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Effect of Aspect on Climate Variation in Mountain Ranges of Shennongjia Massif, Central China

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Abstract: The aim of this study was to better understand the mechanisms of regional climate variation in mountain ranges with contrasting aspects as mediated by changes in global climate. It may help predict trends of vegetation variations in native ecosystems in natural reserves. As measures of climate response, temperature and precipitation data from the north, east, and south-facing mountain ranges of Shennongjia Massif in the coldest and hottest months (January and July), different seasons (spring, summer, autumn, and winter) and each year were analyzed from a long-term dataset (1960 to 2003) to tested variations characteristics, temporal and spatial quantitative relationships of climates. The results showed that the average seasonal temperatures and precipitation in the north, east, and south aspects of the mountain ranges changed at different rates. The average seasonal temperatures change rate ranges in the north, east, and south-facing mountain ranges were from –0.0210℃/yr to 0.0143℃/yr, –0.0166℃/yr to 0.0311℃/yr, and –0.0290 ℃/yr to 0.0084℃/yr, respectively, and seasonal precipitation variation magnitude were from –1.4940 mm/yr to 0.6217 mm/yr, –1.6833 mm/yr to 2.6182 mm/yr, and –0.8567 mm/yr to 1.4077 mm/yr, respectively. The climates variation trend among the three mountain ranges were different in magnitude and direction, showing a complicated change of the climates in mountain ranges and some inconsistency with general trends in global climate change. The climate variations were significantly different and positively correlated cross mountain ranges, revealing that aspects significantly affected on climate variations and these variations resulted from a larger air circulation system, which were sensitive to global climate change. We conclude that location and terrain of aspect are the main factors affecting differences in climate variation among the mountain ranges with contrasting aspects.

Keywords: regional climate variation; slope aspect; Shennongjia Massif; One-way ANOVA; global climate change

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1 Introduction

Accelerating global climate change is reshaping ecological communities through changes in species abundance (Elmendorf et al., 2015), and species interactions (Visser et al., 2006). Understanding the influences of global climate change on regional climates has become a key area of research in a variety of disciplines (IPCC, 2007), and many studies have determined that variations in regional climate mediated by climate change have altered the vegetation in regional terrestrial ecosystems (Cao and Woodward, 1998; Gonzalez et al., 2010; Gottfried et al., 2012; Peng et al., 2013). Therefore, understanding, attributing and predicting the regional climate changes is of great importance. Local atmospheric decoupling in complex topography alters climate change impacts (Daly et al., 2010), which create complex climate patterns in mountains. Studying how mountain

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climate varies with terrain could help to predict how variations in regional climate characteristics may impact on biological systems (Parmesan and Yohe, 2003). Previous studies have investigated the interactions between elevation and climate change (Zhu and Zhang, 2005; Wang and Liu, 2012; Liu and Liu, 2014). The precipitation generally increases with elevation and temperature exhibits a strong, predictable decrease with elevation when the atmosphere is well mixed (Daly et al., 2008). The relationship between elevation and climate is highly variable in many mountain valleys, which have showed a relationship between cold air pooling and contrasting aspects in mountain regions with valley constrictions (Daly et al., 2010). However, there has been limited research into the contributions of aspect and degree of steepness of mountain slopes to local and regional climate variation under global climate change. For example, it has been shown that the variation in vegetation types in the Shennongjia Massif in Hubei Province, Central China is associated with the differences in climate among the eastern, northern, and southern aspects (Peng, 1957; Shen et al., 2004). Whilst the relationship between spatial patterns of climate variation and plant growth, vegetation diversity in Shennongjia has received attention (Ying, 1977; Li and Ban, 1988; Jiang et al., 2000; Pu et al., 2006; Dang et al., 2013). And the nature of the relationship between aspect and climate variation remains little-studied and controversial (Qiao and Xin, 1981; Ma and Ni, 1988). Therefore, I used temperature and precipitation data from 1960 to 2003 from meteorological stations in the Shennongjia Massif to analyze climate variations in mountain ranges with different aspects.

2 Materials and Methods

2.1 Study area

The study area is the Shennongjia Forest District and nine counties nearby in Hubei Province and covers an area of 37 087.23 km^2 (Fig. 1). It is located to the north of the Yangtze (Changjiang) River, Central China, The area is in a transition zone between the sub-tropical and temperate climatic zones of the eastern plains and southeast mountains, and is a watershed between the Yangtze River and the Han River. The mountains of Shennongjia are orientated northeast-southwest and cause climate stratification and differences along the southern and northern aspects of the range. The mountain range is horseshoe-shaped, which is higher in the center and west, and lower in the north, south, and east, where the highest peak of Shennongding reaches an altitude of 3105.4 m a. s. l. Reflecting the ecological importance, the study area includes four national nature reserves, with one of them listed by UNESCO (United Nations Educational, Scientific and Cultural Organization) as a Biosphere Reserve in 1989. The vegetation types in the mountains vary with aspect and altitude, with differences in the vertical zonal spectrum between the northern and southern aspects at an altitude of 200–400 m.

2.2 Climate data

Daily air temperature and precipitation data in 1960–2003 in nine meteorological stations in the study area were obtained from the Meteorological Information and Technical Support Center of Hubei Province Meteorological Bureau. The average temperature and precipitation were calculated by seasons which were divided as flowing: spring, March–May; summer, June–August; autumn, September–November, and, winter: December–February. The meteorological stations in different counties in the study area were grouped according to aspect of the mountain range (Table 1). Climate factors and altitude for each aspect were simulated by linear models, and the effect of meteorological station elevation was minimized. The climate factor data have been interpolated on to an aspect by 1 km grid (Jones and Briffa, 1992), the average temperature and precipitation in aspects over the time period 1960–2003 was calculated.

