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Study on the Changes of Extreme Temperature in the Southwest of Zhejiang Province during the Period of 1953-2022

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Abstract

Under the background of global warming, extreme temperature occurs frequently around the globe, which has a significant and direct impact on social and economic system. Liuchun Lake is an important ecotourism scenic region in Longyou in the southwest of Zhejiang province, it is very important for the local economic development. Based on the daily mean temperature, maximum and minimum temperature from 15 stations, the 13 extreme temperature indices as defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) were calculated, and the characteristics of extreme temperature in the southwest of Zhejiang province were analyzed. The results showed that: 1) The Warmest day (TXx) and Warmest night (TNx) increased at most of the stations, while the coldest day (TXn) and the coldest night (TNn) basically significantly increased at all the stations; 2) The number of frost days (FD0) showed decreased trend, and all the stations passed the 99% significant level, the number of ice days (ID0) also was on downward trend, but it is not significant at all most of the stations, however, both the number of summer days (SU25) and tropical nights (TR20) were on upward trend, and all the stations passed the significant level ($p < 0.1$); 3) Both the number of cold days (TX10P) and cold nights (TN10P) showed a declined trend, while the number of warm days (TX90P) and warm night (TN90P) had an upward trend, especially TN90P had significant increase at all the stations. This implies that the cold events declined and warm events increased in the southwest regions of Zhejiang from 1953 to 2022.

Keywords

Extreme Temperature Indices, Temporal-Spatial Characteristic, Zhejiang

1. Introduction

According to the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change, the global average temperature indicated a significant warming of 0.5˚C (IPCC, 2013). Accompany with the global warming, the extreme temperature events also increased significantly over the last century, especially in the last five decades (Jones et al., 2012; Lawrimore et al., 2011). It is projected that the extreme events will occur frequently in the future (Nangombe et al., 2018). Compared with the increase in mean temperature, regional extreme temperature changes have a more significant and direct impact on social-economic and natural environment, and human health (Chau, 2019; Piya et al., 2019), and have attracted worldwide attention in recent decades.

Many scholars focused on the temporal and spatial characteristics of extreme temperature change on global and regional scales (Zhai & Pan, 2003, Alexander et al., 2006, Vincent & Mekis, 2006). For instance, Alexander et al. (2006) found that the cold nights had a significant decrease in more than 70% of the earth surfaces since 1950, while the warm days increased significantly. On the regional scale, Choi et al. (2009) also suggested that the obvious change of extreme temperature has been observed at more than 70% of stations in the Asia Pacific during the period of 1955-2007, and the frequency of cold nights also declined. Some scholars also indicated that the number of cold days and frost days decreased and the number of extremely high temperature days increased in Australia (Collins et al., 2000), the same feature also appeared in Europe (Tank & Können, 2003), south Asia and central Asia (Tank et al., 2006). In China, the extreme temperature events also had a significant response to the global warming. The number of ice days, frost days, cold days and cold nights showed a statically significant decreasing trend, while warm days and warm nights significantly increased, and had certain regional differences (Ren et al., 2010). In the basin of Huai River, the extreme temperature indices representing warming were on the rise, and the cold indices were on the downward (Wang et al., 2018). In Inner Mongolia, all the intensity, duration and frequency of extremely high temperature increased (Su et al., 2023). In Xinjiang area, most warm indices had an increasing trend, and the cold indices showed a significant decline (Wang et al, 2023), the same characteristic also occurred in the Qinghai plateau, the cold indices had more significant change than the warm indices, the absolute rate of cold indices had larger values at the higher latitudes and high elevations (Feng et al., 2021). So the extreme warm days had an increasing trend, and the extreme cold days showed an opposite character, but the changes of extreme indices possessed regional differences.

Zhejiang, located in the Delta of the Yangtze River, is one of the regions where the high temperature and heat wave frequently occur, it has turned Hangzhou into an oven in recent years (Tan & Cai, 2015). Based on the 24 stations in Zhejiang during the period of 1960-2008, Cai et al. (2012) found that the number of extreme warm days and warm nights had a significant increasing trend, while the extreme cold days and cold nights declined. Yang et al. (2014) suggested that the high temperature days and high temperature intensity in summer increased in most regions of Zhejiang, the same characteristics are also indicated by Yu et al. (2016). So the extreme temperature events have frequently occurred in Zhejiang. Liuchun Lake is the highest peak in Longyou, it is the most potential leisure resort in Zhejiang, which had an important impact on the local economy. Hence the study on the characteristics of extreme temperature events around Liuchun Lake can provide some reference value for the development of local tourism, and disaster prevention and reduction.

2. Data and Methods

The data is provided by the Longyou meteorological bureau, including the daily mean temperature, daily maximum and minimum temperature. After the strictly quality control and the error values correction, the temperature data of 15 stations were selected in this paper (**Figure 1**). The detailed information of the stations can be seen in **Table 1**.

In this paper, 13 extreme temperature indices, are defined by the Expert Team on Climate Change Detection and Indices (ETCCDI). These indices can reflect the intensity, frequency and duration of extreme temperature, and have been widely used in extreme climate events research (Moberg & Jones, 2005; Klein Tank et al., 2006; Toreti & Desiato, 2008). The definition of extreme temperature indices can be seen in **Table 2**.

