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Zongxing Li

Study on Climate Change in Southwestern China

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Zongxing Li

Study on Climate Change in Southwestern China

Doctoral Thesis accepted by
Cold and Arid Region Environment
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7. **Li, Z.X.**, He, Y.Q., Yang, X.M., Theakstone, W.H., Jia, W.X., Pu, T., Liu, Q., He, X.Z., Song, B., Zhang, N.N., Wang, S.J., Du, J.K. (2010): Changes of the Hailuogou glacier, Mt. Gongga, China, against the background of climate change since the Holocene.Quaternary International, 218(2010):166–175. (Reproduced with Permission)

Supervisor's Foreword

This study mainly explores the response of climate change in the cold regions of China to the global changes against the background of the monsoon climate. Based on the observation data, this paper systemically researches the spatiotemporal characteristics of climate in Southwestern China in nearly 50 years, and reveals the driving mechanism of climate change. On this basis, this study also delves into the response of the glacier system to climate changes. The main findings in this study are as follows:

(1) Through analysis of the records of field observations and previous studies, some changes are found in Southwestern China, including sharp temperature rises, slight interannual variability of the precipitation, obvious extreme climate events, significant decrease in sunshine duration and wind speed. Meanwhile, a close relation between spatial variation of climate and elevation has been confirmed. The research constructs the temporal and spatial patterns of climate change in Southwestern China, which makes up for the deficiency of research on the climate change in the study region, and provides a scientific basis for the establishment of countermeasures about slowing down and adapting to climate change.
(2) Aiming at the complexity and uncertainty of climate change in Southwestern China, this study systemically explores the action mechanism between the large-scale atmospheric circulation system, the complicated topography, human activities, and regional climate changes. At the same time, this study reveals the temporal and spatial correlation mechanism between circulation systems and the regional climate changes, confirms the significant influence of the micro-climate effect caused by the topography change to the regional climate change, and evaluates the effects of human activities to climate change, especially the fast urbanization process. These results provide important information for accurate assessment on warming climate and predictions of climate change, and provide a favorable basis for a precipitation in flood season and a forecast of extreme weather. In addition, they improve the level of research on climate change in the cold regions of China, enriching and developing the scientific

theory of global climate change. In 2012, the results were published in a magazine called "Global and Planetary Change". It is particularly pleasing that the results attracted considerable attention compared with others of the same scope, and were included in ESI in 2013.

(3) On the basis of the analyses of observation data on glaciers in Southwestern China, this study analyzes the response of glaciers to climate change from three aspects (the morphology of the glacier, glacial mass balance, and the process of hydrology) so that on one hand, it is clear about the responding relationship between glacier morphologic changes such as area, length and ice surface microrelief, and climate changes; and on the other hand, the mechanism of the action of climate warming to balance between energy and matter is uncovered in order to illustrate the effects of acceleration of glacial ablation to climate change and investigate the influence of meltwater on the hydrologic system. These findings show the response of glaciers in Southwestern China to climate change for the first time, deepen and expand the theoretical research of glacier response, which can provide decision-making basis for the assessment of meltwater change and the specific countermeasures against the disaster from snow and glaciers against the background of global warming. This finding was published in Environmental Research Letters in 2011 and received extensive concern of the international academia. Teppei J. Yasunari, a researcher in NASA invited by the periodical editor, wrote a review article entitled "What influences climate and glacier change in Southwestern China?" Likewise, this finding also was included in ESI in 2013.

In theory, the achievements of this study are important to innovation and development, which have made a significant contribution to research on the response of climate in cold regions, glaciers, and human activities to a global change against the background of the typical monsoon climate, and have provided some scientific bases for predictions, countermeasures against disasters due to extreme weather, utilization of water, and the establishment of counterplans to slow and adapt to climate change. With the intensifying of China's western development, it is believed that these results will play a more important role in our country's sustainable development and ecological construction in Southwestern China.

