Changing temperature trends at subtropical mountains in southeastern China

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Abstract

In the context of global warming, mountain warming has significantly elevation-dependent. Currently, most studies focusing on high-altitude mountainous areas lack examples of middle and low-altitude mountainous areas. Southeastern China's Fujian Province has the Wuyi Mountains in the northwest and coastal plains in the southeast, making it an ideal place to study temperature warming change with elevation. Therefore, based on 64 meteorological stations' daily observation data in Fujian Province from 1961 to 2018, the Mann-Kendall nonparametric test method was used to analyze the spatial-temporal patterns of temperatures and their elevation-dependent warming characteristics. The results show that (1) Fujian Province has experienced significant warming from 1961 to 2018, where the mean temperature is 0.20°C/decade, the maximum temperature is 0.17°C/decade, and the minimum temperature is 0.26°C/decade. The mean, maximum, and minimum temperatures abruptly changed around 1997, 2000, and 1998, respectively. (2) In 1961-1990, more than 63% of stations experienced a decline in annual mean temperature, mainly because the maximum temperature decreased during this period, whereas for 1971-2000, 1981-2010, and 1991-2018, the maximum, minimum and mean temperatures have been increasing. (3) In Fujian Province, there are significant spatial differences in temperature variations, with the maximum warming trend of mean temperature occurring in the southeast coastal plains, the maximum warming trend of maximum temperature occurring in the northwestern mountainous region, and the minimum temperature is warming faster in the southeast coast and northwestern mountains than in the central region. (4) In the study area, no elevation-dependent warming of mean, maximum, and minimum temperatures was observed, indicating that middle and low-altitude mountainous regions of the subtropics do not experience elevation-dependent warming of temperatures.

1 Introduction

Temperature is a crucial indicator for global climate change studies. According to the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6), the global mean surface temperature increased by 0.99°C from 2001-2020 compared to 1850-1900, and by 1.09°C from 2011-2020 (IPCC, 2021), which is more than three times the land warming rate during 1975-2010 (0.30°C/decade) (Rangwala and Miller, 2012). Meanwhile, the temperature warming rate is amplified at high altitudes, and high altitudes in mountainous regions are more sensitive to climate change than low altitudes (Ives, 1997). Temperature warming increases with elevation, called elevation-dependent warming (EDW) (Thakuri et al. 2019).

EDW is one of the characteristics of mountain warming and has become an important aspect of mountain climate change studies (Palazzi et al. 2019). The current research results indicate that EDW occurs mainly in high-altitude mountain areas, such as the Alps (Palazzi et al. 2019), Qinghai-Tibet Plateau (Palazzi et al. 2017), Andes (Aguilar-Lome et al. 2019), and the Rocky Mountains (Minder et al. 2021). In addition, the EDW phenomenon is mainly investigated using a combination of station observations and climate model simulations (Gao et al. 2021). Based on global high-altitude temperature observations during 1961-2010, the warming at high altitudes was 1.24 times faster than at low altitudes.
(Wang et al. 2014). For example, warming rates in the Indian side of the Himalayas between 1971 and 2007 were significantly higher (0.46°C/decade) than in other Indian regions (0.20°C/decade) (Kothawale et al. 2010); European Alps between 1959-2008 experienced 0.33°C/decade higher warming than their eastern counterparts (0.29°C/decade) (Ceppi et al. 2012). During 1953-2008, the South Eastern Rocky Mountains warmed by 0.28°C/decade, a rate higher than that of the lower elevation region (0.19°C/decade) (McGuire et al. 2012). A significant warming trend was observed on the Tibetan Plateau, with a temperature rise of 0.39°C/decade between 1960 and 2014 (Deng et al. 2017), much higher than the global average (0.12°C/decade) (IPCC, 2013) and China's (0.28°C/decade) over the same period (Zhao et al. 2020). Since the mid-20th century, the elevation-dependent warming of the minimum temperature on the Tibetan Plateau had significant seasonal differences, with the most pronounced in winter, followed by spring and autumn, and the weakest in summer (Liu et al. 2009). Meanwhile, based on MODIS LST data, the elevation-dependent warming was analyzed for the northwestern part of the Tibetan Plateau, which is shown that EDW exists between 3000 and 4800 m above sea level, after which the warming rate stabilized at the highest point (> 6200 m) (Qin et al. 2009).

