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Evaluation of ERA5-Land reanalysis datasets for extreme temperatures in the Qilian Mountains of China

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An increase in extreme temperature events could have a significant impact on terrestrial ecosystems. Reanalysis temperature data are an important data set for extreme temperature estimation in mountainous areas with few meteorological stations. The ability of ERA5-Land reanalysis data to capture the extreme temperature index published by the Expert Team on Climate Change Detection and Indices (ETCCDI) was evaluated by using the observational data from 17 meteorological stations in the Qilian Mountains (QLM) during 1979–2017. The results show that the ERA5-Land reanalysis temperature data can capture well for the daily maximum temperature, two warm extremes (TXx and TX90p) and one cold extreme (FD0) in the QLM. ERA5-Land's ability to capture temperature extremes is best in summer and worst in spring and winter. In addition, ERA5-Land can capture trends in all extreme temperature indices except the daily temperature range (DTR). The main bias of ERA5-Land is due to the difference in elevation between the ground observation station and the ERA5-Land grid point. The simulation accuracy of ERA5-Land increases with the decrease of elevation difference. The results can provide a reference for the study of local extreme temperature by using reanalysis data.

KEYWORDS

reanalysis, extreme temperature, ERA5-Land, Qilian Mountains, climate change

1. Introduction

Between 2011 and 2020, the average temperature of the global surface was 1.1°C warmer than it was at the end of the 19th century (before the Industrial Revolution) (IPCC, 2021). Since the 1950s, all inhabited regions have seen more frequent and more intense heat waves, while extreme cold temperatures have become fewer and milder, which affects people's lives and property safety (Shtober-Zisu and Wittenberg, 2021). Global warming has also led to the spread of extreme events to places where they have not been common before. The extent of warming projected by models after the 2050s is associated with taking action against climate change. If carbon dioxide emissions are drastically and rapidly reduced from now on and throughout the 21st century, warming will stop around the middle of the century, and warming will be around 1.5°C or 2°C by the end of the century. With global warming, heat waves, heavy rainfall and droughts will continue to become more severe and frequent (Ruml et al., 2017; Sun et al., 2017; Supari et al., 2017).

Generally, previous research on extreme temperatures utilized observational data (Lin et al., 2017; Ruml et al., 2017; Sun et al., 2017; Supari et al., 2017). However, in mountainous

areas with complex climatic conditions and terrain, there are few meteorological stations, limiting the availability of data. Reanalysis data such as ERA-Interim, ERA5, and NCEP have been extensively applied because of their higher resolution and longer time series (Zhao P. et al., 2020; Virman et al., 2021; Araujo et al., 2022; Zhao and He, 2022b; Zou et al., 2022). However, biases between observations and reanalysis data may exist, suggesting that it is necessary to compare reanalysis error with observations (Liu L. et al., 2020; Huai et al., 2021; Rakhmatova et al., 2021; Wu et al., 2021a,b; Xin et al., 2021; Li et al., 2022). European Centre for Medium-Range Weather Forecasts (ECMWF) implements the Copernicus Climate Change Service (C3S) on behalf of the European Union. As part of the Copernicus project, ECMWF has provided ERA5-Land, a state-of-the-art reanalysis data set for land applications, which is available for free in the Copernicus Climate Data Store (Joaquín et al., 2021). ERA5-Land reanalysis data have finer resolution ($0.1^\circ \times 0.1^\circ$) than ERA5 and ERA-Interim reanalysis data (Alexander and Gregor, 2020; Cao et al., 2020; Jiang et al., 2020; Liu J. et al., 2020; Luis and Johannes, 2020; Pelosi et al., 2020; Konstantinos et al., 2021; Pelosi and Chirico, 2021). Several studies evaluated ERA5-Land data (Cao et al., 2020; Pelosi et al., 2020; Zandler et al., 2020; Jiao et al., 2021; Rakhmatova et al., 2021; Ruqing et al., 2021; Wu et al., 2021b; Jintao et al., 2022). For example, Zou et al. (2022) found that ERA5-Land underestimated the observed temperature of coastal urban agglomerations in southeast China with a mean bias of 0.90°C . Araujo et al. (2022) found that the ERA5-Land reanalysis temperature was reliable for Pernambuco, Brazil. Hong et al. (2021) found that the performance of ERA5 precipitation products in Jiangxi Province, China was worse than that of ERA5-Land in 2019.

The Qilian Mountains are an important ecological protection barrier in northwest China and an important water source for Hexi Corridor (Deng et al., 2013; Yang et al., 2021). Due to the complex terrain and climatic conditions of the QLM, meteorological stations are rare, especially above 3,500 m (Lin et al., 2017; Wang L. et al., 2019; Wang X. et al., 2019; Zhou et al., 2019), necessitating the use of reanalysis data. Zhao and He (2022a) assessed ERA5-Land reanalysis monthly average temperature for the QLM and found that the observed temperature variation was captured very well. Li et al. (2022) found that ERA5-Land was more suitable than China Meteorological Forcing Dataset for analyzing temperature trends in the QLM. However, previous studies which evaluated reanalysis data for the QLM were primarily focused on monthly averages but rarely examined extreme temperature events. The Qilian Mountains and Hexi Corridor are affected by different circulation systems, and the local climate changes are more complicated, with frequent meteorological disasters such as drought, flood, sandstorm, dry hot air, low temperature freezing damage and snow disaster. Therefore, evaluating the reliability of ERA5-Land data is necessary in understanding extreme temperature events in the QLM.

Here, we used temperature data for the years 1979 to 2017 from 17 meteorological stations in the QLM to evaluate the ability of ERA5-Land reanalysis data to capture extreme temperature events. Evaluation of the extremes of temperature with reanalysis datasets provides a reference for the research on climate change in the QLM.

2. Data and methods

2.1. ERA5-Land temperature data (T_e)

ERA5-Land hourly data were downloaded from the website of ECMWF (link:¹). We used ERA5-Land hourly 2 m temperature data for years 1979 to 2017 in this study. The location of cell grid points ranged from 35.8 to 40°N and from 93.5 to 104°E , which covered the entire QLM region (Figure 1). According to the latitude and longitude coordinates of the 17 stations, the ERA5-Land cell closest to each station is selected to avoid spatial interpolation (Zhao and He, 2022a). ERA5-Land hourly reanalysis data is given for UTC time, with an 8-h difference from Beijing time in China; we matched the times of observation and ERA5-Land reanalysis with a time-difference conversion method (Zhao P. et al., 2020; Xu et al., 2022). ERA5-Land grid elevation is extracted from the Digital Elevation Model (DEM) of Geospatial data cloud,² with the information of ASTER GDEM 30 m. The spatial range of DEM used in this study is 33.94 – 45.29°N , 88.81 – 107.24°E , which can cover the entire the Qilian Mountains (Table 1; Figure 1).

2.2. Observations (T_o)

In this study, observational daily temperature data including daily mean temperature (T_{mean}), daily maximum temperature (T_{max}) and daily minimum temperature (T_{min}) at 17 meteorological stations in the QLM were obtained from China Meteorological Data Sharing Service of National Meteorological Information Center.³ These data can be directly used in scientific research after strict quality control by provider from five aspects: climate limit value and allowable value checking, extreme value checking, internal consistency checking between timing value, daily average, and daily extreme value, time consistency checking, and space consistency checking (Zhao C. et al., 2020; Zhao P. et al., 2020; Zhao and He, 2022a). Spatial distribution and specific information on the meteorological stations can be found in Figure 1 and Table 1, respectively.

2.3. Extreme temperature indices

Eleven extreme temperature indices were selected from ETCCDI (Yin and Sun, 2017) based on their application in climatology research in the region (Hu et al., 2017; Yin and Sun, 2017; Yu et al., 2020; Xu et al., 2022). These indices were grouped into four types: (1) absolute indices (TN_x, TN_n, TX_n, and TX_x), (2) threshold indices (ID0 and FD0), (3) percentile-based indices (TN10p, TX10p, TN90p, and TX90p), and (4) other indices (DTR) (Table 2).

1 <https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=form>

2 <https://www.gscloud.cn>

3 <http://cdc.cma.gov.cn/index.jsp>

TABLE 1 Geographical information about meteorological stations used in this study (Zhao and He, 2022a).

No	Site name	Latitude (°)	Longitude (°)	Altitude (m)	H _{ERA} (m)	H _{ERA} -H _{Obs} (m)
1	Jiu Quan	39.67	98.72	1,470	1,397	-73
2	Gao Tai	39.38	99.72	1,357	1,342	-15
3	Zhang Ye	38.92	100.58	1,550	1,500	-50
4	Shan Dan	38.78	101.08	1,760	1801	41
5	Yong Chang	38.23	101.97	1,987	2022	35
6	Wu Wei	38.08	102.92	1,525	1,498	-27
7	Wu Shaoling	37.2	102.87	3,045	3,431	386
8	Gao Lan	36.55	103.67	2,032	2033	1
9	Leng Hu	38.75	93.58	2,762	3,244	482
10	Tuo Te	38.87	98.37	3,460	3,621	161
11	Ye Niugou	38.62	99.35	3,200	3,575	375
12	Qi Lian	38.18	100.3	2,800	3,098	298
13	Da Chaidan	37.83	95.28	3,000	3,257	257
14	De Lingha	37.25	97.13	2,762	2,914	152
15	Gang Cha	37.33	100.17	3,100	3,275	175
16	Men Yuan	37.45	101.62	2,800	4,109	1,309
17	Min He	36.23	102.93	1,900	2,144	244

H_{ERA} is the ERA5-Land grid point height (m), H_{Obs} is the altitude of meteorological stations.

