Testing the transfer functions for Geonor T-200B and Chinese standard precipitation gauge (CSPG) in the central Qinghai-Tibet Plateau

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Abstract: Geonor T-200B weighing precipitation gauge (Geonor) and Chinese standard precipitation gauge (CSPG) are widely used for measuring precipitaion in the Qinghai-Tibet Plateau. However, their measurements must be adjusted due to wetting, evaporation loss and wind-induced undercatch. Some transfer functions had been proposed in previous studies, but their applicability in the Qinghai-Tibetan Plateau has not been evaluated. In our study, a precipitation measurement intercomparison experiment was carried out from August 2018 to September 2020 at a station in the central Qinghai-Tibet Plateau, and these transfer functions are also evaluated based on the results of the experiment. The results show that: (1) the catch efficiency of Geonor for rain, mixed, snow, hail are 92.06%, 85.32%, 68.08% and 91.82% respectively, and the catch efficiency of CSPG are 92.59%, 81.32%, 46.43% and 95.56% respectively. (2) K2017b has the most accurate correction results for Geonor solid and mixed precipitation at 30 minutes time scale, and the M2007e scheme has the most accurate correction results for Geonor solid precipitation at event scale. (3) The current transfer functions for CSPG underestimate the solid precipitation, while overestimate the liquid precipitation. Based on the results of the comparative observation in our study, new CSPG transfer functions are proposed for the central Qinghai-Tibet Plateau. (4) Hail is also an important precipitation type in the central Qinghai-Tibet Plateau. Because the capture rate of hail precipitation is close to that of rain, and the temperature when hail precipitation occurs is high, it is not necessary to determine the hail precipitation type, and the transfer functions recommended in this study can also get a good correction results.

Keywords: precipitation observation errors; transfer function; CSPG; Geonor T-200B; Qinghai-Tibetan Plateau

1. Introduction

Accurate precipitation is of great significance for understanding regional and global water cycle processes (Gebler et al., 2015; Lea et al., 2018; Xu et al., 2020). For now, rain gauges and remote sensing are two important methods for precipitation observation (Sorooshian et al., 2011).

Although remote sensing observation can provide large-scale and high spatial-temporal resolution precipitation data, as an indirect observation means, remote sensing precipitation inversion algorithm and verification are dependent on ground observation data (Ma et al., 2019a; Sharma et al., 2020). Precipitation recorded by different types of rain gauges is generally considered to be the most accurate (Wang et al., 2019). However, due to the influence of system errors and wind-induced undercatch, the precipitation obtained by rain guges often has a certain gap with the ture value (Yang et al., 1999; Ye et al., 2004; Yang, et al., 2005; Pollock et al., 2018; Buisán et al., 2020). Especially in some high latitude and high altitude areas, the error of precipitation obtained by rainfall gauge will be greater (Pierre et al., 2019).

In order to solve the problem of precipitation observation errors, the World Meteorological Organization (WMO) has carried out several precipitation observation programs (Rodda, 1973; Sevruk and Hamon, 1984; Goodison et al., 1998; Lanza et al., 2005; Nitu et al., 2018). In these programs, the precipitation obtained by double fence international reference (DFIR) or doublefence automated reference (DFAR) is taken as the true value to evaluate the capture efficiencies of different rain gauges (Goodison et al., 1998; Zhang et al., 2004; Nitu et al., 2018). Results indicate the rain gauges have the smallest capture efficiencies for solid precipitation, followed by mixed precipitation, and the largest capture efficiencies for liquid precipitation. Some transfer functions for precipitation observation errors of different gauges are also put forward.

The Qinghai-Tibet Plateau is known as the third pole of the world (Yao et al., 2012). At the same time, because several major rivers, such as the Yangtze River, the Yellow River and the Yarlung Zangbo River, all originate in this region, so it is also known as the water tower of Asian (Tang et al., 2019). The average altitude of Qinghai-Tibet Plateau is above 4500 meters, so the climate is cold, and solid precipitation occurs in all seasons of the year (Zhang et al., 2015). With the influence of gale weather, the precipitation observation error is particularly obvious in the plateau area (Ma et al., 2019b). The CSPG and Geonor T-200B are two gauges mainly used for precipitation observation in Qinghai-Tibet Plateau. For the observation error of CSPG, some scholars had carried out precipitation contrast observation experiments in the Tianshan and Qilian Mountains of China, and put forward the transfer functions (Yang et al., 1991; Chen et al., 2015). Geonor T-200B is a commonly used rain gauge in the world, scholars had given many transfer functions based on the comparative observation experiments carried out in different countries (Smith, 2007; Kochendorfer et al., 2017). In the past research on hydrology and meteorology of Qinghai-Tibet Plateau, due to the lack of precipitation contrast observation experiment, the correction of CSPG and Geonor T-200B precipitation directly adopts the transfer functions constructed in other regions (He et al., 2009; Ma et al., 2015; Ma et al., 2019a). However, because the information of precipitation particles is not taken into account, there are great differences in these transfer functions, and unreasonable transfer functions will lead to further increase of precipitation error. Therefore, it is necessary to choose appropriate precipitation correction scheme in the Qinghai-Tibet Plateau.

With the background mentioned above, we selected a comprehensive observation site in the hinterland of the Qinghai-Tibet Plateau and carried out precipitation comparative observation program for two years. Our main objectives are: (1) to choose the most suitable correction scheme for Geonor and CSPG in the central Qinghai-Tibet Plateau by comparing the existing transfer functions for precipitation observation errors; (2) to give a new correction scheme for precipitation observation errors based on the observation of this study.