2.3 Data analysis

2.3.1 Trend analysis

Trend of temperature and precipitation during 1960–2003 in study area were estimated using the linear model:

$$Y = a + bt + \varepsilon \tag{1}$$

where Y is annual or seasonal average temperature or precipitation in year t (t ranges from 1960 to 2003); ε is the random error; a is the intercept of the equation on y-axis, and b is the slope of the equation which represents the linear trend. Estimations of a and b were calculated using the linear least squares method:

$$a = \overline{y} - b\overline{t} \tag{2}$$

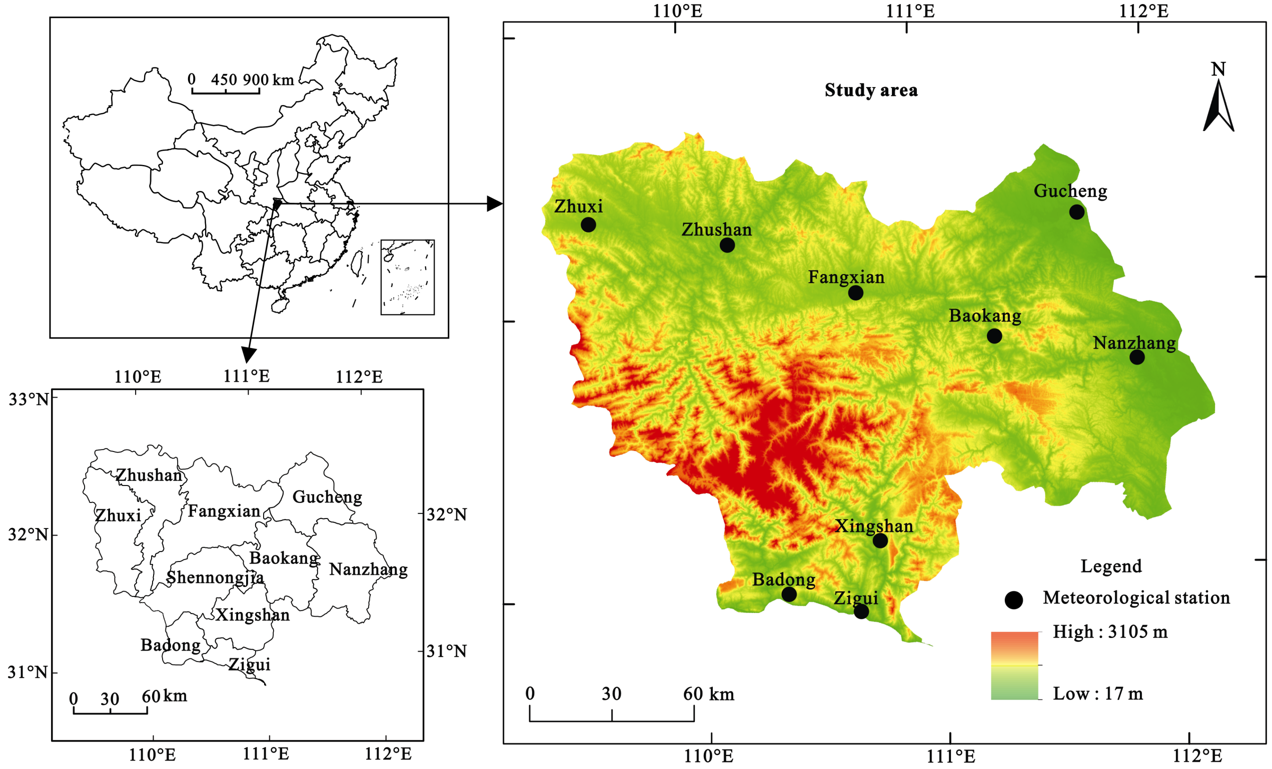

Fig. 1 Locations of study area and meteorological stations

Table 1 Aspect, location and altitude of nine meteorological stations in study area

Station	Aspect	Latitude (°N)	Longitude (°E)	Altitude (m)
Zhuxi	Northerly	32.32	109.68	450.10
Zhushan	Northerly	32.23	110.23	309.00
Fangxian	Northerly	32.05	110.73	427.10
Gucheng	Easterly	32.27	111.63	87.80
Baokang	Easterly	31.88	111.27	330.20
Nanzhang	Easterly	31.78	111.83	108.30
Badong	Southerly	31.07	110.40	295.60
Zigui	Southerly	31.00	110.68	151.50
Xingshan	Southerly	31.23	110.77	275.60

$$b = \frac{\sum_{i=1}^{n}(t_i - \bar{t})(y_i - \bar{y})}{\sum_{i=1}^{n}(t_i - \bar{t})^2} \tag{3}$$

where $\bar{y}$ is average temperature or precipitation and $\bar{t}$ is average years in study phase; t_i represents year i (i ranges from 1960 to 2003) and y_i is average temperature or precipitation in year i. The absolute value and sign (positive or negative) of b indicate climates variable varied in magnitude and direction, respectively. The significance of the trend was calculated using a two-tailed t test, the abrupt change of the trend was performed using Mann-Kendall test, and the statistically significant are at the 5% confidence level.

