# Measuring Heavy Snowfall Using Five Different Windshields and Vibrating-Wire Precipitation Gauges

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## ABSTRACT

During the three-day period 17-19 March 2003, 130 mm of rain and liquid equivalent snow were recorded at the Marshall Field Site located south of Boulder. CO and operated by the National Center for Atmospheric Research. Five heated Geonor T-200B 3-wire gauges continuously recorded 1-minute accumulations of precipitation, each gauge in a different windshield. The five windshields were the WMO Double Fence Intercomparison Reference (DFIR), a two-thirds size DFIR, two double-Alter shields, and a traditional single Alter shield. The event can be characterized as a 16-hour period of discontinuous rain followed by a 37-hour period of continuous snowfall with wind speed between 0 and 11 $ms^{-1}$ and air temperature during snowfall between -1.0°C and 0.5°C.

The results show that the two highest storm total accumulations were from the DFIR and 2/3 size DFIR with the least storm total from the single Alter at 65% of the DFIR. The cause of the undercatch is the design of the windshield. A plot of the decreasing ratio of 15-minute accumulations from the gauge in the single Alter shield to those from the gauge in the DFIR with increasing wind speed is shown. All gauges were heated with a fine wire tape so that the temperature of the gauge orifice usually varied between 0°C and 2°C. During periods of high snowfall rate, the duty cycle of heating influences the 1-minute precipitation rates in a predictable way. Also of interest is the observation of "snow dumps" that occur when an accumulation of snow adhering to the rim of the gauge orifice detaches and falls into the bucket. This precipitation event demonstrates the sensitivity of estimating liquid equivalent snowfall to the type of windshield employed and the comparative insensitivity when only rain is occurring.

Keywords: snow measurement, wind effects on snow measurement, snow windshields, heated snow gauges

## INTRODUCTION

There have been numerous studies of undercatch of snowfall over the past several decades by researchers using different gauges and various types of windshields. Examples are Sugiura et al. (2006), Yang et al. (2000), Goodison et al. (1998), Hanson (1989), Larson and Peck (1974), and Weiss (1961). These studies typically involve semi-daily or daily observations of snow accumulation, mean wind speed, and mean temperature from which various correction schemes have been developed. No universal correction scheme to account for undercatch due to wind has yet to be developed.

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In this paper we examine precipitation measurements of a major snow event in Colorado, especially along the eastern slope of the Rocky Mountains. Our attention is focused on the three-day period 17-19 March 2003, during which period 130 mm of rain and liquid equivalent snow were recorded at the Marshall Field Site located south of Boulder, CO and operated by the National Center for Atmospheric Research.

The research reported here differs from most previous studies in that we made meteorological observations at 1-minute intervals and each of the five gauges was heated. The high time resolution data have allowed us to examine the rate of snowfall, the possible influence of gauge heating on snowfall rate, and the effects of wind on undercatch over 15-minute time intervals.

## FIELD SITE AND INSTRUMENTATION

Fig. 1 shows the layout of the five gauges with their respective windshields. In the lower right part of the figure is a World Meteorological Organization (WMO) international standard windshield referred to as the "double fence intercomparison reference" (DFIR) with outer diameter 12 m, inner diameter 6 m, with the addition of a standard 1.2 m diameter Alter shield surrounding the gauge. A 2/3 size DFIR (sDFIR) is located in the upper right of Fig. 1 that also includes a standard Alter shield. To the west of the sDFIR are two double Alter shields with outer diameter 2.4 m. To their left is a single Alter shield.

Fig. 2 is a view of the DFIR from just inside the outer shield. In the foreground is the inner shield and inside it is the Alter shield and precipitation gauge. Fig. 3 shows the East double Alter (EdAlt) shield in the foreground, the West double Alter (WdAlt) shield behind it, and the single Alter shield (sAlt) to the right of the WdAlt.