2. Methods

2.1 Site Descriptions and observation instruments

Precipitation intercomparison experiments were conducted at Beiluhe site (Figure 1; 92.9°E, 34.8°N, 4628m above sea level), which is located in the central Qinghai-Tibet Plateau. Previous meteorological observation data show that, the mean annual air temperature in Beiluhe is about -3.8°C, with the highest value of 21.3°C in mid-July and lowest value of -21.4°C in later January (Lin et al., 2010; Lin et al., 2011). Affected by the monsoon climate, the precipitation in Beiluhe mainly occurs from April to October, while the precipitation in other months is less, and the annual precipitation is more than 300 mm (Zhang et al., 2015). Due to the high altitude, the temperature in Beiluhe is low and solid precipitation is frequent. Combined with the influence of gale weather on the plateau, the precipitation capture rate is relatively low. In order to solve this problem, a precipitation intercomparison experiment was carried out from 2018. The precipitation observation devices include DFIR, Geonor and CSPG.

CSPG is an artificial rain gauge with a diameter of 20cm and the precipitation observation errors include the wind-induced loss (P_a), evaporation loss (P_e), wetting loss (P_w) and trace precipitation loss (P_t). According to previous studies, for loss by the CSPG per observation, P_w is 0.23mm, 0.3mm and 0.29mm for rainfall, snow and mixed precipitation measurements respectively (Chen et al., 2015). P_e is a near zero value in the warm season and 0.1~0.2mm in winter, P_t is set to 0.1mm no matter how many times trace precipitation occurs during a day (Ye et al., 2004; Ren and Li, 2007). Geonor is a weighing rain gauge with a single-Alter shielded, which does not need to consider the wetting loss and trace precipitation loss. As the oil and antifreeze are added into the gauge, evaporation can be effectively restrained, so the influence of evaporation loss also does not need to be considered. The DFIR device is composed of two octagonal fences, the diameter of the outer shield is 12 meters, and the diameter of the inner shield is 4 meters, and the detailed introduction can be found in the relevant documents of WMO (Goodison et al., 1998). In Beiluhe site, at the center of the inner shield the CSPG is installed in a Tretyakov shield.

2.2 Transfer functions for Geonor and CSPG

2.2.1 Transfer functions at 30 minutes or hourly time scale

Based on the WMO solid precipitation intercomparsion experiment (SPICE), Kochendorfer et al. (2017) proposed universal transfer functions for correcting the observation error of rainfall gauge based on 30 minute observation data:

$$CE = e^{-a(U)(1-[\tan^{-1}(b(T_{air}))+c])} \quad (1)$$

$$CE = (a)e^{-b(U)} + c \quad (2)$$

In functions (1) and (2), *CE* is the catch efficiency of the gauge, and is defined as the ratio of observed precipitation to actual precipitation, T_{air} is the air temperature, *a*, *b* and *c* are the coefficients obtained by fitting based on the observed data. The wind speed *U* can be at the rain gauge height, or at the height of 10 m. When the wind speed is higher than the threshold (7.2 m/s at the gauge height or 9 m/s at 10 m height), the threshold value is directly used. The above functions can be used to correct the precipitation obtained by a rain gauge with or without a single-Alter shielded. Given any temperature in function (1), the relationship between precipitation capture rate and wind speed can be obtained, so it is not necessary to determine the precipitation type. Function (2) needs to determine the precipitation type, when $T_{air} < -2$ °C is solid precipitation, $T_{air} > 2$ °C is liquid precipitation, and -2 °C < T_{air} < 2 °C is mixed precipitation. In order to distinguish them, we rename formula (1) and formula (2) to K2017a and K2017b respectively.

Based on the precipitation intercomparsion experiment in Bratt's Lake, Canada, Smith (2007) proposed the transfer functions for Geonor's solid precipitation measurements on the hourly and daily scales. The transfer function on the hourly scale is as follows:

$$CE_{snow} = 1.18 * \exp(-0.18U_g) \quad (3)$$

Where U_g is the hourly average wind speed at the the rain gauge height, and we rename formula (3) to S2007h.

2.2.2 Transfer functions at daily time scale

At daily scale, there are many transfer functions for CSPG and Geonor. The correction function of solid precipitation for Geonor with a single-Alter shielded given by Smith (2007) is as follows:

$$CE_{snow} = \exp(-0.2U) \quad (4)$$

Where *U* is the daily average wind speed at the rain gauge height and formula (4) is named as S2007d. In the Tanggula area of the Qinghai-Tibet Plateau, Zhao et al. (2014) took the revised CSPG precipitation as a reference and provided the transfer functions for Geonor gauge:

$$CE_{snow} = \exp(-0.135U) \times 100 \quad (5)$$

$$CE_{rain} = \exp(-0.113U) \times 100 \tag{6}$$

$$CE_{mixed} = CE_{snow} - (CE_{snow} - CE_{rain}) \times (T_d - T_{min}) / (T_{max} - T_{min}) \tag{7}$$

$$T_d = \begin{cases} T_{min}, & (T_d < T_{min}) \\ T_{max}, & (T_d > T_{min}) \\ T_d, & (T_{min} \le T_d \le T_{max}) \end{cases} \tag{8}$$

Where U is the average daily wind speed at the gauge height and formula (5) ~ (8) is named as Z2014d. In China, Yang et al. (1991) first proposed the transfer functions for CSPG based on the observations in Tianshan Mountains:

$$CE_{snow} = 100\exp(-0.056U_{10}) \tag{9}$$

$$CE_{rain} = 100\exp(-0.04U_{10}) \tag{10}$$

$$CE_{mixed} = CE_{snow} - (CE_{snow} - CE_{rain})(T_d + 2) / 4 \tag{11}$$

Where U_{10} is the daily average wind speed at the 10m height, T_d is daily average air temperature, and formula (9) ~ (11) is named as Y1991d. In the Qilian Mountains, Chen et al. (2015) also gave the transfer functions for CSPG:

$$CE_{rain} = -1.4U_g^3 + 2.987U_g^2 - 6.116U_g + 100 \tag{12}$$

$$CE_{mixed} = 100e^{-0.12U_g} \tag{13}$$

$$CE_{snow} = 100e^{-0.11U_g} \tag{14}$$

Where U_g is the daily average wind speed at the gauge height and functions (12) ~ (14) are named as C2015d.