2.3.2 Linear correlation

The correlations of the temperature and precipitation among different aspects determined above were calculated using the Pearson correlation analysis method.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{4}$$

where x_i and y_i are the annual or seasonal average temperature or precipitation of different aspects in year i (i ranges from 1960 to 2003), respectively; and, r is the Pearson correlation coefficient which ranges from –1 to 1. $0.8 \le |r| < 1$ represents a very strong correlation; $0.6 \le |r| < 0.8$, indicates a strong correlation; $0.4 \le |r| < 0.6$, represents a moderately correlation; $0.2 \le |r| < 0.4$ indicates a weak correlation and $0 \le |r| < 0.2$ shows no correlation.

2.3.2 One-way ANOVA

One-way ANOVA (Christensen, 1996) was used to test for differences in the main effect of aspect on mean climate variation. The significance is computed using Levene's tests, and differences are taken statistically significant at 0.05 level.

3 Results

The monthly average temperature and monthly precipitation statistics showed that the coldest and warmest months in the study area were January and July, respectively. The effect of mountain aspect on temperature and precipitation in the two months, four seasons, and each year during 1960–2003 was analyzed.

3.1 Climate variation in coldest and warmest months

3.1.1 Coldest month

The average temperature in January was (2.5365 ± 0.8413), (2.2829 ± 1.2509), and (5.8049 ± 0.9470)℃ in the northerly, easterly, and southerly aspects of the mountain range, respectively, over the period 1960–2003 (Fig. 2a). There was an increasing trend in temperature in all three aspects, with an average rises of 0.0112, 0.0231 and 0.0031℃/yr in the northerly, easterly, and southerly aspects, respectively. Average January temperature rise was greatest in the east-facing mountain range and lowest in the south-facing mounting range, but these rises were not significant. Average temperatures in January in all three aspects were lowest in 1977, more stable during the periods 1960–1975 and 1980–1998, and higher during 1960–1975. The highest January temperatures in south-facing mountain ranges occurred in 1987, and in 2002 in the north and east-facing ranges. The highest and lowest overall temperatures occurred in south and north-facing ranges, respectively, and temperature fluctuations in all three ranges were very similar. There was a strong correlation ($r > 0.80$) on average January temperature among three ranges. Compared the mean and variance of the three sequence, eastern aspect and northern aspect have more similarity. There was a significant effect of aspect on average January temperature between the south-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 21.09$; $P = 0.00$).

Precipitation in January during the period 1960–2003 in the north, east, and south-facing mountain ranges were (13.0910 ± 0.3955), (15.2123 ± 0.4635), and (17.1115 ±

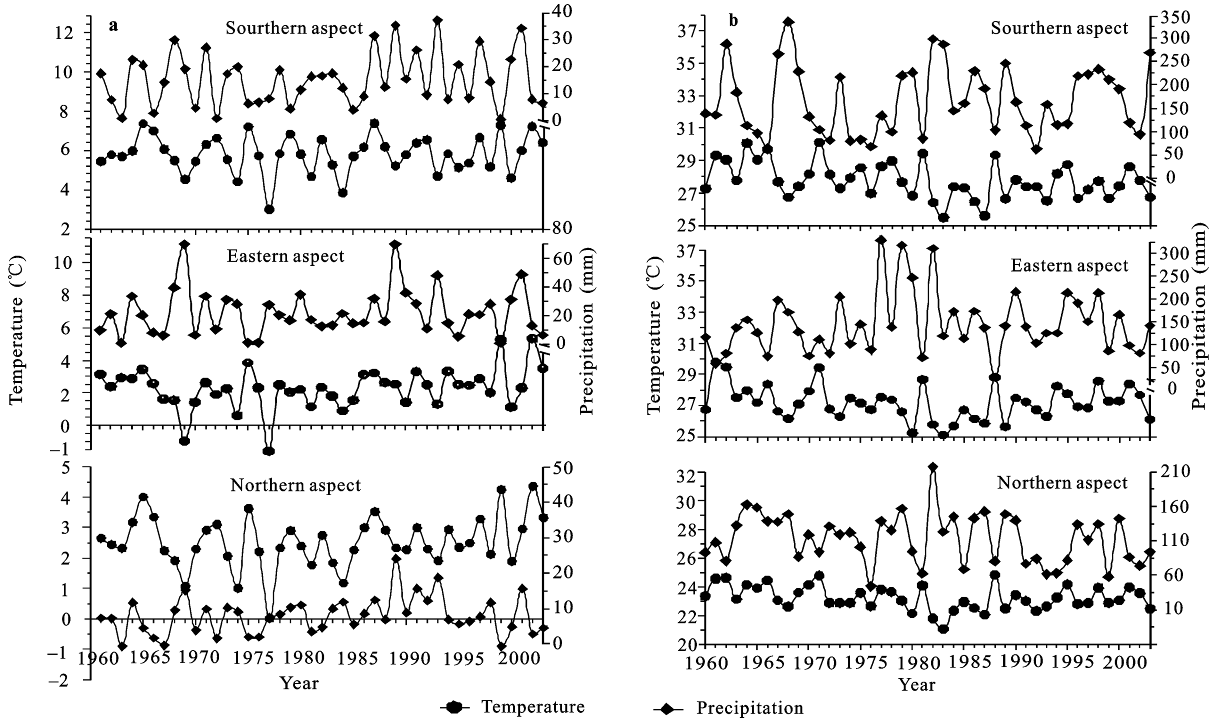

Fig. 2 Variation curves of average temperature and precipitation in different aspects in January (a) and July (b)

0.8340) mm, respectively, and increased by 0.0913, 0.1092, and 0.1403 mm/yr, respectively (Fig. 2a). The trend for increases in precipitation was not significant in all three ranges. The variation in January precipitation was consistent among the ranges, where rain was more abundant in the period 1988–1995 and less so in the period 1960–1968. There was no precipitation in January in the north and east-facing mountain ranges in 1963. Precipitation in the south-facing range was lowest in 1999, when it was also low in the mountain ranges with northerly and easterly aspects. There were correlations between precipitation in the north and east-facing (r = 0.83), south and east-facing (r = 0.71), and south and north-facing (r = 0.70) mountain ranges. There was a significant effect of aspect on January precipitation over the period 1960–2003 ($F_{\mathrm{df}} \geq 3.91$; $P < 0.05$).

