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ONLINE FIRST

Asia-Pacific Journal of Atmospheric Sciences

ISSN 1976-7633

Asia-Pacific J Atmos Sci
DOI 10.1007/s13143-020-00193-3

Asia-Pacific Journal of Atmospheric Sciences
https://doi.org/10.1007/s13143-020-00193-3

Online ISSN 1976-7951
Print ISSN 1976-7633

ORIGINAL ARTICLE

Comparison and Analysis of Meteorological Variables Observed from the Glacier Area over the Tianshan Mountains in Kyrgyzstan and China

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Received: 9 April 2019 / Revised: 24 December 2019 / Accepted: 17 March 2020

Abstract

Due to the special natural environment over the glacier area in the Tianshan Mountains, the observation of meteorological data became difficult and is strictly scarce. Using the available data observed from the automatic meteorological station (AMS) installed on the Western Tianshan Mountain Station (WTMS) in Kyrgyzstan, the daily and seasonal variations of meteorological variables including air temperature (AT, °C), air pressure (AP, hPa), relative humidity (RH, %), and wind direction and speed (WD and WS, deg and m/s, respectively), as well as total radiation (TR, W/m^2) were primarily analyzed during the period from September 2016 to May 2017. These are compared with the meteorological data obtained from the AMS in the Eastern Tianshan Mountain Station (Daxigou Station, hereafter named as ETMS) in China. Further, the comparison study between the observed data from the WTMS and the NCEP/NCAR reanalysis data was performed to test the feasibility of reanalysis data in the vicinity of the Western Tianshan Mountains. The results revealed are as follows: (1) the observed data between the WTMS and ETMS presented high correlations, and the meteorological parameters detected from the ETMS were certainly representative of the variations in the WTMS. (2) The RH in the two regions showed comparatively high values ranging from 40% to 70% indicate the abundant amount of atmospheric water vapor content near the ground in the Tianshan Mountain area. (3) The predominant WD both in the WTMS and ETMS near the ground was along the south-east direction, with the values of WS between 0 and 2 m/s were accounted the largest proportion in two stations. (4) The NCEP/NCAR reanalysis data can reflect the changes in the synoptic weather scale of AT, RH, and AP to some extent. (5) The NCEP/NCAR reanalysis data of AT and RH were underestimated by 7.2% and 45.2% in the WTMS, respectively. Whereas, the values of AP, WD, and WS were overestimated by 83.8%, 28.8%, and 74.3%, respectively over the WTMS.

Keywords Tianshan Mountain · Glacier area · Meteorological variables · Kyrgyzstan · China

1 Introduction

Tianshan Mountain System (TMS), one of the seven major mountain ranges in the world and west-to-east orientation, is located in the center region of Eurasia which is about 4000 m of average altitude, and extends across China, Kazakhstan, Kyrgyzstan, and Uzbekistan. A total length of about 2500 km stretches between 250 and 350 km width in the north-south direction, and the maximum width of the mountain system cover ~800 km. Meanwhile, it is the largest independent zonal mountain range which is the farthest from the sea, and also the biggest mountain system in arid regions globally. The TMS plays a pivotal implication in people's lives owing to its abundant water resources, mineral resources, plant resources, and animal resources. Also, it is the most

Responsible Editor: Tianjun Zhou.

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Published online: 31 March 2020

precious freshwater resource in nature. The topography of the mountain system is the annual snow cover and modern glacial belts. Importantly, the glacier change is a direct result of climate change influenced by the meteorology. Consequently, the analysis of glacier surface meteorological elements of the Western Tianshan Mountain Station (WTMS) and Eastern Tianshan Mountain Station (ETMS) is one of the main contents of glacier-climate change research, which is not only important to reveal and discover the dynamic changes of microclimate in glacier regions. It can also provide meteorological parameters to study the response of glaciers to climate change, but also can lay the foundation of exploration with the interactive relationship between the climate and variation of the cryosphere.

Owing to the unique (natural and geographical) conditions of WTMS and ETMS, there are fewer studies on the property of climate change over the WTM glacier accumulation area in Kyrgyzstan. Moreover, the research is conducted in this region having high altitude, relatively cleaner air quality with less affected by human activities, which is favorable to realize and understand the variations of meteorological factors. The WTMS located on the west of the TMS in Kyrgyzstan, is an important part of the TMS because of its complex topography, harsh climate, sparse population and inconvenient transportation making the field observations extremely difficult in this glacier area (Wang et al. 2012). A few literature studies on the characteristics of surface meteorological variable, and the research on meteorological observations in the central area of glaciers is almost left blank which have paid more attention by the Worldwide scholars to its development and fill the knowledge gap (Shen and Liang 2001; Li et al. 2003; Wang et al. 2005; Jing et al. 2006; Han et al. 2006; Li et al. 2006). Therefore, focusing on the changes in meteorological conditions over this region is favorable to study deeply the climate change over the WTM in the recent years.

Many researchers had claimed the rapid impact on climate change in the recent years, and the reasons behind were natural as well as anthropogenic influences of pollutant sources (Akorede et al. 2012). Glaciers are the main source of water for the surrounding lowlands, and the melting of these glaciers may trigger several outburst floods (Lopez-Moreno et al. 2014). Climate change is likely to change the snow cover area and alter the water availability in the future making long-term water management more challenging (Khadka et al. 2014). At the same time, the variation of meteorological parameters observed over the WTMS and ETMS is closely connected with the variation of climate change. Accordingly, it is necessary to monitor and study closely the meteorological characteristic and change regularity on the glacier and snow surface of WTMS and ETMS at the background of climate warming. Furthermore, choosing the WTMS for observation, the data can make up for the shortage of glacier meteorological observation in the mountain area of Kyrgyzstan. At the same time, the comparative observation between the ETMS and WTMS can obtain accurate and continuous observation data of the Tianshan Mountain, which can provide basic data support and positive response for the meteorological prediction and forecast, national ecological security and sustainable development of social economy in China and Central Asia and serve as 'the Belt and Road' initiative.

