COMMENT

Reflections and future strategies for Third Pole Environment

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Third Pole Environment programme was established to characterize Earth System interactions over the broader Tibetan Plateau region. Despite past successes, more insight and actionable knowledge are needed, particularly regarding the Asian Water Tower's imbalance and associated ecosystem feedbacks and geohazards, and the teleconnections between the Third Pole and other regions.

The Third Pole encompasses the Tibetan Plateau and its surroundings, including the Pamir–Hindu Kush in the west, the Hengduan in the east, the Tienshan and Qilianshan in the north, and the Himalayas in the south. Across the region, substantial Earth System changes have been observed as a result of climatic warming[1,2]; interactions among the cryosphere, atmosphere, hydrosphere and biosphere have caused glacier melt[3], permafrost degradation[4], lake expansion[5], ecosystem change[6], and hydrological imbalance of the critical Asian Water Tower (AWT)[7,8]. As a home to millions of people, these changes to the Third Pole exert large societal impacts[7–9].

To better understand Third Pole environment changes and their ramifications, Third Pole Environment (TPE) programme was launched in 2009 (REF.[10]), and since 2011 has been a sponsored flagship project under the auspices of United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Environment Programme (UNEP), Scientific Committee on Problems of the Environment (SCOPE) and the Chinese Academy of Sciences. TPE now includes over three hundred researchers from 30 countries, with expertise spanning meteorology, hydrology, glaciology, ecology and paleoclimatology. These researchers all work toward TPE's initial goals of integrating multi-sphere processes for multi-disciplinary projects through the implementation of systematic observations and creation of comprehensive datasets.

Reflecting on past achievements

Field observation has been a major focus of TPE, which coordinated and sponsored the construction of a field observation platform. This platform consists of more than twenty stations located in poorly investigated places such as Nam Co, Nyingchi and Qomolangma. Data collected from the TPE observation platform, collated into more than 2,000 datasets from different disciplines, are stored in the TPE big data systems and are publicly available via the TPE global network. By employing these field observations, TPE has helped resolve many key scientific questions (BOX 1), but its achievements are far reaching.

For instance, TPE has been successful in organizing international cooperation and academic exchange. While tackling the complex environmental changes and challenges in the Third Pole, TPE scientists have thought beyond borders and cooperated on more than twenty multi-national projects. These projects have also had a strong interdisciplinary focus, allowing TPE to cross both national and disciplinary borders to better understand the Third Pole. Moreover, TPE has contributed to the education and training of the next generation of scientists, including more than 300 students.

Since its inception, TPE has further established broad links to policymakers, regional sustainability efforts and relevant stakeholders, as demonstrated through interactions with UNEP, World Meteorological Organization (WMO) and World Climate Research Programme (WCRP), among others. These collaborations resulted in the April 2022 UNEP report[9], 'A Scientific Assessment of Third Pole Environment', offering the first comprehensive synthesis of contemporary environmental changes across broader Tibetan Plateau region. Importantly, this report, as well as other organizational collaborations, represents a shift from fundamental research alone to one that also incorporates and considers societal needs.

Future priorities

Despite marked progress by TPE, the intensifying impacts of climate warming[1] and broader environmental change highlight that more work is needed. Thus, while the initial goals of TPE are still highly pertinent, a strategic priority reset and evolution of fundamental research questions are required.

Key science questions TPE aims to answer will shift from the description of the structure and components of the AWT, to better understanding its emerging trends, imbalance and resulting impacts. These evolving priorities will include examining multi-sphere processes linked with abrupt changes in past and present climate, water, ecosystems, and importantly, their subsequent hazards.

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Box 1 | **Scientific highlights of the TPE**

Some of the major achievements of TPE can be reflected in the following four highlights:

Highlight 1: Elevation-dependent warming

Paleoclimate proxies and meteorological records reveal unprecedented warming and elevation dependent warming over the Third Pole in the past 2000 years[1,2]. The surface albedo feedback appears to be the primary contributor to elevation-dependent warming, with a secondary impact from the clear-sky downward longwave radiation feedback. Therefore, snow cover changes below 5,000 m and persistent snow and ice cover for elevations above 5,000 m shape the elevation dependent warming over the Third Pole.

Highlight 2: Imbalance of the Asian Water Tower

The Third Pole functions as the Asian Water Tower, storing water as snow and ice and redistributing water through an extended river system[7]. The Asian Water Tower is unbalanced due to climate warming and the interaction between the westerlies and the Indian monsoon[7]. Severe glacier melt[3] and extensive lake shrinkage[5] are occurring in the monsoon domain in the southern Tibetan Plateau, while the westerly domain in the north is experiencing overall stable or occasional advancing glaciers with lake expansion[3,5]. Glacier melt and changes in lake size are occurring in the transitional domain, although less so than in the monsoon domain[3,5]. These changes threaten the water storage in the AWT and pose serious hazardous consequences.

