Perspectives on Environmental Study of Response to Climatic and Land Cover/Land Use Change over the Qinghai-Tibetan Plateau: an Introduction

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Perspectives on Environmental Study of Response to Climatic and Land Cover/Land Use Change over the Qinghai-Tibetan Plateau: an Introduction

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Mountain areas seem to be especially susceptible to global climate change and are reported to have warmed more, and perhaps sooner, than the rest of the globe (e.g., Beniston and Rebetez, 1996). Liu and Chen (2000) have argued that the Qinghai-Tibetan Plateau is a harbinger of climate change due to its early and accelerated warming. It represents the largest high-elevation region on the globe, over 2.0 million km^2 in size and an average elevation greater than 4000 m, and is surrounded by the world's tallest mountains. Observational evidence indicates that impacts related to climate warming are well underway on the Tibetan Plateau and involve increasing air temperature (Frauenfeld et al., 2005), vegetation degradation (Chu et al., 2007), the cumulative negative mass balance of glaciers (Yao et al., 2007), thickening of the active layer, and increases in permafrost temperature (Zhao et al., 2004; Gao et al., 2005; Cheng and Wu, 2007). The Qinghai-Tibetan Plateau provides an anomalous mid-tropospheric heat source for south-western Asia during summer, and thus plays a prominent role in the Asian monsoon system. It therefore also provides a crucial link for the water resources for most of the Asian continent, thereby impacting the livelihood of over 3.7 billion people. Climate change in this part of the world is arguably of heightened importance due to the plateau's far-reaching impacts across Asia, the northern hemisphere, and the globe.

Numerous environmental and climate change studies over the Qinghai-Tibetan Plateau have been carried out in recent decades worldwide. This issue of *Arctic, Antarctic, and Alpine Research* (AAAR) reflects some of the recent developments and research results. Many of the papers herein have origins in a series of presentations made at the Fourth International Symposium on the Tibetan Plateau, 4–7 August 2004 at Lhasa, China. Over 40 oral and poster presentations were made during the symposium in five special sessions entitled "Land Surface Processes and Their Interactions with the Atmosphere over the Qinghai-Tibetan Plateau." Participants in these sessions presented a broad range of topics and results derived from field and laboratory studies, satellite remote sensing, and numerical modeling. Most of the results presented at that symposium have been updated and presented in this special issue. Other papers in this issue were solicited after the symposium, in order to have broad coverage.

The impact of climate warming over the Qinghai-Tibetan Plateau has been observed in many records and is discussed in many of the papers in this special issue. Tree ring and stable carbon isotope data (Liu, X. H., et al., 2007) show that winter air temperature (December through April) over the northern Qinghai-Tibetan Plateau have experienced significant fluctuations in the past 1000 years. It reveals the above-average temperature from A.D. 900 to 1300, the so-called Medieval Warm Period (MWP), and the occurrence of the Little Ice Age (LIA) from 1600 to 1880. Ostracoda assemblages from lake deposits (Zhu et al., 2007) from western Tibet show lake water level and closely linked regional climate fluctuations occurred during the past 150 years. Lake water level declines from 1960 through 1982 might be due mainly to decreasing precipitation. Zhu et al. (2007) report that since 1982, climate over western Tibet was characterized by less precipitation and warming, which contradicts studies that conclude that climate over the Tibetan Plateau and Northwest China are changing from warm-dry to warm-wet (Shi 2003; Chen et al., 2006; Duan et al., 2006; Shi et al., 2006). Ground-based measurements indicate that the near surface air temperature has increased about 0.6 to 0.8 °C since the mid-1950s on the Qinghai-Tibetan Plateau (Liu and Chen, 2000; Frauenfeld et al., 2005). The magnitude of air temperature increase at individual stations and sites can be significantly greater, up to 0.6 °C/decade, or greater than 3.0 °C/decade (Chu et al., 2007). This warming has caused glacier retreat with negative mass balance over the plateau and the surrounding regions in the past several decades, especially since the beginning of the 1990s (Yao et al., 2007; Kang et al., 2007; Wang et al., 2007). Historical repeated photos and supplemental measurements show that the warming is also contributing to the elevational advance of alpine treeline (Baker and Moseley, 2007). Satellite remote sensing data show that the normalized difference vegetation index (NDVI) has increased from 1985 through 1999 near Lhasa in the central Tibetan Plateau (Chu et al., 2007). Stable carbon isotope composition of plant leaves is a sensitive environmental indicator that shows the response of vegetation to climate variation (Liu, G. X., et al., 2007). The warming climate over the plateau is also contributing to the increase in active layer thickness and permafrost temperature, causing serious engineering and environmental consequences (Cheng and Wu, 2007; Wu et al., 2007).