3.1.2 Warmest month

The average July temperatures in the northerly, easterly, and southerly aspects of the mountain range over the period 1960–2003 were (23.2441 ± 0.8846), (27.1921 ± 1.1411), and (3.2441 ± 0.8846)℃ (Fig. 2b). Mean July temperature reduced by an average of 0.0192, 0.0152, and 0.0335℃/yr in the north, east, and south-facing mountain ranges, respectively, where the trend of decreasing temperature was significant only in the south-facing range. Average July temperatures were stable in all three ranges during the period 1989–2003, but were more varied during the period 1978–1988. The coolest temperatures in all three ranges were in 1983, and the warmest temperatures in the north, east, and south-facing mountain ranges were in 1988, 1961, and 1971, respectively. The average temperature fluctuations within the three ranges were similar ($r > 0.80$). There was a significant effect of aspect on the variation in average July temperatures over the period 1960–2003 ($F_{\mathrm{df}} \geq 3.72$; $P < 0.05$).

Over the period 1960–2003, July precipitation was (113.1233 ± 36.0559), (145.4596 ± 67.0975), and (166.6941 ± 73.2406) mm in the mountain ranges with northerly, easterly, and southerly aspects, respectively, which declined by 0.6810 mm/yr in the north-facing range and increased by 0.4868 and 0.3696 mm/yr in the east and south-facing ranges, respectively (Fig.2b). The mountain range with a northerly aspect tended to be drier than those with easterly and southerly aspects, however these changes in July precipitation were not significant. The variation in precipitation was consistent among the three mountain ranges, where the least precipitation in the south and north-facing ranges occurred in 1976, and one occurred in east-facing range in 1988. July precipitation in the north and east-facing mountain ranges was stable during the period 1962–1974 and 1994–2001, but highly variable in the south-facing range throughout the entire period. There were correlations between precipitation in the north and east-facing (r = 0.55), east and south-facing (r =0.43), and north and south-facing (r = 0.36) mountain ranges. Precipitation sequences in eastern aspect and southern aspect have more similarity. There was a significant effect of aspect on July precipitation between the north-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 3.52$; $P < 0.05$).

3.2 Seasonal climatic variation

3.2.1 Spring

Over the period 1960–2003, average spring temperatures in the north, east, and south-facing mountain ranges were (13.0127 ± 0.5303), (15.1003 ± 0.8350), and (16.9183 ±0.5661)℃, respectively. Average spring temperature increased in the north and east-facing mountain ranges and decreased in the south-facing range by 0.0060, 0.0252, and 0.0059℃/yr, respectively, indicating that east and north-facing ranges tended to be warmer than the south-facing ranges. The increase in temperature over the period 1960–2003 was significant for the east-facing mount range only (Fig. 3a). During the period 1981–1997, decreases in average spring temperature in all three ranges were followed by increases. Variation in average spring temperature was consistent among the three mountain ranges; the warmest and coolest springs in the ranges were in 2000 and 1991, respectively, except for the warmest was 1996 in the south-facing range. There were correlations between average spring temperature in the north and east-facing (r = 0.90), north and south-facing (r = 0.77), and east and south-facing (r = 0.56) and there was a significant effect of aspect on average spring temperature over the period 1960–2003 ($F_{\mathrm{df}} \geq 18.33$; $P = 0.00$).

Spring precipitation over the period 1960–2003 was (177.1797 ± 38.6288), (252.1536 ± 67.0975), and (269.2522 ± 66.9061) mm in the north, east, and south-facing mountain ranges, respectively, which declined by 0.8688, 1.1289, and 0.4547 mm/yr, respectively; none of the decreases in spring precipitation was significant

(Fig. 3a). There was a fluctuating, but decreasing trend in spring precipitation during the entire period of 1963–2000, and there was a relatively stable period from 1980 to 1985. The most variable precipitation occurred in 1960–1966, 1986–1989, and 1998–2003. The least precipitation in the mountain ranges with easterly and southerly aspects occurred in 2000, and in 1965 in the north-facing range, while the greatest precipitation occurred in 1963 in the north and east-facing ranges, and in 2002 in the south-facing range. There were correlations between spring precipitation in the north and east-facing (r = 0.73), north and south-facing (r = 0.55),

