GEOMETRIC EVOLUTION OF WEST CHAMSHEN GLACIER, EAST KARAKORAM

Arjun Pratap Shahi[1], Himanshu Govil[1], Rakesh Bhambri[2], Subhanil Guha[1], Mahesh Kumar Tripathi[1], Monika Besoya[1], Pralay Bhaumik[1], Gaurav Mishra[1]

[1]Department of Applied Geology, National Institute of Technology Raipur- 492010, Chhattisgarh, India

[2]Wadia Institute of Himalayan Geology, Dehradun, India

Email: arjunpratapshahi@gmail.com; hgovil.geo@nitrr.ac.in; rakeshbhambri@gmail.com;
subhanilguha@gmail.com; TRIPATHI.MAHESH1@gmail.com; geniousmonika11@gmail.com;
bhaumik_pralay@yahoo.co.in; mshgaurav04@gmail.com

ABSTRACT

Surge-type glaciers fluctuate between short (months to years) speedy flow and lengthy (tens to hundreds of years) slow flow, which are called the ‘active’ and ‘quiescent’ phases, respectively. In the active phase, a large volume of the glacier’s mass is abruptly transferred from an upper ‘reservoir zone’ into the lower ‘receiving zone.’ Active glacial surges pose serious hazards for the local community when ice overrides downstream villages and destroy the infrastructure (roads, bridges, and trails). Sometimes the glacier advances block the flow of the river and consequently form an ice-dammed lake which generates devastating outburst floods in the downstream areas. Therefore, regular monitoring of glacial surges is crucial. The Karakoram holds one of the world’s largest concentrations of surge-type glaciers. The present study reports first-time surge dynamics of West Chamshen Glacier (36.5 km^2), Eastern Karakoram based on surface displacement and ice volume change using multiple Landsat satellite images and ASTER DEMs. This glacier exhibits surge phase from 2007 to 2013. During the surge, the maximum surface displacement reached 1500 m y^{-1} in 2011. Between 2015 and 2000, the lower receiving zone exhibits maximum thickening of +250 m whereas the upper reservoir zone maximum thinned by -90 m. The glacier terminus advanced 3653 ± 57 m from 2007 to 2013. The reservoir zone received +616. 9 x 10^6 m^3 volume of ice mass between 2000 and 2014. This study will facilitate to understand heterogeneity in glacier surge dynamics and to mitigate hazardous situation arising due to sudden transfer of a huge volume of ice in Saser Muztagh range of the Eastern Karakoram.

Keywords: Surge-type glacier, elevation change, surface displacement, terminus advance, heterogeneity

INTRODUCTION

Glacier surging is quasiperiodic phenomena wherein the glacier flow velocity intermittently switches between prolonged duration of slow flow (tens to hundreds of years) and a brief period of fast flow (months to years), which are commonly known as ‘quiescent’ and ‘active’ phases, respectively (Meier and Post, 1969; Jiskoot 2011; Quincey 2011). In the quiescence phase, the lower part of the glacier becomes stationary or retreat and thinned whereas accumulation of mass in the upper reservoir zone occurs which results in steepening of glacier profile to generate pre-conditions for triggering the next surge (Meier and Post, 1969; Jiskoot 2011). During the active phase, a huge volume of ice mass is transferred from the upper reservoir to the lower receiving zone, which often modifies the downstream landscape.

The Karakoram holds one of the largest glacierized area outside the polar region (Bloch et al. 2012). Surging glaciers in the Karakoram have been considered as “threatening glaciers” (Mason, 1930). The main reason behind glacial surges is still unclear due to inaccessible terrain and lack of detailed ground observation for entire surge-cycle. Surging glacier poses a great threat to human settlement down the valley when the huge volume of ice transport from the reservoir to receiving zone and cease the flow of rivers by the ice dams (Mason, 1930; Quincey and Luckman, 2014; Round et al., 2017; Steiner et al., 2017; Bhambri et al., 2019). The moving active surge ice also damages roads, bridges, buildings, power stations and grazing fields in the down valley (Hewitt, 2011; Donghui et al., 2016; Yao et al., 2019; Bhambri et al. 2020). Therefore, it is important to continuously monitor surging glaciers to mitigate hazardous events.

The main aim of the present study is to investigate and quantify surge characteristics of West Chamshen Glacier, East Karakoram such as mass transferred from the upper reservoir to lower receiving zone and change in terminus position using multiple satellite images and Digital Elevation Models (DEMs) (Bhambri et al., 2017; 2019; Round et al., 2017; Steiner et al., 2017; Mukherjee et al., 2017; Paul et al., 2017; Rashid et al., 2018; Yao et al., 2019).

