Accelerated climate change and its potential impact on Yak herding livelihoods in the eastern Tibetan plateau

**Michelle A. Haynes · King-Jau Samuel Kung ·
Jodi S. Brandt · Yang Yongping · Donald M. Waller**

Abstract The Tibetan Plateau has experienced rapid warming like most other alpine regions. Regional assessments show rates of warming comparable with the arctic region and decreasing Asian summer monsoons. We used meteorological station daily precipitation and daily maximum and minimum temperature data from 80 stations in the eastern Tibetan Plateau of southwest China to calculate local variation in the rates and seasonality of change over the last half century (1960–2008). Daily low temperatures during the growing season have increased greatly over the last 24 years (1984–2008). In sites of markedly increased warming (e.g., Deqin, Yunnan and Mangya, Qinghai), daily and growing season daily high temperatures have increased at a rate above 5 °C/ 100 years. In Deqin, precipitation prior to the 1980s fell as snow whereas in recent decades it has shifted to rain during March and April. These shifts to early spring rains are likely to affect plant communities. Animals like yaks adapted to cold climates are also expected to show impacts with these rising temperatures. This region deserves further investigation to determine how these shifts in climate are affecting local biodiversity and livelihoods.

M. A. Haynes (✉) · D. M. Waller
Department of Botany, University of Wisconsin-Madison, 430 Lincoln Avenue, Madison, WI 53706, USA
e-mail: michelleahaynes@gmail.com

K.-J. S. Kung
Department of Soil Science, University of Wisconsin-Madison, 1525 Observatory Drive, Madison, WI 53706, USA

J. S. Brandt
Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706, USA

Y. Yongping
Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Shuangqing Str. 18, Beijing 100085, China

Present Address:
M. A. Haynes
U.S. Army Corps of Engineers, Institute for Water Resources, 7701 Telegraph Road, Alexandria, VA 22315, USA

1 Introduction

The collision of the Indian plate with the Eurasian plate over 10 million years ago created the Tibetan Plateau and the eastern Himalayas. The eastern Tibetan Plateau extends eastward into the Hengduan Mountains, famous as an international biodiversity hotspot and the site of the Three Parallel Rivers UNESCO World Heritage site (Mittermeier et al. 1999). At least 16 ethnic groups reside within this hotspot (Xu & Wilkes 2002). Rivers originated from the eastern Tibetan Plateau extend east through mainland China and south into southeast Asia, providing water for approximately two billion people (Yunnan 2003).

The Eastern Tibetan Plateau is an ideal location to examine the interactions among geographic complexity, climatic history, and areas of unique biological and cultural significance (Haynes et al. 2013).

The climate of the Eastern Tibetan Plateau is driven by the Indian Ocean southwestern monsoon and the Pacific Ocean southeastern monsoon (CEPF 2002). Recent decades have shown a weakening of the monsoon effect and a slight release from its seasonal distribution of rain, including greater variation in extreme rain events (Li et al. 2012). Studies have also shown significant warming across the Tibetan Plateau (Li et al. 2010; Xu et al. 2008; Yu et al. 2010) as well as increases in precipitation (Li et al. 2012; Qin et al. 2006; Qin et al. 2010; Zhao et al. 2010). These trends of climatic changes alter ecosystem functions with cascading affects and feedbacks on the rich biodiversity and livelihoods in the region (Xu & Wilkes 2002; Li et al. 2010; Xu et al. 2009). Climate change causes grassland systems to change, with resulting decrease in species richness (Klein et al. 2007), increasing shrub encroachment (Brandt et al. 2013), and reducing the outputs of yak (*Bos grunniens*) husbandry (Haynes 2011; Miller 1999; Weiner et al. 2003).

In this study, we examine local patterns of change in climate across the eastern Tibetan Plateau over the past 48 years (1960–2008). We focus on detecting and characterizing changes not only in mean climate parameters but also local daily temperature minima and maxima as well as the seasonality of temperature and precipitation. Our goal is to assess the increase in the rates of climatic change across the region. Any sites identified with particularly dramatic increases in rates of temperature change within the Tibetan Plateau may be useful for assessing impacts of climatic change on alpine vegetation and yak husbandry. Such locations are logical locations for further study to assess whether biological thresholds are being exceeded.

