Comparative analysis of Russian and Norwegian precipitation gauges, measurements in Barentsburg, Western Spitsbergen

Aleksandra V. Urazgildeeva[1,2*], Pavel N. Sviashchennikov[1,2], Boris V. Ivanov[1,2], Ketil Isaksen[3], Eirik J. Førland[3], Ragnar Brækkan[3]

[1]*Arctic and Antarctic Research Institute, Beringa 38, Saint Petersburg, 199397, Russia*
[2]*Saint Petersburg State University, Universitetskaya nab. 7-9, Saint Petersburg, 199034, Russia*
[3]*Observation and Climate Department, Norwegian Meteorological Institute, PO Box 43 Blindern, 0313, Oslo, Norway*

Abstract
Comparative analysis of records of two gauges with different wind shields (Tretyakov gauge and Geonor T200-B) were done, based on time series of parallel measurement in Barentsburg settlement, Svalbard, during two winter times in period from September 2014 to July 2016. All collected data of solid precipitation were divided into two ranges with different wind speed conditions. As it was known from earlier papers, Tretyakov gauge measurements tend to underestimate solid precipitation in case when precipitation is not intensive and wind speed is less than 5 m s^{-1}. Opposite results were obtained for blizzard conditions (wind speed is more than 6 m s^{-1}): Tretyakov gauge shows greater values for amount of solid precipitation than Norwegian sensor. Preliminary results in Barentsburg cannot be described as conclusive ones. Estimation of solid precipitation on Spitsbergen measured by different gauges needs further and more detailed research, which includes fieldwork in Barentsburg in spring, such as detailed snow surveys in the settlement.

Key words: Arctic, solid precipitation, Svalbard, bias-correction method

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Introduction

The freshwater budget in the Arctic is important in the context of global change (glaciers, albedo, freshwater influence on deep-water formation, *etc.*). The Arctic freshwater budget is driven primarily by precipitation ([1], Walsh et al. 1998). Al-

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*Corresponding author: A. V. Urazgildeeva <sasha-urazgildeeva@yandex.ru>
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though the Arctic ocean contains only 1.5% of the world's ocean water, it receives about 10% of a total global run-off, mostly from Siberian rivers. (Førland et Hanssen-Bauer 2000). However, there are large uncertainties in estimation of precipitation amounts in the Arctic. Undercatch caused by wind effects is the largest source of uncertainties, and is especially large for solid precipitation (Førland et Hanssen-Bauer 2000). For rough calculations, the correction factor for solid precipitation is estimated to be 1.85 (Førland et Hanssen-Bauer 2000, Hanssen-Bauer et al. 1996, Sviashchennikov et al. 2007). In a recent Norwegian study only 80% of the assumed true solid precipitation is caught at wind speeds of 2 m s^{-1}, and only 40% at 5 m s^{-1}. The slope of the catch ratio then levels off markedly and stabilizes at 20% at 7-8 m s^{-1} (Wolff et al. 2015). Moreover, an extremely important problem is the lack of reliable intercomparison reference for determining the true amount of solid precipitation and correcting estimates of wind error in precipitation measurements with different rain gauges.

The precipitation gauges around the Arctic ocean are important indicators of changes in the Arctic freshwater budget. Earlier studies have shown a strong positive trend in precipitation at higher northern latitudes during last century. According to the results of (Førland et Hanssen-Bauer 2000) it has been found that parts of the observed positive precipitation trend are fictitious; caused by reduced undercatch in the precipitation gauges.

Due to the mentioned reason one of the main motivations of this study is to make precipitation data series, measured by different gauges in Svalbard Archipelago, comparable. The results of this paper should be used to form joint Russian-Norwegian archive of precipitation data series. Usage of corrected sum of precipitation in climate studies is crucial due to having an adequate estimation of climate system changes.

At Russian weather stations, the amount of precipitation is measured in Tretyakov gauges. Errors caused by wetting and evaporation from Tretyakov gauges can mostly be corrected. For the Tretyakov gauge, three versions of the bias-correction method were developed: the method of the World Meteorological Organization (International Organizing Committee) (WMO - [2], Yang et al. 1995); the method of a group of experts from Norway (Forland et al. 1996); and the method of V. S. Golubev, developed in Russia ([2], Golubev et Simonenko 1998). A comparison of bias-correction results obtained with each of the following method has shown that the magnitudes of the calculated systematic errors are almost equal. According to the conditions of the WMO IOC method application, the correction equations for the wind-induced undercatch of solid precipitation are recommended for wind speeds lower than 6.5 m s^{-1} at the gauge height, and in the absence of blizzards. No solutions for stronger winds and blizzards are suggested by this method. In addition to undercatch, due to the strong wind, solid precipitation can be both blowing in and blowing out for Tretyakov gauges in the Arctic (Bogdanova et al. 2002).