There were a few research on the change in meteorological factors over the area with complex terrain and harsh climate or weather conditions, due to the relatively sparse meteorological observation stations. You et al. (2007a, 2007b) analyzed the characteristics of different meteorological variables and their variations measured during 2005–2006 in the Nam-Co region. They utilized the observed data from the weather stations established at the Nianqing Zhadang Glacier, South Slope, and North Slope to analyze the seasonal variations of meteorological factors in this area, and the reasons for the occurence of climatic differences on the south and north slopes. Sun et al. (2010) also used the meteorological data to investigate the daily and seasonal variations of key meteorological elements observed from September 2006 to August 2007 over the Lagone Glacier in Nianqing Tanggula Mountain. Their results demonstrated that the wind is dominated by southerly and northerly directions accounting for about 75.2% in this area throughout the year. Xie et al. (2007) verified the reliability of the National Environmental Prediction Center/National Atmospheric Research Center (NCEP/NCAR) reanalysis data over the meteorological data measured in the Nianqing Tanggula Mountain area. Their results showed that the NCEP/NCAR reanalysis data better reflected the changes in pressure and temperature, but the values were lower than the corresponding observations. Further, Wang et al. (2012) utilized the meteorological observation data obtained from the snow and ice surface of the Glacier area of the Urumqi River in Tianshan Mountain and the data from Daxigou station for the same period. They analyzed and discussed the characteristics of total solar radiation and ground-atmosphere heat transfer of the ice-and-snow surface on the glacier scale and the surroundings illustrating the variations of meteorological factors as well as its causes. Recently, Kumar et al. (2014) had made an attempt to measure different meteorological parameters at the Naradu Glacier region. Their analysis was based on the records available for a year period and illustrated that the seasonal trends in air temperature showed negative in accumulation season, while the positive trend in the ablation season.

The meteorological data over the WTMS is still scarce due to lack of observations, even blank; and the NCEP/NCAR reanalysis data are relatively coarse which causes the large uncertainty for the credibility in this study area. Therefore, it is necessary to understand the meteorological elements and their inter-relationships over the WTMS. Through the analysis of meteorological observation data that can not only enrich the meteorological data of the region but also provide a comprehensive understanding of climate change in the WTM region.

In this paper, the meteorological variables such as air temperature (AT, °C), atmospheric pressure (AP, hPa), relative humidity (RH, %), wind direction (WD, deg) and wind speed (WS, m/s) were obtained from the WTMS glacier area located in the TMS for the period during September 2016–May 2017, and are analyzed and studied extensively. In addition, the total radiation (TR, W/m^2) measurements obtained from the WTMS during the same above period are also utilized to analyze the average daily and seasonal variations of meteorological variables obtained in the glacier surface of this region. Also, the differences of meteorological elements observed between the wet and dry seasons are also discussed. Further, the differences of meteorological parameters obtained from the WTMS and ETMS are delivered, and possible reasons are given which will provide a reference for the glacier surfaces responding to climate change in the context of global warming. This will provide a more accurate theoretical basis for the future development of ice-snow interaction and energy balance of ice-and-snow surfaces in the Tianshan Mountains. In addition, the comparison and analysis between the observed data of different meteorological variables and the NCEP/NCAR reanalysis data are conducted during the study period in the area. Henceforth, the main purpose of this study is to verify the credibility of the NCEP/NCAR reanalysis data in the Tianshan Mountains.

2 Study Area

The Tianshan Glacier Meteorological Observatory (Western Tianshan Mountain Station, WTMS) located near Kara-Batkak glacier area (42°09’N, 78°16′E, altitude 3280 m) which is established by the Urumqi Institute of Desert Meteorology, China Meteorological Administration (CMA), China and the Kyrgyzstan National Academy of Water Problems and Water Energy Research Institute, Kyrgyzstan. The station identified with the number Y5101 and established on 8th September 2016 (Fig.1). Using the data obtained from the WTMS, the daily and seasonal variations of key meteorological parameters (AT, AP, RH, WD and WS) measured from 8th September 2016 to 23th May 2017, as well as changes in the TR obtained during October 2016, January, April, and July 2017 was preliminary studied and analyzed. In addition, to understand the variations of meteorological elements near the snow surface between the eastward and westward Tianshan mountains, the comparison and analysis were performed combined with the data observed from the Daxigou Glacier Automatic Meteorological Station (AMS) over the Eastern Tianshan Mountain Station (Daxigou Station, ETMS, 43°06′N, 86°50′E, altitude 3544 m). The geographic locations of the WTMS and ETMS are shown in Fig. 2. Besides, the meteorological sensors with their models installed at the WTMS and ETMS are shown in Table 1, where the instruments used in the two AMSs are the same model and are from the Corporation Limited of Jiangsu Radio Science Research Institute, China.

3 Data and Analysis

The scientific experiments were conducted in the WTMS by the Urumqi Institute of Desert Meteorology, CMA, China with the observation of major meteorological variables. It should be noted that the data collected from the AMSs are collected in the collector, and the sequential order of sampled data are presented as AT, RH, precipitation, WD, WS, AP, ground temperature, TR, sunshine, and evaporation. Currently, the effective time of data collection is from 8th September 2016 to 23rd May 2017 which forms the database for the present study. However, some observational data are missing or not collected due to severe weather conditions and lack of human resources to maintain the instrument in time with unstable power. In particular, the lack of data in summer is very serious, it does not have typical representativeness, so this paper does not select the complete summer data for the analysis. The effective data mainly consists of AT, AP, RH, WD, WS and TR. Consequently, we have not conducted an analysis of the rest of the meteorological factors owing to their complete data absence, with the uncertainty to some degree. The data sampling rate of AT, RH, AP, and TR is 6 times per minute, and one maximum and minimum are removed. The remaining four values are calculated by the arithmetically mean at the same time regarding the one-minute mean as the instantaneous value. In addition, the sampling rate of the WD and WS is once per second and calculated the averages of 3 s, 2 min, and 10 min treating the average of 3 s as an instantaneous value. The data observed by the ETMS in this work is obtained from the Xinjiang Meteorological Administration Information Center.

In this paper, the NCEP/NCAR reanalysis data are interpolated to obtain the meteorological factors in the WTMS. Accordingly, the NCEP/NCAR reanalysis data may not reflect partial changes in the observed meteorological values. The NCEP/NCAR reanalysis data is attained by applying the original data to the advanced analysis method/prediction model system (Trenberth 1995; Kalnay et al. 1996; Kistler et al. 2001; Simmon and Keay 2000). The database has been enhanced and refined through various observational data and is considered to be one of the most complete databases of continuous meteorological data (Simmon and Keay 2000; Aquila et al. 2005) containing the mean monthly analysis data gridded at 2.5° × 2.5°, since 1948 (released every 6 h from 00:00 UTC).