Lanzhou, June 2014 Prof. Yuanqing He

Abstract

Southwestern China includes the Sichuan, Yunnan, and Guizhou Provinces, the Xizang Autonomous Region, and Chongqing Municipality, with an area of 2.333×10^6 km^2 accounting for 24.5 % of the total land area of China. The topography declines from west to east and from north to south. There are four geomorphic units: the Xizang Plateau, the Hengduan Mountains, the Sichuan basin, and the Yunnan–Guizhou plateau. Southwestern China is a typical monsoonal climate region, controlled by the South Asia monsoon but also influenced by the East Asia monsoon. In addition, it is influenced by the Xizangan Plateau monsoon and the westerlies. According to the Chinese Glacier Inventory, there were 23,221 glaciers in southwestern China, covering an area of 29,523 km^2, which is 50.16 % of the total glacier number and 49.69 % of the total glacier area in China. Climate research has concentrated mainly on sub-regions or single districts over the study region, however, there has been little systematic analysis of climate change in the whole region. Here, the temporal-spatial variation and its causes of climate change and the glaciers' response in southwestern China during 1961–2008 have been analyzed based on meteorological data from 110 stations, NCEP/NCAR reanalysis data, and the records of glacier changes from field observations and previous studies. The main conclusions of the paper are as follows:

(1) Annual and seasonal warming trends in southwestern China during 1961–2008 were significant. About 77 % of the 110 stations displayed statistically significant increases in annual temperature. The increase was more apparent in higher altitude areas than in lower ones. Warm–dry flow in summer affected the study region, and the southern extent of the winter monsoon has also been weakened, which in part accounts for some of the climate warming experienced, especially in the warmest years in southwestern China. Sunshine hours have a crucial influence on the SB temperature, especially during spring and summer, whereas this influence mainly is effective in winter at the Xizang Plateau-Hengduna Mountains and Yunnan-Guizhou Plateau. In addition, the increased net longwave radiation flux over most areas in the study region and

sea surface temperature in Western Pacific may have also made some contributions to temperature rise. Precipitation variations were less marked than those of temperature, generally showing weak decreasing trends during 1961–2008. About 53 % of the stations experienced a trend of increasing annual precipitation. Stations with precipitation increases were also mainly at higher altitudes mainly owing to the more water vapor flux, but the significance level was low. Northward penetration of the summer monsoon is limited by an increasing northeasterly air flow over the region, and northwesterly winds in the north prevent southward transportation of water vapor from the ocean in summer. In addition, the water vapor flux showed weak variation from the most precipitation years to the least years. These characteristics suggest a weakened monsoonal flow and vapor transportation in recent years, and also partly explain the inconspicuous precipitation variations over southwestern China. In addition, the strengthening Western Pacific Subtropical High also has had some influence on precipitation variations.

(2) Analysis of changes in 12 indices of extreme temperature and 11 of extreme precipitation at 110 meteorological stations in southwestern China during 1961–2008 revealed statistically significant increases in the temperature of the warmest and coldest nights, in the frequencies of extreme warm days and nights, and in the growing season length. Decreases in the diurnal temperature range and the number of frost days were statistically significant, but a decreasing trend of ice days was not significant. In a large proportion of the stations, patterns of temperature extremes were consistent with warming since 1961. Warming trends in minimum temperature indices were greater than those relating to maximum temperature. Warming magnitudes were greater on the Xizang Plateau and the Hengduan Mountains than on the Yunnan-Guizhou plateau and in the Sichuan basin, as confirmed by the decrease of the regional trend from west to east. Changes in precipitation extremes were relatively small, and only the regional trends in consecutive wet days, extremely wet day precipitation, and maximum 1-day precipitation were significant. These trends are difficult to detect against the larger interannual and decadal-scale variability of precipitation. On the whole, the number of rainy days increased on the Xizang Plateau and in the Hengduan Mountains, but the rainy strength has also increased at lower altitude areas. Analysis of large-scale atmospheric circulation changes reveals that a strengthening anticyclonic circulation, increasing geopotential height, weakening monsoonal flow, and vapor transportation over the Eurasian continent have contributed to the changes in climate extremes in southwestern China. The spatial distribution of temporal changes of all climate extreme indices in southwestern China reflects the obvious altitude dependence. Trend magnitudes of temperature extremes are significantly higher for flat stations, followed by summit, intermountain basin, and valley stations. It is obvious that the larger decreasing trend is in summit station, followed by flat

stations, whereas the greater increasing trend mainly occurred in valley stations in southwestern China, and the intermountain stations also showed lower decrease or increase. In addition, the mean contribution of the UHI effect on regional trends of urban stations for cold extremes and warm extremes were 16.0 % and 7.9 %, respectively, based on the preliminary evaluation.

