Adjustment of Daily Precipitation Data at Barrow and Nome Alaska for 1995–2001

Authors: Benning, Jennifer, and Yang, Daqing

Source: Arctic, Antarctic, and Alpine Research, 37(3) : 276-283

Published By: Institute of Arctic and Alpine Research (INSTAAR), University of Colorado

URL: https://doi.org/10.1657/1523-0430(2005)037[0276:AODPDA]2.0.CO;2

Arctic, Antarctic, and Alpine Research, Vol. 37, No. 3, 2005, pp. 276–283

Adjustment of Daily Precipitation Data at Barrow and Nome Alaska for 1995–2001

Jennifer Benning† and Daqing Yang*‡*

*Water and Environmental Research
Center, University of Alaska Fairbanks,
P.O. Box 755860, Fairbanks, Alaska
99775-5860, U.S.A.
†fnjlb2@uaf.edu
‡ffdy@uaf.edu

Abstract

Systematic errors in precipitation measurements are known to affect all types of precipitation gages. These errors are more sensitive for solid precipitation than for rain. In arctic regions, these systematic errors become significantly more pronounced than for other regions due to the relatively slow precipitation rates, low temperatures, high winds, and low annual precipitation amounts that are characteristic of the arctic climate. This study performed the daily adjustments of measured precipitation data for the National Weather Service (NWS) stations at Barrow and Nome, Alaska, over a 7-year study period, from 1995 through 2001. The results of this study indicate that the bias adjustments increase the average monthly gage-measured precipitation by approximately 20%–180% for Barrow and 30%–380% for Nome, with the larger percentages occurring in winter months. The average gage-measured annual precipitation amounts are increased by approximately 70% for Barrow and 130% for Nome. It is expected that these increases will impact climate monitoring, the understanding of the arctic freshwater balance, and the assessment of atmospheric model performance in the Arctic.

Introduction

It is widely acknowledged that systematic errors in precipitation measurements caused by wind-induced undercatch, wetting, and evaporation losses affect all types of precipitation gages and that these errors are more sensitive for solid precipitation than for rain. In arctic regions, systematic errors become significantly more pronounced than for other regions due to the relatively slow precipitation rates (frequent occurrences of "trace" precipitation events), low temperatures, high winds, and low annual precipitation amounts that are characteristic of the arctic climate.

Precipitation gage biases are attributed to (1) the catch efficiency of the specific type of gage used, which is affected by wind, (2) the use of unshielded gages, (3) wetting losses which occur when water is left on the walls of the gage during measurement, (4) evaporation losses that occur between the end of the precipitation event and the time of the measurement, (5) splash into and out of gages, (6) blowing and/or drifting snow, (7) auto recording techniques, and (8) the treatment of trace precipitation as zero precipitation. Of these, wind, particularly when the precipitation is in the form of snow, is the largest source of systematic errors. Wind-induced gage undercatch occurs because the gage acts as an obstruction to the local wind field. As the air is forced to circumvent the gage, it creates a zone of increased wind speed around the gage due to the compression of air, causes a slight updraft, and establishes a pressure differential between the air within and outside of the gage (Sevruk and Klemm, 1989).

In 1985, the World Meteorological Organization (WMO) initiated the Solid Precipitation Measurement Intercomparison in order to derive a method of comparison of various national precipitation gages. The goals of the intercomparison were to (1) determine wind-induced errors in national methods of measuring solid precipitation, including wetting and evaporation losses, (2) derive standard methods for correcting solid precipitation measurements, and (3) introduce a reference method of solid precipitation measurement for general use to calibrate any type of precipitation gage. The study designated the Double Fence Intercomparison Reference (DFIR) as the standard reference gage for the intercomparison (Fig. 1). The DFIR is a Tretyakov gage surrounded by an octagonal vertical double fence (Goodison et al., 1998).

The U.S. National Weather Service (NWS) has used the U.S. standard 8-inch gage as the official measurement instrument for several decades. Although the catch efficiency of the 8-inch gage is dramatically improved when equipped with an Alter shield, relatively few NWS stations use the Alter shield. In 1982, Benson reported that the standard NWS 8-inch gages are particularly sensitive in the arctic climate due to the effects of high wind speeds, the large percentage of solid precipitation (greater than 50% of the total precipitation at Barrow), and the slow rate of precipitation, which results in a large number of "trace" precipitation days. He noted that trace precipitation days sometimes account for nearly 80% of the total number of winter precipitation days, and that this may lead to a significant error in the total precipitation data due to the fact that trace days are recorded as zero precipitation (Benson, 1982).

Yang et al. (1998a, 1998b) developed an adjustment procedure and corrected the biases for selected climate stations in Alaska for years 1982 and 1983. This study, following adjustment procedure of Yang et al. (1998b), conducts daily precipitation adjustments and presents the results of monthly and yearly summary for seven years (1995–2001) for the NWS stations at Barrow and Nome, Alaska, It is expected that these adjustments and changes in monthly and annual precipitation amounts will impact climate monitoring, the understanding of the arctic freshwater balance, and the assessment of atmospheric model performance in the Arctic.

Site Locations

The sites investigated for this study are Barrow and Nome Alaska, each of which has a National Weather Service station. The town of Barrow is the northernmost community in the United States. The station at Barrow lies at a latitude of 71°17′12″ N and a longitude of 156°45′48″ W. The town of Nome is located on the Seward Peninsula of Alaska. The station lies at a latitude of 61°30′48″ N and a longitude