2.4. Evaluation methods

In this study, we used DISO (the distance between indices of simulation and observation) indicator combined with correlation coefficient (r) and mean absolute error (MAE) to assess the reliability of ERA5-Land in capturing daily temperature data and 11 extreme temperature indices in the QLM (Hu et al., 2019; Zhou et al., 2021; Hu et al., 2022; Xu et al., 2022). The equation of DISO is shown in Table 3. DISO is more flexible in expressing the quality of data than other indices (Zhou et al., 2021). The results of DISO value can be divided into two categories in this study: above 0.5 and 0.0–0.5 to analyze the reliability of ERA5-Land in capturing extreme temperature events in the QLM (Hu et al., 2019). It is suggested that ERA5-Land can capture extreme temperature events well when DISO is less than 0.5 (Hu et al., 2019). DISO greater than 0.5 indicates a poor simulation (worst if greater than 1.0), and less than 0.5 indicates a good simulation (best if close to 0.0). In addition, RB was divided into two groups: below 0.0 and above 0.0. The RB below 0.0 or above 0.0 was considered to indicate that ERA5-Land relatively underestimates or overestimates the observational data, respectively. NRMSE shows the mean error of ERA5-Land. NMAE can eliminate the effect of positive and negative offsetting of ERA5-Land errors. The CC is a important indicator of the correlation between ERA5-Land and Observations (Lei et al., 2022).

3. Results and discussion

3.1. Comparisons of daily temperatures

The correlation coefficient (r) between ERA5-Land and observed T_{mean}, T_{max}, and T_{min} was all larger than 0.9 (Table 4), the

determination coefficient (R^2) between ERA5-Land and observed T_{mean}, T_{max}, and T_{min} was 0.99, 0.99, and 0.98, respectively (Figure 2), indicating excellent agreement between ERA5-Land daily temperature and observational daily temperature. The average MAE of T_{mean}, T_{max}, and T_{min} at all stations was 2.24, 3.52 and 2.69, respectively (Table 4). Station No.16 has the smallest r value and the largest MAE, which may be due to the larger altitude difference (1,309m) between T_e and T_o at Station No.16 (Table 1). The DISO value for T_{mean} and T_{max} was <0.5 for 47 and 53% of the stations, respectively (Table 5). The DISO value of T_{min} at all stations is greater than 0.5. The average DISO at all stations of T_{mean}, T_{max}, and T_{min} was 2.44, 0.62, and 2.19, respectively. The spatial distribution of DISO value for T_{mean} and T_{max} is shown in Figure 3. In general, the DISO value was higher within the QLM than in the Hexi Corridor, indicating that the ability of ERA5-Land to capture T_{mean} and T_{max} in this mountainous area was worse than that in the oasis area. In general, reliability of ERA5-Land to capture T_{max} is best in the QLM.

3.2. Comparisons of extreme temperatures

High correlation coefficient (r) of 11 extreme temperature indices between T_e and T_o indicates that ERA5-Land can capture the extreme temperature indices well (Table 6). Only the average r at all stations of DTR is less than 0.8, and the average r at all stations of other extreme temperature indexes is above 0.85. After comparing the MAE of 11 extreme temperature indices between T_e and T_o, we can learn that TX90p have MAE smaller than 1 at all stations (Table 7). DISO of DTR at individual stations ranged from 0.28 to 0.69 with an average across the stations of 0.46, indicating that ERA5-Land simulates DTR

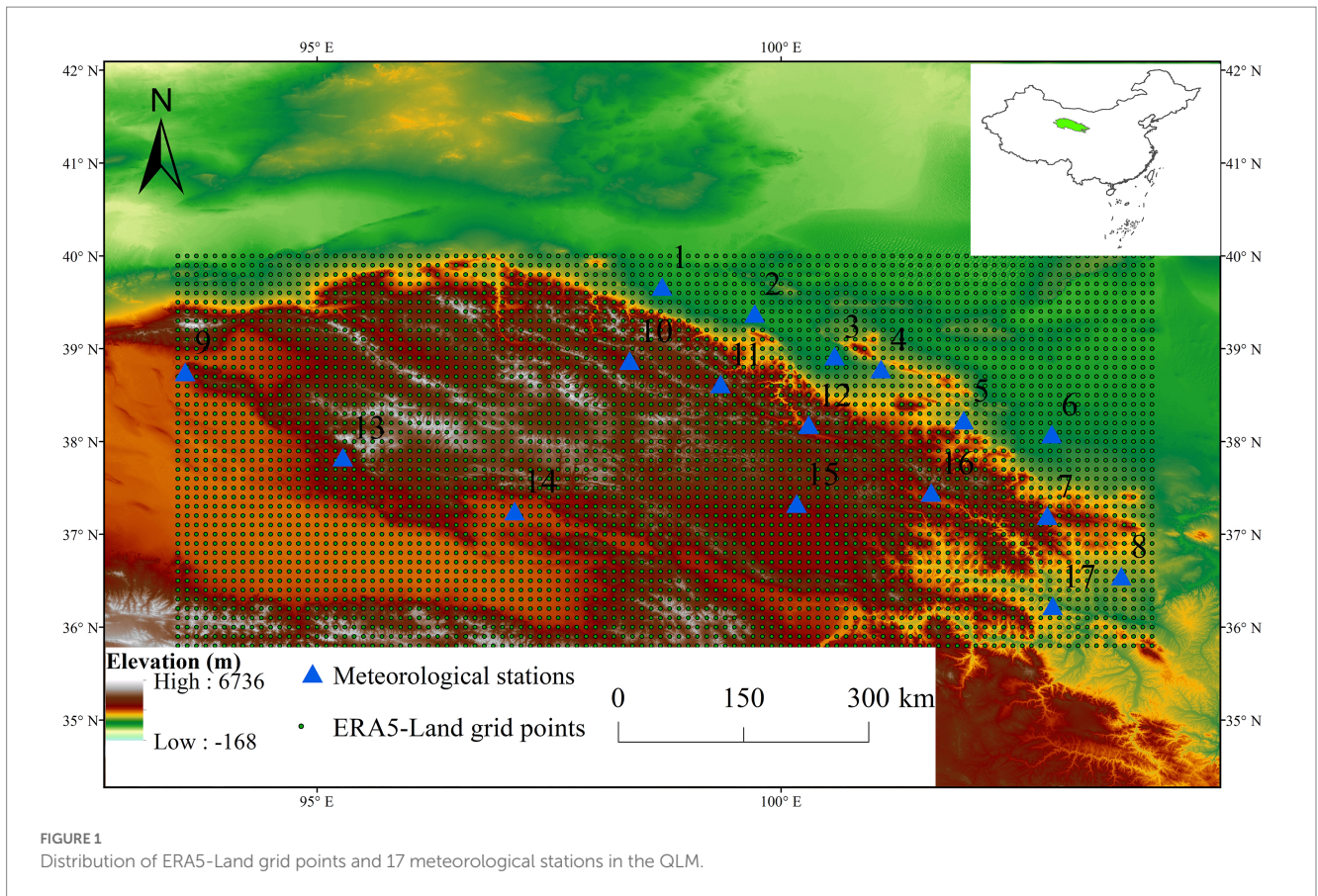


FIGURE 1 Distribution of ERA5-Land grid points and 17 meteorological stations in the QLM.

TABLE 2 Description of extreme temperature indices.

Index	Name	Definition	Unit
TXx	Max T_{max}	Monthly maximum of maximum daily temperatures	°C
TNx	Max T_{min}	Monthly maximum of minimum daily temperatures	°C
TXn	Min T_{max}	Monthly minimum of maximum daily temperatures	°C
TNn	Min T_{min}	Monthly minimum of minimum daily temperatures	°C
FD0	Frost days	Number of days per year when TN (daily minimum) < 0°C	d
ID0	Ice days	Number of days per year when TX (daily maximum) < 0°C	d
TN10p	Cool nights	Percentage of days when TN < 10th percentile	d
TX10p	Cool days	Percentage of days when TX < 10th percentile	d
TN90p	Warm nights	Percentage of days when TN > 90th percentile	d
TX90p	Warm days	Percentage of days when TX > 90th percentile	d
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C

in the QLM well (Table 8). ERA5-Land captured FD0 very accurately, with DISO < 0.5 for 15 meteorological stations and an average of 0.27. ERA5-Land reanalysis performed better for TXx than for TXn, TNn, and TNx. DISO for TXx was < 0.5 at 12 stations accounting for approximately 71% of all stations. TX90p performed better than TN90p, TX10p and TN10p. DISO for TX90p was < 0.5 at 9 stations accounting for approximately 53% of all stations. Zhu et al. (2016) found that ERA-Interim and 20CR reanalysis can capture intensity indices better than frequency indices over China, in agreement with this study. The mean DISO values of the warmest days (TXx) in spring, summer, autumn and winter were 0.31, 0.16, 0.32, and 0.93, respectively (Table 9). The spring DISO values of TXn, TNn and TNx

were the largest. Overall, ERA5-Land reanalysis performed well in summer and poorly in spring and winter, similar to previous studies (Zhao P. et al., 2020; Xu et al., 2022). Figure 3 shows the spatial distribution of DISO values of extreme temperature index. In general, FD0 has the best performance within the Qilian Mountains region.