Fig. 1 The automatic weather station installed on the Western Tianshan Mountain surface in Kyrgyzstan

4 Results and Discussion

4.1 Comparison of Meteorological Variables Obtained from the WTMS and ETMS

For the effective observed data of one year period, we studied and analyzed the monthly mean values of AT, RH, AP, WD, and WS measured from the ETMS and WTMS as both are located on the same latitudes, and having nearly similar altitudes. Accordingly, we performed a comparison of the observation data and investigated the discrepancies of the meteorological elements measured from the two stations near the snow surface over the two regions. Moreover, the seasonal variations in TR obtained from the WTMS were also analyzed.

4.1.1 Variations of Air Temperature (AT)

The comparison results of the monthly mean AT noticed the highest and lowest AT values observed over the WTMS (blue lines) and ETMS (red lines) for the period September 2016–May 2017 (Fig. 3). Over the WTMS, the monthly mean, minimum and maximum values of AT demonstrated the same tendency (upward-downward), and all reaching to the minimum value in January 2017 during the study period. The maximum and minimum values of mean AT were found as 6.4 °C and − 13.7 °C in September 2016 and January 2017, respectively, with a difference in AT of 20.1 °C. Moreover, the maximum of the monthly mean highest and lowest values were observed as 5.7 °C and 7.2 °C in September 2016. On the contrary, the minimum of the monthly mean highest and lowest AT values were noticed to be −14.6 °C and − 12.7 °C in January 2017. The observed AT values from the WTMS and ETMS illustrated the same change in tendency, and the AT in the WTMS was found a little higher than the ETMS for the entire study period, without obvious differences between the two. This may be due to the altitude variations in the WTMS which is lower by 264 m than the ETMS.

4.1.2 Variations of Relative Humidity (RH)

Figure 4 demonstrated that the monthly mean variations of RH between the WTMS and ETMS are consistently showing

Fig. 2 Location map of Western Tianshan Mountain meteorological site (WTMS, Kyrgyzstan) and Eastern Tianshan Mountain meteorological site (ETMS, Daxigou Station, China)

Table 1 The main meteorological variables obtained from the automatic meteorological station (DZZ4 model) for both the ETMS (except TR) and WTMS

Parameter	Sensing Element	Model	Measuring Range	Measuring Accuracy
Air Temperature (AT, °C)	ZQZ-TW3 of high precision platinum resistance sensor	WUSH-BTH	(−50~50) °C	0.1 °C
Air Pressure (AP, hPa)	BAROCAP	PTB330	(500~1100) hPa	0.1 hPa
Relative Humidity (RH, %)	HMP45D of humidity sensor	WUSH-BTH	(5%~100%)	1%
Wind Direction (WD, deg)	Wind vane	ZQZ—TF	(0~360)°	3°
Wind Speed (WS, m/s)	Rotating cup anemometer	ZQZ—TF	(0~60) m/s	0.1 m/s
Total Radiation (TR, W/m^2)	Photodiode	WUSH-BR	(0~2000) W/m^2	0.02 W/m^2

the overall tendency of decrement-increment-decrement, comparatively synchronous, with larger fluctuations. Further, the minimum values were found to be 44.4% and 39.5% in January 2017; and the maximum were found in April 2017 with 66.2% and 64.3% during the study period over the two regions. The RH is strongly influenced by the temperature as when the temperature increases the evaporation may be strengthened results in the enhancement of RH to some extent. Also, the RH has a good correlation with the AT (Sun et al. 2010). Overall, the RH showed higher values between WTMS and ETMS ranging from 40% to 70% revealed that the atmospheric water vapor content is more abundant in the Tianshan Mountain region. Besides, the RH in the WTMS is basically higher than that noticed in the ETMS. Wang et al. (2012) have reported that the ground surface in the ETMS is mainly covered with meadows which can reflect less solar radiation corresponding to absorbing more amount of net solar radiation and transmitting much latent heat from the surface to the atmosphere. On the other hand, the short-wave radiation warms the surface making the evaporation and the water vapor content higher in the atmosphere. Therefore, the observed RH in the ETMS is comparatively higher than the WTMS. However, the altitude in WTMS is lower by about 264 m with a higher temperature of ice-and-snow surface results in larger heat transmittance and stronger surface evaporation leading to a higher amount of atmospheric water vapor content. Consequently, the RH found over the WTMS was observed higher than the ETMS during the study period.

4.1.3 Variations of Air Pressure (AP)

Figure 5 showed the monthly mean variations of AP near the ground between the WTMS and ETMS observed during September 2016–May 2017. The variations of AP in the two regions found consistent trends, and basically synchronous. Both the minimum and maximum values were found in September 2016 and January 2017, respectively at the two sites. Furthermore, the lowest and highest monthly mean AP values over the WTMS were found to be 1016.3 hPa and 1031.8 hPa, respectively, with an annual difference of 15.5 hPa. Similarly, the AP values were observed as 1017.1 hPa and 1031.5 hPa in the ETMS region, respectively, with an annual difference of 14.4 hPa. This illustrated that the annual changes are obviously seen in the two areas.

4.1.4 Variations of Wind Direction and Wind Speed (WD and WS)

The observed data of WS and WD in the two regions are shown as wind-rose diagrams in Fig. 6. In Fig. 6a, the dominant WD was along the south-east direction, and the WS between 0 and 2 m/s occupied 69.4%; whereas, the interval in WS ranging from 2 to 4 m/s accounted for 27.7%. Overall, the WS mainly centered on 0–4 m/s during the study period in the WTMS. Figure 6b demonstrated the variations of WS and WD noticed in the ETMS for the same period. The predominant WD was in the south-west direction, and the WS values between 0 and

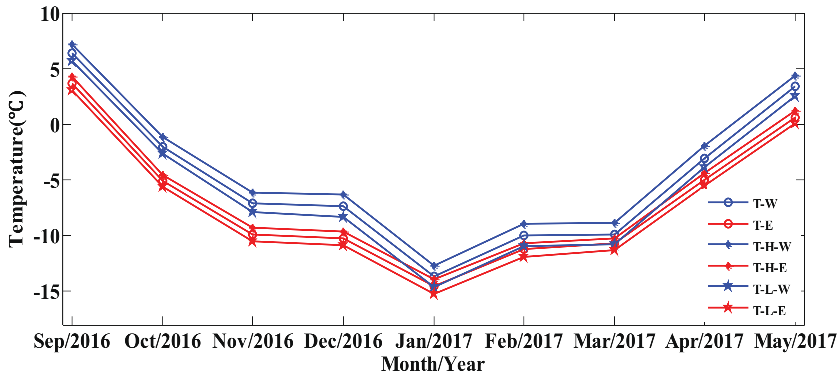

Fig. 3 Monthly and seasonal changes of AT observed from the WTMS and ETMS. The notations in the panel T, T-H, T-L, W and E represent AT, highest AT, lowest AT, WTMS and ETMS, respectively