1523-0430/05 $7.00

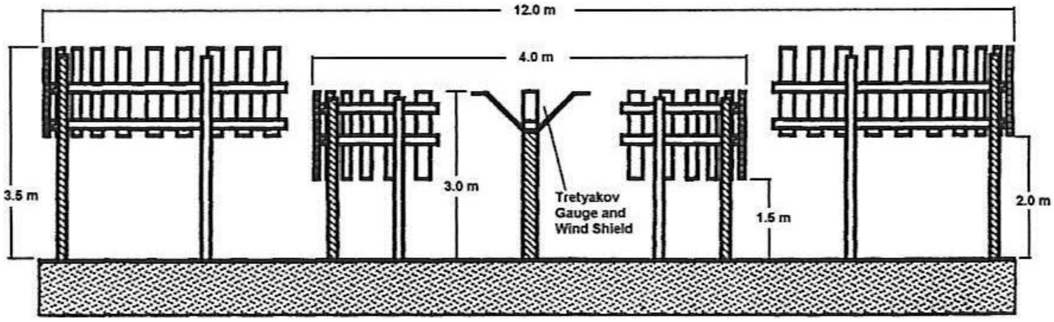

FIGURE 1. Cross-sectional view of a WMO Double Fence Intercomparison Reference (DFIR) gage.

of 165°26′36″ W. The site locations are shown in Figure 2. Both NWS stations use the NWS standard 8-inch non-recording gage to measure precipitation, however the gage at Barrow was equipped with an Alter shield during the study period, while the gage at Nome was unshielded, a condition which significantly increases the wind-induced gage undercatch. The precipitation gage at the Nome station was also located on the roof of the NWS building during the study period, which subjects the gage to increased wind speeds and increased wind-induced gage undercatch. Climate conditions for both sites are summarized in Table 1.

Methods

The bias-correction methods applied in this study are those derived by Yang et al. (1998b) for the adjustments for wind losses, wetting losses, and trace amounts through the analysis of daily climatic data. The daily meteorological data for the period of 1995 through 2001 at Barrow and Nome, Alaska, were obtained from the National Climatic Data Center (NCDC) archives. The data include daily records for maximum, minimum, and mean temperatures; precipitation, with trace records; snowfall, which also includes trace records; resultant wind speed; and the weather code for the weather condition at the time of observation. For this study, weather code is used to determine the precipitation type that occurred during each daily precipitation event. Snow and rain are defined by the sole appearance of a snow or rain code on that day, and mixed precipitation is defined by the appearance of both the codes for snow and rain for the day.

The overall adjustment model is:

$$P_a = K(P_g + \Delta P_w + \Delta P_e) + \Delta P_t, \tag{1}$$

where P_a is the adjusted precipitation; K is the adjustment coefficient (usually $K \geq 1$) for wind-induced errors; P_g is the gage-measured precipitation; ΔP_w is the wetting loss; ΔP_e is the evaporation loss; and ΔP_t is the trace precipitation (Yang et al., 1998b). The correction method for the individual components is discussed in the following sections.

WIND LOSS

The NWS 8-inch standard gage was compared to the WMO Reference gage (DFIR) for three winter seasons at three sites during the WMO Intercomparison. The combined data were used to develop best-fit regressions to determine the daily catch ratio, R, for the NWS 8-inch gage, depending on the daily wind speed at the gage height (Ws, in m/s), the shielding of the gage, and the type of precipitation. The regressions developed in the WMO Intercomparison included corrections for wetting loss, undercatch of the DFIR (relative to a bush shielded gage), wind speed at gage height, and blowing snow. The catch ratio equations for the three considered precipitation types are shown below (Yang et al., 1998a):

Snow:

$$R_{Alter\ Shield} = \exp(4.606 - 0.036\ Ws^{1.75}) \tag{2}$$

$$R_{Unshielded} = \exp(4.606 - 0.157\ Ws^{1.28}) \tag{3}$$

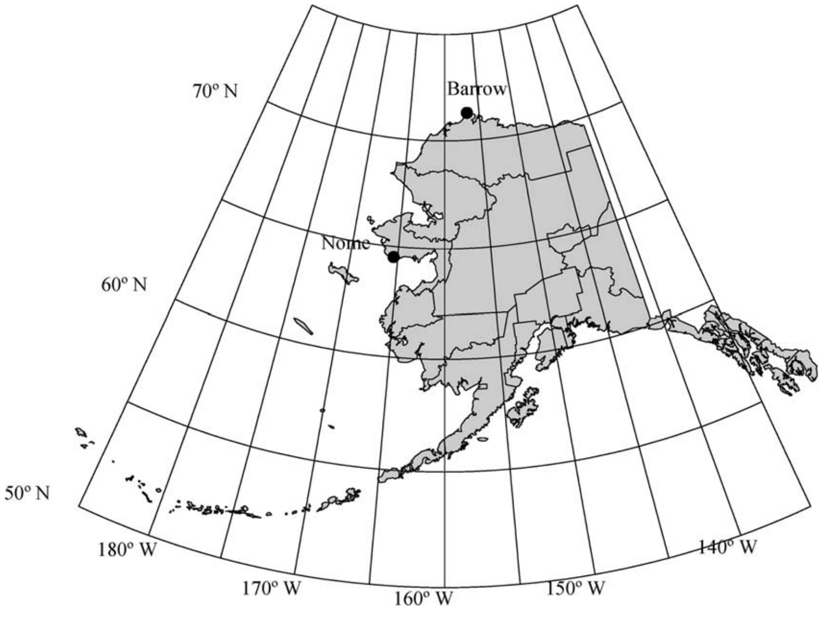

FIGURE 2. Locations of Barrow and Nome in Alaska.

TABLE 1

Normal average temperature, precipitation, and wind speed data for the Barrow and Nome NWS stations, from NCDC archives.