2.2.3 Transfer functions at precipitation event scale

At a site in Saskatchewan, Canada, MacDonald and Pomeroy (2007) presented a transfer function for the the Geonor at precipitation event scale:

$$CE_{snow} = 1.010\exp(-0.09U_g) \tag{15}$$

where U_g is the average wind speed at the gauge height during the precipitation process and function (15) is named as M2007e. For CSPG, Chen et al. (2015) also gave the transfer function at the precipitation event scale:

$$CE_{rain} = 0.181U_{10}^3 - 0.256U_{10}^2 - 0.795U_{10} + 100 \tag{16}$$

$$CE_{mixed} = 100e^{-0.06U_{10}} \tag{17}$$

$$CE_{snow} = 100e^{-0.08U_{10}} \tag{18}$$

where U_{10} is the average wind speed at the 10m height during the precipitation process and functions (16)~(18) are named as C2015e.

2.2.4 Wind speed calculation at different heights

In the transfer functions mentioned above, the wind speed at the gauge height or 10m height will be used. However, most stations in the Qinghai-Tibet Plateau did not observe the wind speed at these two heights. Chen et al. (2015) gave the calculation formula for other heights based on the wind speed at the height of 1.5 m and 2.5 m:

$$U_Z = \frac{ln Z - ln Z_0}{ln 1.5 - ln Z_0} U_{1.5} \tag{19}$$

$$ln Z_0 = \frac{U_{2.5}\, ln 1.5 - U_{1.5}\, ln 2.5}{U_{2.5} - U_{1.5}} \tag{20}$$

In the above formula, Z is the height corresponding to the wind speed to be calculated, $U_{1.5}$ and $U_{2.5}$ are the wind speed values at the height of 1.5 and 2.5 meters respectively. In addition, He et al. (2009) gave the calculation formula for estimating wind speed at other heights based on wind speed of single layer in Tanggula area:

$$U_z = [lg(z / z_0) / lg(h / z_0)] \times U_h \tag{21}$$

Where U_z is the wind speed at height Z, H is the height of wind speed measurement, W_h is the wind speed at the observation height, Z_0 is the rough length.

2.3 Methods for testing of transfer functions

In order to evaluate the applicability of different transfer functions in Beiluhe site of the Qinghai-Tibet Plateau, the following evaluation indexes are used in this study:

(1) Mean absolute error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|P_{Gi} - P_{DFIRi}\right| \tag{22}$$

In the above formula, n is the number of precipitation, PG_i is the precipitation (mm) obtained by corrected or uncorrected Geonor and CSPG, and P_{DFIRi} is the precipitation (mm) obtained by DFIR device. The closer MAE value is to 0, the more accurate the precipitation obtained by this gauge or correction scheme will be.

(2) t-test

A t-test with a significance level of 5% was used to evaluate the significance of differences among corrected or uncorrected precipitation obtained by rain gauges and precipitation obtained by DFIR. If it passes the t-test, it is considered that there is no significant difference between the precipitation recorded by the rain gauge or the precipitation obtained by the correction method and the precipitation obtained by DFIR; otherwise, the difference is significant.

3. Results

3.1 The catch efficiency of CSPG and Geonor

CSPG and DFIR are artificial observation devices, and 170 precipitation events were recorded during the study period, including 57 snow events, 63 rainfall events and 18 mixed precipitation events. Geonor is connected to the data collector, which can record the precipitation data every 30 minutes, but due to instrument maintenance, power supply and other problems, some data are missing. The reference precipitation is obtained by correcting the evaporation loss and wetting loss of DFIR, and the catch efficiency (CE) of CSPG and Geonor for different precipitation types are calculated (Table 1). As can be seen from Table 1, both of the two gauges have higher CE for hail and rain, and have the lowest CE for snow. For the same precipitation type, CSPG and Geonor also have differences in CE. When the precipitation type is hail or rain, CSPG's CE is higher than that of Geonor, mainly because the wind-induced loss of these two precipitation types is small, while Geonor records precipitation every half an hour, so the systematic error leads to the failure to record some small precipitation. However, when the precipitation type is mixed or snow, the wind-induced loss has a great influence on CE. The Geonor with single-Alter shielded can effectively reduce the wind speed, resulting in higher CE of Geonor than that of CSPG. In the Qilian Mountains of the eastern Qinghai-Tibet Plateau, Chen et al. (2015) reported that the CE of CSPG for rain, mixed and snow are 96.7%, 87.6% and 82.9% respectively, while the results obtained in the Beiluhe site show that the CE of CSPG for rain, mixed and snow is 92.59%, 81.32% and 46.32% respectively. Especially when the precipitation type is snow, the CE of CSPG in Qilian Mountains is 36.6% higher, indicating the wind-induced loss in the central part of the Qinghai-Tibet Plateau is higher than that in the eastern part.

