Bias corrections of long-term (1973–2004) daily precipitation data over the northern regions

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Received 12 July 2005; revised 24 August 2005; accepted 31 August 2005; published 6 October 2005.

[1] A consistent daily bias correction procedure was applied at 4802 stations over high latitude regions (North of 45°N) to quantify the precipitation gauge measurement biases of wind-induced undercatch, wetting losses, and trace amount of precipitation for the last 30 years. These corrections have increased the gauge-measured monthly precipitation significantly by up to 22 mm for winter months, and slightly by about 5 mm during summer season. Relatively, the correction factors (CF) are small in summer (10%), and very large in winter (80–120%) because of the increased effect of wind on gauge undercatch of snowfall. The CFs also vary over space particularly in snowfall season. Significant CF differences were found across the USA/Canada borders mainly due to differences in catch efficiency between the national gauges. Bias corrections generally enhance monthly precipitation trends by 5–20%. These results point to a need to review our current understanding of the Arctic fresh water budget and its change. **Citation:** Yang, D., D. Kane, Z. Zhang, D. Legates, and B. Goodison (2005), Bias corrections of long-term (1973–2004) daily precipitation data over the northern regions, *Geophys. Res. Lett.*, *32*, L19501, doi:10.1029/2005GL024057.

1. Introduction

[2] Reliable precipitation measurements are critical for the development of regional precipitation datasets and climatologies in the northern latitudes. Studies have demonstrated large uncertainties in precipitation estimates over the Arctic regions. For example, *Legates* [1995] reviewed the existing global precipitation climatologies and found significant inconsistencies in northern regions. *Walsh et al.* [1998] reported a considerable variation between Arctic precipitation estimates from different sources. Such discrepancies complicate verification of model simulations of Arctic hydrological processes, including our understanding of both terrestrial and Arctic Ocean fresh water balances. They have also led to uncertainties in climate change analyses and difficulties in understanding hydrologic response to climate change and variation over the Arctic regions. For instance, annual runoff increases have been reported for large Russian arctic rivers [*Peterson et al.*, 2002; *Yang et al.*, 2004], while basin yearly precipitation has decreased or changed very little [*Berezovskaya et al.*, 2004]. This inconsistency in basin precipitation and runoff trends deserves our research attention, particularly with regard to data quality in a degrading Arctic observing network. Recently, it has been recognized that narrowing the uncertainty of precipitation observations must be a high priority in Arctic climatic and hydrologic research [*Walsh et al.*, 1998; *Vorosmarty et al.*, 2001].

[3] Uncertainties exist in the estimation of precipitation climatology over the high latitude regions mainly due to sparse observation networks, space-time discontinuities of precipitation data, and biases of gauge observations. Of these factors, biases in gauge measurements, such as wind-induced undercatch, wetting loss (water adhesive to the surface of the inner walls of the gauge that cannot be measured by the volumetric method), evaporation loss (water lost by evaporation before the observation is made), and underestimation of trace precipitation amounts [*Goodison et al.*, 1998], are particularly important, because they affect all types of precipitation gauges, especially those used in the cold regions.

[4] To assess the national methods of solid precipitation observations, the World Meteorological Organization (WMO) initiated the Solid Precipitation Measurement Intercomparison Project in 1985. The octagonal vertical Double Fence surrounding a shielded Tretyakov gauge was designated as the Intercomparison Reference (DFIR). Thirteen countries participated in this project and the experiments were conducted at 20 selected sites from 1986 to 1993 [*Goodison et al.*, 1998]. The WMO experiment has developed bias correction procedures for many precipitation gauges commonly used around the world, including those used in the high latitude countries [*Goodison et al.*, 1998]. These bias correction methods have been applied in the high latitude regions (including the Arctic Ocean drifting station records) and resulted in significantly higher estimates of precipitation [*Yang et al.*, 1998; *Yang*, 1999].