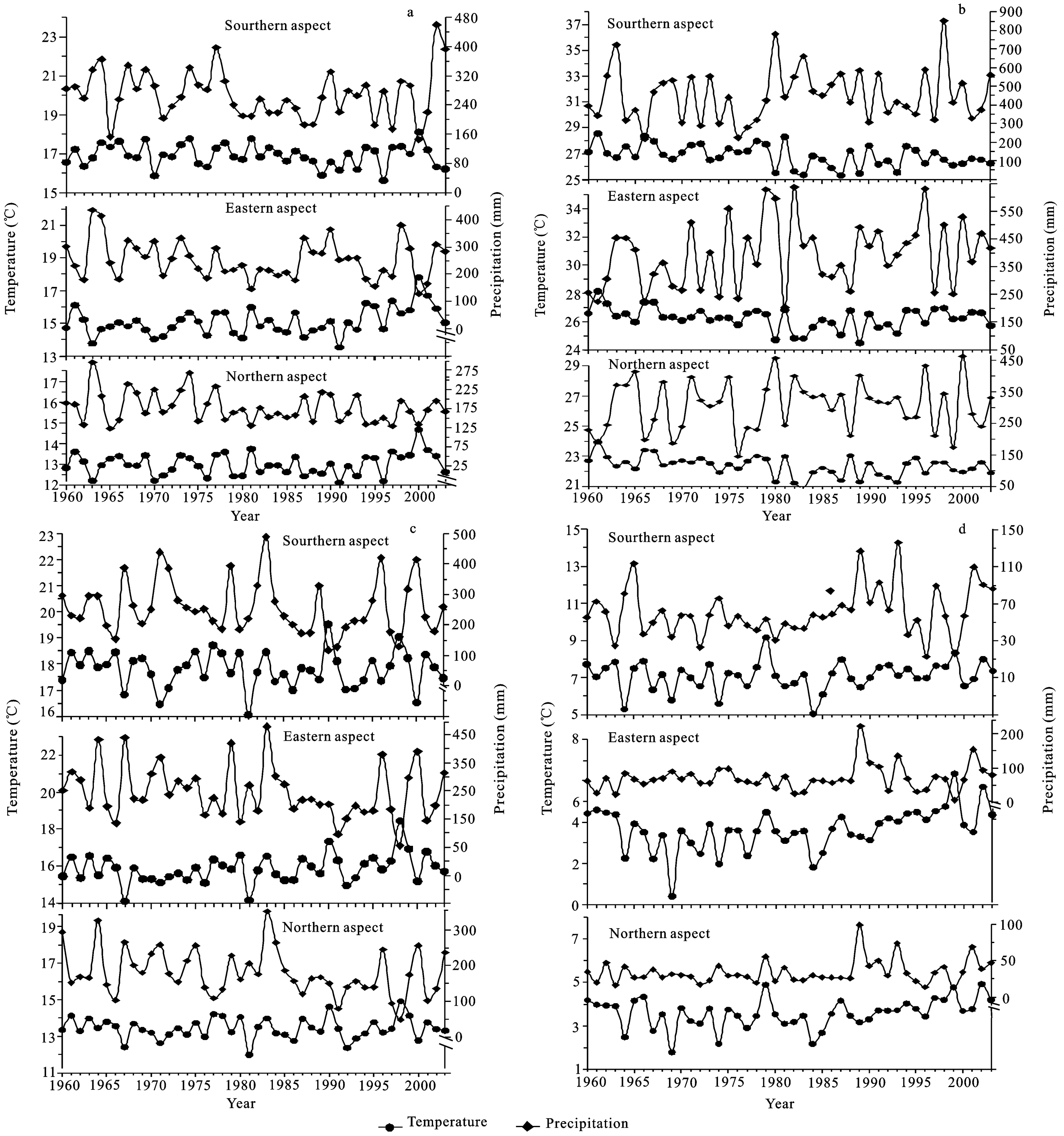

Fig. 3 Variation curves of average temperature and precipitation in different aspects in spring (a), summer (b), autumn (c), and winter (d)

and east and south-facing (r = 0.55) mountain ranges. Precipitations in east and south-facing mountain ranges had more similarity. There was a significant effect of aspect on spring precipitation between the north-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 8.22$; $P = 0.00$).

3.2.2 Summer

Average summer temperatures over the period 1960–2003 in the north, east, and south-facing mountain ranges were (22.3390 ± 0.6395), (26.2492 ± 0.7598), and (26.8291 ± 0.8392)℃, respectively, which declined by 0.0210, 0.0166, and 0.0290℃/yr, respectively (Fig. 3b). The declines in average summer temperature over the period 1960–2003 were significant in the north and south-facing mountain ranges. The average temperature in all three ranges was quite low from 1980 to 1994 and fluctuated greatly during the periods 1980–1983 and 1987–1990; there was a period of stability from 1996 to 2003, during which time there was a decreasing trend. Similarly, there was a decrease in temperature in the three ranges during the period 1960–1980, but the trend in the south-facing range aspect was more stable. The variations in average summer temperature were consistent among the three mountain ranges, and the warmest summer was in 1961 and the coolest was in 1987. There were correlations between the average summer temperatures in the north and east-facing (r = 0.93), north and south-facing (r = 0.90), and east and south-facing (r = 0.84) mountain ranges. There was a significant effect of aspect on average summer temperature over the period 1960–2003 ($F_{\mathrm{d}} \geq 5.12$; $P = 0.00$).

Over the period 1960–2003, summer precipitation in the north, east, and south-facing mountain ranges was (305.7342 ± 120.0848), (391.6931 ± 120.0848), and (452.1217 ± 142.5336) mm, respectively, which increased by 0.6217, 2.6182, and 1.4077 mm/yr, respectively (Fig. 3b). However, none of these increases was significant. Variations in summer precipitation were consistent among the three mountain ranges. The least precipitation in the north, east, and south-facing ranges was in 1976, 1981, and 1966, respectively, while greatest precipitation occurred in 2000, 1982, and 1998, respectively. There were correlations between summer precipitation between the north and east-facing (r = 0.76), north and south-facing (r = 0.54), and east and south- facing (r = 0.50) mountain ranges. There was a significant effect of aspect on summer precipitation over the period 1960–2003 ($F_{\mathrm{df}} \geq 3.43$; $P < 0.05$).