2 Methods

2.1 Meteorology data

We accessed daily high temperature, daily low temperature, and precipitation data for 100 meteorology stations on the eastern Tibetan Plateau region. These stations are maintained by the National Meteorological Administration of China and undergo quality control prior to release (Qin et al. 2010). We conducted preliminary analyses to determine the range of dates included, consistency of records, and number and type of gaps in the station data. Because some of the stations began recording data prior to others, we selected 1960 as the starting year for our analyses (the earliest year for which we had data from all selected stations). The few stations located outside the study region were excluded as were stations with large gaps in their records. To guard against overestimates, we also removed three stations from the results that showed inordinate rates of warming (for example, 22 °C/100 year for daily high temperature). Such rates appear improbable and could be misleading. In the end, 80 stations were included in our analyses from 1960 to 2008, covering about 756,000 km^2 (Fig. 1).
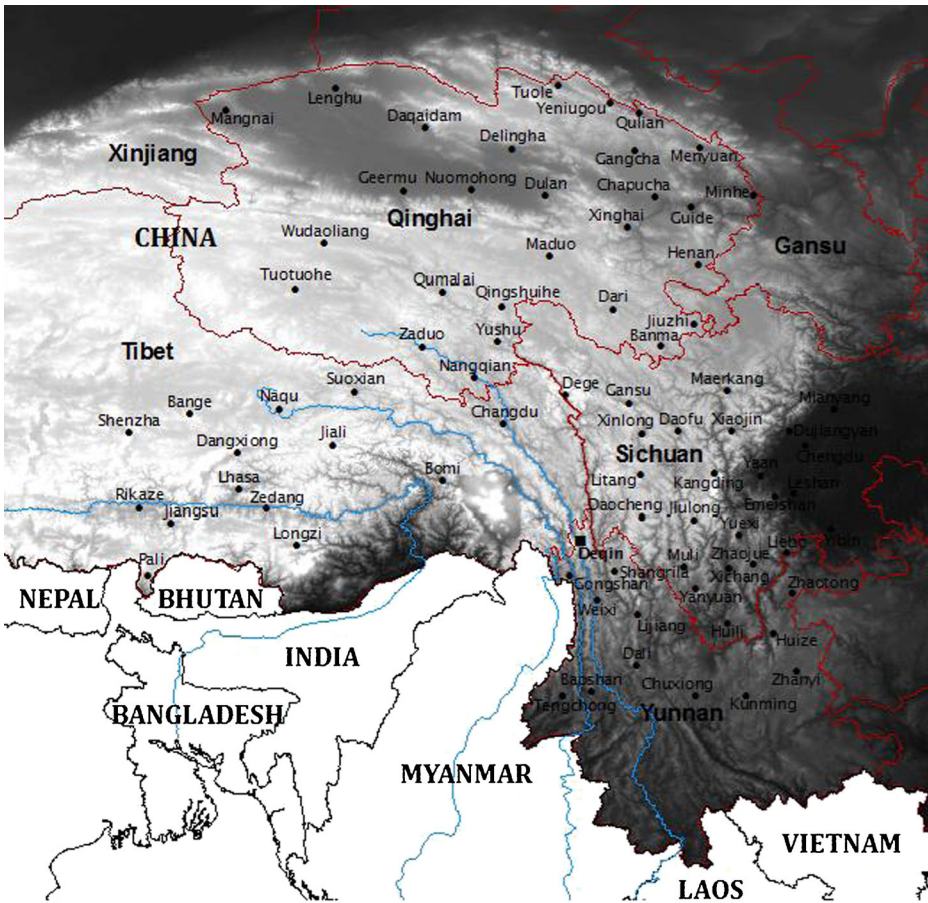
Fig. 1 Map of meteorology stations in the eastern Tibetan Plateau used in our analyses. Provincial and international boundaries shown, as well as the major rivers originating on the Tibetan Plateau. Deqin, one of the sites in northwest Yunnan, is designated with a square

2.2 Analyses - cumulative change

Annual cycles and certain anomalies can be observed using unmodified temperature data. However, to detect and quantify the scope and amount of temperature and precipitation anomalies, we used the cumulative method (Lozowski et al. 1989). Random fluctuations in climate lead to no net effect on cumulative climate statistics, but any consistent trend will cause summed climate variables to accumulate positive or negative trends over time (Hasanean & Basset 2006; Lozowski et al. 1989; Maechel et al. 1998). This cumulative method sums the variable across the desired range of time and uses this curve to calculate the second derivative providing an estimate of the rate of change (Figs. 2a, S1). In contrast to slope calculations, the curvature method for calculating rates of change reduces error, especially with smaller rates of change (Figs. 2b, S1). It does so by effectively filtering the noise while retaining the signal. Preliminary time series analyses of the dataset revealed that the rate of temperature increase was not linear, with the rate of temperature increase during the recent decades much faster than that during the early decades. Global climate showed a cooling pattern in the 1960–1970s
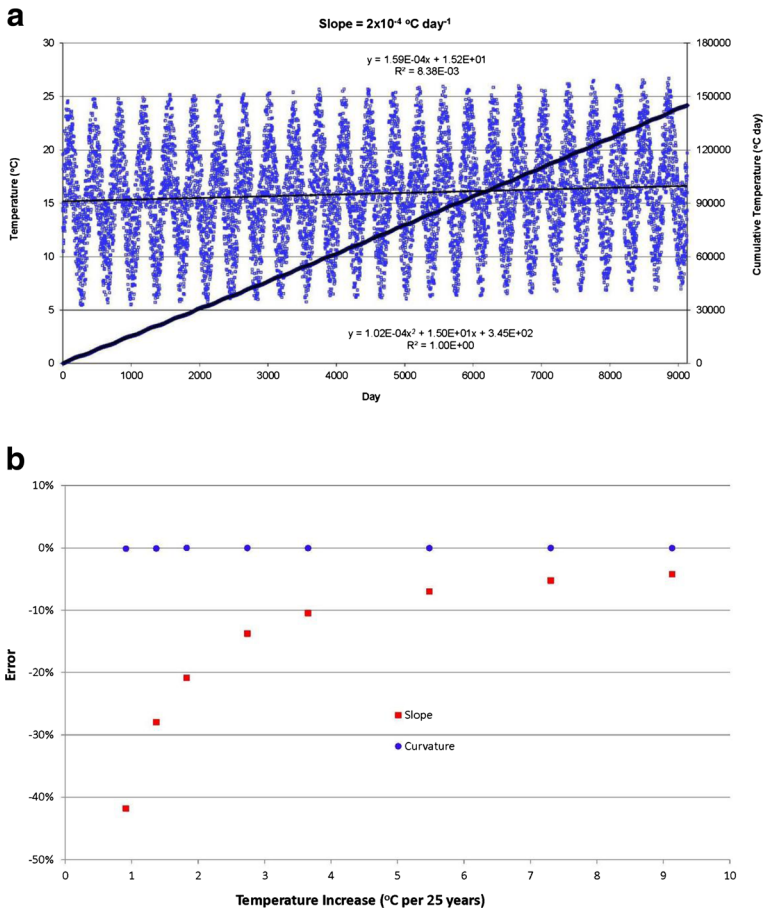
Fig. 2 Comparison of linear slope vs. cumulative curvature methods. **a** A sine-wave daily temperature pattern was generated with 15 °C mean temp, 20 °C seasonal amplitude, ∀5 degrees daily random fluctuation, superimposed with a 2×10^{-4} degree per day linear slope (7.3 °C per 100 years) to simulate a temperature increase induced by climate change. The linear regression of the sine-wave temperature pattern with R^2 value is shown at the *top*. The *diagonal thick line* is the cumulative daily temperature (with a best fit second power polynomial shown at the *bottom*). The first derivative (i.e., the coefficient of the x term of the linear regression) is the slope of the linear slope method. The second derivative (i.e., two times the coefficient of the x^2 term of the polynomial fit) is the calculated slope of the curvature method. **b** Because the superimposed slope is known, the error of each method can be calculated. We generated 50,000 sets of 25-year daily random temperature fluctuations to compare the averaged errors of the two methods. The comparison is repeated while the rates of temperature increase per 25 years change from 1 to 10°

(IPCC 2007). Our data confirms this effect at most stations. Since we were interested in assessing how the rate of temperature change has increased over recent decades, we chose to compare the 48- year rates of change with the 24- year rates of change. All calculations are presented in °C/100 year rates in order to standardize and enable comparison to other studies.

