1986) confirmed the existence and magnitude of the distortion, but showed some differences.

2. Observational equipment

An optical array probe, actually called a 2D2-C by PMS, was mounted on a post on a special front bumper on a Dodge Ramcharger truck. Beside it was mounted an anemometer on another post, as illustrated in Fig. 1. A battery-powered data acquisition system was mounted in the rear of the truck. A pivot allowed the 2D-C probe to be in horizontal orientation, as when flown on an aircraft, or in vertical orientation with an aspirator.

In horizontal orientation, an attempt was made to place the laser beam above and forward of all of the airflow distortion of the moving truck. A calibrated cup anemometer was used to control the strobe rate of the 2D-C in this position. In vertical orientation, an aspirator was placed on top of the 2D-C instrument to provide a constant 13.45 m s^{-1} airflow, according to PMS and later confirmed by our own hot wire anemometer measurements. On the front of the data acquisition system was a variable resistor attached to a readable dial, calibrated in m s^{-1}, which controlled the strobe rate when the aspirator was used.

As in the studies of Humphries and of Deshler et al., the aspirator was operated without the supplied hexcell flow straightener. (The hexcell tended to become clogged by wet snow and graupel, causing the fan motors to burn out.) This allowed the creation of a vortex flow within the aspirator. Our hot wire anemometer measurements of this flow showed a tangential speed of about 4 m s^{-1} near the aspirator walls adjacent to the laser beam. The orientation of strings suspended in the flow confirmed the vortex.

Snow particles generally are not accelerated to the speed of the air as they pass the laser beam. Using the "square image" option with a PMS gray-scale 2D-C probe on loan from CRREL, we observed the automatically determined strobe rate which indicated that the speeds for snow particles were about 8 m s^{-1}. Similar strobe rates were needed to equalize the dimensions of round particles in the equipment used by Humphries. The use of a different strobe rate with the aspirator produces a distortion in the image of the particle, but correction to the true size of a particle is

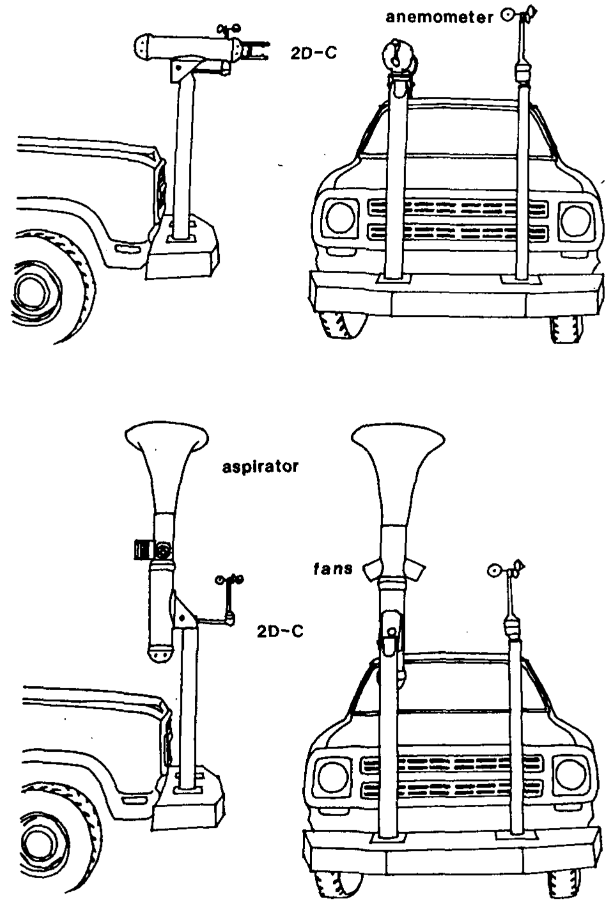

FIG. 1. Perspective views of the truck-mounted 2D-C and anemometer in the aircraft-style orientation and with the aspirator.

easily accomplished by software. The sample volume with an aspirator is constant, determined by the 13.45 m s^{-1} airspeed, and is not affected by the strobe rate chosen.

