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Editorial: The atmospheric and environmental impact of anthropogenic activities on mountain cryosphere: a multidisciplinary perspective

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Editorial on the Research Topic
The atmospheric and environmental impact of anthropogenic activities on mountain cryosphere: a multidisciplinary perspective

The field of Atmospheric and Environmental Sciences has increasingly focused on the impact of anthropogenic activities on the mountain cryosphere, which includes regions like the Arctic, the Alps, and the Tibetan Plateau. These areas, despite their sparse populations, are highly sensitive to air pollution due to their relatively pristine environments. The global-scale climatic transformations driven by industrial and economic growth have significant environmental impacts on these cryospheric regions, potentially more so than other areas on Earth. While substantial research has been conducted on the production and transport of pollutants in South Asia, there is a notable gap in studies focusing on the environmental impacts of atmospheric pollutants on the global cryosphere. Recent studies have highlighted the need for a deeper understanding of how these pollutants affect glacial and peri-glacial environments, emphasizing the importance of addressing this gap to better predict and mitigate future impacts.

The five articles published in this Research Topic primarily focus on key components of the mountain cryosphere—namely glacier, permafrost, and mountain snowpack—which also act as critical reservoirs for atmospheric deposition of pollutants (Wei et al., 2019; Dong et al., 2020; Zhu et al., 2023). While the articles do not explicitly address the distribution, transformation, or ecological impacts of pollutants within these environmental media, the lay important theoretical groundwork for understanding how anthropogenic contaminants interact with cryospheric systems. Specifically, by means of seasonal predictions of the snowpack, freeze–thaw cycles in permafrost, and the distribution patterns of cyanobacteria in glacier cryoconite, these studies provide valuable insights into the potential release of pollutants via meltwater and their subsequent effects on downstream water resources and ecosystems.

Cryoconite is a type of sediment found on glacier surfaces, encompassing both biogenic and geogenic components (Wharton et al., 1985). Filamentous cyanobacteria inhabiting cryoconite play a crucial role in entrapping debris and atmospheric contaminants within the sediment matrix (Cook et al., 2016; Huang et al., 2019; Pittino et al., 2018), making cryoconite an efficient reservoir for potentially toxic substances. In their study of Urumqi Glacier No. 1 in China, Chen et al. elucidate the functional role of cyanobacteria in cryoconite, offering valuable insights into the mechanisms by which atmospheric deposition pollutants are retained and enriched in cryoconite. Chen et al. identify three morphologically distinct taxa of filamentous cyanobacteria—Types A, B, and C—within cryoconite granules, with Types B and C being dominant across all size fractions. As shown in these authors' study, type B cyanobacteria commonly exhibit numerous small mineral particles attached to their filament surface, whereas those of type C are typically devoid of such particles or contain only a very small concentration of mineral particles. The findings of Chen et al. indicate that different cyanobacterial taxa contribute variably to the binding of mineral particles within cryoconite granules, and that the coexistence of multiple filamentous taxa facilitates the effective development and stability of cryoconite on the glacier surface.

The mountain snowpack stores months' worth of winter precipitation at high elevations, providing a critical source of snowmelt for agriculture and human consumption in lowland areas during drier seasons. At the same time, snowmelt may also lead to the secondary release of atmospheric deposition pollutants. Therefore, accurate seasonal snowpack predictions are essential for assessing changes in downstream water resources and ensuring water security. Writing in this Research Topic, Berg et al. demonstrate that dynamically downscaled COSMO-1E data can be combined with a snow transport-enhanced model (FSM2trans) to yield the most accurate seasonal snowpack simulations over complex Alpine terrain. Their results highlight the critical role of high-resolution meteorological inputs and snow transport processes, marking the first evidence of dynamical downscaling's effectiveness at the catchment scale.

Furthermore, permafrost has freeze–thaw dynamics that are critical for understanding the release of contaminants and their impacts on downstream ecosystems (Zhu et al., 2023). An extensive dataset on the meteorological and freeze-thaw characteristics of Jagdaqi, situated in the southern Da Xing'anling Mountains, has been published in the data report by Shang et al., published in the present Research Topic. In their report, the authors show that the annual average temperature at 5 m height, averaged over 2022–2023, amounts to 1.04 °C, with air freezing and thawing indices assuming values of −2,318.95 °C·d and 2,698.52 °C·d, respectively.

In a related study, also published in the present Research Topic, Liu et al. show that soil freezing in Bei'an County, Heilongjiang Province, commences in mid-November and concludes by mid-March, with thawing finishing by mid-April. The maximum freezing depth reported by these authors was 1.75 m as registered by mid-March, with a freezing rate of 2.3 cm/day. Liu et al. explain that thawing progresses both upward and downward in the study area, at rates of 2.94 cm/day and 1.91 cm/day, respectively.

Furthermore, a small permafrost watershed in Northeast China is described by Zhang et al. Writing in this Research Topic, these authors identify supra-permafrost water and precipitation as the primary and secondary contributors to river discharge in the studied basin, accounting for approximately 85% and 15% of the flow, respectively. These findings underscore the dominant role of supra-permafrost water as the main recharge source sustaining runoff. This predominant contribution suggests that significant quantities of pollutants sequestered within the permafrost may be mobilized and transported into the small watershed system.

In conclusion, the studies published in this Research Topic contribute to a better understanding of a broad range of dynamic processes associated with key environmental components in the cryosphere. By providing insights obtained from both field measurements and model predictions, the research articles and data reports written in this Research Topic are relevant for future theoretical studies that aim at improving the quantitative assessment of secondary cryosphere pollutant release across our planet.

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