We calculated mean daily low and mean daily high temperatures from 1960 to 2008 for all stations to show the variation represented across the region sampled. Next we calculated 24- and 48- year rates of change for precipitation, annual daily low, annual daily high, growing season daily low, growing season daily high, winter daily low, and winter daily high. We defined growing season as months which the monthly mean daily high ≥5 °C (in NE Qinghai

we used ≥0 °C, because no monthly mean ≥5 °C), and winter as November–March, inclusive. To graphically depict the rates of change across stations, we constructed circle maps using ArcGIS 9.3.

2.3 Analyses - biological thresholds

To explore some of the effects of rapid shifts in temperature on thresholds relevant to alpine meadows, important sources of medicinal plants and vital for Tibetan yak herding livelihoods in northwest Yunnan (Haynes & Yang 2013), we investigated when the freezing threshold occurs to determine if it has changed between 1960 and 2008. We used temperature data at the Deqin County station (3,320 m), and data from 13 other stations ranging from 1,646 to 4,292 m within Deqin County based on at least 20-year means (Le'anwangdui 2001).

We calculated the linear lapse rate adjustment for each month (Dodson and Marks 1997) as this technique does not require interpolation, often inaccurate for the Himalayas (Leemans & Cramer 1991; Rolland 2003), and provides greater detail than the global mean lapse rate of -6.5 °C km−1 (Barry & Chorley 1987). Average daily low and high temperatures at Deqin climate station were then used to calculate low and high temperatures for February through June at 4,000 and 4,400 m using the lapse rate adjustments. We noted when the average low temperatures shifted from below-freezing to above-freezing temperatures, plotted against elevation. To see if temperature changes were accompanied by changes in precipitation type, we also plotted annual rainfall, snowfall, and total precipitation from 1960 to 2008 for each month from February through June.

We also investigated whether temperature changes have reached thresholds directly relevant to yak physiology, since yak husbandry is the dominate livelihood across most of the Tibetan Plateau region (Haynes & Yang 2013). The yak has adapted to withstand cold temperatures but experiences rising respiration rates at only 13 °C (Weiner et al. 2003). At 16 °C its heart rate and body temperature start to rise, and at 20 °C it stops moving, grazing, drinking or ruminating. Therefore, we counted the number of days per month in winter that were above 13 °C, 16 °C, and 20 °C to see if the number of times that these thresholds have been exceeded has increased between 1960 and 2008 and reported the results for 16 °C. We focused on the winter months when using the direct historical data, since livestock are herded at the lower elevations in winter, closer to the meteorology stations in those areas. We also used the lapse rate adjustments calculated for Deqin county and our DEM to determine average daily high temperatures for May and June at all elevations in the alpine zone (>3,800 m), comparing the decadal average from 1958 to 1968 with 1999–2008. Linear lapse rates fit within global estimates and followed the expected trend from months of lower moisture to higher moisture (Barry & Chorley 1987; Dodson & Marks 1997; Rolland 2003) (February, -6.65 °C km−1; March, -6.35 °C km−1; April, -6.25 °C km−1; May, -5.91 °C km−1; June, -5.59 °C km−1, all $r^2 > 0.97$). We also searched the literature and interviewed key informants in the study region for news of yak mortality, particularly in February and March when yaks may already be weakened by inadequate diet during the winter.

3 Results

Temperatures from these 80 stations in the eastern Tibetan Plateau region reported mean annual daily lows between -11.4 and 15.3 °C (Fig. 3a), and mean annual daily highs of 2.4 °C to 23.3 °C (Fig. 3b). Over the past 48 years, overall rates of change in temperature varied between -1.6 and 5.3 °C/100year. These results are consistent with those reported (Li et al.
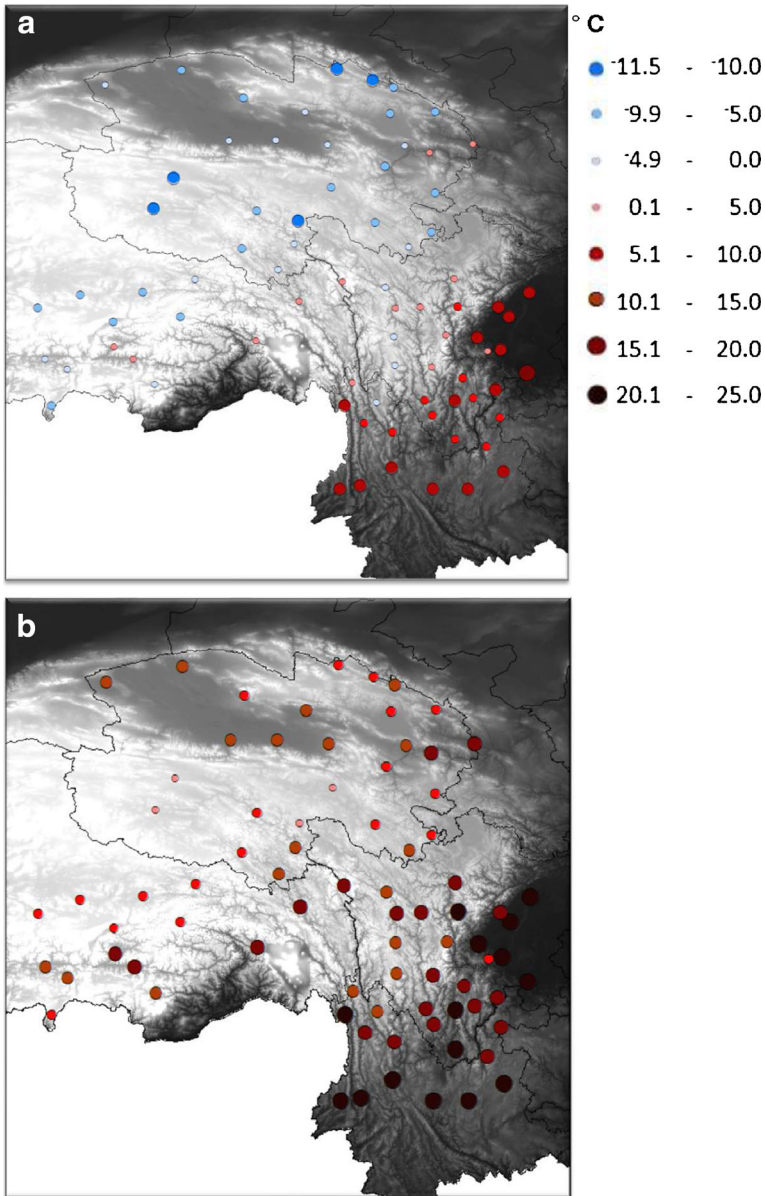
Fig. 3 Map of **a average daily low** and **b average daily high** temperatures across stations