3. Experiment

A comparison of the two modes of 2D-C operation, with and without the aspirator, was made on 28 March 1985 during the local morning daylight hours between 1643 and 1852 GMT. The winds were near calm with generally steady snow of moderate intensity. The particles visibly consisted of large (2 cm) dendritic aggregates and numerous smaller particles that one's eye tends to ignore. The truck was driven east and west along a 3.2-km section of straight road of slight, steady incline east of Montrose, Colorado. During truck movement the 2D-C was oriented horizontally, as for aircraft operations, and the strobe rate was determined by the anemometer. At each end of the course the truck was stopped, the 2D-C was oriented vertically, the aspirator placed on top, and the snow sampled for about 5 min. The variable resistor controlling the strobe rate with the aspirator was arbitrarily set to 17 m s^{-1}.

When the truck was parked the average wind speeds ranged from 0.2 to 0.9 m s^{-1} with a two-hour average of 0.5 m s^{-1}, thereby documenting near calm conditions. The truck was driven initially at speeds as low as 11 m s^{-1}, but most runs were made at about 17 m s^{-1}. Average concentrations for the two hours were about 10 L^{-1}, ranging over about a factor of 4 from lowest to highest for horizontal orientation; the range was about a factor of 3 for the aspirated samples. No significance is claimed for this difference other than natural variability.

4. Analysis

The entire dataset was examined in order to isolate periods, with 30-s resolution, of uniform sampling for each mode. Excluded were periods of transition between modes of operation when improper strobe rates produced highly distorted images.

The probe was operated with the end-element rejection disabled so that all particles triggering the probe would be recorded. Analysis techniques and thresholds are like those given by Holroyd (1985). Software rejection techniques were used to reject zero-area images, continued images after an overload, particles closer than 1 mm to the previous particle (a selectable threshold), particles obviously too long or with long x and narrow y dimensions, those with gaps in the x or y direction, and those smaller than 0.1 mm maximum dimension (another selectable threshold). Protection against streakers by hollowness criteria was not needed because the lack of a water cloud and the low airspeeds during sampling did not create streakers in this ground-level experiment. Particles truncated by an overload were saved if they passed the other criteria even though they would later be undersized. Particles were also rejected if it appeared that their centers were outside the field of view of the diode array. Most particles touching at least one edge were examined by a least-squares fit to a parabola describing the distribution of total occultations of each of the 32 diodes. The particle was accepted if the parabola peaked (suggesting the center of mass) within the field of view.

The maximum dimension of all acceptable particles was then estimated. For summary purposes, those sizes were then assigned to bins of equal logarithmic width of ten bins per order of magnitude.

The sample volume corrections provided by PMS for small sizes were ignored. Their table applies principally to particles smaller than the 0.1 mm minimum size limit selected for this analysis. Sample volumes for aspirated conditions are affected by sedimentation as well as flow speed. They were, therefore, increased by a factor of $(v + V)/v$, where v is the aspirator flow velocity and V an estimated particle terminal velocity. Some small errors (about 10 percent) are introduced by the use of a generic expression for terminal velocity. Additional errors (about 5 percent) enter because the particles are not accelerated to the aspirator airspeed. Note that this correction was not applied to those portions of the data for which the aspirator was not in use and the probe was aimed horizontally. Apart from this difference, the same software techniques were used for both datasets.

Software estimates of particle habit, mass, refined terminal velocity, and precipitation rate (Holroyd, 1985) have not been calculated for this comparison. A distortion of the habit spectrum for this particular aggregate and dendrite snowstorm is not anticipated. A snowfall composed of a mix of graupel and small plates or irregulars, for example, might suffer distortion by the aspirator because the graupel particles may not be able to be deflected sufficiently by the airflow in the aspirator.