[5] Based on the regional applications of the WMO bias correction methods, we expand our analyses to the Pan-Arctic scale, using available long-term daily data collected at locations above 45°N across national boundaries. The major advantage of this approach is the capability of examining the discontinuity of precipitation records across

0094-8276/05/2005GL024057$05.00

national borders. This paper briefly summarizes the results of bias corrections of daily precipitation data by a consistent method at 4802 meteorological stations during 1973–2004 over the Arctic regions. Improved monthly and yearly precipitation datasets (available at http://www.uaf.edu/water) have been developed from the bias corrections. Results of this study will have a significant impact on analyses of Arctic climate change and fresh water budget, and validations of global/regional climate models.

2. Correction Methods and Data Sets

[6] Corrections of precipitation data should be made for trace events, wetting loss, evaporation loss, and wind-induced error caused by the wind field deformation over the gauge orifice. As wind field deformation affects the total gauge catch including the wetting and evaporation losses, we modified the general model [*Sevruk and Hamon*, 1984] for precipitation correction to:

$$\mathrm{P_c = K(P_m + \Delta P_w + \Delta P_e + \Delta P_t), \quad K = 1/CR} \tag{1}$$

where $\mathrm{P_c}$ is the corrected precipitation, $\mathrm{P_m}$ is the measured precipitation, $\Delta\mathrm{P_w}$ and $\Delta\mathrm{P_e}$ are wetting and evaporation losses, respectively, $\Delta\mathrm{P_t}$ is the trace precipitation, and K is the correction coefficient for wind-induced error. CR is the catch ratio (%), defined as a function of wind speed and temperature [*Goodison et al.*, 1998].

[7] The wind-induced undercatch is the largest error in precipitation measurements. Methods for correcting this bias have been derived from local field experiments [*Goodison*, 1978; *Larson and Peck*, 1974], and recently from the WMO gauge intercomparison project [*Goodison et al.*, 1998]. The major difference between the WMO results and local experiments is that the WMO project has a common reference gauge, while the local studies used different instruments or methods to determine the true snowfall amount. The other important advantage of the WMO results is the combination of gauge intercomparison data from different sites [*Goodison et al.*, 1998], thus creating a much larger dataset to better represent a broader range of climatic/physical conditions.

[8] Methods of determining each of the terms in equation (1) have been developed from the WMO intercomparison results and applied in the northern regions [*Yang et al.*, 1998; *Yang and Ohata*, 2001] and recently at the global scale [*Adam and Lettenmaier*, 2003]. The successful applications of the correction methods in the northern regions demonstrate the general applicability of the WMO results in cold climate conditions, although uncertainties exist in the bias corrections at very high wind speeds particularly during blowing snow events.

[9] Blowing snow events on snowfall days are a special case in gauge bias corrections. Since wind speeds are generally greater during blowing snow events, a larger correction for undercatch could be applied to a measured total already augmented by blowing snow. To avoid the possible over-correction caused by high wind and blowing snow, a threshold wind has to be determined [*Goodison et al.*, 1998]. Corrections at higher wind speed are estimated using this threshold wind, since the WMO intercomparison results are only valid statistically for the wind speed intervals for which they are developed. The threshold was set up at 6.5 m/s at gauge height, as blowing snow events were often reported when mean daily wind speeds at 2 m were higher than 6.5–7.0 m/s at the WMO experimental sites, indicating that 6.5 m/s wind might be a reasonable value for blowing snow initiation. Studies show that blowing snow often occurs in Arctic coastal regions; and, wind speeds on snowfall days are often lower than 6.5 m/s at most inland sites [*Yang et al.*, 1998, *Yang and Ohata*, 2001]. This seems to justify the use of the WMO bias correction methods with the threshold wind speed in the high latitude regions.

[10] Several necessary adjustments were made in the implementation of the WMO correction methods to the Arctic regions. First, wetting loss correction was not necessary for Russian data, as it has been added to the gauge measurements [*Groisman et al.*, 1991]. Secondly, evaporation loss correction was neglected due to insufficient information of regional evaporation rates from the national gauges. Thirdly, trace precipitation events were corrected on a daily basis, not for each event in a day; and no wind correction was applied to the trace events. Finally, for a few national gauges (such as France and Poland) not tested in the recent WMO experiment, earlier results from *Sevruk and Hamon* [1984] were used. Since the WMO reference gauge does not overcatch snow [*Goodison et al.,* 1998], the bias corrections presented here should be regarded as conservative for majority of the Arctic regions.

