

Systematic error aspects of gauge-measured solid precipitation in the Arctic, Barrow, Alaska

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[1] This report provides insight into systematic errors of gauge-measured precipitation in the Arctic by the precipitation gauge intercomparison experiment at Barrow, Alaska. Reference gauges and various national standard gauges used in the Arctic regions were installed. The bias of trace precipitation was recorded with high frequency and varied widely from 6 to 130% increase of the gauge-measured amounts due to a variety of gauge types. The blowing snow experiment showed that the number flux of aeolian snow particles at a gauge orifice height verily increased with the occurrence of blowing snow, and it seems reasonable to suppose that blowing snow particles are an overestimation bias of gauge-measured precipitation. These suggest that the systematic errors of gauge-measured precipitation for Arctic conditions must mainly take into consideration of not only wind-induced undercatch, wetting and evaporation losses, but also the influence of blowing snow and trace precipitation loss. *INDEX TERMS*: 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 1833 Hydrology: Hydroclimatology; 1655 Global Change: Water cycles (1836); 1827 Hydrology: Glaciology (1863); 9315 Information Related to Geographic Region: Arctic region. **Citation**: Sugiura, K., D. Yang, and T. Ohata, Systematic error aspects of gauge-measured solid precipitation in the Arctic, Barrow, Alaska, *Geophys. Res. Lett.*, 30(4), 1192, doi:10.1029/2002GL015547, 2003.

1. Introduction

[2] Precipitation is all liquid and solid products of water that are deposited from the atmosphere on the ground, and is generally caught by precipitation gauges at a point. If a spatial scale looking for is expanded, it is effective that many precipitation gauges are installed in the area or precipitation of the area is estimated using radar. Further, in the case that precipitation is expanded to a grid scale, the estimation using satellites is effective. Since the amount of precipitation using radar and satellites is necessary to compare with that of precipitation gauges, the precipitation measured by the precipitation gauges is fundamental and important values.

[3] However, it has been recognized widely so far that gauge-measured precipitation has systematic errors mainly

caused by wind-induced undercatch, wetting and evaporation losses and that the error of snowfall observation in high wind speeds is very large. Since many types of precipitation gauges are used in the world at present [Sevruk and Klemm, 1989], the different types are measuring different precipitation amounts, respectively [e.g., Goodison *et al.*, 1981]. From a viewpoint of accurate precipitation data set for better understanding of the water cycle and providing them to the modeling activities, we should not neglect this scientific issue.

[4] In order to test the performance of precipitation gauges and to adjust the precipitation measurements, the World Meteorological Organization (WMO) initiated international precipitation measurement intercomparisons (1: Precipitation 1960–1975, 2: Rain 1972–1976, 3: Snow 1986–1993) [Goodison *et al.*, 1998]. Although adjustment procedures and reference measurements have been developed [Goodison *et al.*, 1998; Mekis and Hogg, 1999; Yang, 1999; Yang *et al.*, 1998, 1999, 2000; Yang and Ohata, 2001], the results of the WMO precipitation measurement intercomparisons have not been fully tested in Arctic conditions. Since the Arctic climate for precipitation is special conditions (cold, generally low precipitation and high winds), it is necessary to pay special attention to the systematic errors of gauge-measured precipitation. It is required that an intercomparison experiment should be conducted to test and assess further the existing bias correction procedures of the national precipitation gauges commonly used at Arctic locations in Arctic regions.

[5] The Frontier Observational Research System for Global Change (FORSGC) and the Water and Environmental Research Center, University of Alaska Fairbanks (UAF) carried out an intercomparison experiment of precipitation gauges in high latitude regions of high winds. A solid precipitation measurement intercomparison experiment has been started in 2000 at Barrow, Alaska. This paper tries to provide insight into systematic errors of gauge-measured precipitation in the Arctic by the precipitation gauge intercomparison experiment.

