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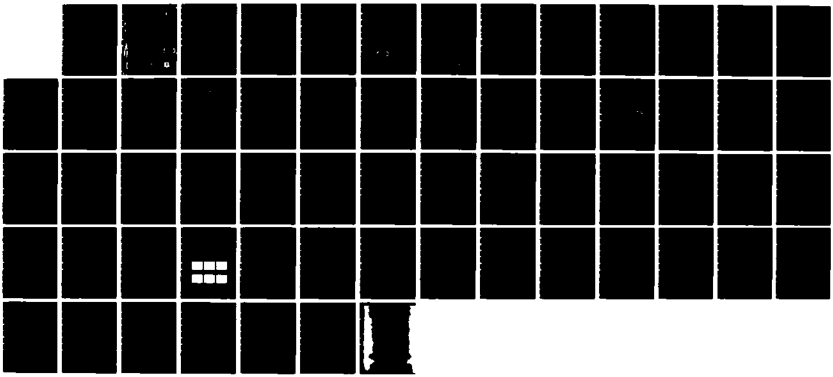

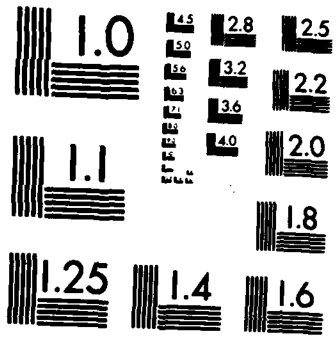

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SNOW-ONE-A and B Characterization Measurements and Data Analysis

R. O. BERTHEL
V. G. PLANK
B. A. MAIN

20 September 1983

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METEOROLOGY DIVISION PROJECT 6670
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

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ARNOLD A. BARNES, JR.
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FOR THE COMMANDER

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To make realistic estimates of precipitable hydrometeors, meteorological modeling requires valid inter-relationships for the parameterization of mass concentrations, precipitation rates, fall velocities, number densities, etc. In response to these needs, AFGL has initiated a modest effort with objectives of defining such relationships and providing the means to verify model outputs.

Measurements documenting the characteristics of naturally falling snow were obtained during the SNOW-ONE-A and SNOW-ONE-B field experiments.

20. (Contd)

These consist of data acquired by three unique instruments: a snow-rate meter (SRM), a fall-velocity indicator (FVI), and a snow-structure recorder (SSR). This report describes the results of our participation in these field programs.

Snow rates, particle-fall velocities, and snow-crystal information are presented. Correlations between snow rate and electro-optical transmittance/attenuation and mass-concentration measurements are illustrated. Relationships of fall velocity with snow-crystal size from analyzed data are given along with a method of determining fall velocity through knowledge of snow rate and liquid-water content.

The data obtained during these two field experiments indicate that it may be possible to define mathematical relationships between precipitation rate and mass concentration and between fall velocity and snowflake size for broad categories of snow types.

Preface

The authors wish to thank Susan Sadofsky for her work in reducing the FVI data, to Don McLeod for the SSR data, and to Carolyn Fadden for typing this manuscript. A special thanks to Anthony Matthews, SMSgt Stephen Crist, and SSgt. Dennis LaGross for their operation of the equipment.

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SNOW-ONE-A and B Characterization Measurements and Data Analysis

1. INTRODUCTION

Precipitation will generally obstruct, to some degree, anything that attempts to transverse it. This effect is evidenced by everyday military operations such as the degradation of line-of-sight observations, attenuation of electromagnetic energy, and, in some cases, degradation of missile performance. The degree of degradation varies not only with types of operational systems but also with the physical characteristics of the precipitation.

The effects of precipitation present two separate but related problems. The first is the problem of evaluating a particular system's performance in defined precipitation environments. Experimental programs are currently being conducted in this area. One notable series is the SNOW field experiments sponsored by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The second problem is the meteorological definition of weather conditions in specific operational areas by inference from remote sensing or forecasting. Perhaps the greatest effort now underway in this area is the development of computerized mesoscale meteorological models for predicting conditions at specific times and places that will, in turn, allow predictions of the operational efficiency of particular systems.

(Received for publication 20 September 1983)

These two problems have a common factor: the specific definition of hydrometeor environments. In the first, in situ measurements can be used. In the second, hydrometeor characteristics must be inferred from information supplied by remote-sensing techniques, forecasting, or meteorological modeling. Measurements are also necessary in this second scenario because a data base of intelligent relationships must exist so that realistic inferences can be drawn. Testing the validity of any predictive scheme also requires measurements. Thus, the definition of the physical properties of precipitable hydrometeors has been and continues to be a subject of interest and concern.

The problem of meteorological definition of weather conditions in particular operational areas by inference from remote sensing or forecasting is the primary focus of the Cloud Physics Branch of the Air Force Geophysics Laboratory (AFGL). We have had considerable experience in aircraft measurement of hydrometeors and establishing cloud physics relationships for environment definition from remote sensing. We acquired a large portion of this experience while we were actively engaged in weather definition tests conducted on reentry vehicles.[1,2,3,4,5] With the cessation of aircraft measurements, emphasis has been shifted to modeling or predictive methodology. The data that were collected in conjunction with the re-entry studies are currently being re-analyzed in an attempt to establish definitive hydrometeor parameterization for inclusion in mesoscale models. We have made some inroads in the parameterization of rain distributions[6] and are now concentrating on the infinitely more complex problem of ice hydrometeors.

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1. Barnes, A.A., Nelson, L.D., and Metcalf, J.I. (1974) Weather documentation at Kwajalein Missile Range, 6th Conference on Aerospace and Aeronautical Meteorology, American Meteorological Society, 66-69, Air Force Surveys in Geophysics, No. 292, AFCRL-TR-74-0430, AD A000925.

2. Barnes, A.A., Metcalf, J.I., and Nelson, L.D. (1974) Aircraft and radar weather data analysis for PVM-5, Air Force Surveys in Geophysics, No. 297, AFCRL/Minuteman Report No. 1, AFCRL-74-0627, AD B004290.

3. Plank, V.G. (1974) Hydrometeor parameters determined from the radar data of the SAMS Rain Erosion Program, Environmental Research Papers, No. 477, AFCRL/SAMS Report No. 2, AFCRL-TR-74-0249, AD 78654.

4. Plank, V.G. (1974) Liquid-water-content and hydrometeor size-distribution information for the SAMS Missile Flights of the 1971-72 season at Wallops Island, Virginia, Special Reports, No. 178, AFCRL/SAMS Report No. 3, AFCRL-TR-74-0296, AD A002370.

5. Plank, V.G. (1977) Hydrometeor data and analytical-theoretical investigations pertaining to the SAMS Missile Flights of the 1972-73 season at Wallops Island, Virginia, Environmental Research Papers, No. 603, AFGL/SAMS Report No. 5, AFGL-TR-77-0149, AD A051192.

6. Berthel, R.O., and Plank, V.G. (1983) High resolution snow and rain rate measurements, Reprints of the Fifth Symposium on Meteorological Observations and Instrumentation, Toronto, Canada, Apr 11-15, 1983, AFGL-TR-83-0030, AD A130080.

As a supplement to the aircraft data analysis effort, we have initiated a ground-based experimental program utilizing highly specialized research instruments that were designed, developed, and built in our laboratory. These consist of sensitive precipitation gauges for both rain and snow,[7] an instrument for the measurement of the fall velocity of snow/ice particles, and a device for the identification of the crystalline type of prevailing snow.[8,9]

The three snow-characterization instruments were operated at the CRREL-sponsored Scenario Normalization for Operations in Winter Observation and the National Environment (SNOW-ONE) winter field experiments, SNOW-ONE-A and SNOW-ONE-B. This report describes the results of our participation in these exercises.

2. SNOW-ONE-A FIELD EXPERIMENT

We arrived at Camp Ethan Allen, Vt., the site of the SNOW-ONE-A field experiment, with newly developed instruments untried in winter weather conditions. The initial phase of the experiment turned out to be an instrument evaluation and testing period. Examples of field-acquired data, the problems encountered, and the remedies employed are detailed in other reports[10, 11, 12] and need not be repeated here.

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7. Plank, V.G., and Berthel, R.O. (1983) High resolution snow and rain rate measurements, Reprints of the Fifth Symposium on Meteorological Observations and Instrumentation, Toronto, Canada, Apr 11-15, 1983, AFGL-TR-83-0107, AD A128296, 27-33.

8. Gibbons, L.C., Matthews, A.J., Berthel, R.O., and Plank, V.G. (1983) Snow characterization instruments, Instrument Papers No. 316, AFGL-TR-83-0063, AD A131984.

9. Plank, V.G., Matthews, A.J., and Berthel, R.O. (1983) Instruments used for snow characterization in support of SNOW-ONE-A and SNOW-ONE-B, Proceedings of SPIE Technical Symposium East 83, Session "Optical Engineering for Cold Environments," Sub-session "Optical Hardware in the Cold."

10. Berthel. R.O. (1982) Snow characterization measurements at SNOW-ONE-A, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-2, May 1982, AFGL-TR-82-0003, AD A118140, 421-437.

11. Berthel, R.O., Plank, V.G., and Matthews, A.J. (1982) AFGL snow characterization measurements at SNOW-ONE-A, Reprints of Snow Symposium II, CRREL, Hanover, N.H., Aug 10-12, AFGL-TR-83-0121, AD A128606, 35-48.

12. Plank, V.G., Berthel, R.O., and Main, B.A. (1983) Snow characterization measurements and E/O correlations obtained during SNOW-ONE-A and SNOW-ONE-B, Proceedings of SPIE Technical Symposium East 83, Session "Optical Engineering for Cold Environments," Sub-session "Electro-Optical/Infrared Systems and Effects."

There were essentially four storms with substantial snowfall during the course of the field experiment.[13, 14] Because of instrument problems, we were restricted during the earlier part of the testing period to limited measurements with the fall-velocity indicator (FVI) on the storms of 9 and 16 December 1981. The snow-structure recorder (SSR) and snow-rate meter (SRM) were operating along with the FVI during the storm of 31 January 1982. We completely missed the storm of 7 February 1982 because we had already terminated field operations and our personnel had returned to Hanscom AFB. In several other periods of light snow or snow showers in January, we obtained some limited measurements.

We explored the possibility of weather radar measurements at SNOW-ONE-A with the thought of correlating these data with the surface measurements. The Staff Meteorology Office at Hanscom AFB made contact with Plattsburg AFB, N.Y., for radar support, and measurements were made during the storm of 9 December 1981. The results showed that the signal range of the available equipment coupled with the region's mountainous terrain were insurmountable obstacles for this endeavor.

Satellite coverage was provided by the Satellite Meteorology Branch of AFGL during the storm of 9 December 1981. This coverage was discontinued after that because the type of information supplied by satellite is of very limited interest in such an experiment. However, the feasibility of obtaining satellite information has been established for possible future use.

3. OPERATIONS: DECEMBER 1981

The FVI was the only instrument operating throughout December 1981. Some fall-velocity data were acquired on 9 and 16 December as shown in the fall velocity vs size plots in Figures 1 and 2. Particle size (ℓ) is the longest measured dimension. These data are of limited value, however, because the validity of the recorded strobe frequencies used on these days is doubtful.

4. OPERATIONS: JANUARY 1982

An emergency repair of a malfunction in the electronic balance on the SRM by

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13. Bilello, M.A. (1982) Synoptic weather conditions during selected snowfall events between December 1981 and February 1982, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 9-42.

14. Bates, R. (1982) Meteorology, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 43-180.

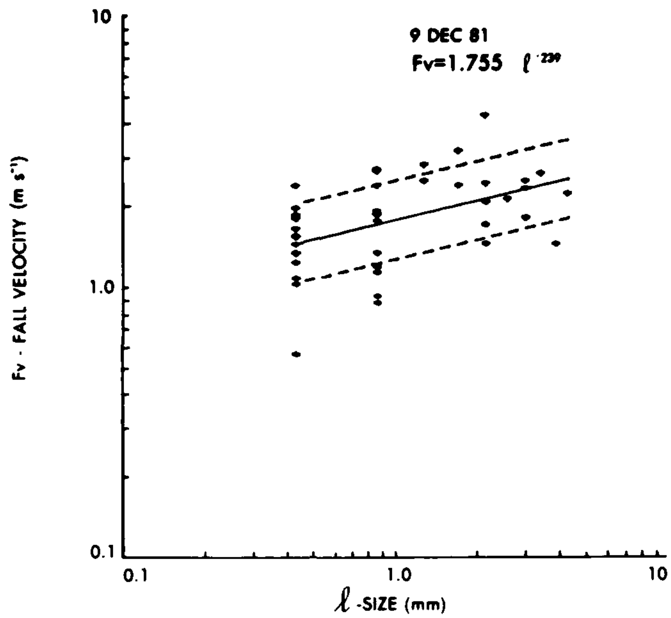

Figure 1. Fall Velocities of Individual Particles on 16 Dec 1981 (ℓ is the longest measured dimension)

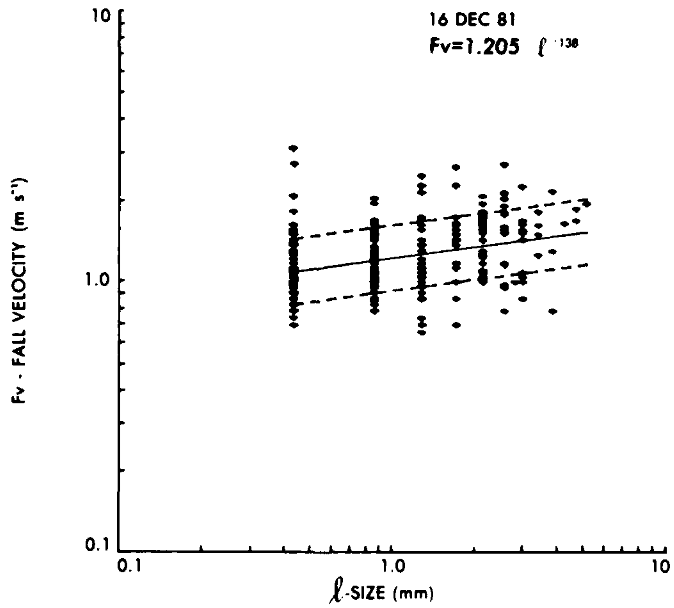

Figure 2. Fall Velocities of Individual Particles on 16 Dec. 1981 (ℓ is the longest measured dimension)

the manufacturer allowed testing to resume in the second half of the experiment in January 1982. On-site adaptation, adjustments, and repairs on the SSR gave us hope that this device would also operate as planned. Unfortunately, no major storms occurred until 31 January. Before that, some light snow or snow showers occurred that, because of high winds or instrument collection efficiencies, were not measured by the FVI or SSR, although we did obtain some data with the SRM.

The SRM testing revealed a substantial drift in weight readings as a heater turned on and off while attempting to maintain the temperature of the electronic balance's remote-sensing head within the range specified by the manufacturer. The thermostatic control was removed, and a constant voltage sufficient to maintain mid-range temperatures was applied to the heater. Under these conditions, the weight readings were found to drift slightly with changes in ambient temperature, although the rates of change were so small that they had minimal effect on the resulting snow rate.

4.1 13 January 1982

The data recorded on 13 January 1982 demonstrate the problem of the heater voltage. The plot in Figure 3 shows the 2.81 second, raw-weight data plotted vs time (all times in this report are local or EST).

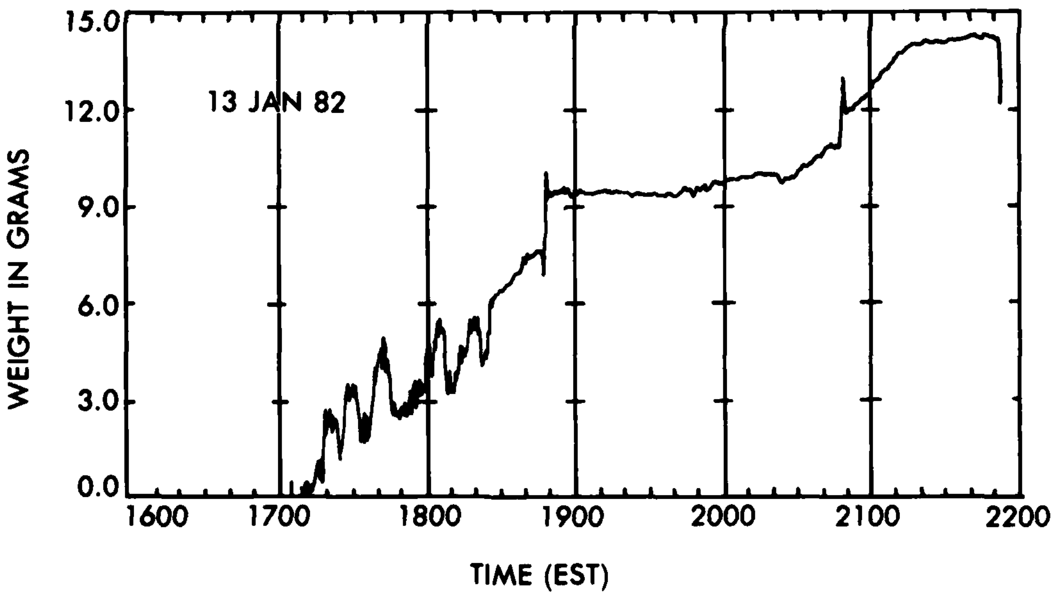

Figure 3. Weights of Snow as Recorded by the Electronic Balance on 13 Jan 1982

The pronounced weight oscillations during the initial 80 minutes were caused by varying the heater voltage. The trace displays a considerable smoothing when the voltage was held constant after 1820; the gradual increase after that time reflects the weight of collected snow. The abrupt weight changes at 1845 and 2045 are the result of a bearing impeding the natural movement of the shaft as the weight increased. The bearing was removed, and subsequent operations indicate that the problem was corrected.

4.2 23 and 29 January 1982

Figures 4 and 5 show data recorded in windy conditions of very light and blowing snow on 23 and 29 January 1982. As shown in the raw-data plots in the upper diagram of each of these figures, the weight measurements exhibit considerable fluctuation about the base line. This noise is attributed to wind effects. The center plots show that the noise can be suppressed and the data smoothed by averaging.

Several comments are pertinent about the assumptions and methods of this data smoothing. First, an implicit assumption concerning the basic data is that the positive and negative components of the wind pumping are approximately symmetrical over time periods that contain about 10 pumping fluctuations. Second, smoothing was obtained by use of a running-mean-type averaging that incorporated η data points (intervals) about a central point. The value at the central point was corrected by finding the least-square parabola of best fit for the 2 +1 points of the data set. This was done for each data point and neighbors moving along the time curve of the basic weight data. The method is described by Hildebrand[15] and Lanczos.[16] The η value for the smoothed data of the center plots of Figures 4 and 5 is $\eta = 50$, which means that the time resolution of the snow rates (lower plots) is 284 seconds.