3. Results

3.1. The Spatial Change of Extreme Temperature Indices

Figure 2 illustrates the spatial distribution of extreme temperature indices. It can be seen from **Figure 2(a)** that TXx had an increasing trend in most parts of southwest Zhejiang, about 33.3% of stations passed the significance test at the 0.01 level, the maximum value occurred at the PJ and WY stations, which can reach about 0.32˚C/10a. TNx had a more significant warming trend than TXx, about

Table 1. The information of stations used in this paper.

Stations	Longitude	latitude	Altitude (m)	Stations	Longitude	latitude	Altitude (m)
CS	118˚30'25"	28˚54'26"	136.2	CA	119˚1'57"	29˚36'22"	222.1
JD	119˚16'28"	29˚28'29"	89.1	JS	118˚36'6"	28˚42'36"	126.1
JH	119˚39'21"	29˚6'46"	62.6	LX	119˚28'32"	29˚13'5"	50.2
LQ	119˚7'57"	28˚4'50"	105.1	LY	119˚11'7"	29˚2'1"	161.4
PJ	119˚52'20"	29˚28'30"	115.6	QZ	118˚53'27"	28˚59'38"	82.4
SC	119˚16'9"	28˚35'42"	236.6	TL	119˚40'8"	29˚48'21"	44.4
WY	119˚48'33"	28˚53'24"	105.1	YW	120˚5'14"	29˚20'27"	90
YH	119˚35'51"	28˚6'25"	169.1				

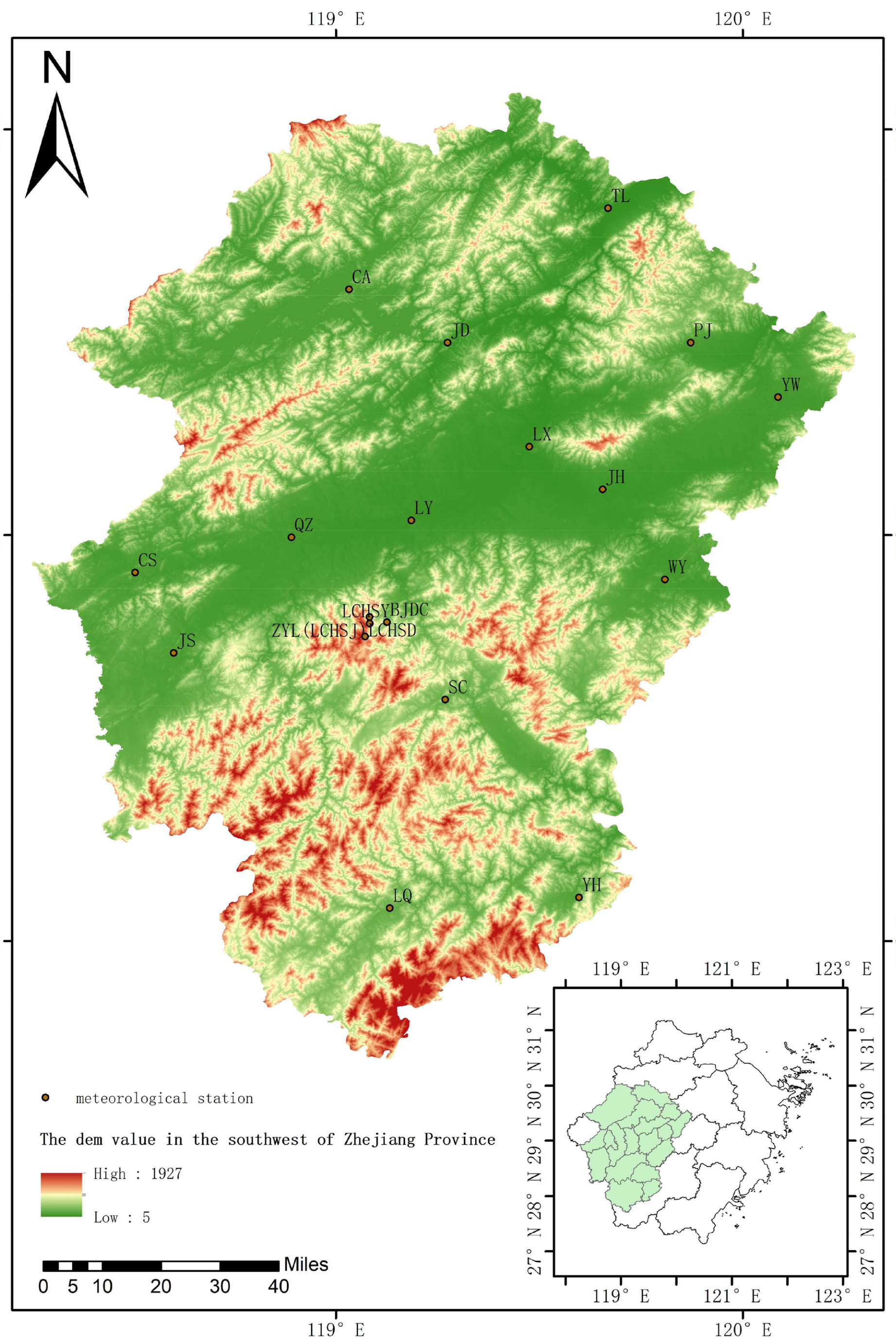

Figure 1. The study area and the location of the meteorological stations used in this study.

