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Third Pole Environment (TPE)

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ABSTRACT

The Tibetan Plateau and surrounding mountains represent one of the largest ice masses of the Earth. The region, referred to by scientists as the Third Pole, covering 5 million km^2 with an average elevation of >4000 m and including more than 100,000 km^2 of glaciers, is the most sensitive and readily visible indicator of climate change. The area also demonstrates considerable feedbacks to global environmental changes. The unique interactions among the atmosphere, cryosphere, hydrosphere and biosphere on the Third Pole ensure permanent flow of Asia's major rivers, thus significantly influencing social and economic development of China, India, Nepal, Tajikistan, Pakistan, Afghanistan and Bhutan where a fifth of the world's population lives. Like Antarctica and the Arctic, a series of observations and monitoring activities in the Third Pole region have been widely implemented. Yet for a comprehensive understanding of the Third Pole, current observational resources need to be integrated and perfected, and research goals and approaches need to be updated and identified. The Third Pole Environment (TPE) program aims to attract relevant research institutions and academic talents to focus on a theme of 'water–ice–air–ecosystem–human' interactions, to reveal environmental change processes and mechanisms on the Third Pole and their influences on and responses to global changes, and thus to serve for enhancement of human adaptation to the changing environment and realization of human–nature harmony.

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1. Introduction

1.1. Geographical definition of the Third Pole

The Tibetan Plateau and its surrounding mountains are referred to by scientists as the Third Pole (Qiu, 2008). It covers an area over 5 million km^2, stretching from the Pamir and Hindu Kush in the west to the Hengduan Mountains in the east, from the Kunlun and Qilian mountains in the north to the Himalayas in the south (Fig. 1). With an average elevation over 4000 m, the Third Pole is geomorphologically the largest and highest mountain region on Earth. All the peaks in the world over 7000 m a.s.l. are on the Third Pole, including fourteen worldly-acknowledged mountains over 8000 m a.s.l. such as the Qomolangma (8844 m a.s.l.), Nanga Parbat (8125 m a.s.l.), K2 (8611 m a.s.l.), Annapurna (8078 m a.s.l.), Xixabangma (8027 m a.s.l.), Kanchenjunga (8586 m a.s.l.), etc. (Yao et al., 2007).

1.2. Significance of the Third Pole

Due to its high altitude and large area, the Third Pole plays a significant role in the Earth's climate system (Jin et al., 2005), with its unique and complex interactions of atmospheric, cryospheric, hydrological, geological and environmental processes bearing a large effect on the Earth's biodiversity, climate and water cycles.

Beyond that, the Third Pole borders more than 10 countries and impacts more than 1.5 billion of the population in and around the region. It provides resources – water, pasture, timber, among others – as well as recreational and tourism opportunities to the billions of people inhabiting the plateau and the surrounding regions including Afghanistan, Bangladesh, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Myanmar, Nepal, Pakistan, Tajikistan and Uzbekistan.

It is widely acknowledged that environmental conditions on the Third Pole have changed significantly in the last century (Gautam et al., 2003; Jin et al., 2008; Moors et al., 2011). In addition there is growing evidence of influences of anthropogenic activities on the Third Pole Environment (Sun and Kuntsi, 2004; Agarwal, 2009). These changes and those anticipated in the future may pose a potential threat to livelihood that depends on the Third Pole resources and environment. Besides, ecological changes due to global warming in the Third Pole currently observed jeopardize social and economic sustainability in the region (Wang et al., 2007a), and may also drive the climate and environmental changes at local, regional and even global scales.