4.3 31 January 1982

The FVI, SSR, and SRM were all operating during the storm of 31 January 1982. Measurements from the FVI taken during brief periods of each hourly 20-min Intensive Measurement Period (IMP) are shown in Figure 6. The time-consuming labor required for the reduction of these data has prevented a complete analysis. Only a representative sample (~ 30 measurements) from each IMP from 1600 through 2000 were initially analyzed. The least-squares regression line and

15. Hildebrand, F.B. (1956) Introduction to Numerical Analysis, McGraw-Hill, New York.
16. Lanczos, C. (1961) Applied Analysis, Prentice Hall, Inc., Englewood Cliffs, N.J.

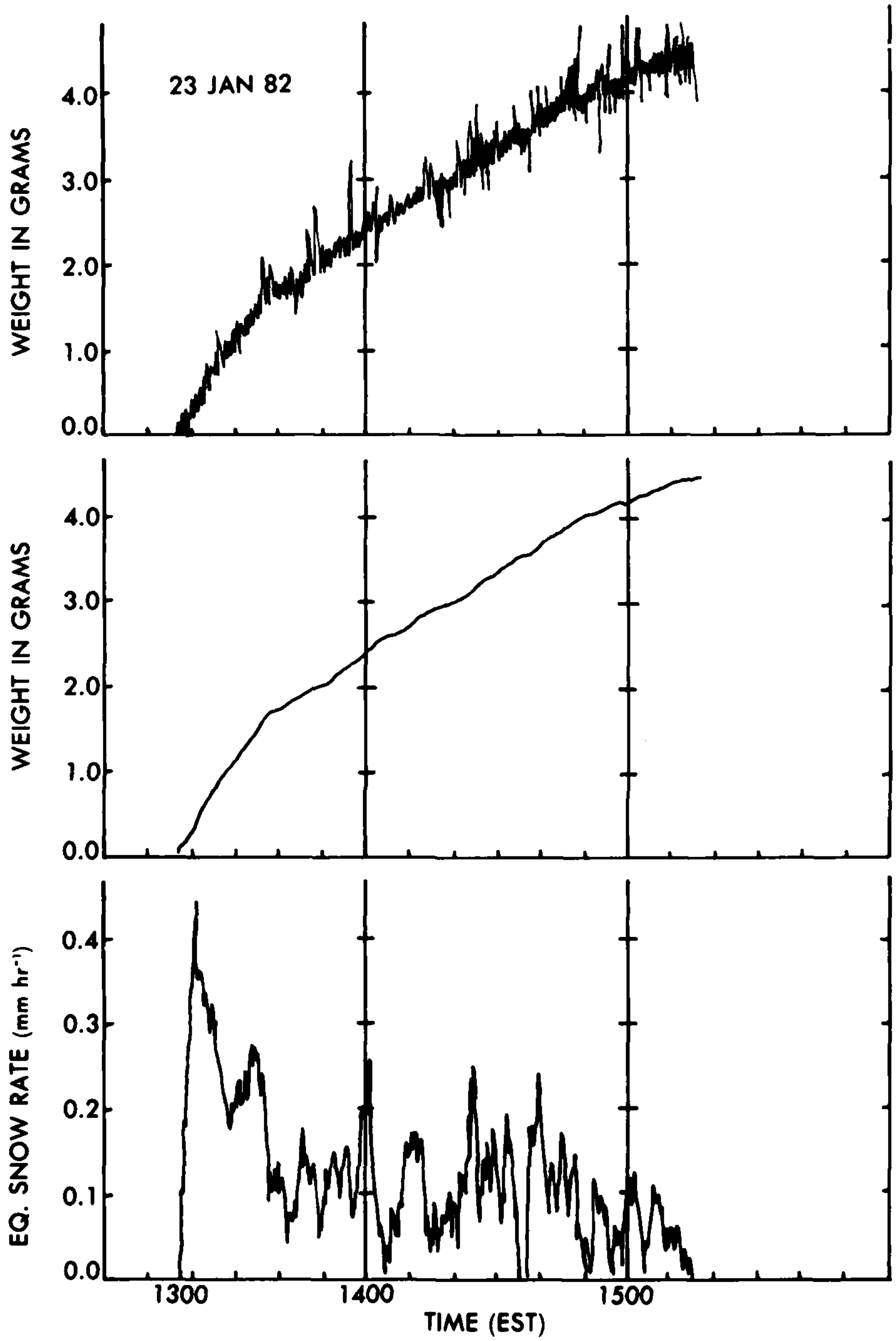

Figure 4. Snow Weights and Rates on 23 Jan 1982

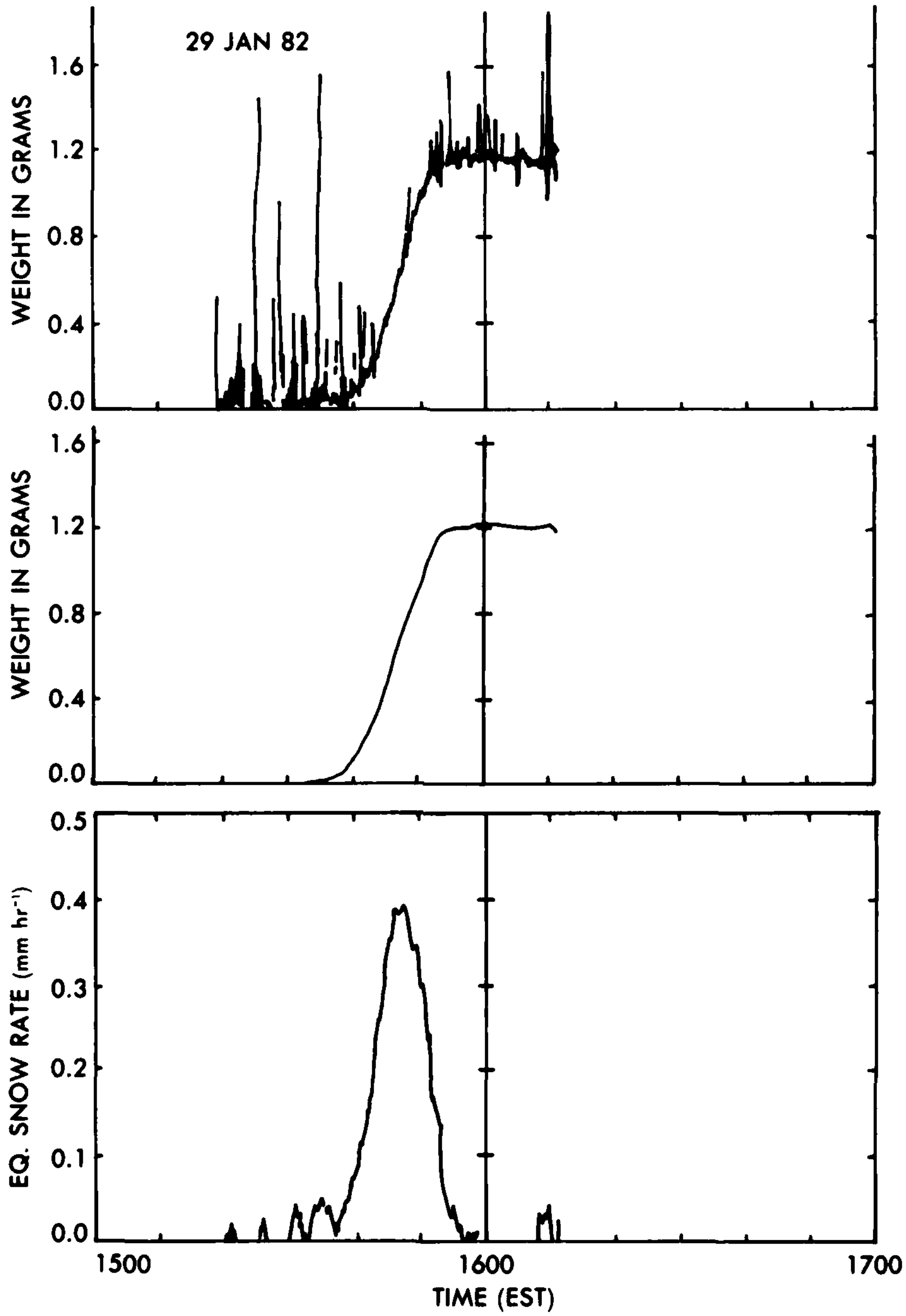

Figure 5. Snow Weights and Rates on 29 Jan 1982

the standard deviation are shown. Few data were recorded after ~2000 because of an increase in winds.[14, 17]

Inherent uncertainties exist in these data because of instrument collection efficiency, video resolution, and analyst subjectivity. The measurements may not

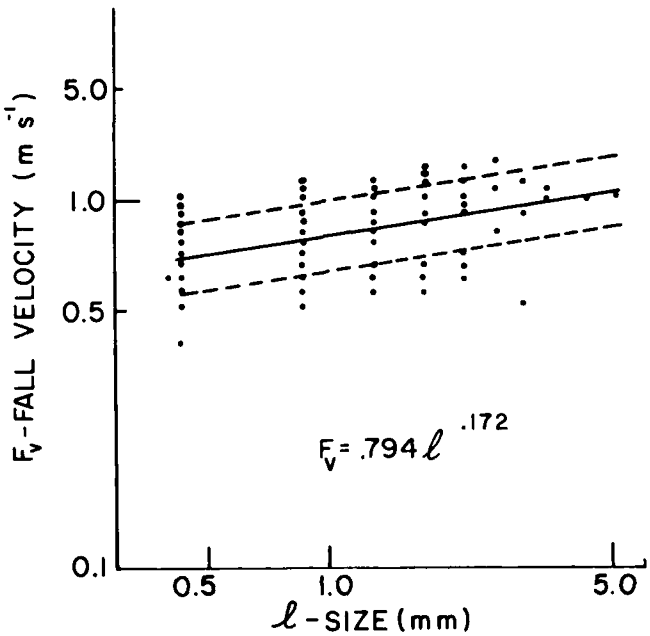

Figure 6. Fall Velocities of Individual Particles on 31 Jan. 1982 (ℓ is the longest measured dimension). The least-squares regression line (——) and ± 1 standard deviation (- - -) are shown

be representative of the number and sizes of the natural snowfall distribution because of wind effects and the small sampling volume. Some particles, most noticeably the smaller ones, reflect less light and result in faded video images. The faded video image combined with limited video resolution and image magnification often prevents the analyst from determining if a particle is tumbling or turning.

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17. Olsen, R., Okrasinski, R., and Brown, D. (1982) TACS data report for SNOW-ONE-A, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 181-216.

Therefore, the measurement of fall distance may not be made on the same part of the falling snowflake. An apparent large scatter in fall velocities can result because of such uncertainties in fall distance. Similar effects may also influence the determination of the largest particle dimensions.

One of the objectives of the fall-velocity measurements is the determination of mathematical relationships that may be used to describe broad categories of the many snow-crystal types. Thus, we were initially concerned about the effects that the inherent data variations would have on the resulting regression equations when making comparisons of different situations. In an attempt to mitigate these effects, some earlier analyses were performed on fall velocity and size measurements that were class averaged.[18] Subsequent studies were conducted on assumed distributions with specific fall velocity-size relationships. These assumed distributions were regressed to give reference equations, and were then subjected to random variations in number densities, fall velocities, and physical sizes. They were then analyzed so that the resulting regression equations could be compared with that of the original. These investigations revealed that class-averaged analyses will not consistently produce better relationships. We have concluded that the degree of improvement in the regression equations obtained by using class averaging compared with those obtained from using the raw data does not warrant the extra effort required.

The fall velocity-size relationship presented in Figure 6 is the analytical result of data from discrete periods taken hourly throughout the storm. More comprehensive analyses are needed for each IMP since the fall velocity vs size relationships show variations with changes in crystal type.

An in-depth analysis was performed on the 1900 IMP. We divided the 20-min period into four discrete entities with start times of 1900, 1905, 1910, and 1915. The first 100 particles of each period (~1 min of data) were measured and subjected to a regression analysis. The plots and resulting equations for these four 1-min periods are presented in Figure 7.

It is interesting to note that the fall velocity-size relationships of the 1905 and 1910 plots show little variation. This indicates that the snow-crystal type remained fairly consistent at least throughout that 10-min period. The difference between these plots and Figure 6, the plot covering the 1600 through 2000 IMP's, implies that some changes in the nature of the snow crystals occurred during that portion of the storm.

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18. Berthel, R.O., Plank, V.G., and Main, B.A. (1983) Analyses of snow characterization data acquired at SNOW-ONE-A and B, Snow Symposium III, CRREL, Hanover, N.H., Aug 9-11, 1983.

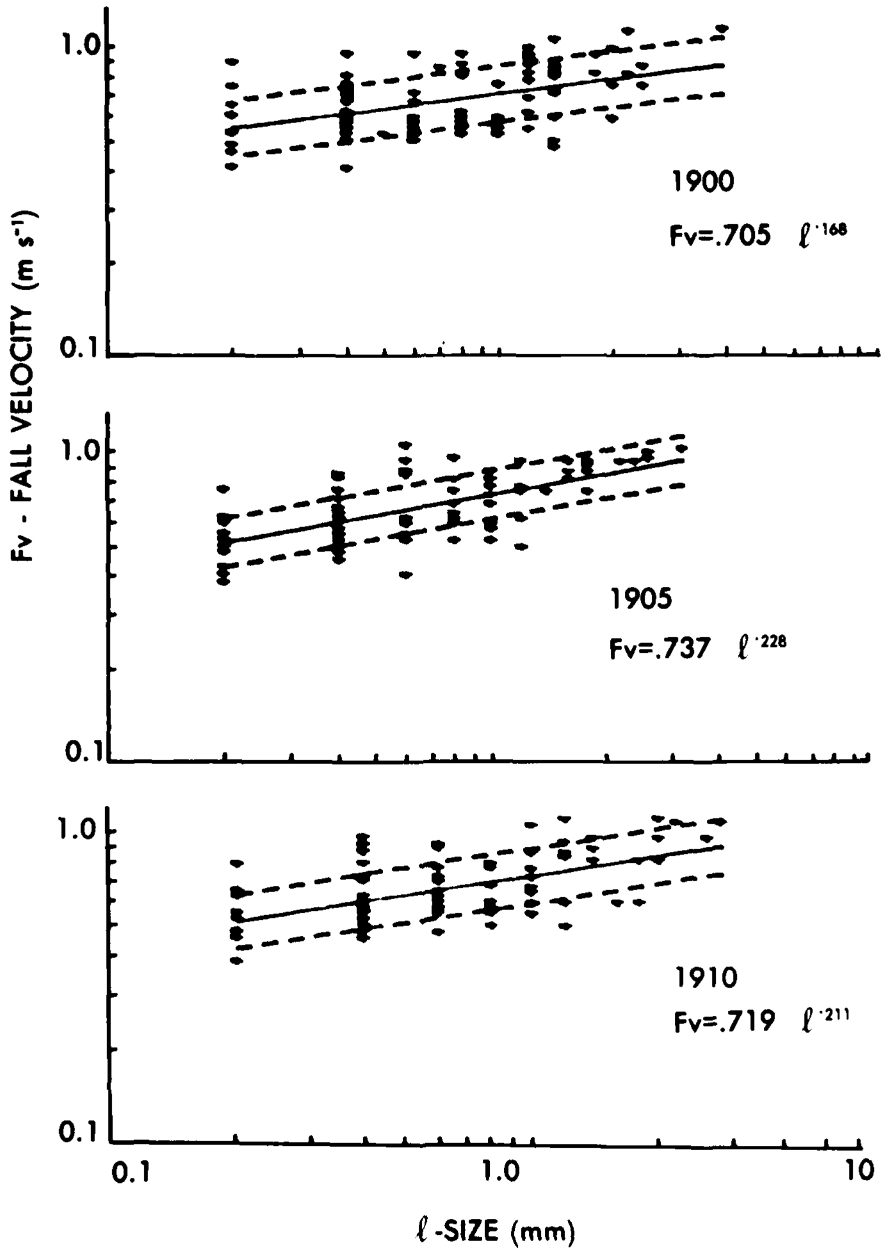

Figure 7. Fall Velocities of Individual Particles From the 1900 IMP on 31 Jan 1982 (ℓ is the longest measured dimension) (Part 1)

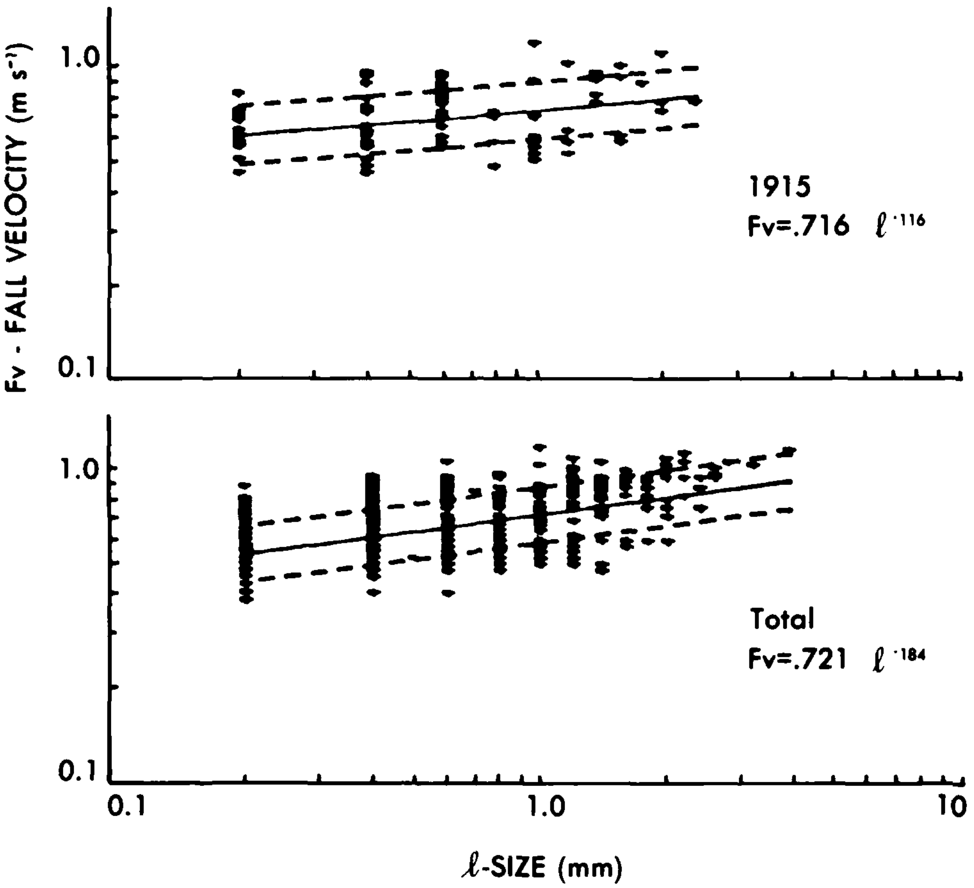

Figure 7. Fall Velocities of Individual Particles From the 1900 IMP on 31 Jan 1982 (ℓ is the longest measured dimension) (Part 2)

The SSR produced some data on this day although the quality was not up to expectation. The particular instrument used during SNOW-ONE-A employed a continuously moving belt utilizing strobe lighting to provide "stop action." Two detrimental effects of this configuration were noted. First, the flash rate had to be synchronized with the speed of the belt to avoid multiple images on a single video frame. Second, the intense flash-tube light produced reflections from the snow crystals, which tended to cause blurred images. Thus, the data quality was poor and could not contribute to the analysis.