The warming EDW phenomenon has been observed in many mountainous regions around the globe, but its widespread distribution is still debated (You et al. 2020). Due to the large concentration of meteorological stations in low-elevation regions and the absence of monitoring data in high-elevation regions, diametrically opposite results may be obtained using station data and model simulations (Beniston et al. 1997). For example, reanalysis results indicate no obvious EDW above 2000 meters on the Tibetan Plateau (You et al. 2010). Satellite remote sensing technology has compensated for the lack of ground-based stations in recent years; however, its relatively short time series, long revisit period, and image inversion errors limit the reliability of EDW signal detection (Rasmussen et al. 2011). In addition, current studies have mainly focused on high-elevation mountains, and there need to be more studies on middle and low-elevation mountains, which makes the existence of the EDW phenomenon in middle and low-elevation mountains still needs to be discovered.

More than 80% of Fujian Province is mountainous and hilly, with the Wuyi Mountains in the northwest and the coastal plains in the southeast, making it an ideal place to study elevation-dependent warming. Therefore, this study analyzes the temporal-spatial patterns of temperature variations and EDW in Fujian Province based on daily observation data from 64 meteorological stations during 1961-2018 and then explores whether the temperature change in middle and low-elevation mountains has EDW characteristics. The study’s results will fill a gap in the current understanding of EDW in mountainous areas at mid- and low elevations.

2 Methods

2.1 Study area

Fujian Province is located in the southeastern coastal region of China, between 23°33'-28°20’N and 115°50’-120°40’ E. It has a land area of 124,000 km², of which more than 80% is mountainous and hilly.
The terrain is generally shows a high northwest and low southeast, with the Wuyi Mountains in the northwest and the highest peak, Huanggang Mountain, at an altitude of 2,158 meter, and hills and coastal plains along the eastern coast (Zhang and Liu, 2022). The region has a mid-subtropical monsoon climate with an average annual temperature of 20~25°C Lu et al. 2022.

2.2 Data

The temperature data were obtained from daily-scale observations of 64 meteorological stations in Fujian Province (Fig. 1a) provided by the China Meteorological Data Network (https://data.cma.cn/), which was subjected to strict quality control. The time range of the observed data is from 1961 to 2018. 76% of the stations are mainly located below 300 m above sea level (Fig. 1b).

2.3 Statistical methods

Mann-Kendall (M-K) tests, which disallow outliers and require no particular distribution, are more useful to type and order variables, are highly applicable, and are easier to calculate. Time series can be tested by the method for trends and abrupt changes. The M-K nonparametric test is commonly used to assess the significance of trends of meteorological and hydrological time-series data (Deng et al. 2022; Hirsch and Slack, 1984).

(1) M-K trend test

In the Mann-Kendall trend test, X is a sample series with an independent and random distribution in time, S is the statistic for the sample series X, which is defined in equation (1), and sgn is the signum function, which is defined in equation (2).

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i)
\]

\[
\text{sgn} (\theta) = \begin{cases} 
1, & \theta > 0 \\
0, & \theta = 0 \\
-1, & \theta < 0
\end{cases} 
\]

where the \(x_j\) is the \(j\)th data value of the time series; \(n\) is the length of the data sample, \(n \geq j > i=1\).

When \(n \geq 10\), the statistic \(S\) approximately obeys the standard normal distribution, and the test statistic \(Z\) is defined for the trend test:
For a sample sequence $X$ with $n$ number of samples, an order column $S_k$ is constructed, and the $S_k$ order column is the cumulative number of numbers satisfying at moment $i$ greater than moment $j$. The random independent lower statistic $UF_k$ is defined.

\[
Z = \begin{cases} 
\frac{S - 1}{\sqrt{Var(S)}}, & S > 0 \\
0, & S = 0 \\
\frac{S + 1}{\sqrt{Var(S)}}, & S < 0 
\end{cases} \quad (3)
\]

where $\sqrt{Var(S)}$ is the variance of the statistic $S$. The statistic $Z > 0$ indicates an upward trend of the series, and $Z < 0$ indicates a downward trend of the series.