2. Methods

[6] In 2000, a field site inspection was carried out in the Arctic regions, and a field site was selected on the various conditions such as geographical features, meteorological

information and facilities. A study of solid precipitation measurement intercomparison was set up in the Arctic at Barrow, Alaska, at the NOAA/CMDL site (71.323°N, 156.609°W).

[7] To measure true snowfall amount, we installed a Double Fence Intercomparison Reference (DFIR) that has double octagonal lath-fences and a Russian Tretyakov gauge with a windshield is within the fences. The diameter is 4 and 12 m and the heights are 3 and 3.5 m from the ground. The third international intercomparison of WMO decided to use the DFIR as an international reference standard [Goodison *et al.*, 1998].

[8] Wyoming gauge system consisting of two octagonal windshields called the Wyoming shield is a US reference gauge for snowfall observations, and has been widely used in the United States, particularly in Alaska [Yang *et al.*, 2000]. The Wyoming gauge system installed at the site has a Russian Tretyakov gauge without a windshield within the Wyoming shield.

[9] Other national standard gauges currently used in Arctic regions were installed for test, such as a Canadian Nipher gauge, a Hellmann gauge, a NOAA II gauge, a Russian Tretyakov gauge and a US 8" gauge. The Canadian Nipher gauge is a Canada standard gauge for snowfall observations. The Hellmann gauge is for Greenland, Denmark and Germany. The Russian Tretyakov gauge is a Russian standard gauge, also used in Mongolia. The US 8" gauge is a US standard gauge.

[10] The buckets of the DFIR, the Wyoming gauge system, the Canadian Nipher gauge, the Hellmann gauge, the Russian Tretyakov gauge and the US 8" gauge are replaced respectively, the collected precipitation in the buckets is drained into the measuring glasses respectively, and the amount of precipitation is measured respectively. On the other hand, the NOAA II gauge automatically measures the collected precipitation in the bucket. The bucket orifice height of the Canadian Nipher gauge, the Hellmann gauge, the Russian Tretyakov gauge and the US 8" gauge is 2 m above the ground, and the NOAA II gauge is 1 m above the ground.

[11] A snow particle counter system (SPC-S7 special version, Niigata Electric.) was introduced for trying to investigate the blowing snow effect on the actual precipitation measurements. The snow particle counter has a laser diode, a sampling area of 2 mm × 25 mm, electric pulse signals of snow particles passing through the sampling area are sent to an analyzing logger, and snow mass fluxes at different particle diameters are estimated [Sugiura *et al.*, 1998]. To introduce the snow particle counter in the Arctic enables us to make precise analysis of snowfall. The snow particle counter system was installed in the observation site for selected blowing snow observations. The number flux of aeolian snow particles, that is the number of aeolian snow

Table 1. Collected Precipitation Events Up to the End of March 2002

Gauge	Event	Rainfall case	Snowfall case
DFIR	63	0	63
Wyoming	69	3	66
Canadian Nipher	20	0	20
Hellmann	50	3	47
Russian Tretyakov	69	3	66
US8"	64	3	61

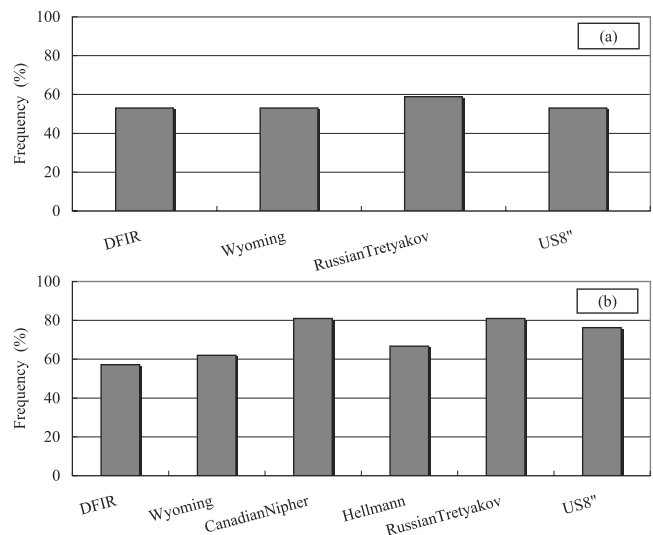


Figure 1. Frequency of trace precipitation at the site, Barrow, Alaska, during (a) Nov 23–Dec 10, 2001, (b) Feb 10–Mar 3, 2002.

particles per second per area, was measured every three minutes at several heights.