Good snow-rate data were acquired on this storm as shown in Figure 8. The upper plot is the weight data as recorded by the electronic balance; the lower, the derived snow rates using a weight-smoothing value of η = 50 (284 s avg). Although

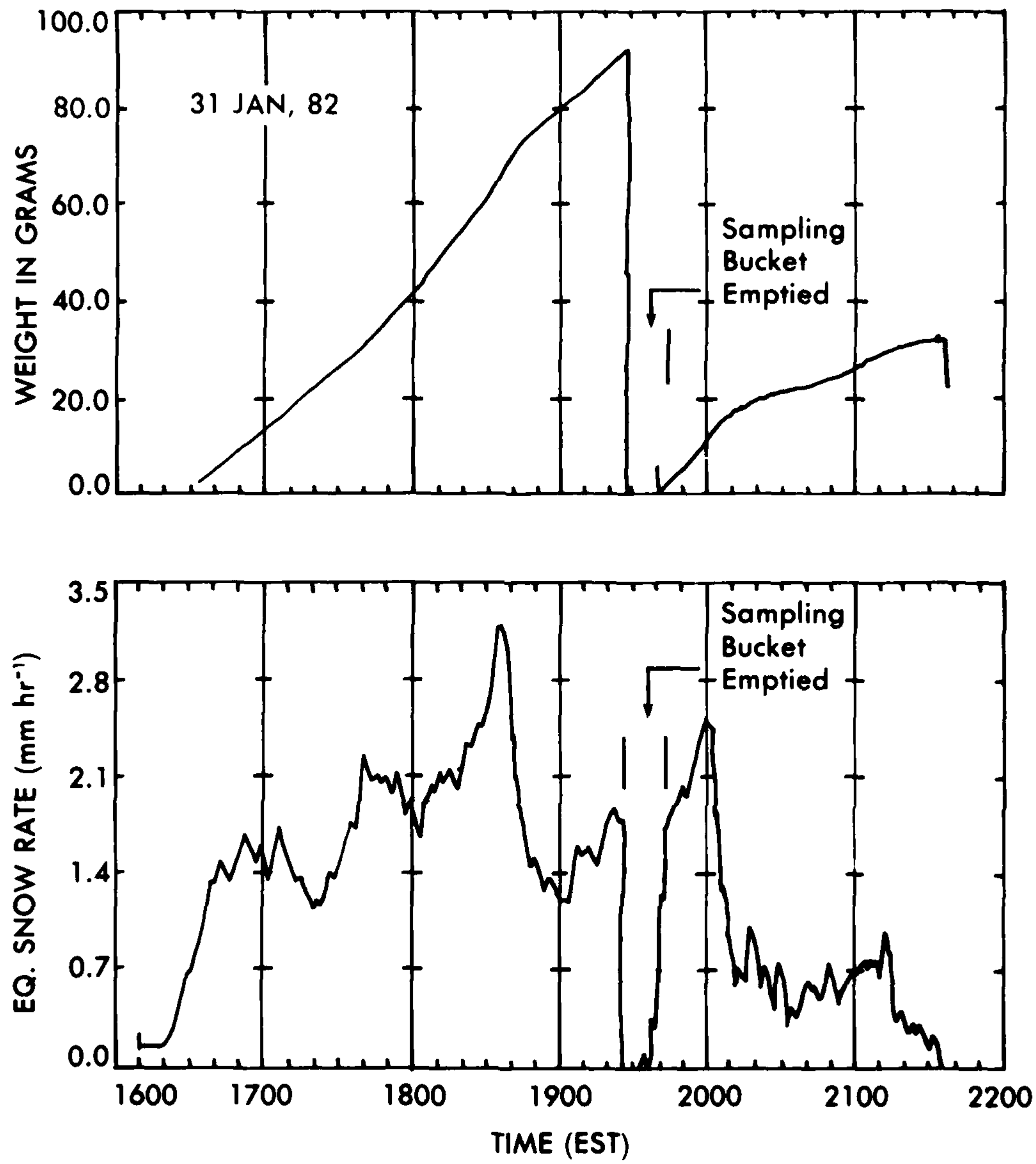

Figure 8. Snow Weights and Rates on 31 Jan 1982

wind "noise" does exist in these data, it is obscured by the 100 g ordinate scaling and is not evident in the weight trace.

A question arises about how one determines what is adequate but not excessive smoothing. Since it is impossible to have negative snow rates, if one knows that there were observational periods during the data period when it was not snowing, these can be used as reference periods of zero snow rate that can serve as guides to the proper η number or smoothing required. This is not always an easy procedure, and more work needs to be done in this area. It might also be remarked that the amount of smoothing required may differ depending on the nature of the turbulence during different periods of a storm or between different stormy days.

Figure 9 graphically demonstrates these comments. This figure shows the

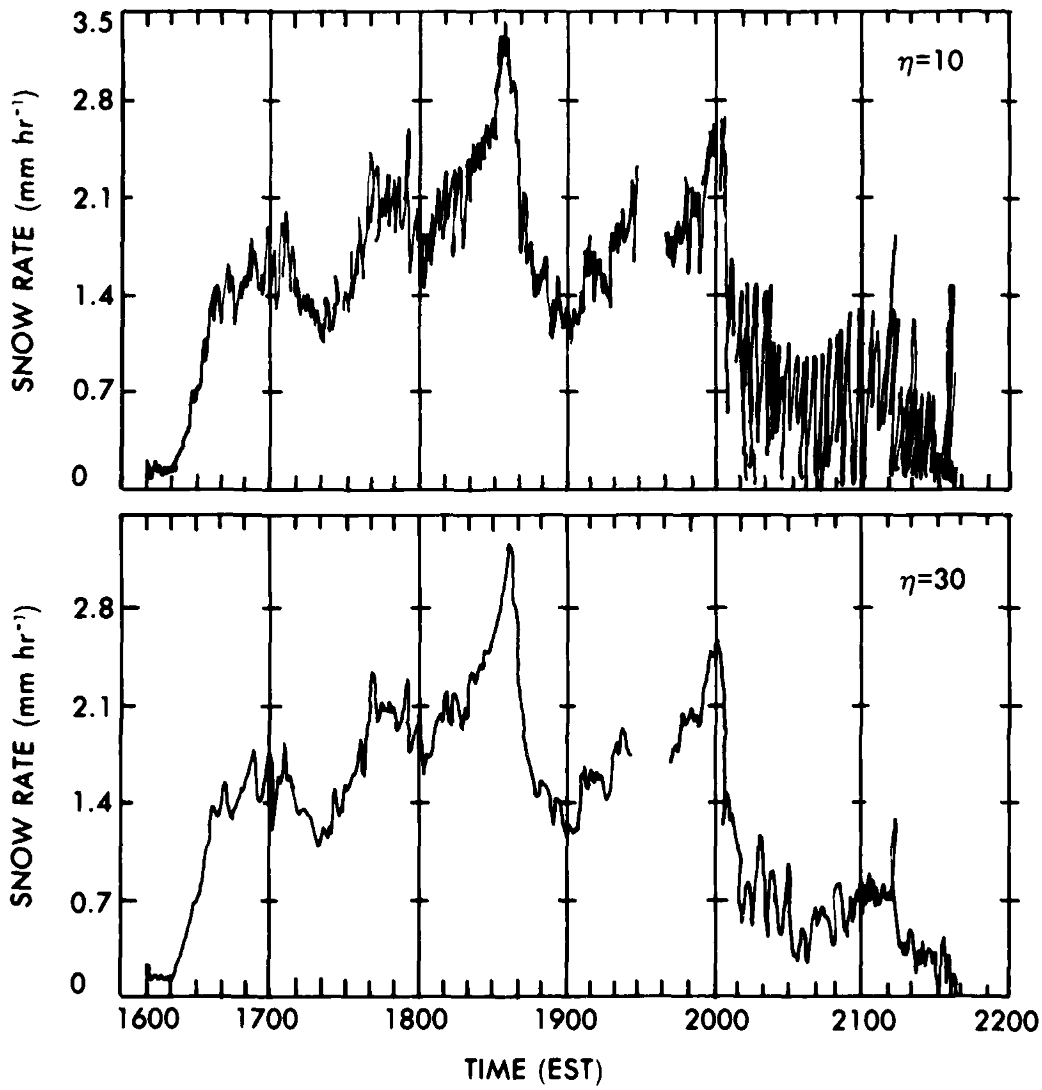

Figure 9. Snow Rates on 31 Jan 1982 With Different Averaging

snow rates that were derived from the weight data of Figure 8 when η = 10 and η = 30. The lower trace, where η = 30, exhibits considerably more resolution than the η = 50 snow-rate plot of Figure 8. The upper trace, the one of least smoothing (η = 10), shows yet another increase in snow-rate resolution. This value may be adequate up to ~ 2000 but, after that time, the increase in wind velocity (increased noise) becomes evident in negative (zero) snow-rate spikes. This smoothing value is clearly inadequate for the weight data after ~ 2000 on this day.

Transmittance and attenuation data were obtained by the Ballistic Research Laboratory (BRL), the Navy Research Laboratory (NRL), and by the Optical Physics Branch (OPA) of AFGL on this day. Liquid-water-content data were also acquired by CRREL from their Airborne-Snow Concentration Measuring Equipment (ASCME) instruments. All these results have been published in the SNOW-ONE-A data report.[19] Time correlations between the AFGL snow-rate data and attenuation data obtained by BRL are shown in Figure 10. The BRL data are for three frequencies in the millimeter band, as identified. The casual correlation of the data with snow rate can be seen.

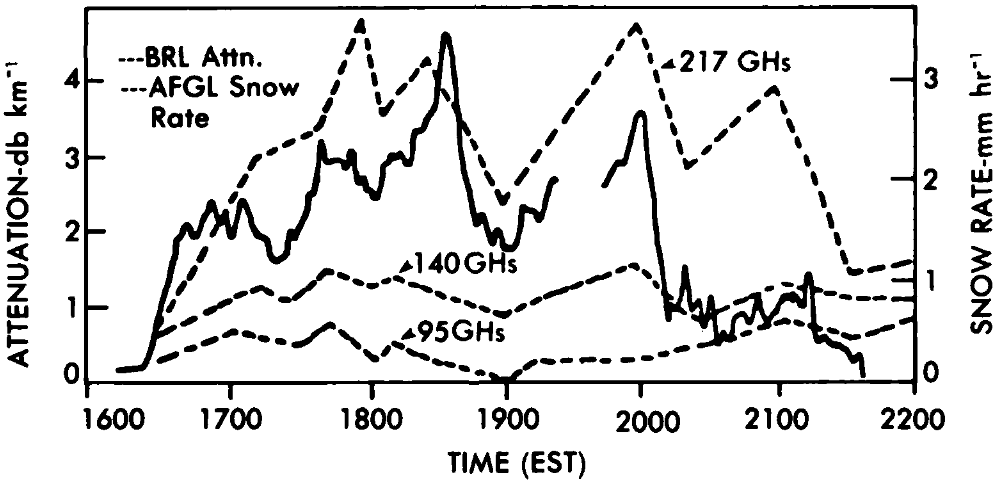

Figure 10. Time Comparisons of BRL Attenuation Data With Snow Rates on 31 Jan 1982

19. Ballistic Research Laboratory (1982) Millimeter-wave propagation at 35, 95, 140 and 217 GHz frequencies through snowfall, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 283-294.

In Figure 11, a casual correlation can also be observed between the AFGL snow-rate data (plotted inverted) and the transmittance data of NRL[20] for four wavelengths in the visible and infrared region.

The curves in Figure 12 show snow rate and the visual extinction coefficient

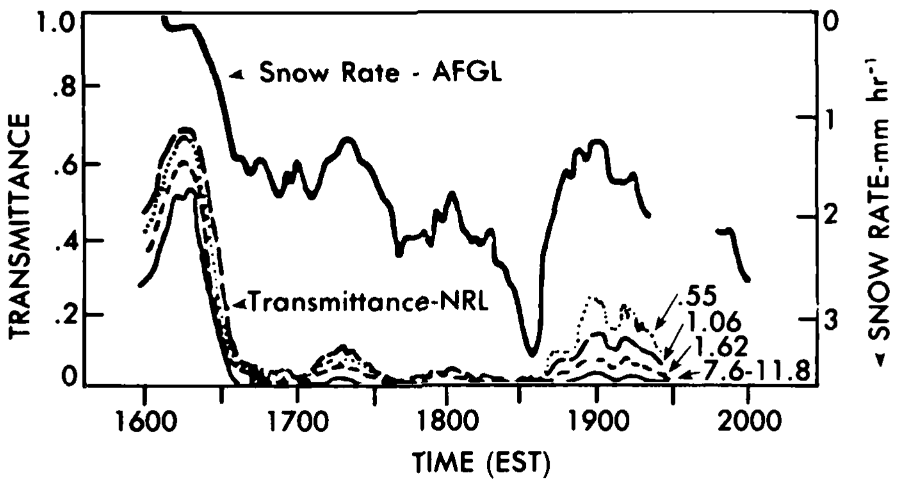

Figure 11. Time Comparison of NRL Transmittance Data and Snow Rates on 31 Jan 1982 (snow rate inverted)

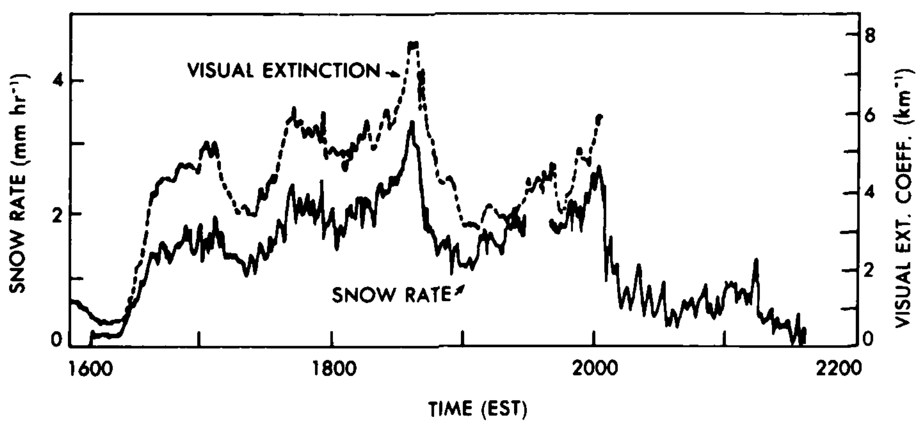

Figure 12. Time Comparison of AFGL (OPA) Visible-Extinction-Coefficient Values and Snow Rates on 31 Jan 1982

20. Curcio, J. (1982) Visible and infrared propagation data, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 283-294.

(VEC) as obtained by OPA[21] for an optical link that was operated on 31 January 1982. The time correlation here is more apparent.

CRREL operated three ASMCE instruments during SNOW-ONE-A, and we obtained tapes of the recorded data* for correlation with our SRM measurements. In Figure 13, snow-rate data vs time is compared with the liquid-water-content (LWC)

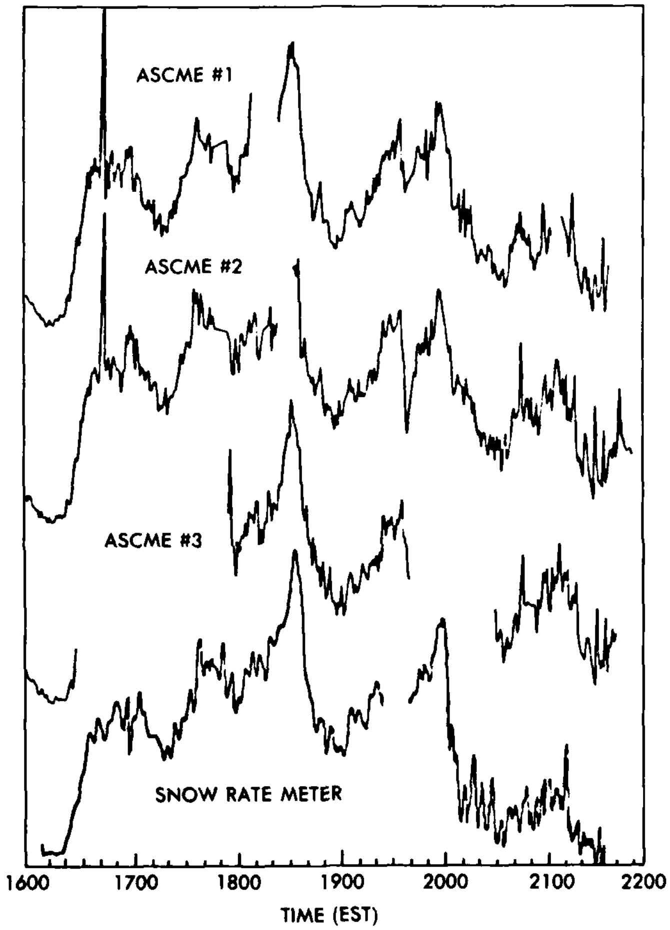

Figure 13. Time Comparisons of the Data From 3 ASCME Instruments (CRREL) and Snow Rates on 31 Jan 1982

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*Courtesy of J. Lacombe, CRREL

21. OPA, AFGL (1982) SNOW-ONE-A preliminary data report, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 437-526.

or mass concentration (M) data for the ASCME instruments.[22] The time correlation between the curves is evident.