3.3. Trends in daily and extreme temperatures

Figures 4–7 shows trends in daily temperature and extreme temperature indices based on ERA5-Land and observations during

TABLE 3 Evaluation criteria used in this study.

Metric	Name	Formula	Optimal value	Unit
NRMSE	Normalized root mean square error	$\frac{1}{\bar{O}} \sqrt{\frac{1}{n} \sum_{i=1}^n (E_i - O_i)^2}$	0	/
NMAE	Normalized mean absolute error	$\frac{1}{n\bar{O}} \sum_{i=1}^n E_i - O_i $	0	/
RB	Relative bias	$\frac{\sum_{i=1}^n (E_i - O_i)}{\sum_{i=1}^n O_i} \times 100$	0	%
CC	Pearson correlation coefficient	$\frac{\sum_{i=1}^n (E_i - \bar{E})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^n (E_i - \bar{E})^2} \sqrt{\sum_{i=1}^n (O_i - \bar{O})^2}} \times 100$	1	/
DISO	Distance between indices of simulation and observation	$\sqrt{NRMSE_i^2 + NMAE_i^2 + RB_i^2 + (CC_i - 1)^2}$	0	/
RMSE	Root-mean-square-error	$\sqrt{\frac{1}{n} \sum_{i=1}^n (E_i - O_i)^2}$	0	°C

n represents the number of samples; \bar{E} and \bar{O} represent the mean values of extreme temperature indices obtained from ERA5-Land and observations, respectively; and E_i and O_i are values of extreme temperature indices obtained from ERA5-Land and observations, respectively.

TABLE 4 Correlation coefficient (*r*) and mean absolute error (MAE) between observational daily temperature and ERA5-Land daily temperature at 17 stations in the QLM from 1979 to 2017.

No	<i>r</i>			MAE		
	T_mean	T_max	T_min	T_mean	T_max	T_min
1	0.992	0.991	0.976	1.20	1.80	2.06
2	0.989	0.990	0.972	1.89	1.40	2.55
3	0.991	0.986	0.978	1.38	1.45	2.09
4	0.992	0.987	0.980	1.20	2.49	1.86
5	0.988	0.987	0.969	1.26	2.03	2.03
6	0.992	0.988	0.981	1.21	1.35	1.66
7	0.977	0.978	0.953	1.57	1.52	2.55
8	0.982	0.983	0.963	2.25	4.62	2.43
9	0.991	0.993	0.971	1.75	4.30	2.21
10	0.970	0.969	0.949	2.83	4.85	2.94
11	0.968	0.961	0.941	4.63	7.29	4.36
12	0.969	0.960	0.944	4.48	7.01	4.25
13	0.987	0.990	0.961	2.50	4.80	2.65
14	0.988	0.987	0.966	1.23	1.39	2.52
15	0.983	0.982	0.961	1.26	2.22	1.97
16	0.960	0.949	0.925	5.65	8.51	4.86
17	0.987	0.983	0.963	1.72	2.74	2.70
Average	0.983	0.980	0.962	2.24	3.52	2.69

TABLE 5 Statistics of DISO for ERA5-Land daily temperature at 17 stations in the QLM from 1979 to 2017.

Statistics	T_mean	T_max	T_min
0–0.5 (%)	47	53	0
> 0.5 (%)	53	47	100
Average	2.44	0.62	2.19

1979–2017 in the QLM. Daily temperature data obtained from ERA5-Land reanalysis and observation datasets showed significant positive trends from 1979 to 2017. This indicated that the warming trend in observed data at daily scale was captured accurately by the ERA5-Land reanalysis temperature. TXx (warmest day), TNx (warmest night), TX90p (warm days), and TN90p (warm nights) exhibited a significant positive trend. With global warming, extreme heat events are increasing in intensity and frequency (Xu et al., 2022). Also, extreme high-temperature indices were captured by ERA5-Land well. In addition, TX10p (cool days), TN10p (cool nights), ID0 (ice days), and FD0 (frost days) based on observations and ERA5-Land exhibited negative trends. Both TNn (coldest night) and TXn (coldest day) calculated from T_e and T_o showed a positive trend, showing that the intensity of extreme low temperature events in the QLM increases with global warming. Zhou et al. (2016) analyzed the variation in extreme temperature indices over China using high-resolution gridding data (CN05), and found that the coldest day (TXn) had less variability than the coldest night (TNn), and the warmest day (TXx) had less variability than the warmest night (TNx), similar to the results of this study. Our conclusion is that the trend in extreme

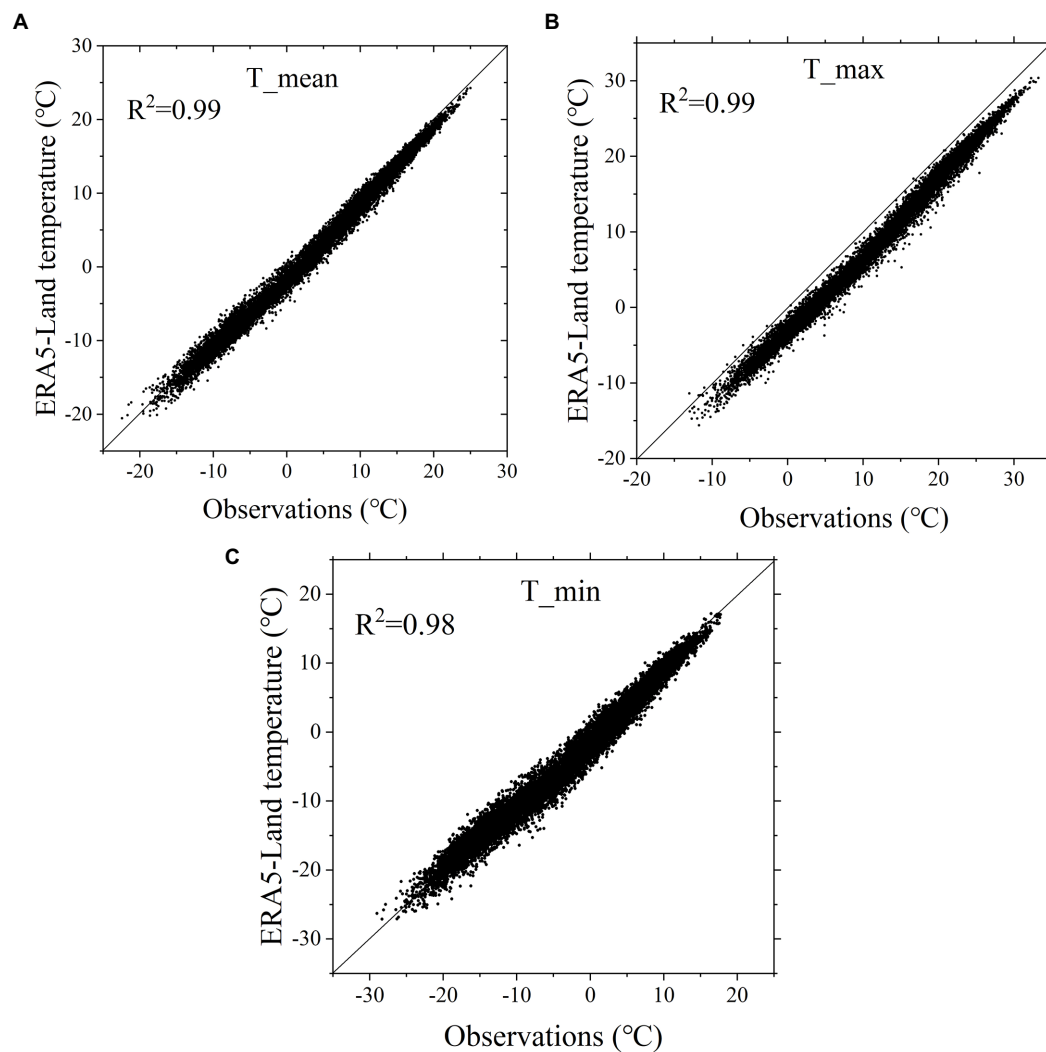


FIGURE 2

Scatter plots of ERA5-Land daily temperature and observed values of T_{mean} (A), T_{max} (B), and T_{min} (C). The solid line is 1 :1 line.

low-temperature indices can be captured by ERA5-Land well. The observational DTR showed a large decreasing trend ($-0.162^{\circ}\text{C}/\text{decade}$), while DTR of ERA5-Land showed only a slightly decreasing trend ($-0.009^{\circ}\text{C}/\text{decade}$), indicating that ERA5-Land did not capture the trend in DTR well (Table 10). Generally, all tendencies in extreme temperature events except DTR were captured well by ERA5-Land in the QLM.