[12] Furthermore, an automatic weather station was installed at the site to measure weather conditions, such as wind speed, air temperature and relative humidity.

3. Results

[13] To begin with, several gauges have been installed since March 2001. After that, several gauges have begun to be installed, respectively. Table 1 shows collected precipitation events in collected precipitation data up to the end of March 2002, roughly one year after a start of gauge-measured solid precipitation intercomparison at Barrow, Alaska. These event data were sometimes total accumulation of several precipitation events, as the gauges were not emptied at a fixed time.

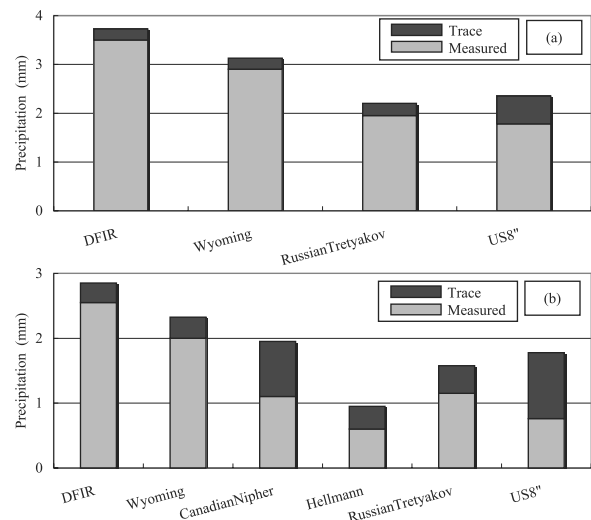


Figure 2. Sum of the daily gauge-measured precipitation and the bias-correction at the site, Barrow, Alaska, during (a) Nov 23–Dec 10, 2001, (b) Feb 10–Mar 3, 2002.

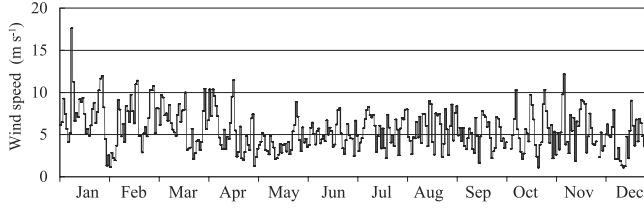


Figure 3. Daily wind speeds at the national standard height 10 m at the site, Barrow, Alaska, Jan 1–Dec 31, 2001.

3.1. Trace Precipitation

[14] Trace precipitation is less than a measurable amount of precipitation in the gauge. Figure 1 shows the frequency of trace precipitation during some observed periods. The frequency of trace precipitation, F_{trace} , is given as

$$F_{trace} = \frac{N_{trace}}{N_{total}} \times 100 \quad (1)$$

where N_{trace} is the number of trace precipitation days and N_{total} is of total precipitation event days. The periods in Figure 1 are some of obtained daily data, and during the periods the precipitation gauges were replaced every day at an appointed time. It was shown that the trace precipitation frequency of Nov 23–Dec 10, 2001, was around 50% and that of Feb 10–Mar 3, 2002, was over 50%. Since trace precipitation was confirmed, trace amounts must be considered as non-zero value. It is important to note that trace precipitation based on daily measurements at this site, the Arctic regions, is recorded in all gauges with high frequency.