93.3% of the total stations are featured by the increasing trend, and 64.3% of them had significant increasing trend ($p < 0.01$), the maximum value of the trend of TNx is about 0.35˚C/10a. In general, TNx had a more pronounced increase with larger range and intensity, this means the cold index had a more significant change than warm index. Figure 2(c) indicates that all TXn showed a positive trend at all the stations, and about 95% of them had a significant increasing trend ($p < 0.01$), the maximum value reached about 0.53˚C/10a. TNn

Table 2. Definition of the extreme temperature indices used in this study.

Category	indices	Definitions	Descriptive Name	units
Relative indices	TX10P	Number of days with T_{max} < 10th percentile	Cold days	d
	TN10P	Number of days with T_{min} < 10th percentile	Cold nights	d
	TX90P	Number of days with T_{max} > 90th percentile	Warm days	d
	TN90P	Number of days with T_{min} > 90th percentile	Warm nights	d
Absolute indices	FD0	Annual count when TN (daily maximum temperature) < 0˚C	Frost days	d
	ID0	Annual count when TX (daily minimum temperature) < 0˚C	Ice days	d
	SU25	Annual count when TX > 25˚C	Summer days	d
	TR20	Annual count when TN > 20˚C	Tropical nights	d
Extremal indices	TXx	Annual highest TX	Warmest day	˚C
	TNx	Annual highest TN	Warmest night	˚C
	TXn	Annual lowest TX	Coldest day	˚C
	TNn	Annual lowest TN	Coldest night	˚C

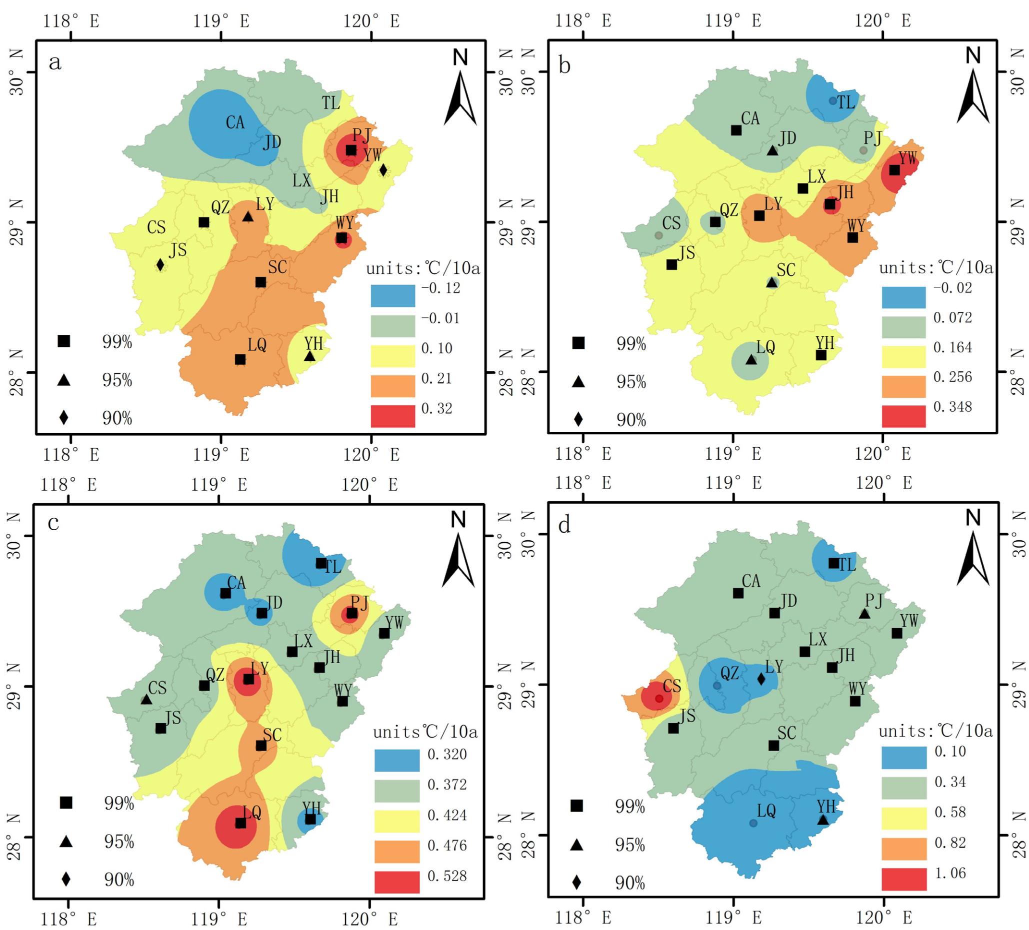

Figure 2. The spatial distribution of linear trend of TXx (a), TNx (b), TXn (c), TNn (d) in the southwest of Zhejiang during 1953-2022.

had the same changes with TXn, but the trend was more larger than that of TXn, the peak value can reach about 1.06˚C/10a. Under the background of global climate warming, the coldest index had more obvious response to climate warming than the warmest index.