(2) M-K mutation test

For a sample sequence $X$ with $n$ number of samples, an order column $S_k$ is constructed, and the $S_k$ order column is the cumulative number of numbers satisfying at moment $i$ greater than moment $j$. The random independent lower statistic $UF_k$ is defined.

\[
S_k = \sum_{i=1}^{k} r_i, \quad k = 2, 3, \ldots, n \quad (4)
\]

\[
r_i = \begin{cases} 
1, & x_i > x_j \\
0, & x_i \leq x_j 
\end{cases} \quad (5)
\]

\[
UF_k = \frac{[S_k - E(S_k)]}{\sqrt{Var(S_k)}}, \quad k = 1, 2, \ldots, n \quad (6)
\]

where $UF1 = 0$, $E(S_k)$ and $\sqrt{Var(S_k)}$ are the mean and variance of $S_k$. $UF_k$ is the statistical series calculated from the sample sequence $X$ that satisfies the standard normal distribution, and then the inverse process $UB_k = -UF_k$ by the sample sequence $X$ ($k = n, n-1, \ldots, 1$). $UB1 = 0$, the inverse process is calculated to obtain (Xu J.H., 2016).

3 Result

3.1 The temporal characteristics of temperature change

3.1.1 Trend of temperature

From 1961 to 2018, the annual mean temperature in Fujian Province was 19°C, with the a high of 20.3°C in 1998 and a low of 18.4°C in 1984 (Fig. 2a). The annual mean temperature showed a warming trend with a warming rate of 0.020°C/yr ($p < 0.01$). In particular, the warming trend since the mid-1980s is significant. The annual mean maximum temperature was 24°C, with a maximum of 25.7°C in 2003 and a minimum of 23.2°C in 1984 (Fig. 2b). The overall trend was fluctuating and increasing, with a warming rate of 0.017°C/yr ($p < 0.05$). The mean annual minimum temperature was 16°C, with a maximum of
17.0°C in 2016 and a minimum of 14.5°C in 1962 (Fig. 2c). The interannual variation of the annual minimum temperature showed an increasing trend with a rate of 0.026°C/yr ($p < 0.01$). Therefore, annual minimum temperature had the largest warming rate, followed by annual mean temperature, and annual maximum temperature had the smallest warming rate in Fujian Province during 1961-2018.

**Table 1** An analysis of the mean, maximum, and minimum temperatures of the seasons in Fujian Province from 1961 to 2018.

<table>
<thead>
<tr>
<th>Season</th>
<th>$T_{mean}$ Trend (°C/yr)</th>
<th>$p$-value</th>
<th>$T_{max}$ Trend (°C/yr)</th>
<th>$p$-value</th>
<th>$T_{min}$ Trend (°C/yr)</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>0.017</td>
<td>0.0744</td>
<td>0.021</td>
<td>0.0870</td>
<td>0.018</td>
<td>0.0490</td>
</tr>
<tr>
<td>Summer</td>
<td>0.016</td>
<td>0.0354</td>
<td>0.016</td>
<td>0.1041</td>
<td>0.022</td>
<td>0.0084</td>
</tr>
<tr>
<td>Autumn</td>
<td>0.022</td>
<td>0.0087</td>
<td>0.013</td>
<td>0.1353</td>
<td>0.030</td>
<td>0.0032</td>
</tr>
<tr>
<td>Winter</td>
<td>0.025</td>
<td>0.0110</td>
<td>0.016</td>
<td>0.1690</td>
<td>0.035</td>
<td>0.0029</td>
</tr>
</tbody>
</table>

The seasonal variation of the mean, maximum, and minimum temperatures was also analyzed (Table 1), which revealed a warming trend in the seasonal variation of the mean, maximum, and minimum temperatures. The mean temperature of the autumn and winter seasons grew by 0.022°C/yr ($p < 0.001$) and 0.025°C/yr ($p < 0.05$), respectively (Table 1), which was higher than the spring and summer temperatures. All of the maximum temperature seasonal trends were insignificant ($p > 0.05$); in autumn and winter, the annual minimum temperature increased by 0.03°C/yr and 0.035°C/yr, respectively, which were higher than the rates of warming in spring and summer (Table 1). In Fujian Province, autumn and winter warmed more rapidly than spring and summer. Meanwhile, the annual minimum temperature warmed fastest, followed by the mean temperature and the maximum temperature slowest.