3.2.3 Autumn

Average autumn temperatures over the period 1960–2003 in the north, east, and south-facing mountain ranges were (13.4334 ± 0.5817), (15.8671 ± 0.7720), and (17.7931 ± 0.6898), respectively (Fig. 3c). Average temperatures over this period increased in the north and east-facing mountain ranges by 0.0016 and 0.0182℃/yr, respectively, and decreased in the south-facing range by 0.0026℃/yr. The change in average autumn temperature in the east-facing range was significant. Except the period 1960–1965, average autumn temperature fluctuated greatly in all three mountain ranges, and the variations in temperature were consistent among the ranges. The coolest autumn temperature occurred in 1981 in the south and north-facing ranges; and in 1967 in the east-facing range. The highest autumn temperatures occurred in 1998 in north and east-facing mountain ranges and in 1990 in south-facing range. There were correlations between average temperatures in the north and east-facing (r = 0.92), north and south-facing (r = 0.92), and east and south-facing (r = 0.81) mountain ranges. There was a significant effect of aspect on average autumn temperatures over the period 1960–2003 ($F_{\mathrm{df}} \geq 18.63$; $P = 0.00$).

Autumn precipitation over the period 1960–2003 was (180.6824 ± 65.0955), (246.4868 ± 59.1894), and (257.3803 ± 88.2484) mm in the north, east, and south-facing mountain ranges, respectively, which decreased by 1.4940, 1.6833, and 0.8567 mm/yr, respectively (Fig. 3c). None of the decreases in autumn precipitation in the three mountain ranges was significant. Precipitation became increasingly more stable during the period 1967–1998 and variability in precipitation was consistent among the three mountain ranges. There were correlations in autumn precipitation between the north and east-facing (r = 0.85), east and south-facing (r = 0.76), and north and south-facing (r = 0.72) ranges. There was a significant effect of aspect on autumn precipitation between the north-facing mountain range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 5.21$; P = 0.00).

3.2.4 Winter

Average winter temperatures over the period 1960–2003 in the north, east, and south -facing mountain range were (3.3853 ± 0.6845), (3.6315 ± 1.0363), and (7.0914 ± 0.7797)℃, respectively, which increased by 0.0143, 0.0311, and 0.0084℃/yr, respectively (Fig. 3d). The increase in average winter temperature in the east-facing mountain range was significant. There were wide fluctuations in winter temperature during the period 1962–1979, but temperatures generally rose gradually from 1988 to 1998. Variations in average temperature over the period were consistent among the three mountain ranges. The coolest temperatures occurred in 1969 in the east and north-facing mountain ranges, and in 1984 in the south-facing range. The warmest temperatures occurred in 2002 and 1999 in the north and east-facing mountain ranges, respectively, and that in 1979 in the south-facing range. There were correlations in average winter temperature between the north and east-facing (r = 0.92), north and south-facing (r = 0.91), and east and south-facing (r = 0.80) mountain ranges. Eastern aspect and northern aspect have more similarity. There was a significant effect of aspect on average winter temperature between the south-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 29.11$; $P = 0.00$).

Over the period 1960–2003, winter precipitation in the north, east, and south-facing mountain ranges were (34.1151 ± 37.2103), (70.3501 ± 37.2103) and (60.8026 ± 27.0279) mm, respectively, which increased by 0.3052, 0.5391, and 0.4384 mm/yr, respectively (Fig. 3d). None of the increases in winter precipitation in the three mountain ranges was significant. From 1960 to 1987, winter precipitation was stable. There were downward fluctuations in winter precipitation during the period 1988–2001. Winter precipitation in east and north-facing ranges was greatest in 1989, that in south-facing range was greatest in 1993, and lowest in the north and east-facing ranges in 1999 and one in the south-facing range in 1996. Variations in average winter precipitation over the entire period were consistent among the three mountain ranges. There were correlations in winter precipitation between the north and east-facing (r = 0.90), north and south-facing (r = 0.75), and east and south-facing (r = 0.72) mountain ranges. Precipitations in east and south-facing ranges had more similarity. There was a significant effect of aspect on winter precipitation between the north-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 6.28$; $P = 0.00$).

3.3 Annual climatic variation

We found that average annual temperatures in the north, east, and south-facing mountain ranges over the period 1960–2003 were (13.0910 ± 0.3599), (15.2123 ± 0.5463), and 17.1151 ± 0.3840℃, respectively (Fig. 4). The average annual temperatures increased in the north and east-facing mountain ranges by 0.0002 and 0.0145℃/yr and decreased in the south-facing range by 0.0073℃/yr. The increase in temperature in the east-facing range was significant. The highest average annual temperature in the north, east, and south-facing ranges occurred in 1961, 1998, and 1966, respectively, and the coolest in the north, east, and south-facing ranges occurred in 1984, 1969, and, 1989, respectively. There were correlations in average annual temperature between the north and east-facing (r = 0.88), north and south-facing (r = 0.84), and east and south-facing (r = 0.62) mountain ranges. There was a significant effect of aspect on average annual temperature over the period 1960–2003 ($F_{\mathrm{df}} \geq 28.82$; $P = 0.00$).

Annual precipitation in the north, east, and south-facing mountain ranges was (682.7670 ± 128.3930), (973.4519 ± 180.1518), and (1041.5640 ± 175.7790) mm, respectively, which increased in the east and south-facing mountain ranges by 0.3451 and 0.5347 mm/yr, respectively and decreased by 1.4358 mm/yr in the north-facing range. None of these changes was significant (Fig. 4). The highest precipitation in the north and east-facing ranges was in 1964 and that in the south-facing range in 1983. The lowest precipitation in all three ranges was in 1966. The variations in precipitation over the period 1960–2003 were consistent among the three mountain ranges. There were correlations in annual precipitation between the north and east-facing (r = 0.80), north and south-facing (r = 0.65), and east and south-facing (r = 0.68) mountain ranges. Precipitation in east and south-facing mountain ranges has more similarity. There was a significant effect of aspect on annual precipitation between the north-facing mounting range and the other ranges over the period 1960–2003 ($F_{\mathrm{df}} \geq 11.81$; $P = 0.00$).