Month	Barrow				Nome			
	Temperature (°C)		Normal precipitation (mm)	Wind speed (m/s)	Temperature (°C)		Normal precipitation (mm)	Wind speed (m/s)
	Maximum	Minimum			Maximum	Minimum		
January	−22	−29	4.3	5.5	−10	−19	20.1	4.9
February	−24	−31	3.8	5.3	−11	−20	15.2	4.8
March	−22	−29	4.3	5.3	−8	−18	13.7	4.4
April	−14	−22	5.1	5.3	−3	−12	17.3	4.6
May	−4	−10	4.1	5.6	6	−1	15.7	4.5
June	4	−1	7.1	5.3	12	4	28.4	4.3
July	8	1	23.9	5.4	14	7	55.1	4.2
August	6	1	24.4	5.7	13	7	68.8	4.8
September	1	−3	15.2	5.9	9	2	61.7	5.0
October	−7	−12	11.4	6.1	1	−6	34.3	4.7
November	−15	−21	6.4	5.9	−5	−12	26.4	5.2
December	−21	−27	4.1	5.5	−10	−18	21.1	4.7
Annual	−9	−16	114.0	5.6	1	−7	378.0	4.6
Years of record	52	52	30	34	52	52	30	39

Mixed Precipitation:

$$R_{Alter\ Shield} = 101.04 - 5.62\ Ws \tag{4}$$

$$R_{Unshielded} = 100.77 - 8.34\ Ws \tag{5}$$

Rain:

$$R_{Alter\ Shield} = \exp(4.606 - 0.041\ Ws^{0.69}) \tag{6}$$

$$R_{Unshielded} = \exp(4.605 - 0.062\ Ws^{0.58}) \tag{7}$$

The NWS station anemometer at Barrow is located at 31 ft (9.5 m) above ground level, and the precipitation gage is located at 6 ft (1.8 m) above ground level. At the Nome NWS station, the anemometer is located at a height of 21 ft (6.4 m) above ground level, while the precipitation gage is located on the roof of a building, at 14 ft (4.3 m) above ground. Therefore, the following wind speed adjustment, which applies a logarithmic wind field profile to reduce the wind speed from the anemometer height to the precipitation gage height, is used.

$$U(h) = U(H)\left[\frac{\ln(h/z_0)}{\ln(H/z_0)}\right], \tag{8}$$

where $U(h)$ is the estimated daily wind speed in m/s at the gage orifice, $U(H)$ is the measured daily wind speed in m/s at the anemometer height, h is the height in meters of the gage, H is the height in meters of the anemometer, and z_0 is the roughness parameter in meters, equal to 0.01 m for the cold period (September–May) and 0.03 m for the warm period (June–August) (Yang et al., 1998b).

Blowing snow has been reported with high winds. The WMO results are applicable for wind speeds below 6.5 m/s. Thus, a maximum wind speed of 6.5 m/s is applied for each daily precipitation event in order to prevent the overestimation of the precipitation adjustment during possible blowing snow events. The resultant daily wind speed, after adjustment to the gage height and application of the threshold wind speed, is used to estimate the catch ratio for each daily precipitation event. The wind loss adjustment, K, is equal to $1/R$ (Yang et al., 1998b).

Although station history records do not indicate whether the NWS 8-inch gage was shielded at the Barrow NWS station, it was confirmed through contact with the NWS office in Barrow that the gage was equipped with an Alter shield during the study period. It was confirmed through the NWS office in Fairbanks, Alaska, that the precipitation gage at Nome was unshielded during the study period.

WETTING LOSS

Wetting losses vary depending on the type of gage, the precipitation type, and the number of times the gage is emptied (WMO/CIMO, 1993). For this study, on each day that precipitation was observed, 0.03 mm or 0.15 mm is added to the daily gage-measured precipitation for rain events or snow and mixed events, respectively (Sevruk, 1982; Golubev et al., 1992). These values represent the experimentally determined losses per observation for the NWS 8-inch gage. Thus, the adjustments represent minimum adjustments since, generally, observations are made once every 6 h during precipitation events, although the adjustments are applied only daily (Yang et al., 1998b).

EVAPORATION LOSS

Studies indicate that evaporative losses vary by gage type and time of year. At a Russian site for the WMO Intercomparison study, an experiment concluded that the evaporative loss for the NWS 8-inch standard gage was small enough that it could be neglected (WMO/CIMO, 1993). Also, without site-specific data, which would depend on the daily weather conditions, it is not appropriate to apply an averaged adjustment derived for different sites. Therefore, no adjustments are made in this study for evaporative losses (Yang et al., 1998b).

TRACE PRECIPITATION

Trace precipitation days are defined by the notation of a “T” in the daily precipitation data and/or a “T” notation in the daily snowfall with a measurement of zero in the precipitation data. Ideally, since the focus of this study is the adjustment of gage-measured precipitation, a trace precipitation day would be defined by a trace notation in the daily precipitation data; however, examination of the data used in this study indicates some potential recording discrepancies. For example, in December 2000, zero trace days are recorded in the daily precipitation data, while there are thirteen trace notations in the daily snowfall data. Through comparison of daily precipitation data for this month to historical data, it is unlikely that zero trace days occurred during the month. Therefore, it appears more appropriate to include daily snowfall data in the definition of trace days for consistency.

Following the adjustment procedure derived by Yang et al. (1998b), trace precipitation is accounted for in this study by adding 0.10 mm for each day of occurrence. This is considered to be

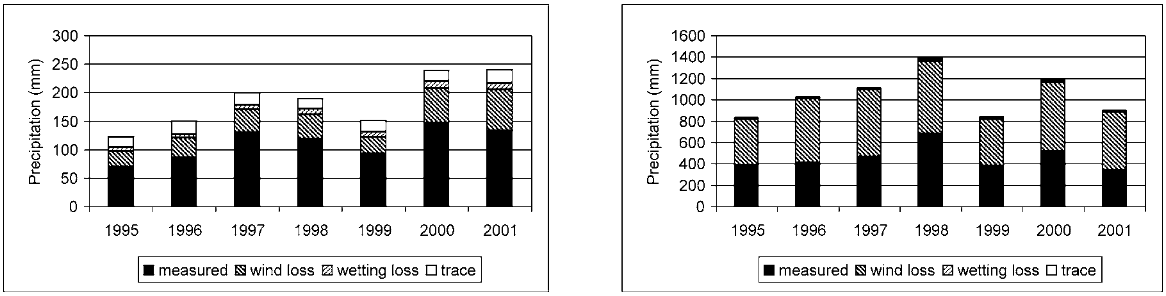

FIGURE 3. Total annual adjustments for precipitation at Barrow (left) and Nome (right) for 1995–2001.

a conservative estimate, since observations are generally made every 6 h, and, therefore, multiple trace precipitation events are recorded as a single trace precipitation day (Yang et al., 1998b).