Figure 3 shows the trend distribution of FD0, ID0, SU25 and TR22. The number of FD0 decreased in the whole region, and all passed the significant level ($p < 0.01$). The trend ranged from −4.66 d/10a to −2.08 d/10a, the significant decline occurred at the WY station. The number of ID0 also showed a negative trend, about 70% of the stations passed the significant level ($p < 0.05$), and there were two stations with no obvious changing trend, maybe this is related to that the ice days occur much less frequently in the southwest of Zhejiang. The number of SU25 showed an increasing trend, with a trend of 1.81 - 5.91 d/10a, and about 94% of the stations passed the significant level ($p < 0.01$), the most obvious increase occurred at the PJ station. The number of TR20 also generally showed an increasing trend, with a change magnitude of 1.63 - 3.67 d/10a, and all the stations passed the significant level test ($p < 0.01$).

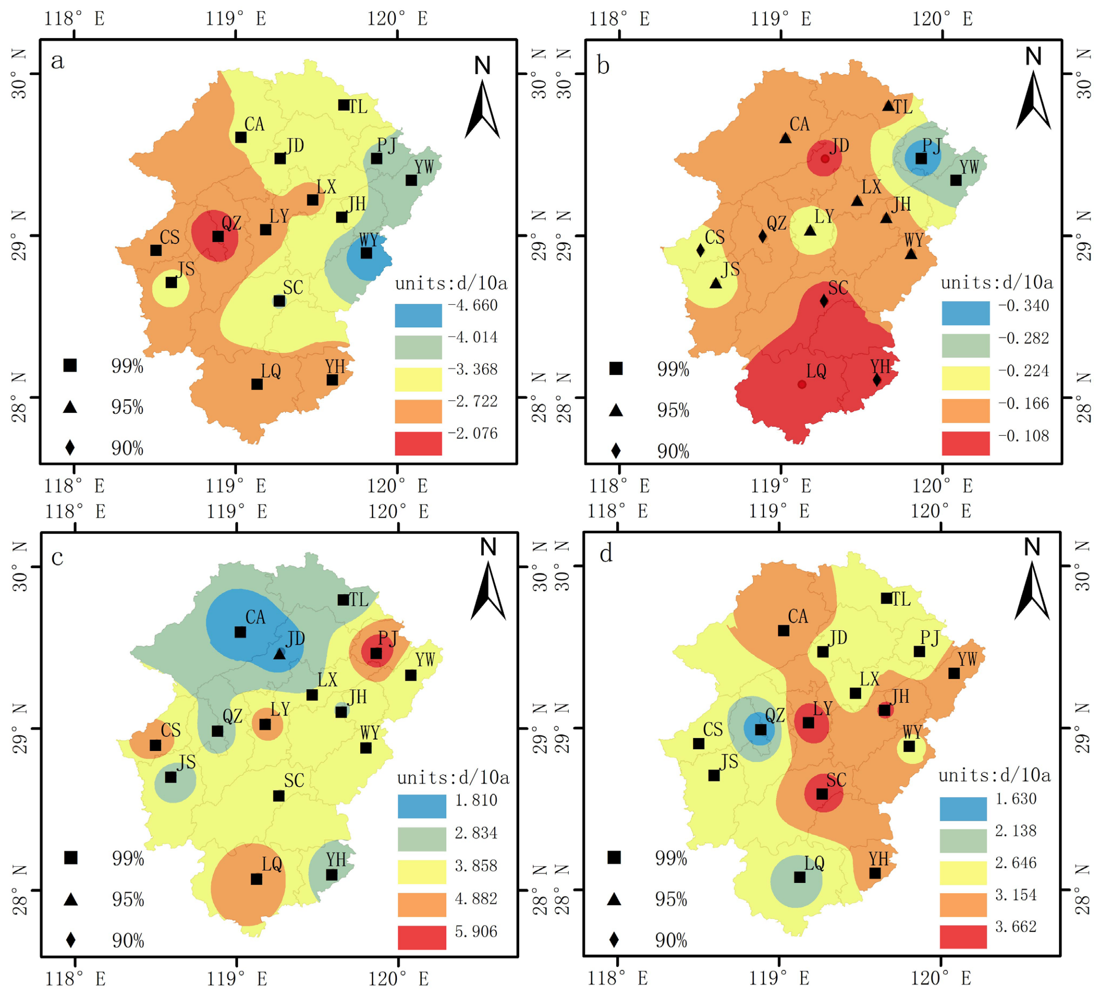

Figure 3. Spatial distribution of linear change trend of FD0 (a), ID0 (b), SU25 (c), TR20 (d) in the southwest part of Zhejiang during 1953-2022.

It can be seen from Figure 4 that there were obvious differences in the distribution of the trend for TX10P. TX10P had a negative trend in most of the stations, with the trend of −2.96 - −1.12 d/10a, but there were only 20% of the stations passing the significant level ($p < 0.01$), and 53% of the stations passed the 95% significant level. However, TN10P at all the stations showed a decreasing trend, and 93.3% of the stations passed the 99% significant test ($p < 0.01$), the most significant decreased rate was about −5.25 d/10a, occurring at the YW and WY stations. This implies that the declines of cold nights were more significant that the cold days. Figure 4(c) indicates that except for the CA and JD stations, TX90P had an increasing trend at the other stations, and 46.7% of the stations passed the 99% significant level ($p < 0.01$), the most obvious increase was about 4.34 d/10a, and occurred at the PJ and LQ stations. However, TN90P had an increasing trend at all the stations, and 93.3% of the stations passed the 99% significant level, and the increasing rate ranged from 0.44 - 7.44 d/10a. In general, the change rate of the index representing the night is larger that of the day.