3.4. Possible bias analysis

Observational data in the QLM were underestimated by ERA5-Land for daily temperature, DTR, and absolute indices of extreme temperature (Figures 4, 5). Our results are similar to previous studies. (Zhao P. et al., 2020; Huai et al., 2021; Zou et al., 2022; Zhao and He, 2022a). Many studies indicated that the main reason for bias in reanalysis temperature data is the elevation difference between T_e and T_o (Gao et al., 2014, 2018; Xu et al., 2022). The linear relationship between T_e and T_o bias and elevation difference is shown in Figure 8, the R^2 values of T_{mean} , T_{max}

and T_{min} were 0.541, 0.454, and 0.469, respectively. The daily biases were related to the elevation difference between T_e and T_o , especially for T_{mean} . The simulation reliability of ERA5-Land increased with a decrease in the elevation difference (Zhao and He, 2022a). Therefore, it is possible to correct ERA5-Land reanalysis temperature through a temperature lapse-rate model to further reduce the error and improve the precision of temperature reanalysis (Dee and Uppala, 2009; Gao et al., 2012; Di Giuseppe et al., 2013; Gao et al., 2017). The number of meteorological stations used in this study is small, especially above 3,500 m. However, many studies have shown that the limited number of meteorological stations is sufficient to effectively and accurately evaluate the applicability of reanalysis data (Huai et al., 2021; Jiao et al., 2021). We believe that the bias is mainly caused by the elevation difference between T_e and T_o . Other factors, such as the interpolation method, terrain complexity, and glaciers, are also potential sources of bias (Huang et al., 2022; Zhao and He, 2022a). The DISO values of T_{mean} , T_{max} and T_{min} were 2.44, 0.62 and 2.19, respectively. Due to the high altitude of the Qilian Mountain, complex terrain and few meteorological observation

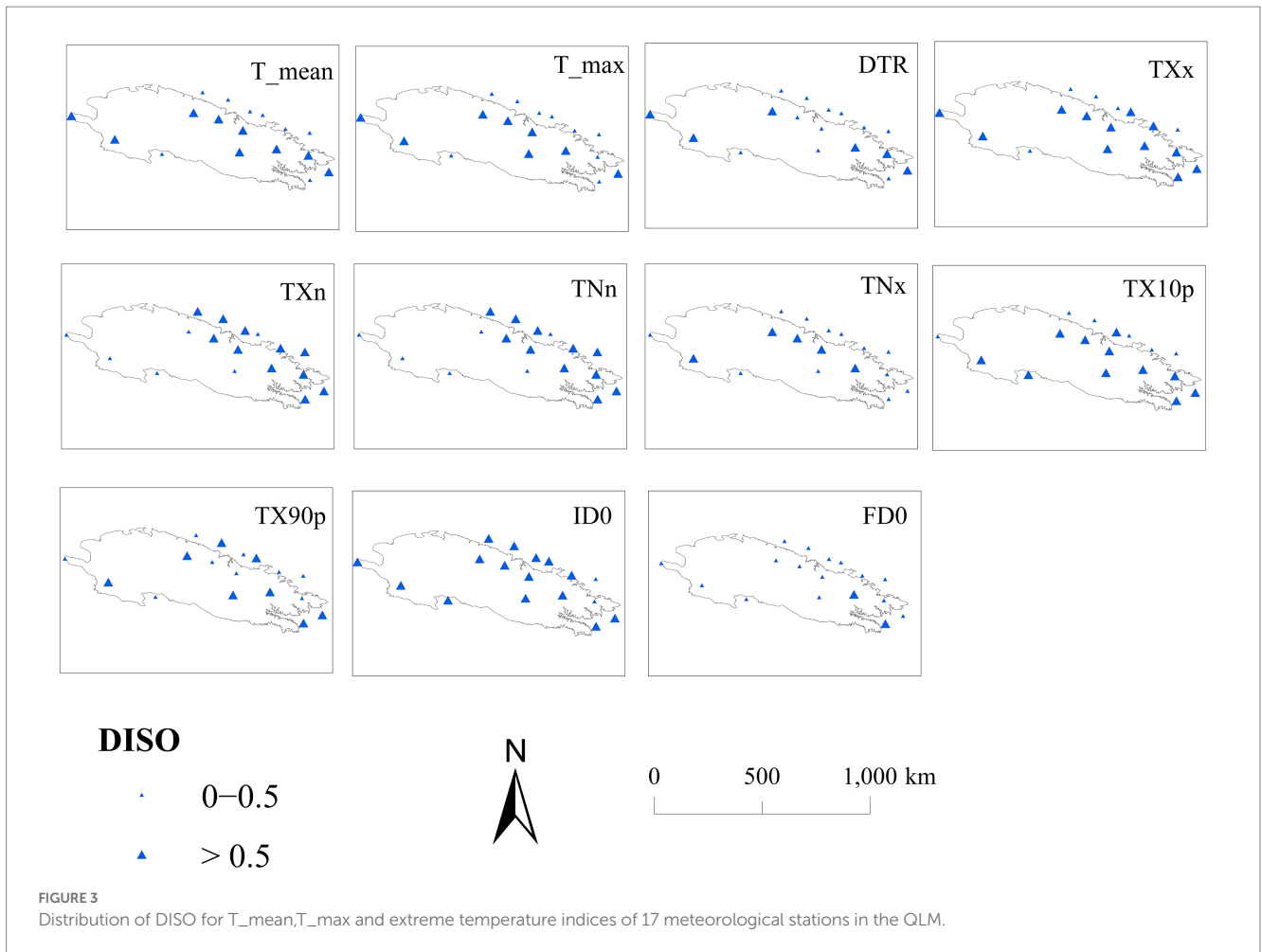


TABLE 6 Correlation coefficient (*r*) between observational extreme temperature indices and ERA5-Land extreme temperature indices at 17 stations in the QLM from 1979 to 2017.

No	DTR	TXn	TNn	TXx	TNx	TX10p	TN10p	TN90p	TX90p	ID0	FD0
1	0.746	0.991	0.984	0.994	0.980	0.980	0.955	0.943	0.977	0.967	0.989
2	0.808	0.988	0.978	0.992	0.985	0.974	0.932	0.946	0.965	0.972	0.982
3	0.790	0.984	0.980	0.991	0.982	0.965	0.941	0.956	0.974	0.962	0.986
4	0.825	0.987	0.986	0.991	0.985	0.977	0.936	0.965	0.963	0.966	0.986
5	0.829	0.988	0.967	0.989	0.982	0.977	0.891	0.961	0.967	0.965	0.981
6	0.839	0.988	0.984	0.991	0.984	0.988	0.952	0.921	0.969	0.984	0.989
7	0.718	0.987	0.960	0.979	0.978	0.937	0.828	0.963	0.977	0.978	0.987
8	0.819	0.982	0.980	0.988	0.979	0.962	0.925	0.945	0.954	0.895	0.983
9	0.663	0.994	0.986	0.995	0.980	0.976	0.882	0.968	0.973	0.909	0.994
10	0.727	0.973	0.922	0.980	0.971	0.872	0.827	0.960	0.968	0.884	0.949
11	0.760	0.971	0.912	0.964	0.974	0.915	0.763	0.965	0.973	0.755	0.896
12	0.743	0.976	0.926	0.961	0.975	0.850	0.762	0.963	0.967	0.769	0.937
13	0.650	0.991	0.975	0.992	0.973	0.964	0.928	0.948	0.965	0.889	0.970
14	0.669	0.985	0.982	0.992	0.980	0.964	0.952	0.965	0.973	0.978	0.970
15	0.669	0.978	0.949	0.990	0.977	0.921	0.875	0.974	0.971	0.956	0.960
16	0.591	0.963	0.934	0.948	0.970	0.853	0.767	0.945	0.957	0.688	0.891
17	0.786	0.983	0.954	0.987	0.981	0.954	0.889	0.952	0.967	0.927	0.946
Average	0.743	0.983	0.962	0.984	0.979	0.943	0.882	0.955	0.968	0.909	0.964

TABLE 7 Mean absolute error (MAE) between observational extreme temperature indices and ERA5-Land extreme temperature indices at 17 stations in the QLM from 1979 to 2017.

No	DTR	TXn	TNn	TXx	TNx	TX10p	TN10p	TN90p	TX90p	ID0	FD0
1	2.93	1.72	2.23	1.83	1.60	0.47	0.72	0.96	0.53	1.34	0.96
2	2.96	1.61	2.50	1.40	1.83	0.56	0.91	0.84	0.63	0.84	1.12
3	2.41	1.59	2.16	1.36	1.90	0.70	0.88	0.81	0.56	0.69	0.99
4	2.30	2.03	1.55	2.92	1.64	0.53	0.90	0.70	0.66	1.65	1.12
5	2.17	1.60	2.25	2.23	1.71	0.52	1.24	0.75	0.62	1.59	1.33
6	1.94	1.27	1.45	1.39	1.48	0.43	0.77	1.05	0.60	0.54	0.94
7	2.43	1.26	3.56	1.58	1.85	0.91	1.59	0.74	0.51	1.65	1.11
8	4.55	4.33	1.72	4.46	2.54	0.72	1.01	0.91	0.79	2.86	1.33
9	4.55	4.20	1.94	4.42	2.40	0.51	1.26	0.66	0.57	3.70	0.76
10	4.09	4.32	3.79	5.46	2.55	1.31	1.59	0.74	0.66	4.74	2.48
11	4.00	6.78	6.07	7.68	4.39	1.09	1.93	0.67	0.64	8.19	4.08
12	3.74	6.99	6.48	7.57	3.74	1.45	1.93	0.72	0.66	7.45	3.13
13	4.03	4.58	2.13	4.98	2.62	0.63	0.98	0.88	0.66	4.70	1.68
14	2.38	1.30	1.65	1.57	2.24	0.66	0.84	0.71	0.57	1.25	1.87
15	2.66	1.78	2.39	2.90	1.62	1.02	1.35	0.63	0.65	2.56	1.87
16	4.70	8.12	6.29	9.09	5.17	1.43	1.89	0.96	0.84	9.81	4.28
17	2.21	2.78	3.03	3.03	2.05	0.69	1.21	0.79	0.61	1.57	2.57
Average	3.18	3.31	3.01	3.76	2.43	0.80	1.24	0.79	0.63	3.24	1.86

TABLE 8 Statistics of DISO for ERA5-Land extreme temperature indices at 17 stations in the QLM from 1979 to 2017.