3.2 Testing transfer functions for Geonor

Transfer functions for Geonor snow precipitation include K2017a, K2017b, S2007h, S2007d, Z2014d and M2007e. In this study, the Geonor snow precipitation was corrected based on these six transfer functions, and then the corrected half-hour and hour precipitation were integrated into precipitation event scale or daily scale, and compared with the precipitation recorded by DFIR. Figure 2 shows the linear fitting results of Geonor and DFIR snow precipitation, it can be seen that the original snow precipitation recorded by Geonor is significantly lower than that recorded by DFIR. After corrected by K2017a scheme, the precipitation has increased significantly, but it is still lower than that recorded by DFIR. After corrected by S2007h, S2007d and Z2014d schemes, the precipitation is much higher than that of DFIR. Only snow precipitation corrected by K2017b and M2007e schemes have the best consistency with DFIR.

Transfer functions for Geonor mixed precipitation include K2017a, K2017b and Z2014d. Using these three functions, the Geonor mixed precipitation is corrected and compared with the DFIR. It can be seen from Figure 3 that the mixed precipitation recorded by Geonor is lower than that recorded by DFIR, while the precipitation recorded by Geonor is much lower after corrected by K2017a scheme, which indicates that K2017a is not suitable for mixed precipitation correction. After corrected by K2017b and Z2014d, the mixed precipitation recorded by Geonor is higher than that recorded by DFIR, but the Geonor precipitation corrected by Z2014d is seriously overestimated. Therefore, K2017b is more suitable for the correction of mixed precipitation in Beiluhe site.

The scheme for Geonor liquid precipitation correction is less, only Z2014d. By comparing the Geonor corrected and uncorrected liquid precipitation with DFIR (Figure 4), it is found that the liquid precipitation recorded by Geonor is slightly lower than that recorded by DFIR. However, after corrected by Z2014d, the precipitation of Geonor is seriously overestimated. It shows that Z2014d scheme is not suitable for Geonor liquid precipitation correction in Beiluhe site.

In order to quantitatively evaluate the advantages and disadvantages of different transfer functions, the MAE values between Geonor precipitation corrected by different transfer functions and DFIR precipitation are calculated, and t-test is used to determine whether there are obvious differences between the corrected Geonor and DFIR precipitation data (Table 2). The results show that there are obvious differences between the Geonor solid precipitation corrected by S2007d and the DFIR, indicating that this transfer function cannot be used for the correction of Geonor solid precipitation in Beiluhe site. There is no significant difference between the Geonor precipitation corrected by other correction schemes and the DFIR. However, from the perspective of MAE value, K2017b or M2007e is the best method for the correction of Geonor solid precipitation in Beiluhe region, and K2017b is the best method for the correction of mixed precipitation, which is consistent with the conclusion drawn in Figure 2-4.

3.3 Testing transfer functions for CSPG

The transfer functions for CSPG includes C2015e and C2015d given by Chen et al. (2015) in Qilian mountains of eastern Qinghai-Tibet Plateau and Y1991d given by Yang et al. (1991) in Tianshan mountains of Xinjiang. Because the transfer functions for CSPG liquid precipitation constructed by Chen et al. (2015) did not reach the significance level, C2015e and C2015d were not used for CSPG liquid precipitation correction in Beiluhe site. The correction results of different types of CSPG precipitation based on C2015e, C2015d and Y1991d are shown in Figure 6~8. It can be seen from Figure 5 that the original snow precipitation recorded by CSPG is seriously underestimated. After corrected by the three transfer functions, the CE has increased, but there is still an obvious underestimation. For liquid precipitation, the CSPG precipitation modified by Y1991d scheme is significantly higher than that of DFIR (Figure 7). The mixed precipitation of

CSPG corrected by C2015e and C2015d is also significantly higher than that of DFIR (Figure 6), while the mixed precipitation corrected by Y1991d scheme has a high consistency with the DFIR. However, since the correction scheme of Y1991d for the mixed precipitation is obtained by integrating the snow and rain precipitation correction schemes, it is considered that Y1991d cannot be used for the correction of the mixed precipitation in the central Qinghai-Tibetan Plateau.

MAE value and t-test are also used to quantitatively evaluate the precipitation correction scheme of CSPG (Table 3). The results show that there is a significant difference between the original CSPG solid precipitation and DFIR, but there is no significant difference between CSPG solid precipitation corrected by C2015e and C2015d schemes and DFIR, and the MAE value has decreased significantly. The corrected CSPG mixed and liquid precipitation have no significant difference with DFIR, but from the MAE value, the C2017d scheme leads to the increase of the observation error of CSPG mixed precipitation, and Y1991d scheme also leads to the increase of the observation error of CSPG liquid precipitation.

4. Discussion

4.1 Recommended transfer functions

According to the evaluation results of the existing transfer functions at Beiluhe site, it is considered that K2017b is suitable for the correction of Geonor snow and mixed precipitation in the central Qinghai-Tibet Plateau. Considering that the scheme is obtained by the WMO based on the precipitation comparison observation results of multiple stations in the word, it is recommended to use the K2017b scheme for the future correction of Geonor snow and mixed precipitation in the whole Qinghai-Tibet Plateau. M2007e also has a good performance in snow precipitation correction in Beiluhe area. However, considering that the scheme is obtained in a single site, no systematic verification has been carried out in other regions. Therefore, it is recommended to use this scheme when the Geonor precipitation only can be obtained at event scale. The applicability of the existing CSPG transfer functions at Beiluhe site is poor as a whole. The Y1991d scheme has a good correction result for CSPG mixed precipitation, however, it is based on the rain and snow correction scheme, and the snow precipitation after corrected by Y1991d scheme is underestimated and the rain precipitation is overestimated. Therefore, Y1991d scheme is not suitable for the central region of Qinghai-Tibet Plateau.