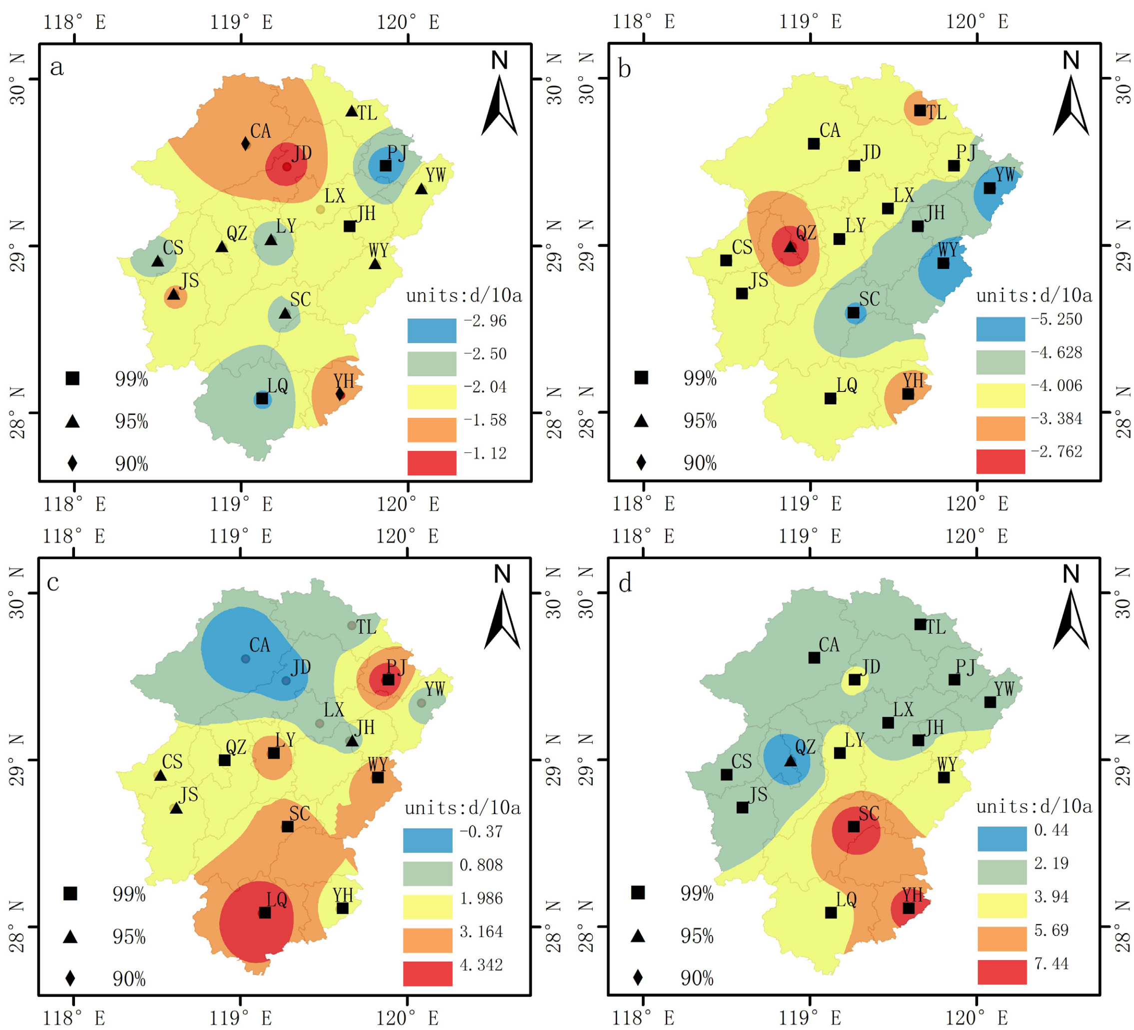

Figure 4. Spatial distribution of linear change trend of TX10P (a), TN10P (b), TX90P (c), TN90P (d) in the southwest of Zhejiang during 1953-2022.

3.2. The Annual Variation of Extreme Temperature Indices

Figure 5 indicates the annual variation of TXx, TNx, TXn, TNn. TXx increased with a trend of 0.02˚C/10a, however, TXn evidently increased with a trend of 0.31˚C/10a, especially after 2000, the change was more obvious. TNx and TNn also had an increasing trend, and the rate can reach about 0.08˚C/10a and 0.23˚C/10a, respectively. This implies that the warmest event strengthened, and the coldest event weakened, the change of extreme temperature at night was larger than that during the day, this is consistent with the previous result (Yin & Sun, 2018).