An automatic Norwegian gauge GEONOR T200-B was installed on the meteorological site in Barentsburg (August 2014) in framework of the Russian-Norwegian project "Isfjorden - past and present climate". Thus, it is possible to make comparative analysis of two data series in this area: precipitation estimated by Tretyakov gauge and GEONOR T200-B. Although similar researches have been performed in Ny-Ålesund and results were described in (Førland et Hanssen-Bauer 2000, Hanssen-Bauer et al. 1996), preliminary results in Barentsburg cannot be described as a conclusive ones.

Material and Methods

The meteorological site of Barentsburg, where the following study was condacted, is a Russian meteorological station operated by Roshydromet and has one of the longest climate records in the Arctic, starting in 1932. For analysis the daily records of precipitation data from two main sources were used: weather journals stored in ([3]) (Tretyakov's gauge records) and archive of Norwegian Meteorological Institute for GEONOR T200-B records ([4]).

Comparative analysis was made for the cold period of the year when only solid precipitation was observed. Hereby we had 2 winter times' data sets for the whole period of parallel measurements (September 2014 – July 2016). Typically for the Arctic climate snowfall are under strong winds and blizzards conditions throughout the entire cold period. Under these conditions fresh snow from the earth surface can be blowing up into the bucket (or opposite – blowing out of the bucket). In case when precipitation is liquid and not intensive, wind speed is less than 5 m s^{-1}, some of precipitation can evaporate from the bottom of the bucket; it leads to underestimating of precipitation amount. Due to this reason, all collected data was divided into 2 groups according to wind speed ranges: 0-5 m s^{-1} and 6-10 m s^{-1} (Aleksandrov et al. 2005, Bryazgin 1976). Also, days with no precipitation during cold period were omitted. As a result were created two samples of data.

The last stage of study consisted of Tretyakov gauge's time series adjustment to GEONOR T200-B data, using method of linear regression:

$$y_i = a * x_i + b + \varepsilon_i \qquad \textit{Eqn.}1$$

where x_i – Geonor's data, mm; y_i – adjusted Tretyakov gauge dataset, mm; i =1, N, where N – length of a dataset; *a* and *b* – correction coefficients; and ε - error.

Mann-Kendall (MK) test were used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test is a non-parametric (distribution-free) test.

The MK (Mann 1945, Kendall 1975, Gilbert 1987) test is applicable in cases when the data values *y* can be assumed to obey the model, which is described by equation (1). In this case residuals *ε* can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. To estimate the true slope of the regression line the Sen's non-parametric test is used.

The adequacy of the least squares estimation results depends on several assumptions:

- ✔ Correct model specification – all relevant variables are included, correct functional form. Specification error gives biased estimation.
- ✔ The random error term satisfies:
  - Mean $(\varepsilon_i) = 0$ for all i
  - Var $(\varepsilon_i) = \sigma^2$ for all i
  - Cov $(\varepsilon_i, \varepsilon_j) = 0$ for $i \neq j$

where σ – standard deviation; i, j = 1, N.

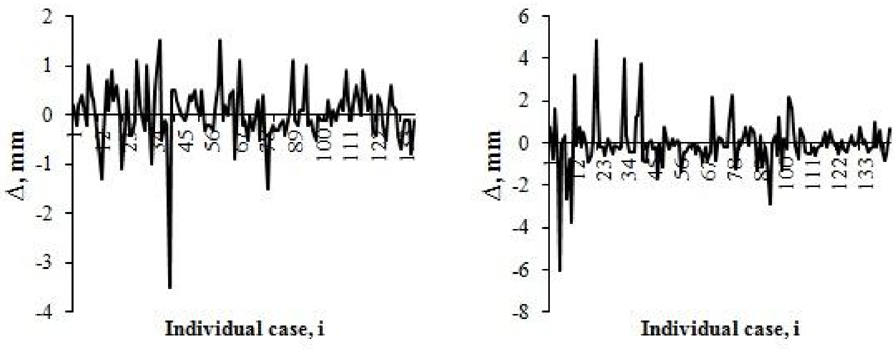
Two last assumptions state the errors are homoscedastic and uncorrelated. To test heteroscedasticity Goldfeldt-Quandt (GQ) test (Goldfeld et Quandt 1965) were used. Residuals are normally distributed and there is no autoregression. The test compares the variance of error terms across discrete subgroups.

The dataset is divided into three groups, the middle part is rejected. For the first and the third parts of a dataset, separate least squares regressions were fitted and error variance for both groups was estimated. It is important that the lengths of both series, *l*, are equal. For each group the sum of the squared residuals (SSR_i) is used. Ratio of SSR_3 and SSR_1 (GQ) was calculated. Using F-test we checked homoscedasticity. If $GQ > F_{\alpha;\,k1,\,k3,}$ then hypothesis that residuals are homoscedastic was rejected on significance level α; (k_1=l_1-1 and k_3=l_3-1, k_1 and k_3 – number of degrees of freedom of each group).

Results

Fig. 1 shows difference, Δ, between Tretyakov and GEONOR T200-B gauges'measurements under different wind speed conditions.