### 3.1.2 Abrupt change of temperature

During 1961-2018, the annual mean temperature abruptly changed in 1998, the annual minimum temperature in 1997, and the annual maximum temperature in 2000. The mean temperature change was relatively stable before 1998. Since 1998 (Fig. 3a), it has shown a significant upward trend. A relatively stable change in maximum temperature before 2000 and a significant increase after 2000 (Fig. 3b). Annual minimum temperature with relatively smooth change before 1997 and significant increases after 1997 (Fig. 3c).

### 3.2 Spatial characteristics of temperature variation in Fujian Province

#### 3.2.1 Mean temperature
There were significant differences in the spatial variations of the mean temperature across different periods. In 1961-1990, the mean temperature of 40 stations decreased, and the remaining 24 stations were on an increased trend (Fig. 4a). In the Wuyi mountain region, the mean temperature decreased up to -0.19°C/decade, whereas in the coastal zone, the mean temperature increased by 0.10°C/decade. Over the period 1971-2000, 63 stations rose, and only one declined. The most significant warming areas are still more concentrated in coastal zones, up to 0.30 ~ 0.42 °C/decade (Fig. 4b). During 1981-2010, all stations showed an increasing trend, and the spatial variations were similar to those of 1971-2000, with the strongest warming trend occurring on the southeast coast plains (0.50-0.60°C/decade) (Fig. 4c). During 1991-2018, all stations continued to show an increasing trend, and the warming rate in the northwestern mountainous region increased (Fig. 4d). Therefore, the mean temperature decreased in 1961-1990 and increased in 1971-2000, 1981-2010, and 1991-2018.

3.2.2 Maximum temperature

The results in Figure 5a shows that the annual maximum temperature decreased at 58 stations from 1961 to 1990, while only six stations showed an increase. Overall, most areas experienced a decrease in this period, and the northwestern mountainous regions experienced a greater decline than the southeastern coastal regions. From 1971 to 2000, only six stations showed a decrease in trend, as opposed to 58 stations that showed an increase (Fig. 5b). Most of the region's warming rate is between 0.20 and 0.40°C/decade, and Fuzhou City reached 0.60 to 0.67°C/decade. All stations had an increased trend in 1981-2010 (Fig.5c), and the coastal region had the highest warming rate of over 0.55°C/decade, while the central region had the lowest warming rate. Only one station showed a decreasing trend from 1991 to 2018 (Fig. 5d). The results indicate that warming continues to dominate, but the southeast coast's warming rate has slowed, while the northwestern mountains' warming rate has increased. Therefore, in this region, the annual maximum temperature cooled before the 1990s and warmed after the 1990s, with significant warming regions moving from the east coast to the northwest.

3.2.3 Minimum temperature

The minimum temperature increased at 58 stations and decreased at six stations in 1961-1990 (Fig. 6a). Meanwhile, Northwestern mountainous areas warmed faster than coastal areas. It shows a diametrically opposite trend to the annual mean and maximum temperatures during the period. By combining Figures 4a and 5a, the mean temperature decreased in 1961-1990 due to reducing maximum temperatures. All stations warming trend was observed in the study region between 1971 and 2000 (Fig. 6b), with faster warming rates in the southeast coast and Wuyi mountainous region than in the central part. Over the period 1981-2010, all stations warmed, but the southeast coast warmed faster than the central part and Wuyi mountainous areas (Fig. 6c). In the period 1991-2018, all stations were still on a warming trend, especially in Wuyi mountainous regions (Fig. 6d).