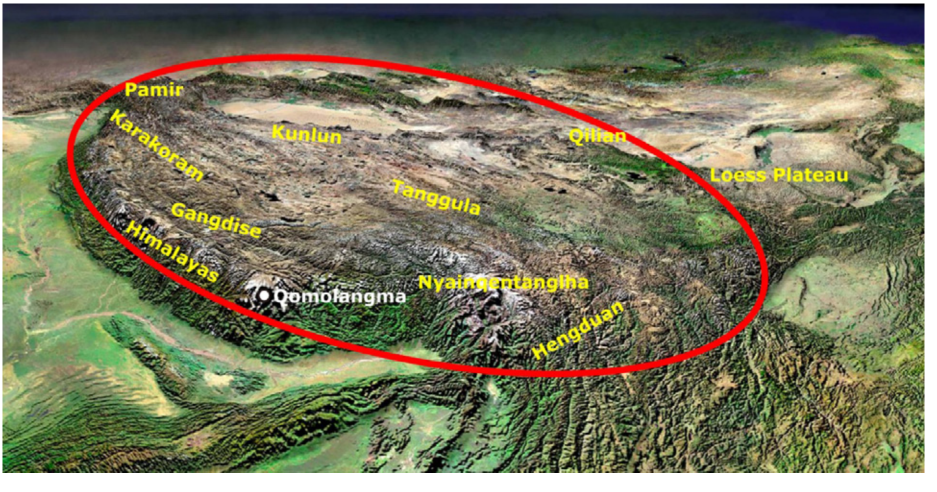

Fig. 1. The geographical location of the Third Pole. The Third Pole stretches from the Pamir and Hindu Kush in the west to the Hengduan Mountains in the east, from the Kunlun and Qilian mountains in the north to the Himalayas in the south.

1.3. Background of the Third Pole Environment (TPE) Program

Like Antarctica and the Arctic, the Third Pole region is drawing increased attention of the international academic community. A series of observations and monitoring programs in the Third Pole region has been widely implemented. Multinational efforts have been engaged in the establishment of in situ observations of atmospheric processes, glaciers, lakes, rivers and ecosystems, etc. Sparse field stations have been established to acquire data including hydrological data, aerosols, and cryospheric dynamics, including the Namco station, Qomolangma station, Southeast Tibet station, Muztag Ata station, Ngari station, Lhasa Plateau Ecological Research station, Haibei station, Gongga station, Cryosphere Research Station, Pyramid Laboratory-Observatory, etc. However, data necessary to precisely assess the environmental, societal and economic changes caused by alterations in the Third Pole dynamics are either lacking or insufficient. There is an increasingly urgent need for a comprehensive and coordinated international research, monitoring and capacity building initiative to address the influence of such changes on human populations and to provide timely options for mitigation and adaptation strategies.

Thus sponsored by the Chinese Academy of Sciences (CAS), the Institute of Tibetan Plateau Research, CAS, called upon the 1st Third Pole Environment (TPE) Workshop at Beijing in 2009. During that workshop, the Third Pole Environment (TPE) program was initially proposed and agreed upon by participants from China, India, Germany, Italy, Japan, Nepal, the Netherlands, Norway, Pakistan, US, Canada, Tajikistan, and Switzerland. The TPE program tends to focus on the development of international, interdisciplinary and integrated studies of the Third Pole Environment involving natural and social scientists, as well as experts and practitioners with long-term experience, institutional mandates and functions to assess past, ongoing and future environmental change processes and mechanisms at local, regional and global scales. It aims to develop the scientific knowledge, cultivate scientific talents, and suggest on adaptation strategies for sustainable development of the Third Pole confronting global environmental changes. The TPE Program is designed to involve countries in and around the Third Pole region, as well as any other country that wishes to contribute to its mission.

2. Key scientific topics on the Third Pole Environment

2.1. The Third Pole climate evolution

Studies show that the uplift of the Third Pole has intensified the Indian monsoon (Kearey et al., 2009). Investigation on when and how the Third Pole uplift did this could advance the understanding of climate history and long-term climate change (Qiu, 2008). So far, various proxies have been used to infer the uplift history and process of the Third Pole. Studies with the composition of oxygen isotopes in rocks and lake sediments show that various areas of the Tibetan Plateau were at elevations of over 4000 m about 11–35 million years ago (DeCelles et al., 2007; Garzione et al., 2000; Rowley and Currie, 2006). The shape and size of fossil leaves also help to shed light on the uplift history of the Tibetan Plateau that, about 15 million years ago the elevation of southern plateau was more than 4600 m (Spicer et al., 2003).

