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Introduction—Changing cryosphere under a warming climate

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The cryosphere covers areas or regions with temperatures ≤0 °C in the Earth System and contains water in its frozen state, such as solid precipitation, snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground. The presence of frozen water in the atmosphere, on land, and on the ocean surface affects energy, moisture, gas and particle fluxes; clouds; precipitation; hydrological conditions; and, atmospheric and oceanic circulation. The cryosphere is sensitive to climate change simply because ice is the only natural substance with a melting point at temperatures normally found on Earth. A small change in mean annual air temperature in cold regions could cause substantial changes in the cryosphere. Evidence shows that climate warming has been amplified in the Arctic and in some mountainous regions (IPCC, 2013) in part due to snow/ice albedo feedback impact. Consequently, substantial changes in the cryosphere have been observed in various parts of the world (IPCC, 2013; Vaughan et al., 2013). To better understand the response of the cryosphere to climate change, an international cryospheric science conference was held in Sanya City, Hainan Province of China, in October 2013. The conference covered a variety of topics related to the cryosphere , and we selected a theme of "Changing Cryosphere under a Warming Climate" to attract papers for a Cryosphere Special Issue to be published in *Arctic, Antarctic, and Alpine Research.* There are 12 papers in this special issue, mainly covering studies on the active layer and permafrost, glaciers, and seasonal snow cover in Alaska and China.

Soil organic carbon within the active layer and permafrost has become a key research topic because of its potential impact on the global carbon budget. Gusmeroli et al. (2015) demonstrates that, due mainly to the difference in soil water content, ground-penetrating radar (GPR) can be used to measure the thickness and properties of the near-surface organic layer within the active layer. This is because the porous organic layer can contain more water (up to 87% by volume) than the underlying mineral soils (about 45% by volume), resulting in a strong dielectric contrast and radar reflection. This GPR method will help to better estimate the carbon storage in the active layer worldwide. On the other hand, Mu et al. (2015a) uses a conventional method to study soil carbon and nitrogen properties in permafrost over western China. Their results showed that the storage of soil organic carbon, total nitrogen, and soil inorganic carbon is higher in permafrost than in the overlying active layer. Combined with results from previous studies, Mu et al. (2015b) recently found that the average soil organic content in permafrost regions over the Qinghai-Tibetan Plateau is higher than that in the Arctic and subarctic. Their results show that the total carbon storage in permafrost regions of the northern hemisphere is about 1832 Pg, approximately 2.5 times greater than the current atmospheric carbon content.

The near-surface soil freeze-thaw cycles could have a dramatic impact on surface energy balance, plant growth, and ecosystem as a whole. Jin et al. (2015) documents changes in the near-surface (up to 5 cm) soil freeze-thaw cycle from 1978 through 2008 in China using passive microwave satellite remote sensing data. Their results demonstrate that the near-surface soil freezing in autumn was delayed by about 19 days, while the near-surface soil thawing in spring was advanced by 19 days, resulting in a lengthening of growing season by 34 days in China over the study period. However, the frozen soil algorithm requires further in situ data validation. The results from this study could be critical to explain changes in the boreal carbon sink during the past few decades. Using soil temperature data from 12 meteorological stations, Wang et al. (2015) demonstrates that mean annual soil temperatures at 0.0–0.20 m depths increased by about 2.0 °C over the Heihe River basin in western China from 1972 through 2006. However, their results also show that the near-surface soil freezing in autumn was delayed by about 7 days, while the near-surface thawing was advanced by about 14 days, resulting in an increase in growing season of about 20 days over the study period. Results from Wang et al. (2015) show a smaller magnitude of changes in the near-surface soil freeze-thaw cycles over a small river basin in western China compared to the results from satellite remote sensing over all of China reported by Jin et al. (2015). By contrast, Liu et al. (2015) finds that the first date of air temperature less than 0 °C was delayed by about 8 days in autumn over East China from 1961 through 2009, about the same magnitude found in near-surface soil freezing dates delay over the Heihe River basin in western China (Wang et al., 2015).