4.2 New transfer functions for CSPG and Geonor in the central Qinghai-Tibetan Plateau

For Geonor, K2017b and M2007e are suitable for snow or mixed precipitation correction. Although Geonor has a high CE of rainfall, there is no suitable correction scheme so far. Through the evaluation of the existing transfer functions for CSPG, it is found that the existing functions underestimates the CSPG snow precipitation, but overestimates the CSPG rain precipitation. Based on the precipitation comparative observation results at Beiluhe site, the transfer functions for Geonor liquid precipitation and CSPG at event scale are given:

$$CE_{Geonor,rain} = 1.1412e^{-0.034U_{10}},\ R^2 = 0.1998 \tag{23}$$

$$CE_{CSPG,snow} = e^{-0.1028(U_{10})(1-[\tan^{-1}(0.2496(T_{air}))+0.06669])},\ R^2 = 0.587 \tag{24}$$

$$CE_{CSPG,rain} = 1.0891e^{-0.026U_{10}},\ R^2 = 0.213 \tag{25}$$

$$CE_{CSPG,mixed} = Q_{snow} \times CE_{CSPG,snow} + (1 - Q_{snow}) \times CE_{CSPG,rain} \tag{26}$$

In formula 23~26, U_{10} is the average wind speed at 10m height during the precipitation process; T_{air} is the average temperature. Q_{snow} is the proportion of snow in the mixed precipitation. Based on the precipitation type recorded by laser raindrop spectrometer and the precipitation recorded by Geonor in Tanggula site of Qinghai-Tibet Plateau, the calculation method of Q_{snow} is obtained by combining the average temperature:

$$\begin{cases} Q_{snow} = 1,\ T_{air} < -7 \\ Q_{snow} = -0.0547T_{air} + 0.5823,\quad -7 \le T_{air} \le 5 \\ Q_{snow} = 0,\ T_{air} > 5 \end{cases} \tag{27}$$

4.3 Correction for hail precipitation

During the study period, in addition to rain, mixing and snow, 32 hail precipitation events were recorded, with the total precipitation of more than 200 mm. In the past, the correction scheme for hail precipitation has not been proposed. By analyzing the data, it is found that the average temperature at the time of hail occurrence is between 3.71 ℃ and 10.55 ℃. According to the previous precipitation type determination scheme, hail will be determined as rain. Based on the precipitation intercomparison results in the Beiluhe site, the hail precipitation CE is close to the rain, and the hail is corrected by the correction scheme recommended in this paper, results are shown in Figure 8. Both of the hail precipitation recorded by CSPG and Geonor have increased after correction, the CE of CSPG hail precipitation increased from 95.56% to 99.89%, and Geonor increased from 91.82% to 100.26%. From this result, it is not necessary to give a separate precipitation type determination scheme and correction scheme for hail precipitation.

5 Conclusions

Based on the precipitation observation results from August 2018 to September 2020 at Beiluhe site in the central Qinghai-Tibetan Plateau, the capture efficiency of CSPG and Geonor rain gauge are analyzed, and the applicability of six existing transfer functions for Geonor and three transfer functions for CSPG precipitation observation errors in the central Qinghai-Tibetan Plateau is evaluated. The results show that both of CSPG and Geonor T-200B have the highest CE for rain and the lowest CE for snow in Beiluhe area. Although the CE of CSPG for rain was slightly higher than that of Geonor T-200B, the CE of Geonor for snow and mixed precipitation was significantly higher than that of CSPG, indicating that the addition of single-Alter shielded could effectively improve the CE of snow and mixed precipitation. Through the evaluation of the existing transfer functions in Beiluhe area, the results show that K2017b scheme has the best correction effect on Geonor solid and mixed precipitation in the central Qinghai-Tibetan Plateau at the half-hour time scale. Considering that the scheme is proposed by WMO based on multiple global observation stations, it is considered that the scheme can be widely applied to the correction of Geonor solid and mixed precipitation in the whole plateau. At the event scale, M2007e has the best correction effect on Geonor snow precipitation in Beiluhe area, but the scheme is proposed based on the observation of a single station, so its applicability in other areas needs to be further evaluated. The existing transfer functions for CSPG is not suitable for Beiluhe area. The overall performance is that the revised snow precipitation is underestimated and rain precipitation is overestimated. In view of these shortcomings, this research also gives the transfer functions suitable for different types of precipitation in the central Qinghai-Tibet Plateau based on the results of precipitation comparison observation in Beiluhe area.