The huge area extent of the Third Pole, its geographical location, and its high elevation make it key to hemispheric, or even the entire global atmospheric circulation systems. The elevated topography of the Third Pole not only acts as a barrier to the mid-latitude westerlies, but also triggers strong dynamical and thermo-dynamical impacts, thus contributing greatly to global circulation as well as regional and hemispherical environmental changes (Bothe et al., 2011). The Third Pole also plays a prominent role in the evolution of the Asian monsoon system, which is critical for the moisture fluxes and precipitation patterns in the region (An et al., 2001).

Besides, land surface processes on the Third Pole affect the atmospheric circulation patterns in Eurasia and thus significantly influence the climate system in the northern hemisphere (Fig. 2). The winter Eurasian snow cover south of 52°N was found to show a significant correlation with the following Indian summer monsoon by Hahn and Manabe (1975). Further study showed that heavy

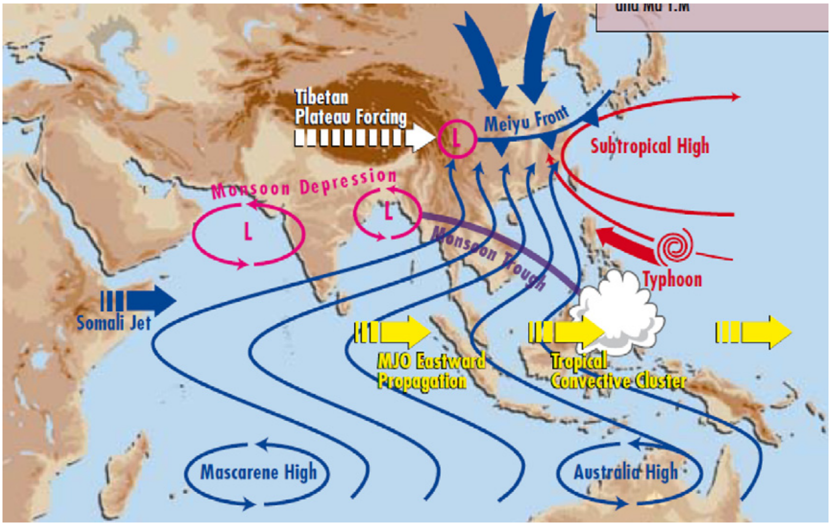

Fig. 2. Atmospheric general circulation processes affecting the Third Pole during boreal summer. Water-heat cycle is closely linked in the tropical and sub-tropical regions with the Tibetan Plateau forcing. *Note*: L represents low pressure cyclonic core (Yao et al., 2011).

snowfall over the Tibetan Plateau can both weaken and prolong the duration of the summer monsoon system in the region (Liu et al., 2004).

2.2. *Cryosphere under global warming*

The Third Pole shows a large-scale warming trend that began in the mid-1950s. In other words, a rise in temperature of up to 0.3 °C per decade has been going on for fifty years, which is approximately three times the global warming rate (Qiu, 2008). The air temperature increases most significantly in the central, eastern, and northwestern parts of the Plateau (Liu and Chen, 2000). The warming trend in the cold season was greater than that in the warm season (Zhao et al., 2004). While the warming is predominantly caused by increased greenhouse gas emissions, changes in cloud cover, and snow-albedo feedback, the Asian brown clouds and land use changes also partly contribute (Duan et al., 2006; Frauenfeld et al., 2005; Liu et al., 2006; Ramanathan et al., 2007; Zhang, 2007). As a result, cryospheric processes in the Third Pole are reacting sensitively to global changes, including glacier retreat, snow cover increase, and permafrost degradation. In the past half-century, 82% of the plateau's glaciers have retreated. In the past decade, 10% of its permafrost has degraded (Qiu, 2008).