(3) Sunshine-hours is one of the most important factors affecting climate and environment. Trends of temporal and spatial patterns in sunshine hours and associated climatic factors over southwestern China are evaluated for the period 1961–2008 based on data from 110 meteorological stations. The results show that southwestern China is experiencing statistically decreasing sunshine hours with a rate of 31.9 h/10a during 1961–2008, and the statistically significant decrease in sunshine hours mainly occurred in lower altitude regions, especially in Sichuan basin and Guizhou plateau. It showed the close temporal and spatial correlation between wind speed and sunshine hours, and the larger decreasing trend displayed declining trend on non-windy days than that on windy days. This is strongly suggestive of the fact that stronger winds lead to longer sunshine hours, further validating that wind speed directly and strongly influences sunshine hours in southwestern China. The relative humidity also has great influence on sunshine hours reflected by the significant correlation and the similar trend between the two variables. Sunshine hours also have high correlation with precipitation and surface downwards solar radiation flux, whereas the effect from urbanization on regional-scales trend was inconspicuous. The increased total cloud cover and cloud water content from the 1960s to 1970s, and the decreased relative humidity and increased surface downwards solar radiation flux between the 1980s and 1990s have also influenced the variation in sunshine hours. In addition, the clear local influence of topography can be reflected by the decreasing magnitudes increased from summit to flat stations.

(4) Daily wind speed data from 110 stations in southwestern China were analyzed to determine trends, spatial differences, and possible causes. There was a statistically significant decrease of 0.24 m/s/10a in the annual mean wind speed during the period 1969–2008. The decreasing trend was faster (0.37 m/s/10a) during 1969–2000. Between 2001 and 2008, there was a significant increase. The pattern of seasonal changes was similar. Stations with stronger, significant decreasing trends were mainly on the Xizang Plateau, the Hengduan Mountains, and the Yunnan Plateau, and stations with significant increasing trends were mainly in the Sichuan basin, indicating the influence of altitude on wind speed. Surface wind speeds in southwestern China have been affected in recent years by both the changed large-scale atmospheric circulation and the regional and global warming. The analysis has confirmed that the decreasing wind speed during 1969–2000 was caused mainly by the decreasing monsoonal circulation and Westerlies, and the strengthening latitudinal wind speed has made some contributions to the increasing wind speed after 2000. And what is more, the

strengthening Xizangan monsoon has also made some contributions to wind change, which indicates lower wind speeds were related to increased temperatures, particularly to a rise in the minimum temperature in recent years. The weak wind speed may also be caused by the asymmetric decreasing latitudinal gradients of surface temperature and pressure gradient during 1969–2008. The data indicated a positive correlation between wind speed and sunshine hours suggesting another possible influencing factor. Topographical influences are evident in the higher annual and seasonal trends at summit and intermontane basin stations and the lower trends at valley stations. In addition, a minor influence from urban effect on wind speed has also been found.

(5) Glaciers are distributed in Nyainqntanglha Mountains, Himalayas, Tanggula Mountains, Gangdise Mountains, and Hengduan Mountains in southwestern China. Under temperature rise, especially the increasing warming with altitude recorded by 110 stations, ice cores, and tree rings in southwestern China, four characteristics of glacier variations occurred during the recent decades: the fronts of 32 glaciers and areas of 13 glacial basins have retreated, mass losses of ten glaciers have been considerable, glacial lakes in six regions have expanded and meltwater discharge of four basins has also increased; the typical glacier shows the accelerative ablation. The remarkable regional differences in glacier change in southwestern China may be caused by the following two factors: differences in temperature and precipitation; and differences in glacier location, scale, and frontal altitude. As response to climate change, eight monsoonal temperate glaciers were in stationary or advancing between the 1900s–1930s and the 1960s–1980s, and were in retreat from the 1930s to the 1960s and from the 1980s to the present. In other words, it is evident that the glacier retreat stages are in the warm and wet phases, and vice versa. The accumulated mass balance in Hailuogou basin is −10.83 m water equivalent in the past 45 years, an annual mean value of −0.24 m water equivalent, and 29 years are negative mass balance year, showing that it suffered a sustained mass loss of snow and ice in the period 1959/1960–2003/2004. And what is more, the warming climate has had an impact on the hydrological cycle at glacial area. As the glacier area subject to melting has increased and the ablation season has become longer, the contribution of meltwater to annual river discharge has increased, which can be reflected by the increased runoff in the downstream region of the glacial area of the Yanggongjiang basin during 1979–2003 and Hailuogou basin during 1999–2004, and the mean contribution of the runoff in the downstream region of the glacial area to the whole basin are 35.8 % and 54.7 %, respectively. The earlier onset of ablation at higher elevation glaciers has resulted in the period of minimum discharge occurring earlier in the year, and seasonal runoff variations are dominated by snow and glacier melt. The increased amplitude of runoff in the downstream region of the glacial area is much stronger than that of precipitation, resulting from the prominent increase