Results

The daily adjustments for the study period are summarized to show total annual and average monthly precipitation adjustments (Figs. 3 and 4). Figure 3 illustrates the total annual adjustments at both sites during the 7-year study period. The relative contributions of each type of adjustment vary with the total annual measured precipitation. The magnitudes of the wetting losses are generally proportional to the total annual precipitation. Trace losses, however, tend to account for a larger percentage of the adjustment in years with less precipitation. The trace losses are particularly important at Barrow, where the magnitudes of the annual trace adjustments are approximately twice the magnitudes of the adjustments at Nome. The annual adjustments for wind at Nome are 99.7%–159.7% of the annual gage-measured precipitation, while at Barrow, they are only 30.0%–54.5%. The much higher wind adjustment at Nome is due to the placement on the roof and unshielding of the precipitation gage at that station. The annual adjustment factors (equal to the adjusted precipitation divided by the gage-measured precipitation) range from 1.5 to 1.8 at Barrow and range from 2.3 to 3.8 at Nome, indicating that there is considerable interannual variability in the adjustment factors. The annual percentage increases to the gage-measured precipitation for the study years range from 48% to 72% for Barrow and 103% to 166% for Nome.

The average monthly adjustments for each site over the 7-year study period are illustrated in Figure 4 and summarized in Table 2. The monthly-adjusted precipitation amounts increase the gage-measured precipitation by 14%–272% (increases of approximately 2–13 mm) for Barrow and by 19%–379% (approximately 7–124 mm) for Nome. For Barrow, the monthly wind adjustments range from 1 to 10 mm, while wetting and trace adjustments each range from <1 to 2 mm. At Nome, the adjustments are 6–122 mm, <1 to 2 mm, and <1 mm, for wind, wetting, and trace adjustments, respectively.

The role of trace precipitation is particularly important to consider at Barrow. The monthly percent contribution of trace adjustments to the average monthly adjustments is greater than the percent contribution of wind adjustments for many months, March through June (Fig. 5). This is due to a high ratio of trace precipitation days to measurable precipitation days that is typical of Barrow's climate (Fig. 6).

At Nome, the high magnitude of the wind adjustment (Figs. 4 and 5), particularly in winter months, is related to the percentage of monthly precipitation that comes as snow (Fig. 7), since snow has a higher surface area to mass ratio than rain, and thus is more influenced by wind. At Barrow, this effect is offset by relatively low precipitation during the winter months.

There is a potential for the over-adjustment of precipitation data due to blowing snow, i.e., when the average daily wind speed for a precipitation day is greater than 6.5 m/s. This is particularly important at Nome, where the precipitation gage is located on the roof, and therefore is subjected to higher wind speeds. At Nome, the percentage of precipitation days with daily average wind speeds greater than 6.5 m/s at the gage height to the total precipitation days is 34.0% for the cold period (October to April) during the study period. At Barrow, this percentage is 16.0% for the period from October to May. This demonstrates the importance of gage location on the potential accuracy of the precipitation gages. The potential effects of blowing snow are discussed in more detail in the following section.

Overall, the trends in the adjustment percentage (equal to the difference between the adjusted precipitation and the gage-measured precipitation divided by the gage-measured precipitation, expressed as a percentage) reflect the combined effects of the monthly percentage of precipitation received as snow and the average wind speed on precipitation days (Fig. 8). At both stations, the adjustment percentage (and correction factor) decreases as the percentage snow decreases in spring and summer, and then increases again as the percentage of snow increases in fall. Some of the deviations from this trend are explained by variations in the average monthly wind speed on precipitation days.

Discussion

Various researchers have recognized the need to adjust precipitation data, particularly in cold climates that receive large percentages of snowfall in yearly precipitation, and many studies have

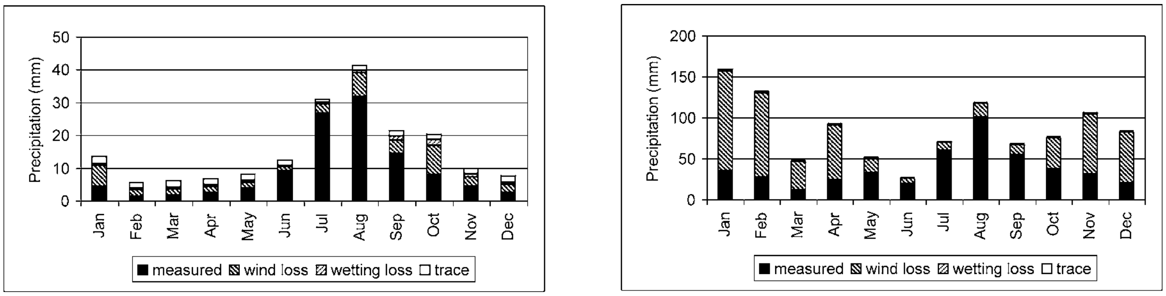

FIGURE 4. Average monthly adjustments for precipitation at Barrow (left) and Nome (right) for 1995–2001.

TABLE 2

Summary of adjustments to gauge-measured average monthly precipitation for 1995–2001 at Barrow and Nome, Alaska.