2.2.1. *Glacier retreat*

The Third Pole contains glaciers with a total area of ~100,000 km^2 (Yao et al., in press). Glacier retreat is one of the most significant environmental changes observed at the Third Pole. Since the 1990s, most of the glaciers in the region have undergone considerable retreat though the extent in retreat varies geographically (Kang et al., 2010). Dominated by a continental climate, the central part of the Third Pole exhibits the least extent of glacial retreat, while the southeastern part under the influence of a maritime climate has the greatest extent in retreat (Pu et al., 2004). For example, glaciers in the eastern part of the Kunlun Mountains have retreated by 17% over the past 30 years, which is ten times faster than those in the central plateau (Qiu, 2008). Studies show that glaciers in the Third Pole are undergoing accelerated retreat in recent years (Kang et al., 2007; Yao et al., 2004).

Rising temperatures, changing precipitation pattern and black carbon depositions are currently under discussion by scientists as major causes for the strong glacier melt (Menon et al., 2009). Scientists have projected a 43% average decrease in glacial area by the year 2070, and a 75% decrease by the end of the 21st century under the current warming rate (Walsh, 2009).

Hydrological changes resulted from glacial retreat, such as increased discharge, rises in lake level, more frequent glacial lake outbursts leading to flooding, enhanced glacial debris flows, and changes in water resources have been the focus of many studies (Li et al., 2008; Xiao et al., 2008; Yao et al., 2004). Nevertheless, the Third Pole glacier retreats under global warming trend and the concurrent environmental changes require many more studies (Kang et al., 2010).

2.2.2. Snow cover change

Snow cover is about 59% of the Tibetan Plateau in winter (Qin et al., 2006). The most persistent snow cover in the Third Pole is located on the southern and western edges where precipitation from the Indian monsoon spills over onto the high plateau (Pu et al., 2007). The blocking mountains keep the interior of the Third Pole very dry (Qin et al., 2006). The annual cycle of the Third Pole snow cover is characterized by an early peak occurring in January, very slow snow decay, and a long snow dissipation progress from February to June. The increased snow depth in the Third Pole after the mid-1970s might be a cause of the weakening or delay of the Asian summer monsoon (Zhu and Ding, 2007).

2.2.3. Permafrost degradation

A significant portion of the Third Pole is underlain by permafrost with varying thickness of 1–130 m (Yang et al., 2010) and soil temperature between -0.5 and -3.5 °C (Cheng, 1997). Overall, the temperature of seasonally frozen ground and sporadic permafrost rose 0.3–0.5 °C during the past 15–20 years (Wang et al., 1996). Furthermore, the duration of seasonal ground freezing has shortened in response to the winter air temperature increase (Yang et al., 2010), and the thickness of the active layer has increased by 0.15–0.50 m between 1996 and 2001 (Cheng and Wu, 2007).

Widespread permafrost plays a fundamental role in the Third Pole ecosystem, thus its degradation could greatly affect regional environment and livelihood. With rapid degradation and thinning of the permafrost, large carbon pools sequestered in permafrost could be released to increase net sources of atmospheric carbon, creating a positive feedback and accelerated warming (Jin et al., 1999). Frost heave, thaw settlement, and thaw slumping also lead to severe damage to human infrastructure in the permafrost region (Wu et al., 2003). Finally, permafrost degradation results in extended desertification in the formerly permafrost-covered region. As a result, extensive desertification processes are apparent in the eastern and western portions of the Tibetan Plateau (Jin et al., 2003; Li et al., 2005), with the area occupied by desert increasing annually by about 1.8% from 1957 to 1977 (Shi, 1992).

Still, the impact and quantification of permafrost degradation on energy and water exchange processes between the ground and the atmosphere require further examination (Yang et al., 2010). Large-scale intensive monitoring networks, remote sensing investigations, and models for frozen soil are needed to clarify regional details of climate change, permafrost degradation, and their environmental effects.