[11] Daily meteorological data of precipitation, temperature and wind speed are needed to determine the CR. A global daily surface data archive for over 8,000 stations around the world has been acquired from the National Climatic Data Center (http://www.ncdc.noaa.gov/cgi-bin/res40.pl). *Adam and Lettenmaier* [2003] used these data for a short period (1994–1998) for their bias corrections. Other regional precipitation bias analyses for Alaska, Greenland, and Siberia [*Yang et al.*, 1998; *Yang*, 1999; *Yang and Ohata*, 2001] also used short-term datasets of less than 10 years. This study is different, because it focuses on a much longer period from January 1973 to December 2004. These long-term data enable us to develop more reliable precipitation climatologies, and to examine, for the first time, the impact of bias corrections on precipitation trend analyses in the northern regions.

[12] To focus our effort on the high latitude regions, a subset of the global daily data, 4802 stations located north of 45°N with data records longer-than 15 years during 1973–2004, was created and used for this analysis (Figure 1). This spatial coverage was chosen to specifically include the source areas of the largest northern flowing rivers - the Ob, Yenisei, and Lena in Siberia, and the McKenzie in Canada. Additional metadata and information were obtained from the WMO and relevant national weather services. Combinations of meteorological data and the station metadata satisfy the data requirements for daily precipitation corrections in the northern regions.

3. Results

[13] Regional pattern and site-specific feature of bias corrections have been reported [*Yang and Ohata*, 2001; *Adam and Lettenmaier*, 2003], as gauge biases depend on