Statistics	DTR	TXn	TNn	TXx	TNx	TX10p	TN10p	TN90p	TX90p	ID0	FD0
0–0.5 (%)	71	29	35	71	35	35	0	0	53	12	88
>0.5 (%)	29	71	65	29	65	65	100	100	47	88	12
Average	0.46	8.80	0.68	0.39	1.87	0.67	1.02	0.65	0.51	1.54	0.27

TABLE 9 DISO for ERA5-Land daily temperature and extreme temperature indices at seasonal scales from 1979 to 2017.

	Spring	Summer	Autumn	Winter	Annual
mean	0.70	0.13	0.55	0.21	0.58
max	0.46	0.20	0.48	25.79	0.46
min	2.68	0.19	0.84	0.16	0.84
DTR	0.29	0.25	0.40	0.46	0.48
TXn	1.39	0.30	1.24	0.61	1.22
TNn	0.52	0.50	0.36	0.15	0.30
TXx	0.31	0.16	0.32	0.93	0.32
TNx	0.84	0.17	0.59	0.38	0.72

points, the accuracy of simulation is influenced (Xu et al., 2022). Large DISO values have been found at those stations located within the QLM. Therefore, the bias between the observed values and the reanalysis values within the QLM is higher than that in the surrounding areas such as Hexi Corridor. This may be due to the complicated terrain inside the Qilian Mountains (Zhao and He, 2022a).

4. Conclusions

In this study, we evaluated the ability of ERA5-Land reanalysis to capture extreme temperatures in the Qilian Mountains. The R^2 between ERA5-Land and observed T_{mean} , T_{max} , and T_{min} was 0.99, 0.99, and 0.98, respectively, which indicates that ERA5-Land can capture observational daily temperature data well. However, an average DISO at all stations of T_{mean} , T_{max} , and T_{min} was 2.44, 0.62, and 2.19, respectively, indicating that the reliability of capturing the T_{max} of ERA5-Land reanalysis temperature data is better than that of the T_{mean} and T_{min} in the QLM. ERA5-Land performed well in capturing extreme temperature indices TXx, TX90p and FD0. DISO for TXx was <0.5 at 12 stations accounting for approximately 71% of all stations. DISO for TX90p was <0.5 at 9 stations accounting for approximately 53% of all stations. ERA5-Land captured FD0 very well, with DISO <0.5 for 15 meteorological stations and an average of 0.27. The mean DISO values of the warmest days (TXx) in spring, summer, autumn and winter were 0.31, 0.16, 0.32 and 0.93, 131 respectively, showing that evaluation results of the extreme temperature index on the seasonal scale show that the capture results of ERA5-Land

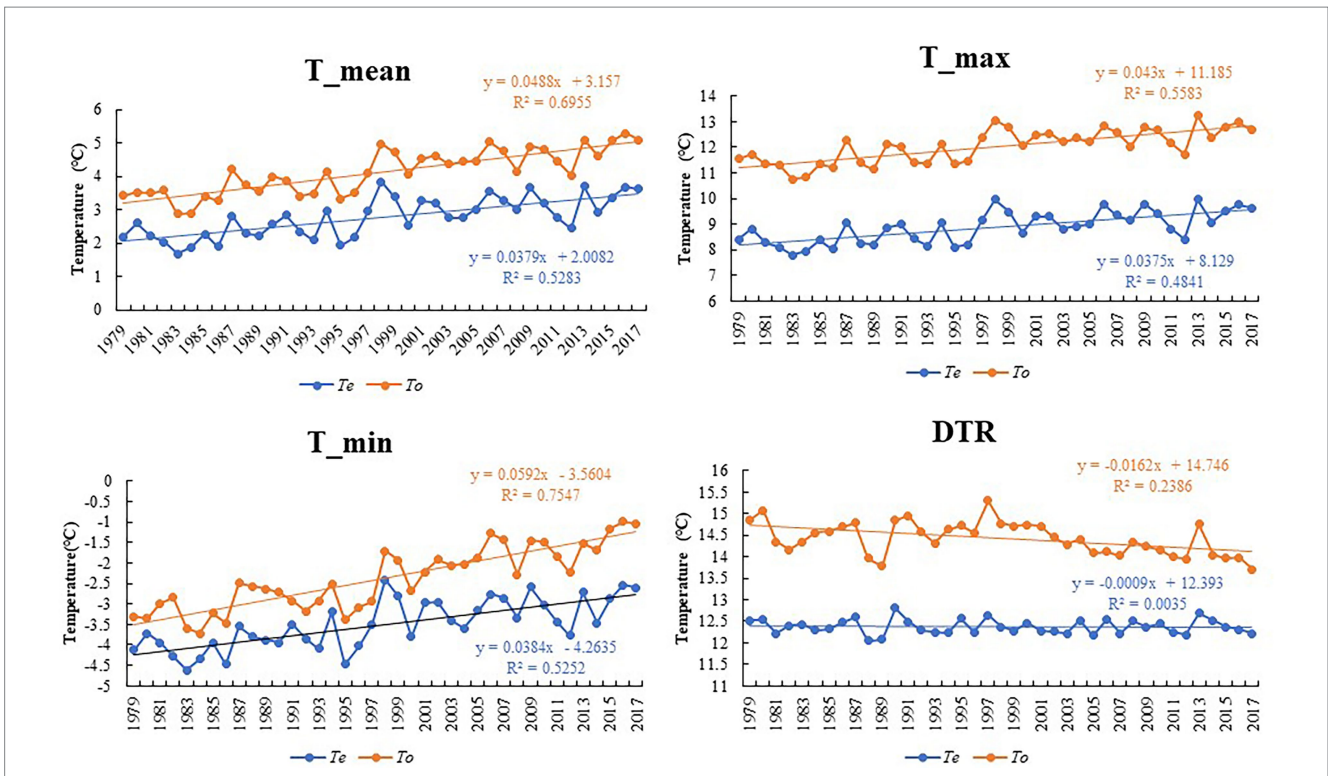


FIGURE 4 Trends in daily temperature and DTR in observation and ERA5-Land datasets from 1979 to 2017 in the QLM.

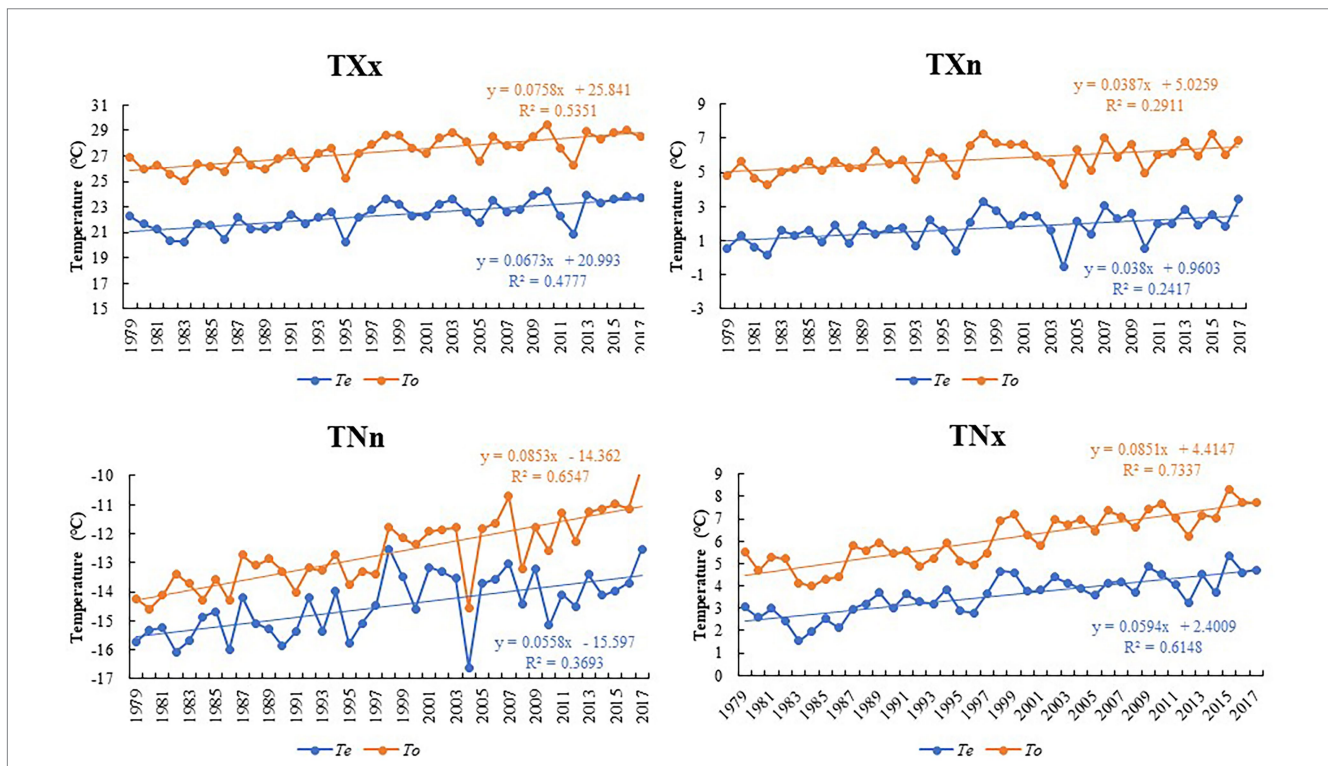


FIGURE 5 Trends in absolute indices of extreme temperature in observation and ERA5-Land datasets from 1979 to 2017 in the QLM.