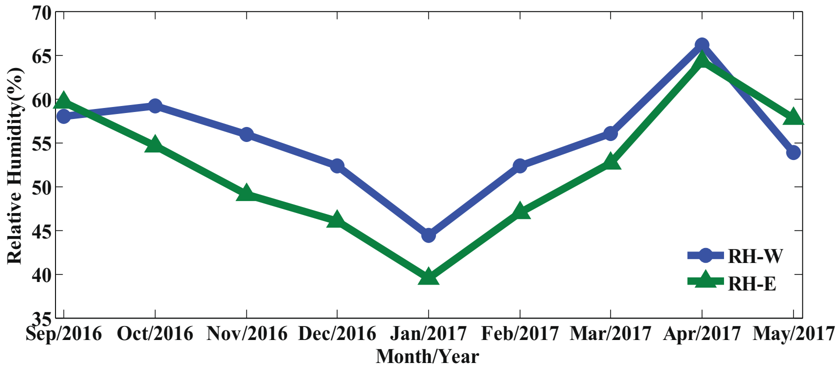

Fig. 4 Seasonal variations of RH between the WTMS and ETMS

2 m/s take up about 36.85%. While the wind speed of 2–4 m/s represent 25.0%, and the interval from 4 to 6 m/s, and 6 to 8 m/s were accounted for 23.6% and 11.1%, respectively. In addition, the WS mainly concentrates in the frequency range of 0–8 m/s. The values of WS in the range 0–2 m/s are accounting for the biggest proportion in these two regions.

4.1.5 Variations of Total Radiation (TR)

We defined the TR value as the mean value before one hour at a certain time (local time). In order to clearly understand the seasonal variations and regularity of TR in the WTMS region, we selected October 2016 and January, April, July 2017 as the typical months representing the autumn, winter, spring and summer seasons, respectively to obtain the daily mean variations of the TR by averaging hourly mean data. As shown in Fig. 7, the daily mean variations of TR in the typical months representing different seasons showed low values in the morning and evening, reached to a high value in the noon after 12:00 (local time), which is well fitted and agreed fairly with the general rule of variations in solar radiation (Wang et al. 2012). However, there are some differences in the time of occurrence of radiation value and maximum daily value. In addition, the monthly variations of TR showed minimum and maximum values of 469.73 W/m^2 and 705.15 W/m^2 in January and April, respectively, observed in the noontime at 12:00 (local time); whereas, the respective high and low values were found to be 641.22 W/m^2 and 471.20 W/m^2 noted in July and October at 11:00 AM (local time). Overall, the monthly mean values of TR observed in the month of April (summer) were found higher than the values noted in the other months or seasons attributed due to less cloud cover over the region, and the sunshine duration is for a longer time. On the contrary, the minimum value of TR appeared in January during the study period over the WTMS.

4.2 Comparison of Measured Meteorological Variables with the NCEP/NCAR Data

Due to some specific circumstances such as typical geographical and harsh climatic conditions, the observations over the stations becomes greatly difficulty, with extreme data scarcity over the glacier area of TMS. Therefore, many climate change studies will use the NCEP/NCAR reanalysis data (Xie et al. 2007; Kang et al. 2006) to overcome the lack of data that resulted in large uncertainty. However, the spectral model terrain employed by the assimilation system was different from the real terrain, and hence, some ground observations are discarded (Kistler et al., 1996). So, it is necessary to test the feasibility and reliability of ground-based measured meteorological elements observed from the WTMS are compared with the NCEP/NCAR reanalysis data. The researchers of relevant scholars help us to understand the meteorological conditions in the Tianshan Mountain region, but the demand for the