The gauge in each shield is a Geonor T-200B vibrating-wire all-weather precipitation gauge (developed by the Norwegian Geotechnical Institute, Oslo), each continuously weighing the accumulation in the collection bucket with time. Fig. 4 shows an external view of a Geonor gauge with the upper Kapton flexible heating element visible. Another similar heating element surrounds the lower part of the orifice (below the shoulder of the case) and is not visible. The consequences of not heating the gauge in wet snow can be seen in Fig. 7 (not shown here) of a paper by Rasmussen et al. (2001). They show that wet snow easily sticks to the sides and rim of the orifice, thereby changing the wind flow dynamics around the gauge and reducing the effective diameter of the opening. The result was a 30-40% reduction in the measured rate of snowfall.

Fig. 5 is a sideview of a Geonor T-200B gauge with the case removed. Each of the five gauges used three vibrating-wire transducers as observed in the figure. The 12 L bucket rests on a support pan which is suspended by the three vibrating wire transducers attached to the upper rim. Duchon (2008) discusses the operation and performance of the Geonor T-200B gauge in considerable detail for rainfall measurements. A Campbell Scientific, Inc. CR10X data logger recorded all data at 1-minute intervals – precipitation as an accumulation, other meteorological variables as 1-minute averages or instantaneous values.

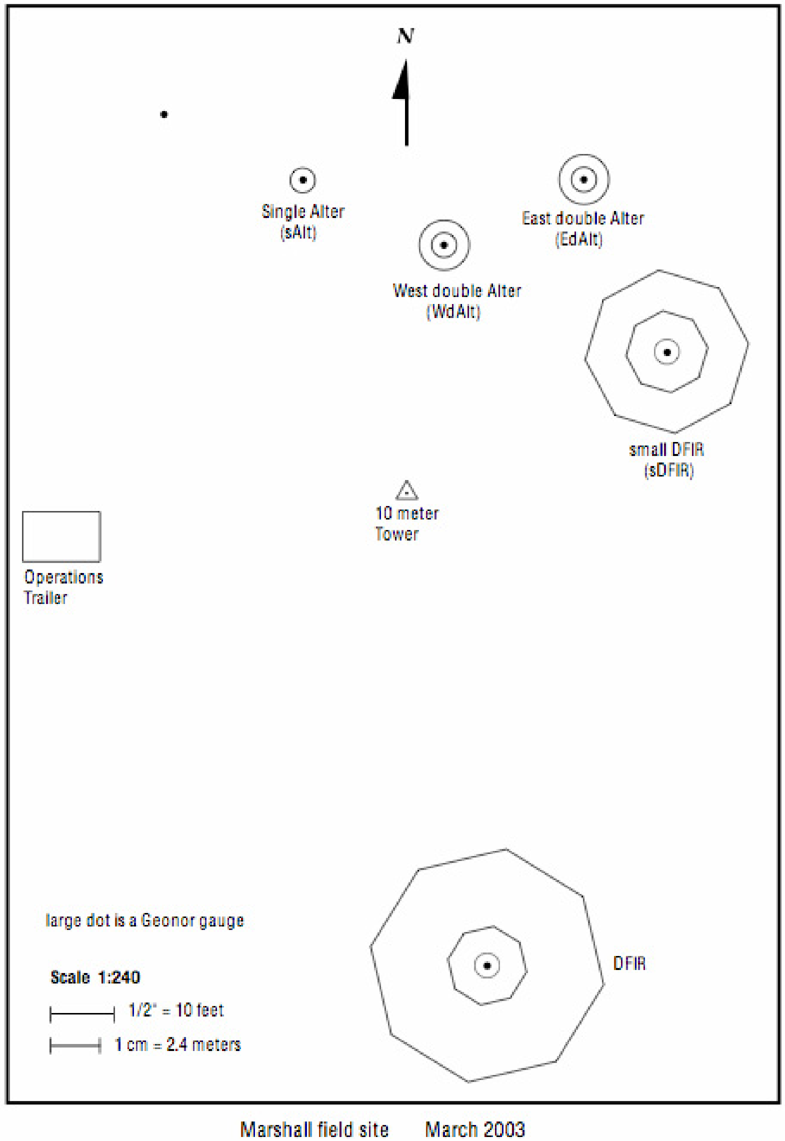


Figure 1. The location of gauges at the Marshall Field site.
The outlined area is 38 m (125 ft) x 54 m (177 ft).