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Appendix

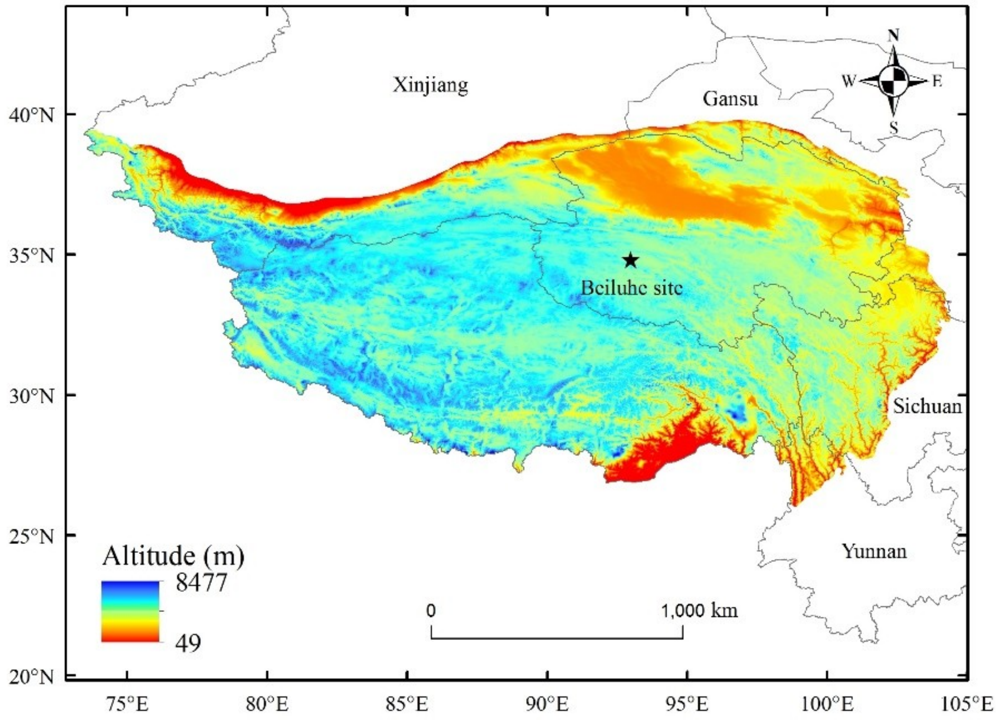

Figure 1. The geographical location of Beiluhe site

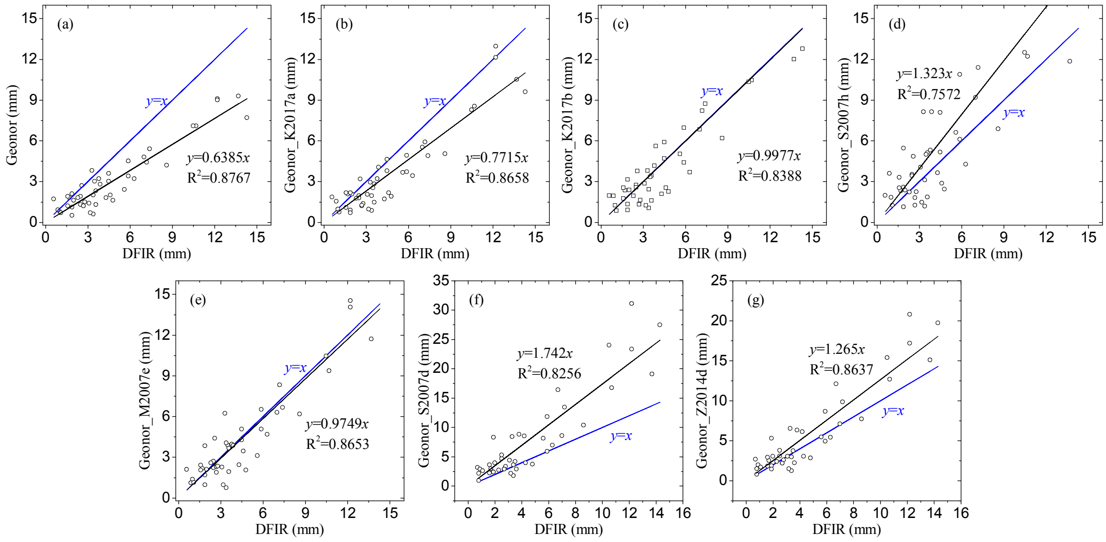

Figure 2. Comparison of snow precipitation recorded by DFIR and Geonor. Geonor_K2017a, Geonor_K2017b, Geonor_S2007h, Geonor_M2007e, Geonor_S2007d and Geonor_Z2014d represent the precipitation corrected by K2017a, K2017b, S2007h, M2007e, S2007d and Z2014d schemes respectively.

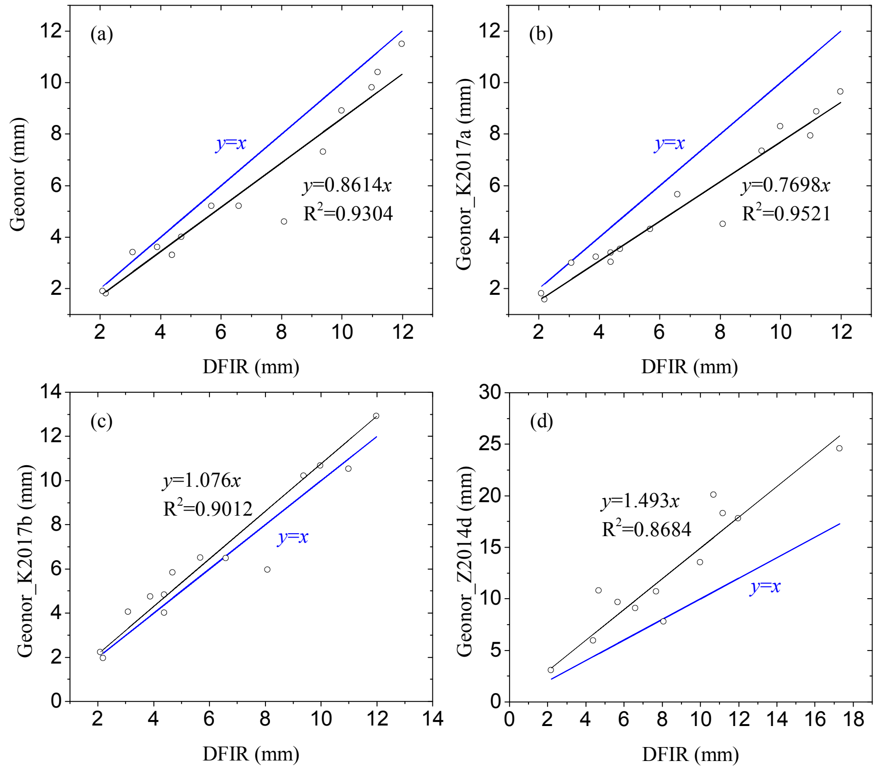

Figure 3. Comparison of mixed precipitation recorded by DFIR and Geonor. Geonor_K2017a, Geonor_K2017b and Geonor_Z2014d represent the precipitation corrected by K2017a, K2017b and Z2014d schemes respectively.