5. Results

The average concentration for each sample, its duration and anemometer speed, and the summaries of those values are listed in Table 1. The natural variations in concentration over the two hours can be readily seen,

TABLE 1. Average snow particle concentrations and sample wind speeds.

Sample start time GMT	Sample duration (min)	Concentration (L^{-1}) without aspirator	Concentration (L^{-1}) with aspirator	Average wind speed ($m\ s^{-1}$)
1644:00	4.0	6.409		11.73
1652:00	4.0		13.02	0.81
1701:00	2.0	3.529		10.67
1707:00	4.0		21.90	0.60
1712:30	3.5	7.917		13.27
1719:00	5.0		20.47	0.33
1726:00	2.5	7.025		14.71
1732:30	3.0		8.050	0.87
1741:00	2.5	3.005		15.42
1746:30	4.5		24.07	0.47
1753:00	2.5	13.00		16.72
1800:00	3.0		18.64	0.74
1805:30	2.5	10.24		16.52
1810:30	4.5		8.844	0.49
1817:00	2.5	7.422		16.96
1822:00	4.5		13.03	0.29
1828:00	2.5	3.268		16.52
1833:00	4.5		12.15	0.20
1839:00	2.5	7.434		17.66
1844:30	4.5		21.40	0.55
1851:00	1.0	5.187		16.50
Mean		6.77	16.16, ratio = 2.4	
Standard deviation		3.05	5.80	
Time-weighted mean wind speed		14.91	0.51	
Approximate total sample volume, m^3		1.222	1.634	
Approximate total particles		8100	25 900	

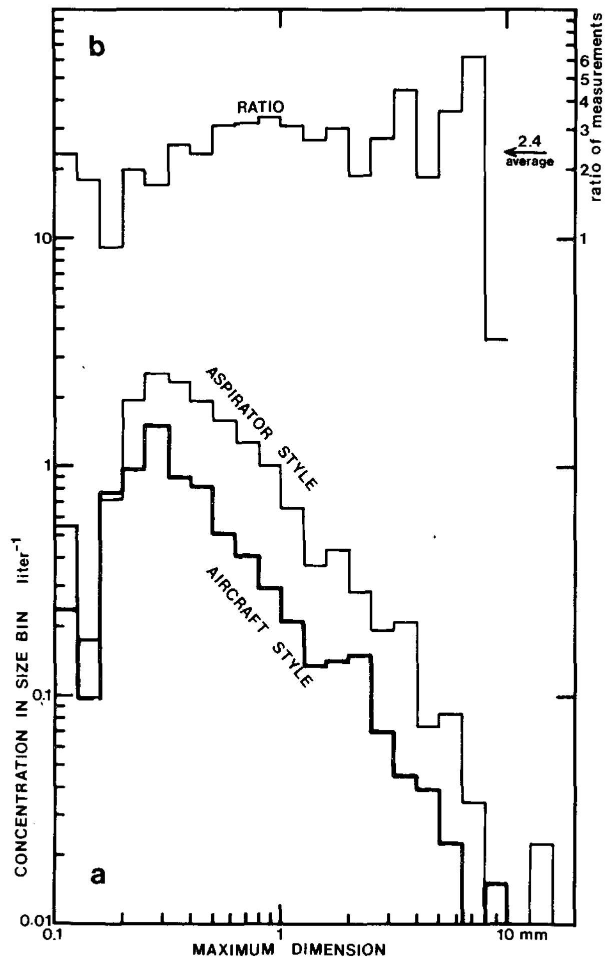

FIG. 2. (a) The average concentrations of ice particles in each size bin according to the two modes of sampling; (b) the ratio of those concentrations.

indicating need for the rapid alternation between sampling modes. The simple means and standard deviations of the average concentrations are listed at the bottom of the table. The ratio of the means indicates that the aspirator increased the concentration by a factor of about 2.4, confirming the suspicions mentioned in the introduction. This factor may only apply to this particular composition of snowfall. Other sizes and habits may behave differently in the aspirator.