Figure 2. A view of the DFIR from just inside the outer shield. In the foreground is the inner shield and, in addition, an Alter shield surrounds the gauge.

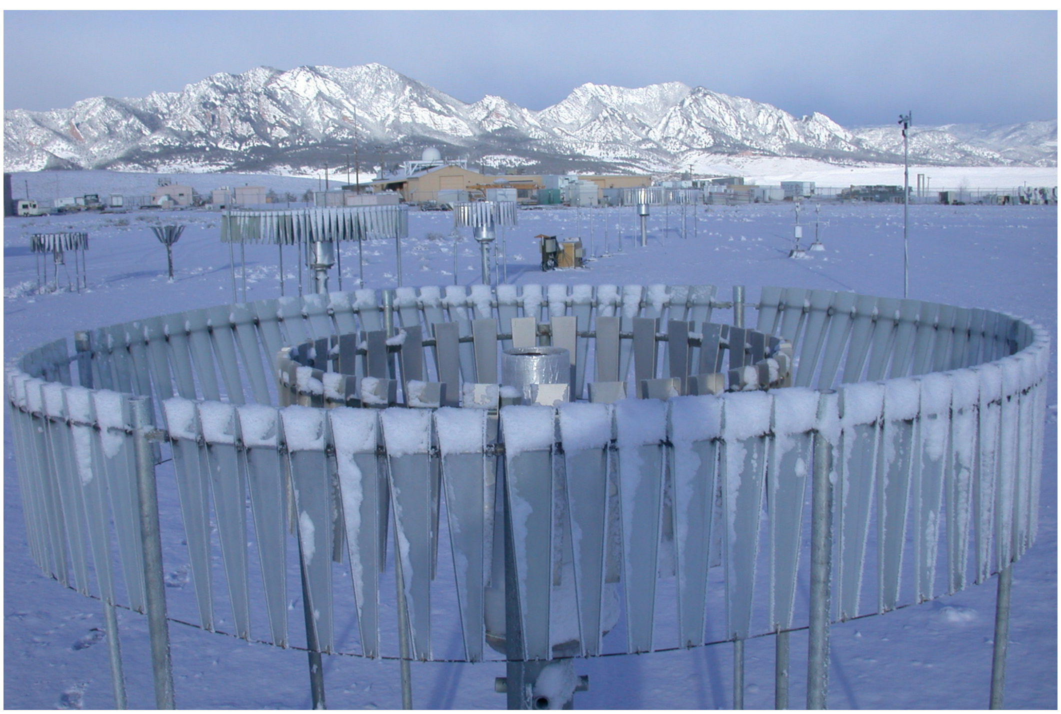

Figure 3. The east double Alter shield (EdAlt) is in the foreground, the west double Alter (WdAlt) is behind it, and the single Alter shield (sAlt) is to the right of WdAlt.

Figure 4.  A T-200B Geonor gauge showing the upper Kapton flexible heating element.  A similar heating element is affixed to the section of the orifice below the shoulder of the gauge.