Figure 6 illustrates that the averaged FD0 was about 22 d in the southwest region of Zhejiang. The maximum of FD0 can reach about 45 d. during the period of 1953-2022, FD0 had a decline with the trend of −2.0 d/10a. ID0 also showed a decreasing trend, but the change was not obvious, maybe it is related that ID0

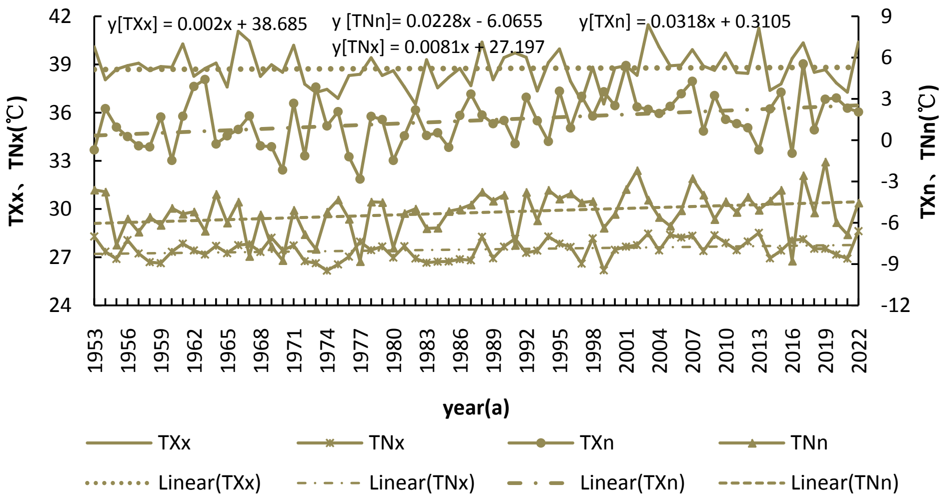

Figure 5. Annual variations of TXx, TNx, TXn and TNn in the southwest region of Zhejiang during 1953-2022.

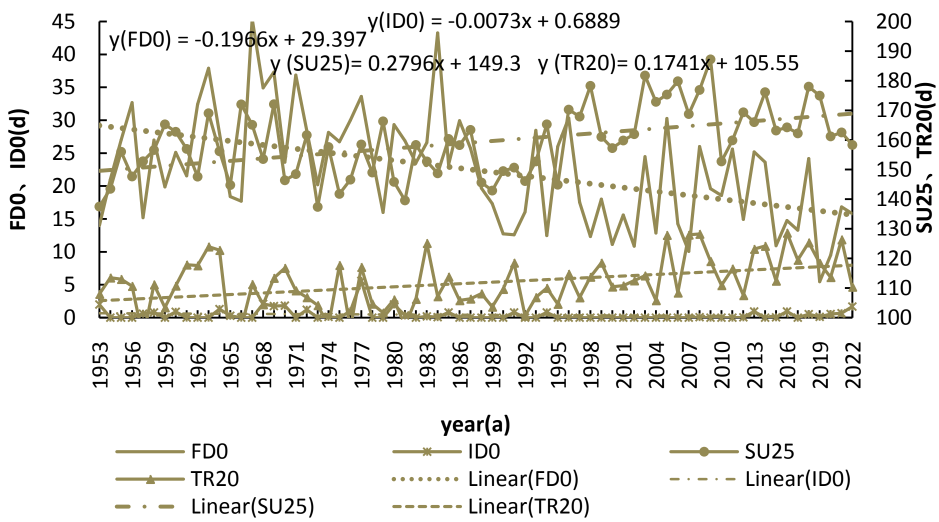

Figure 6. Annual variations of FD0, ID0, SU25 and TR20 in the southwest region of Zhejiang during 1953-2022.