Month	Wind Speed During Precipitation Events (m/s)	Precipitation Days	Trace Days	Snow (%)	Mixed (%)	P_g (mm)	Adjustments (mm)			P_a (mm)	Adjustment factor
							Wind	Wetting	Trace		
Barrow											
January	8.2	4	21	100	0	4.4	6.5	0.5	2.1	13.6	3.1
February	7.4	3	17	100	0	1.5	2.1	0.4	1.7	5.7	3.8
March	6.1	4	20	100	0	1.9	1.9	0.6	2.0	6.3	3.4
April	5.2	4	19	100	0	2.6	1.7	0.6	1.9	6.7	2.6
May	4.6	5	20	75	6	3.9	1.7	0.6	2.0	8.2	2.1
June	4.7	6	16	7	18	9.2	1.3	0.4	1.6	12.5	1.4
July	5.5	9	10	0	6	26.6	3.0	0.5	1.0	31.1	1.2
August	6.3	12	14	13	19	31.8	7.3	0.8	1.4	41.3	1.3
September	5.1	12	16	29	27	14.5	4.2	1.3	1.6	21.5	1.5
October	6.6	11	18	91	9	8.2	8.8	1.7	1.8	20.5	2.5
November	5.6	6	18	98	2	4.4	2.8	0.9	1.8	10.0	2.3
December	6.8	4	20	100	0	2.5	2.6	0.6	2.0	7.7	3.0
Nome											
January	5.5	12	6	96	4	35.5	121.9	1.8	0.6	159.8	4.5
February	6.4	11	8	88	12	27.8	103.1	1.6	0.8	133.4	4.8
March	5.3	7	6	88	13	11.8	35.3	1.0	0.6	48.8	4.1
April	5.8	8	8	74	26	24.2	67.1	1.2	0.8	93.4	3.9
May	4.8	10	7	23	28	33.0	17.3	0.9	0.7	51.9	1.6
June	4.0	9	5	3	5	20.0	6.6	0.3	0.5	27.5	1.4
July	4.8	11	7	0	0	60.0	10.3	0.3	0.7	71.4	1.2
August	5.3	18	4	0	0	100.6	17.8	0.5	0.4	119.4	1.2
September	5.2	15	4	1	5	55.4	12.4	0.5	0.4	68.8	1.2
October	5.3	11	8	44	30	37.2	38.2	1.3	0.8	77.5	2.1
November	5.8	10	8	63	35	31.5	73.2	1.5	0.8	107.0	3.4
December	5.4	8	6	86	14	20.5	62.5	1.2	0.6	84.8	4.1

applied different methods to adjust gage-measured precipitation data for systematic biases (Sevruk, 1982; Groisman et al., 1991; Legates and DeLiberty, 1993; Metcalfe and Goodison, 1993; Groisman and Legates, 1994; Goodison and Yang, 1995; Yang et al., 1998b). Some studies perform adjustments by applying constant correction factors to monthly precipitation data (Groisman and Easterling, 1994; Groisman et al., 1996); however, the applicability of this method may depend on the objective of the study. Specifically, in the case of climate change studies, daily adjustments that account for fluctuations in precipitation types and differences in the wind speeds during precipitation days may be more appropriate.

As it was noted previously, the annual adjustments range from 1.5–1.8 at Barrow to 2.3–3.8 at Nome, indicating that there is considerable interannual variability in the adjustment factors (Fig. 3). The results from Yang et al. (1998b) indicate annual adjustments for 1982 and 1983 of 1.73 and 1.77, respectively, for Barrow and 2.01 and 1.87, respectively, for Nome. A comparison of average monthly precipitation adjustment trends for this study (Fig. 4) and the 1982 and 1983 data, indicate that at Barrow the average monthly trends for 1995–2001 are similar to the 1983 data, but appear substantially different from the trends in 1982. For Nome, there is a dramatic peak in the adjusted precipitation in November 1982; however, this peak is dampened in the averages for 1995–2001, while the later study shows much higher adjustments for January and February than does the earlier study. Since this study and Yang et al. (1998b) applied the same daily adjustment procedure, it seems clear that, for studies involving interannual variability, the use of a constant correction factor may not be appropriate.

Variability in wind speeds is an important factor in the application of precipitation adjustment procedures. In Figure 9, the average monthly wind speed on precipitation days over the 7-year period, the average monthly wind speed for the 7-year period (at Barrow only), and the average monthly wind speed for the period-of-record (prior to any adjustments to gage-height) are compared. There appears to be

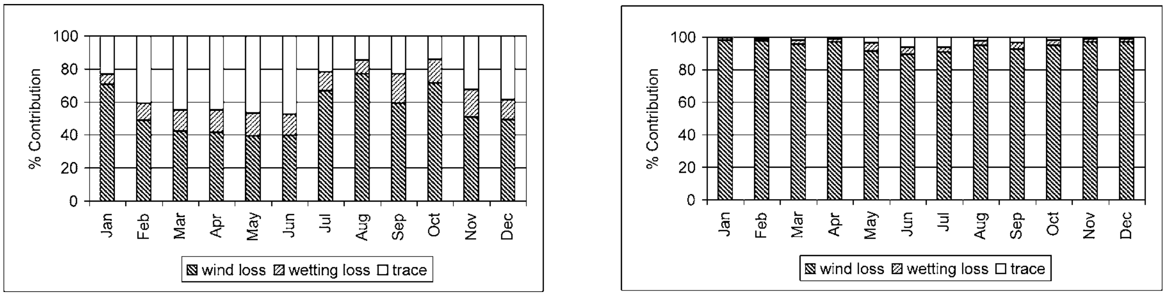

FIGURE 5. Contribution (%) of adjustments for wind loss, wetting loss, and trace amounts of the total average adjustment for each month at Barrow (left) and Nome (right) for 1995–2001.

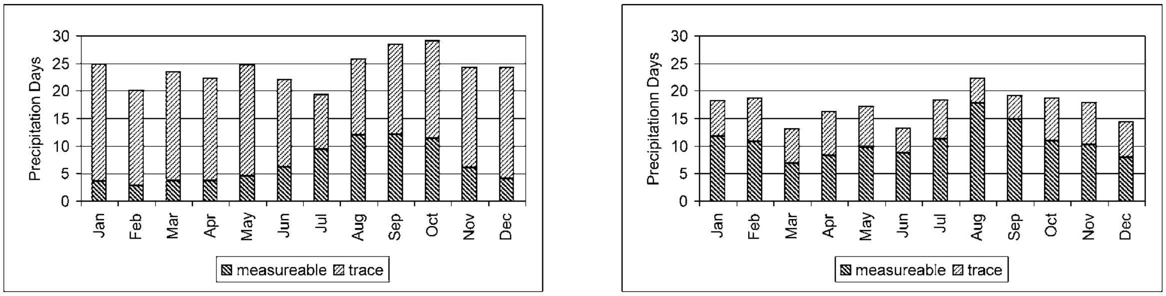

FIGURE 6. Average number of days of measurable and trace precipitation days at Barrow (left) and Nome (right) for 1995–2001.

considerably more fluctuation in the monthly wind speed on precipitation days than in the average monthly wind speed for the 7-year period or in the average monthly wind speed for the period-of-record. It is important to note also that for Barrow, the average monthly wind speeds for the study period were generally slightly greater than the average monthly wind speeds for the period of record. If climatic changes, such as increased severity of storms, occur during the course of long-term studies, the effects of changing wind speeds during precipitation events on both precipitation observations and adjustments should be considered in hydrologic or climate change studies (Førland and Hanssen-Bauer, 2000).

