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The hydrological impacts of near-surface soil warming in the Tibetan Plateau

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Annual air temperature mainly ranges between -2 and 2 ^{o}C in the Tibetan Plateau (TP), so the current warming likely causes possible changes in regional freeze/thaw processes, which have important impacts on local hydrology process. However, sparse in-situ measurements generally limited our understanding about regional freeze/thaw changes over the whole TP. In the study, multi-layer soil temperatures at 45 weather sites from 1981 to 2015 were taken to investigate the spatial patterns and temporal changes in near-surface temperature gradients (with downward as positive) and freezing/thawing onset so as to examine possible variations in frozen soil related to climate warming. The influences of frozen soil degradation on runoff change were analyzed in three basins, i.e. the source regions of Yellow River, Yangtze River and Nujiang River. Our results showed the contrasting seasonal trends ($p<0.05$) of 0-5 cm soil temperature gradient in warm season (averagely 0.019 ± 0.008 ^{o}C a^{-1} at 30 sites) and cold season (-0.031 ± 0.013 ^{o}C a^{-1} at 34 sites), which indicated increasingly more heat transferred downward from ground surface at annual scale. In deeper layer (5-10 cm), the thermal transfer likely became weaker as reflected by the decreasing temperature gradients in both cold (-0.007 ± 0.004 ^{o}C a^{-1} at 31 sites, $p<0.05$) and warm (-0.008 ± 0.004 ^{o}C a^{-1} at 21 sites, $p<0.05$) seasons. The frozen soil degradation was distinctly indicated by the delayed freezing onset (0.368 ± 0.158, 0.319 ± 0.141 and 0.271 ± 0.109 day a^{-1} respectively in the layer of 0, 5 and 10 cm, all $p<0.05$) and advanced thawing onset (-0.417 ± 0.146, -0.373 ± 0.176 and -0.373 ± 0.145 day a^{-1} respectively in the layer of 0, 5 and 10 cm, all $p<0.05$). The baseflow in cold season increased significantly in the source regions of Yangtze River (0.387 m^3 s^{-1} a^{-1}, $p<0.05$) and Nujiang River (0.676 m^3 s^{-1} a^{-1}, $p<0.05$) where the increasingly soil warming likely played an important role ($R=0.380\sim0.481$, $p<0.05$). However, the baseflow of Yellow River source region in cold season showed decrease due to significant decrease in precipitation, which may surpass the impacts of freezing degradation. Our study suggested that the near-surface soil layer would become warmer due to the heating by increasingly hotter ground surface in the TP, and the weakened freezing processes induced-by the increasingly soil warming would have complex impacts on the hydrology process.