STUDY AREA

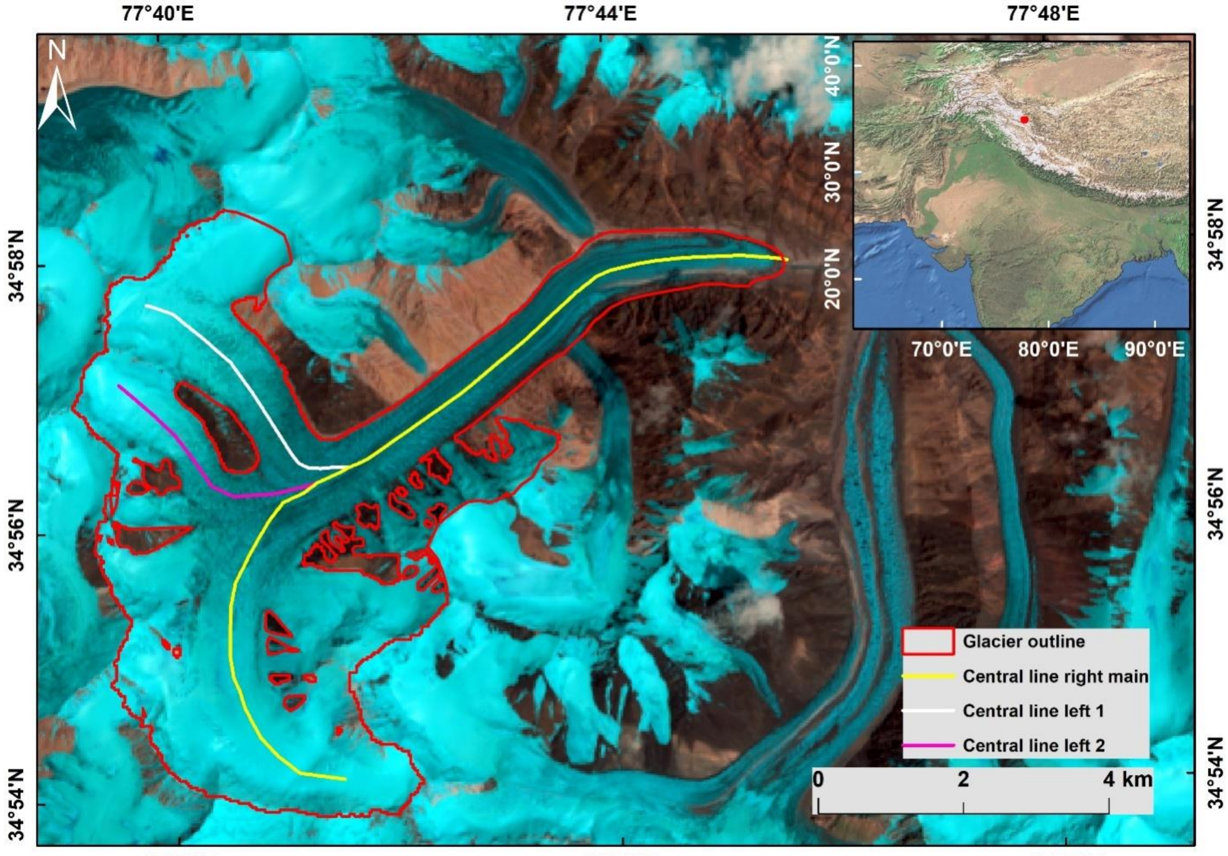

Figure 1: The overview of the study area. The base image is presented by Landsat band combination 6-5-4 (06-08-2018).

The West Chamshen Glacier (77°40'55.2"N 34°56'6"E; GLIMS ID: G077682E34935N) is a part of Chamshen group of glaciers located in Saser Muztagh range of the Eastern Karakoram (Figure 1). Chamshen Glacier descends from a height of 6415 m and flows eastward to drains in Shyok River and terminating at 4762 m. The glacier is 12.2 km long and covers an area of 36.5 km^2 (RGI Consortium, 2017). The study area comes under winter snow regime and receives maximum snowfall between November and April (55% of total snowfall) due to westerly air masses originating from the Mediterranean Sea and/or Atlantic Ocean (Thayyen and Gergan,2010). The other major surge-type glaciers in the Shyok valley is Rimo, Chong Kumdan, Kichik Kumdan and Aktash glaciers. In the past, some of these glaciers have ceased the flow of Shyok River and have caused ice dam failures ((Mason, 1930; Hewitt, 1982; Raina and Srivastava,2008; Hewitt and Liu, 2010).

