An Attempt to Calculate Snowfall Intensity at Times of Strong Winds : Comparison Observation of a DFIR and Precipitation Gauges

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1. Introduction

In designing blowing-snow control facilities such as snow fences, the snowdrift transport rate is an important index. To mitigate snowstorm damage, it is necessary to quantitatively measure the intensity of blowing snow. The snowdrift transport rate is the amount of snow that passes a unit width perpendicular to the wind direction per unit time. The snow that is measured for the snowdrift transport rate consists of falling snow particles and blowing snow particles resuspended by strong wind. Direct and continuous measurement of the snow transport rate is difficult. So, many researchers have proposed empirical equations for that rate. However, these empirical equations only cover resuspended snow particles. It does not include falling snow particles. This is because it is difficult to accurately measure snowfall when strong winds are blowing.

In this study, to calculate the accurate snowfall intensity at times of strong winds, snowfall observation using the Double Fence Intercomparison Reference (DFIR) was done. The DFIR is a precipitation gauge that is specified by the World Meteorological Organization (WMO) as secondary standard equipment. By using the DFIR, it is possible to obtain snowfall measurements that are closer to true values than those measured by conventional techniques. In this report, a common technique for observing snowfall and its problems will be explained, and the results of comparison between the common technique and the DFIR observation will be shown.

2. Common techniques for measuring snowfall, and their limitations

Measurements of snowfall amount and snowfall intensity are common techniques for determining the physical quantity of snowfall. Snowfall amount is defined as the depth of snow that accumulates in a given period of time. The Japan Meteorological Agency (JMA) defines an hour's snowfall as the change in snow depth measured by snow depth meter every hour. According to this system, 'no snowfall' is recorded when fresh snow is blown away by strong winds or when the snow depth does not increase due to densification of the snow pack. The snowfall intensity is defined as the water depth equivalent to the weight of snow falling in a unit area per unit time. The meteorological observation station in Japan use mainly three types of precipitation gauges for precipitation observation;

(i): Tipping bucket precipitation gauge (without wind guard)

(ii): Heated tipping bucket precipitation gauge (without wind guard) (iii): Overflow precipitation gauge (with wind guard)

Each of these types has a funnel diameter of 20 cm. The precipitation gauges used for the Automated Meteorological Data Acquisition System (AMeDAS) stations of the JMA in Hokkaido are all heated tipping bucket precipitation gauge equipped with wind guard (hereinafter: the Hokkaido type gauge). The exterior of the Hokkaido type gauge and a diagram that shows the internal structure of the gauge are shown in Figure 1 and Figure 2. The diameter of the wind guard is 50 cm. The Hokkaido type gauge is equipped to melt snow (i.e., antifreeze liquid heated by a heater is used in the equipment). The snow particles fall into the funnel are melted. The water is collected in the tipping bucket, and the precipitation is calculated from the number of tips made by the bucket (it tips every 0.5 mm of precipitation). However, measurement error occurs because not all the snow particles that fall above the funnel are collected into the funnel.

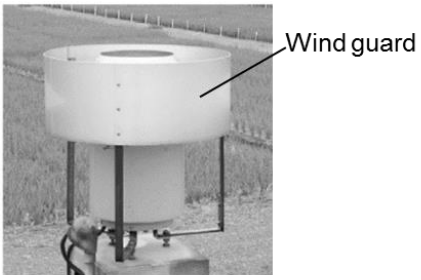

Figure 1 Heated tipping bucket precipitation gauge with wind guard (Hokkaido type gauge)

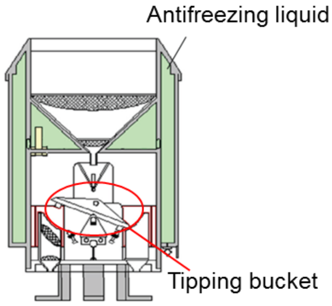

Figure 2 Internal structure of the Heated tipping bucket precipitation gauge

Many research institutions have been trying to bring the values measured by various types of precipitation gauges closer to the true values. A major example of such efforts is the Solid Precipitation Measurement Intercomparison Project, which was conducted by the WMO from 1986 to 1993. This project found that the snow particle catch ratio of the precipitation gauge decreased with increase in wind speed. It was reported that the catch ratio was 70% when the gauge was equipped with a wind guard and that it was only 20% when the gauge was not equipped with a wind guard (at the wind speed of 6m/s and air temperature of −2℃)[1]. Other than the wind speed, factors contributing to error are the catch loss caused by disturbance in airflow, wetting loss from wetting the inside of the funnel (2 to 10%), and evaporation loss from evaporation before the measurement (0 to 4%). As described above, measurements of snowfall amount and snowfall intensity involve various measurement errors. Therefore, obtaining accurate values in direct observation is difficult.

