OPTICAL SNOW PRECIPITATION GAUGE

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ABSTRACT

The most common quantitative measurement of falling snow is the precipitation rate. The time resolution of conventional mechanical snow gauges is poor, and their accuracy in measuring light snowfall is severely limited. An optical device designed to give an accurate instantaneous measurement of rain rate has been modified to operate in falling snow. Snow rates are inferred from statistical averages of intensity fluctuations caused by snow particles as they fall through a beam of light. Test results show that the optical device is extremely sensitive to light snowfall and may be a significant improvement over mechanical techniques to measure snow precipitation rates.

INTRODUCTION

The most common quantitative measurement of falling snow is the precipitation rate. This is usually measured by recording the snowfall that has accumulated over a period of time, using either the tipping-bucket or the weighing-type snow gauge. These mechanical gauges have poor time resolution, which can range from several minutes to over an hour, depending on the snowfall intensity. These gauges are inadequate for applications where short-term variations in snowfall rate are required. In addition, the ability of the mechanical gauges to accurately measure light snowfall is limited.

Many attempts to improve techniques for measuring snowfall rate have been reported. Lillesaeter (1965) and Warner and Gunn (1969) made transmission measurements and found the attenuation of a collimated light beam to be linearly related to the snowfall rate. Robertson (1973) also measured optical attenuation and found that the snowfall rate could be reliably measured if the snow crystal types were known. Berthel et al. (1983) and Lacombe (1984) used a sensitive electronic balance to weigh the snow in order to improve the time resolution for measuring snowfall rate. These optical attenuation and electronic balance techniques were successful to varying degrees; however, they were not suited for large-scale field deployment.

A new optical technique for measuring snowfall rate which may be suitable for field applications is under development. Instead of measuring optical attenuation, the statistical average of the light intensity fluctuations caused by snow particles as they fall through a beam of light is correlated with the snowfall rate. A field test was conducted to determine if this optical technique could provide a reliable measure of snowfall rate. This paper presents preliminary results comparing the snowfall rates measured with the new optical gauge and with other instruments capable of rapidly monitoring changes in snowfall intensity.

INSTRUMENTATION

Optical Snow Gauge

The optical snow gauge used in our study is shown in Figure 1. This instrument was originally designed to measure instantaneous rain rates (Wang et al., 1983); it has been slightly modified for operation in snowfall. The light source for the optical gauge is an infrared light-emitting diode which is partially collimated by a lens. At the receiver end, a narrow slit is located behind a convergent lens that focuses the infrared light on a photodetector. The sample area, which is defined by the width of the slit and the distance

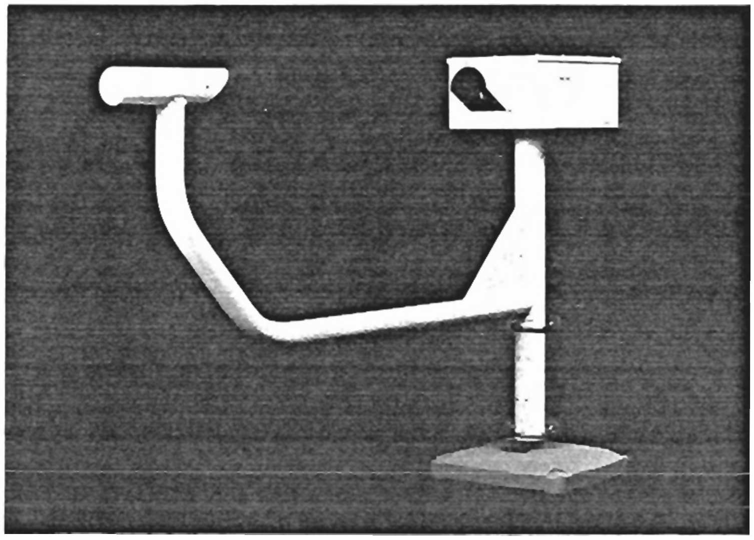


Figure 1. Optical snow gauge.

between the source and the receiver, measures approximately 290 cm^2. Snow particles falling through the sample area break the light beam and shadow the receiver to produce light intensity fluctuations. The fluctuating signals are then passed through a bandpass filter (75 - 900 Hz). Among the principal factors affecting the spectrum of the signal fluctuations are the size, shape and fall velocity of snow particles and the geometry of the optical beam. The output of the snow gauge is a slowly varying (0.1-Hz time constant) DC voltage that is proportional to the snow rate. The calibration factor that will give the optimum fit between the voltage output of the optical gauge and the snow rate has yet to be determined.