METHODOLOGY

The glacier outline was obtained from the Randolph Glacier Inventory version 6.0 (RGI Consortium, 2017) which were modified using 2018 Landsat image. Twelve ASTER (AST_L1A product) imagery with minimal snow and cloud cover mainly from late July to October were obtained from the United States Geological Survey (USGS; https://search.earthdata.nasa.gov/). The ASTER DEMs were generated by ERDAS Imagine Photogrammetry Suite 2015 at the resolution of 30 m with no ground control points (GCPs).

The coregistration of DEMs is an important step to ensure each pixel in all the DEMs corresponds to the same location on the ground. The universal coregistration method developed by Nuth and Kääb,(2011) was used for removal of planimetric shifts from the DEMs. The SRTM 2000 DEM was used as a reference DEM. In total five iterations were performed until the bias came within acceptable (±1 m) limits. A total of twelve elevation change maps were generated using DEM differencing method and used the +250 and −250 m elevation ranges to remove outliers in the elevation change maps. The entire glacier was divided at 100 m altitude interval and computed mean surface elevation change for each altitude range. The volume change was estimated by multiplying mean surface elevation change with the area of the respected glacier altitude range. We determined the surface displacement using the manual method (separated annually) based on visual interpretation of morphological features on Landsat satellite imagery.

We also estimated the frontal length change of West Chamshen Glacier terminus based on the central line. The uncertainty in frontal length change and surface displacement using the manual method was estimated using the following equation proposed by Hall et al., (2003)

$$e = \sqrt{(\mathrm{x1})^2 + (\mathrm{x2})^2} + \mathrm{E_{reg}} \qquad (1)$$

Where

e = error in frontal change,

x1 = pixel resolution of imagery 1,

x2 = pixel resolution of imagery 2,

Ereg = horizontal shift

RESULT AND DISCUSSION

Surface displacement, elevation Change and terminus advancement

Table 1: Surface displacement over the surge period (2007-2013) of West Chamshen Glacier

S. No.	Year	Surface displacement (m)
1	2006-2007	5.7± 57
2	2007-2008	70.0 ± 57
3	2008-2009	227.6 ± 57

4	2009-2010	446.8 ± 57
5	2010-2011	1500.1 ± 57
6	2011-2012	752.0 ± 57
7	2012-2013	381.5 ± 57
8	2013-2014	42.6± 29
	Total	3426.3 ± 53

The surface displacement between 2006 and 2007 was very low (5.7 ± 57 m y^{-1}). During 2007 to 2008, it increased to 70.8 ± 57 m y^{-1} which further accelerated to 227.6 ± 57 m y^{-1} between 2008 and 2009. The maximum surface displacement (1500.1± 57 m y^{-1}) was observed between 2010 and 2011. The surface displacement decelerated to 752 ± 57 m y^{-1} in 2011-2012. During 2012 to 2013, the surface displacement (381.5 m y^{-1}) gradually decreased which further decelerated (42.6 ± 29 m y^{-1}) between 2013 and 2014 (Table 1). The glacier terminus advanced 3653 ± 57 m from 2007 to 2013 (Figure 5).

The very slow surface displacement before 2007 is indicative of the quiescent phase. The acceleration of surface displacement from 2007 to 2013 represents a prolonged active phase (six years) of West Chamshen Glacier, which is longer than the neighboring glaciers such as Kichik Kumdan (two years) and Aktash (three years) glaciers (Bhambri et al. 2013). The gradual deceleration of surface displacement for one year (2012-2013) exhibits slow termination of the surge. Similarly, slow surge termination (~1 year) is reported on an unnamed glacier in the Yarkand river basin, Karakoram (Singh et al., 2020). Due to the lack of information about previous surges, we could not estimate the surge cycle of the West Chamshen Glacier.

We computed twelve elevation change maps for the main trunk and two left tributaries, using multiple ASTER DEMs. Between 21 July 2001 and 29 October 2005, the whole glacier average thickened by +19.7 m and the upper reservoir zone (~10 km up-glacier from terminus) exhibit maximum thickening of +60 m. In the receiving zone (~4 km up-glacier from terminus) surge front achieved the height of +100 m and the reservoir zone maximum thinned by -45 m during 2005 and 2010. Between 28 September 2011 and 03 August 2014, the reservoir zone further shows maximum thinning of -100 m whereas the surge front moved ~2 km down the glacier and the maximum ice thickness increased to +270 m in the receiving zone (~2 km up-glacier from terminus) (Figure 2).