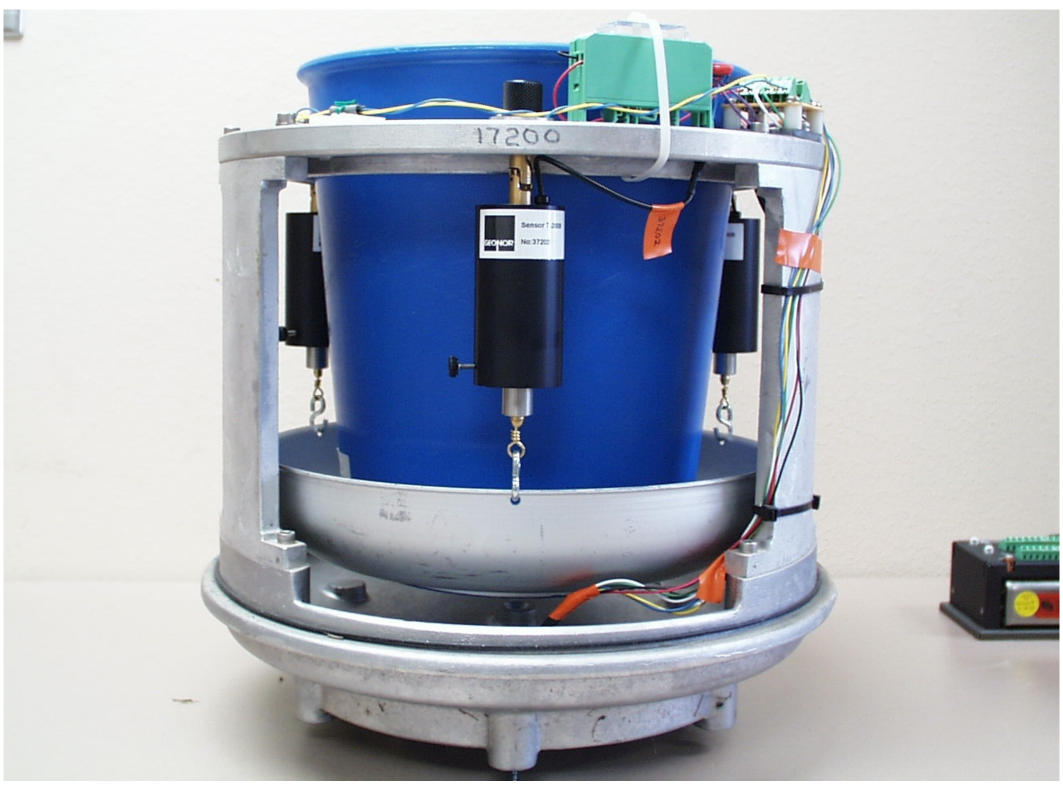


Figure 5.  Sideview of T-200B gauge with the case removed.  Each of the five gauges used three vibrating-wire transducers as seen in the photo.

## EVENT ACCUMULATIONS

Fig. 6 shows rain and liquid equivalent snowfall accumulations from the five gauges with time. The maximum difference in rainfall totals among the gauges was 0.40 mm (0.02 in). The maximum difference in liquid equivalent snowfall totals among the gauges was 43.41 mm (1.17 in). Two large "snow dumps" are evident at about hour 37. These occur when melting of snow inside the orifice cannot keep up with the rate of snowfall. At some point in time the accumulated mass of snow can no longer "stick" to the inside wall of the orifice and falls into the bucket.

Surprisingly, the greatest event total is from the sDFIR; the DFIR total is 5 mm less. Of course, there is the possibility of one windshield altering the wind field of the downstream windshield. During the period of snowfall, the 1-minute mean wind speed varied from 0 to 11 m/s and the wind direction varied from 320° to 360°. With the separation between the closest sides of the sDFIR and DFIR about 22 m, as seen in Fig. 1, and an average direction about 350°, we would not expect much wind effect from the sDFIR on the snow accumulation measured in the DFIR. However, there may be some wind effect from the EdAlt on snow accumulation measured in the sDFIR (see Fig. 1). If there is some influence, it is unknown whether it would result in an increase or decrease in snowfall in the sDFIR.

As expected, based on other snow events, the total accumulation from the sAlt was the lowest among the five windshields. However, we are perplexed that the accumulations from the two essentially identical dAlt shields were so different (see Fig. 6). The rain-only totals from the EdAlt and WdAlt were within 0.03 mm. After snowfall began, their accumulations increasingly diverged. The relative accumulation from the EdAlt is consistent with other snow events. While total accumulations from the WdAlt were typically less than totals from the EdAlt in other snow events, there was no case in which the disparity was as large as seen here. We are unable to account for the huge difference in accumulations.