It is likely that the calibration factor will be dependent on the snow crystal type. If the difference in the calibration factor is significant, the signal in the bandwidth of 75 to 900 Hz can only provide an estimate of the snow rate. The optical gauge has been designed to provide additional information about the snowfall, which may be used to better determine the snowfall rate. In addition to the DC voltage output, the optical gauge generates pulses as the snow particles fall through the sample volume. These pulses can be counted to find the number flux of snow particles. The height of the pulses may be analyzed to provide a rough estimate of snow particle sizes. In addition, the frequency spectrum of the intensity fluctuations may provide information about the snow crystal type.

Rapid Response Precipitation Gauge

The Rapid Response Precipitation Gauge (RRPG) is a weighing type device that directly measures the snowfall rate. It was developed at the U.S. Army Cold Regions Research and Engineering Laboratory to meet the requirement for detailed measurements of snowfall rate. To improve the time resolution an electronic balance is used to weigh the snow. A simplified cross-sectional representation of the system is shown in Figure 2.

Snow falls through an 8-inch-diameter opening and is collected in a pan containing an ethylene-glycol solution. The pan is supported by a precision electronic balance within a heated enclosure. A signal corresponding to the cumulative weight supported by the balance is continuously transmitted via an RS232 interface. Once every minute, a motor is activated which slides a door over the collection opening. This action prevents further loading of the balance by winds and precipitation. The balance is supported independently from the system's external housing to isolate it from vibrations generated by the motor and drive assembly. A few seconds are allowed to elapse after the door has closed, to provide time for the balance reading to settle. Output from the balance is then recorded and the door reopened for further sampling.

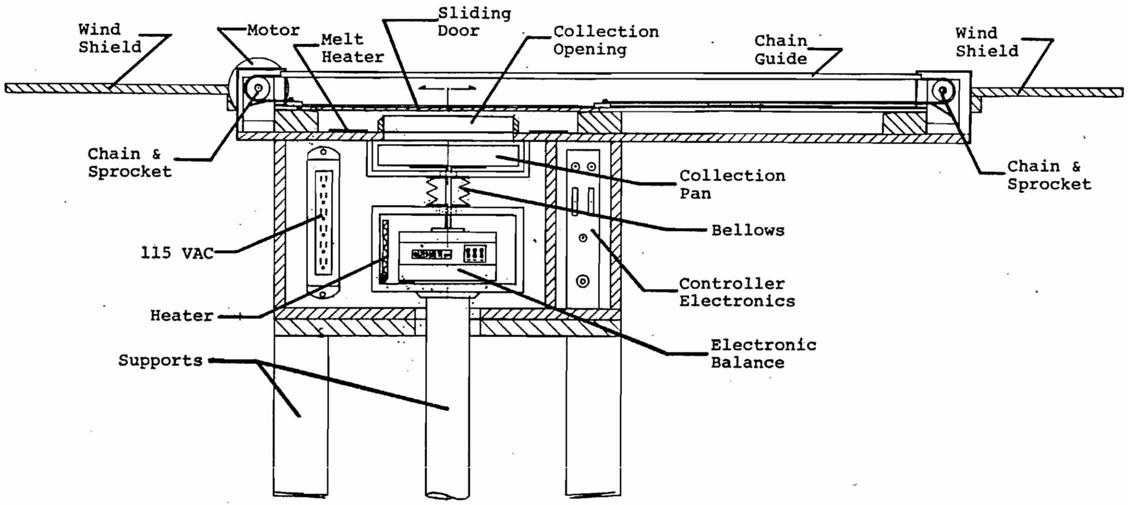


Figure 2. A cross-sectional representation of a snow gauge using an electronic balance (Rapid Response Precipitation Gauge).

The effective sampling time for each precipitation reading is 47 seconds. System resolution is 0.024 mm/hr of equivalent water, and system accuracy (although not well defined) is within 0.07 mm/hr.