3. Outline of the DFIR

The device that allows us to measure snowfall amount and snowfall intensity as closely as possible to the true values is the BUSH Gauge. This gauge consists of a precipitation gauge installed at the center of an artificial bush. The rim of the funnel on the gauge is kept at the height of the top surface of the "bush" around the gauge. However, the BUSH Gauge requires about 3 hectares of land to install, and maintenance of the gauge is labor-intensive. Therefore, the WMO specifies the DFIR as secondary standard equipment that substitutes for the BUSH Gauge. The WMO considers that the values measured by using a DFIR and converted by using the equation provided by the Goodison *et al.* [1)] are close to the true values measured by using the BUSH Gauge. Figure 3 shows the exterior of the DFIR, and Figure 4 shows the plan view of the DFIR.

Figure 3　Exterior of DFIR

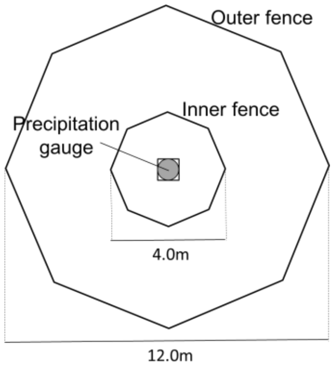

Figure 4　Plan view of DFIR

The DFIR consists of two regular octagonal wind break fences of different sizes (the diagonal length of the outer fence is 12.0 m and that of the inner fence is 4.0 m). The outer and inner fences are made of boards 1.5 m in height. The void ratio of the fence is 50%. A precipitation gauge (GEONOR CGR-T-200B series) is installed at the center of the area surrounded by the two fences. The height of the precipitation gauge is equal to the rim of the fence. The precipitation collected in this gauge are weighed with a vibrating wire load sensor, which gives a frequency output. The amount of precipitation can be computed from these outputs. The value measured by using the DFIR M_{dfir} is converted to the BUSH Gauge value (regarded as the true value) by using Equation (1) when the measured precipitation is snowfall, and is converted to the BUSH Gauge value by using Equation (2) when the measured precipitation is sleet (mix of snowfall and rainfall). The WMO specifies that, in the case of rainfall-only precipitation, the DFIR measurement does not need to be converted to the BUSH Gauge value. Where, *Ws* (m/s) is the wind speed at the height of the precipitation gauge.

Equation (1) :

$$True\ value = (100 + 0.439 \times Ws + 0.246 \times Ws^2) \times 0.01 \times M_{dfir}$$

Equation (2) :

$$True\ value = (100 + 0.194 \times Ws + 0.222 \times Ws^2) \times 0.01 \times M_{dfir}$$

4. Outline of observation and the result

The snowfall observation values obtained by using each of three precipitation gauges commonly used in Japan ((i) - (iii)) and the values measured by using the DFIR were compared by Yokoyama *et al.* [2)] and Shiraki [3)]. These previous studies proposed relational equations for the catch ratio of snow particles and the wind speed that can be applied to measurements from precipitation gauges. However, these studies by Yokoyama *et al.* and Shiraki had not conducted comparative observations using the Hokkaido type gauge (as shown at Figure 1 and Figure 2). In addition, there are not so many observation data under strong wind condition.

In this study, we conducted comparative observations by using the DFIR and the Hokkaido type gauge focusing on the strong winds. The observations were done at the Ishikari Blowing Snow Test Field of the Civil Engineering Research Institute for Cold Region (N 43°12', E141°23') from January 23 to February 28, 2015. Figure 5 shows the location of this test field. The prevailing wind direction at the Ishikari Blowing Snow Test Field is northwest, and this field frequently have blowing snow.