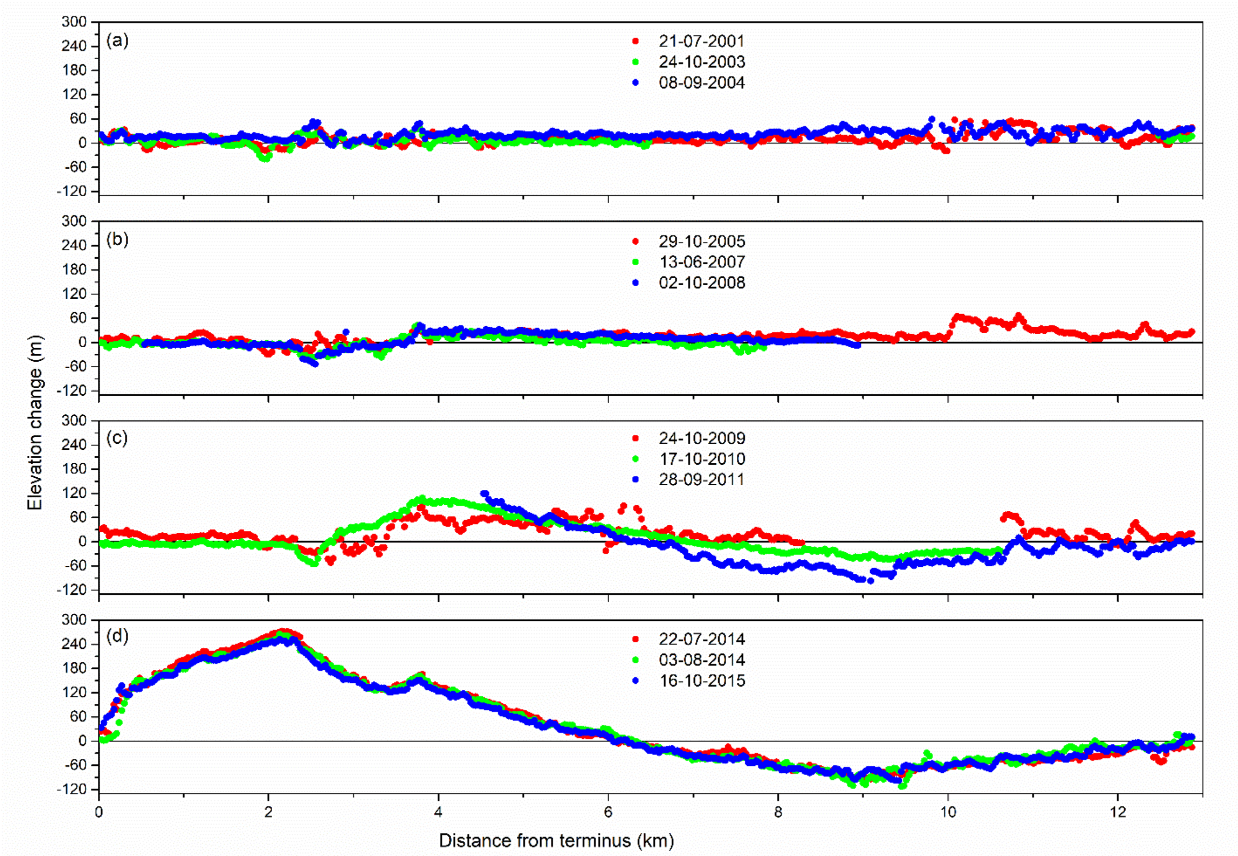

Figure 2: Surface elevation changes of main West Chamshen Glacier. Elevation changes were extracted using the right main central line (shown in Figure 1). All the ASTER DEMs (in legend) were subtracted with reference SRTM DEM.