Highlight 3: Widespread greening

Since the 1980s, greening has occurred across the Tibetan Plateau due to an extended growing season from earlier spring-like conditions and later autumn-like conditions[6]. In addition, trees are spreading into higher elevations, with a mean upslope shift of ~18 m over the past century. Since the optimum temperature for plant growth is below the present growing-season air temperature, this greening is expected to persist in a warmer world. Greening could, in turn, affect climate change through biophysical and biogeochemical feedbacks, either enhancing evapotranspiration and attenuating surface warming, or enhancing the land carbon sink through greening-related increases in atmospheric CO_2 absorption. At the same time, permafrost thawing will cause carbon release and potential environmental consequences[4].

Highlight 4: Innovative technological approaches

Interdisciplinary collaboration has allowed creation of new tools and techniques. As an example, a 3D observational system of tethered balloons has been used to measure isotopes in situ over the TP. This system is now an important platform for integrating observations of water vapour, greenhouse gases, black carbon and aerosols, allowing systematic and continuous real-time, high-precision monitoring of the multi-sphere interaction over the Third Pole[8].

Indeed, the imbalance of the AWT has triggered several disasters in the Third Pole, causing substantial loss of life and economic damage. These disasters include glacier collapses in the western Tibetan Plateau in 2016, in the lower reaches of the Yarlung Zangbo in 2018, and in the southern Himalayas in 2021. Potential amplification of the frequency and magnitude of such events with climatic warming emphasizes the need to better understand, identify and offer early warning of these hazards.

In addition to prioritizing understanding of AWT imbalance-related hazards, TPE will also focus on improving knowledge of the carbon budget of the region. This knowledge is vital given that climatic warming is rooted in the globally disturbed carbon budget, including Third Pole ecosystems. Indeed, nearly half of the AWT contains temperature-sensitive and carbon-rich permafrost which continued warming threatens to mobilize, and in doing so, erode carbon sinks. Hence, it is vital to enhance understanding of the stocks and fluxes of Third Pole carbon.

Examples of important research questions pursued by TPE would therefore include, but are not limited to: how will changes in the Third Pole environment impact water resources and carbon storage; what would be the critical environmental risk caused by multi-sphere changes and their interactions; what are the major Pan-Third Pole teleconnections; and what guides for climate adaptation can the TPE community suggest locally, regionally, and globally?

Addressing these critical questions requires deeper integration of an expanding multi-sphere monitoring network, a wide range of new techniques and platforms to observe key AWT processes, and the development of advanced coupled atmosphere–cryosphere–hydrosphere models, guiding TPE observation activities. For example, TPE is establishing river-basin-scale observational platforms. These include the Lhasa River Earth System Observation Platform, consisting of five stations from the high elevation Kuoqiong Glacier to Lhasa where human activities are intensive, as well as the Sedongpu Ice Collapse Early Warning Platform, encompassing a multi-process monitoring system of ice collapse, river discharge and earthquakes. These platforms will incorporate cryosphere processes, water transport processes, greenhouse processes, and protection and restoration governance of the regional ecosystems. Emphasis will be placed on expanding monitoring networks into hotspot areas of environmental change.

Field expeditions will additionally complement these expanded observations, generating even more data across the Third Pole. These expeditions, organized by the Second Tibetan Plateau Scientific Expedition (STEP), will be more focused on the head waters related to the big rivers of the AWT, where more challenging Earth System processes are taking place, and extreme high elevation mountain ranges neighbouring the Qomolangma, Xixiabangma and Cho Oyu, where very little information is available.

An integrative model-data approach will also be used to examine and predict future AWT imbalance challenges, establishing model priorities for TPE. High resolution multi-sphere Earth System models, based on an optimized coupling between observation and modelling, will be an important focus. In a WCRP/Coordinated Regional Climate Downscaling Experiment (CORDEX) flagship project, well-designed and coordinated kilometre-scale climate modelling is being conducted, providing the TPE community with unprecedented opportunities to study complex processes.

The combination of these expanded process-based observations and high-resolution modelling will help integrate understanding of individual processes into an internally consistent framework at larger spatial scales, ranging from watersheds to the entire Third Pole and beyond. While knowledge of large-scale changes is reasonably well established, bridging the gap between scientific understanding and action requires much needed local-scale information. Indeed, these data and corresponding research questions will pave the way for deeper investigation into past, present and future changes, and in doing so, enable production of informed policy advice for societal adaptation and mitigation strategies.

While TPE is set to evolve, many existing aspects will remain. TPE will continue to promote international cooperation and pursue partnerships with relevant organizations in order to better understand the changes in the Third Pole environment, better assess their societal impacts, and deliver updated environmental assessment for future green growth and sustainable development. Future workshops will promote this scientific exchange and build international cooperation. Training of young scientists through international educational efforts will remain a priority.

Thus, TPE will evolve to address critical knowledge gaps and predictive capacity focusing on the Asian Water Tower's imbalance with associated ecosystem feedbacks and potential geohazards, and in the teleconnections between the Third Pole and the rest of the world. This knowledge will provide critical information and services toward sustainable development of the region and beyond.

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Competing interests

The authors declare no competing interests.