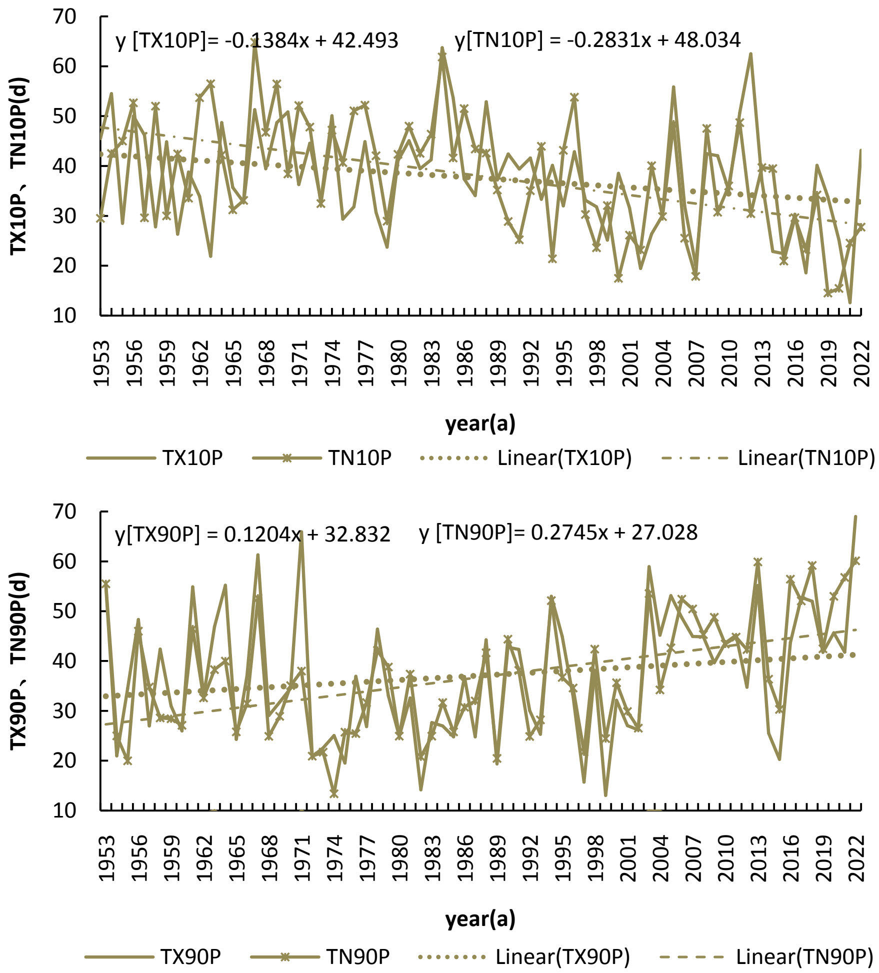

Figure 7. Annual variations of TX10P, TN10P, TX90P and TN90P in the southwest region of Zhejiang during 1953-2022.

was equal to zero. Both SU25 and TR20 obviously increased with the trend of 2.80 d/10a and 1.74 d/10a. In sum, the characteristics of FD0, ID0, SU25 and TR20 were consistent with that in the global, but there are still some differences in the amplitude of change of the indexes (Donat et al., 2013; Yin & Sun, 2018).

Figure 7 shows that TX10P had a declined trend, and the trend was about −1.39 d/10a, the maximum of TX10P was about 63 d, and the minimum was only about 12 d. TN10P also declined with the trend of −2.83 d/10a. Both TX90P and TN90P significant increased, with the trend of 1.20 d/10a and 2.75 d/10a, respectively. This is consistent the previous result in the globe and China (Donat et al., 2013; Yin & Sun, 2018; Yuan et al., 2021).

4. Conclusion

Liuchun Lake is an important ecotourism scenic region in Zhejiang province. The analysis of the extreme temperature is helpful for the development of the local tourist economy. This paper mainly analyzes the temporal and spatial characteristics of extreme temperature index in the southwest region of Zhejiang.

The main results are as follows:

TXx had an increasing trend at most of the stations, TNx had the same spatial distribution with TXx, but the intensity and range of the increasing TNx were stronger and larger than that of TXx. Both TXn and TNn had an increasing trend at all the stations, and more than 70% of the stations passed the 95% significant level.

FD0 showed a decreasing trend at all the stations, and all the stations passed the 99% significant level. Although ID0 had a decreasing trend, it is not significant. SU25 and TR20 basically showed an increasing trend at all the stations, and change of SU25 was larger than TR20.

TX10P was on downward trend at most of the stations, TN10P had a significant decreasing trend, with about 93.33% of the stations passing the 99% significant level. TN90P increased at most of the stations, and only 46.67% of the stations passed the significant level ($p < 0.01$). While TN90P was significantly on an upward trend at all the stations.

The annual variation shows that TXx, TNx, TXn, TNn, SU25, TR20, TX90P and TN90P had an increasing trend, while FD0, ID0, TX10P and TN10P decreased during the period of 1953-2022.

In this paper only 15 stations after quality control were used, which may have impacted the characteristic of extreme temperature indices. Therefore, more temperature data should be collected in the future study, which can help more extensively understand the change of extreme temperature events around the Liuchun Lake in the southwest of Zhejiang province.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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References

Alexander, L. V., Zhang, X. B., Peterson, T. C. et al. (2006). Global Observed Changed in Daily Climate Extremes of Temperature and Precipitation. *Journal of Geophysical Research Atmospheres, 111,* D05109. https://doi.org/10.1029/2005JD006290

Cai, M., Shen, J. D., Huang, Y. et al. (2012). Analysis of Extreme Temperature Events and Its Response to the Regional Climatic Warming in Zhejiang Province. *Bulletin of Science and Technology, 28,* 44-50.

Chau, K. (2019). Integration of Advanced Soft Computing Techniques in Hydrological Predictions. *Atmosphere, 10,* Article 101. https://doi.org/10.3390/atmos10020101

Choi, G. C., Collins D., Ren, G. Y. et al. (2009). Changes in Means and Extreme Events of

Temperature and Precipitation in the Asia-Pacific Network Region, 1955-2007. *International Journal of Climatology, 29,* 1906-1925. https://doi.org/10.1002/joc.1979

Collins, D. A., Della-Marta, P. M., Plummer, N. et al. (2000). Trends in Annual Frequencies of Extreme Temperature Events in Australia. *Australian Meteorological Magazine, 49,* 277-292.

Donat, M. G., Alexander, L. V., & Yang, H. (2013). Global Land-Based Datasets for Monitoring Climatic Extremes. *Bulletin of the American Meteorological Society, 94,* 997-1006. https://doi.org/10.1175/BAMS-D-12-00109.1

Feng, X. L., Duo, M. Z. R., Li, W. Z. et al. (2021). The Temporal-Spatial Characteristics of Extreme Temperature Indices in Qinghai Tibet during 1961-2018. *Journal of Arid Meteorology, 39,* 28-37.