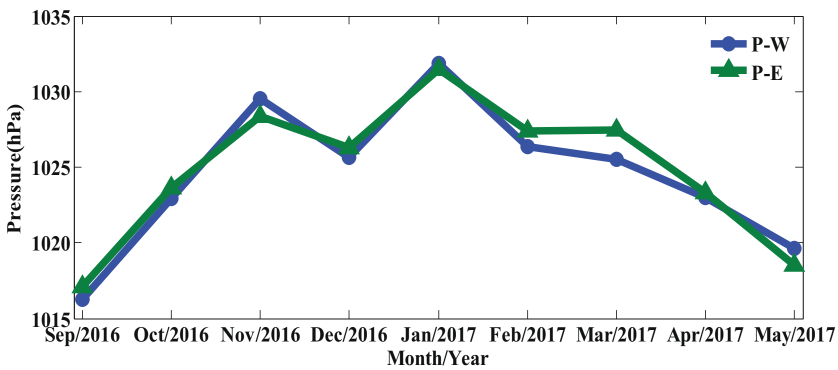

Fig. 5 Seasonal variations of AP between the WTMS and ETMS

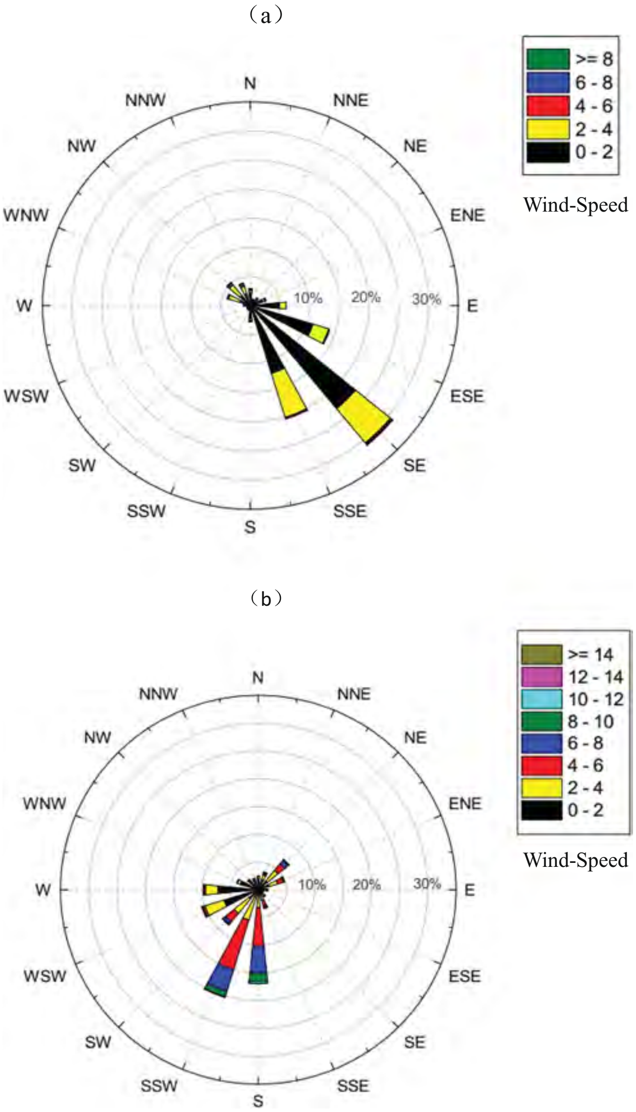

Fig. 6 Wind-rose diagrams of WS and WD presented in the two regions (a) WTMS and (b) ETMS

acquisition of meteorological data throughout the region is still necessary and urgent particularly, for the climate change studies (Xie et al. 2007).

4.2.1 Comparison of Air Temperature

The comparison of daily mean AT between the observed data from the WTMS and NCEP/NCAR reanalysis data during the period from September 2016 to May 2017 is shown in Fig. 8a. With the commencement of the spring season (March–May), the AT showed an increasing trend in the patterns of two datasets which is caused by the warmer and thicker of the tropospheric layer due to a rise in temperature (Moore and Semple 2004). The mean values of the measured and NCEP/NCAR reanalysis data were observed as −5.1 °C and − 5.0 °C, respectively, with notably found less difference between the two datasets. Moreover, the maximum of daily mean AT was observed on 18th September and 3rd October 2016, with 10.5 °C and 5.2 °C, respectively. Figure 8b showed a mild positive correlation (R = 0.23, $P = 0.001$) between the observed and NCEP/NCAR data which revealed that the NCEP/NCAR reanalysis data can certainly reflect the variations in the weather scale. The standard deviations of the observed and reanalyzed AT were found to be 6.9 °C and 6.4 °C, respectively. Therefore, the reanalyzed AT data was underestimated when compared with the observed data by 7.2% in the WTMS region.

4.2.2 Comparison of Relative Humidity

Figure 9a demonstrates the comparison of daily mean RH between the observed data from the WTMS and NCEP/NCAR reanalysis data during the study period. Overall, the mean of the measured data and NCEP/NCAR reanalysis data were noticed as 55.0% and 85.7%, respectively, with the larger difference observed between the two. Moreover, the maximum values of daily mean RH were found to be 99.9% and 93.3% observed on the 3rd and 18th April 2017, respectively. Figure 9b illustrated the correlation analysis between observed RH and NCEP/NCAR reanalysis data with a slight positive correlation (R = 0.21, $P = 0.003$). This shows that the reanalysis data can reflect the variations in the weather scale to some extent. The standard differences noted in the observed and

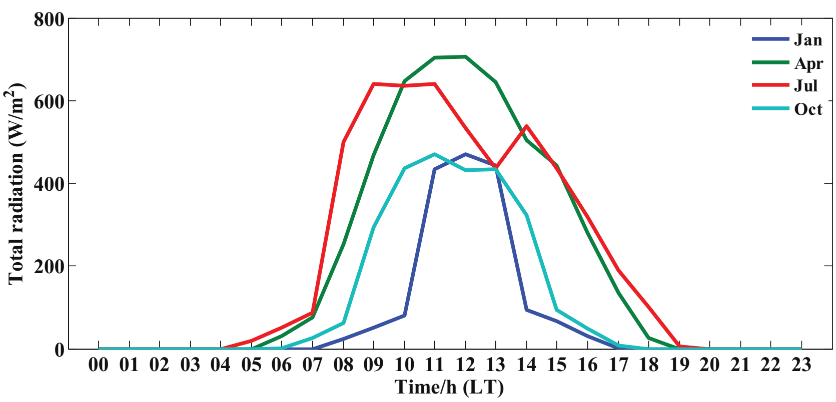

Fig. 7 The mean diurnal variations (local time) of the total radiation during the typical months measured in the WTMS region

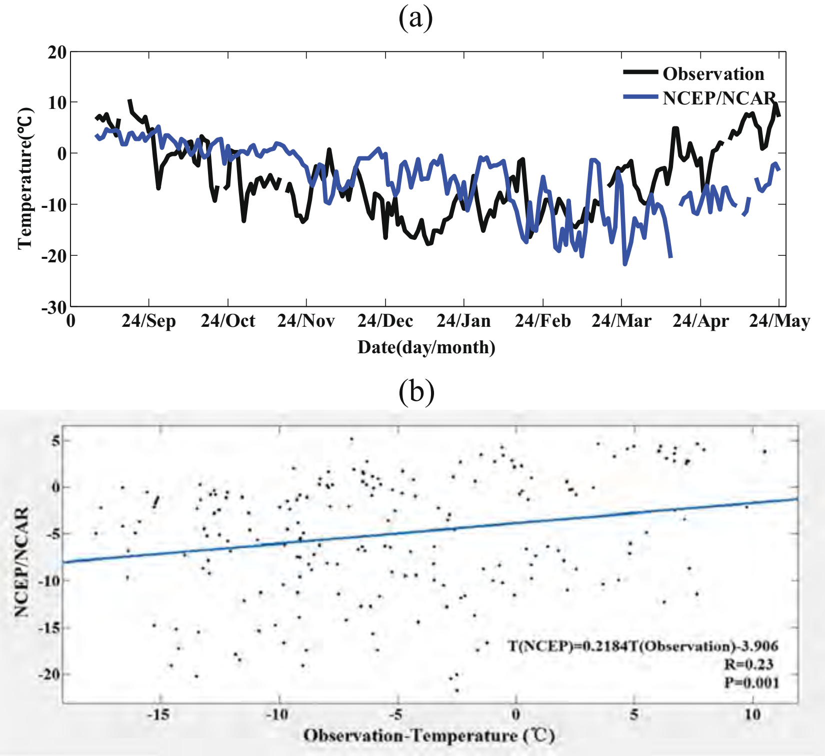

Fig. 8 (a) The daily mean AT (in °C) between the observed data of the WTMS and NCEP/NCAR reanalysis data during the study period and (b) their scatter plot shown with the correlation coefficient (R) and *P*-values obtained from the significance test

reanalysis RH data were noticed as 17.7% and 9.7%, respectively. Thus, it is understood that the reanalyzed data showed the underestimation in RH, with the observed by a variation amplitude of 45.2%.