4 Discussion

4.1 Results of climate variations

The trends of climate variations indicated that the climates responses to global warming varied among the three mountain ranges in the Shennongjia massif which had different aspects, and these variations may be con sidered regional in scale. Over the period 1960–2003,

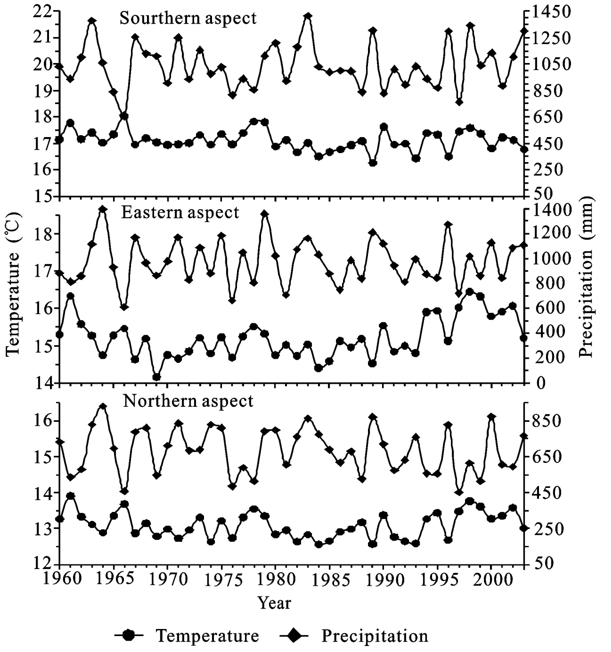

Fig. 4 Variation curves of average annual temperature and precipitation in different aspects

the annual climates in the mountain range with an easterly aspect tended to become warmer and wetter and the climate in the north-facing range tended to become hotter and drier, which were consistent with those associated with global warming (IPCC, 2013). However, the climate in the mountain range with a southern aspect tended to become cooler and wetter over the same period, which was counter to the warming trend reported for the northern hemisphere (Jansen et al., 2007). Climates in all three mountain ranges tended to become wetter and cooler in summer, and wetter and warmer in winter, respectively, which is consistent with changes in regional and global climates (Stanhill and Cohen, 2001). Spring and autumn precipitation in all three mountain ranges tended to decrease from 0.4547 to 1.6833 mm/yr, and the change was greatest in the east-facing range and the least one was in the south-facing ranges. It is likely that the decline in annual precipitation in the range with a northerly aspect was a result of precipitation decreases in spring, especially in autumn. Over the period 1960–2003, spring and autumn temperatures in the north and east-facing mountain ranges tended to become warmer, which increased from 0.0016 to 0.0252℃/yr, while those in the south-facing range tended to become cooler. I suggest that these seasonal changes in temperature contributed to those recorded for annual temperatures. In particular, the east-facing mountain range experienced the greatest increases in spring and autumn temperature, contributing to the significant increase in average annual temperature.

In general, the temporal pattern of climate changing in all three mountain ranges, the period 1960–1980 tended to be cold, followed by climate warming that began in 1985, which is similar to the east Asian and global climates (Trenberth et al., 2007; Shi and Xu, 2008). Although temperature in the south-facing mountain range showed a significant decrease in the late 1980s, followed by that the general upward trend continued, indicating that the warming may have been lagged behind large scale climate changing (Zhang et al., 2012). I measured the variations of temperature and precipitation in the three mountain ranges during 1960–2003 using the Mann-Kendall (MK) test, the climate jumps occurred mainly in the 1960s and 1980s. This phenomenon was consistent with the temporal pattern that precipitation in China increased in 1950s, decreased until the 1970s, and increased again after the 1980s. However, some jumps in the three mountain ranges occurred in the 1980s and 1990s were not completely consistent with those in global. The climate jumps therefore showed the characteristics of regional and global climate change. Thus, the climate variations in all three mountain ranges showed some inconsistency with general trends in global climate change.

4.2 Causes of climate variations

The climates in coldest and warmest months, four seasons, and a year were shown to be affected by aspect. Controlling factors associated with aspect may include geographical location and terrain, which lead to different susceptibilities to monsoon paths; degree of cold air pooling and efficiency of drainage; and, degree and duration of solar radiation. The mountain range with a southerly aspect is located in the transition zone of two atmospheric aerosols (Chen et al., 2004) and the spring, summer, autumn, and annual temperatures showed an antiphase variation in global warming, which may be due to the combined effects of the atmospheric aerosol and southwest warm trough (Chen et al., 1994). The mountain range with a northerly aspect is located to the south of the Nanxiang Basin, through which the winter monsoons travel, the lower summer temperature and July precipitation may resulted from reduced solar radiation (Stanhill and Cohen, 2001), and weaker summer monsoons because of the Shennongjia and Jingshan Mountains blocking the southwest and southeast warm air, which was good for cold air pooling from Siberia. The climate of the south-facing mountain range is mainly controlled by warm air in summer and by the winter monsoon in winter, spring, and autumn (Daly et al., 2010), which was intervened by the northwest monsoon and the southwest warm trough under the influence of the Yunnan-Guizhou Plateau in the southwest atmospheric circulation (Chen et al., 1994). The climate in the mountain range with an easterly aspect is mainly controlled by monsoon airs from the large monsoon system that circulates along the Jianghan Plain.