The data were also examined to see how the increase in concentration was distributed by size. Figure 2a shows the particle concentration in each of the size bins for the two modes of operation. Figure 2b shows the ratio of the two concentrations for each bin. This ratio becomes noisy at large sizes because of more limited sample sizes. Variations at small sizes may be caused by rejection criteria. The aspirator appears to measure higher concentrations by a factor of about 2 at sizes less than 0.5 mm and about 3 at larger sizes. In consideration of the noise at the small and large sizes, it appears safe to generalize to a constant factor of 2.4 over all sizes.

6. Discussion and conclusions

The alternation between two modes of sampling with a 2D-C in near uniform snowfall under near calm conditions has documented that the use of an aspirator appears to result in higher concentration values than those using a probe in an orientation and sampling mode typical of aircraft installations. An increase by an average factor of 2.4 appeared to be uniformly applicable to all sizes of the ice particle spectrum though some change in this factor with size may be present.

Deshler et al. (1986) describe two types of subsequent experiments. In one series, concentrations were measured by swinging an oil-coated slide in the vicinity of the aspirator. The aspirator produced higher concentrations on three days of sampling by factors ranging from about 2 to 5. In the other experiment, the University of Wyoming King Air aircraft was flown 10 to 20 m above the aspirator, located at the Laramie airport, for four passes. The winds in this open location were about 5 m s^{-1} during the passage of the fast-moving snow shower. The aspirator indicated total concentrations always higher by a factor of about 3. But unlike the truck-mounted experiment the ratio was strongly size-dependent. Compared to the aircraft measurements, the aspirator oversampled the small particles and undersampled the large ones. The habits sampled in their experiments were not mentioned.

The aspirator in an airport setting should have similarities to an unshielded precipitation gage. According to Linsley et al. [(1958), p. 29], an unshielded precipitation gage should miss about 40% of a snowfall in a 5 m s^{-1} wind. Presumably, the smaller particles would tend, without aspiration, to flow over the top of an unshielded gage and not be sampled. The big ones would strike the far interior side before falling into the measuring apparatus. For an aspirator, however, the small particles should be diverted by the aspirator suction and go through the laser beam. The big ones, after striking the walls of the aspirator, would fail to fall through the laser beam except as smaller fragments. The observed size relationship (undersampling of the large particles) of the aircraft intercomparison appears consistent with the expected effects of the crosswind.

The behavior of the aspirator with graupel and other ice particle habits may give different results from those presented here. A numerical study by Norment (1986) suggests that certain sizes of water drops may be impossible to sample under certain wind and aspirator orientation conditions. His conclusions recommend against relying upon the use of an aspirator for quantitative field measurements, especially in a crosswind. However, his study for a vertical aspirator 1) had a 2 m s^{-1} horizontal wind, 2) did not consider turbulence and vortex flow that exist in the aspirator, and 3) did not consider ice particles having drag characteristics significantly different from water drops. He, therefore, had not yet modeled conditions comparable to those in this experiment. The present study shows no size spectrum distortions from aspirator use in a dendrite/aggregate snowfall under near calm conditions—only a generally constant increase in concentration at all sizes.

It is not yet known how this increase occurs. Yet it appears that the use of an aspirator results in higher concentration measurements than from all other techniques tried. Somehow more particles must be getting into the sample volume than were there in the free air, or else all of the other techniques mentioned (holography was not tried) were undersampling the concentrations. Future runs of Norment's model may be the best help here. He is able to calculate concentration ratios of similar size by measuring the particle flux distortion caused by interaction of particle inertia with flow perturbations in the aspirator.

This experiment, those of Deshler et al., and Norment's calculations need to be extended to other snowfall conditions to see how the concentration factor varies with size for other ice habits. But all uses of the aspirator for sampling falling snow at the surface must be in near calm conditions. These and other studies are needed to determine exactly how the aspirator is affecting the sampling of snow particles.

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