Airborne Snow Concentration Measuring Equipment

Another instrument capable of rapidly monitoring changes in snowfall intensity is the Airborne Snow Concentration Measuring Equipment (ASCME), which is shown in Figure 3. The ASCME is designed to measure the amount of snow per unit volume of air. The concept for measuring snow concentration was pioneered by Stallabrass (1976) and later improved by Lacombe (1982). The ASCME operates in the following manner. A collection head mounted on an arm rotating in a horizontal plane sweeps a known volume of air, and the air/snow mixture enters the collection orifice. The snow particles are then separated from the air and melted by an electric heater. The water is then forced centrifugally through a machined needle, producing equal-sized droplets. These droplets are photoelectrically counted, from which the mass concentration can be readily obtained.

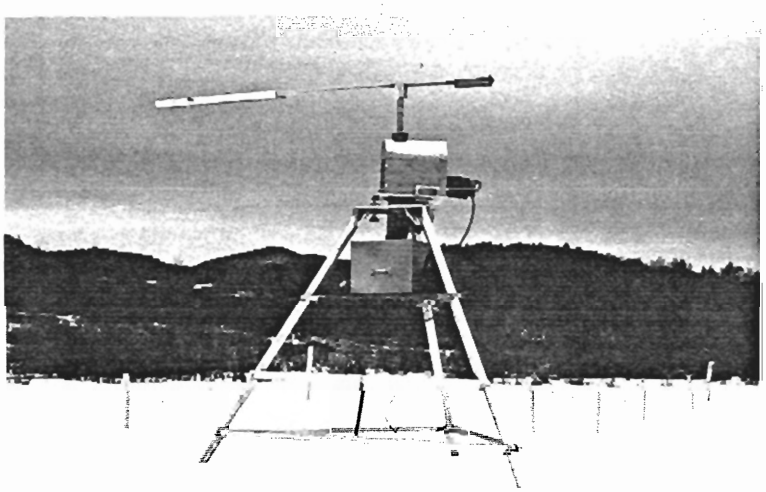


Figure 3. Instrument to measure snow mass concentration (Airborne Snow Concentration Measuring Equipment).

Transmissometer

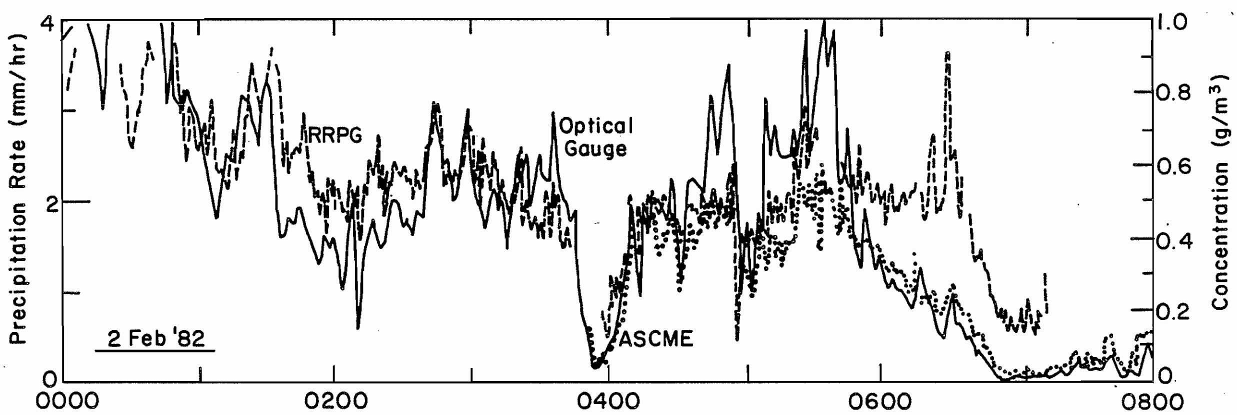
In addition to measurement of the snow precipitation rate and mass concentration using the instruments described above, transmission in the visible wavelength over a 400-m path was measured. Since transmission is affected by the size and number of snow particles, it is an indirect measure of snowfall rate. The transmissometer consisted of a transmitter and a receiver, each using a 0.9-m f/5.5 Newtonian telescope. The field of view of the receiver is 5 mrad.