2.3. Cyosphere–hydrosphere–atmosphere interactions

The unique atmospheric and hydrological processes vary highly across the Third Pole and are shaped by the dynamics of glaciers, permafrost, persistent snow and water. These processes directly impact the geological, ecological and climate features of the region.

The melt water from glaciers of the Third Pole gives birth to Asia's largest rivers, from the Yangtze and the Yellow River to the Mekong and the Ganges (Immerzeel et al., 2010). They are lifelines for some of Asia's most densely populated areas. About two billion people in more than a dozen countries, i.e., nearly a third of the world's population, depend on rivers fed by the snow and ice of the Third Pole region.

The quantitative contribution of glacial melt water to rising lake level has been investigated for many lakes on the Third Pole (Yao et al., 2004; Ye et al., 2007). A recent study (Ma et al., 2010) indicates that 60 new lakes appeared on the Third Pole during the last 50 years. Another study finds that among 56 salt lakes examined, 50 of them show a tendency of lake level increase with mean lake water level increase rate as 0.27 m/year during the 2003–2009 period (Zhang et al., 2011).

These recent lake changes support accelerated glacier melting with global warming as the most likely cause (Zhang et al., 2011). There are two major potential water sources contributing to the lakes, increased glacier/snow melt and increased snowfall/rainfall. Observation from 1961 to 2001 on the Third Pole shows an annual mean precipitation of 444 mm and annual mean evaporation of 1924 mm (Xu et al., 2006). Although there is about 0.001 m/year of precipitation increase in the past 10 years, the fact that 11% of the investigated salt lakes show a water level decrease indicates that precipitation increase alone is not enough to offset the water loss from evaporation, while there is not enough water recharge from other sources such as glacier/snow cover melt (Zhang et al., 2011). Therefore, the only possible primary cause for the salt lakes' water level increase is the water recharge from accelerated melting of glacier and perennial snow cover, as documented in several studies, due to global warming (Chen et al., 2007; Shangguan et al., 2008; Yao et al., 2007; Ye et al., 2007).

Given the close ties of glacier–lake interactions to regional water cycle variability, fluctuation in glacial mass balance has a far-reaching effect not only on the behavior of glaciers and lakes in the Third Pole region, but also on water resources for the populace and social stability in the region. The most significant hydrological hazards in the Third Pole region are the floods caused by the recent glacier melt-supplied lake expansion and outburst (Cui et al., 2010; Yao et al., 2011). Scientists have identified 34 such glacial lakes on the northern slopes of the Himalayas, and 20 outburst floods have been recorded in the past 50 years. These floods pose a threat to habitats and social wealth downstream. In addition, glacial–terminus lake outburst floods (GLOF) intensify with glacial retreat, which can pose geological and diplomatic difficulties as well as serious dangers to people and habitats (Cui et al., 2010; Wang et al., 2008). Glacial retreat also induces glacial–water-fed lake expansion floods (GLEF) which looms large on pastures and livestock in the catchment (Bajracharya and Mool, 2009; Cui et al., 2010).

The fluctuation of glaciers has a direct effect on water supply and social stability in the wider region. Increased glacier melt augments flow at the present time, but in the longer term will result in diminished water flow with consequences on pastures, livestock, agriculture and human populations living in the rivers basins (Cyranoski, 2005). As glaciers retreat, water volume and flow are likely to decline and might become seasonal rather than year-long in the dry regions of the Third Pole. Ensuing water shortages will add to the already existing pressure on water supply with far-reaching impacts on the economy and society (Qiu, 2008).