3.3 Elevation-dependent warming
The annual mean temperature in the region has been warming at about 0.20°C/decade from 1961 to 2018 (Fig. 7a). The warming rates of the faster station are 0.33°C/decade, while those at the lower station are only 0.05°C/decade. Based on Figure 7b, the regional average warming rate of the annual maximum temperature is about 0.17°C/decade from 1961 to 2018. There is a warming rate of 0.48°C/decade at the faster warming station (9.6 m) and a warming rate of 0.04°C/decade at the lower warming station (310.6 m). Figure 7c shows that the regional average warming rate of the annual minimum temperature is 0.26°C/decade from 1961 to 2018. There is a warming rate of 0.40°C/decade at the faster warming station (81.8 m) and a warming rate of 0.12°C/decade at the lower warming station (149.3 m). Fig. 7 shows that the warming rate of mean, maximum, and minimum temperatures decreased with elevation (Fig. 7).

The mean temperature decreased by about -0.02°C/decade during 1961-1990, and 40 of the 64 stations decreased during this period (Fig. 8a). As shown in Fig. 8b, the maximum temperature also reduced from 1961 to 1990 with a decreasing rate of -0.17°C/10a, and 58 out of 64 stations had a decreasing trend. While the minimum temperature was warming during this period by 0.13°C/decade, there was an increase at 58 stations (Fig. 8c).

The annual mean temperature increased by 0.19°C/decade between 1971 and 2000, with nearly all stations (63/64) increasing (Fig. 8d). There was an increase in annual mean maximum temperature of 0.17°C/decade, with 58 out of 64 stations showing an upward trend (Fig. 8e), and the remaining stations showing a downward trend. The annual mean minimum temperature was warming at a rate of about 0.13°C/decade, and all 64 stations were increasing, with warming rates between 0.01°C/decade and 0.71°C/decade (Fig. 8f).

The annual mean temperature increased by 0.37°C/decade between 1981 and 2010. All 64 stations experienced an increase, ranging from 0.09°C/decade to 0.57°C/decade (Fig. 8g). The annual mean maximum temperature warmed by 0.48°C/decade. The 64 stations showed an increasing trend ranging from 0.27°C/decade to 0.73°C/decade (Fig. 8h). The annual mean minimum temperature warmed about 0.33°C/decade, ranging from 0.01°C/decade to 0.62°C/decade (Fig. 8i).

During 1991-2018, the annual mean temperature warmed by approximately 0.30°C/10a, and all 64 stations showed an upward trend between 0.00°C/decade and 0.50°C/decade (Fig. 8j). The annual maximum temperature increased by about 0.29°C/decade at 63 of the 64 stations, while one station decreased (-0.10°C/decade) (Fig. 8k). The annual minimum temperature warmed by 0.36°C/decade (Fig. 8l).

According to Fig. 9a, the mean temperature increased by 0.17°C/decade in spring. Almost all stations showed a warming trend, with a maximum warming rate of 0.34°C/decade (Fig. 9a). In summer, the warming rate was 0.16°C/decade, with a maximum warming rate of 0.30°C/decade (Fig. 9b). Autumn's warming rate was 0.22°C/decade (Fig. 9c). In Figure 9c, all stations showed warming trends exceeding 0.05°C/decade, with a maximum warming rate of 0.34°C/decade. In winter, the warming rate was 0.25°C/decade, with a maximum rate of 0.39°C/decade (Fig. 9d).
The temperature in Fujian Province showed a significant warming trend from 1951 to 2018, consistent with the IPCC AR3 (IPCC, 2015). The annual mean temperature shows the most robust warming trend at 0.020°C/yr, which is lower than the average warming rate in China of 0.026°C/yr during the same period (Climate Change Centre, 2021) but much greater than global warming at 0.012°C/yr. The warming rate of the annual minimum temperature reaches 0.026°C/yr, which is similar to the conclusion that the China minimum temperature has the highest warming rate (Lu, 2009). The annual maximum temperature in Fujian is warming at only 0.017°C/yr, which is slower than the minimum. In Fujian, abrupt changes in mean, maximum, and minimum temperatures occurred around 1997, 2000, and 1998, in agreement with Huang (Huang et al. 2020) and Ma (Ma et al. 2021).