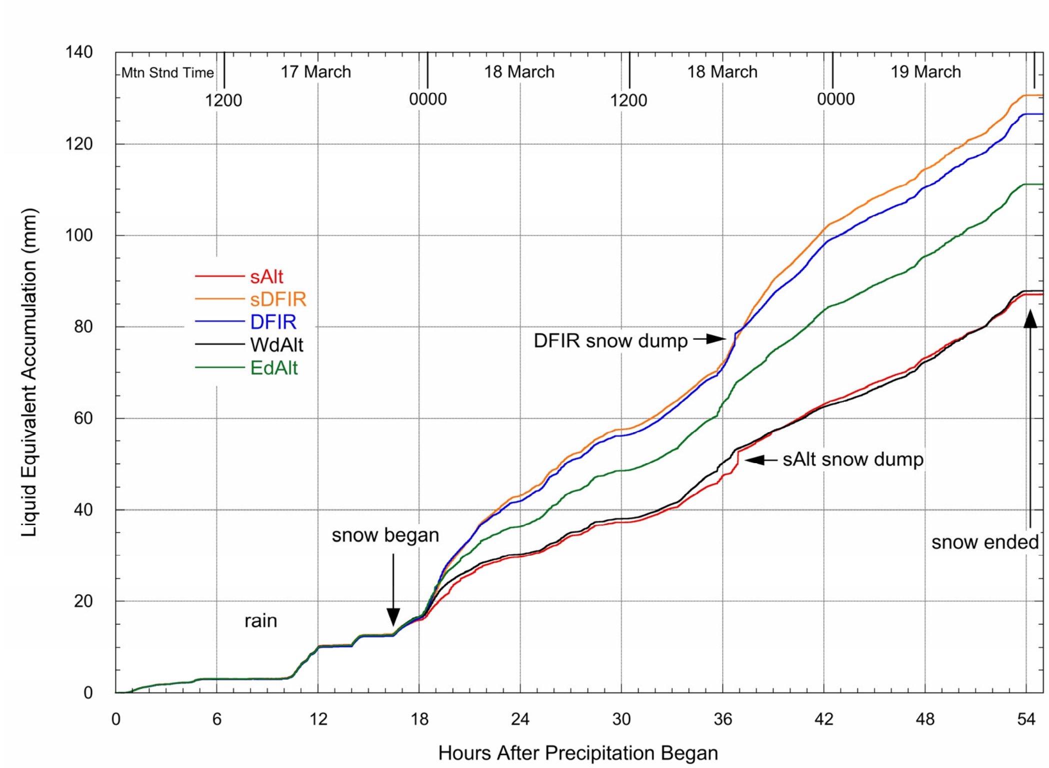


Figure 6. Rain and liquid equivalent snowfall accumulations from each of the five gauges.

## GAUGE HEATING

Figure 7 shows the 3 m air temperature and temperature of the orifice of the Geonor in the WdAlt. The latter temperature sensor is located 7.5 cm below the rim of the orifice. The two heating elements in each gauge were turned on when the orifice temperature of the Geonor in the WdAlt dropped below 0°C and turned off when the orifice temperature reached 1°C. It is clear, however, that overshoot occurred during much of the time. From hour 27 to about hour 36 there was sufficient solar heating and/or the air temperature was above freezing that no forced heating was required. Around sunset the air temperature dropped below 0 C resulting in, again, on-off heater cycling.