Global warming induces large-scale degradation of permafrost on the Third Pole, not only affecting how heat and moisture flow between the ground and the atmosphere (Cheng and Wu, 2007) but also introducing significant quantities of CH_4 and CO_2 to the atmosphere, thus likely to accelerate the Greenhouse effect (Cheng and Wu, 2007). With convection layer shifted further up over the Third Pole than normal situation elsewhere (Ma et al., 2009), the heat emitted by the land surface can reach higher and make the air warmer at the base of the stratosphere. Therefore, more water vapor is able to get to the stratosphere without being frozen or precipitated (Qiu, 2008). Water vapor has a stronger greenhouse effect than carbon dioxide per molecule, thus resulting in higher temperatures and maybe inducing increased glacial melting (Qiu, 2008).

2.4. Ecosystem changes and feedbacks

Ecosystems in high-altitude regions are proved to be more sensitive to climatic changes. The special geological, topographic, and weather conditions on the Third Pole make its ecosystem fragile (Zhao et al., 2006). It has been suggested that the current biosphere changes on the Third Pole are mainly caused by permafrost degradation (Wang et al., 2001, 2007a), while alpine meadows and steppes in some regions of the Third Pole were improving during 1982–2009 because of increased precipitation and growing season length (Ding et al., 2010; Piao et al., 2006). During the 20th century, the simulation by the Terrestrial Ecosystem Model (Melillo et al., 1993; Zhuang et al. 2001) indicates that the alpine ecosystems may change from a small carbon source or neutral in the early part of the century to a sink later, with a large inter-annual and spatial variability due to changes of climate and permafrost conditions (Figs. 3–5, Zhuang et al., 2010). However, such a simulation cannot consider the land cover changes induced by global warming and increased human activities because our knowledge of how permafrost degradation can directly result in vegetation changes and sandy desertification is still incomplete. Then it is a big challenge how to assess the vulnerability of alpine ecosystems under global changes.

Significant land cover changes on the Tibetan Plateau include permafrost and grassland degradation, urbanization, deforestation and desertification (Cui and Graf, 2009).

- Permafrost degradation will likely cause a drier ground surface (Cheng and Wu, 2007) and significantly affect soil properties (Wang et al., 2006).
- Grassland occupies an area of about 1.5 million km^2 (Cui and Graf, 2009). Significantly degraded grasslands account for approximately 14–16% of total grassland area on the plateau (Wang et al., 2006). The reasons for the degraded grassland include warmer temperature, changes in combination of temperature and precipitation, decreasing glaciers, melting frozen soil, overgrazing and rat damages (Shang and Long, 2007).
- Due to unsustainable logging practices, agricultural use and urbanization, deforestation on the Third Pole began in the 1950s and accelerated in the 1960s (Houghton and Hackler, 2003; Liu et al., 2005; Studley, 1999), which may impair forest functions of safeguarding watersheds and river flow (Houghton and Hackler, 2003).

Fig. 3. Dramatic retreat of Ata Glacier, southeast Tibetan Plateau, from 1933 (upper) to 2006 (lower) due to global climate changes.

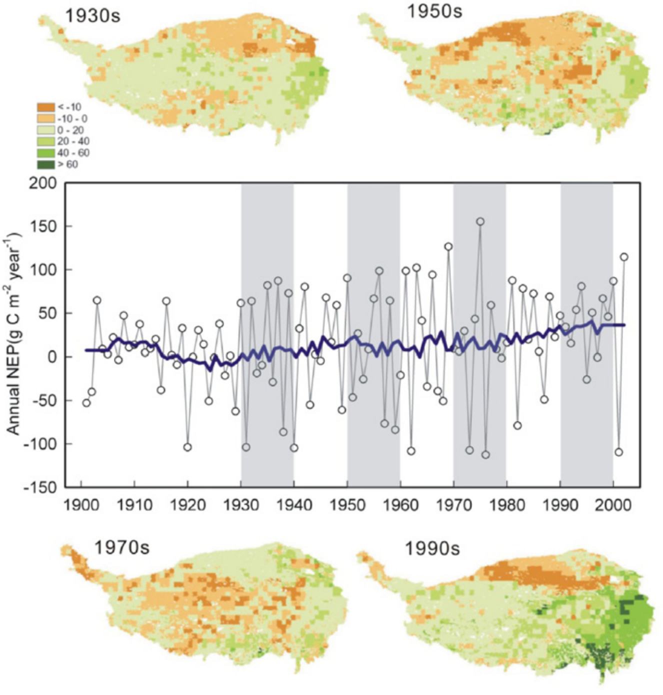

Fig. 4. Chronological and geographical variations in annual net ecosystem production (NEP) during 1900–2000 (adapted from Zhuang et al. 2010). The values are simulated with the Terrestrial Ecosystem Model (TEM) considering the effects of permafrost dynamics.