The Qinghai-Tibetan Plateau is located in arid and semiarid climate zones. Atmospheric moisture sources and changes in precipitation are also discussed in this special issue. Using glacier ice cores and ground-based measurements, Wang et al. (2007) investigated changes in precipitation on the Qinghai-Tibetan

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Plateau over the past 500 years. Their preliminary results reveal that precipitation has been decreasing in the relatively dry northern plateau and increasing in the southern plateau with a south-north dividing line along the 32–33°N latitudinal line. Based on glacier ice core data and NCEP/NCAR reanalysis data, Kang et al. (2007) report that intensification of atmospheric circulation and increase in sea surface and air temperatures are responsible for moisture availability and transport, causing the increase in glacier ice accumulation in southern Qinghai-Tibetan Plateau since the 1980s. However, moisture availability decreases substantially from south to north in the western Qinghai-Tibetan Plateau as revealed from stable isotope variations (Yu et al., 2007). Using data and information from intensive ground-based measurements, Yang et al. (2007) emphasize that local water recycling could account for up to 60 to 70% of the precipitation during the period from July through August 1998. Although this water recycling estimate might have a huge positive bias, local convective precipitation indeed plays an important role over the plateau. Studies of local severe storm rainfall (Chen et al., 2007) and circulation (Li and Gao, 2007) on the Qinghai-Tibetan Plateau are also briefly discussed in this special issue.

The entire Qinghai-Tibetan Plateau is either underlain by permafrost or experiencing deep seasonal freezing and thawing. Most permafrost on the Qinghai-Tibetan Plateau is relatively warm with its temperature within a few degrees of the melting point (Zhou et al., 2000; Wu et al., 2007). The warm permafrost is extremely sensitive to climate change or any surface disturbance, especially engineering constructions (Wu et al., 2007). Cheng and Wu (2007) reported that the near surface permafrost temperature has increased several tenths of a degree in the past decade. Using ERA-40 reanalysis air temperature and satellite passive microwave remote sensing snow depth as input forcing data, modeling results indicate that active layer thickness has increased greater than 0.30 m over the northern plateau from 1980 through 2001 (Oelke and Zhang, 2007). At selected local areas, the modeled increase in active layer thickness could be up to 0.90 m (Oelke and Zhang, 2007), which is consistent with ground-based measurements of increase in active layer thickness by up to 1.0 m since the late 1970s (Zhao et al., 2004). The depth of seasonally frozen ground has decreased substantially (Zhao et al., 2004). In many places, permafrost degradation has been observed, including upward movement of the lower permafrost boundary, talik expansion along river banks, lake thaw expansion, and various forms of thermokarst features (Cheng and Wu, 2007). Thickening of the active layer and degradation of permafrost are the main causes responsible for lowering ground water table at the source areas of the Yangtze River and the Yellow River, which in turn results in lowering lake water levels, drying up of swamps, and shrinking grassland and wetlands (Cheng and Wu, 2007). The impact of changes in permafrost conditions on engineering construction cannot be underestimated. Wu et al. (2007) report that degrading permafrost would have direct and immediate impacts on the stability and reliability of engineering infrastructures over permafrost on the Qinghai-Tibetan Plateau.