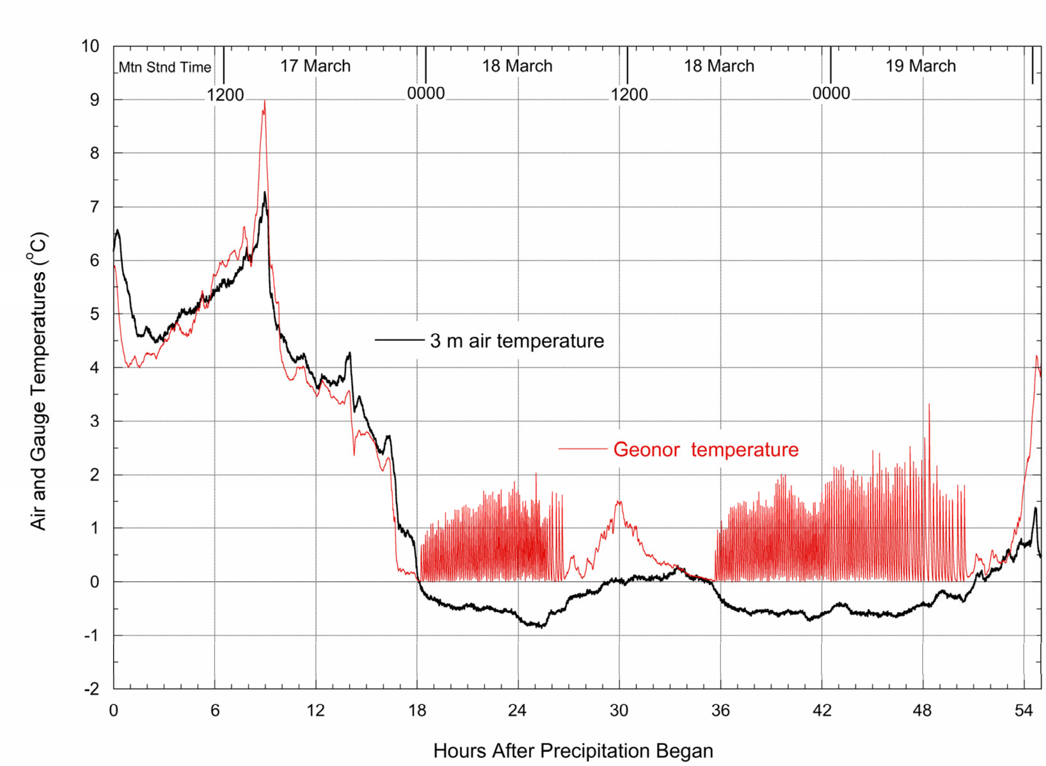


Figure 7. Air temperature at 3 meters and Geonor temperature in the WdAlt.

## RAIN AND SNOW RATES

Rain and liquid equivalent snow rates for the complete event are shown in Fig. 8. There were two periods of high snow rates, from about hour 18 to hour 21 and from about hour 36 to hour 39 as measured by the Geonor in the sDFIR. The maximum liquid equivalent snow rate was about 20 $mmh^{-1}$ during the first period and about 25 mm/h the second period. We can see that the second period of snowfall lasted only about one hour as measured by the Geonor in the DFIR. In fact, as seen in Fig. 6, only the sDFIR shows a three-hour period of high snow rate. There is no obvious explanation for the persistent high snow rate. Apart from hour 36 to hour 39, 1-minute liquid equivalent snow rates from the sDFIR and DFIR track each other quite well.