[15] Given the amount of trace precipitation, we are now able to correct the total precipitation. As stated above, trace precipitation means less than a measurable amount of precipitation in the gauge. Each recorded precipitation is measured using own measuring glass, and measuring-glass digits are various. A digit is 0.1 mm for the DFIR, the Wyoming, the Hellmann and the Russian Tretyakov, 0.2 mm for the Canadian Nipher, and 0.01 inch for the US 8". Since it may be measurable in the case of half of a measuring-glass digit, to be conservative the amount of trace precipitation was corrected as a quarter of a digit in this study. Daily trace correction depends on gauge types, that is measuring-glass digits. Figure 2 presents the sum of the daily gauge-measured precipitation and the bias-correction during Nov 23–Dec 10, 2001 and Feb 10–Mar 3, 2002. Since the period in Figures 2 and 1 is the same and short, the sum of the daily gauge-measured precipitation is small and is ranging from 0.6 to 3.5 mm, with the minimum in the Hellmann and the maximum in the DFIR. Correction for trace varied from 1 to 0.2 mm, or 6 to 130% increase of the gauge-measured amounts and was more effective for the Canadian and the US 8" due to high frequency of trace precipitation and large measuring-glass digits (0.2 mm and 0.254 mm). These results suggest that it is necessary to re-review our understanding of the Arctic hydrological cycle mechanism obtained on the basis of the gauge-measured precipitation.

3.2. Blowing Snow

[16] Golubev and Simonenko dealt with account of false precipitation due to general and land blizzards in the WMO Solid Precipitation Measurement Intercomparison Final

Report [Goodison *et al.*, 1998] and described that false precipitation due to the general blizzard might be caught by the precipitation gauge during snowfalls at the wind speeds higher than 4.2 m s^{-1} . Thus, to investigate the frequency of blowing snow, Figure 3 shows wind speed at the national standard height (10 m) at the site, Barrow, Alaska. It is shown that this area is windy throughout the year, and wind speed over 17 m s^{-1} in winter was measured. Therefore, it seems that blowing snow occurs often. Here, for example, is the data of number fluxes of aeolian snow particles obtained at observation site in a clear sky, as shown in Figure 4. It shows that the number flux of larger particles, in contrast to that of smaller particles, decreased with increase in height, and disappeared. This indicates that the types of motions of snow particles transit from saltation to suspension. It is clear that snow particles could reach higher point near the bucket orifice height, and nearly four millions of snow particles per second per area were blown over this flat snowfield at a 2 m height.

[17] The procedure for an estimate of the intensity of falling snow particles, $I_{falling-z}$, is given by

$$I_{falling-z} = \frac{\sum_d N_{d-z} \frac{4}{3} \pi \left(\frac{d}{2}\right)^3 \rho_{particle}}{V_{blowing-z} \rho_{particle}} V_{falling} \quad (2)$$

where N_{d-z} is the number flux of diameter d at a height of z , $\rho_{particle}$ is the density of snow particle assumed to be 917 kg m^{-3} , $V_{blowing-z}$ is the horizontal snow particle speed assumed to be horizontal wind speed at a height of z , and $V_{falling}$ is the falling snow particle speed assumed to be