Sevruk (1982) recognized that the average monthly wind speeds are generally 15%–20% less than the wind speeds during precipitation events. A method was derived to adjust the average monthly wind speed to a wind speed during precipitation through the use of an empirical coefficient, based on the number of days of precipitation in the month and the precipitation type (Sevruk, 1982). This method is applied to the average monthly wind speeds for the study period for both Barrow and Nome and compared to the average monthly wind speeds on precipitation days for the study period. For Barrow, the ratio of the wind speed derived via the method of Sevruk (1982) to the average monthly wind speed for precipitation days ranged from 0.87 to 1.57, with an annual average of 1.19. For Nome, the ratios ranged from 0.93 to 1.30, with an annual average of 1.08. For Nome, the use of the method of Sevruk would therefore on average only overestimate the wind speed for precipitation days by 8%; however, for Barrow this overestimation is 19%. Thus, it appears that the use of the method of Sevruk is more appropriate for Nome, which receives higher amounts of precipitation and generally lower wind speeds, than for Barrow.

Numerous studies have identified the potential concern for over-adjustment of precipitation data due to blowing snow fluxes (Li and Pomeroy, 1997; Pomeroy and Gray, 1995) and potential false precipitation, defined as blowing snow fluxes that are caught in precipitation gages (Struzer, 1971; UNESCO, 1978; Bardsley and Williams, 1997). The potential effects of false precipitation can lead to overestimation of snowfall amounts and is a particular concern at locations where the winter wind speeds tend to be high. Russian methods and results for estimating false precipitation for eight sites were reported by Golubev et al. (1997). This study indicated that at seven of the sites, the correction factors for gage-measured snowfall differed by less than 20% when false snowfall was and was not considered. However, at a Siberian location subject to high wind speeds, the difference in the correction factor with and without false snowfall was 140% (Golubev et al., 1997). Yang and Ohata (2001) analyzed the effects of false precipitation on gage-bias adjustments for the Tiksi station in northern Siberia for 1986. Their analysis yielded an annual bias correction of 25% when blowing snow was estimated, compared to 50% when blowing snow was not considered (Yang and Ohata, 2001). Williams et al. (1998) compared gage-measured winter precipitation with moisture sensor data for the Saddle site located in an alpine region of the Colorado Front Range in order to estimate the effects of false precipitation. At this location, it was estimated that an overcatch of 61% was collected during 10 years of study, and this was attributed to blowing snow. This site experiences mean winter wind speeds of 10–13 m/s, with after-storm gusts typically greater than 20 m/s (Williams et al., 1998). In comparison, at both Barrow and Nome, winter wind speeds are generally much lower, with monthly mean winter wind speeds during precipitation events ranging from around 5–8 m/s at Barrow and 5–6 m/s at Nome.

Yang and Ohata (2001) presented the results of detailed analysis of daily wind speeds on snowfall days for 10 Siberian stations. Their study indicates that at locations in northern Siberia, along the Arctic coast, there is a general tendency for high gage-measured snowfall amounts associated with high daily wind speeds, suggesting that some of the gage-measured snowfall on days with high winds may be caused by blowing snow into the gage. In Figure 10, the relationships are illustrated between daily precipitation and daily wind speed at gage height for the cold seasons during two years, 2000 and 2001, at Barrow and Nome. The cold seasons are defined by the long-term normal

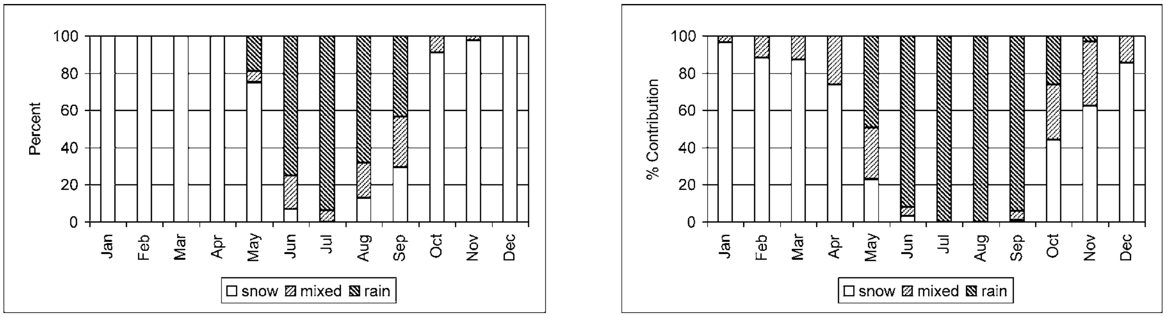

FIGURE 7. Monthly average percentage contribution of snow, rain, and mixed precipitation to the total gauge-measured precipitation at Barrow (left) and Nome (right) for 1995–2001.

