A rapid glacier surge on Mount Tobe Feng, western China, 2015

Kelayayilake Glacier, located on Mount Tobe Feng, western China, surged dramatically during the spring of 2015, accompanied by a glacier avalanche. By July 2015, a glacier area of 8.9 km², length, 12 km had been influenced by the surge event. The surge and avalanche swallowed 1000 ha of grazing meadow and damaged 61 herdsmen’s houses with hundreds of livestock missing in Akto County, Xinjiang. It caused no human casualties. Glacier surges occur regularly in western China. However, a large-scale surge like that of Kelayayilake Glacier is rare (Quincey and others, 2015). Because most surges take place in rural areas, they often remain unnoticed until they become a hazard, damaging local property.

Glacier surges are short-term events during which a glacier can advance substantially, reaching velocities up to tens or hundreds of times greater than normal (Meier and Post, 1969; Kamb and others, 1985), and it is possible to obtain accurate and detailed measurements of glacial surface motion with optical images such as Landsat (Haug and others, 2010; Yang and others, 2013). In this study, the operational use of satellite images has been implemented using the software, COSI-Corr (Co-Registration of Optically Sensed Images and Correlation), which has proven effective in a number of studies including glacial movement (Leprince and others, 2007; Herman and others, 2011). We analyzed 11 Landsat-8 Operational Land Imager images from several months during and before the surge of the west branch of Kelayayilake Glacier to detect fluctuations of the glacier.

Considering the limitations of the images acquired, we separate this surge duration into four periods: March (12–21 March), April (13–22 April), May (8–15 May), and June and July (16 June–11 July). The time interval between each image pair is sufficient to obtain a relatively large displacement while avoiding the signal being buried by noise and we use COSI-Corr calculations to derive the velocity maps for the four periods. With a total length of 15.0 km, the velocity profiles for the west branch center line are extracted from these velocity maps. Along with the elevation of the west branch center line, which is obtained from ASTER Global DEM (GDEM Version 2), these profiles are filtered, providing a smoothing effect. They are shown in Fig. 2. The distance along the west branch center line was selected as the abscissa and the point of origin is the location where the west branch converges with the trunk glacier, i.e. where the glacier appears to be stable. Because the highest ice velocities in this region under normal conditions occur in September, the velocity profile for September 2014 is also shown. These profiles can provide some insight into the evolution of the surge.

Almost all September 2014 values were in the range, 0–50 m month⁻¹. Very few parts in the upstream region had values near or above 100 m month⁻¹. From March to May, the peak velocity rose abruptly (March: ~315 m month⁻¹, April: ~415 m month⁻¹, May: ~605 m month⁻¹). In June and July, it fell to 110 m month⁻¹, clearly demonstrating that the surge was most active during May. From km 13 to km 15 upstream, ice and snow are exposed to air without debris cover (Fig. 1). Even though the terrain varies irregularly in this section (Fig. 2), the glacier’s motion was approximately constant. Most of this km 13 to km 15 upstream section is located above the snow line. From km 12 to km 13, the velocity suddenly increased. An increased topographic gradient led to this acceleration. The partial conversion of vertical velocity into a horizontal component contributed to the sudden velocity increase seen in the satellite images. At km ~10.5 (~3750 m a.s.l.) two upstream branches converge into one,
resulting in another velocity increase. For March, April and May, the velocity profiles peaked before the west branch glacier encountered the trunk glacier at a distance of km ∼6 and decreased suddenly to almost zero at km 3.3, km 3.1 and km 2.7. For June and July, the velocity profile peaked a little closer to the front of the glacier (at km ∼5)

Fig. 1. Landsat-8 image (bands 654 combined) of Kongur, with superimposed Kelayayilake Glacier and glacier center line. The location of the study area in China and a 3-D terrain stereogram are shown. Evolution of the surge: (a) 26 September 2014, (b) 21 March 2015, (c) 15 May 2015, (d) 11 July 2015. The yellow straight lines indicate distinct surface features and their location. The white segments indicate the width of the trunk glacier. The dashed line and segment in (d) show the relative position of each feature in September 2014 before the surge. Note that the blue-white region represents the exposed snow or ice; the red region represents the debris-covered glacier or bare land.

Fig. 2. Center line velocity profiles characterizing the evolution of the Kelayayilake Glacier surge and corresponding elevation of the glacier along the blue center line shown in Fig. 1. Surge fronts for each of the studied periods are noted.
and the surge front located at km 1.5. The glacier front appeared to be stable and showed no apparent motion, indicating that the surge did not impact this area by the time of July 2015. In June and July, when the surge was in its decaying stage, the surge affected a much longer distance, despite velocities as low as 1/6 of those during May in all parts of the glacier. The value of deceleration in the downstream section is higher than the acceleration in the upstream portion of the glacier, even when considering the velocity increase caused by convergence of the two upstream branches. Two factors might contribute to the sudden stop of the surge: (1) the geomorphological change from a narrow passage to a broader valley, and/or (2) the resistance caused by the trunk glacier. It is difficult to identify exactly when the glacier surge was initiated, as the images available for January and February are heavily cloud-covered.

Even though the Kelayayile Glacier has now ceased surging, a large amount of accumulated glacial material will continue to flow into the trunk glacier. The surge left numerous crevasses on the surging glacier and a changed meltwater flow from the glacier front, along with an increased risk of subglacial lake outburst flood.

ACKNOWLEDGEMENTS
This research was supported by the International Cooperation and Exchange of the National Natural Science Foundation of China [No.41120114001, 41590852]; International Cooperation Program of CAS [No.131211 KYSB20150035]; Natural Science Foundation of Jiangsu Province [No.BK20150189]; The ASTER GDEM and Landsat-8 images were respectively downloaded from ERSDAC and from http://glovis.usgs.gov. We greatly appreciate the constructive comments by anonymous reviewers, which helped improve an earlier version of this manuscript.

REFERENCES

MS received 31 December 2015 and accepted in revised form 12 February 2016; first published online 26 April 2016

1School of Earth Sciences and Engineering, Nanjing University, Nanjing, China, 2Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China, 3Jiangsu Key Laboratory of Resources and Environmental Engineering, School of Environment Science and Spatial Informatics, China University of Mining and Technology, Xuzhou, China

E-mail: Liu Guang <liuguang@radi.ac.cn>