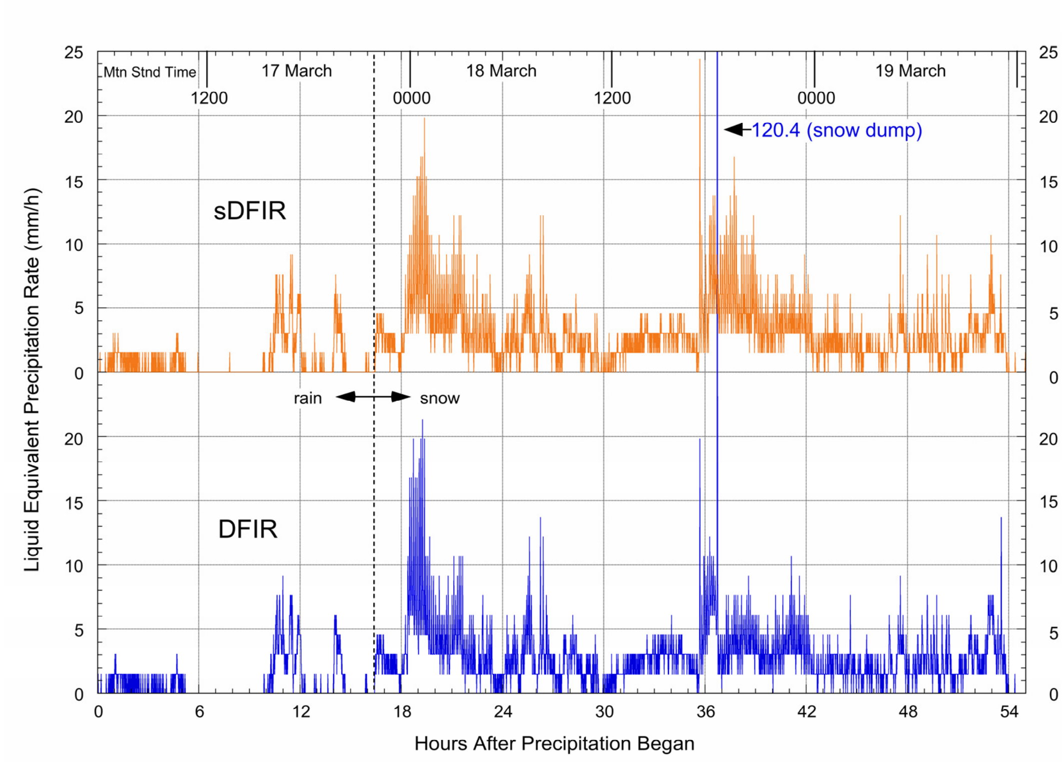


Figure 8. One-minute rain and snow rates (liquid equivalent precipitation) for the sDFIR and DFIR.

## PRECIPITATION RATE AND GAUGE TEMPERATURE

Figure 9 is a detailed look at a two-hour period of the relation between liquid equivalent snow rate in the DFIR and Geonor temperature in the WdAlt. We can see the strong systematic connection between these two variables. As the heating strip raises the temperature of the interior of the orifice above 0°C, the snow melts, and the associated precipitation rate increases sharply. When the heater is turned off (at about 1°C), the melting rate reaches its peak and begins to decline until the heater is turned back on and the cycle of heating – changing precipitation rate repeats itself. Thus the observed cyclical precipitation rate is more reflective of the melting rate as a consequence of gauge heating than the actual precipitation rate. The actual precipitation rate lies between the extremes in the apparent liquid equivalent precipitation rate.

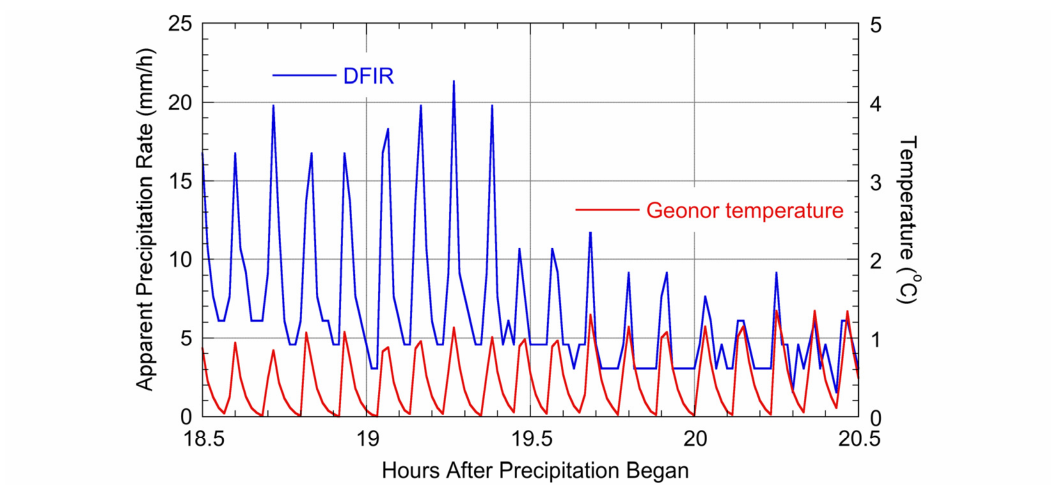


Figure 9. The relation between the DFIR liquid precipitation rate and Geonor temperature (WdAlt).