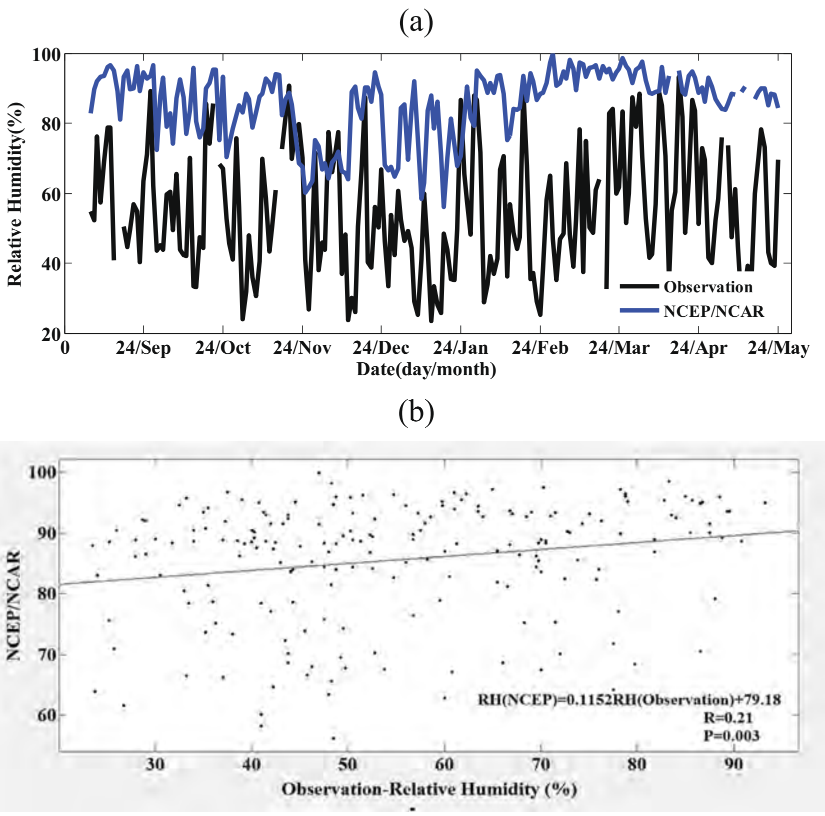

Fig. 9 Same as in Fig. 8, but for the RH

4.2.3 Comparison of Air Pressure

The comparison of daily mean AP between the observed data from the WTMS and NCEP/NCAR reanalysis data during the study period is shown in Fig. 10a. Generally, it is revealed that the observed data of AP is larger than the NCEP/NCAR reanalysis data. The mean AP of the measured and NCEP/NCAR reanalysis data were observed as 1024.53 hPa, and 1008.33 hPa, respectively, with a larger difference between them. Moreover, the maximum values of the daily mean AP were 1040.65 hPa and 1031.24 hPa found on 3rd October 2016 and 1st May 2017, respectively. Further, the observed and NCEP/NCAR reanalysis data of AP showed a slight negative correlation (R = -0.24, $P = 0.001$) showed that the reanalysis data can reflect the variations in the weather scale to some extent again. The standard differences found between the observed and reanalyzed AP were 7.36 hPa and 13.53 hPa, respectively. Therefore, the reanalyzed AP data found overestimated when compared with the observed data with a change of 83.8%.

4.2.4 Comparisons of Wind Direction and Speed

Similarly, the comparison of daily mean WD and WS between the observed data from the WTMS and NCEP/NCAR reanalysis data were performed during the study period (Fig. 11a and c). On the whole, the observed data and the NCEP/NCAR reanalysis data were not matched well and found with a bigger difference. Figure 11b and d revealed that the observed and NCEP/NCAR reanalysis WD and WS data presented the strictly negligible negative correlations (R = −0.02, $P = 0.693$; R = −0.02, $P = 0.551$). The standard differences between the observed and reanalyzed WD was 75.5° and 106.0°, respectively. Therefore, in comparison with the observed data, the reanalyzed WD is overestimated by the variation of 28.8%. At the same time, the observed WS is basically smaller than the reanalyzed data and the standard deviation of two were observed as 0.9 m/s and 3.5 m/s. When compared with the observed data, the reanalyzed data of WS showed overestimation with the variation amplitude of 83.8%. Thus it reveals the bigger difference which existed in the two-type of datasets.

Based on the comparison of observed data with NCEP/NCAR reanalysis data, it is found that reanalysis data can reflect the changes in synoptic-scale to some degree, but the two still present comparatively large errors which may be due to several reasons. Firstly, the observational site near the Tianshan Mountain is very rare, leading to the large differences in the interpolated values of the NCEP/NCAR reanalysis data. Further, the data observed by the AMS are point data, but the NCEP/NCAR reanalysis data are grid data that represent the average of a certain area. Therefore, the spatial scales are inconsistent for two kinds of datasets and the mean square errors become smaller after the averaged process. Finally,