Ran et al. (2015) uses MODIS Aqua/Terra Land Surface Temperature products from 2003 through 2010 to derive the mean annual surface temperature and the surface frost number to map

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permafrost distribution in China. Their results show that the 0 °C isotherm of the mean annual surface temperature and 0.5 surface frost number contour agree well with the currently identified southern/lower limits of permafrost in China. This is the first time that MODIS land surface temperature data products are used to map permafrost. However, the errors of the MODIS land surface temperature data are still quite large, and thus the accuracy of the mapped permafrost area in this study is limited.

Based on in situ measurements, Chang et al. (2015) investigates the impact of vegetation on the active layer and permafrost in northwestern China. Their primary results indicate that vegetation indeed has a strong insulation effect. Further, they demonstrate that soil temperatures were lower in places with denser vegetation, showing the cooling effect of vegetation on the ground thermal regime. However, soil temperatures would increase when vegetation degrades. It may be that the vegetation cooling effect can be explained by its shading and evapotranspiration impacts on the underlying soils. However, the combined effect of vegetation with snow cover can also be important. Further monitoring is needed to better comprehend the vegetation effect on the active layer and permafrost thermal regime.

Glaciers are key cyrospheric elements in western China. Because glaciers may occupy vast regions, in situ measurements to detect the areal extent of changes are still difficult and costly. Satellite remote sensing is a useful tool to overcome these limitations. Using MODIS daily snow albedo measurements, Wu et al. (2015) investigated changes in summer surface albedo on a glacier over central Qinghai-Tibetan Plateau from 2002 through 2012. Their results indicate that summer surface albedo on the glacier exhibited a decreasing trend due mainly to changes in summer precipitation and air temperature. They further demonstrate that surface albedo decreased by about 34% when air temperature increases about 1 °C and the summer precipitation decreases about 94.5 mm. A lower summer surface albedo would result in loss of glacial mass. Guo et al. (2015) uses LANDSAT 30 m resolution data from clear sky conditions at the end of 21 summer melt seasons to study changes in firn lines and the ice boundaries on Qiyi Glacier in western China. They find that the firn line altitudes on the Qiyi Glacier increased from 4540 m a.s.l. to 5000 m a.s.l. from 1990 through 2011, with an average rate of about 22 m per year. The firn zone area decreased with the increase of the firn line altitude. The firn zone area decreased by about 1.19 km^2 over the study period. Increase in the firn line altitude and decrease in the firn zone area were consistent with air temperature increase over the study period. Using satellite remote sensing data and historical topographic maps, Wei et al. (2015) investigates changes in glacier volume on the north bank of Bangong Co basin in northern western Qinghai-Tibetan Plateau. Glaciers in the study area experienced a general mass loss but at different rates. Overall, the total mass loss was about 4.45 ± 0.63 km^3 or -0.18 ± 0.03 m yr^{-1} water equivalent from 1968 through 2007 over the study area.

Assessment of water storage in seasonal snow cover is of great practical application in hydrological studies and water resources utilization. Using Synthetic Aperture Radar (SAR) data, Sun et al. (2015) investigates snow water equivalent over the areas with shallow dry snow cover. Han et al. (2015) conducted extensive field work to study seasonal changes in electrical conductivity of snow and snow/glacial meltwater over the headwater of the Urumqi River during the summer seasons from 2003 through 2008. Electrical conductivity was generally inversely correlated with runoff that originated from glacial meltwater, indicating a high possibility of using changes in electrical conductivity to study the intensity of glacial ablation.

Papers from this special issue summarize the current progress on cryospheric studies mainly in western China. However, these studies may be just a jump-start on many scientific questions. How much carbon is currently frozen in permafrost on the Qinghai-Tibetan Plateau? How does the frozen carbon in permafrost respond to permafrost degradation due to the global warming? How much water is stored in glaciers, snow cover, and even ground ice in western China? How will changes in the cryosphere affect water resources, thus human society as a whole? All of these issues require further intensive studies from broad scientific communities in order to better provide a scientific basis for policy makers and serve society as a whole.

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