In Fujian Province, temperature changes tend to go down from the southeastern coast to the northwestern inland. Because the southeastern coast has low topography, alluvial plains downstream of rivers, medium and large cities are mainly located there, and there is much human activity, so it is warming up more. In contrast, the density of human activity in the northwestern mountainous areas is lower, and the warming rate is correspondingly lower (Li et al. 2018). Second, human activities can alter the vegetation cover, resulting in an increase in latent heat flux from transpiration, which in turn reduces the temperature (Peng et al. 2012); therefore, the change in vegetation cover in Fujian Province has a significant impact on the distribution of temperatures (Li et al. 2020; Li et al. 2018). Moreover, human activities are often concentrated in areas with significant urbanization, increasing urban construction intensity (Yow, 2007), and decreasing surface albedo (Stewart and Oke, 2012). Depending on the degree of urbanization in Fujian Province, the size of cities varies, so the mean, minimum, and maximum temperatures may differ in coastal and mountainous areas in all seasons (Pepin et al. 2015; Pepin and Lundquist, 2008).

4 Discussion

The temperature in Fujian Province showed a significant warming trend from 1951 to 2018, consistent with the IPCC AR3 (IPCC, 2015). The annual mean temperature shows the most robust warming trend at 0.020°C/yr, which is lower than the average warming rate in China of 0.026°C/yr during the same period (Climate Change Centre, 2021) but much greater than global warming at 0.012°C/yr. The warming rate of the annual minimum temperature reaches 0.026°C/yr, which is similar to the conclusion that the China minimum temperature has the highest warming rate (Lu, 2009). The annual maximum temperature in Fujian is warming at only 0.017°C/yr, which is slower than the minimum. In Fujian, abrupt changes in mean, maximum, and minimum temperatures occurred around 1997, 2000, and 1998, in agreement with Huang (Huang et al. 2020) and Ma (Ma et al. 2021).

In spring, the minimum temperature warmed by 0.18°C/decade (Fig. 11a), with a maximum warmed by 0.36°C/decade. In summer, the minimum temperature warmed by 0.22°C/decade (Fig. 11b). There was a maximum warming rate of 0.38°C/decade at the station with an elevation of 206.0m and a minimum warming rate of 0.02°C/decade at the station with an elevation of 114.3m. In autumn, the minimum temperature warmed by 0.30°C/decade (Fig. 11c). The maximum warming rate reached 0.51°C/decade at the station with an elevation of 521.4m, and the minimum was 0.15°C/decade at the station with an elevation of 149.3m. In winter, the minimum temperature warmed by 0.35°C/decade (Fig. 11d). There was a maximum warming rate of 0.52°C/decade and a minimum warming rate of 0.23°C/decade.
It is well known that mountains are more sensitive to climate change than other regions, and altitude-dependent warming is one of their distinctive characteristics. A lot of existing studies in high-altitude regions show that high-altitude mountainous areas usually warm up based on their altitude (Palazzi et al. 2019; Palazzi et al. 2017; Aguilar-Lome et al. 2019; Liu et al. 2009), while low-altitude mountainous areas have relatively little research on their altitude-dependent warming characteristics. A study in this paper examines the altitude-dependent warming characteristics of the Wuyi mountain, which can be used to represent low-altitude subtropical mountainous areas in southeastern China. It is consistent with the findings of Zhang (Zhang et al. 2006). Probably because the lower elevation sites are more obviously affected by the urban heat island effect (Pepin and Lundquist, 2008). Fujian province is growing urbanized, which leads to a higher warming trend at lower elevations, while the higher elevations show a relatively lower warming trend. Moreover, this paper's study on the warming rate of different seasons shows that only the maximum temperature shows a weak altitude-dependent warming trend in winter. However, the rest of the temperature indicators do not show altitude-dependent warming. The reason for a more pronounced warming trend in mountainous areas during the winter is primarily associated with the inversion of temperature that often occurs in the lower mountains during the winter months. As a result, the rate of direct temperature reduction at lower altitudes decreased significantly compared to higher altitudes (Ma et al. 2021). One of the reasons for the lack of apparent altitude-dependent warming characteristics is the small number of high-altitude stations used in this study.