4.3 Causes of climate differences

It was found that the variation in temperature in January and in the winter in the east and north-facing mountain ranges were homogenous, which may be due to the fact that these mountain ranges had same susceptibilities to the cold winter monsoon air from the Nanxiang Basin. There were significant differences in temperature among the mountain ranges in the other seasons, which may be a result of the effect of the southwest warm trough, atmosphere aerosol and the cold air drainage and pooling (Daly et al., 2010). Precipitation in all three mountain ranges in July, summer, and winter tended to increase, possibly due to the weakening monsoon and south-moving rain belt. The south and east-facing ranges are at lower latitudes than the north-facing range, and the annual precipitation tended to increase in these mountain ranges. The variation of winter precipitation in these ranges may be controlled by the middle latitude westerly wind belt and the cold air activity path. Summer precipitation in the south-facing mountain range is controlled by warm summer monsoon lifted by Wuyi Mountain and disturbed by the atmospheric aerosol, whereas that in the east-facing range is only controlled by warm summer monsoon from the large monsoon system.

Spring and autumn precipitation in all three mountain ranges tended to decrease. It may be mainly due to weaker summer monsoons and strengthened winter monsoon by the Shennongjia and Jingshan mountains blocking the warm summer monsoon or winter monsoon and reducing the interactive strength between warm air and cold air, which reduced precipitation in the north-facing mountain range in spring and autumn, and slightly increasing in summer, with the overall effect of decreasing annual precipitation. The variations in precipitation in July and spring, autumn, annual in the east and south-facing mountain ranges were homogenous. The phenomenon may result from the effect of that the climates in these mountain ranges were controlled mainly by the summer monsoon. Precipitation in summer, winter and January was significantly different among the three mountain ranges, the differences possibly attributed to the effect that precipitation in there mountain ranges were controlled respectively by atmospheric aerosols, summer monsoon or the winter monsoon coming from different paths, cold air pooling and draining. So the climate in north-facing mountain range is likely to be characterized by global dry heating (Shi et al., 2004).

4.4 Causes of climate correlations

Since it is likely that the large monsoon circulation system controls temperatures in the three mountain ranges, the temperatures of the ranges were found to be correlated. The east and north-facing mountain ranges are adjacent to the Nanxiang Basin and are exposed to cold air in winter, spring, and autumn, such that temperatures within the ranges are affected similarly. Precipitations in the three mountain ranges were also correlated, but to a lesser degree than for temperature, indicating that aspects have stronger control ability to precipitation changes than temperature. The seasonal precipitation among the three mountain ranges were significantly correlated, which indicated that precipitation in four seasons in three aspects have mutual inductance. These may be due to the effect that the precipitations in the three mountain ranges were controlled mainly by a large atmospheric circulation system. These correlations are possible that there is a feedback loop between the climate system and vegetation (Cox et al., 2000).

5 Conclusions

The research revealed that trends in average temperature and precipitation variations in the hottest and coldest months, in the four seasons, and each year in the three mountain ranges in the Shennongjia massif were different over the period 1960–2003, reflecting a complicated change of the regional climates in mountain ranges with contrasting aspects that had different aspects responses to global warming, which showed some inconsistency with general trends in global climate change. The annual climate of north, east, and south-facing mountain ranges tended to become drier and warmer, wetter and warmer, and wetter and cooler respectively. The north and east-facing ranges in spring and autumn tended to be dry and warm, nevertheless, the south-facing range in spring and autumn tended to be dry and cold. Summer tended to be cold, winter tended to be warm, and annual temperature range tended to be small for all three mountain ranges. There were significant variation trends in spring, autumn, winter, and annual temperatures in east-facing range, summer temperature in north and south-facing ranges, and July temperature in the south-facing range. These differences in responses to global warming among the mountain ranges with contrasting aspects may be attribute to the combined effects of the global climate anomaly, atmospheric aerosols from industrial and agricultural activities, and topography. The terrain of the study area and vicinity, which influences monsoon activity, has an important effect on climate variations among the mountain ranges with contrasting aspects, such as the Shennongjia and Jingshan mountains, and Wuyi Mountain, the Yunnan-Guizhou Plateau. The variations in annual temperature show that regional-scale climates changes lag behind large scale climate warming.

The temperature and precipitation in the three mountain ranges were significantly and positively correlated, hinting same and larger air circulation systems that affected climate changes in the three mountain ranges, which resulted from the global climate anomaly. The temperatures among the mountain ranges with contrasting aspects were significantly different, showing that different factors controlled respectively the climates in these aspects. The factors may be global climate anomaly, atmospheric aerosols from industrial and agricultural activities, and topography in Shennongjia Massif in three mountain ranges. The terrain of the study area and vicinity might have more important effect on climates in the mountain ranges with contrasting aspects than other factors. Aspect had a stronger influence on precipitation than temperature, which indicated that precipitation was dominated by more complex factors. The temperature and precipitation among mountain ranges with contrasting aspects were homogenous, which indicated these mountain ranges had same susceptibilities to an atmospheric circulation. The temporal and spatial patterns of climate correlations and difference among mountain ranges with contrasting aspects changed in intensity. Studying on these patterns may increase the understanding of monsoon dynamics in complex terrains, which may improve interpreting the mechanisms of regional climate variation in mountain ranges with contrasting aspects as mediated by changes in global climate.

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