The scatter diagrams in Figure 14 show the correlations of the AFGL snow

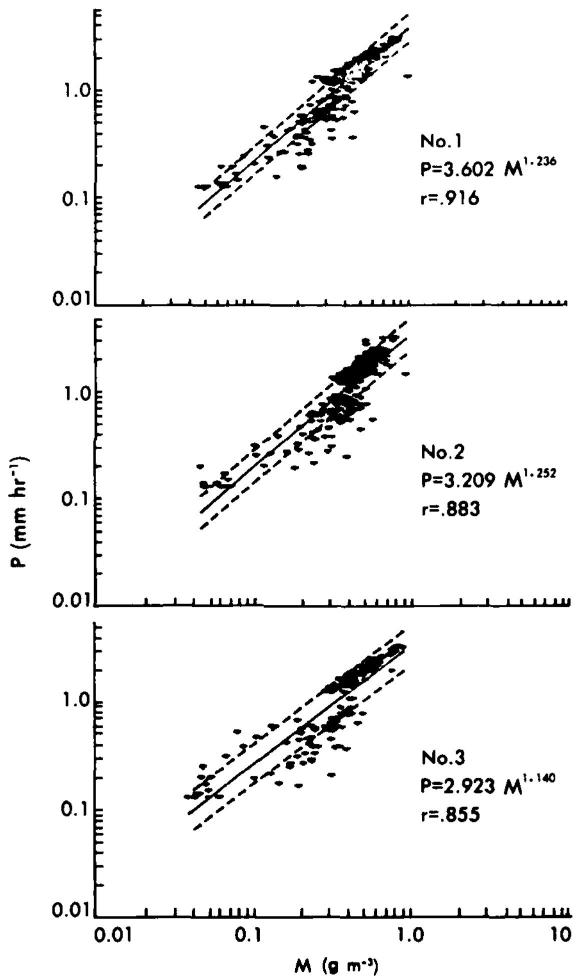

Figure 14. Correlations of Snow Rate (P) and Mass Concentration (M) for 3 ASCME Instruments From 1610 to 2135 on 31 Jan 1982

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22. Lacombe, J. (1982) Measurements of Airborne-snow concentration, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 225-282.

rate (precipitation rate, P) values for 31 January 1982 vs the CRREL mass-concentration measurements for each of their instruments. The SRM data were averaged over 1-min periods to conform with the ASCME 1-min data. The power function equations and coefficients of correlation from the least-squares regression (solid lines) are listed on each plot. The dashed lines are ±1 standard deviation. These scatter diagrams reveal that the correlations are best for the largest mass-concentrations and snow-rate values, and that the scatter increases as the P and M become smaller.

To reduce the scatter, we applied a 7-point running-mean to both the ASCME No. 1 and SRM data used in Figure 14. The scatter diagram and regression line (solid line) of these averaged data are shown in Figure 15. The suppression of the

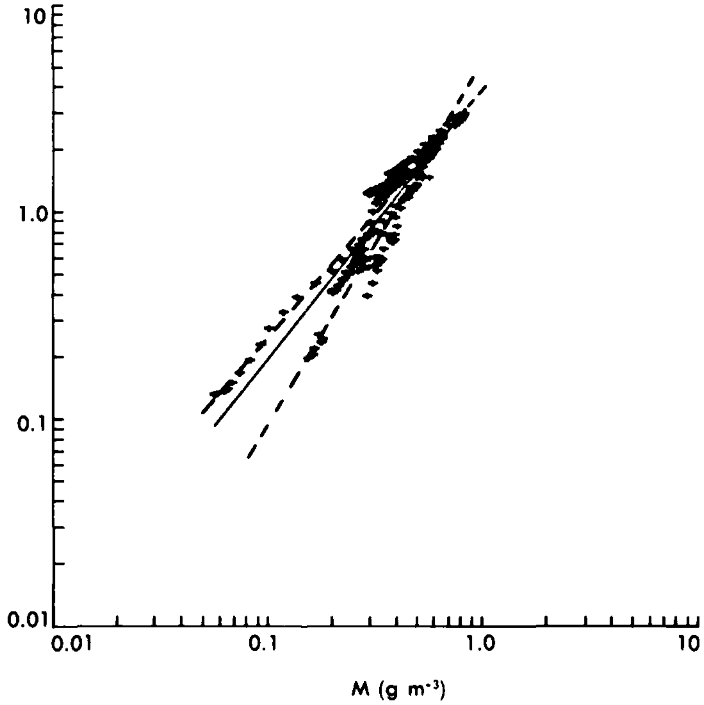

Figure 15. Correlations of P and M for ASCME No. 1 Using 7-Min Averaging From 1610 to 2135 on 31 Jan 1982

scatter gives results that show two distinct P vs M trends as indicated by the dashed lines. These results are representative of the other two instruments.

In Figure 13, it is apparent that the points that give the most scatter are from the data obtained during the period of light snowfall beginning at ~2010. The data were divided at that time into two separate sets, the first spanning 1610-2010, and the second, 2011-2135. The P-M plots, least square-regression lines, and equations for each ASCME instrument are shown in Figures 16 and 17. The regression

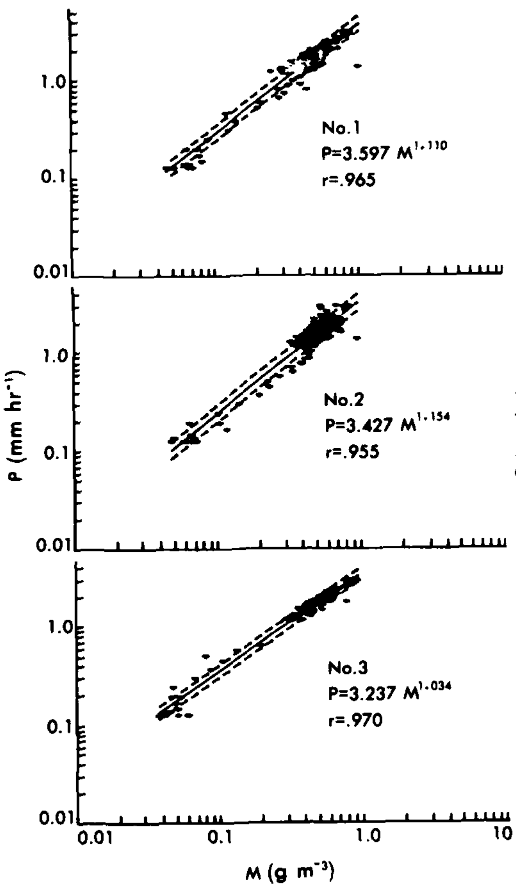

Figure 16. Correlations of P and M for 3 ACSME Instruments From 1610 to 2010 on 31 Jan 1982

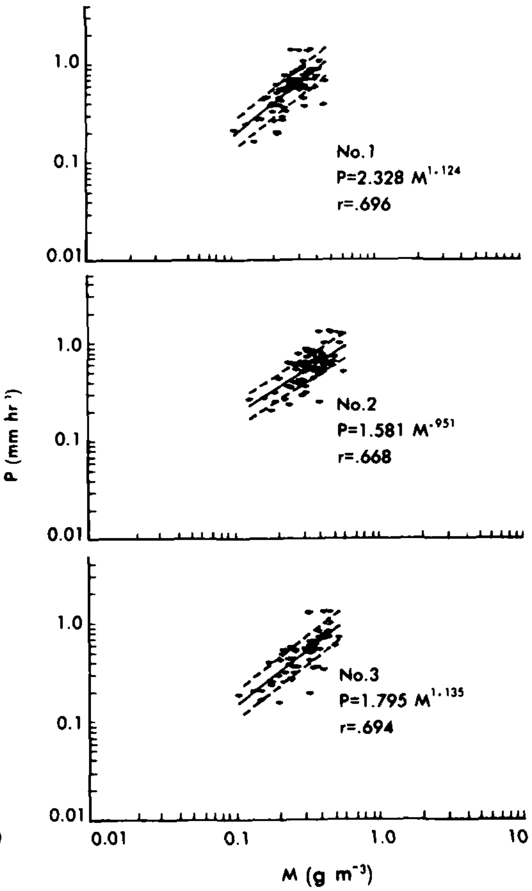

Figure 17. Correlations of P and M for 3 ACSME Instruments From 2011 to 2135 on 31 Jan 1982

equations from the data of the two time periods differ considerably from one another and from the complete data sets of Figure 14. These differences suggest the possibility that a change in the nature of the snowfall occurred at about 2000.

Koh and O'Brien[23] of CRREL monitored crystal habit by Formvar replication during the storm of 31 January 1982. At 1910, they observed "orthogonally intersecting broad-branched crystals, perpendicularly intersecting columns, assemblages of plates and/or side planes . . . with some cloud droplets attached"; at 1930, "crystal types similar to 1910 but with heavy cloud droplet accumulations"; at 2045, "crystal type(s) similar to 1930 but broken into finer particles by the wind." These observations indicate that a change in the characteristics of the snowfall did occur at ~1930-2030 with smaller sized particles of higher density (because of cloud droplet accumulations) being more prevalent after ~2000.

Additional evidence of a change in snowfall characteristics can be obtained by analyzing the ASCME and the SRM data in a different manner. The natural dimensional units of snow rate are M/L^2T or g per length squared (L^2) per unit time (T). The units of LWC are g/L^3. Thus, if snow rate in mm hr^{-1} is divided by LWC (P/3.6M), the resulting parameter has units of L/T and is a measure of the average integrated fall-velocity of the snowflakes.

We performed such division for the LWC data of the three CRREL ASCME instruments. The resultant fall-velocity values for ASCME No. 2 are shown plotted vs time in Figure 18 (these are representative of the other two instruments). The

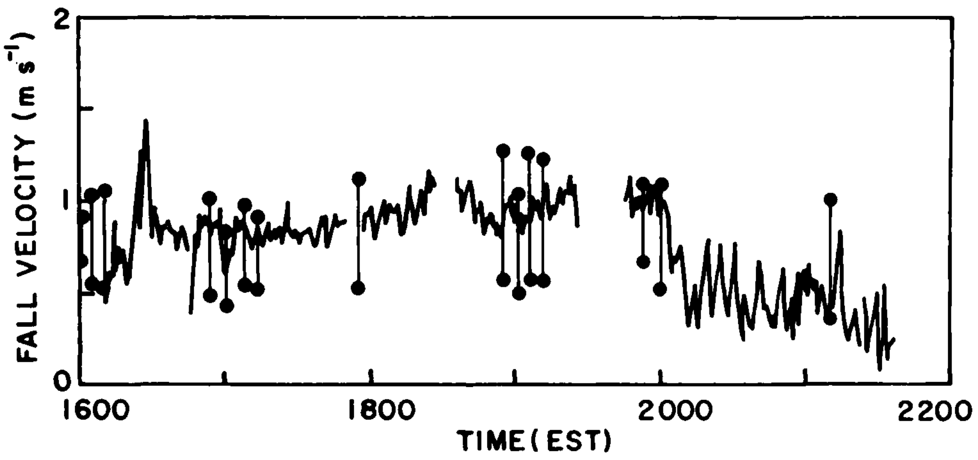

Figure 18. Fall Velocities Derived From P and M Using ASCME No. 2 on 31 Jan 1982

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23. Koh, G., and O'Brien, H. (1982) Snow crystal habit, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 181-216.

plot shows that the P/M snowfall velocities were smallest during the latter portion of the snowfall period when the LWC and snow-rate values were also smallest.

Also shown in Figure 18 are the ranges of the fall-velocity values for individual snowflakes as determined from the FVI. Although range values are shown at ~ 2100, an increase in wind velocity seriously impeded instrument operation after the 2000 IMP, and we only managed to make a few (16) measurements from 2100-2115. It is seen that the P/M velocity values generally conform to the upper half of the range of the FVI measurements up through the 2000 IMP and the lower portion of the 2100 IMP.

The FVI measurements from the 2100 IMP are plotted in Figure 19 along with

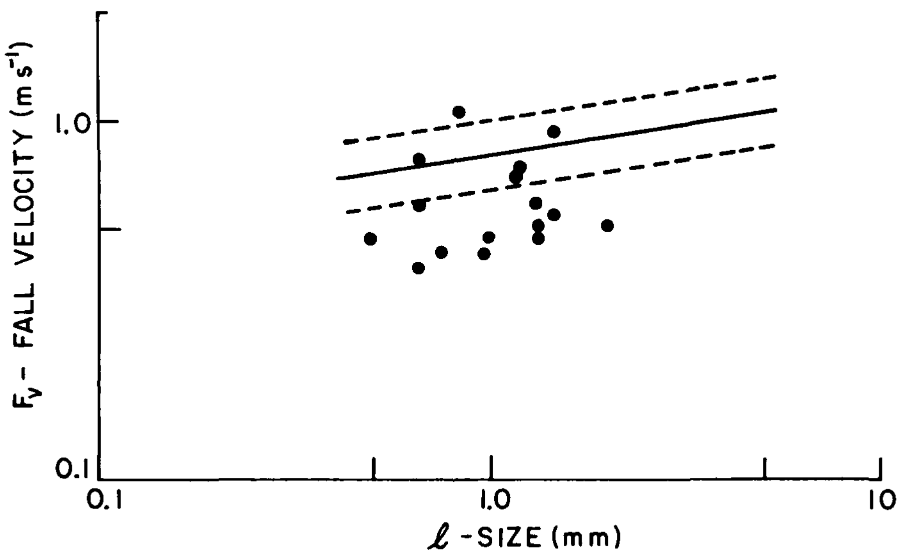

Figure 19. Fall Velocities of Individual Particles Measured From 2100 to 2115 on 31 Jan 1982 (ℓ is the longest measured dimension)

the regression and standard deviation lines from the individual-particle, fall-velocity measurements (Figure 6) acquired prior to ~ 2100. The individual particles that were measured are of predominantly smaller sizes with velocities that generally fall below the solid regression line, and the majority of the points are less than the lower standard deviation limit. The mean value of these measurements, however, are slightly larger than the fall-velocity determinations from the ASCME and SRM during the same time period.

Data obtained after ~ 2000 presents some conflicting evidence. For instance, the ASCME data in Figure 13 shows a mass concentration at 1900 that is approximately comparable with that at 2100. The precipitation rate in the same figure is considerably lower at 2100 than at 1900. This finding is also evident when comparing the P-M plots of Figures 16 and 17. Conversely, the attenuation data in Figure 10 shows an increase at 2100 compared with the 1900 measurement.

To justify a smaller snow rate with an increase in attenuation at the same value of M, one can postulate an increased number of particles of smaller sizes. This could also account for the smaller fall-velocities. The reduction in snowflake size is substantiated by the CRREL observations noted during this period and confirmed by the FVI measurements in Figure 19. However, the same observations noted the accumulation of cloud droplets on these smaller, broken flakes. Since these minute water droplets would increase the particle density, one would expect an increase in fall velocity for given particle sizes that is contradictory to the data plotted in Figure 19. One possible explanation is the increase in wind velocity at ~ 2000 that may have produced sufficient turbulence to affect both the FVI and SRM measurements, thus resulting in artificially small fall-velocity determinations.

5. SNOW-ONE-B FIELD EXPERIMENT

The SNOW-ONE-B field experiment was conducted during December 1982 at Fort Grayling, Mich., a site with a meteorological history of substantial snowfall. Unfortunately, history did not repeat itself during this month's operations, and only periodic light snow and shower activity were encountered.

Our snow characterization efforts[24] during SNOW-ONE-B concentrated on repeating the three primary thrusts made during SNOW-ONE-A: fall-velocity measurements, snow-rate measurements, and crystal identification.

The fall-velocity indicator was essentially the same instrument used in SNOW-ONE-A. A minor modification was made in the electronics that controls the strobe lighting to ensure the validity of the flash rates. Fall-velocity data were acquired on four days during the experiment.

The SRM was modified during the summer months by reducing the distance (shaft length) between the collection bucket and the electronic balance remote-sensing head. This alteration necessitated installation of a baffle between the bucket and heated-chamber housing to ensure against the possibility of escaping heat affecting the sample. The modification, although relatively minor, drastically changed the nature of the acquired data. The instrument configuration used in

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24. Berthel, R.O., Plank, V.G., and Main, B.A. (1983) AFGL snow characterization measurements at SNOW-ONE-B: Preliminary report. SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, AFGL-TR-83-0174, AD A130556, 197-208.

SNOW-ONE-A displayed wind effects that varied somewhat symmetrically about the weight measurements. The SNOW-ONE-B data displays a decidedly biased effect on the positive side of the weight measurements (downward wind force on the collection bucket) with little deflection on the negative side. This change required a totally new method of analysis that will be discussed in conjunction with the data presentation in Section 5.1. The SRM operation during the field experiment was excellent, and measurements were made on six separate days.

The SSR was extensively modified during the summer months. As mentioned in Section 4.3, the device used during SNOW-ONE-A employed a continuously moving belt utilizing strobe lighting to provide "stop action." The SNOW-ONE-B instrument incorporates low intensity incandescent lighting with belt action in a "move and stop" sequence controlled by a geneva drive mechanism. Thus, recordings during this experiment were made under reduced lighting when the belt was stationary. Data were recorded on four days during the experiment.

5.1 8 December 1982

The SRM operated from 0910 to 1520 on 8 December 1982 although no FVI or SSR recordings were made. Data from the SRM indicates that a period of light snow occurred between 1000 and 1100, with occasional flurries before and little or nothing afterwards.

Figure 20 shows the SRM measurements made during this 1-hour period. These data are typical of the measurements taken by the SRM after the modification mentioned in Section 5. Therefore, they can be used for the purpose of discussing the new method of analysis.

The upper diagram of Figure 20 (a) is a time plot of the weight of collected snow as measured by the electronic balance. The line representing the weight measurements can easily be visualized, although major positive and minor negative fluctuations are periodically superimposed upon the base line. These deviations are wind-induced effects. The positive spikes can be attributed to the force of the wind on the collection bucket. The negative spikes are, most likely, an effect of over-compensation as the balance attempts to return to normal position after removal of that force. Data on other days with stronger winds show occasional larger negative spikes (1/3 the magnitude of the positive) that cannot be explained by compensation, but may be the result of reduced pressure caused by wind flowing across the open collection bucket. It is evident that any averaging technique used on the biased data in this plot would produce results that are much larger than reality whenever winds are present.