RESULTS AND DISCUSSION

The results obtained using the above-mentioned instruments are compared for two snowstorms that occurred during February 1986 in southern Maine. In this preliminary analysis of the results, only the DC voltage output from the optical gauge is considered. The relationship between the DC voltage and the snow rate was assumed to be

$$\text{snow rate} = 10^{(V_{out} - 1.5)} \times 0.1 \text{ mm/hr} ,$$

where V_{out} is in volts and snow rate is in mm/hr. This calibration was somewhat arbitrary; after more data are accumulated, a regression analysis should yield a better fit.



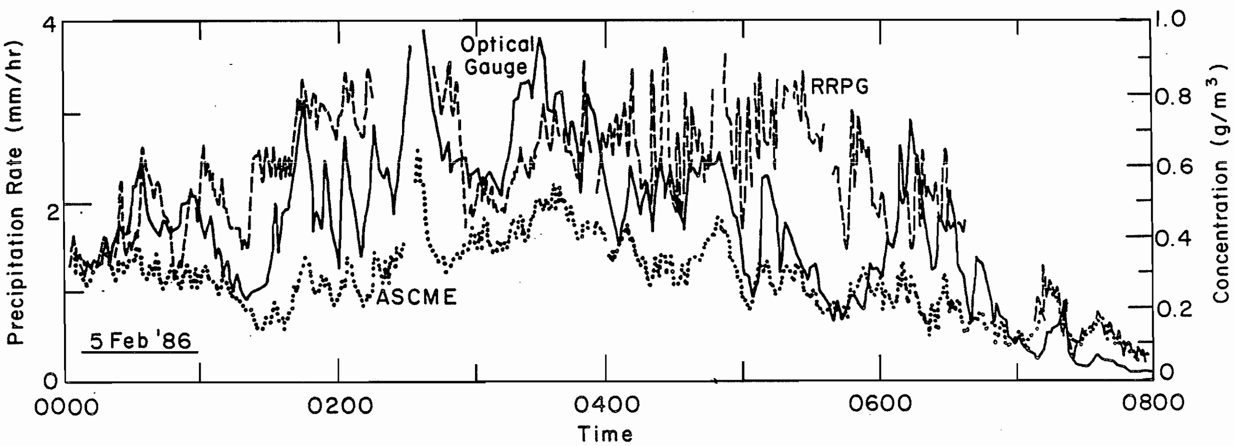


Figure 4. Snow precipitation rates (mm/hr) and mass concentration (g/m^3) for two snowstorms. The solid, dashed and dotted lines represent the results from the optical gauge, Rapid Response Precipitation Gauge, and Airborne Snow Concentration Measuring Equipment, respectively.

Figures 4a and 4b illustrate the snowfall rates measured with the optical gauge and RRPG, and the snow mass concentration measured with the ASCME. The solid and dashed lines represent the snowfall rates measured with the optical gauge and RRPG, respectively. There is general agreement between the optical gauge and RRPG for most of the February 2 snowstorm. However, a notable difference is observed near the end of the storm between 0600 and 0800 hours. The agreement between the two gauges during the February 5 snowstorm is again reasonable, with the exception of the time period between 0500 and 0600 hours.

The relationship between precipitation rate and mass concentration can be determined if the mass and fall velocity of the snow particles are known. Since these properties of snow particles are not routinely measured, the precise relationship between precipitation rate and mass concentration for a particular snowfall event is difficult to determine. However, a comparison of the mass concentration and precipitation rates, as illustrated in Figures 4a and 4b, shows a qualitative agreement between the ASCME and the precipitation gauges.

The transmission data and the snowfall rate measurements are compared in Figures 5a and 5b. The transmission data track the snowfall rates rather consistently. The relationship between light attenuation and snowfall rate was not determined. However, one can expect some discrepancy since the cross-sectional area per unit mass will be different for various snow crystal types. It is also pointed out that the presence of other aerosols, such as fog, will affect the relationship between the light attenuation and the snowfall rate.

