



Rapid development of permafrost thermokarst landforms detected by repeated Unmanned Aerial Vehicle surveys in the northeastern Qinghai-Tibetan Plateau

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The number and area of thermokarst landforms are continuously increasing on the Qinghai-Tibet Plateau due to climate warming and anthropogenic disturbance since 1950s. To quantify the development of thermokarst landforms, we investigated sinkhole, thermal erosion gullies and slump-gully-complex three types of hillslope process thermokarst landforms by differencing high-resolution digital terrain models (DSMs) acquired by Unmanned Aerial Vehicle in 2016 and 2017 summers. Different development patterns are observed in these three types of thermokarst landforms: the sinkhole presents up to -5 m/year subsidence rate, the erosion gully shows up to 15 m/year headwall retreat rate, while the subsidence and headwall retreat rate of slump-gully-complex falls in between of the other two types. The results show that the Qinghai-Tibet Plateau is undergoing rapid thermokarst landforms development. The fast development of thermokarst landforms will likely amplify the ecological, geomorphology, environment and engineering-related hazards impacts.