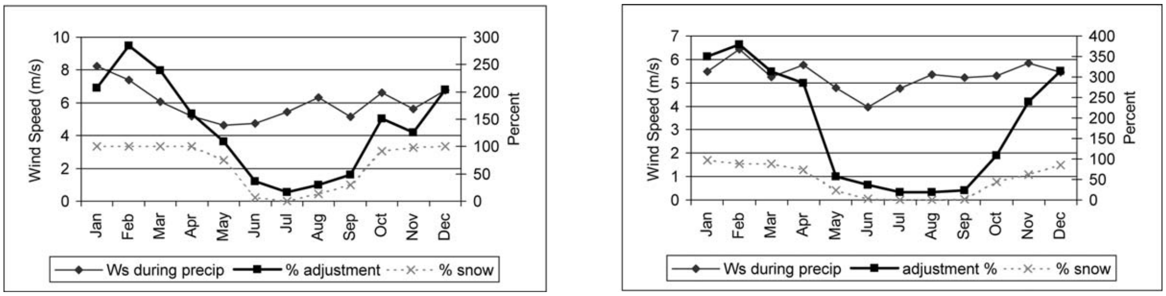

FIGURE 8. Average wind speed during precipitation events, percentage contribution of snow, and percent increase of adjustment to the gauge-measured precipitation for each month at Barrow (left) and Nome (right) for 1995–2001.

monthly minimum and maximum temperatures (Table 1). For Barrow, this includes the months from October through May for Barrow and the months from October through April for Nome (note, however, that at Nome, the normal maximum for October is 1°C, which is slightly warm; also from Fig. 5, there is some contribution to monthly precipitation from rain). At Barrow, there is no association of high gage-measured precipitation at high wind speeds. This is different from the Siberian Arctic coast stations, which demonstrated this trend (Yang and Ohata, 2001). This result suggests possibly less potential for over-adjustment of precipitation data at Barrow. At Nome, however, there is large scatter in the daily measured precipitation at increasing wind speeds, likely due to the placement of the precipitation gage on the roof of the building. This suggests that at Nome there is likely a greater potential for over-adjustment of precipitation due to blowing snow, and indicates that methods should be developed to estimate the effects of false precipitation for this region. At wind speeds above the threshold of 6.5 m/s, there is considerable uncertainty in the reliability of the precipitation data collected by standard and reference gages as well as of the adjustments. Efforts are underway to examine and quantify blowing snow impact on gage observation in the arctic regions through well-designed field experiment (Sugiura et al., 2003).

It is important to note that the status of shielding of gages at U.S. NWS stations is difficult to obtain from national and regional data centers. However, wind adjustments are dramatically impacted by the presence or absence of Alter shields on the U.S. standard 8-inch gages, as can be observed in the differences between the magnitude of the contribution of the wind adjustments as a percentage of gage-measured precipitation at the Nome and Barrow stations. Therefore, it is critical to obtain information on the status of gage shielding when performing precipitation adjustments.

Conclusions

Underestimates of precipitation due to wind-induced undercatch, especially of solid precipitation, wetting losses, and trace amounts represent an important source of error, particularly in the arctic climate. This study applies a method of adjusting the gage-measured precipitation measurements for known biases in order to develop a more accurate data archive. The results of the bias adjustments indicate that measured precipitation data significantly underestimate the monthly and annual precipitation received at both the Barrow and Nome stations, with a pronounced contribution of the wind-induced undercatch at the Nome station due to the elevation of the unshielded gage at the station. Overall, the adjustments result in increases of 42%–72%, or 50–85 mm, to the annual total gage-measured precipitation for the 7-year study period at the two sites. The average monthly adjustments increase the monthly average gage-measured precipitation by 14%–272% (2–13 mm).

Accurate precipitation data archives are important for climate monitoring, understanding the arctic freshwater balance, and the assessment of atmospheric model performance in the Arctic. Therefore, this effort will continue in order to apply the precipitation adjustments to the Barrow NWS station for the entire period of record as well as to other locations in Alaska.

Acknowledgments

The authors would like to thank the Climate Research Branch of the Meteorological Service of Canada, Japan Frontier Observational Research System for Global Change, and the International Arctic Research Center (IARC), University of Alaska Fairbanks, for funding this project. We appreciate assistance from the staff of the U.S. National Weather Service offices in Barrow and Fairbanks, Alaska. Thanks to the technical reviewers for this paper, Dr. David Legates and Dr. Mark Losleben. This work is partly supported by the National Science Foundation under grant no. 0230083. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

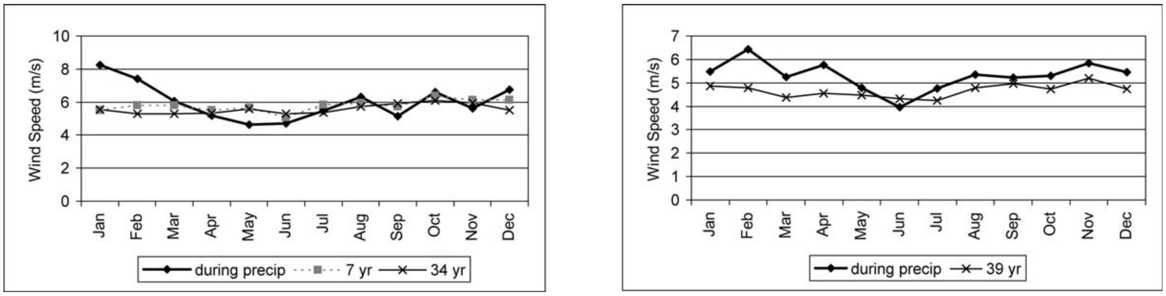

FIGURE 9. Average monthly wind speed during precipitation events, average monthly wind speed from 1995 to 2001, and long-term average monthly wind speed at Barrow (left) and Nome (right) for 1995–2001.

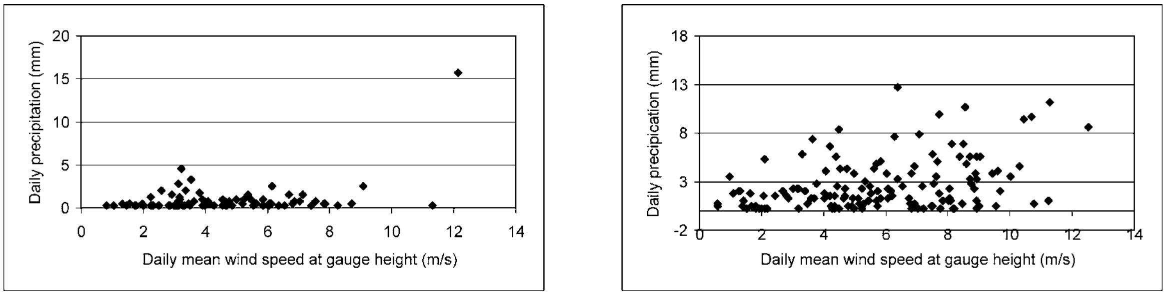

FIGURE 10. Daily precipitation versus daily wind speed adjusted to precipitation gauge height for cold seasons in 2000 and 2001 at Barrow (left) and Nome (right).