2010; Qin et al. 2010; Xu et al. 2008). More recently, however, these rates have greatly accelerated at many sites. Comparing 24- and 48-year rates of change showed much higher recent rates at most stations for most categories of change. Changes in growing season daily high temperatures were particularly dramatic with ratios of rates of increase over the past 24 years to overall rates of increase over 48 years ranging up to >20 (Fig. 4).

Taken as a whole, daily low temperatures have increased more than daily high temperatures (Fig. 5) as already reported (Li et al. 2010; Qin et al. 2010; Xu et al. 2008; Yu et al. 2010).
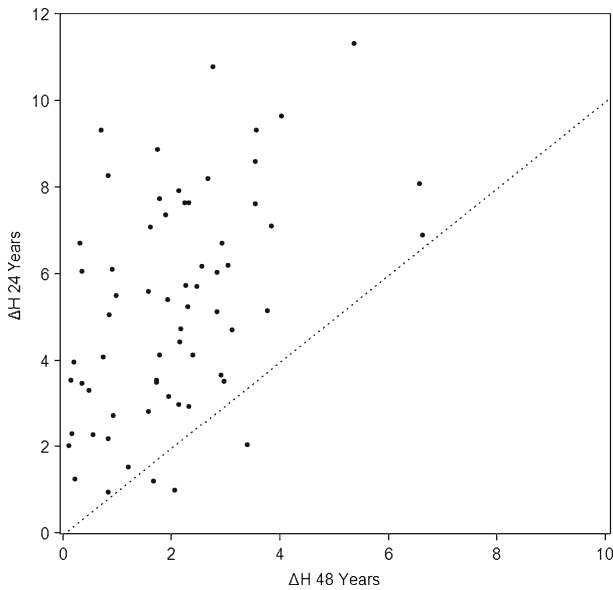
Fig. 4 Rate of temperature increase comparison showing 48-year rates and 24- year rates of change in growing season daily high temperatures

There are, however, sites that show a different pattern. The change in daily high temperature in Deqin, Yunnan over the past 24 years was 7.24 °C/100 years. The rate of change in daily low temperatures over the same period was much less (1.38 °C/100 years). For daily high temperatures over the past 24 years, 11 stations reported >4.0 °C/100 year rates of change and 43 reported >3.0 °C/100 years (Fig. 5c).

Growing season daily lows in the region have increased more than growing season daily highs over the last 24 years, both in terms of the number of stations reporting this pattern and the reported levels of recent change (Fig. 6). These rates of change for growing season daily low temperatures exceeded >3.0 °C/100 years at 35 stations, 4.0 °C at 21 stations, 5.0 °C at eight stations, and 6.0 °C at two. Increases in growing season daily high temperatures over the past 24 years exceeded 3.0 °C at 30 stations and 4.0 °C at 12 (Fig. 6c). Mangya, Qinghai showed >4.7 °C/100 year rates of change in every category measured, demonstrating a warming trend that began before 1980 at that location.

Precipitation rates varied in complex ways across the region reflecting the complex topography and interactions with changing temperatures and the monsoons. As these changes have already been described in detail (Qin et al. 2010; Zhao et al. 2010), we present just one figure of these marked changes for Deqin, Yunnan (Fig. 7). Since the mid-1980s, the amount of precipitation from February–April has not changed significantly here but the type of precipitation has switched. An area that previously experienced snow between February to April now instead experiences only rain.

Many stations also experienced a marked increase in the number of days over critical temperature thresholds in the winter months (Table 1). We expect these increases affect yak health and survival. Our literature search revealed a scarcity of publications focusing on cases and counts of local yak mortality, probably due to the difficulty in obtaining this level of data. While warming above the freezing threshold can cause a shift in precipitation type from snow to rain, warmer than usual winters can also contribute to heavy snowfall events. Interviews of
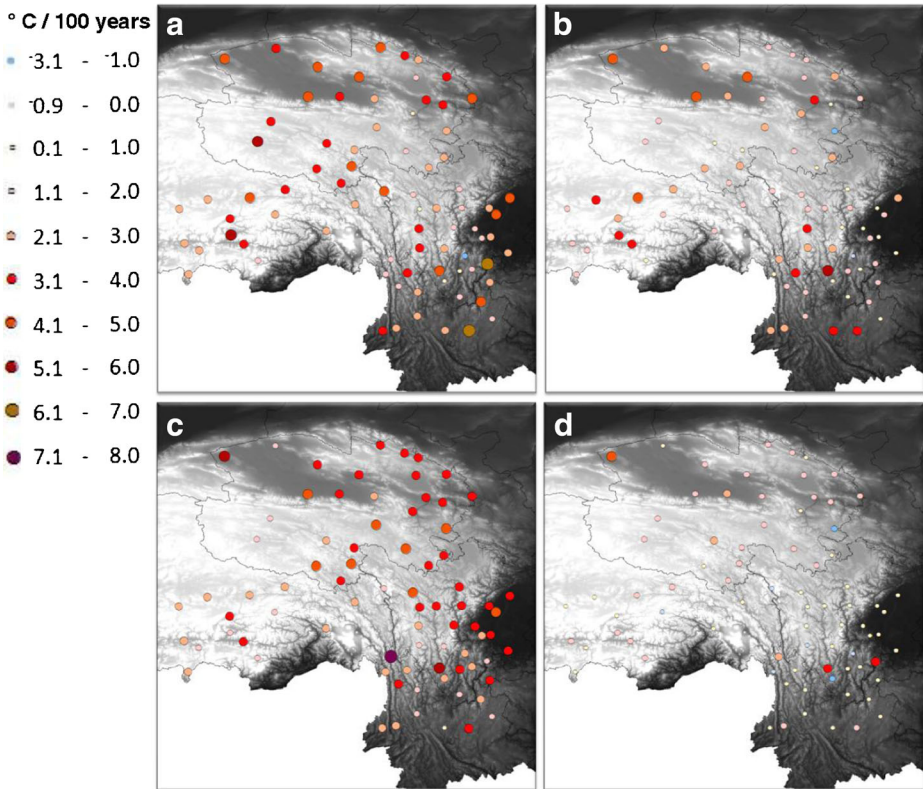
° C / 100 years