Scrutiny of these data show that quiescent periods with little or no fluctuations occur between spikes or series of spikes. The logic of the new analysis argues

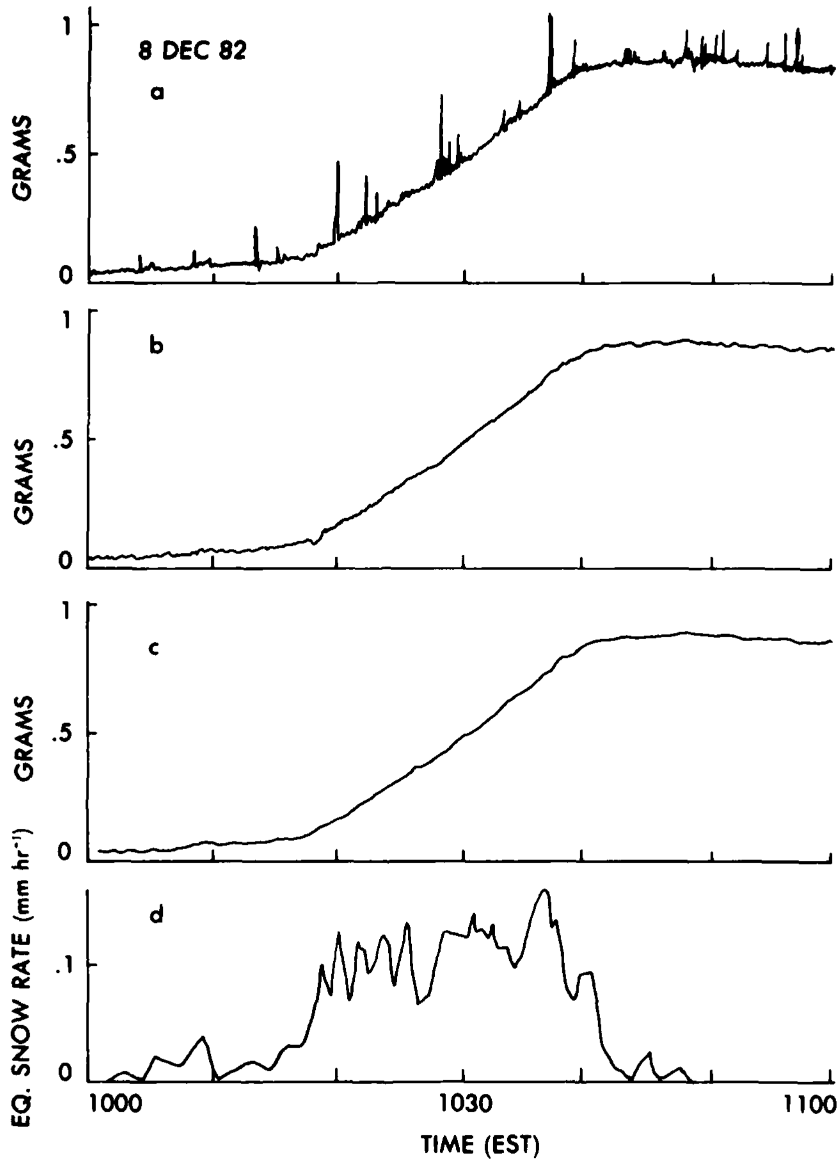

Figure 20. Snow Weights and Rates on 8 Dec 1982. Diagram (a) shows the weight readings as recorded by the electronic balance; (b) is the same data with the noise removed; (c) is a plot of the smoothed data; and (d) is the snow rate (water equivalent)

that these quiescent periods represent weight measurements unaffected by wind. The computer has been instructed to search for and identify these periods and to connect them by straight lines. The calculated line values for each 2.81 s time interval are then compared with the actual weight-readings. If the measurement agrees with the line value within a specified tolerance (usually 0.01 g, the basic weight resolution of the balance), that actual reading is retained. If not, the reading is considered to be noise and the calculated line value is used as a substitute.

The plot in Figure 20 (b) shows the basic raw-weight data with the noise eliminated in the manner just described. These corrected data are then subjected to a running-mean averaging with a variable number of points being averaged depending upon the nature of the data (2.81-284 s). The smoothed data, from which the rates are determined, are shown plotted in Figure 20 (c). Figure 20 (d) is the plot of snow rate (water equivalent) vs time.

This method of SRM analysis was used on the data of 31 January 1982 (Section 4.3) for a comparison of the two methods. The first 2 hours of data are shown in Figure 21, with the light line representing the parabolic-weighted averaging me-

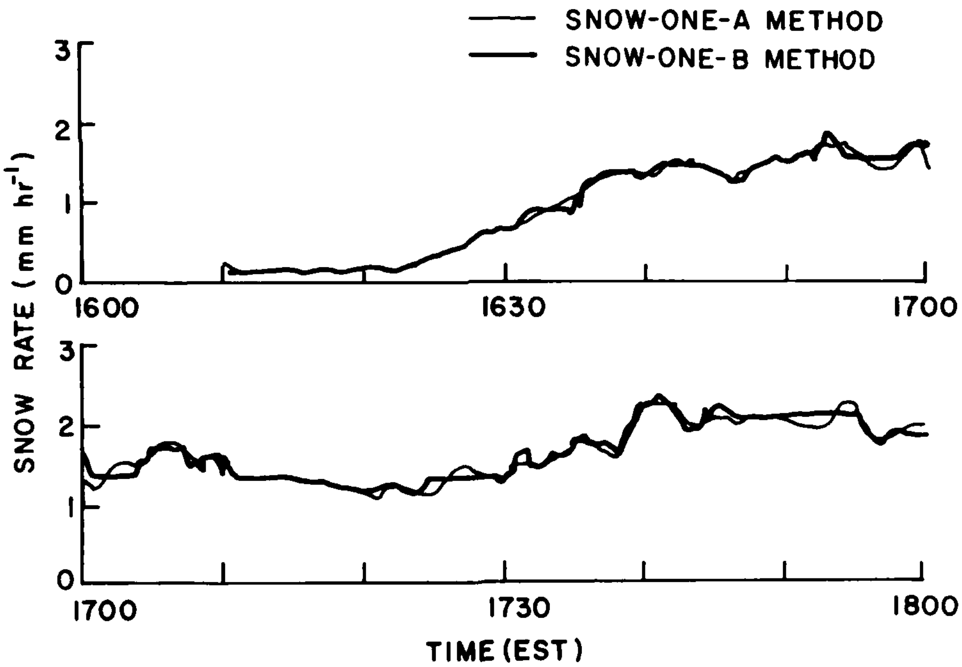

Figure 21. Comparison of Two Analytical Methods on Data From 31 Jan 1982

thod used on SNOW-ONE-A measurements (η = 30, see Figure 9), and the heavy line, the method used on the SNOW-ONE-B data. Minor deviations are evident, but they are so slight that the methods can be considered comparable.

5.2 10 December 1982

The FVI and SSR were operated for a brief period in the morning on 10 December 1982 from 0900 to 0908 and again during the evening hours from 1800 to 1915. The preliminary SSR analysis showed small graupel-type snow particles and rimed broken pieces. Very little FVI data were obtained, and it has not been analyzed.

The SRM was turned on at 0905 and was left running until the end of the recording tape at 0243 on the morning of 11 December. The weight readings indicate that there were only occasional flurries during the daylight hours, with a brief period of slightly heavier activity occurring between 1730 and 1800. A substantially stronger shower began at ~ 2040 with very light snow continuing to the end of the tape. Snow rates for the time period 1700, 10 December, to 0243, 11 December, are shown in Figure 22.

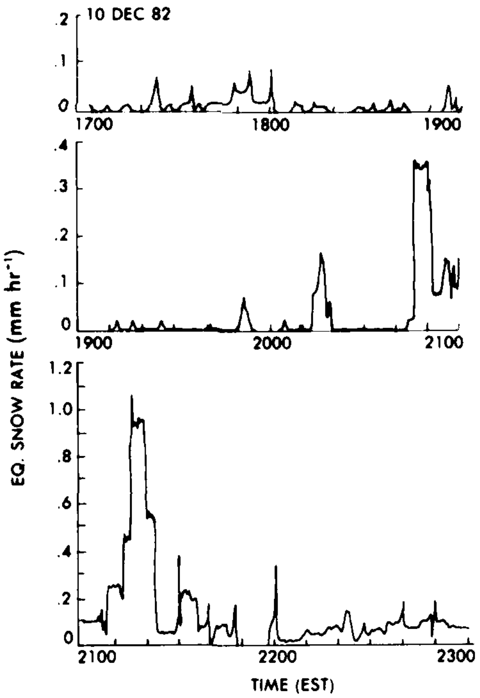

Figure 22. Snow Rates on 10 Dec 1982 (Part 1)

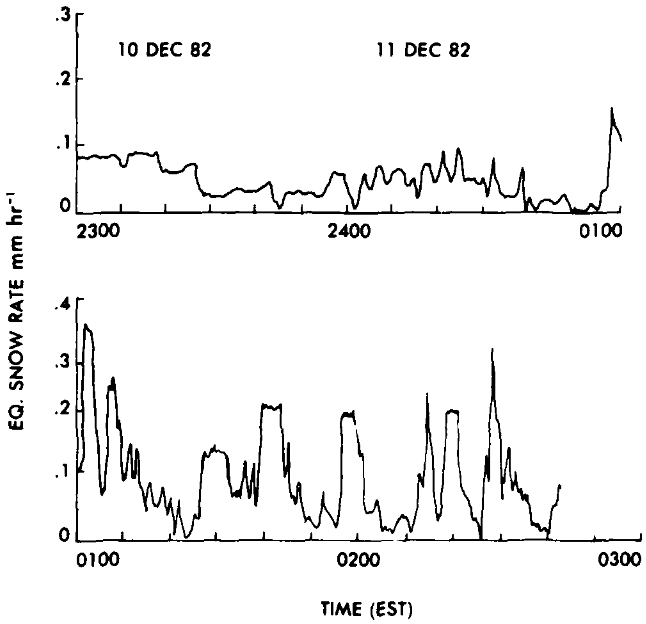

Figure 22. Snow Rates on 10 Dec 1982 (Part 2)

Although a majority of the experimenters had left the site before the 2040 shower, several systems were in operation during this period. Thus, we are able to show time comparisons between our SRM data and three sets of transmittance measurements. Figure 23 shows the inverse of snow rate plotted with the ASL/-SMART measurements[25] for the time period of 2000-2130. The NRL transmittance data[26] are shown in Figure 24 with the inversed snow rate for the times of 2245, 10 December, to 0200, 11 December 1982. Figure 25 shows four separate measurement periods of the ASL/LOVIR data[27] between 2306 on 10 December to 0219 on 11 December 1982 along with the inverse of snow rate. The casual time correlations between snow rate and the data from these three systems are obvious.

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25. Hanley, S.T., Bean, B.L., Watkins, W.R., Crow, S.B., and Dise, R.A. (1983) SNOW-ONE-B ASL/SMART measurements, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 155-195.

26. Curcio, J.A., Lebow, P., and Woytko, M. (1983) Transmittance measurements, SNOW-ONE-B, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 215-237.

27. Ben-Shalom, A., Okrasinski, R., Olsen, R., and Butterfield, J.E. (1983) Visible/IR transmission and meteorological data, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 89-127.

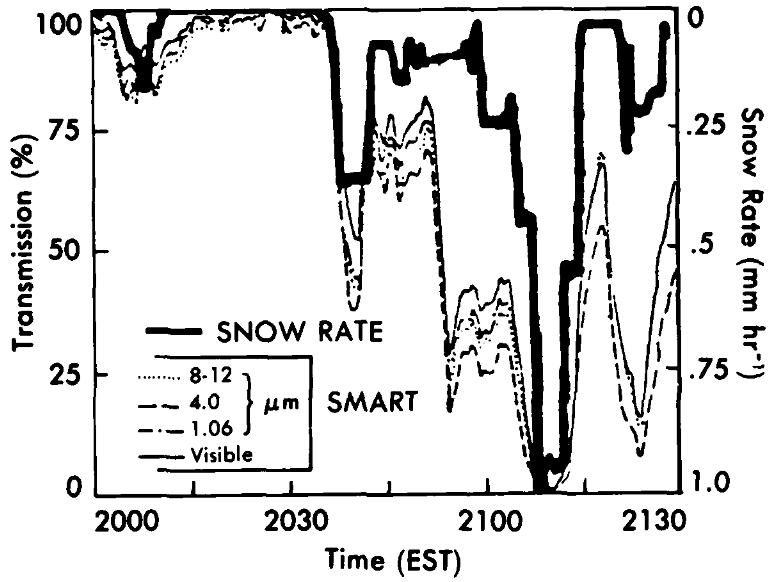

Figure 23. Time Comparison of ASL/SMART Transmittance Data and Snow Rate on 10 Dec 1982

One ASCME instrument[28] operated during this storm. The data provided, as well as the SRM data, are plotted vs time in Figure 26. The heavy line represents the ASCME, and the light line represents the SRM. The snow-rate data has been averaged over 1-min intervals to conform to the ASCME measurements. The general correlation is obvious although many inconsistencies are evident, particularly at the very small concentrations and rates.

These inconsistencies are also evident in the considerable scatter shown in the 1-min data plot of P vs M in Figure 27. However, this scatter is quickly reduced when the data is subjected to a running-mean averaging as in the other plots in the same figure.

The averaged fall-velocities, derived by dividing P by M, are shown in Figure 28. Considerably scatter is evident in these plots, possibly because of small mass-concentrations and snow rates. Unfortunately, independent measurements from the FVI are not available for comparison.

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28. Berger, R.H., Fisk, D., Koh, G., and Lacombe, J. (1983) Snow characterization at SNOW-ONE-B, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 155-195.

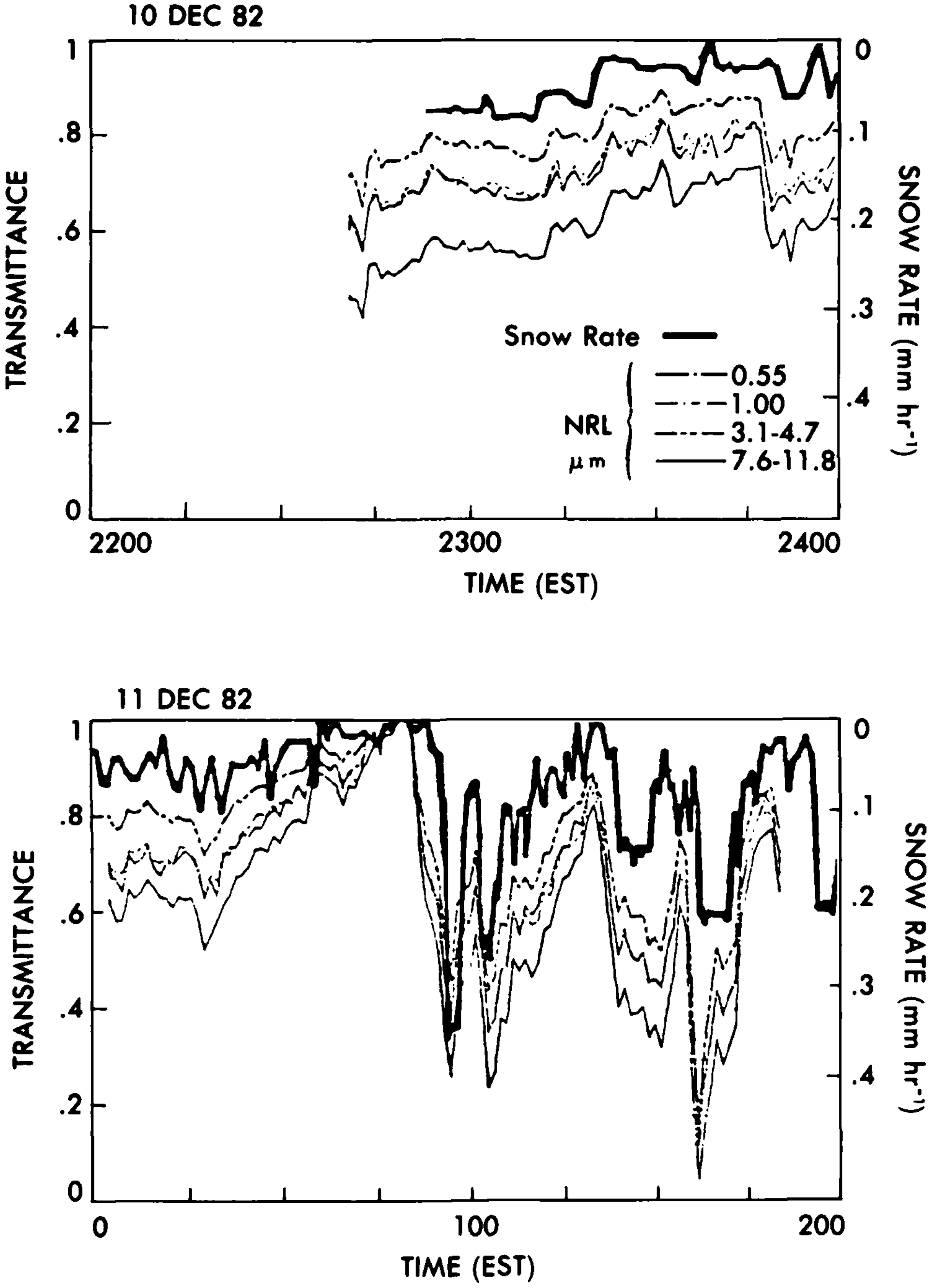

Figure 24. Time Comparison of NRL Transmittance Data and Snow Rate on 10-11 Dec 1982

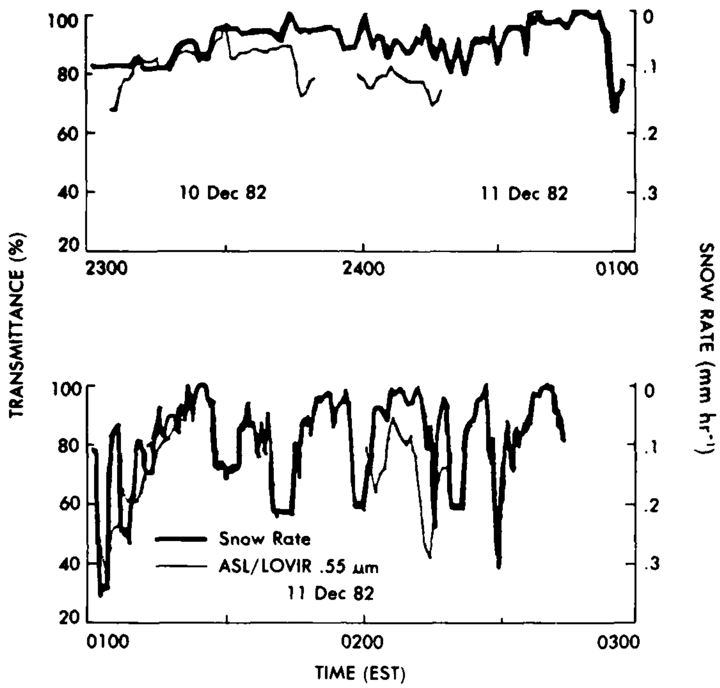

Figure 25. Time Comparison of ASL/LOVIR Transmittance Data and Snow Rate on 10-11 Dec 1982