## WIND EFFECTS

The length of the snow event enabled us to examine the relative undercatch of different windshields as a function of wind speed. We selected the poorest windshield, namely, the sAlt windshield for comparison with the DFIR windshield. Thus Fig. 10 shows the reduction in snow accumulation from the single Alter (sAlt) windshield relative to the DFIR with increasing 3 m wind speed. The dots are ratios for 15-minute accumulations, the minimum accumulation time required to get a relatively stable estimate of the ratio. The natural variability is enhanced by the rise and fall of apparent precipitation rates in Fig. 9.

Although the R-squared value is low, there is an unmistakable average systematic decrease in catch from the sAlt with increasing wind speed. Wind speed is the primary cause of the decrease in accumulation of the two double Alter windshields (EdAlt and WdAlt) as well. Experience has shown there is a lot of scatter in this type of plot, and Fg. 10 is no exception.

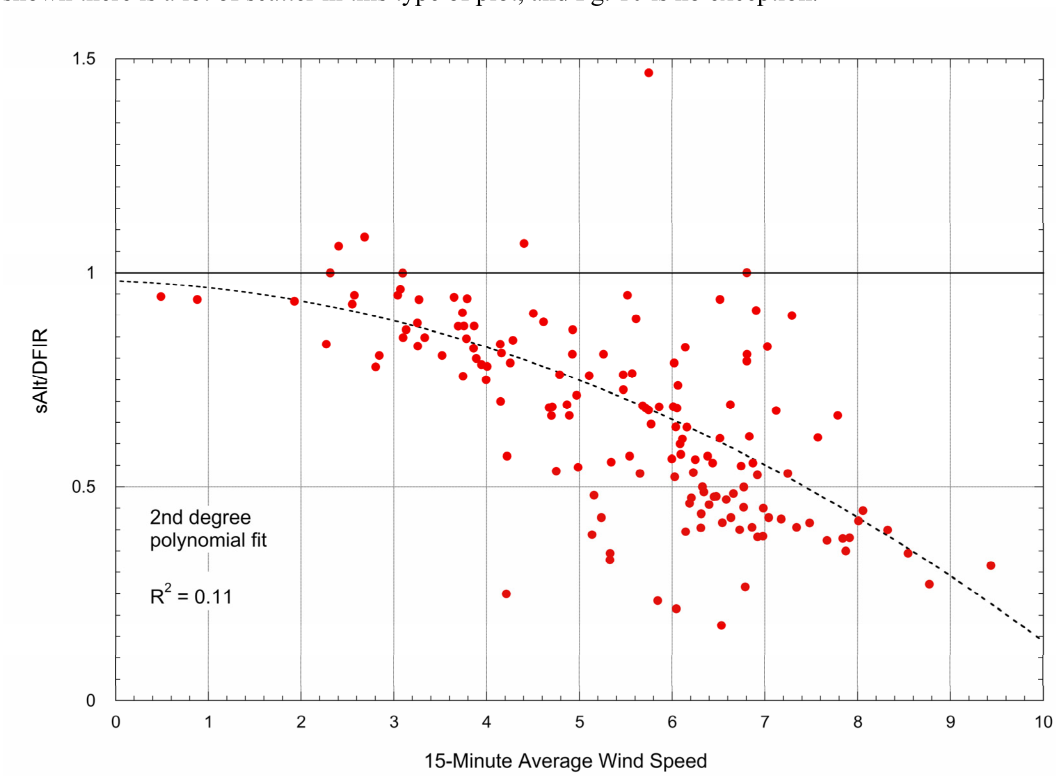


Figure 10. Reduction in snow accumulation from the single Alter (sAlt) windshield relative to the DFIR with increasing 3 meter wind speed.

## CONCLUSIONS

1. Accurately measuring snow accumulation continuous in time is difficult to do. The principal reason is that the catch is dependent on the design of the windshield in the way it responds to the speed of the wind.

2. An improved method of heating the gauge is needed. The current on-off system results in a cyclical apparent precipitation rate in concert with the heating cycle and associated melting.

3. There are aspects of this investigation that remain unexplained: the seemingly high precipitation rates associated with the small DFIR (sDFIR) after hour 37 in Fig. 8, and the

systematic difference in snow accumulation with time associated with the two double Alter windshields in Fig. 6.

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