IPCC (2013). *Climate Change 2013: The Physical Science Basis: Summary for Policymakers*. https://www.ipcc.ch/site/assets/uploads/2017/09/WG1AR5_Frontmatter_FINAL.pdf

Jones, P. D., Lister, D. H., Osborn, T. J. et al. (2012). Hemispheric and Large-Scale Land-Surface Air Temperature Variations: An Extensive Revision and an Update to 2010. *Journal of Geophysical Research-Atmospheres, 117,* D05127. https://doi.org/10.1029/2011JD017139

Klein Tank, A. M. G., Peterson, T. C., Quadir, D. A. et al. (2006). Change in Daily Temperature and Precipitation Extreme in Central and South Asia. *Journal of Geophysical Research, 111,* D16105. https://doi.org/10.1029/2005JD006316

Lawrimore, J. H., Menne, M. J., Gleason B. E. et al. (2011). An Overview of the Global Historical Climatology Network Monthly Mean Temperature Data Set, Version 3. *Journal of Geophysical Research, 116,* D19121. https://doi.org/10.1029/2011JD016187

Moberg, A., & Jones, P. D. (2005). Trend in Indices for Extremes in Daily Temperature and Precipitation in Central and Western Europe, 1901-1999. *International Journal of Climatology, 25,* 1149-1171. https://doi.org/10.1002/joc.1163

Nangombe, S., Zhou T., Zhang, W. et al. (2018). Record-Breaking Climate Extremes in Africa under Stabilized 1.5˚C and 2˚C Global Warming Scenarios. *Nature Climate Change, 8,* 375-380. https://doi.org/10.1038/s41558-018-0145-6

Piya, L., Maharjan, K. L., & Joshi, N. P. (2019). Livelihood Impacts of Climate Change and Extreme Events. In *Socio-Economic Issues of Climate Change* (pp 153-160). Springer. https://doi.org/10.1007/978-981-13-5784-8_11

Ren, G. Y., Feng, G. L., & Yan, Z. W. (2010). Progresses in Observation Studies of Climate Extremes and Changes in Mainland China. *Climatic and Environmental Research, 15,* 337-353.

Su, R. H., Guo, E. L., Wang, Y. F. et al. (2023). Extreme Climate Changes in the Inner Mongolia and Their Impacts on Vegetation Dynamics during 1982-2020. *Acta Ecologica Sinica, 43,* 419-431. https://doi.org/10.5846/stxb202112073469

Tan, H. J., & Cai, R. S. (2015). New Characteristics of Heat Extremes in Fuzhou Since 2000 and the Possible Causes. *Chinese Journal of Atmospheric Sciences, 39,* 1179-1190.

Tank, A. K., & Können, G. P. (2003). Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946-1999. *Journal of Climate, 16,* 3665-3680. https://doi.org/10.1175/1520-0442(2003)016<3665:TIIODT>2.0.CO;2

Tank, A. M., Peterson, T. C., Quadir, D. A. et al. (2006). Changes in Daily Temperature and Precipitation Extremes in Central and South Asia. *Journal of Geophysical Research Atmosphere, 111,* 709-720. https://doi.org/10.1029/2005JD006316

Toreti, A., & Desiato, F. (2008). Changes in Temperature Extremes over Italy in the Last

Years. *International Journal of Climatology, 28,* 733-745. https://doi.org/10.1002/joc.1576

Vincent, L. A., & Mekis, É. (2006). Changes in Daily and Extreme Temperature and Precipitation Indices for Canada over the Twentieth Century. *Atmosphere, 44,* 177-193. https://doi.org/10.3137/ao.440205

Wang, B. L., Zhang, M. J., Wei, Z. L. et al. (2013). Changes in Extreme Events of Temperature and Precipitation over Xinjiang, Northwest China, during 1960-2009. *Quaternary International, 298,* 141-151. https://doi.org/10.1016/j.quaint.2012.09.010

Wang, W., Yan, D. H., He, X. Y. et al. (2018) Trends in Extreme Temperature Indices in Huang-Huai-Hai River Basin of China during 1961-2014. *Theoretical and Applied Climatology, 134,* 51-65. https://doi.org/10.1007/s00704-017-2252-0

Yang, X. X., Chen, F., Zhu, W. P. et al. (2014). Urbanization Effects on Observed Change in Summer Extreme Heat Events over Zhejiang Province. *Journal of Tropical Meteorology, 30,* 719-726.

Yin, H., & Sun, Y. (2018). Detection of Anthropocentric Influence on Fixed Threshold Indices of Extreme Temperature. *Journal of Climate, 31,* 6341-6352. https://doi.org/10.1175/JCLI-D-17-0853.1

Yu, Z. Y., Li, Z. Q., Zhang, Y. H. et al. (2016). Decadal Variation Characteristics of Extreme Temperature Events and Their Differences between Urban and Rural Areas. *Meteorological Science and Technology, 44,* 972-978.

Yuan, K. S., He, T. R., Wang, L. P. et al. (2021). Temporal and Spatial Variation Characteristics of Extreme Temperature in Xinjiang from 1971-2016. *Environmental Protection of Xinjiang, 43,* 37-45.

Zhai, P., & Pan, X. (2003). Trends in Temperature Extremes during 1951-1999 in China. *Geophysical Research Letters, 30,* 169-172. https://doi.org/10.1029/2003GL018004