Thickening of the active layer and thawing of permafrost over the Qinghai-Tibetan Plateau would potentially release carbon trapped in earlier times into the atmosphere. However, modeling results indicate that although there is a strong seasonal variation of carbon fluxes, the Qinghai-Tibetan Plateau is still a carbon sink on an annual basis (Fan et al., 2007). This result is consistent with increase in summer NDVI in the central plateau (Chu et al., 2007). Certainly, there is still much work remaining to be done in this area.

Anthropogenic greenhouse gas forcing is generally considered to be the main cause of the observed warming over the Qinghai-Tibetan Plateau and its surrounding areas. However, like elsewhere on the globe, an equally important anthropogenic component to climate change may be land cover/land use change. To date, study on the impact of land cover and land use change on local and regional climate on the Qinghai-Xizang Plateau has received little attention from the scientific community and related governmental agencies. Since the Qinghai-Tibetan Plateau is a high-altitude semiarid environment, both temperature and moisture limited, it is especially susceptible to potential degradation resulting from land cover changes. Such local–regional surface effects from agriculture and urbanization potentially outweigh greenhouse gas forcing. Recent research has suggested that land cover and land use change may largely account for the observed warming on the Qinghai-Tibetan Plateau (Frauenfeld et al., 2005). Significant warming has been observed for *in situ* surface temperature station records, which are biased toward low-lying populated regions. However, similar to the methodology and findings of Kalnay and Cai (2004) and Lim et al. (2005), reanalysis sources, verified to provide a remarkably realistic depiction of temperature variability on the Qinghai-Tibetan Plateau (Frauenfeld et al., 2005), indicate no long-term temperature increases. Furthermore, intensive land exploitation has occurred on the Qinghai-Tibetan Plateau and in western China as a result of which extensive land surface changes have occurred in recent decades. For instance, since the early–late 1950s, and accelerated since the 1980s, significant urban expansion and changes in agricultural and industrial practices have shaped this part of the world. The socioeconomic drivers of the land cover and land use change are therefore inextricably intertwined with environmental changes, and any research aimed at understanding land surface processes must consequently also focus on these socioeconomic factors.

Although the population of the Tibetan Plateau is sparse at present, it has increased at 2.19% per year since the 1950s and has tripled over the last 45 years (Fu and Zheng, 2000). The recently completed railroad across the plateau will cause a dramatic influx of people from inland China and attract tourists from around the world, potentially resulting in substantial increases in population, infrastructure, and related human activities. The population growth that has occurred across the plateau has promoted extensive local and regional land use/land cover change, and has resulted in increased urbanization (Fu, 2004). Over 62% of the plateau is used for agriculture: farmlands, forests, and a majority (80%) are used for livestock grazing. According to some studies, the carrying capacity in parts of the Tibetan Plateau has been far exceeded—livestock numbers have increased up to 250% since 1978 (Wei and Chen, 2001; Du et al., 2004), partly due to inappropriate land management practices. Consequently, overgrazing has caused severe land degradation and desertification at an alarming rate (Zhu and Li, 2000; Zeng et al., 2003). Due to government initiatives such as sedentarization of nomadic herders and the emergence of crop production, livestock grazing areas have shifted from lowlands and river valleys to even more marginal, higher elevation hilly areas. Due to more favorable conditions on south-facing slopes, livestock almost exclusively graze in these regions, resulting in severe overgrazing. The conversion from grazing to crop lands in lower elevations has become a particular threat to Tibet's grasslands and has led to extensive desertification, rendering the land unusable for agriculture and grazing. In the Gonghe River Basin on the northeast Qinghai-Tibetan Plateau, Zeng et al. (2003) found that severe desertification from overgrazing affected almost 42% of grasslands between 1987 and 1996, and sand-covered areas increased by 18%.