References Cited

Bardsley, T., and Williams, M. W., 1997: Overcollection of solid precipitation by a standard precipitation gage, Niwot Ridge, Colorado. *Proceedings of Western Snow Conference,* Banff, AB, Canada, Western Snow Conference, 354–362.

Benson, C. S., 1982: *Reassessment of winter precipitation on Alaska's Arctic slope and measurement on the flux of wind blown snow.* Fairbanks, Geophysical Institute, University of Alaska, 26 pp.

Førland, E. J., and Hanssen-Bauer, I., 2000: Increased precipitation in the Norwegian Arctic: True or false? *Climatic Change,* 46: 485–509.

Golubev, V. S., Groisman, P. Y., and Quayle, R. G., 1992: An evaluation of the U.S. 8-inch nonrecording rain gage at the Valdai polygon, Russia. *Journal of Atmospheric and Oceanic Technology,* 49(5): 624–629.

Golubev, V. S., Bogdanova, E. G., and Simonenko, A. Yu., 1997: The effect of blizzards on the precipitation gauge readings and proposals on the experiment check of the correction method of precipitation data in the Arctic region. *Proceedings of Workshop on the Implementation of the Arctic Precipitation Data Archive (APDA) at the Global Precipitation climatology Centre (GPCC)*, Offenbach, Germany, WMO/TD No. 804, 74–79.

Goodison, B. E., and Yang, D., 1995: In-situ measurement of solid precipitation in high latitudes; The need for correction. *Proceedings of the ACSYS Solid Precipitation Climatology Project Workshop.* Geneva, World Meteorological Organization, WMO/TD-739, 1–12.

Goodison, B. E., Louie, P. Y. T. and Yang, D., 1998: *WMO solid precipitation measurement Intercomparison.* Final Report, WMO/TD-No. 872, 212 pp.

Groisman, P. Y., and Easterling, D. R., 1994: Variability and trends of total precipitation and snowfall over the United States and Canada. *Journal of Climatology,* 7(1): 184–205.

Groisman, P. Y., and Legates, D. R., 1994: The accuracy of United States precipitation data. *Bulletin of the American Meteorological Society,* 75(2): 215–227.

Groisman, P. Y., Koknaeva, V. V., Belokrylova, T. A., and Karl, T. R., 1991: Overcoming biases of precipitation measurement: A history of the USSR experience. *Bulletin of the American Meteorological Society,* 72(11): 1725–1732.

Groisman, P. Y., Easterling, D. R., Quayle, R. G., and Golubev, V. S., 1996: Reducing biases in estimates of precipitation over the United States: Phase 3 adjustments. *Journal of Geophysical Research,* 101(D3): 7185–7195.

Legates, D. R., and DeLiberty, T. L., 1993: Precipitation measurement biases in the United States. *Water Resources. Bulletin,* 29(5): 854–861.

Li, L., and Pomeroy, J. W., 1997: Probability of blowing snow occurrence by wind. *Journal of Geophysical Research,* 102: 21955–21964.

Metcalf, J. R., and Goodison, B. E., 1993: Correction of Canadian winter precipitation data. *Proceedings of the 8th Symposium on Meteorological Observations and Instrumentation.* Boston, Massachusetts, American Meteorological Society, 338–343.

Pomeroy, J. W., and Gray, D. M., 1995: *Snowcover—accumulation, relocation and management.* Environment Canada, National Hydrological Research Institute Science Report 7, 135 pp.

Sevruk, B., 1982: *Method of correction for systematic error in point precipitation measurement for operational use.* Geneva, World Meteorological Organization, WMO-589, 91 pp.

Sevruk, B., and Klemm, S., 1989: Types of standard precipitation gages. *In:* Sevruk, R. (ed.), *Proceedings of Workshop on Precipitation Measurements.* Geneva, World Meteorological Organization, 227–236.

Struzer, I. R., 1971: On the ways of account of precipitation gage errors caused by falling of false precipitation into precipitation gage during blizzards. *Transactions of the Main Geophysical Observatory,* 260: 35–60.

Sugiura, K., Yang, D., and Ohata, T., 2003: Systematic error aspects of gage-measured solid precipitation in the Arctic, Barrow, Alaska. *Geophysical Research Letters,* 30(4): 1192, doi:10.1029/2002GLO15547.

UNESCO, 1978: *World water balance and water resources of the earth.* Studies and Reports in Hydrology 25. Paris, UNESCO, 663 pp.

Williams, M. W., Bardsley, T., and Rikkers, M., 1998: Oversampling of snow and overestimation of inorganic nitrogen wetfall using NADP data, Niwot Ridge, Colorado. *Atmospheric Environment,* 32(22): 3827–3833.

WMO/CIMO, 1993: *Final report of the sixth session.* Geneva: World Meteorological Organization/Commission on Instruments and Methods of Observation, International Organizing Committee for the WMO Solid Precipitation Measurement Intercomparison, 140 pp.

Yang, D., and Ohata, T., 2001: A bias-corrected Siberian regional precipitation climatology. *Journal of Hydrometeorology,* 2: 122–139.

Yang, D., Goodison, B. E., and Metcalfe, J. R., 1998a: Accuracy of NWS 8″ Standard Nonrecording Precipitation Gage: results and application of WMO intercomparison. *Journal of Atmospheric and Oceanic Technology,* 15: 54–68.

Yang, D., Goodison, B. E., and Ishida, S., 1998b: Adjustment of daily precipitation data at 10 climate stations in Alaska: Application of World Meteorological Organization intercomparison results. *Water Resources Research,* 34(2): 241–256.

Revised ms received April 2004