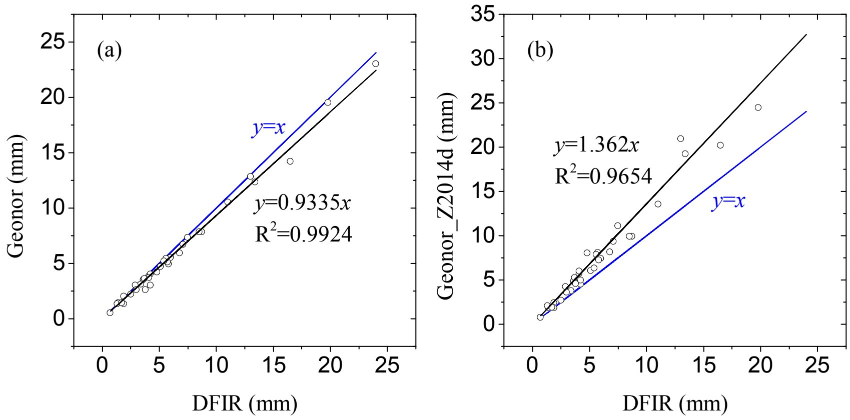

Figure 4. Comparison of rain precipitation recorded by DFIR and Geonor. Geonor_Z2014d represent the precipitation corrected by Z2014d scheme.

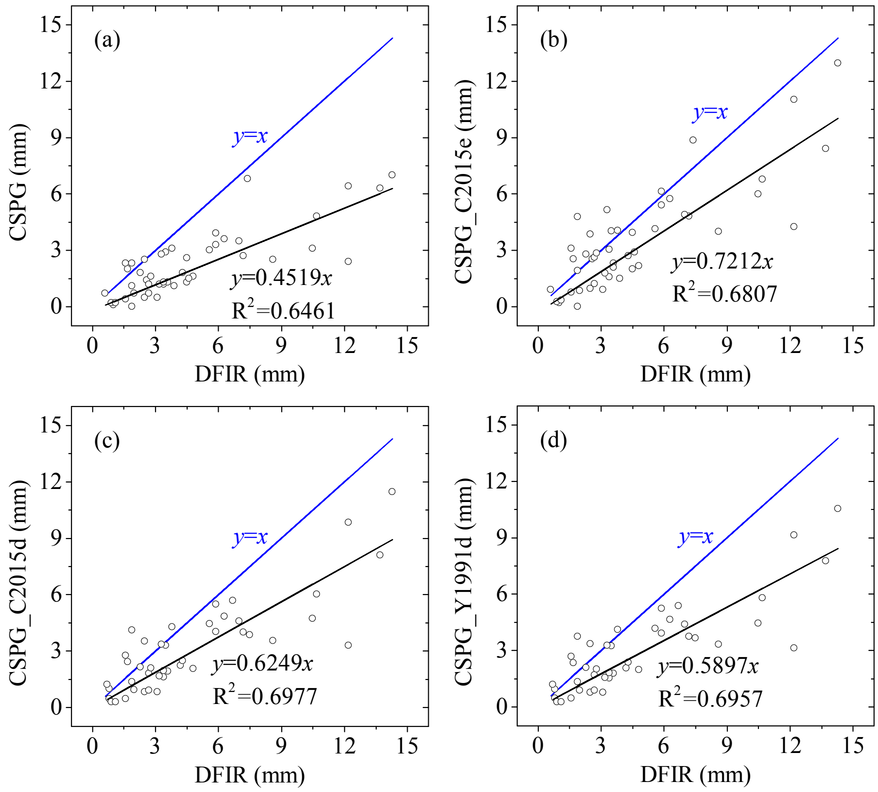

Figure 5. Comparison of snow precipitation recorded by DFIR and CSPG. CSPG_C2015e, CSPG_C2015d and CSPG_Y1991d represent the precipitation corrected by C2015e, C2015d and Y1991d schemes.