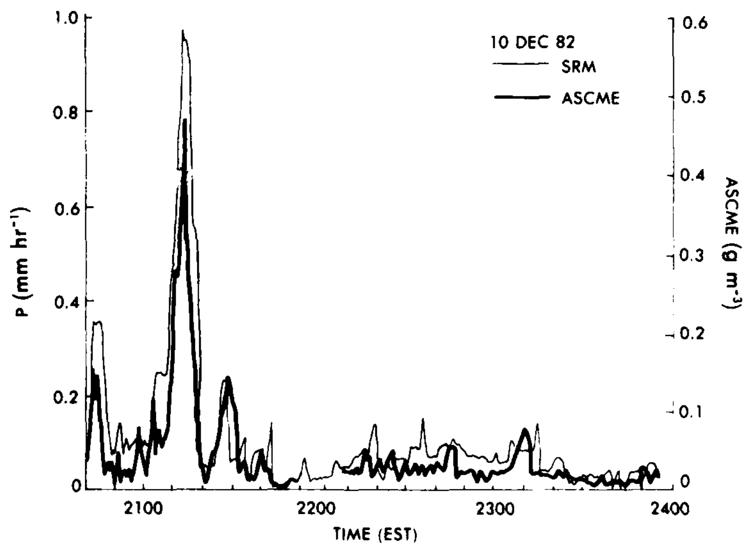

Figure 26. Time Comparison of ASCME and Snow Rate Data on 10 Dec 1982

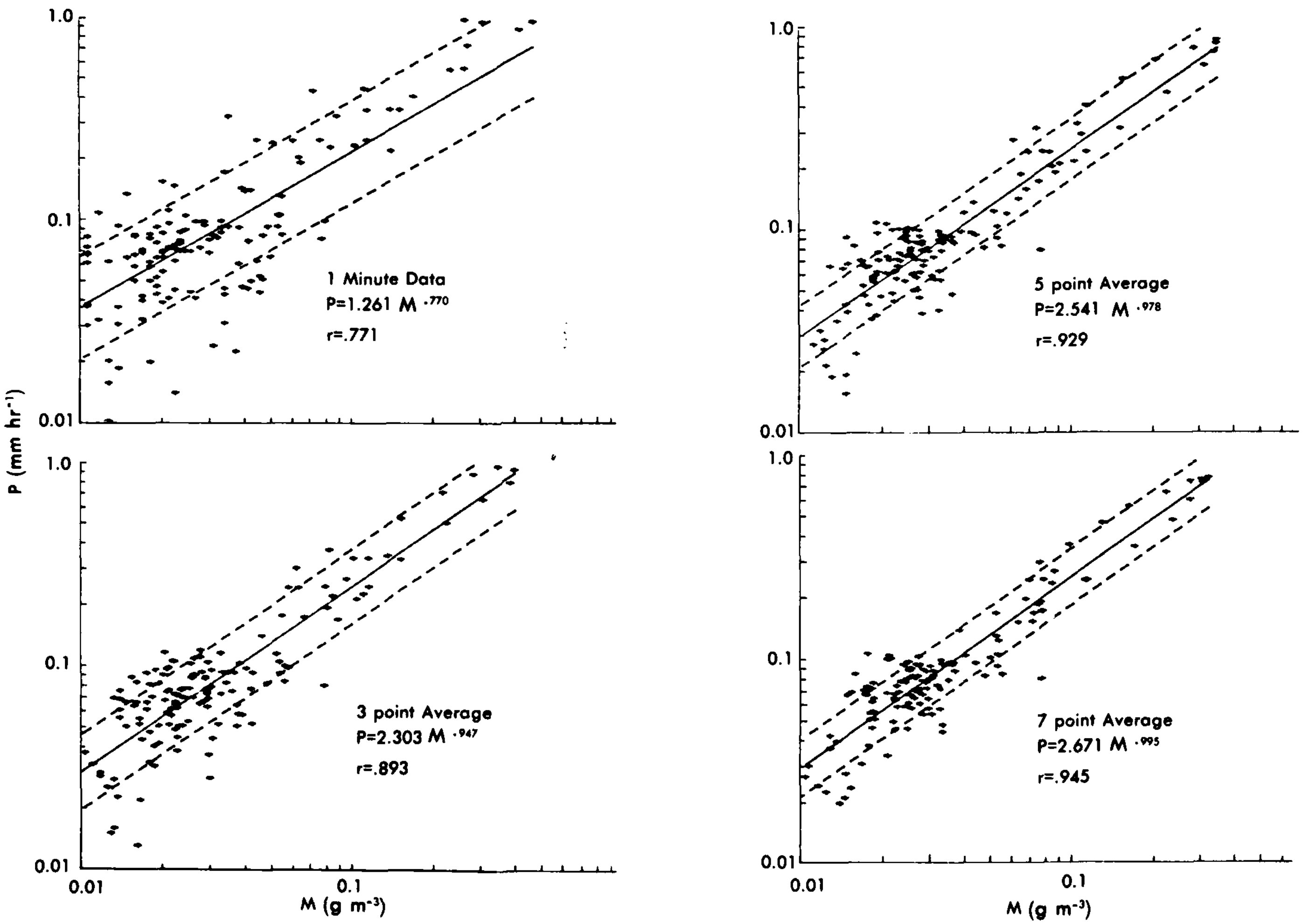

Figure 27. Correlation of Snow Rate and Mass Concentration on 10 Dec 1982

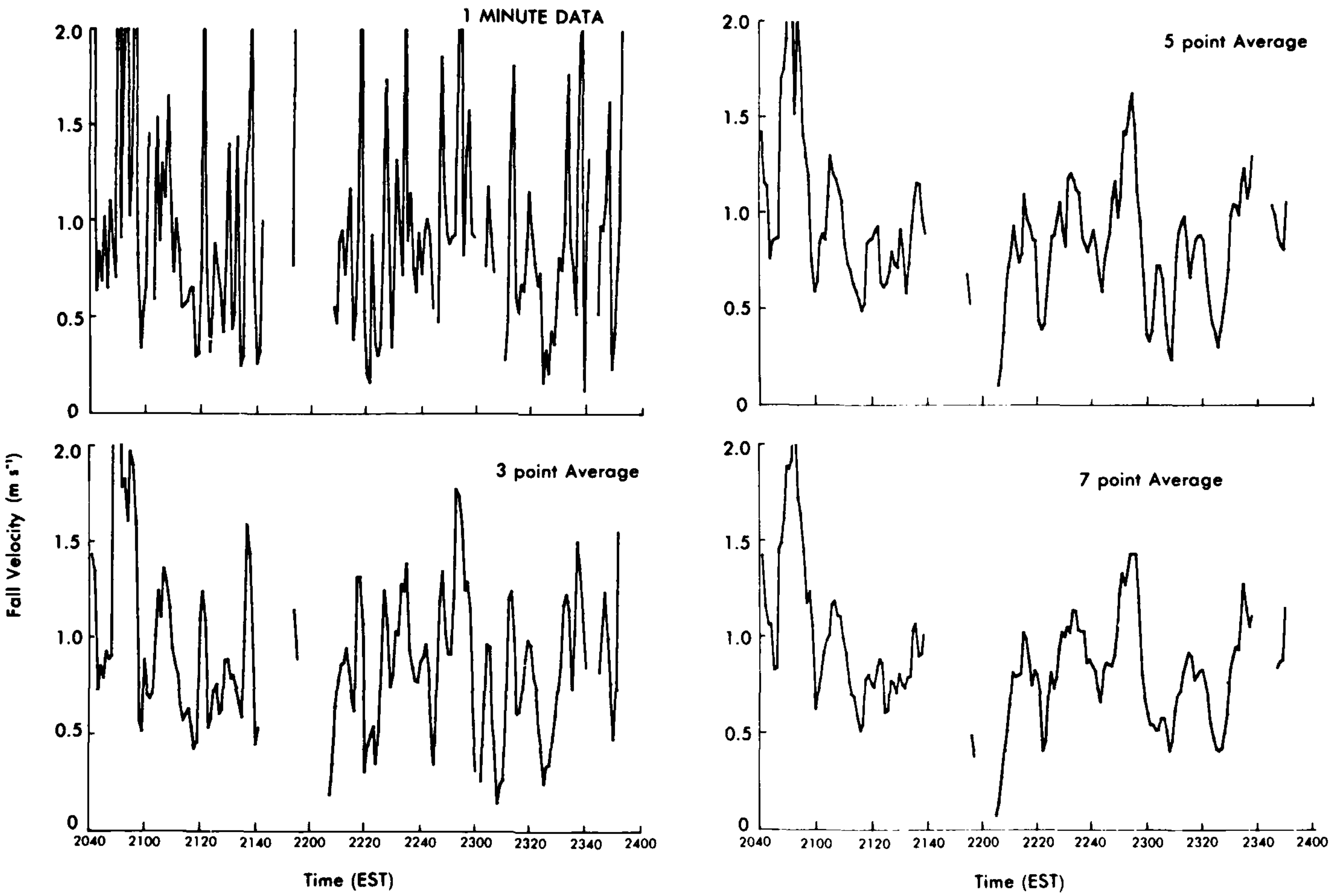

Figure 28. Fall Velocities Derived From P and M on 10 Dec 1982

5.3 11 December 1982

All instruments were put into operation at 0919 on 11 December 1982. The SRM data in Figure 29 shows that light snow occurred until ~1015 with very little

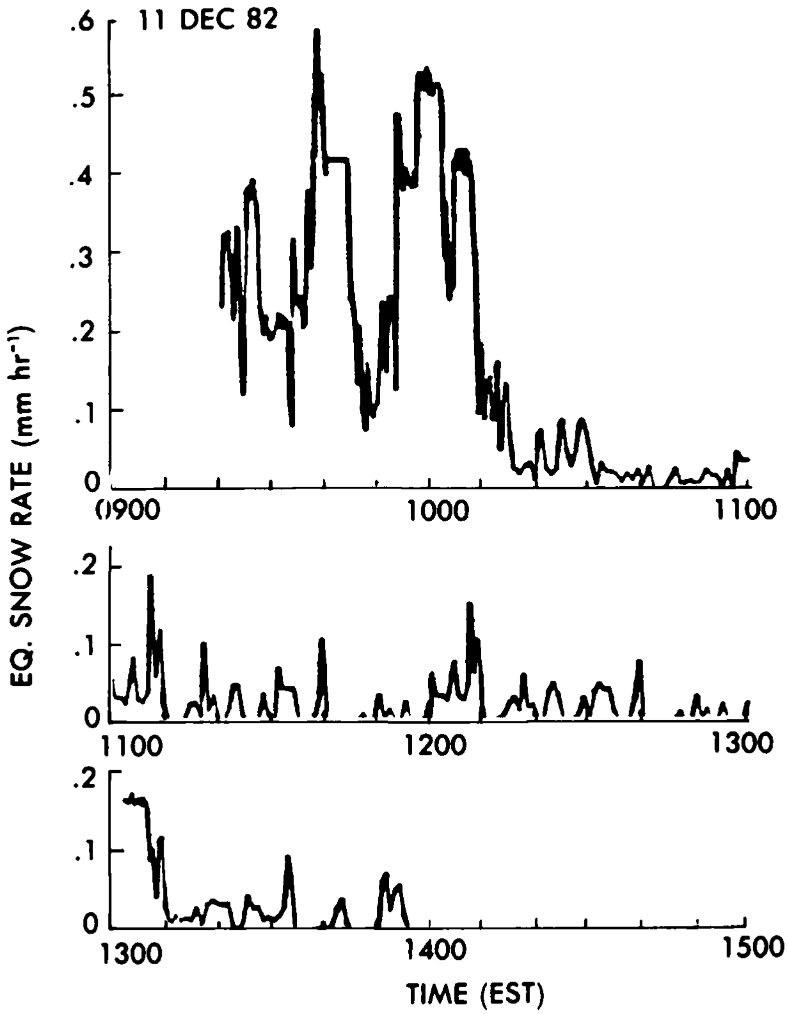

Figure 29. Snow Rates for 11 Dec 1982

activity the rest of the day. SRM operation was terminated at 1450.

Both the FVI and SSR were run for ~ 2 h, and some usable data were recorded. Because of time restraints, these data were not reduced. The preliminary analysis on the SSR shows small unidentifiable particles at the start of operation with a few stellars and dendrites occurring later in the day.

5.4 12 December 1982

Of the six days of recorded snow-rate data, 12 December 1982 provided the most extensive period of snowfall during daylight hours. All instruments were turned on at 0855. The SRM was left running until the end of the recording tape at 0230 on 13 December; the SSR and FVI were terminated at 1350 on 12 December.

Analysis of the video recordings from the SRR revealed graupel-type particles mixed with larger stellars and dendrites. The constituents of the mix remained fairly consistent throughout the storm although the percentages of the particular types varied continuously. It is estimated that stellars and dendrites composed less than 10 percent of the particles that were sampled. Some examples of the particles captured by the SSR on this day are shown in Figure 30. (The notes from the SSR analysis are included in Appendix A.)

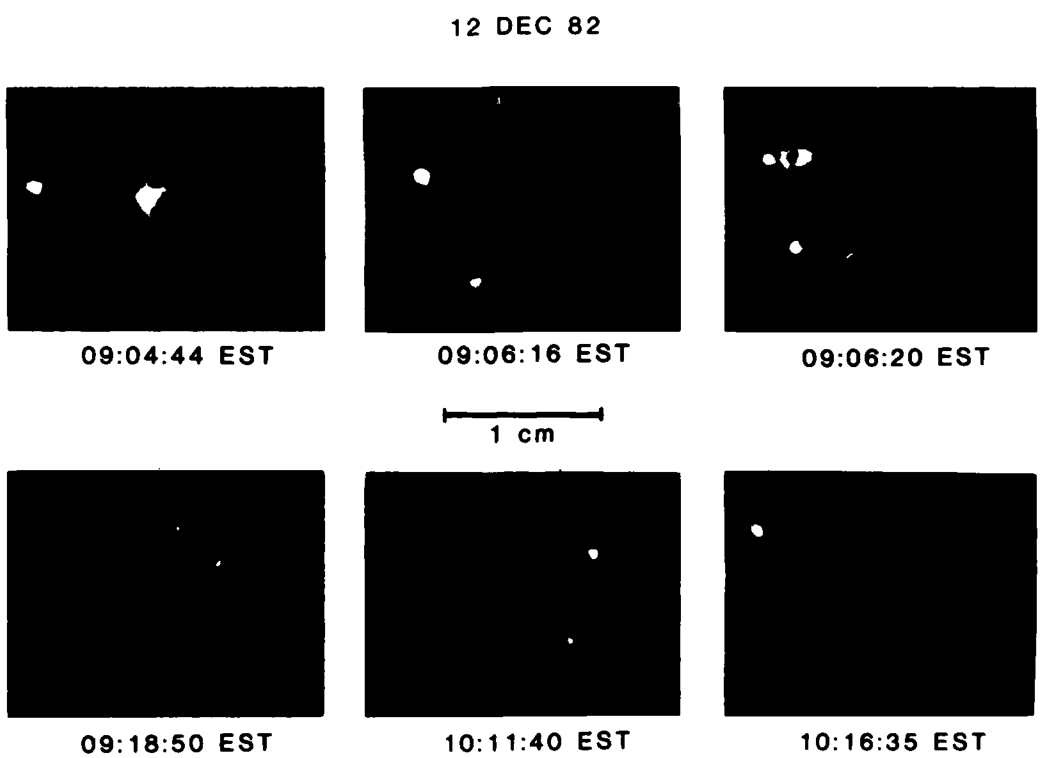

Figure 30. Typical Data Obtained With the SSR on 12 Dec 1982

Because of the time-consuming labor necessary for the reduction of the FVI data, the initial analysis consisted only of representative recordings taken within the times conforming to the intensive measurement periods. Figure 31 is a plot of fall velocity vs size over those time periods.

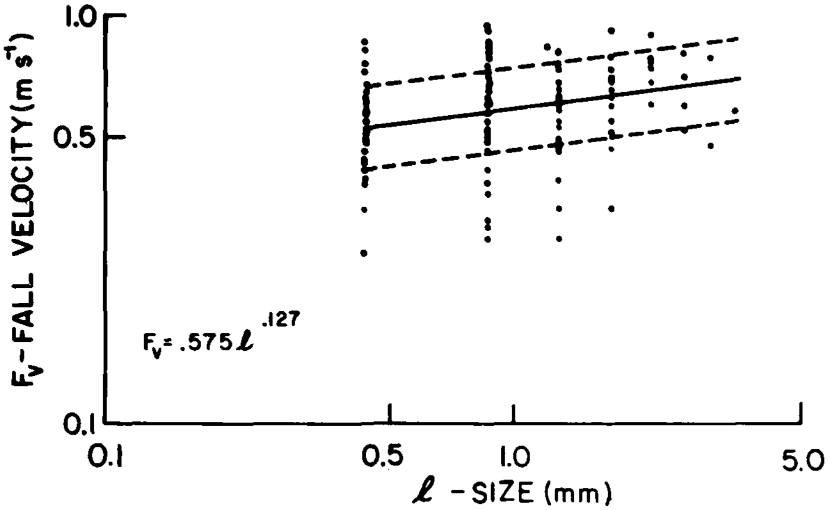

Figure 31. Fall Velocities of Individual Particles on 12 Dec 1982 (ℓ is the longest measured dimension)

Snow rates between the start of operation and 1430 are plotted in Figure 32. No weight increases were recorded after that time except for a very minor 5-min period centered on 1710. The ASL/LOVIR transmittance measurements[27] between 1000 and 13000 on this day are shown in Figure 33 along with the inversed snow rate. The casual time correlation is apparent.

A better correlation is obtained when snow rates converted to 1-min data are compared with the CRREL/ASCME measurements[28] as shown in Figure 34 for the time period of 0930 and 1430 on this day. Again, as for 10 December 1982, the general correlation is obvious although many inconsistencies are evident, particularly at the very small concentrations and rates.

The inconsistencies are the cause of the considerable scatter shown in the 1-min data plot of P vs M in Figure 35. As for the 10 December measurements, this scatter is quickly reduced when the data are subjected to a running-mean averaging as in the other plots.