on the extreme temperature index are best in summer. Furthermore, our results show that ERA5-Land is able to capture trends in all

extreme temperature indices except DTR, for the observational DTR showed a large decreasing trend ($-0.162^{\circ}\text{C}/\text{decade}$), while

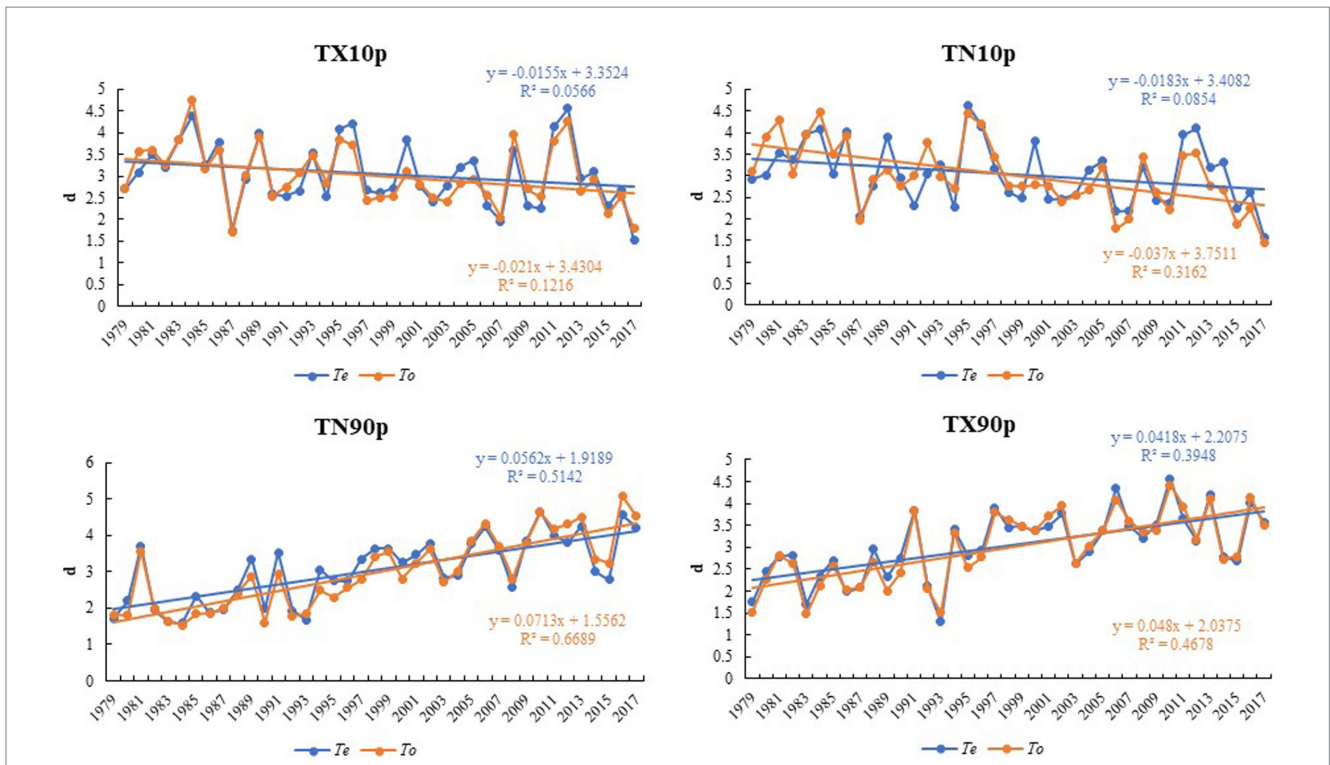


FIGURE 6 Trends in percentile-based indices of extreme temperature in observation and ERA5-Land datasets from 1979 to 2017 in the QLM.

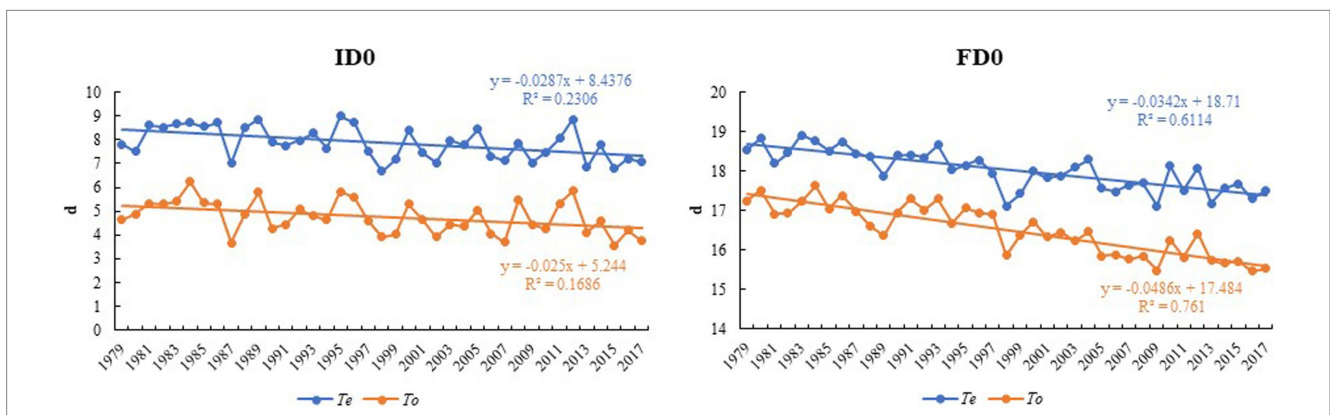


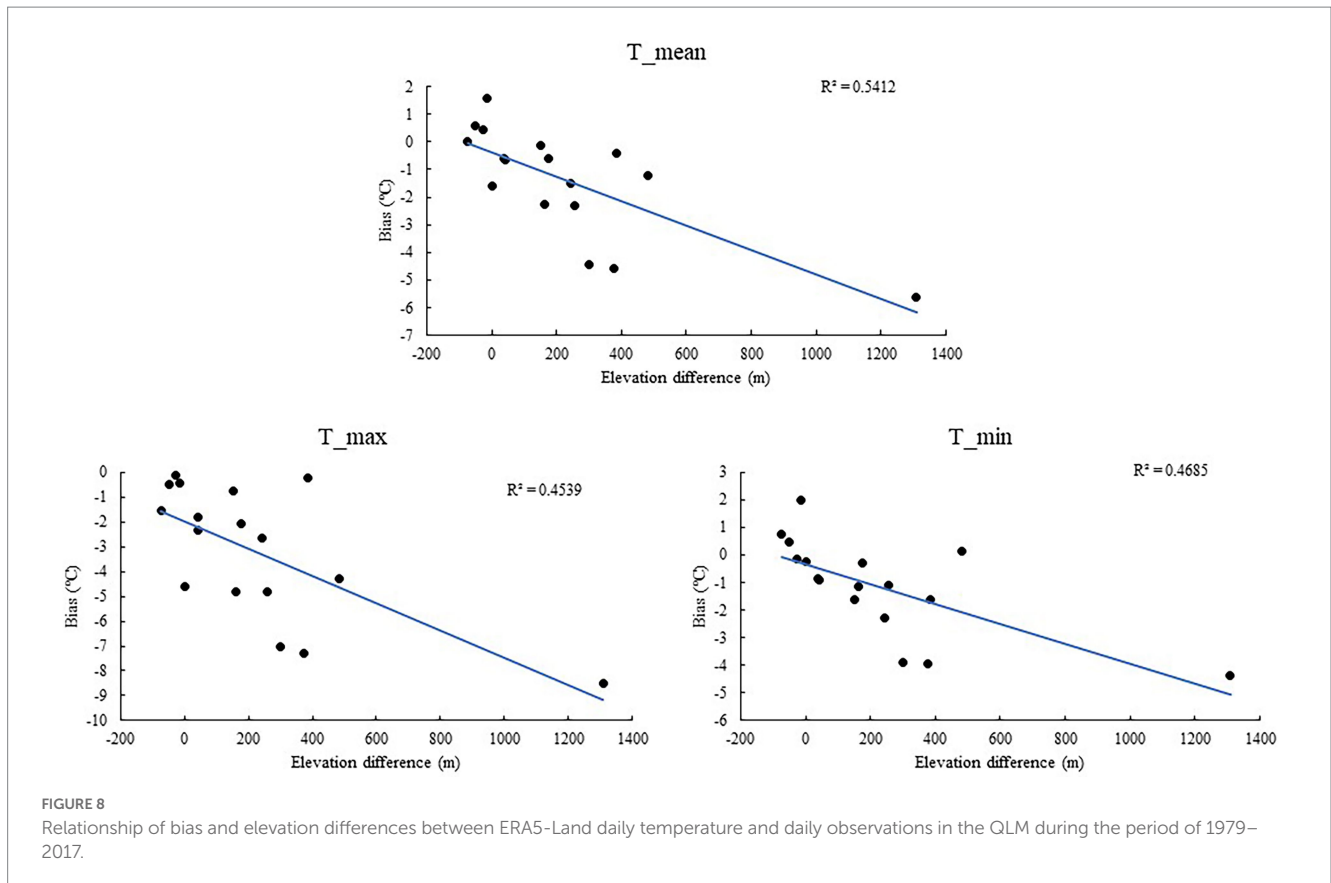
FIGURE 7 Trends in threshold indices of extreme temperature in observation and ERA5-Land datasets from 1979 to 2017 in the QLM.