- `3.1 - `1.0
- `0.9 - 0.0
- 0.1 - 1.0
- 1.1 - 2.0
- 2.1 - 3.0
- 3.1 - 4.0
- 4.1 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 8.0

Fig. 5 Map of average daily **low a** 24- and **b** 48-year and average daily **high c** 24- and **d** 48-year **rates of change** across stations

yak herders and county agency staff did confirm large herd die-offs had occurred in some areas, typically in February and March, attributing the deaths to heavy snowfall causing starvation in weakened animals and/or increases in parasites. Comparing the elevation where average May and June temperatures crossed 13 °C, 16 °C, and 20 °C thresholds in 1958–1968 with 1999–2008 shows dramatic increases in spatial area experiencing temperatures that negatively affect yak physiology and performance have occurred (Fig. 8). During the month of June, the area underneath the 13 °C threshold for yak performance diminished from 24 % to 8 % of the landscape over fifty years.

4 Discussion

The cumulative method for analyzing historical climate data (Lozowski et al. 1989) can reduce noise and improve clarity for assessing anomalies to provide greater sensitivity for assessing trends of climate change (S1). Our results confirm the warming pattern documented in other assessments of the region (Fan et al. 2009; Qin et al. 2010; Yu et al. 2010) and highlight sites with increasing rates of change within the region. We do not believe that stations reporting high rates of change reflect an urban heat island effect (Li et al. 2010). Such effects should be manifest throughout the year. Even stations with the highest rates of change for certain
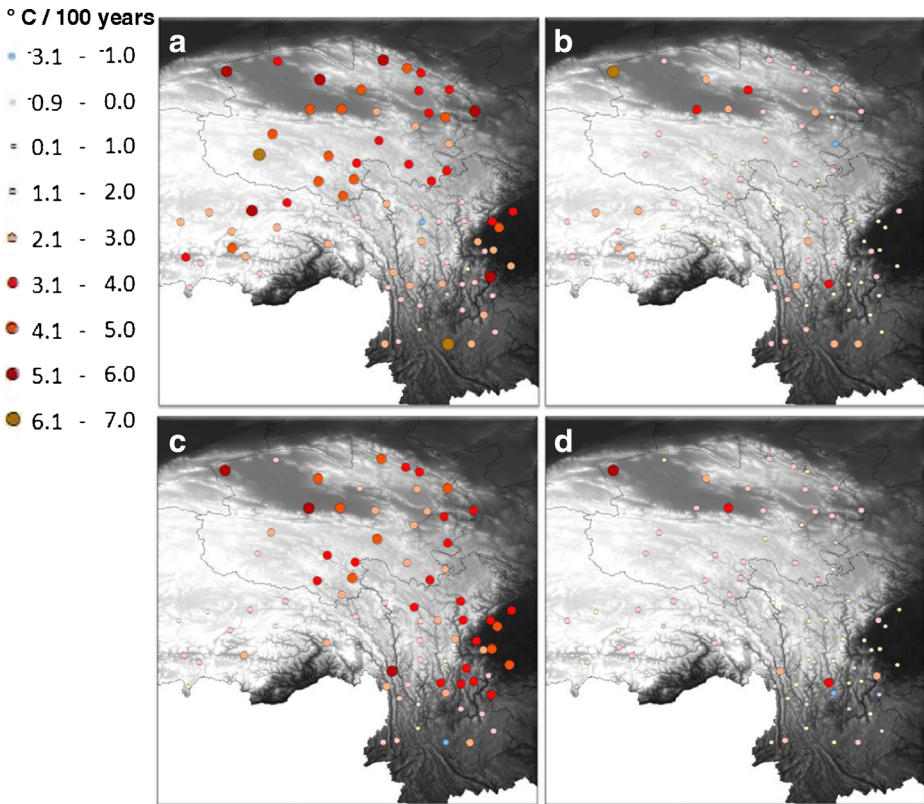
° C / 100 years

Fig. 6 Map of **growing season** average daily **low a** 24- and **b** 48-year and average daily **high c** 24- and **d** 48-year **rates of change** across stations

variables did not record increases in other variables (e.g., daily high increases despite consistent daily lows). The patterns also showed seasonality, decreasing in magnitude and direction during certain months.

Experimental climate change simulations have showed rapid plant community response to warming temperatures (Klein et al. 2004, 2007; Yu et al. 2010). However, none have yet simulated temperature increases of the kind we found at many stations exceeding 5 °C/100 years.

Such extreme changes can result in vegetation shifts. For example, Thuiller et al. (2008) report up-slope movements of certain plant species in the Northern Hemisphere at a rate of 6.1 m per decade that appear correlated with shifts in precipitation and temperature over the last 50 years. Globally, each 1 °C of temperature change moves ecological zones by 160 m higher in altitude (Thuiller 2007). Therefore, the rate of change of 7.2 °C/100 years that was recorded over the last 24 years at Deqin county corresponds to a 276.5 m altitudinal shift, over 11 m each year. In addition, Brandt et al. (2013) measured an annual shrub expansion rate of 2.1 % in northwest Yunnan related to early snow melt and climate warming in this area. Other studies in northwest Yunnan have shown similar increases in treeline using repeat photography (Baker & Moseley 2007; Moseley 2006).