The scatter is more apparent in the calculated P/M fall-velocity values of Figure 36, but, as in the P vs M plots, it is reduced by averaging. The most

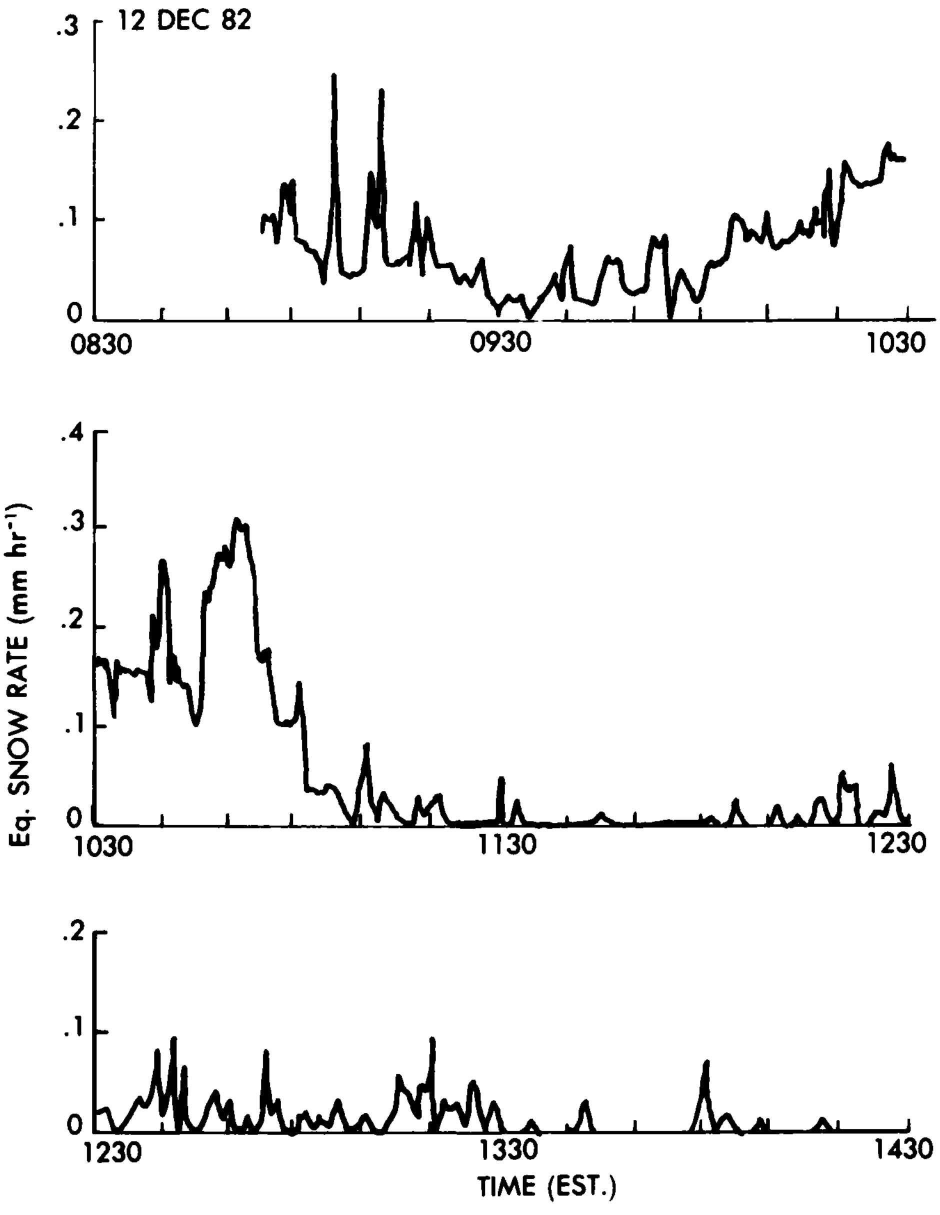

Figure 32. Snow Rates on 12 Dec 1982

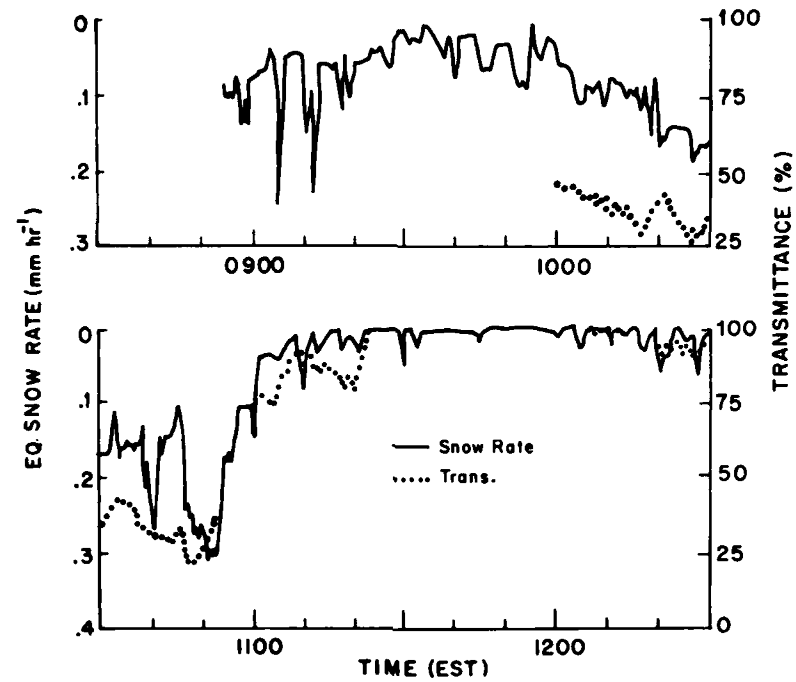

Figure 33. Time Comparison of ASL/LOVIR Transmittance and Snow Rate Data on 12 Dec 1982

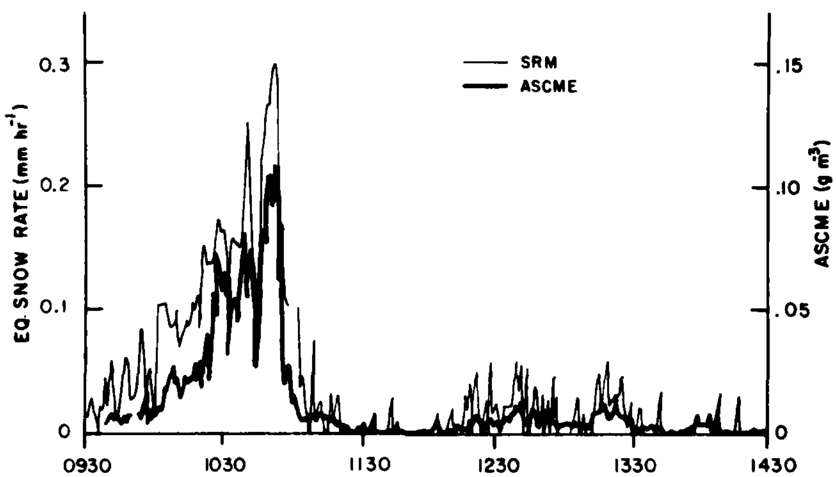

Figure 34. Time Comparison of ASCME and Snow Rate Data on 12 Dec 1982

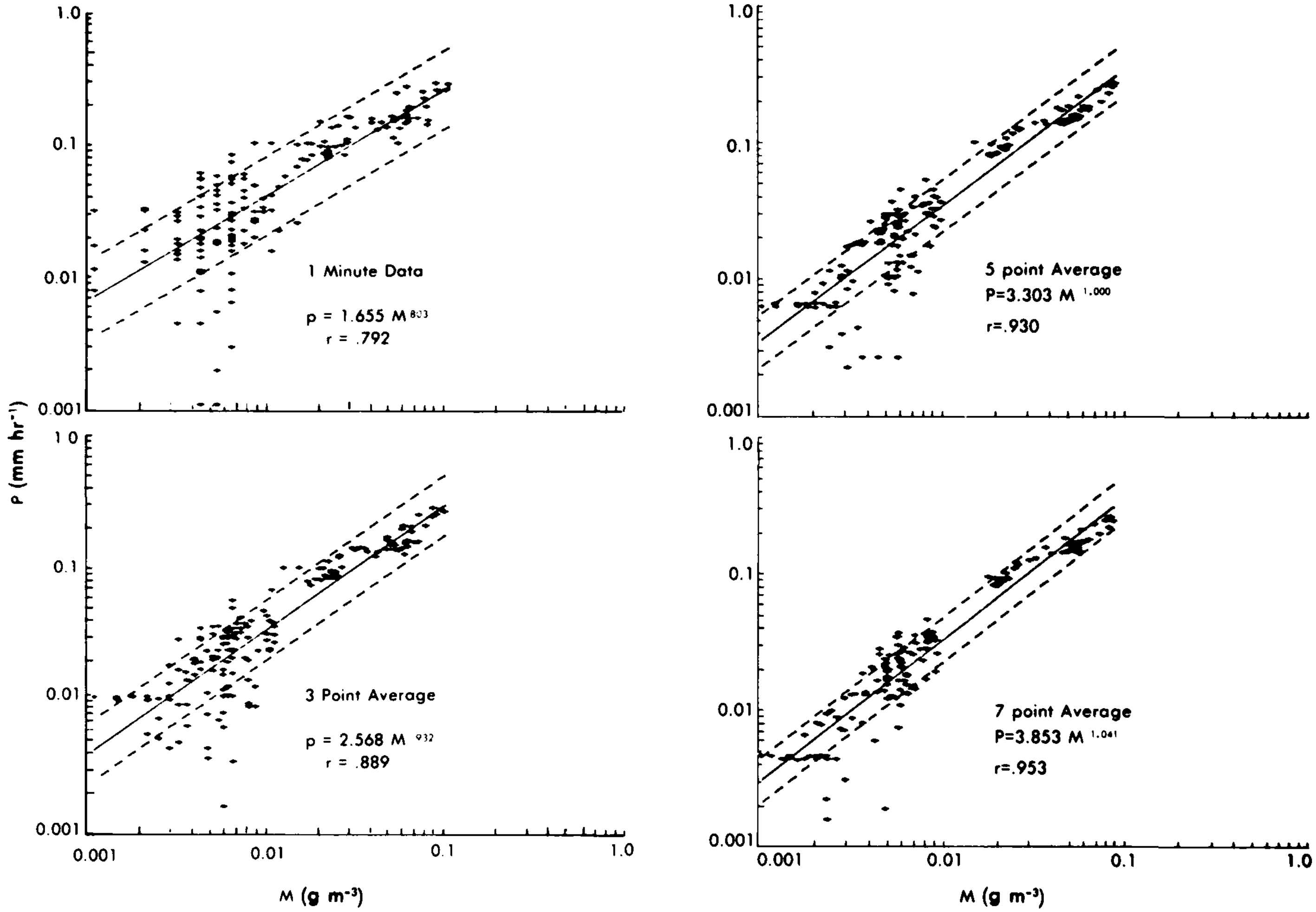

Figure 35. Correlation of Snow Rate and Mass Concentration on 12 Dec 1982

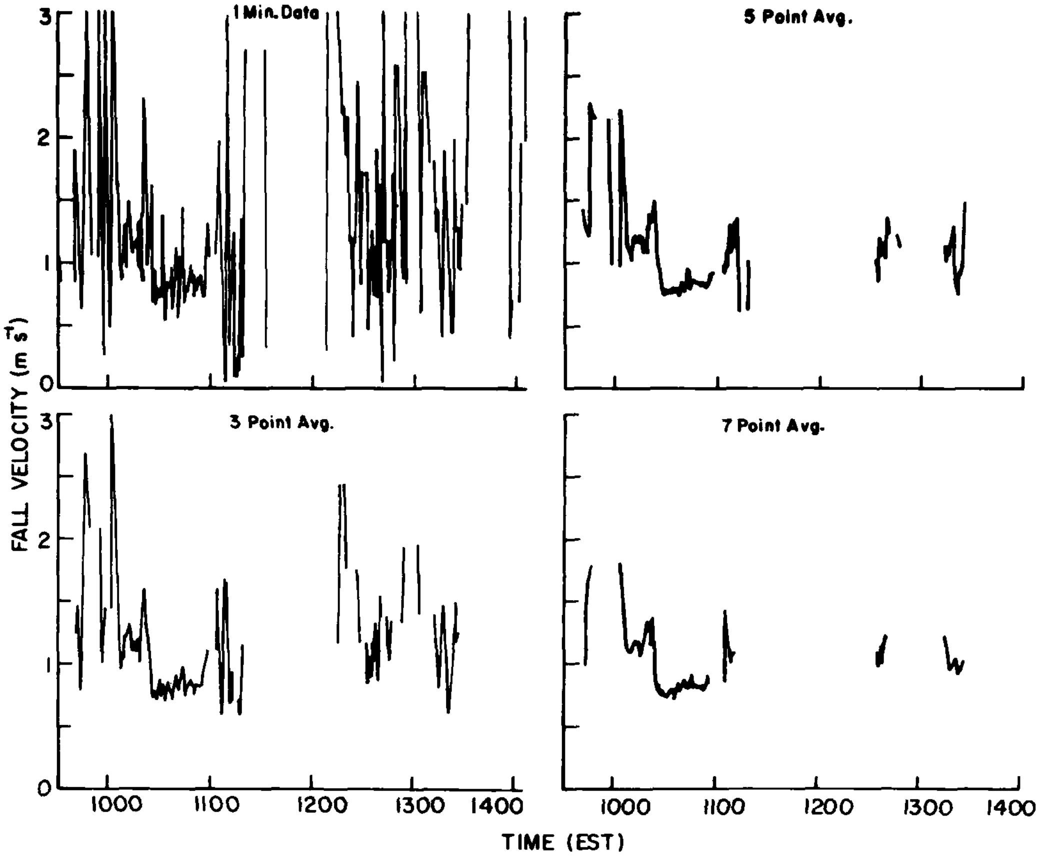

Figure 36. Fall Velocity Derived From P and M on 12 Dec 1982

stable period is between ~1025 and ~1055, the time limits corresponding to the largest snowfall intensity (P = > ~.13, M = > ~.06). The second most stable region falls between ~1005 and 1025, when P = ~.1 and M = ~.02. All other times experienced less snowfall.

It is unclear at this time if the P/M fall velocities between 1005 and 1025 (~1.2 m s^{-1}) are, in fact, true. The indications are that they may not be, since no velocity above 1 m s^{-1} was observed in the measurements of the individual flakes (Figure 31).

The 1000 IMP was divided in the same manner as the 1900 IMP of 31 January 1982 to check both the fall velocities of the individual flakes and the consistencies of the F_v - ℓ relationships throughout the period. Because of the lesser amount of snow falling on this day, 50 particles were counted starting at 1000, 1005, 1010, and 1015. The plots are shown in Figure 37. The times over which these 50 mea-

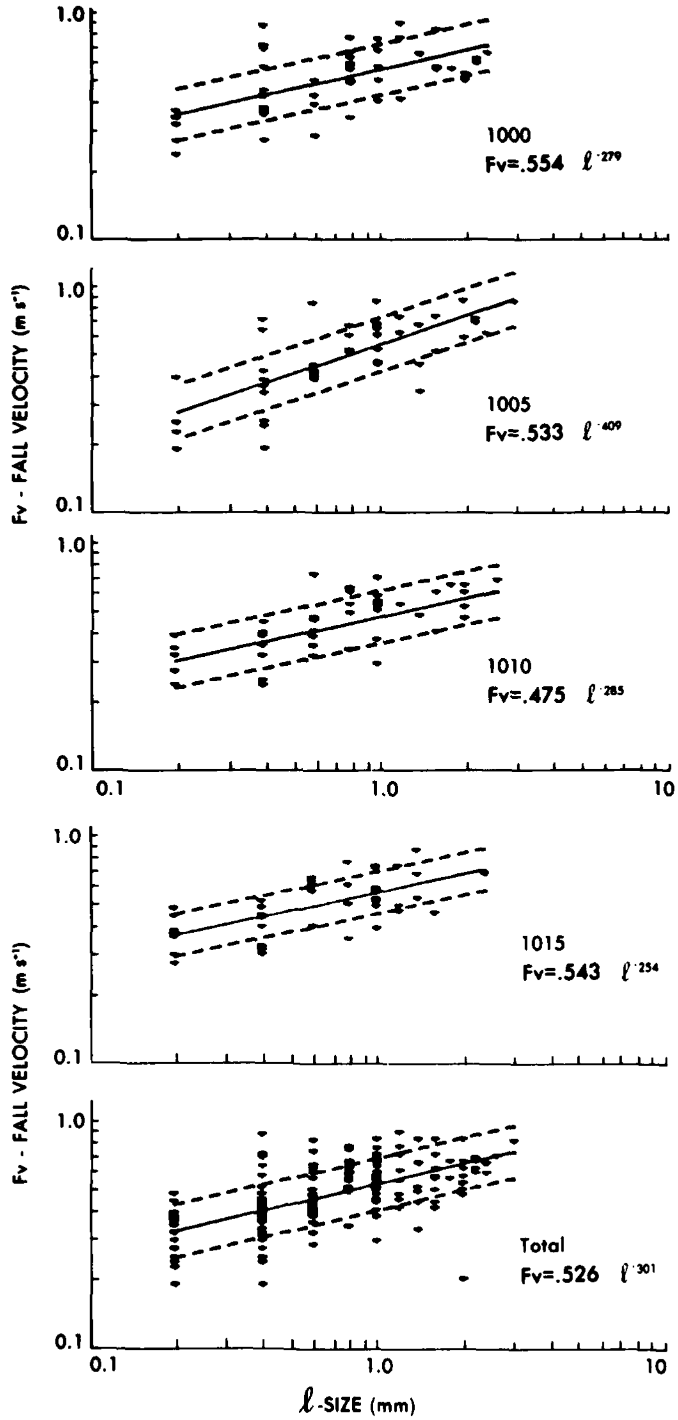

Figure 37. Fall Velocities of Individual Particles From the 1000 IMP on 12 Dec 1982

surements were made ranged from ~4-5 minutes. Again, as additional evidence questioning the validity of the P/M fall velocities of Figure 36 during the 1000 IMP, no reading > 1 ms^{-1} was recorded.

The resulting regression equations presented in Figure 37 are inconsistent, indicating a changing nature in the snowfall during this period. All have steeper slopes than the equations derived from the composite IMP data set shown in Figure 31. This leads one to suspect that the data from at least one other IMP (or possibly more) produced a slope more shallow than that of the composite. This, in turn, suggests a variability in snow characteristics during the course of the storm and confirms the findings from the SSR.

As a check on the P/M velocities obtained from 1025 to 1055, we measured 50 individual flakes starting at 1030. These measurements are plotted in Figure 38.