of meltwater from glacial region in two basins. As the acceleration of ablation velocity, the lengthening of ablation period and the extension of ablation area, changes of internal and upper surface morphology also occurred characterized by many ice-clefts, glacier collapses, decrease in thickness, enlargement of glacial caves, and reduction in the size of seracs, providing evidence of the response to climatic warming in recent years. However, it is difficult to discuss the quantitative relationship between climate change and glacier behavior in southwestern China owing to the limited observation in the glacial accumulation areas and the complexity of climate change and glacier dynamic response.

Keywords Climate change · Glaciers · Southwestern China

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Contents

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Honors and Awards (only in postgraduate stage)

Outstanding post doctor of Cold and Arid Region Environment and Engineering Research Institute, Chinese Academy of Sciences, 2013;
Outstanding doctoral dissertations of Chinese Academy of Sciences, 2013;
Outstanding graduates of Graduate University of Chinese Academy of Sciences, 2012; Chinese Academy of Science (CAS) president special award, 2012;
The BHPB Scholarship of Graduate University of Chinese Academy of Sciences, 2011;
Excellent League member of Chinese Academy of Sciences, 2011;
Young Researcher New Star Scientist Award in the "2010 SCOPUS Young Researcher Award Scheme for Climate Change", 2010;
The "Lu Jiaxi Scholarship for Excellent doctoral student", 2010;
The "Zhu Li Yue Hua Scholarship for Excellent doctoral student", 2010;
The Tri-excellent student of Chinese Academy of Science, 2010;
Second-Class of Physical Science Prize in Gansu Province, 2009;
The Chinese Academy of Science (CAS) president award of excellence", 2009;
The "Liu Tungsheng Scholarship for Earth Sciences", 2009;
Second-Class Scholarship of the Third "ORGANO PRIZE", 2009;
Third-Class Scholarship of the second "ORGANO PRIZE", 2008;
"Excellence Award" paper in the doctoral consortium, 2008.

Social Service

As the reviewer for Climate Dynamics, International Journal of Climatology, Quaternary International, Journal of Earth Sciences, Journal of Geographical sciences, Mountain Research and Development, Fresenius Environmental Bulletin, Acta Geographica Sinica and Scientia Geographica Sinica.

Chapter 1
Introduction

1.1 Background and Significance of Topics

> "Climate Change is not only an environmental issue, but also a development issue, in the final analysis it is the development problem." Climate Change Research, a hot spot in today's international scientific research field, is related to national survival and development space. Thus, a thorough study on climate change in southwest China is helpful to have a comprehensive understanding of the process of the the climate change in this region and the response of the global change. It will raise the level of the climate change research in the area and provide a scientific basis for the establishment of countermeasures to slow and adapt to climate change.