5 Conclusion

(1) Fujian Province experienced a significant warming trend between 1961 and 2018. The annual minimum temperature is warming the most, at 0.026°C/yr, followed by the annual mean temperature at 0.020°C/yr and the annual maximum at 0.017°C/yr. The mean, maximum, and minimum temperatures abruptly changed around 1997, 2000, and 1998. Furthermore, Fujian Province's temperature variation exhibits interdecadal characteristics. Over the period 1961-1990, most stations saw a cooling trend in mean and maximum temperatures, but they also saw a warming trend in minimum temperatures. It can be assumed that the maximum temperature mainly explains why the annual mean temperature cooled. The annual mean, maximum, and minimum temperatures increased in 1971-2000, 1981-2010, and 1991-2018. The warming trend became more and more significant as time went by.

(2) There is a significant variation in the spatial distribution of temperature changes in the study area. A significant warming area of the maximum temperature extends from the eastern coast to the coastal zone and then shifts to the northwest mountainous region. The significant warming area of the minimum temperature is mainly located in the northwest mountainous region from 1961 to 1990, and the warming rate of the southeast coastal stations gradually accelerates over time. There has been a significant upward trend in minimum temperatures in most parts in recent years, with the southeast coast and northwestern mountains showing more significant warming than the central region.

(3) The Wuyi mountain has no apparent altitude-dependent warming feature, measured by mean, maximum, and minimum temperatures. According to the interannual and interdecadal mean, maximum,
and minimum temperatures between 1960 and 2018, the stations with the most significant warming rates are primarily under 200 m above sea level. The mean, maximum, and minimum temperatures do not exhibit EDW phenomena in all seasons except for the maximum temperature, which shows a weak trend of increasing temperature with elevation in winter.

Declarations

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Competing Interests

The authors have no conflict of interest.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Yihui Qin, Yuxing Wei, Jiayi Lu, Jiahui Mao, Haijun Deng, Xingwei Chen, Lu Gao, Ying Chen, Meibing Liu. The first draft of the manuscript was written by Yihui Qin, Yuxing Wei, Jiayi Lu, and Jiahui Mao and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References


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**Figures**
Figure 1
The distribution of meteorological stations in Fujian Province

Figure 2
The annual mean (a), maximum (b), and minimum (c) temperatures in Fujian Province from 1961 to 2018.
Figure 3

M-K abrupt test of annual mean, maximum and minimum temperatures in Fujian Province from 1961 - 2018

Figure 4
Interdecadal variation of mean temperature in Fujian Province between 1961 and 2018

Figure 5

It is similar to Fig. 4, but it shows the annual maximum temperature.
Figure 6

It is similar to Fig. 4, but it shows the annual minimum temperature.
Figure 7

The correlations between warming rate and elevation in the study region from 1961 to 2018. (a) is mean temperature, (b) is maximum temperature, and (c) is minimum temperature.
Figure 8

Interdecadal variations in annual mean temperature (a, d, g, j), annual maximum temperature (b, e, h, k), and annual minimum temperature (c, f, i, l) at 64 stations between 1961 and 2018. The layers from left to right are annual mean temperature, annual maximum temperature, and annual minimum temperature; from top to bottom are 1961-1990, 1971-2000, 1981-2010, and 1991-2018, respectively.
Figure 9

Seasonal mean temperature changes at 64 stations in Fujian Province from 1961 to 2018, a for Spring, b for Summer, c for Autumn, and d for Winter.
Figure 10

Seasonal maximum temperatures changes at 64 stations in Fujian Province for 1961 to 2018, a for Spring, b for Summer, c for Autumn, and d for Winter.
Figure 11

Seasonal minimum temperatures changes at 64 stations in Fujian Province from 1961 to 2018, a for Spring, b for Summer, c for Autumn, and d for Winter.