In Fig. 1 it can be clearly seen that when wind speed is less than 6 m s^{-1} (Fig. 1a), differences between two gauges' readings mostly lie in a range from -2 to +2 mm. Due to one of the systematic error of Tretyakov gauge – loss in cases when the measured precipitation is less than one-half of the smallest gradation of the measuring device – it sometimes does not record any precipitation while GEONOR T-200B does. The latter quantity is recorded as "0.0" or "trace", and is ignored in further summation. Due to its design feature GEONOR T200-B can record even small amount of precipitation.

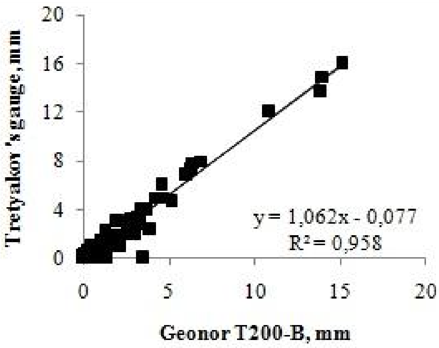


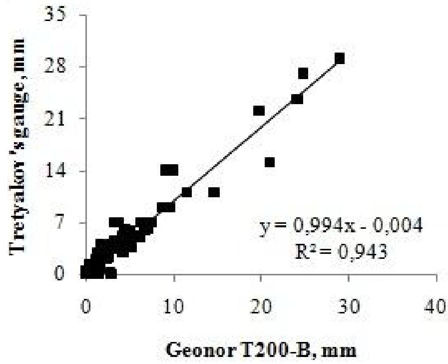
a) 0-5 m s^{-1} b) 6-10 m s^{-1}

Fig. 1. Differences between records of Tretyakov gauge and Geonor T200-B gauge for solid precipitation during period of parallel measurements under different wind speed conditions. (Δ = Tretyakov g. – Geonor T200-B)

When considering differences under stronger wind speeds, it can be found that values vary more – all differences lie in range from -6 to +6 mm. The average difference value for two cold periods is -0.1 mm, which means that Tretyakov gauge underestimates solid precipitation due to undercatch. But we can make still a preliminary conclusion that there is no definite dependency. That leads us to the idea of using more parameters for further comparison.

Results of regression analysis are shown in Figs. 2a and 2b; parameters of linear regression equations are given in Table 1.





a) 0-5 m s^{-1} b) 6-10 m s^{-1}

Fig. 2. Linear regression analysis for Tretyakov gauge adjustment to GEONOR T200-B for different wind speed ranges.

According to the data in Table 1 it can be concluded that coefficients, *a*, are both close to 1, which means that even though there are differences between the records of two gauges these differences are not considerable. This conclusion can be confirmed with values of coefficient of determination, R^2 which are almost equal to 1. All coefficients were statistically significant at level $\alpha = 0.05$. Used GQ test showed that errors ε for both groups of measurements are homoscedastic at level $\alpha = 0.05$.

For precipitation amount measured under the lower wind speed, coefficient, *a,* is more than 1, which corresponds with earlier conclusion that Tretyakov gauge underestimates precipitation under these conditions. Controversially, when speed is greater or equal to 6 m s^{-1}, solid precipitation partly can be blowing out from the measuring device. And that brings up a question: whether Tretyakov gauge's records overestimated due to "overcatch" or GEONOR T200-B underestimates precipitation because of the aerodynamic factor.

Parameter	0-5 m s^{-1}	6-10 m s^{-1}
a	1.062	0.994
b	-0.077	-0.004
R^2	0.958	0.943

Table 1. Parameters of linear regressions' equations.

Discussion

Parallel measurements of two different precipitation gauges at meteorological site in Barentsburg settlement make it possible to make some preliminary conclusions and define unsolved questions that needed to be solved in future studies.

According to comparative analysis of precipitation time series the records of both gauges are similar. But there are particular differences:

(1) In case when precipitation is not intensive, wind speed is less than 5 m s^{-1}, some of precipitation can evaporate from the bottom of the bucket of Tretyakov gauge; it leads to underestimating of precipitation amount. As contrasted with GEONOR T200-B, this has special antifreeze compound and oil covering the measuring bucket. That prevents evaporation of melted snow from the surface and makes it possible to record even smaller amount of precipitation.

(2) For the Arctic climate, snowfalls are typical under strong winds (< 6 m s^{-1}) and blizzard conditions. It leads to "overcatch" of Tretyakov gauge due to false precipitation raised by the wind from the snow surface and caught by the gauge. This statement was confirmed by the results of comparative analysis. Indeed, Tretyakov gauge under these conditions is prone to overestimate amount of solid precipitations.

Still there are some uncertainties have been determined during following study. Thus far, we cannot make definite conclusion about what kind of data stored in weather journals ([3]) (Tretyakov's gauge records) and which steps of bias-correction were done with this record.

For further research, we should develop more accurate correction method not only for solid type of precipitation, but also, topographic features of site and temperature conditions should be considered.

Additional field work in spring should be done to make more accurate determination: to estimate the errors caused by aerodynamic factors in the measurement of solid precipitation, snow surveys should be performed near (but without disturbing consistency of surrounding snow surface) to the official meteorological station in Barentsburg. Similar fieldwork was done earlier and described in paper (Sviashchennikov et al. 2007).

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