A conscious effort by the Chinese government to urbanize the plateau has resulted in a significant population influx in recent decades, which is expected to increase dramatically in the coming years. Urbanization, which can result in 8–11°C higher temperatures than in surrounding rural areas (e.g., Brandsma et al., 2003), has also occurred in plateau regions such as Lhasa, Golmud, and Xining. However, as in high-latitude regions, even villages and small towns at high altitudes can exhibit a strong urban heat island effect (Hinkel et al., 2003), especially during the cold season. In cold regions like the Qinghai-Tibetan Plateau, this is accompanied by earlier snowmelt and increased thickness of the thawed layer, resulting in permafrost degradation and thus a further altered land surface. Earlier thaw dates for frozen soils have already been reported (Gao et al., 2005), and Zhao et al. (2004) reported significant reductions in the depth and duration of seasonally frozen ground. The construction and operations of the Qinghai-Xizang railroad and highway expansion projects will lead to further and greatly accelerated population increases and hence a further altered land surface in the future.

The extensive land surface changes that have occurred on the Qinghai-Tibetan Plateau over the last five decades have not been quantified and related to regional or global climate processes. In fact, a comprehensive evaluation and quantification of the various land surface processes, e.g., air temperature, vegetation cover, soil moisture and temperature, frozen ground, and snow depth/extent, etc., on the plateau have not been performed. Although many studies have tried to link the Qinghai-Tibetan Plateau to climate processes, e.g., the Asian monsoon, only individual parameters such as snow extent have been investigated, often using coarsely gridded data products that are unable to describe the plateau's highly complex terrain. In addition, it is not appropriate to evaluate only the physical processes and disregard the complex socioeconomic factors that have contributed to, and will impact, land cover and climate change. This is especially important for a region with such inextricable links between the land and its people.

At the core of the issue of land cover and land use change—and hence climate change—on the Qinghai-Tibetan Plateau is political and socioeconomic forces that have driven the observed changes in land surface processes. As government practices over the last ~50 years have resulted in an exploitation of the plateau's resources, the system has responded via a series of positive feedbacks, exacerbating the deterioration of the landscape. The pastoral society residing on the Qinghai-Tibetan Plateau was in equilibrium with its ecosystem for thousands of years, practicing seasonal moves to sustain the productivity of the land. As these nomadic herders were forced to settle and large numbers of immigrants arrived on the plateau, extensive regions were overgrazed, replaced by cropland, and ultimately converted to landscapes with greatly reduced vegetation, even producing barren ground.

It can be hypothesized that it is these land surface changes that are responsible for the reported climate change on the Qinghai-Tibetan Plateau. This is supported by recent results which indicate that, indeed, the surface warming seems confined to low-lying, populated regions (Frauenfeld et al., 2005) but is absent from data that are free of surface contamination. We can also argue that as a result of the vegetation changes, soil moisture is reduced significantly, which feeds back to further decrease vegetation, but also increase sensible (versus latent) heat fluxes, and hence increase temperatures. Such local–regional temperature changes in response to agricultural practices have been reported for many other regions of the world (e.g., Balling et al., 1998). In turn, the higher air temperatures lead to a further drying out of the landscape and a reduction in frozen ground, as well as changes in precipitation patterns. In parts of the plateau, the precipitation changes are manifest as decreased rainfall and increased snowfall. Greater snow depths act to insulate the ground, further enhancing the degradation of permafrost, while decreased precipitation drives further reductions in vegetation and soil moisture. There is thus a complex chain of events that have led to the current state of the ecosystems over the Qinghai-Tibetan Plateau. The land degradation also affects the socioeconomics of the region, which will have significant repercussions in the future, if current trends indeed accelerate as anticipated. There is thus an urgent need to conduct comprehensive investigations on the impact of land cover and land use change on climate change over the Qinghai-Tibetan Plateau. More specifically, these studies should focus on (1) the impacts and feedbacks of climate change on land-surface processes related to land cover/land use change; (2) the socioeconomic causes of land cover/land use change and the social effects of climate change; and (3) the generation of a variety of data sets and time series describing land cover/land use change as well as climate change on the Qinghai-Tibetan Plateau and western China as a whole.

However, exploring processes of land cover and land use change over the plateau and western China does not imply that greenhouse gas–induced changes are not also happening and important. Indeed, climate trends caused by the increase in greenhouse gases are already a component of the *in situ*, reanalysis, and remote-sensed data products, and this component of climate change as discussed in many papers in this issue is hence automatically included (see, e.g., Kalnay and Cai, 2004).

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