According to the IPCC's fourth assessment report (2007), the observed results including rising global mean temperatures and SST, a wide range of ice and snow melt, and the global mean sea level rise in the recent hundred of years, etc., showed that the tendency of climate warming has becoming more and more obvious. Its concrete manifestation are presented as follow:

(1) In the last 100 years, global mean temperatures increased 0.74 °C, and there are 11 years in top 12 warm years between 1995 and 2006. (2) Sea level rise is echoed by the trends of the climate warming. The global mean rate of sea-level rise is 1.8 mm/a; since 1993, the mean rate has increased to 3.1 mm/a. Reasons of resulting in such status are complicated. Thereinto, the thermal expansion and the melting of glacier, ice cap and polar ice sheets is deep prime matter. (3) The snow and the see ice area significantly reduced. It is showed by the satellite data that since 1978, the arctic sea ice sheets has been shrinking at a rate of 2.7 %/10 a. Indeed, the rates of retreat is more significant, 7.4 %/10 a, and mountain glaciers and snow cover area of both the Northern and Southern hemisphere also show a trend of shrinking. (4) From 1900 to 2005, the precipitation in the east area of North and South America, Northern Europe, Northern Asia and Central Asia increased significantly, but in Sahel, Mediterranean, South Africa and parts of South Asia, precipitation is reducing year by year. It's on the cards that since 1970s, the affected area of the global area have expanded. (5) Over the past 50 years, the frequency of cold day, cold night and frost in the most of the land had reduced. Whereas, warm day and warm night had

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become more frequent, followed by more severe precipitation events, regional floods, and strong storm. (6) The observed data confirmed that since around 1970, tropical cyclone activity of the North Atlantic has been increasing. (7) The observations of the land and the most of ocean demonstrate that a lot of natural systems are affected by regional climate change, especially the rising temperature. Along with the change of the snow, glaciers and permafrosts, the size and number of glaciers and lakes continue to go up, and the instability of the mountain and the permafrost is increasing, even some changes in ecosystems of both North and South pole emerge. The obvious augment of river runoff appeared in the rivers supplied by glaciers and snow and the preact of maximum flow in spring have made an impact on some hydrological systems. In addition, the warming of rivers and lakes also affect their thermal structure and water quality. (8) In the terrestrial ecosystems, with the earlier arrival of spring events, the growing range of the plants and the animals goes toward the poles and high altitude area. These changes are related to the recent warming. Similarly, in some marine and freshwater systems, the migration and changes of breeding ranges of the algae, plankton and fish are related to the warmer water and the related changes of ice caps, oxygen content and circulation (IPCC 2007). Moreover, in the 20th century, the temperature under 200–1,000 m deep ascended 0.5 °C, and about 80 % of the borehole temperature is rising (Huang et al. 1997; Pollack et al. 1998). According to the analysis of the sounding data, it was found that since 1958, the general warming trend of the underlying level of the troposphere are nearly similar to that of the strata, warming approximately 0.1 °C/10 a (Gaffen et al. 2000). The results got through the satellite microwave verified that the warming trend of the underlying level in troposphere is 0.05 °C/10 a (Brown et al. 2000). Over half a century, the tropospheric atmospheric temperature in the southern hemisphere showed a trend of growing, with temperatures range rising from low to high gradually. Thereinto, the heating rate of the 1,000 hPa in the ground floor is 0.013 °C/a, the heating rate of the 500 hPa in the middle of troposphere is 0.019 °C/a, the warming rate of 300 hpa in the upper troposphere is 0.036 °C/a.

In the recent hundred of years, as the main characteristics of climate changes, warming have taken place in many sections of China: (1) From 1905 to 2001, China's annual mean temperature appeared to be on the rise. It increases by 0.79 °C in 1997; the 1940s and after the middle of 1980s are two special periods, in which the temperature obviously is on the rise. (2) From 1905 to 2001, the change in China's mean annual precipitation is not very significant. It decreases by 8.6 mm in 1997; more precipitation occur in the 1910s, 1930s–1940s and 1980s–1990s, whereas less precipitation occur in other periods (Country Assessment of Climate Changes 2007). (3) In the recent 50 years, the frequency and intensity of China's main extreme weather and climate events emerge significant changes, mainly showing as the worsening drought conditions in north and northeast of China and the aggravating flood over the middle and lower reaches of the Yangtze River and China's southeast area. Since 1990, the annual precipitation is more than ordinary year, which resulted in 'southern flood and northern drought' and frequent drought and flood damage (Country Assessment of Climate Changes 2007). (4) During the period of 1950s–1990s, the mean rate of sea-level rise of china's coastal area is