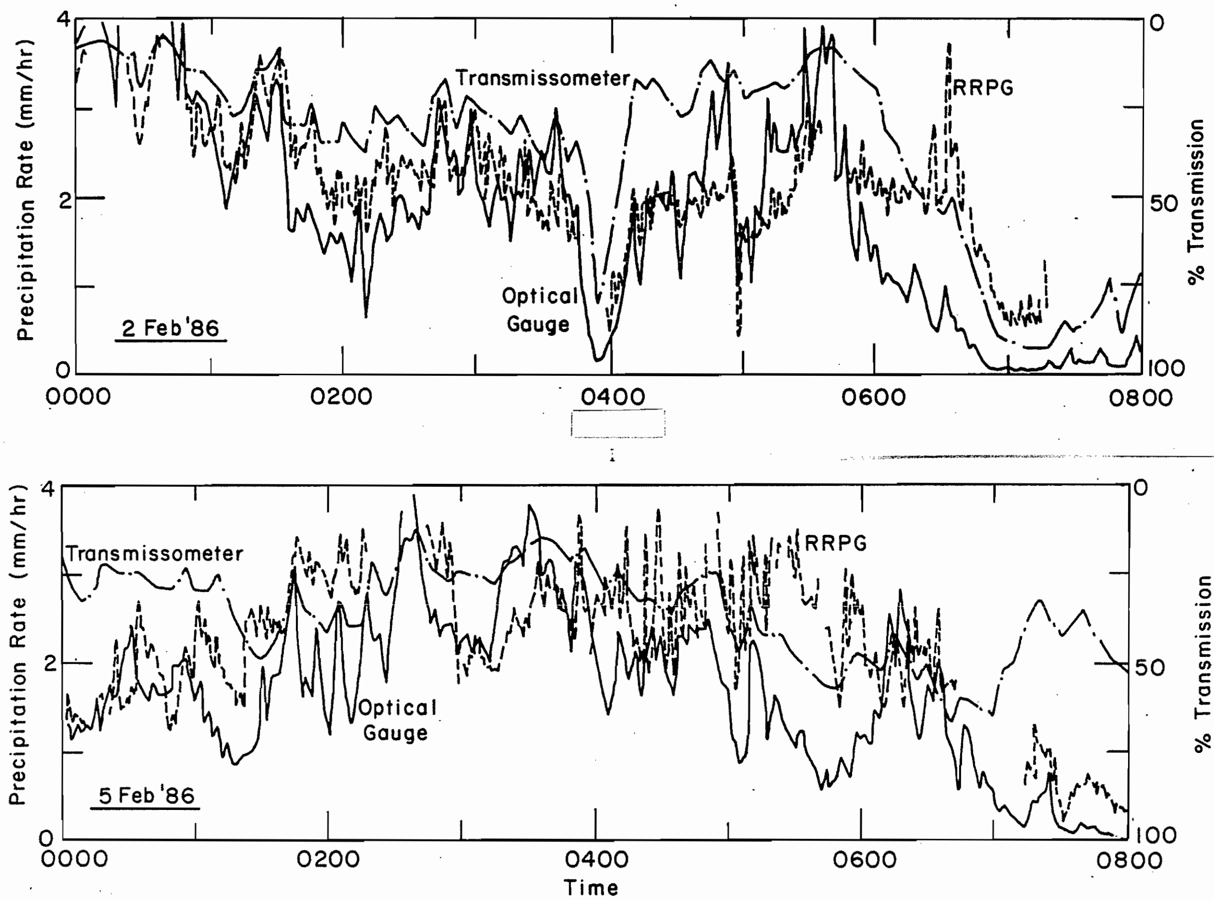


Figure 5. Snow precipitation rates and transmission data for two snowstorms.

A cursory examination of the data indicates that the optical gauge may be used to rapidly measure the snow rate. The optical gauge has features and capabilities which offer distinct advantages over conventional methods. Among these are better time resolution, wider measurement dynamic range and less required maintenance. The wider dyanmic range of the optical gauge was apparent during periods of light snow. On several occasions the optical gauge was the only instrument that was able to detect light snow. The minimal maintenance requirement makes the optical technique ideal for use in unattended applications. The accuracy of measurement of the optical snow gauge is still unresolved. More tests are required to compare the optical gauge with other direct methods of measuring snowfall rate under a wide range of snowfall conditions.

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