It remains uncertain whether species will have the capability to respond by colonizing new areas or rapidly adapting their physiological behavior to match changing habitat conditions (Parmesan 2007; Woodward 1987). Most alpine plants control growing season activities in
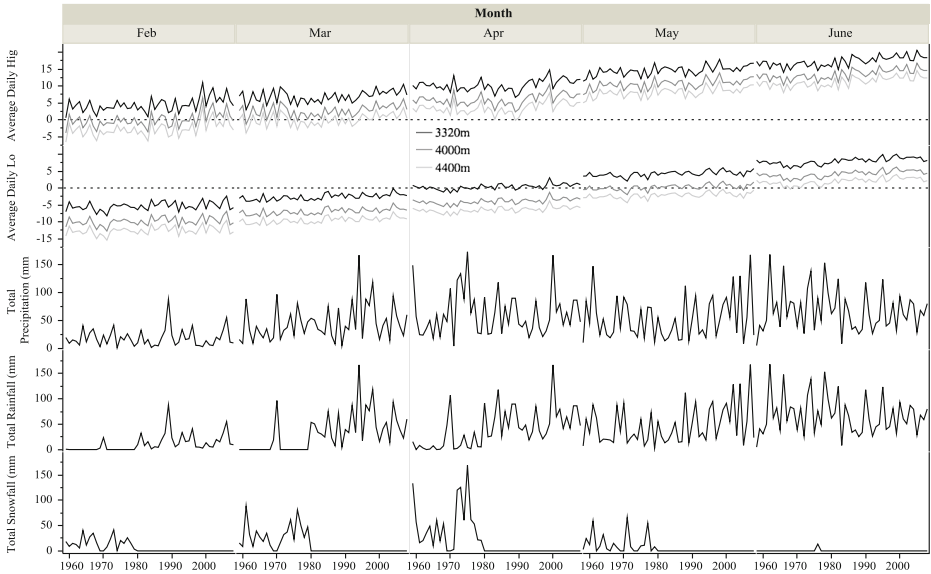
Fig. 7 Average daily low and daily high temperatures (°C) at Deqin station (3,320 m) and calculated at 4,000 m and 4,400 m using the linear lapse rates. Shifts from snowfall to rainfall between 1960 and 2008 in February, March, April, May and June at the Deqin station (3,320 m)

response to photoperiods rather than temperature (Körner & Basler 2010; Keller & Körner 2003). This precludes the potential benefit of longer growing seasons, causing extra stress due to respiratory losses when plants are not covered by snow (Körner 2009). Wang et al.(2011) shows increases in soil temperature and permafrost temperatures, particularly over the last 20

Table 1 Regions showing increased incidence of winter temperatures >16 °C in February and March. Prior to 1984 these stations show no recorded daily highs >16 °C in February and March, during the months that yaks are at lower elevations closer to the stations

| Station	Province	Years exceeding 16 °C threshold
Nangqian (囊谦)	S Qinghai	1999, 2003, 2004, 2007
Yushu (玉树)	S QingHai	1999, 2004, 2007
Jiangsu (江孜)	SE Tibet	1999, 2004, 2007
Zaduo (杂多)	SE Tibet	1999, 2004, 2007
Bomi (波密)	SE Tibet	2004, 2007
Changdu (昌都)	SE Tibet	1999, 2004, 2006, 2007
Longzi (隆子)	SE Tibet	1999, 2001, 2004, 2007
Rikaze (日喀则)	S Tibet	1999, 2001, 2004, 2007
Daocheng (稻城)	SW Sichuan	1999, 2007
Litang (理塘)	SW Sichuan	1999, 2007
Ma'erkang (马尔康)	W Sichuan	1999 to 2008
Dege (德格)	W Sichuan	1999, 2004, 2006, 2007
Gansu (甘孜)	W Sichuan	1999, 2004, 2007
Daofu (道孚)	W Sichuan	1999, 2001, 2002, 2006, 2007
Xinlong (新龙) >20 °C	W Sichuan	1999, 2004, 2005, 2006, 2007