TABLE 10 Trends in daily temperature and extreme temperature indices in ERA5-Land and observation datasets in the QLM from 1979 to 2017 (The units of T_{mean} , T_{max} , T_{min} , TX_n , TN_n , TX_x , TN_x , and DTR are $^{\circ}C/decade$; the units of TX_{10p} , TN_{10p} , TX_{90p} , TN_{90p} , ID_0 , and FD_0 are $day/decade$).

Temperature	T_{mean}	T_{max}	T_{min}	DTR	TX_n	TN_n	TX_x	TN_x	TX_{10p}	TN_{10p}	TN_{90p}	TX_{90p}	ID_0	FD_0
T_e	0.379	0.375	0.384	-0.009	0.38	0.558	0.673	0.594	-0.155	-0.183	0.562	0.418	-0.287	-0.342
T_o	0.488	0.43	0.592	-0.162	0.387	0.853	0.758	0.851	-0.21	-0.37	0.713	0.48	-0.25	-0.486
$T_o - T_e$	0.109	0.055	0.208	-0.153	0.007	0.295	0.085	0.257	-0.055	-0.187	0.151	0.062	0.037	-0.144

DTR of ERA5-Land showed only a slightly decreasing trend ($-0.009^{\circ}C/decade$). The R^2 values between temperature bias and

elevation difference of T_{mean} , T_{max} , and T_{min} were 0.541, 0.454 and 0.469, respectively, showing that the elevation difference



between ERA5-Land reanalysis temperature data and observation data may be the main cause of temperature bias. Generally, ERA5-Land reanalysis temperature data were reliable in simulating temperature data and identifying extreme temperature events; we conclude that ERA5-Land can be applied in the QLM for climate change research.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number (s) can be found below: <https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=form>.

Author contributions

PZ: designed study, collected meteorological data, and write article. DM and WW: final edit. ZH: provide fund support. All authors contributed to the article and approved the submitted version.

References

- Alexander, M., and Gregor, B. (2020). Demystifying the use of ERA5-land and machine learning for wind power forecasting. *IET Renew. Power Gen.* 14, 4159–4168. doi: 10.1049/iet-rpg.2020.0576
- Araujo, C. S. P., Silva, I., Ippolito, M., and Almeida, C. (2022). Evaluation of air temperature estimated by ERA5-land reanalysis using surface data in Pernambuco. *Brazil Environ. Monit. Assess.* 194:381. doi: 10.1007/s10661-022-10047-2
- Cao, B., Gruber, S., Zheng, D., and Li, X. (2020). The ERA5-land soil temperature bias in permafrost regions. *Cryosphere* 14, 2581–2595. doi: 10.5194/tc-14-2581-2020
- Dee, D. P., and Uppala, S. (2009). Variational bias correction of satellite radiance data in the ERA-interim reanalysis. *Q. J. R. Meteorol. Soc.* 135, 1830–1841. doi: 10.1002/qj.493

