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Climate change over the past 2000 years in Western China

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Abstract

Western China, defined here as the land falling within the geographical boundaries of the People's Republic of China in the west, south and north, and the approximate eastern extent of the Tibetan and Alaxa Plateaux to the east, occupies an important climatic region, influenced by the Asian and Indian summer monsoons, the mid-latitude westerlies and the dry, cold central Asian winter monsoon. The Tibetan Plateau itself is a prominent topographic feature that exerts major control on regional atmospheric circulation. Previous compilations of meteorological data and documentary sources suggest that western China, and the Tibetan Plateau in particular, is highly sensitive to anthropogenically induced climate change. Temperature increases appear to be greatest at higher altitudes: moreover, precipitation variations seem to have been marked, although spatially complex. The region contains a wealth of information about past climate derived from instrumental, documentary and proxy sources although meteorological time series are generally too short to capture the full range of recent climatic variability. Documentary and proxy sources are therefore important. We review studies of climate change in western China for the past two millennia. Documentary records are complemented by proxy data from ice cores, tree rings, lake sediments, groundwater profiles and glacial geomorphology. Although general patterns of change can be identified, proxy records of past climate are often semi-quantitative at best, open to alternative interpretations and sometimes poorly dated. Despite evidence for marked variations in climate over the past 2000 years, changes during the 20th century, especially in temperature, may have been unprecedented. The density of data points over western China is currently too low for spatial patterns to be identified, especially in precipitation variation. However, there does seem to have been an increase in warming with altitude over the most recent past.

1. Introduction

The purpose of the present paper is to provide an overview of climate and climatic variations in arid western China for the past 2000 years. We do not attempt a new synthesis of data, but rather provide a critical appraisal of available data, identify general patterns of climate change and highlight gaps in existing knowledge. The past 2000 years is the period during which anthropogenic effects have increasingly become superimposed on natural climate variability. It is also a time of significant cultural development in China and, moreover, there is a wealth of proxy and documentary evidence available, although the potential of this evidence has not yet been fully realized.

Western China, defined here as the area falling within the geographical boundaries of the People's Republic of China to the west, south and north, and the approximate eastern extent of the Tibetan and Alaxa Plateaux to the east (Fig. 1), is climatically a very important region. The Tibetan Plateau itself rises to over 4000 m above sea level (a.s.l.) and has an area of almost 2,000,000 km^2. This prominent topographic feature has a major influence on regional and hemispheric atmospheric circulation patterns and in particular exerts substantial control on the Asian monsoons (Hahn and Manabe, 1975). The Tibetan Plateau is bounded to the south by the Himalayas, which rise to over 8000 m a.s.l. in places. Several large intermontane basins lie to the north of the Tibetan Plateau. In the north and west is the Junggar Basin, separated from the vast Tarim Basin by the Tien Shan mountain range and bounded to the south by the Kun Lun Mountains. The Qaidam Basin lies further to the east and is separated from the Hexi Corridor by the Qilian Mountains. East of the Qaidam Basin and the Qilian Shan lies the Qinghai Basin, which is home to Lake Qinghai, China's largest natural