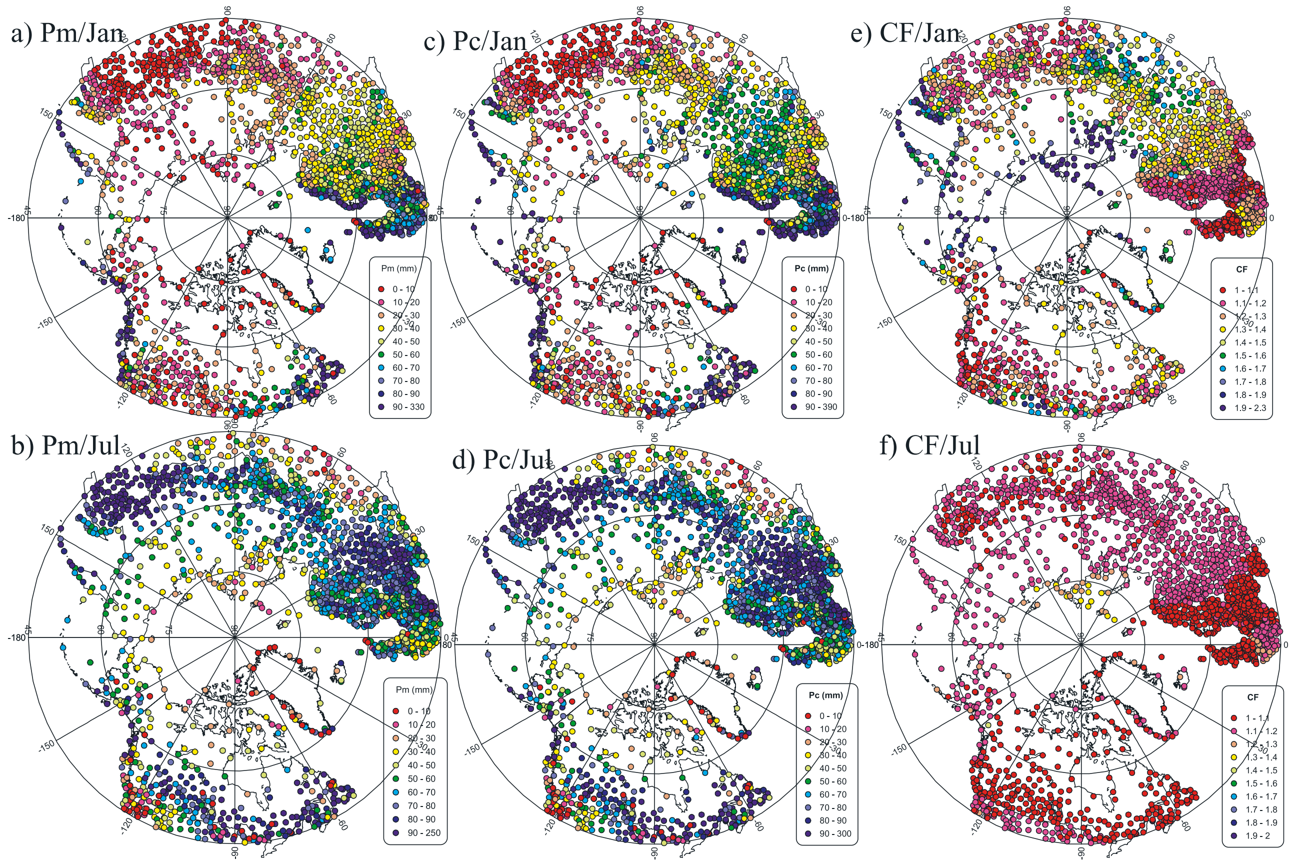

Figure 1. Monthly mean gauge-measured (Pm) and bias-corrected (Pc) precipitation, and correction factor (CF) for January and July.

climate factors (wind and snowfall percentage) and gauge siting characteristics (wind shield and gauge height). To illustrate the biases over the northern regions, we present the results for each individual station. Figure 1 displays examples of the monthly means of gauge-measured, bias-corrected precipitation and the correction factor (CF = corrected/measured precipitation) for January and July, respectively. Yearly results will be discussed separately in other publications.

[14] Monthly gauge-measured precipitation generally ranges from 10 to 90 mm in January over the northern regions. The spatial patterns are characterized by low precipitation over Siberia, Alaska and northern Canada and Greenland, moderate precipitation over continental Europe, and high precipitation in west coast of Europe and both west/east coasts of the North America (Figure 1a). July precipitation usually varies from 30 to 150 mm. The spatial distribution shows low rainfall along the Arctic coasts, moderate rainfall in west Europe, and high rainfall in central Europe and the east Asia/and North America due to summer monsoons (Figure 1b). These spatial patterns in January and July precipitation are generally consistent with other precipitation maps for the northern latitudes [*Legates*, 1995; *Adam and Lettenmaier*, 2003; *Fekete et al.*, 2004], indicating that the precipitation data used for this analysis are compatible with other datasets.

[15] Bias corrections in January vary from 2 to 22 mm over the study area. Wind-induced undercatch is the greatest error in all regions, and both wetting loss and trace amount are important particularly in the low precipitation regions. Spatially, the corrections are small over northern Asia, moderate over Europe, and high over both North America coasts and along the Arctic coastal regions. Bias corrections in July are generally less than 10 mm, with little spatial variations, for most regions. The biases in July are much lower than in January mainly due to less gauge undercatch of rainfall than snowfall. The spatial patterns of January and July precipitation have not changed much due to the bias corrections (Figures 1c and 1d).

[16] The mean correction factors (CF) for January (Figure 1e) are higher (70–100%) along the Arctic coasts of Russia and Alaska, and over east coast regions of Asia, high (60–100%) along Greenland coasts and over west Siberia, moderate (30–60%) in east Europe, and low (10–30%) in northern Canada, central Siberia and west Europe. The winter CFs are relatively higher for northern US stations (including Alaska) and lower over Canada, because catch efficiency of the Canadian Nipher snow gauge is much higher than the US NWS 8-inch standard gauge particularly for high wind speeds. This result is important for climate analyses over large regions, as it clearly demonstrates a significant incompatibility in precipitation records across the national borders. This inconsistency will certainly affect precipitation trend analysis over large spatial scales, such as North America and the Arctic as a whole. In addition, siting characteristics also affect gauge measurement biases. For instance, the CFs are much higher for some Alaska stations along the west coast, such