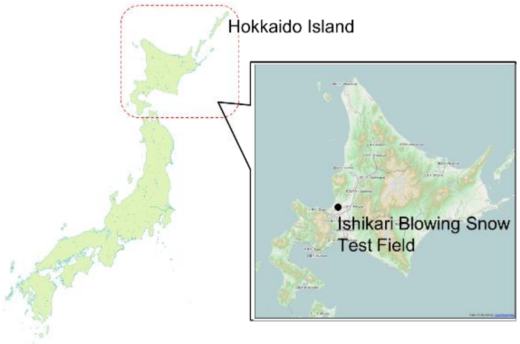

Figure 5 Location of Ishikari Blowing Snow Test Field

Figure 6 shows the results for a comparison of cumulative precipitation from January 23 to February 28, 2015. The values measured by the Hokkaido type gauge are about 50% of the true value determined by converting the values measured by the DFIR. Next, the relationship between the catch ratio and the wind speed was compared for each snowfall event. The cases extracted for the comparison were those that had 1.5 mm or higher precipitation in a series of snowfall events for measurements using the DFIR and measurements using the Hokkaido type gauge. The end of a continuous snowfall event was defined as the cessation of precipitation for one hour as recorded by DFIR. Based on the above criteria, a total of 9 snowfall events were extracted from the period from January 23 to February 28, 2015. The shortest continuous snowfall event lasted about an hour, and the longest lasted about 12 hours. The wind speed of a continuous snowfall event was defined as the weighted average of wind speed for each 10 minutes during that snowfall event. The precipitation for the 10 minutes was used as a weight. The catch ratio was determined by dividing the measured value by the precipitation obtained by using the conversion equation (the true value). The relationship between

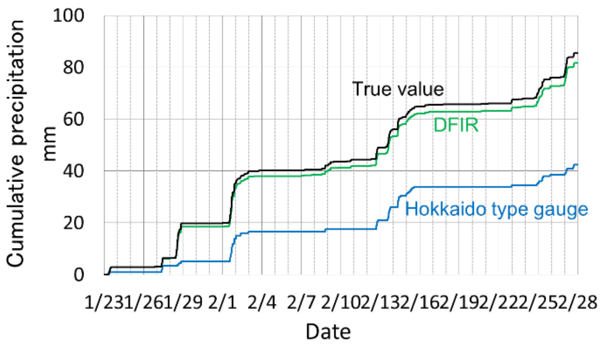

Figure 6 cumulative precipitation

(January 23 to February 28, 2015)

the catch ratio and the wind speed is shown in Figure 7. The comparison observation found that the catch ratio decreased with increase in wind speed, which was similar to the results of previous researches. In Figure 7, the regression curve obtained from our measurements is shown as a solid line, and the correction equation for catch loss is also shown. This equation was obtained by regressively fitting our results to the empirical equation obtained by Yoshida [4], which was similar to the technique used by Yokoyama *et al*. The regression curves presented by Yokoyama *et al.* are also shown in the Figure 7 as a dotted line for (i), as a dashed line for (ii) and as a chain line for (iii). Where, *CR* is the catch ratio, *U* is the mean wind speed (m/s) at the height of precipitation gauge.

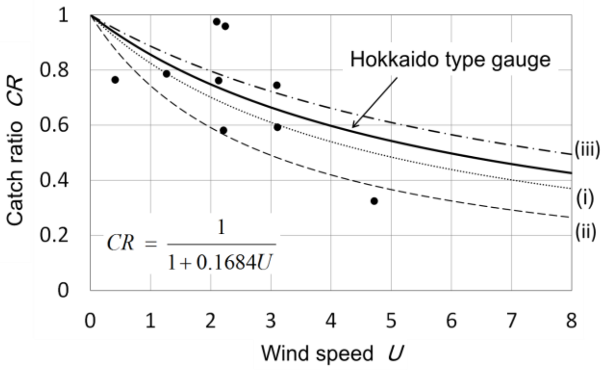

Figure 7 Relationship of catch ratio and wind speed

5. Conclusion

This report explained common snowfall observation methods and their limitations. We conducted a comparison observation using a heated tipping bucket precipitation gauge with a wind guard (Hokkaido type gauge) and a DFIR. The comparison study demonstrated that the cumulative snowfall measured by using the Hokkaido type gauge underestimated the true value, which was obtained by converting the DFIR value, and that the Hokkaido type gauge showed about 50% of the true value. When the precipitations were compared for each snowfall event, it was found that the snow particle catch ratio of the Hokkaido type gauge decreases with increase in wind speed. We will continue to collect and analyze observation data, and make efforts to calculate snowfall intensity with higher accuracy.

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