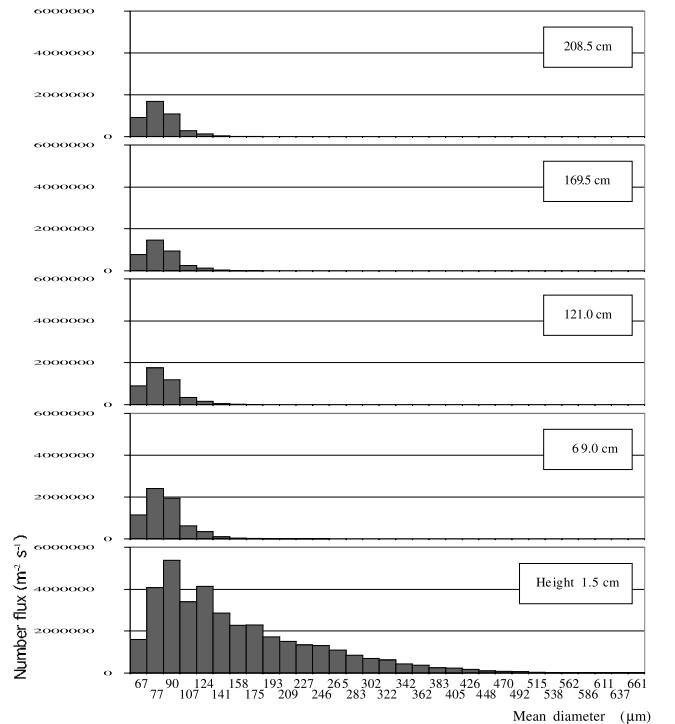


Figure 4. Example of the number flux profile of aeolian snow particles in a clear sky at the site (12:17–12:37 AKST, March 15, 2001). Mean wind speed of 7.3 m s^{-1} at a 2.5 m height. Mean air temperature of -25.2 at a 2.5 m height.

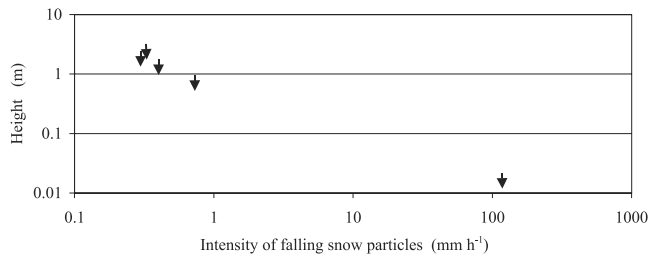


Figure 5. Estimated intensity of falling snow particles using the data of Figure 4.

0.5 m s^{-1} as the mean value according to *Takahashi et al.* [1984]. Estimated values using the data of Figure 4 are plotted in Figure 5. The estimated intensity is increasing with decreasing height, because blowing snow occurs due to strong wind. If no wind, the intensity is a constant. Therefore, we see from this figure that blowing snow affects true precipitation. It seems reasonable to suppose that blowing snow particles are an overestimation bias of precipitation measured by a gauge, especially with a windshield which reduces the wind. More blowing snow observations are required to get the formation to describe blowing snow effect on precipitation.

4. Discussion

[18] Up to here we have given a condensed account of systematic errors of gauge-measured solid precipitation in the Arctic region. These results show that gauge-measured precipitation in the Arctic is characterized by specially trace precipitation and blowing snow. *Allerup et al.* [1997] presented a comprehensive model for correcting point precipitation, and the general model for correction of systematic errors in precipitation measurements is

$$P_c = k(P_m + \Sigma\Delta P_{im}) \quad (3)$$

where P_c is the corrected or “true” amount of precipitation, P_m is the measured amount, $\Sigma\Delta P_{im}$ is the sum of various error sources among which wetting and evaporation losses are the most important, and k is the correcting factor due to wind effect. As has been suggested, trace precipitation confirmed frequently and blowing snow was occurring on the observation area due to the strong wind. These suggest that the systematic errors of gauge-measured precipitation for Arctic conditions must mainly take into consideration of not only wind-induced undercatch, wetting and evaporation losses, but also the influence of blowing snow and trace precipitation loss. We are now able to summarize that error sources, P_{im} , which we should consider for correcting point precipitation in Arctic conditions, are

$$P_{im} = P_{wetting} + P_{evaporation} + P_{blowing} + P_{trace} \quad (4)$$

where $P_{wetting}$ is wetting loss, $P_{evaporation}$ is evaporation loss, $P_{blowing}$ is the influence of blowing snow and P_{trace} is trace

precipitation loss. This suggests reduction in the uncertainty of various error sources in precipitation estimates for the Arctic regions, and will be of value to estimate the quantity of the systematic errors. Future continuous work at the site located in Barrow, Alaska, will allow us to test and assess the adjustment procedures of WMO in the Arctic regions and to the formulation suitable for the Arctic regions.

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