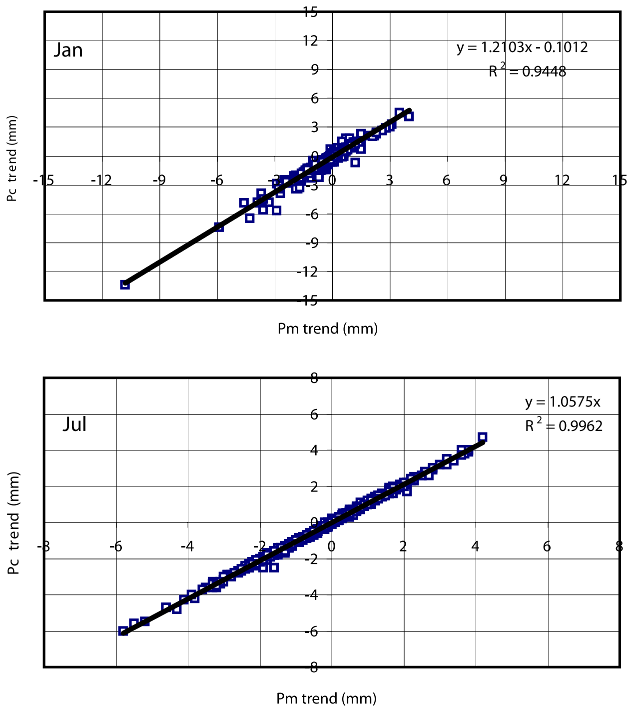

Figure 2. Comparison between measured and corrected precipitation trends for January and July, at the selected stations with data records longer than 25 years during 1973–2004.

as Nome, because the gauge there was placed at the top of the weather office building (3–4m above the ground) and subject to higher winds during precipitation days [*Yang et al.*, 1998]. On the other hand, the CFs in July are usually less than 10% due to higher gauge catch efficiency for rainfall and large amount of precipitation in summer. The spatial patterns of July CFs are similar to January, although the variations are much smaller in July. For instance, the higher and lower CFs remain along the Arctic coasts and Europe, respectively, and the differences between Canada and USA border also exist (Figure 1f). The spatial patterns of CFs for January and July are different from the measured and corrected precipitation. It is therefore necessary to generate monthly CF time series and examine its variations over space and time.

[17] *Forland and Hanssen-Bauer* [2000] reported that bias corrections in the Norwegian Arctic affect precipitation trends. To examine the impact of bias corrections on long-term precipitation changes over the northern regions, we calculated monthly trends for measured and corrected precipitation for the selected stations with records longer than 25 years during 1973–2004. Trend maps show mixed results of increasing and decreasing precipitation over the Arctic regions. To quantify the overall impact of bias corrections on precipitation trends, Figure 2 compares the trend results at 921 and 948 stations for January and July, respectively. It shows that bias corrections generally enhance monthly precipitation trends mainly due to increases in precipitation amounts. Regression analyses demonstrate that, relative to the measured data, the corrected precipitation trends are, on average, 21% and 6% higher for January and July, respectively. This suggests that precipitation trends have been underestimated, particularly for the regions with large changes, over the northern regions.

4. Conclusions

[18] This study applied a consistent bias correction procedure at 4802 stations in the high latitude regions across the national borders, and quantified the biases of wind-induced undercatch, wetting losses and trace precipitation amount on a daily basis for the last 30 years. The corrections have increased the gauge-measured monthly precipitation significantly by up to 22 mm for winter months, and by about 10 mm during the summer season. Wind-induced gauge undercatch is the largest error, but wetting loss and trace precipitation are also important particularly in the low precipitation regions. Relatively, the correction factors are small in summer (less than 10%) and very large in winter (up to 80–120%) because of the increased effect of wind on gauge undercatch of snowfall. The CFs also vary over space, particularly in snowfall season. The spatial patterns of CF are different from the measured and corrected precipitation especially in winter, with low CFs (20–40%) over the higher mid-latitudes and very high values (over 100%) along the windy Arctic coasts of low precipitation. Significant CF differences were also found across the USA/Canada borders mainly due to difference in catch efficiency between the national standard gauges. This inconsistency affects climate analyses over large regions, such as the Arctic as a whole. Bias corrections generally enhance the long-term trends of monthly precipitation – indicating underestimation of precipitation changes over the northern regions. These results clearly point to a need to utilize bias-corrected precipitation estimates to provide a better understanding of the Arctic fresh water budget and its change.

[19] **Acknowledgment.** This study was sponsored by the Meteorological Service of Canada and a NSF Grant OPP-0230083.

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