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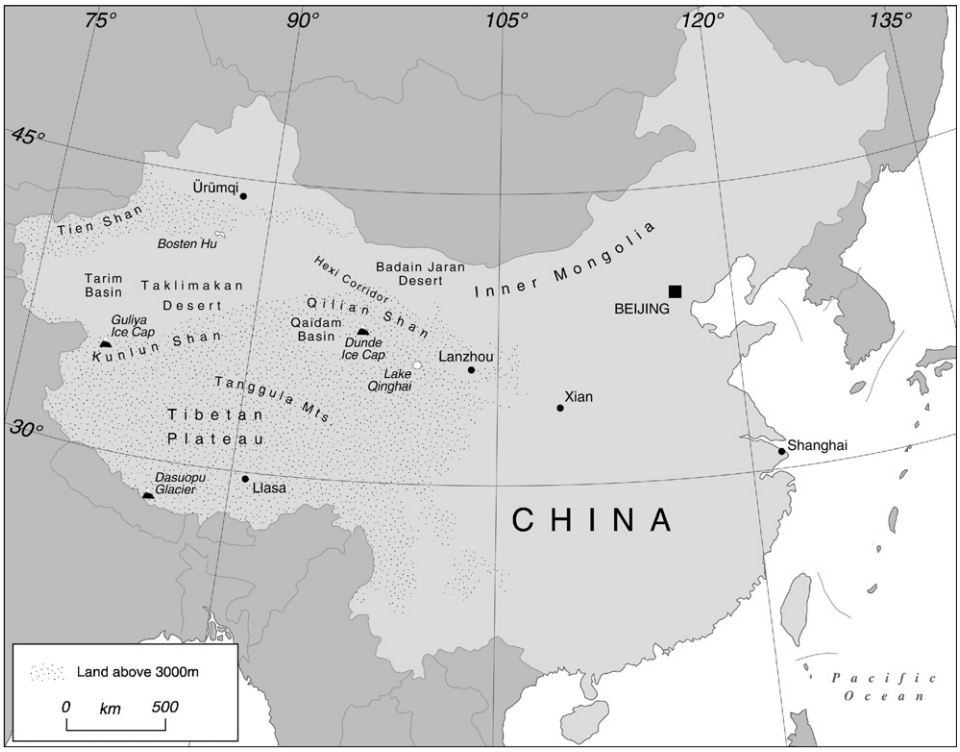

Fig. 1. Location of study region and its main topographic features, showing main sites referred to in the text.

lake. North of the Hexi Corridor is the Alaxa Plateau and the sand deserts of Inner Mongolia, including the Badain Jaran and Tengger Deserts. Politically, our study area covers the Provinces of Xizang and Qinghai and the Xinjiang Autonomous Region, together with parts of Gansu Province and the Autonomous Region of Inner Mongolia.

Western China is climatically complex. It is affected by the Indian and East Asian summer monsoons from the southwest and southeast, respectively, by westerly airflow in both summer and winter, and by northerly circulation in winter. Precipitation derived from the Asian summer monsoons currently extends to the southern and eastern parts of our study area although the summer monsoon penetrated markedly further north during the early to mid-Holocene (Fig. 2). The Tanggula Mountains, in the middle part of the Plateau (Fig. 1), seem to mark a climatic threshold: to the north of this range, precipitation from the monsoon is largely replaced by that derived from westerly depressions, at present mainly during the summer. The complex interaction of the different circulation patterns gives rise to a sharp southwest to northeast precipitation gradient over western China. Annual precipitation declines from about 800 mm in the southwestern part of the Tibetan Plateau—rather higher in the Himalayas—to $\ll$50 mm in the arid basins further to the north and west, although this broad pattern is modified locally by the effects of topography, where precipitation typically increases with altitude.

Despite the existence of meteorological stations on the Tibetan Plateau and elsewhere in western China, the overall number is relatively small given the size of the region, especially compared with eastern China. Moreover, the length of records is typically very short ($\leqslant$40 years for most stations), making it difficult to isolate long-term trends in climate from meteorological data alone. However, meteorological data indicate that significant 20th century warming is taking place over the vast Tibetan Plateau (approximately 24% of the total area of China) in parallel with warming over the Northern Hemisphere, and the rate of warming appears to increase with elevation (Liu and Chen, 2000). These findings are based on the analysis of 97 surface air temperature records above 2000 m a.s.l. that for the most part do not begin until after 1950. Thus, from these data, it is impossible to determine if the observed warming over the Tibetan Plateau in the latter half of the 20th century has truly exceeded the range of natural temperature variability or is just part of a longer-term natural fluctuation. That the latter could conceivably be the case is suggested by a record of temperature anomalies constructed for China since 1880 by Wang et al. (2001), which indicates that the 1940s may have been as warm as the late-20th century period examined by Liu and Chen (2000), with an intervening cooler period from about 1955 to 1985. Given that the large majority of the instrumental records used by Wang et al. (2001) came from the eastern half of China however, it is difficult to know if their temperature anomalies truly reflect all of China in an unbiased way. Wang and Gong (2000) illustrated the importance of this data coverage issue by comparing temperature anomalies of eastern China with those for all of China that included data from the Tibetan