Average Daily High Temperatures
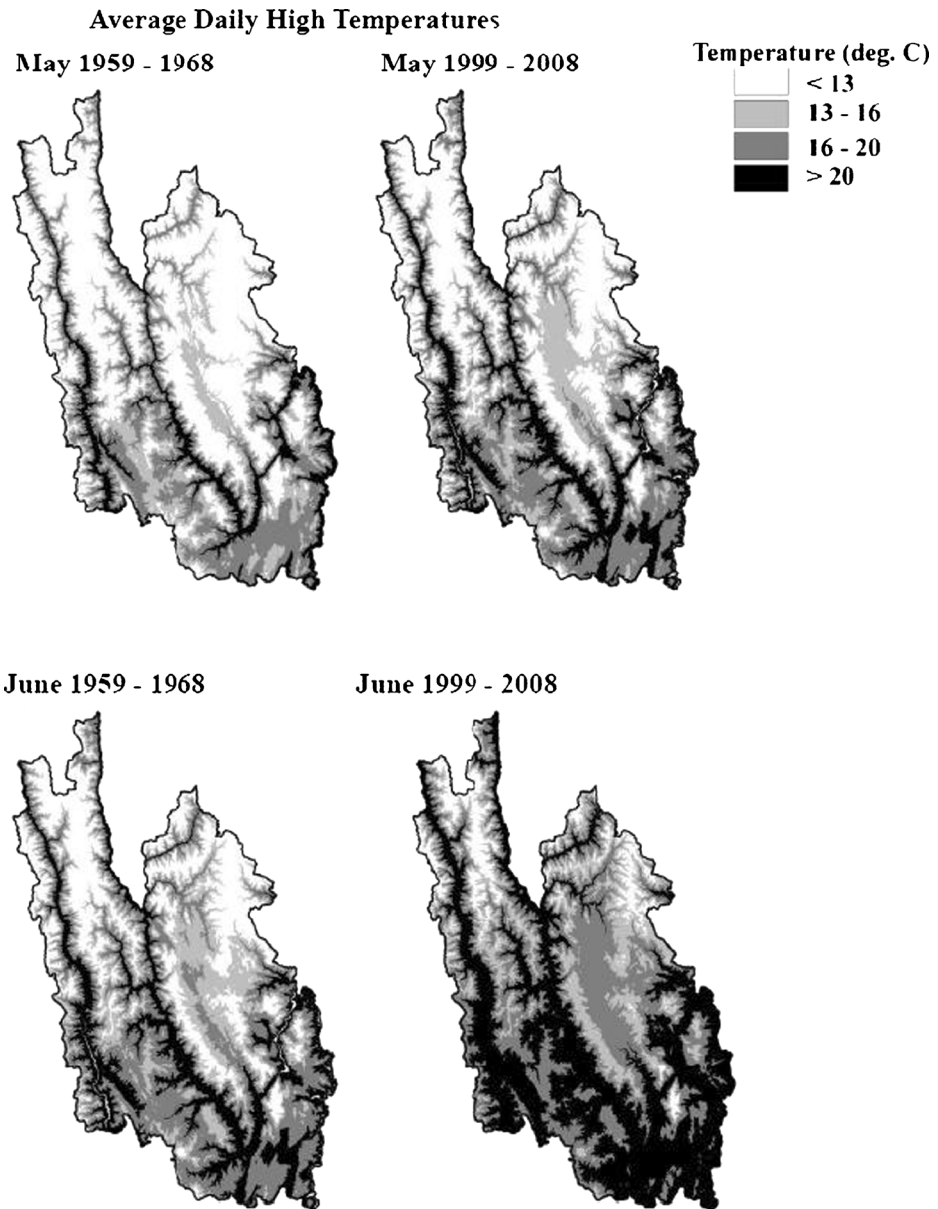
Fig. 8 May and June average daily high temperatures in the alpine zone in Deqin county from 1959–1968 and 1999–2008, showing 13 °C, 16 °C, and 20 °C thresholds with adversely impact yak physiology and performance

years. Changes in the type of precipitation may also significantly change vegetation, as rain soaks directly into the ground whereas snow accumulates over the winter before being released during the late spring or early summer (Freppaz et al. 2008; Peng et al. 2010; Zhao et al. 2010). Transitions in evapotranspiration rates in response to climatic drivers (Fan & Thomas 2013) and coupled impacts of climate and anthropogenic induced changes including habitat

fragmentation (Wischnewski et al. 2011) may cause shifts in hydrologic systems including water retention, runoff, and erosion.

Our initial investigation into the impact of temperature increase on yaks suggests that yaks suffer because temperatures are surpassing yaks' physiological thresholds. However, impacts of changing climate on yak health and husbandry overall may be complex, interacting, and far-reaching. Heavy snowfall, for example, may be precipitated by warm winter temperatures, which can result in reduced forage and large-scale herd die-offs. (Li et al. 2010). There may also be cycles of impact, as when warmer spring temperatures stimulate shifts in timing when herders move their livestock across the landscape, increasing the potential for parasite infestation as they spend more time by warm pools of stagnant water that support parasite populations. Such factors accentuate the already drastic decrease in June habitat below the 13 °C threshold by two-thirds since 1958–1968. These multiple causes warrant further investigation, as yaks continue to provide the livelihoods for the majority of the region's inhabitants.

5 Conclusion

We confirm regional assessments of climate change in the eastern Tibetan Plateau and challenge those results by assessing more detailed patterns including sites with increasing rates of climate change. The extreme warming and shifts in precipitation observed at some sites suggest that rapid climate change may be exerting strong effects on vegetation, hydrology, livestock health, and thus livelihoods in the area (Xu et al. 2009). Such impacts warrant further study as rates of warming above 5 °C/100 years exceed the upper limits of most warming scenarios. These historical rates of change are higher than even the worst case predicted changes in temperature increases for the eastern Tibetan Plateau. Given that such rapid rates of warming have already happened in this region, we need further research to investigate its consequences. Thus, the eastern Tibetan Plateau could serve as a valuable opportunity to understand how other areas will likely respond to changing climates and explore mitigation and adaptation strategies that target those impacts.

References

Baker B, Moseley R (2007) Advancing treeline and retreating glaciers: implications for conservation in Yunnan, P.R. China. Arct Antarct Alp Res 39:200–209
Barry R, Chorley R (1987) Atmosphere, Weather, and Climate, 5 edn. Routledge
Brandt JS, Haynes MA, Kuemmerle T, Fang ZD, Waller DM, Radeloff VC (2013) Regime shift on the roof of the world: alpine meadows converting to shrublands in the southern Himalayas. Biol Conserv 158:116–127
Critical Ecosystem Partnership Fund (CEPF) (2002) Ecosystem profile. Mountains of Southwest China hotspot. Conservation International, Washington
Dodson R, Marks D (1997) Daily air temperature interpolated at high spatial resolution over a large mountainous region. Climate Res 8
Fan Z-X, Brauning A, Yang B, Cao K-F (2009) Tree ring density-based summer temperature reconstruction for the central Hengduan Mountains in southern China. Global Planet Change 65:1–11
Fan Z-X, Thomas A (2013) Spatiotemporal variability of reference evapotranspiration and its contributing climatic factors in Yunnan Province, SW China, 1961–2004. Clim Change 116:309–325

Freppaz M, Celi L, Marchelli M, Zanini E (2008) Snow removal and its influence on temperature and N dynamics in alpine soils (Vallee d'Aoste, northwest Italy). J Plant Nutr Soil Sci 171:672–680

Hasanean HM, Basset HA (2006) Variability of summer temperature over Egypt. Int J Climatol 26:1619–1634

Haynes MA (2011) Impacts of a changing climate and yak herding practices on alpine rangelands and Tibetan livelihoods in southwest China. PhD Thesis in Botany. University of Wisconsin-Madison, Madison, WI.