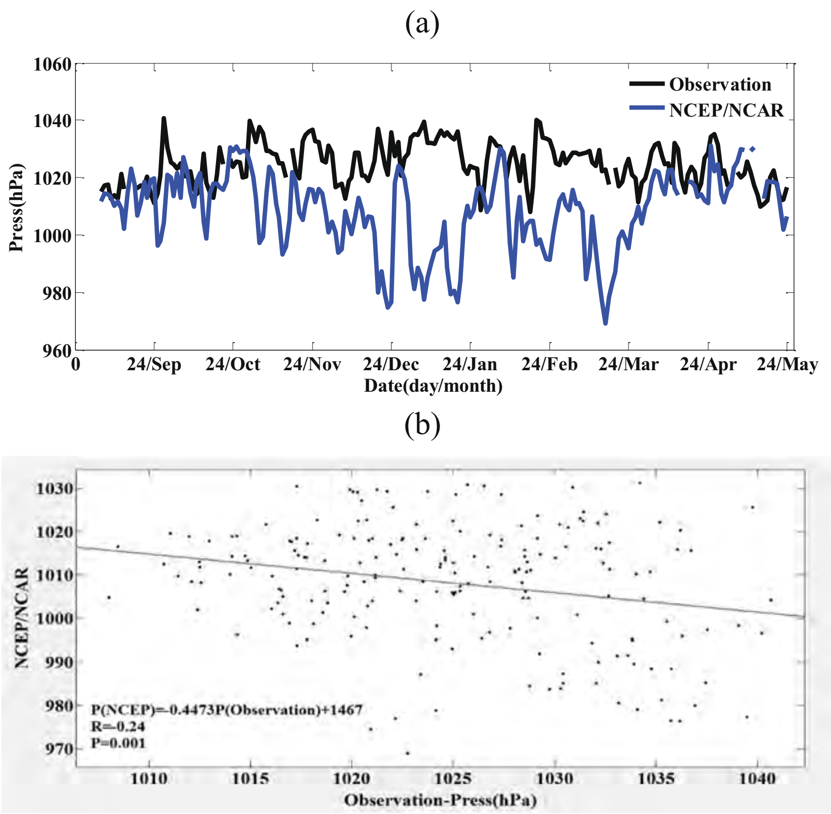

Fig. 10 Same as in Fig. 8, but for the AP

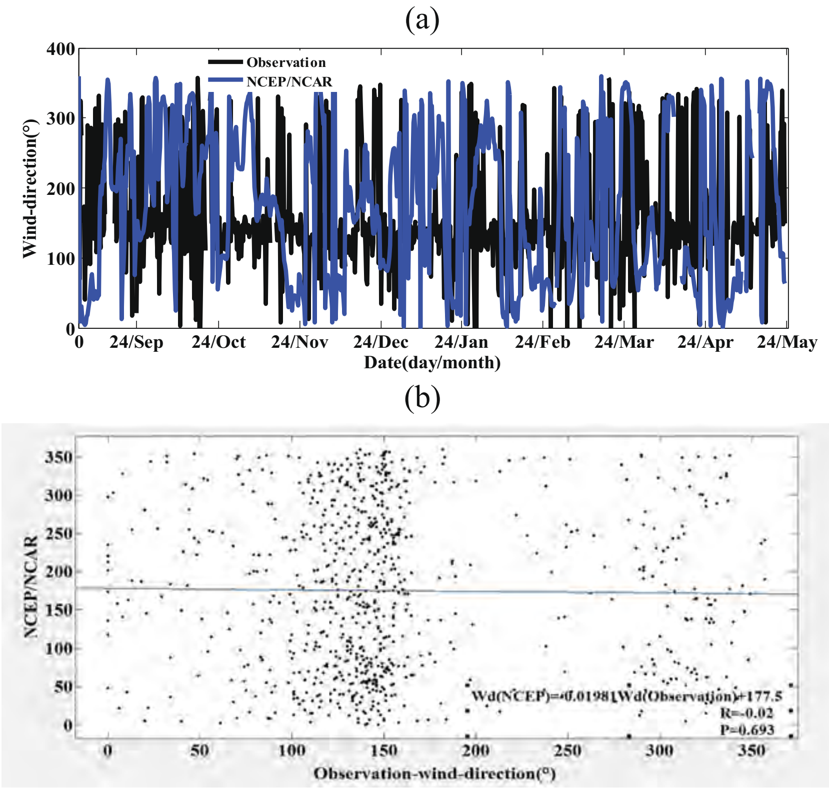

Fig. 11 Same as in Fig. 8, but for the WD and WS

some extreme weather events may be rejected by the NCEP/NCAR reanalysis data. Kistler et al. (2001) have reported the overestimation or underestimation of the reanalysis data is mainly caused by the terrain in the reanalysis and the assimilation model is different from the real situation.

5 Summary of Conclusions

In this paper, the meteorological variables including AT, AP, RH, WD, and WS, etc., obtained from the WTMS located in Kyrgyzstan and ETMS in China are primarily analyzed and compared for the study period from September 2016 to May 2017. Moreover, the comparison study between the observed and NCEP/NCAR reanalysis data obtained over the WTMS is also conducted. The major conclusions drawn from this study are as follows:

1) When compared the AT observed from the WTMS and ETMS, it is illustrated the same change in their patterns with an overall AT showed higher observed from the WTMS than the ETMS, but with significantly less difference. Also, the lowest and highest values of monthly mean AT showed the same tendency (upward-downward), reaching a maximum and minimum in September 2016 and January 2017, respectively.
2) Overall, the RH showed higher values ranging from 40% to 70% observed between the WTMS and ETMS indicate that the atmospheric water vapor content near the ground is more abundant in the Tianshan Mountain region. However, the altitude in the WTMS is lower by 264 m than the ETMS with a higher temperature of the ice-and-snow surface, larger heat transmittance, and stronger surface evaporation results in a higher amount of atmospheric water vapor content. Consequently, the humidity is higher in WTMS than the ETMS.
3) The monthly mean AP near the ground demonstrates that consistent tendency exists between the WTMS and ETMS, and basically synchronized. The minimum and maximum values of AP occur at the same time as September 2016 and January 2017.
4) The dominant direction of the wind (WD) was observed along the south-east direction in the WTMS, and the wind speed mainly centered in 0–4 m/s. Conversely, the predominant wind direction is also observed along south-west in the ETMS, and the values mainly concentrated in the range 0–8 m/s. The values of WS in 0–2 m/s are all accounting for the highest proportions (~50%) in both the regions.
5) In WTMS, the monthly mean TR in April is obviously higher than in January, July, and October, and the TR with the minimum mean was noticed in the month of January 2017.
6) The NCEP/NCAR reanalysis data of AT and RH in the WTMS are underestimated by 7.2% and 45.2%, respectively; whereas, the AP, WD, and WS are overestimated by 83.8%, 28.8%, and 74.3%, respectively. Based on the same

background of circulations, the observed data in the WTMS and ETMS present high correlation when compared with the NCEP/NCAR reanalysis data which reflect the variation of NCEP/NCAR data on the weather scale to some extent. However, the measured values of WD and WS in the WTMS showed lower correlations with the NCEP/NCAR reanalysis data for the study period at Tianshan Mountain.