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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- Deng, S.-F., Yang, T.-B., Zeng, B., Zhu, X.-F., and Xu, H.-J. (2013). Vegetation cover variation in the Qilian Mountains and its response to climate change in 2000–2011. *J. Mt. Sci.* 10, 1050–1062. doi: 10.1007/s11629-013-2558-z
- Di Giuseppe, F., Molteni, F., and Dutra, E. (2013). Real-time correction of ERA-interim monthly rainfall. *Geophys. Res. Lett.* 40, 3750–3755. doi: 10.1002/grl.50670
- Gao, L., Bernhardt, M., and Schulz, K. (2012). Elevation correction of ERA-interim temperature data in complex terrain. *Hydrol. Earth Syst. Sci.* 16, 4661–4673. doi: 10.5194/hess-16-4661-2012
- Gao, L., Bernhardt, M., Schulz, K., and Chen, X. (2017). Elevation correction of ERA-interim temperature data in the Tibetan plateau. *Int. J. Climatol.* 37, 3540–3552. doi: 10.1002/joc.4935
- Gao, L., Hao, L., and Chen, X.-W. (2014). Evaluation of ERA-interim monthly temperature data over the Tibetan plateau. *J. Mt. Sci.* 11, 1154–1168. doi: 10.1007/s11629-014-3013-5
- Gao, L., Wei, J., Wang, L., Bernhardt, M., Schulz, K., and Chen, X. (2018). A high-resolution air temperature data set for the Chinese Tian Shan in 1979–2016. *Earth Syst. Sci. Data* 10, 2097–2114. doi: 10.5194/essd-10-2097-2018
- Hong, T., Li, H., and Chen, M. (2021). Comprehensive evaluations on the error characteristics of the state-of-the-art gridded precipitation products over Jiangxi Province in 2019. *Earth Space Sci.* 8. doi: 10.1029/2021EA001787
- Hu, Z., Chen, D., and Chen, X. (2022). CCHZ-DISO: a timely new assessment system for data quality or model performance from Da Dao Zhi Jian. *Geophys. Res. Lett.* 49:e2022GL100681. doi: 10.1029/2022GL100681
- Hu, Z., Chen, X., Zhou, Q., Chen, D., and Li, J. (2019). DISO: a rethink of Taylor diagram. *Int. J. Climatol.* 39, 2825–2832. doi: 10.1002/joc.5972
- Hu, L., Huang, G., and Hu, K. (2017). The performance of multiple datasets in characterizing the changes of extreme air temperature over China during 1979. *Theor. Appl. Climatol.* 133, 619–632. doi: 10.1007/s00704-017-2215-5
- Huai, B., Wang, J., Sun, W., Wang, Y., and Zhang, W. (2021). Evaluation of the near-surface climate of the recent global atmospheric reanalysis for Qilian Mountains, Qinghai-Tibet plateau. *Atmos. Res.* 250:105401. doi: 10.1016/j.atmosres.2020.105401
- Huang, X., Han, S., and Shi, C. (2022). Evaluation of three air temperature reanalysis datasets in the alpine region of the Qinghai-Tibet plateau. *Remote Sens.* 14, 1–24. doi: 10.3390/rs14184447
- IPCC (2021). Climate Change 2021: The Physical Science Basis. V. Masson-Delmotte et al. ed. Contribution of Working Group I to the Sixth assessment report of the intergovernmental panel on climate change Cambridge, United Kingdom: Cambridge University Press.
- Jiang, L., Tawia, H. D. F., and Yi, L. (2020). Global land surface temperature change (2003–2017) and its relationship with climate drivers: AIRS, MODIS, and ERA5-land based analysis. *Remote Sens.* 13, 1–20. doi: 10.3390/rs13010044
- Jiao, D., Xu, N., Yang, F., and Xu, K. (2021). Evaluation of spatial-temporal variation performance of ERA5 precipitation data in China. *Sci. Rep.* 11:17956. doi: 10.1038/s41598-021-97432-y
- Jintao, X., Ziqiang, M., Songkun, Y., and Jie, P. (2022). Do ERA5 and ERA5-land precipitation estimates outperform satellite-based precipitation products? A comprehensive comparison between state-of-the-art model-based and satellite-based precipitation products over mainland China. *J. Hydrol.* 605, 1–16. doi: 10.1016/j.jhydrol.2021.127353
- Joaquín, M. S., Emanuel, D., Anna, A. P., Clément, A., Gabriele, A., Gianpaolo, B., et al. (2021). ERA5-land: a state-of-the-art global reanalysis dataset for land applications. *Earth Syst. Sci. Data* 13, 4349–4383. doi: 10.5194/essd-13-4349-2021
- Konstantinos, S., George, V., Aikaterini, V., Anastasios, P., and Elias, D. (2021). Delineating the relative contribution of climate related variables to chlorophyll-a and phytoplankton biomass in lakes using the ERA5-land climate reanalysis data. *Water Res.* 196, 1–16. doi: 10.1016/j.watres.2021.117053
- Lei, X., Xu, W., Chen, S., Yu, T., Hu, Z., Zhang, M., et al. (2022). How well does the ERA5 reanalysis capture the extreme climate events over China? Part I: extreme precipitation. *Front. Environ. Sci.* 10:921658. doi: 10.3389/fevs.2022.921658
- Li, Y., Qin, X., Liu, Y., Jin, Z., Liu, J., Wang, L., et al. (2022). Evaluation of long-term and high-resolution gridded precipitation and temperature products in the Qilian Mountains, Qinghai-Tibet plateau. *Front. Environ. Sci.* 10:906821. doi: 10.3389/fevs.2022.906821
- Lin, P., He, Z., du, J., Chen, L., Zhu, X., and Li, J. (2017). Recent changes in daily climate extremes in an arid mountain region, a case study in northwestern China's Qilian Mountains. *Sci. Rep.* 7:2245. doi: 10.1038/s41598-017-02345-4
- Liu, L., Gu, H., Xie, J., and Xu, Y. P. (2020). How well do the ERA-interim, ERA-5, GLDAS-2.1 and NCEP-R2 reanalysis datasets represent daily air temperature over the Tibetan plateau? *Int. J. Climatol.* 41, 1484–1505. doi: 10.1002/joc.6867
- Liu, J., Hagan, D. F. T., and Liu, Y. (2020). Global land surface temperature change (2003–2017) and its relationship with climate drivers: AIRS, MODIS, and ERA5-land based analysis. *Remote Sens.* 13, 1–20. doi: 10.3390/rs13010044
- Luis, R. C., and Johannes, S. (2020). Simulation of multi-annual time series of solar photovoltaic power: is the ERA5-land reanalysis the next big step? *Sustain. Energy Technol. Assess.* 42, 1–12. doi: 10.1016/j.seta.2020.100829
- Pelosi, A., and Chirico, G. B. (2021). Regional assessment of daily reference evapotranspiration: can ground observations be replaced by blending ERA5-land meteorological reanalysis and CM-SAF satellite-based radiation data? *Agric. Water Manag.* 258:107169. doi: 10.1016/j.agwat.2021.107169
- Pelosi, A., Terribile, F., D'Urso, G., and Chirico, G. B. (2020). Comparison of ERA5-land and UERRA MESCAN-SURFEX reanalysis data with spatially interpolated weather observations for the regional assessment of reference evapotranspiration. *Water* 12, 1–22. doi: 10.3390/w12061669
- Rakhmatova, N., Arushanov, M., Shardakova, L., Nishonov, B., Taryannikova, R., Rakhmatova, V., et al. (2021). Evaluation of the perspective of ERA-interim and ERA5 Reanalyses for calculation of drought indicators for Uzbekistan. *Atmos.* 12, 1–14. doi: 10.3390/atmos12050527
- Ruml, M., Gregorić, E., Vujadinović, M., Radovanović, S., Matović, G., Vuković, A., et al. (2017). Observed changes of temperature extremes in Serbia over the period 1961–2010. *Atmos. Res.* 183, 26–41. doi: 10.1016/j.atmosres.2016.08.013
- Ruqing, Z., Li, L., Zhang, Y., Huang, F. N., Li, J. D., Liu, W., et al. (2021). Assessment of agricultural drought using soil water deficit index based on ERA5-land soil moisture data in four southern provinces of China. *Agriculture* 11, 1–19. doi: 10.3390/agriculture11050411
- Shtober-Zisu, N., and Wittenberg, L. (2021). Long-term effects of wildfire on rock weathering and soil stoniness in the Mediterranean landscapes. *Sci. Total Environ.* 762:143125. doi: 10.1016/j.scitotenv.2020.143125
- Sun, X.-B., Ren, G. Y., Shrestha, A. B., Ren, Y. Y., You, Q. L., Zhan, Y. J., et al. (2017). Changes in extreme temperature events over the Hindu Kush Himalaya during 1961–2015. *Adv. Clim. Chang. Res.* 8, 157–165. doi: 10.1016/j.accre.2017.07.001
- Supari, T. F., Juneng, L., and Aldrian, E. (2017). Observed changes in extreme temperature and precipitation over Indonesia. *Int. J. Climatol.* 37, 1979–1997. doi: 10.1002/joc.4829
- Virman, M., Bister, M., Räisänen, J., Sinclair, V. A., and Järvinen, H. (2021). Radiosonde comparison of ERA5 and ERA-interim reanalysis datasets over tropical oceans. *Dynam. Meteorol. Oceanogr.* 73, 1–7. doi: 10.1080/16000870.2021.1929752
- Wang, L., Chen, R., Han, C., Wang, X., Liu, G., Song, Y., et al. (2019). Change characteristics of precipitation and temperature in the Qilian Mountains and Hexi oasis, northwestern China. *Environ. Earth Sci.* 78, 1–13. doi: 10.1007/s12665-019-8289-x
- Wang, X., Chen, R., Han, C., Yang, Y., Liu, J., Liu, Z., et al. (2019). Response of frozen ground under climate change in the Qilian Mountains, China. *Quat. Int.* 523, 10–15. doi: 10.1016/j.quaint.2019.06.006
- Wu, Z., Feng, H., He, H., Zhou, J., and Zhang, Y. (2021a). Evaluation of soil moisture climatology and anomaly components derived from ERA5-land and GLDAS-2.1 in China. *Water Resour. Manag.* 35, 629–643. doi: 10.1007/s11269-020-02743-w
- Wu, Z., Feng, H., He, H., Zhou, J., and Zhang, Y. (2021b). Evaluation of soil moisture climatology and anomaly components derived from ERA5-land and GLDAS-2.1 in China. *Water Resour. Manag.* 35, 629–643. doi: 10.1007/s11269-020-02743-w
- Xin, Y., Lu, N., Jiang, H., Liu, Y., and Yao, L. (2021). Performance of ERA5 reanalysis precipitation products in the Guangdong-Hong Kong-Macao greater Bay Area, China. *J. Hydrol.* 602:126791. doi: 10.1016/j.jhydrol.2021.126791
- Xu, W., Lei, X. Y., Chen, S. T., Yu, T. T., Hu, Z. Y., Zhang, M., et al. (2022). How well does the ERA5 reanalysis capture the extreme climate events over China? Part II: extreme temperature. *Front. Environ. Sci.* 10, 1–15. doi: 10.3389/fevs.2022.921659
- Yang, L., Feng, Q., Adamowski, J. F., Alizadeh, M. R., Yin, Z., Wen, X., et al. (2021). The role of climate change and vegetation greening on the variation of terrestrial evapotranspiration in Northwest China's Qilian Mountains. *Sci. Total Environ.* 759:143532. doi: 10.1016/j.scitotenv.2020.143532
- Yin, H., and Sun, Y. (2017). Characteristics of extreme temperature and precipitation in China in based on ETCCDI indices. *Adv. Clim. Chang. Res.* 9, 218–226. doi: 10.1016/j.accre.2019.01.001
- Yu, X., Ren, G., Zhang, P., Hu, J., Liu, N., Li, J., et al. (2020). Extreme temperature change of the last 110 years in Changchun Northeast China. *Adv. Atmos. Sci.* 37, 347–358. doi: 10.1007/s00376-020-9165-z
- Zandler, H., Senftl, T., and Vanselow, K. A. (2020). Reanalysis datasets outperform other gridded climate products in vegetation change analysis in peripheral conservation areas of Central Asia. *Sci. Rep.* 10:22446. doi: 10.1038/s41598-020-79480-y
- Zhao, P., Gao, L., Wei, J., Ma, M., Deng, H., Gao, J., et al. (2020). Evaluation of ERA-interim air temperature data over the Qilian Mountains of China. *Adv. Meteorol.* 2020, 1–11. doi: 10.1155/2020/7353482
- Zhao, C., Gong, J., Wang, H., Wei, S., Song, Q., et al. (2020). Changes of temperature and precipitation extremes in a typical arid and semiarid zone: observations and multi-model ensemble projections. *Int. J. Climatol.* 40, 5128–5153. doi: 10.1002/joc.6150

- Zhao, P., and He, Z. (2022a). A first evaluation of ERA5-land reanalysis temperature product over the Chinese Qilian Mountains. *Front. Earth Sci.* 10. doi: 10.3389/feart.2022.907730
- Zhao, P., and He, Z. (2022b). Temperature change characteristics in Gansu Province of China. *Atmos.* 13, 1–13. doi: 10.3390/atmos13050728
- Zhou, Q., Chen, D., Hu, Z., and Chen, X. (2021). Decompositions of Taylor diagram and DISO performance criteria. *Int. J. Climatol.* 41, 5726–5732. doi: 10.1002/joc.7149
- Zhou, J., Li, Q., Wang, L., Lei, L., Huang, M., Xiang, J., et al. (2019). Impact of climate change and land-use on the propagation from meteorological drought to hydrological drought in the eastern Qilian Mountains. *Water* 11, 1–19. doi: 10.3390/w11081602
- Zhou, B., Xu, Y., Wu, J., Dong, S., and Shi, Y. (2016). Changes in temperature and precipitation extreme indices over China: analysis of a high-resolution grid dataset. *Int. J. Climatol.* 36, 1051–1066. doi: 10.1002/joc.4400
- Zhu, J., Huang, D.-Q., Yan, P.-W., Huang, Y., and Kuang, X.-Y. (2016). Can reanalysis datasets describe the persistent temperature and precipitation extremes over China? *Theor. Appl. Climatol.* 130, 655–671. doi: 10.1007/s00704-016-1912-9
- Zou, J., Lu, N., Jiang, H., Qin, J., Yao, L., Xin, Y., et al. (2022). Performance of air temperature from ERA5-land reanalysis in coastal urban agglomeration of Southeast China. *Sci. Total Environ.* 828:154459. doi: 10.1016/j.scitotenv.2022.154459