Haynes MA, Fang ZD, Waller DM (2013) Grazing impacts on the diversity and composition of alpine rangelands in northwest Yunnan. J Plant Ecol 6(2):122–130

Haynes M, Yang Y (2013) Adapting to change: transitions in traditional rangeland management of Tibetan yak herders in northwest Yunnan. Environ Dev Sustain 15:1065–1077

IPCC (2007) Summary for policymakers of climate change 2007: the physical science basic contribution of work group to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Keller F, Körner C (2003) The role of photoperiodism in alpine plant development. Arct Antarct Alp Res 35:361–368

Klein JA, Harte J, Zhao XQ (2004) Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau. Ecol Lett 7:1170–1179

Klein JA, Harte J, Zhao XQ (2007) Experimental warming, not grazing, decreases rangeland quality on the Tibetan Plateau. Ecol Appl 17:541–557

Körner C (2009) Mountain vegetation under environmental change. In: Jandl R, Borsdorf A, Van Miegroet H, Lackner R, Psenner R (eds) Alpine Space—Man and Environment, vol 7: Global change and sustainable development in mountain regions. Innsbruck University Press, Innsbruck, pp 25–30

Körner C, Basler D (2010) Plant science. Phenology under global warming. Science 327:1461–1462

Le'anwangdui (2001) Diqing Zangzu Zizhizou Zhi, Zhonghua Renmin Gongheguo Di Fang Zhi Cong Shu. Yunnan minzu chubanshe (in chinese), Kunming Shi

Leemans R, Cramer W (1991) The IIASA database for mean monthly values of temperature, precipitation and cloudiness on a global terrestrial grid. IIASA Research Report RR-91-18

Li L, Yang S, Wang Z, Zhu X, Tang H (2010) Evidence of warming and wetting climate over the Qinghai-Tibet plateau. Arct Antarct Alp Res 42:449–457

Li Z-X, He Y-Q, Wang P-Y, Theakstone WH, An W-L, Wang X-F et al (2012) Changes of daily climate extremes in sourthwestern China during 1961–2008. Global Planet Change 80/81:255–272

Lozowski EP, Charlton RB, Nguyen CD, Wilson JD (1989) The use of cumulative monthly mean temperature anomalies in the analysis of local interannual climate variability. J Climate 2(9):1059–1068

Maechel H, Kapala A, Flohn H (1998) Behavior of the centres of action above the Atlantic since 1881. Part 1: characteristics of seasonal and interannual variability. Int J Climatol 18:1–22

Miller D (1999) Herders of forty centuries: nomads of Tibetan rangelands in western China. People and rangelands, building the future, proceedings of the VI international rangeland congress. CSIRO, Queensland, Australia

Mittermeier R, Meyers N, Mittermeier N, Gil P, Ford H (1999) Hot spots: earth's biologically richest and most endangered terrestrial ecoregions, cemex. Conservation Int, Mexico City

Moseley RK (2006) Historical landscape change in northwestern Yunnan, China: using repeat photography to assess the perceptions and realities of biodiversity loss. Mt Res Dev 26:214–219

Parmesan C (2007) Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Glob Chang Biol 13:1860–1872

Peng S, Piao S, Ciais P, Fang J, Wang X (2010) Change in winter snow depth and its impacts on vegetation in China. Glob Chang Biol 16:3004–3013

Qin DH, Liu SY, Li PJ (2006) Snow cover distribution, variability, and response to climate change in western China. J Climate 19:1820–1833

Qin N, Chen X, Fu G, Zhai J, Xue X (2010) Precipitation and temperature trends for the Southwest China: 1960–2007. Hydrol Processes 24:3733–3744

Rolland C (2003) Spatial and seasonal variations of Air temperature lapse rates in alpine regions. J Climate 16:1032–1046

Thuiller W (2007) Climate change and the ecologist. Nature 448:550–552

Thuiller W, Albert CH, Araújo MB, Berry PM, Cabeza M, Guisan G, Hickler T, Midgley GF, Paterson J, Schurr FM, Sykes MT, Zimmermann NE (2008) Predicting global change impacts on plant species distributions: future challenges. Perspect Plant Ecol 9:137–152, Evolution and Systematics

Wang G, Bai W, Li N, Hu H (2011) Climate changes and its impact on tundra ecosystem in Qinghai-Tibet Plateau, China. Clim Change 106:463–482

Weiner G, Han JL, Long RJ (2003) The yak. 2nd ed. The regional Office for Asia and the Pacific, Food and Agriculture Organization of the United Nations, Bangkok, Thailand

Wischnewski J, Kramer A, Kong Z, Mackay AW, Simpson GL, Mischke S, Herzschuh U (2011) Terrestrial and aquatic responses to climate change and human impact on the southeastern Tibetan Plateau during the past two centuries. Glob Chang Biol 17:3376–3391

Woodward FI (1987) Climate and plant distribution. Cambridge Univ. Press, Cambridge, UK

Xu J, Grumbine RE, Shrestha A, Eriksson M, Yang X et al (2009) The melting Himalayas: cascading effects of climate change on water, biodiversity and livelihoods. Conserv Biol 23:520–530

Xu J, Wilkes A (2002) People and ecosystems in mountain landscape of northwest Yunnan: causes of biodiversity loss and ecosystem degradation. Glob Environ Res 6(1):103–110

Xu ZX, Gong TL, Li JY (2008) Decadal trend of climate in the Tibetan Plateau—regional temperature and precipitation. Hydrol Processes 22:3056–3065

Yu H, Luedeling E, Xu J (2010) Winter and spring warming result in delayed spring phenology on the Tibetan Plateau. Proc Natl Acad Sci 107:22151–22156

Yunnan Management Bureau of Three Parallel Rivers National Park. (2003) Three Parallel Rivers of Yunnan Protected Area Nomination for World Natural Heritage Status - Additional Information. Yunnan Province, China. 22pp

Zhao P, Yang S, Yu R (2010) Long-term changes in the rainfall over eastern China and associated atmospheric circulation under the global warming scenario. J Climate 23:1544–1562