In summary, it is found that the ETMS and WTMS are in the same context of large-scale wind circulations. The meteorological parameters detected from the ETMS are certainly representative of the variations in the WTMS. Moreover, the NCEP/NCAR reanalysis data with the relatively coarse resolution and its credibility are still low in the study areas where the climate is harsh, few observation stations, and scarce meteorological data. Further, we will pay more attention in the future to perform the observational study in combination with the meteorological variables observed by the ground-based stations, and retrieved from the multiple remote sensing methods to lay a foundation for a comprehensive understanding of climate changes in the Tianshan Mountain area.

Acknowledgments This work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences, Grant No. XDA20100306, National Natural Science Foundation of China (Grant Nos. 41565003, 91644224), Scientific Research Service fee (Grant No. IDM2018005), and Desert Meteorological Scientific Research Foundation of China (Grant No. Sqj2017011). One of the authors KRK is grateful to the Department of Science and Technology (DST), Govt. of India for the award of DST-FIST Level-1 (SR/FST/PS-1/2018/35) scheme to Department of Physcis, KLEF. The authors would like to acknowledge support from the Urumqi Institute of Desert Meteorology, China Meteorological Administration (CMA), China and Govt. of Kyrgyzstan for supporting the project in Kyrgyzstan for the establishment of Western Tianshan Mountain site located near Kara-Batkak glacier area. The authors would like to acknowledge Prof. Tianjun Zhou, the Editor-in-Chief of the journal and the anonymous reviewers for their helpful comments and constructive suggestions towards the improvement of an earlier version of the manuscript.

Compliance with Ethical Standards

Conflict of Interest Authors declare no conflict of interest in the present work.

References

Akorede, M.F., Hizam, H., AbKadir, M.Z.A., Aris, I., Buba, S.D.: Mitigating the anthropogenic global warming in the electric power industry. Renew. Sust. Energ. Rev. **16**(5), 2747–2761 (2012)

Aquila, A., Ruti, P.M., Calmanti, S., et al.: Discrepancies in southern hemisphere mid-latitude atmospheric variability of the NCEP-NCAR and ECMWF Reanalyses. Physics. **112**(D8), 409–427 (2005)

Han, T.D., Ding, Y.J., Ye, B.S., et al.: Mass-balance characteristics of Urumqi glacier no.1, Tianshan, China. Ann. Glaciol. **43**, 323–328 (2006)

Jing, Z.F., Jiao, K.Q., Yao, T.D., et al.: Mass balance and recession of Urumqi glacier no.1, Tianshan, China over the last 45 years. Ann. Glaciol. **43**, 214–217 (2006)

Kalnay, E.E., Kanamitsu, M., Kistl, R.: The NCEP/NCAR 40-year reanalysis project. Bulletin of American Meteorological Society. **77**, 437–471 (1996)

Kang, S., Qin, D., RenJiawen, et al.: Relationships between an ice core record ETMS from southern Tibetan plateau and atmospheric circulation over Asia. Quaternary Sciences. **26**(2), 153–164 (2006)

Khadka, D., Babel, M.S., Shrestha, S., Tripathi, N.K.: Climate change impact on glacier and snow melt and runoff in Tamakoshi basin in the Hindu Kush Himalayan (HKH) region. J. Hydrol. **511**, 49–60 (2014)

Kistler, R., Kalny, E., Collins, W.: The NCEP/NCAR 50-year reanalysis: monthly means CD-ROM and documentation. Bulletin of American Meteorological Society. **82**(2), 247–267 (2001)

Kumar R, Randhawa S S, Singh S. Meteorological Parameters of Naradu Glacier Valley, India: An analysis. Journal of Engineering & Applied Sciences, 2014

Li, Z., Han, T., Jing, Z., et al.: A summary of 40-year observed variation facts of climate and Glacier No.1 at the headwaters of Urumqi River, Tianshan, China. Journal of Glaciology and Geocryology. **25**(2), 117–123 (2003)

Li, X., Li, Z., You, X., et al.: Study of the ice formation zones and stratigraphy profiles of snow pits on the Glacier No.1 at the headwaters of Urumqi River. Journal of Glaciology and Geocryology. **28**(1), 37–44 (2006)

Lopez-Moreno, J.I., Fontaneda, S., Bazo, J., Revuelto, J., Azorin-Molina, C., Valero-Garces, B., Moran-Tejeda, E., Vicente-Serrano, S.M., Zubieta, R., Alejo-Cochachin, J.: Recent glacier retreat and climate trends of ETMS in cordillera Huaytapallana, Peru. Glob. Planet. Chang. **112**, 1–11 (2014)

Moore, G.W.K., Semple, J.L.: High Himalayan meteorology: weather at the south col of Mount Everest. Geophys. Res. Lett. **31**(18), 77–100 (2004)

Shen, Y., Liang, H.: Global ice melting accelerated would threaten to human environmental safety. J. Glaciol. Geocryol. **24**(2), 208–211 (2001)

Simmon, E.T.M.S.I., Keay, K.: Mean southern hemisphere extra tropical cyclone behavior in the 40-year NCEP-NCAR reanalysis. J. Clim. **13**, 873–885 (2000)

Sun, W., Xiang, Q.I.N., Xiping, H., et al.: Variations of the meteorological elements at the Lanong glacier in the Nyainqentanglha range. J. Glaciol. Geocryol. **32**(1), 62–69 (2010)

Trenberth, K.E.: Atmospheric circulation climate changes. Climate Change. **13**, 873–885 (1995)

Wang, G., Yongping, S., Maoweiyi: Climate warming at headwater of Urumqi River, Xinjiang in past 44 years and its impact on glacier shrinking. J. Glaciol. Geocryol. **27**(6), 813–819 (2005)

Wang, M.-z., Wen-shou, W.E.I., Rong-yi, C.H.E.N., Xin-chun, L.I.U.: Observations and analyses of near surface meteorological elements on glacier no.1 at headwaters of Urumqi River, Tianshan Mountains. J. Glaciol. Geocryol. **34**(1), 12–20 (2012)

Xie, A., Dahe, Q., Jiawen, R., et al.: Reliability of NCEP/NCAR reanalysis on mount Qomolangma and Western Nyainqentanglha range. Acta Geograph. Sin. **62**(3), 268–278 (2007)

You, Q., Kang, S., TianKeming, et al.: Preliminary analysis on climate features at Mt. Nyainqentanglha Tibetan Plateau. J. Mt. Sci. **25**(4), 497–504 (2007a)

You, Q., Kang, S., Li, C., et al.: Variation features of meteorological elements at Namco Station. Tibetan Plateau. Meteorological Monthly. **33**(3), 54–60 (2007b)