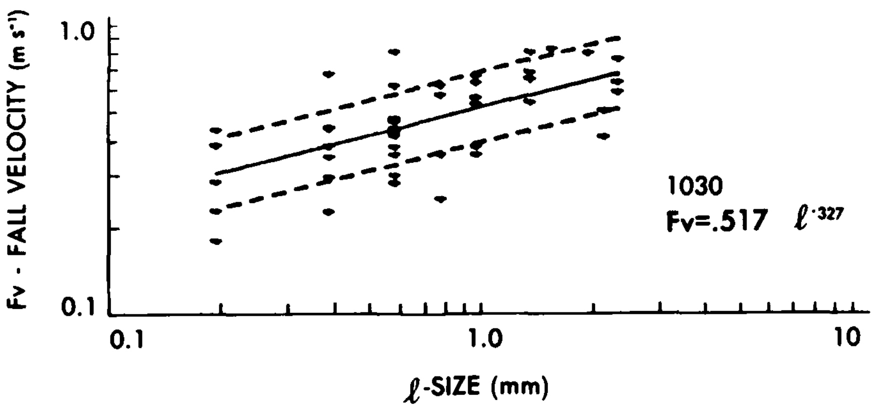

Figure 38. Fall Velocities of Individual Particles From 1030 to 1035 on 12 Dec 1982 (ℓ is the longest measured dimension)

The results of the analysis gives an equation compatible with the total of the 1000 IMP of Figure 37. The mean value of 0.5 m s^{-1} from these individual velocities does not agree with the integrated values (~.8 m s^{-1}).

The non-compatibilities mentioned above point to possible errors in the data supplied by one, two, or all three of the instruments (FVI, SRM, or ASCME) involved in these analyses. Three possible scenarios are the following:

(1) A wind effect (updraft) on the FVI could result in low fall-velocities.

(2) A wind effect (updraft) on the SRM could cause low rate-values, and, since the integrated fall-velocities are determined by P/M, the resultant velocities would be high.

(3) Lower than actual values from the ASCME could cause high integrated-fall-velocities.

It must be emphasized that we have not defined a source of error. At this time, we can only bring attention to the inconsistencies that seem to indicate measurement error.

5.5 14 December 1982

No FVI or SSR data were taken on 14 December 1982. The SRM was turned on at 1438 and was left running until ~ 0630 on 15 December with light sporadic precipitation recorded throughout that period. The first six hours of operation are shown in Figure 39.

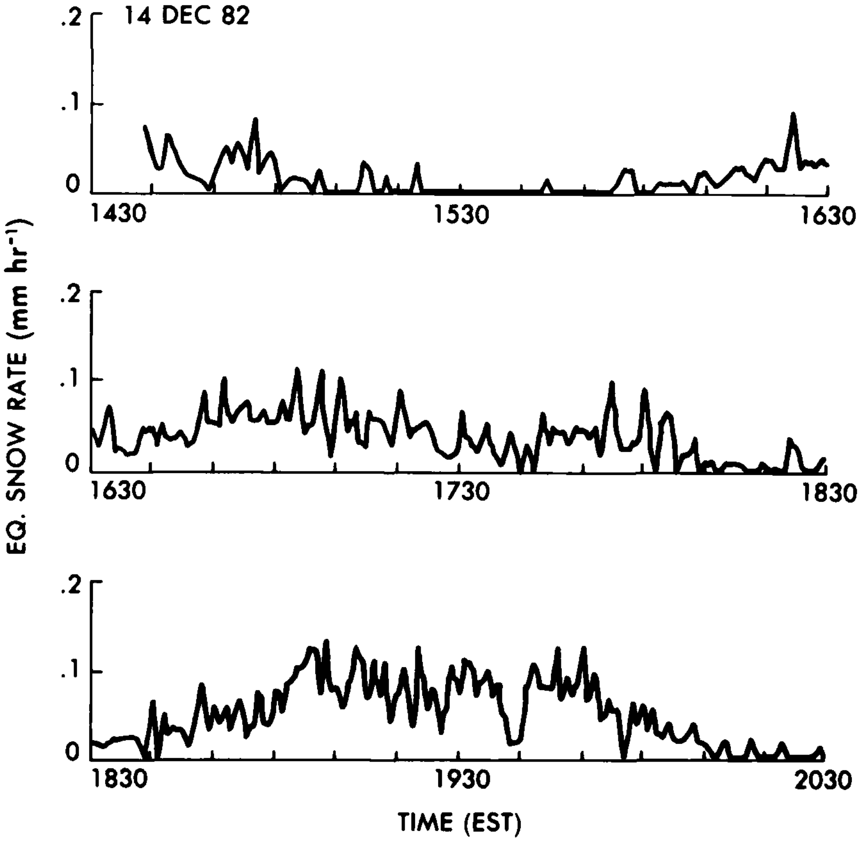

Figure 39. Snow Rates on 14 Dec 1982

5.6 17 December 1982

The SSR, FVI, and SRM were all turned on at 0942 on 17 December 1982. Although the SSR and FVI were terminated at 1005, the SRM was left running until the end of the recording tape at ~0200 the morning of 18 December. Because little or nothing was recorded after 1430, the snow rate plots in Figure 40 are terminated at that time. The SSR recordings show 0.5 to 1 mm stellars as the predominant crystal size and type. The FVI data were not reduced.

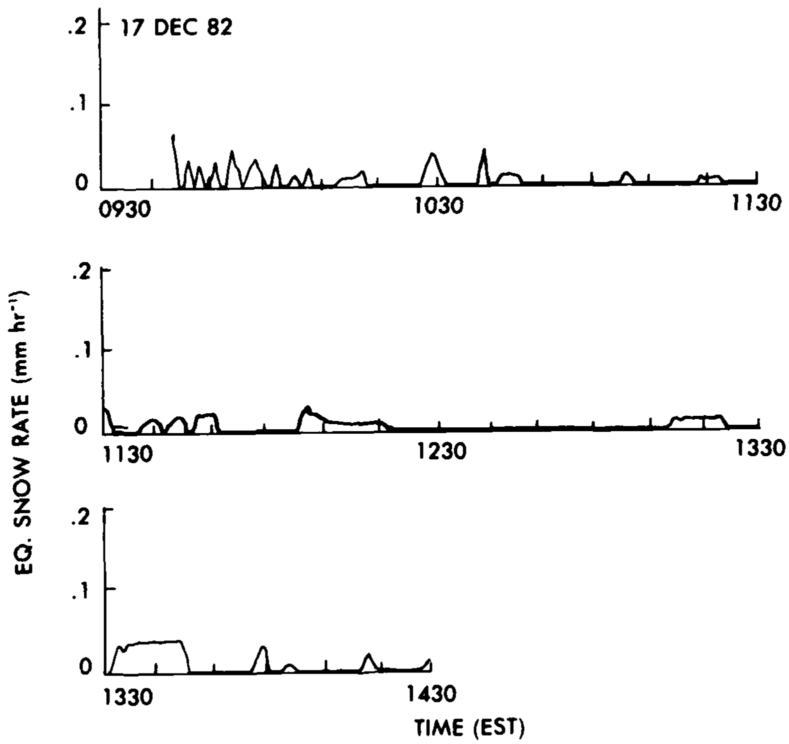

Figure 40. Snow Rates on 17 Dec 1982

6. CONCLUDING COMMENTS

Modifications made to our instruments during the summer months following SNOW-ONE-A have greatly contributed to an improved performance as demonstrated in SNOW-ONE-B. We are conducting further modifications that we hope will still better our measurements. A new concept of back lighting on the FVI, that gives shadow recordings of the falling snowflakes, is currently undergoing laboratory testing and promises sharper video images for more accurate measurements. The SSR is also being reconfigured to improve collection efficiency. A snow-volume recorder and a total-number instrument are also being considered.

The data acquired during SNOW-ONE-A and B raised questions regarding wind effects and the accuracy of light precipitation determinations. We are planning to conduct some airflow studies under varying wind conditions on both the FVI and SRM that may provide some useful information. However, until we can define a fault in the SRM operation in light snow conditions, we can only presume the readings to be correct.

The limited amount of data obtained thus far indicates that both the snow rate vs mass concentration and fall velocity vs size relationships may be heavily dependent upon snowflake type or mixture of types. Since snow particles can attain a multitude of different sizes, shapes, and crystal structures, it is impossible to form characteristic relationships to describe every eventuality. We hope to be able to define broad categories of snow types where more general equations are applicable. A normal winter season with ample snowfall during the upcoming SNOW II field experiment may provide sufficient data to establish the validity of this supposition.

In the process of developing class-averaged fall-velocities using the 400 individual snowflake measurements from the 1900 EST IMP on 31 January 1982 and the 200 from the 1000 EST IMP on 12 December 1982, we also produced the number of particles contained within each size class. When these number densities are plotted vs the mid-class values of the particle's longest dimension in a semi-logarithmic format (Figures 41 and 42), they show a general conformity to an exponential shape. This agrees with our past findings using aircraft-acquired data and raises the possibility of estimating realistic number-density distributions using the exponential assumption in combination with data supplied by the available ground-based measurements. Theoretical work along these lines is currently in progress.

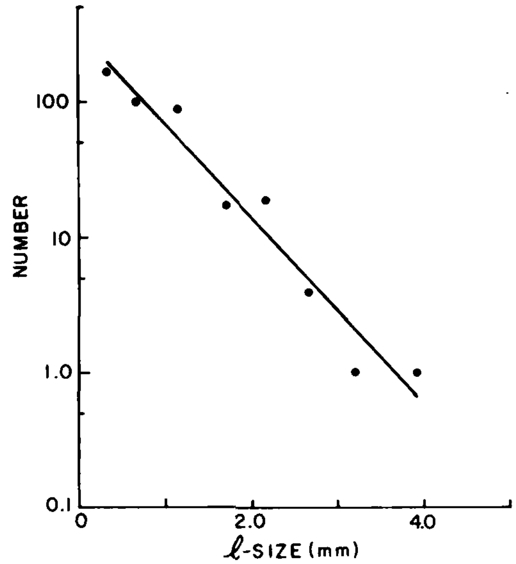

Figure 41. Number Density Distribution From the FVI Data of the 1900 IMP on 31 Jan 1982 (ℓ is the longest measured dimension)

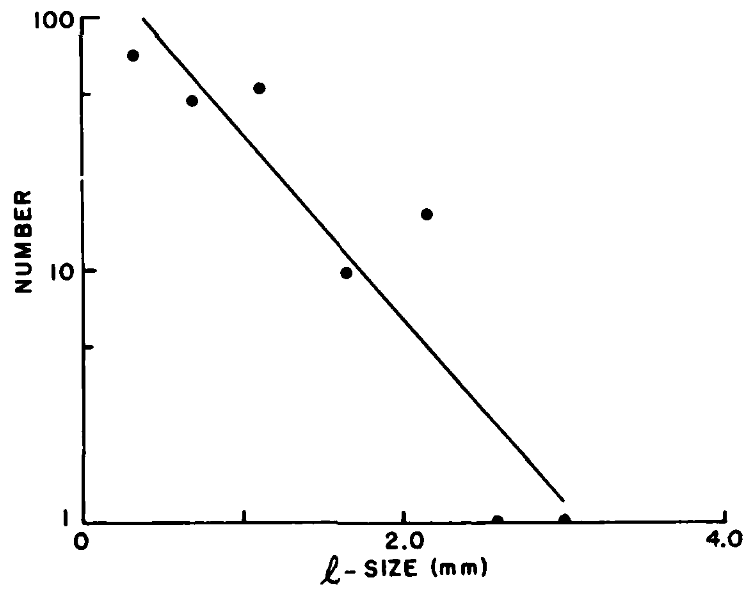

Figure 42. Number Density Distribution From the FVI Data of the 1000 IMP on 12 Dec 1982 (ℓ is the longest measured dimension)

References

1. Barnes, A.A., Nelson, L.D., and Metcalf, J.I. (1974) Weather documentation at Kwajalein Missile Range, 6th Conference on Aerospace and Aeronautical Meteorology, American Meteorological Society, 66-69, Air Force Surveys in Geophysics, No. 292, AFCRL-TR-74-0430, AD A000925.

2. Barnes, A.A., Metcalf, J.I., and Nelson, L.D. (1974) Aircraft and radar weather data analysis for PVM-5, Air Force Surveys in Geophysics, No. 297, AFCRL/Minuteman Report No. 1, AFCRL-74-0627, AD B004290.

3. Plank, V.G. (1974) Hydrometeor parameters determined from the radar data of the SAMS Rain Erosion Program, Environmental Research Papers, No. 477, AFCRL/SAMS Report No. 2, AFCRL-TR-74-0249, AD786454.

4. Plank, V.G. (1974) Liquid-water-content and hydrometeor size-distribution information for the SAMS Missile Flights of the 1971-72 season at Wallops Island, Virginia, Special Reports, No. 178, AFCRL/SAMS Report No. 3, AFCRL-TR-74-0296, AD A002370.

5. Plank, V.G. (1977) Hydrometeor data and analytical-theoretical investigations pertaining to the SAMS Missile Flights of the 1972-73 season at Wallops Island, Virginia, Environmental Research Papers, No. 603, AFGL/SAMS Report No. 5, AFGL-TR-77-0149, AD A051192.

6. Berthel, R.O., and Plank, V.G. (1983) A model for the estimation of rain distributions, Environmental Research Papers, No. 822, AFGL-TR-83-0030, AD A130080.

7. Plank, V.G., and Berthel, R.O. (1983) High resolution snow and rain rate measurements, Reprints of the Fifth Symposium on Meteorological Observations and Instrumentation, Toronto, Canada, Apr 11-15, 1983, AFGL-TR-83-0107, AD A128296, 27-33.

8. Gibbons, L.C., Matthews, A.J., Berthel, R.O., and Plank, V.G. (1983) Snow characterization instruments, Instrument Papers No. 316, AFGL-TR-83-0063, AD A131984.

9. Plank, V.G., Matthews, A.J., and Berthel, R.O. (1983) Instruments used for snow characterization in support of SNOW-ONE-A and SNOW-ONE-B, Proceedings of SPIE Technical Symposium East 83, Session "Optical Engineering for Cold Environments," Sub-session "Optical Hardware in the Cold."

10. Berthel, R.O. (1982) Snow characterization measurements at SNOW-ONE-A, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-2, May 1982, AFGL-TR-82-0003, AD A118140, 421-437.

11. Berthel, R.O., Plank, V.G., and Matthews, A.J. (1982) AFGL snow characterization measurements at SNOW-ONE-A, Reprints of Snow Symposium II, CRREL, Hanover, N.H., Aug 10-12, AFGL-TR-83-0121, AD A128606, 35-48.

12. Plank, V.G., Berthel, R.O., and Main, B.A. (1983) Snow characterization measurements and E/O correlations obtained during SNOW-ONE-A and SNOW-ONE-B, Proceedings of SPIE Technical Symposium East 83, Session "Optical Engineering for Cold Environments," Sub-session "Electro-Optical/Infrared Systems and Effects."

13. Bilello, M.A. (1982) Synoptic weather conditions during selected snowfall events between December 1981 and February 1982, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 9-42.

14. Bates, R. (1982) Meteorology, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 43-180.

15. Hildebrand, F.B. (1956) Introduction to Numerical Analysis, McGraw-Hill, New York, N.Y.

16. Lanczos, C. (1961) Applied Analysis, Prentice Hall, Inc., Englewood Cliffs, N.J.

17. Olsen, R., Okrasinski, R., and Brown, D. (1982) TACS data report for SNOW-ONE-A, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 181-216.

18. Berthel, R.O., Plank, V.G., and Main, B.A. (1983) Analyses of snow characterization data acquired at SNOW-ONE-A and B, Snow Symposium III, CRREL, Hanover, N.H., Aug 9-11, 1983.

19. Ballistic Research Laboratory (1982) Millimeter-wave propagation at 35, 95, 140 and 217 GHz frequencies through snowfall, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 283-294.

20. Curcio, J. (1982) Visible and infrared propagation data, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 305-322.

21. OPA, AFGL (1982) SNOW-ONE-A preliminary data report, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 437-526.

22. Lacombe, J. (1982) Measurements of airborne-snow concentration, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 225-282.

23. Koh, G., and O'Brien, H. (1982) Snow crystal habit, SNOW-ONE-A Data Report, U.S. Army Corps of Engineers, CRREL Special Report 82-8, 181-216.

24. Berthel, R.O., Plank, V.G., and Main, B.A. (1983) AFGL snow characterization measurements at SNOW-ONE-B: Preliminary report, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, AFGL-TR-83-0174, AD A130556, 197-208.

25. Hanley, S.T., Bean, B.L., Watkins, W.R., Crow, S.B., and Dise, R.A. (1983) SNOW-ONE-B ASL/SMART measurements, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 155-195.

26. Curcio, J.A., Lebow, P., and Woytko, M. (1983) Transmittance measurements, SNOW-ONE-B, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 215-237.

27. Ben-Shalom, A., Okrasinski, R., Olsen, R., and Butterfield, J.E. (1983) Visible/IR transmission and meteorological data, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 89-127.

28. Berger, R.H., Fisk, D., Koh, G., and Lacombe, J. (1983) Snow characterization at SNOW-ONE-B, SNOW-ONE-B Data Report, U.S. Army Corps of Engineers, CRREL Special Report 83-16, 155-195.

Appendix A

Notes from the SSR Analysis for 12 December 1982

IMP #1

Frame Number	Start 0900 EST Frame 18000
18000	Occasional 2 mm graupel
18810	Good dendrite 1.8 mm
23000	Occasional graupel and dendrites
30000	Only occasional particles now 1.3 mm
34000	Size of occasional particles back up to 1.8 mm
34990	Stellars 3.5 mm and graupel 1.8 mm
35362	4 mm aggregate
40850	Rimed stellar 4 mm
43912	5 mm aggregate
44094	1.3 mm dendrites
48740	Dendritic crystal with plates on ends 2 mm
54682	Mixed 2 mm dendrites and 1.3 mm hexagonal graupel
72000	All hexagonal graupel averaging 1 mm very occasional aggregate and dendrite

NOTE: Entire IMP Precipitation was very light

IMP #2

	Start 1000 EST Frame 234,000
235000	Very few small particles 0.5-1 mm, looks like hexagonal graupel with a very occasional 1.25 mm rimed stellar
275000	Intensity increasing some mostly 1.2 mm hexagonal graupel
293750	Single 2.5 mm plate with dendritic extensions; otherwise all graupel with dendritic tendencies
301000	Back to very few particles
305000	Intensity back up again 2.5 mm particles

IMP #3

Start 1100 EST Frame 14,400

14400	Few small particles up to 0.8 mm graupel with dendritic tendencies
23000	Few broken branches mixed in
27376	Several graupel particles 0.8 mm on same frame
50000	Particles fewer and smaller
54538	1 mm graupel and 1.5 mm plate with dendritic extensions
70000	Particles few and far between, 0.5 mm graupel
80000	Some up to 1.5 mm

IMP #4

Start 1200 EST Frame 93,600

93600	No particles at start of IMP. May be some 0.1 mm graupel now and again
117000	No particles at end of IMP

END

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