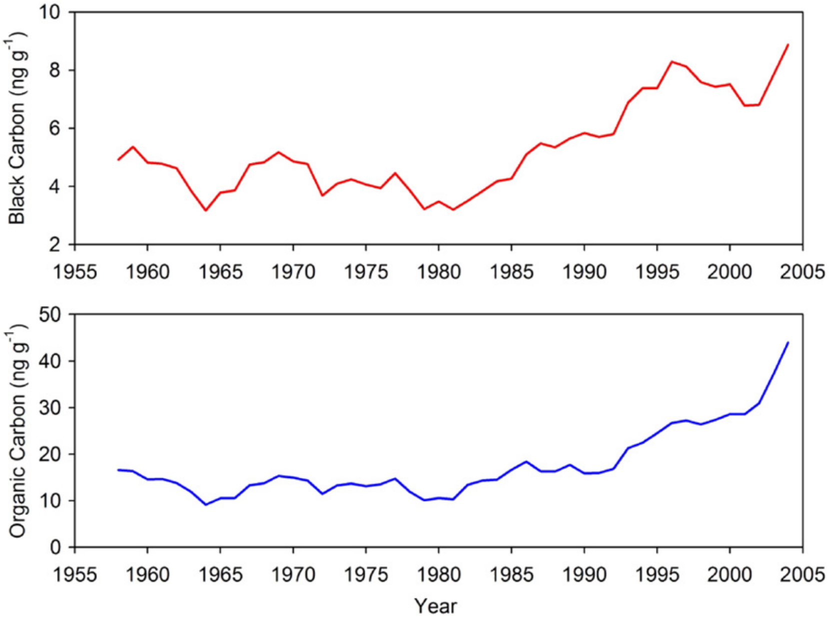

Fig. 5. Increase trends of black carbon and organic carbon concentrations in a Tibetan ice core since 1980s.

- Sandy desertification land of the Third Pole covers a total area of about 3×10^5 km^2, of which moderate sandy desertification land occupies 55.4%, and slight and serious sandy desertification land constitute 30.8% and 13.7%, respectively (Liu et al., 2005).

Future possible land cover changes under future global climate warming are important but hard to assess due to the deficiencies of global climate model in this topographically complex area. Integration of climate, ecosystems, and human activities is highly recommended for future studies (Cui and Graf, 2009).

2.5. Anthropogenic impacts and implications

Human activities in and around the Third Pole region have complicated the variation of the Third Pole Environment. With the rapidly increasing human activities on the plateau during the last half-century, there are apparent alternations in land uses, which may impact regional environment (Cui and Graf, 2009). It is suggested by general atmospheric circulation models that human induced land use changes on the Third Pole would have a significant impact on local to regional scale climate (Kang et al., 2010). Therefore, the climate and environmental changes over the Third Pole region are more and more influenced by anthropogenic inputs.

The increasing industrial and transportation emissions into the atmosphere combined with different atmospheric circulation systems, such as the general westerlies and monsoon circulation have a significant impact on the Third Pole region. Impacts of the increased greenhouse gas emissions upon the climate change on the Third Pole are probably more serious than the rest of the world (Duan et al., 2006). Recently, more and more studies concentrate on the impact of black carbon on atmospheric heating and glacier melting (Ramanathan and Carmichael, 2008; Xu et al., 2009) as well as on distribution and possible sources of Persistent Organic Pollutants (POPs) on regional climate (Wang et al., 2010, 2007b).