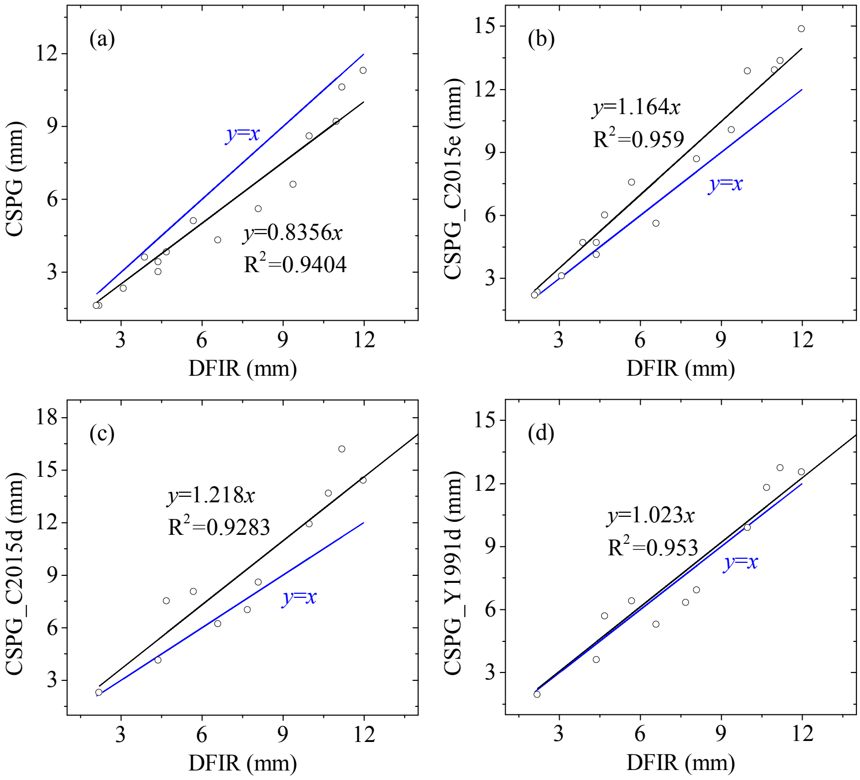

Figure 6. Comparison of mixed precipitation recorded by DFIR and CSPG. CSPG_C2015e, CSPG_C2015d and CSPG_Y1991d represent the precipitation corrected by C2015e, C2015d and Y1991d schemes.

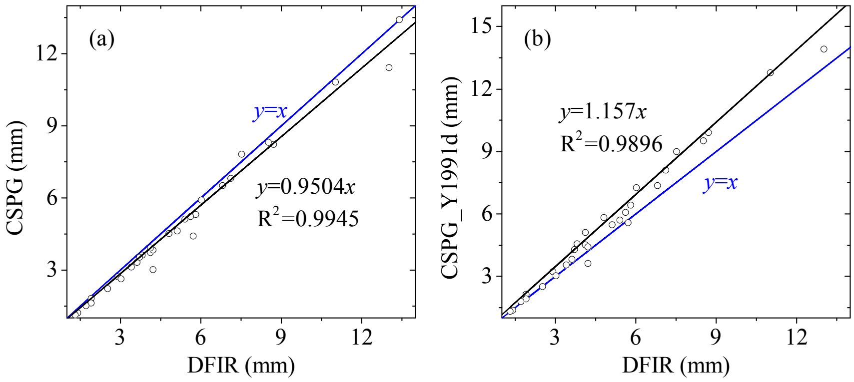

Figure 7. Comparison of rain precipitation recorded by DFIR and CSPG. CSPG_Y1991d represents the precipitation corrected by Y1991d scheme.

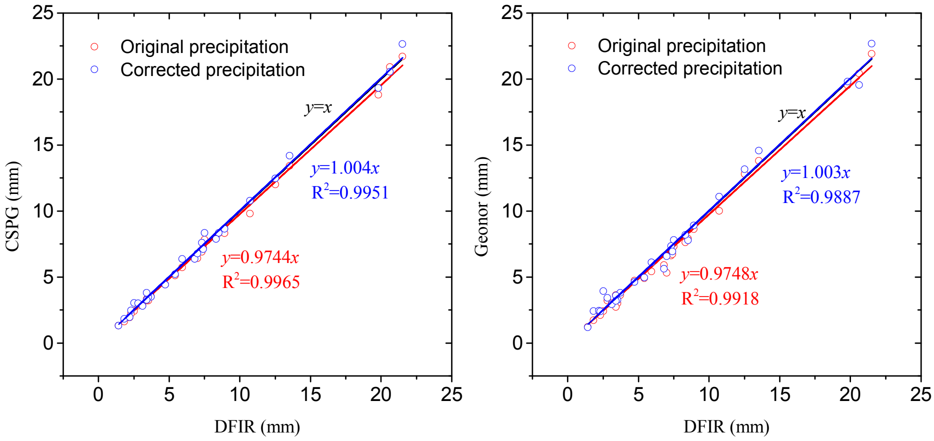

Figure 8. Comparison of CSPG and Geonor hail precipitation with DFIR

Table 1. CE of CSPG and Geonor T-200B for different precipitation types

Precipitation type	CSPG			Geonor		
	n	TP (mm)	CE (%)	n	TP (mm)	CE (%)
All	170	780.8	79.98	155	794.8	85.87
rain	63	348.3	92.59	59	327.7	92.06
mixed	18	101.5	81.32	18	106.5	85.32
snow	57	116.4	46.43	48	154.4	68.08
hail	32	214.6	95.56	30	206.2	91.82

Table 2. MAE values and t-test results between Geonor and DFIR precipitation. The value of t-test is 0, which means there is no significant difference under the confidence level of α= 0.05, and 1 means there is significant difference, "-" means no data.

	snow		**mixed**		**rain**	
	MAE	t-test	MAE	t-test	MAE	t-test
Geonor	1.7723	1	1.0047	0	0.5323	0
K2017a	1.3615	0	1.5007	0	-	-
K2017b	1.1928	0	0.9320	0	-	-
S2007h	2.2757	0	-	-	-	-
M2007e	1.0578	0	-	-	-	-
S2007d	3.3538	1	-	-	-	-
Z2014d	1.6896	0	4.2802	0	2.0511	0

Table 3. MAE values and t-test results between CSPG and DFIR precipitation. The value of t-test is 0, which means there is no significant difference under the confidence level of α= 0.05, and 1 means there is significant difference, "-" means no data.

	snow		**mixed**		**rain**	
	MAE	t-test	MAE	t-test	MAE	t-test
CSPG	2.5064	1	1.2033	0	0.4369	0
C2015a	1.6343	0	1.1233	0	-	-
C2017d	1.9087	0	1.9320	0	-	-
Y1991d	2.0271	1	0.8867	0	0.8587	0