An essential issue is predicting the extent to which rapid economic development and increased anthropogenic activities will have on environmental conditions in the Third Pole. While overgrazing and poor environmental management have resulted in degradation of natural vegetation cover and soils (Yang et al., 2010), sustainable development of the Third Pole will require more strategic management based on a more thorough understanding of the environmental change processes and mechanisms. For example, as a major source of income in some areas on the Third Pole, tourism affects heavily the local economy but also influences heavily on environment, if not properly managed. Along the needs for transport, food and accommodation will exert enormous stress to the ecology of the Third Pole (Cui and Graf, 2009). Causes for rangeland degradation are generally attributed to a combination of over-stocking of livestock, unscientific livestock management, etc. (Shen et al., 2004).

3. TPE Program

3.1. TPE principal objectives

The Third Pole Environment (TPE) Program is to attract relevant research institutions and academic talents to focus on such a theme as 'water–ice–air–vegetation–human' interactions in the Third Pole region, to reveal environmental change processes and mechanisms on the Third Pole and their influences on and responses to global changes, and thus to serve for enhancement of human adaptation to the changing environment and realization of human–nature harmony.

3.2. TPE Program Management and Structure

The basic program structure for TPE was outlined during the 1st TPE workshop at Beijing in August 2009. The outline details a 3-pronged approach involving program management, data management, and monitoring networks and stations. The program is establishing the science committee, which functions to propose scientific questions, clarify research objectives, evaluate research approaches, and coordinate tasks. Co-chairs of the program are Profs. Tandong Yao at Institute of Tibetan Plateau Research, CAS, China; Lonnie G. Thompson at Byrd Polar Research Center, the Ohio State University, USA; and Volker Mosbrugger at Senckenberg Research Center for Nature Study, Germany.

The TPE office handles matters delegated down by the co-chairs, particularly on issues relating to organization of workshops, special sessions at international conferences and training programs, publishing TPE workshop reports and newsletters, maintenance of ritual correspondence, and updating the TPE website.

3.3. TPE Program implementation

While responding to scientific and policy needs, the TPE Program will provide a forum for science–policy dialog. Its outputs and capacity building initiatives are expected to significantly contribute to regional development planning and elaboration of mitigation, adaptation and management options and strategies. Current implementation includes:

- cooperating and coordinating with relevant international programs, organizations and research institutions;
- organizing joint scientific expeditions through cooperation of surrounding countries such as Nepal, Tajikistan, Pakistan, India and China. Five transects might be the priority: Koshi River–Xixabangma transect, Koshi River–Everest transect, Pamir transect, Karakorum transect and Kailas transect;
- setting up integrated observation and research stations with cooperation of neighboring countries, and combining them with existing field stations as the Pyramid project in Nepal, and Tibetan Observation and Research Platform (TORP) on the Tibetan Plateau to form the Third Pole Environment Platform (TPEP);
- holding the TPE workshop annually, such as the 1st TPE Workshop in China in 2009, the 2nd TPE workshop in Nepal in 2010 and the 3rd TPE Workshop in Iceland in 2011;
- getting the first-hand observation data to form a TPE database;
- constructing the TPE website and publishing regularly the TPE newsletters; and
- holding training schools for international young talents.

3.4. UNESCO–SCOPE–UNEP Policy Briefs

In order to encourage regional cooperation for policy development through the advancement of relevant knowledge on the environmental changes occurring at the Third Pole and their ecological, social and economic impacts, an international scientific program entitled "Third Pole Environment (TPE)" is to be launched by UNESCO, SCOPE, UNEP and CAS. UNESCO, SCOPE, UNEP and other partners will consider environmental and ecological impacts of climate change during the last 2000 years; water cycles and the Indian monsoon; ecosystems at high elevation under global warming including biodiversity and land use changes; glacial retreat and glacial mass balance; and lakes affected by glaciers and related potential hazards.

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