The elevation change of central line left 1 suggests that the upper reservoir zone (near 9.5 km up-glacier from terminus) experienced maximum thinning of -39 m between 28 September 2011 and 03 August 2014 however the elevation change in the upper reservoir zone was nearly zero during 2001 to 2011 (Figure 3). The elevation change of central line left 2 indicate that between 2001 and 2009 the reservoir zone (~8.5 km up-glacier from terminus) exhibit no elevation change. During 2010-2011, the reservoir zone (~8.5 km up-glacier from terminus) average thinned by -22 m. Between 28 September 2011 and 03 August 2014, the reservoir zone exhibits a maximum lowering of -55 m which is higher than the left 1 tributary (Figure 4). The transfer of mass between 2007 and 2014 resulted in a net loss of -422.1 x10^6 m^3 and a net gain of +616.9 x 10^6 $m^3$of ice in the reservoir and receiving zones, respectively. Pitt et al. (2016) also reported net loss of -110 x10^6 m^3 and a net gain of +100 x 10^6 m^3 of ice in the reservoir and receiving zones, respectively for Horcones Inferior Glacier, Mount Aconcagua, Central Andes.

The formation of surge front, thickening of the receiving zone and the lowering of reservoir zone of main trunk and tributaries exhibit that the whole West Chamshen Glacier system experienced surge from 2007 to 2013.

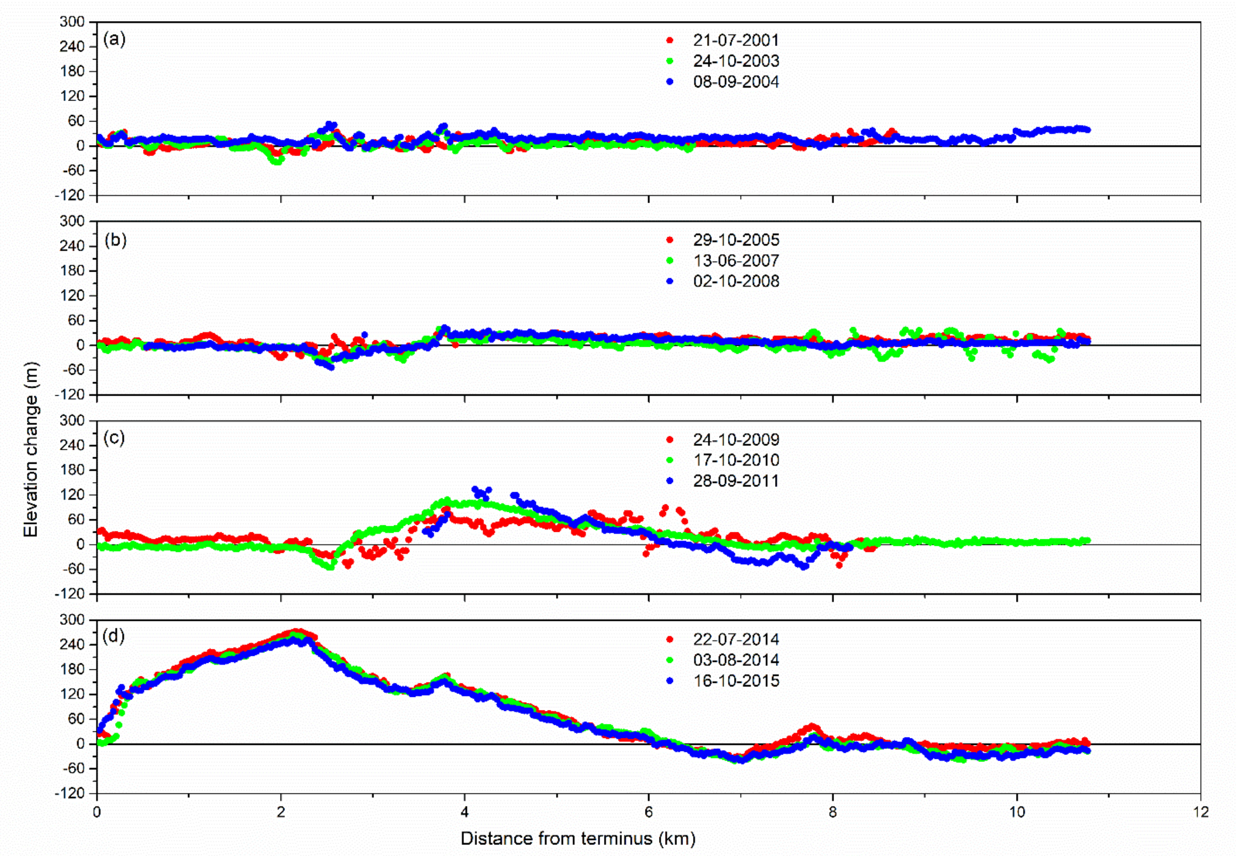

Figure 3: Surface elevation changes of West Chamshen Glacier. Elevation changes were extracted using central line left 1 (shown in Figure 1). All the ASTER DEMs (in legend) were subtracted with reference SRTM DEM.

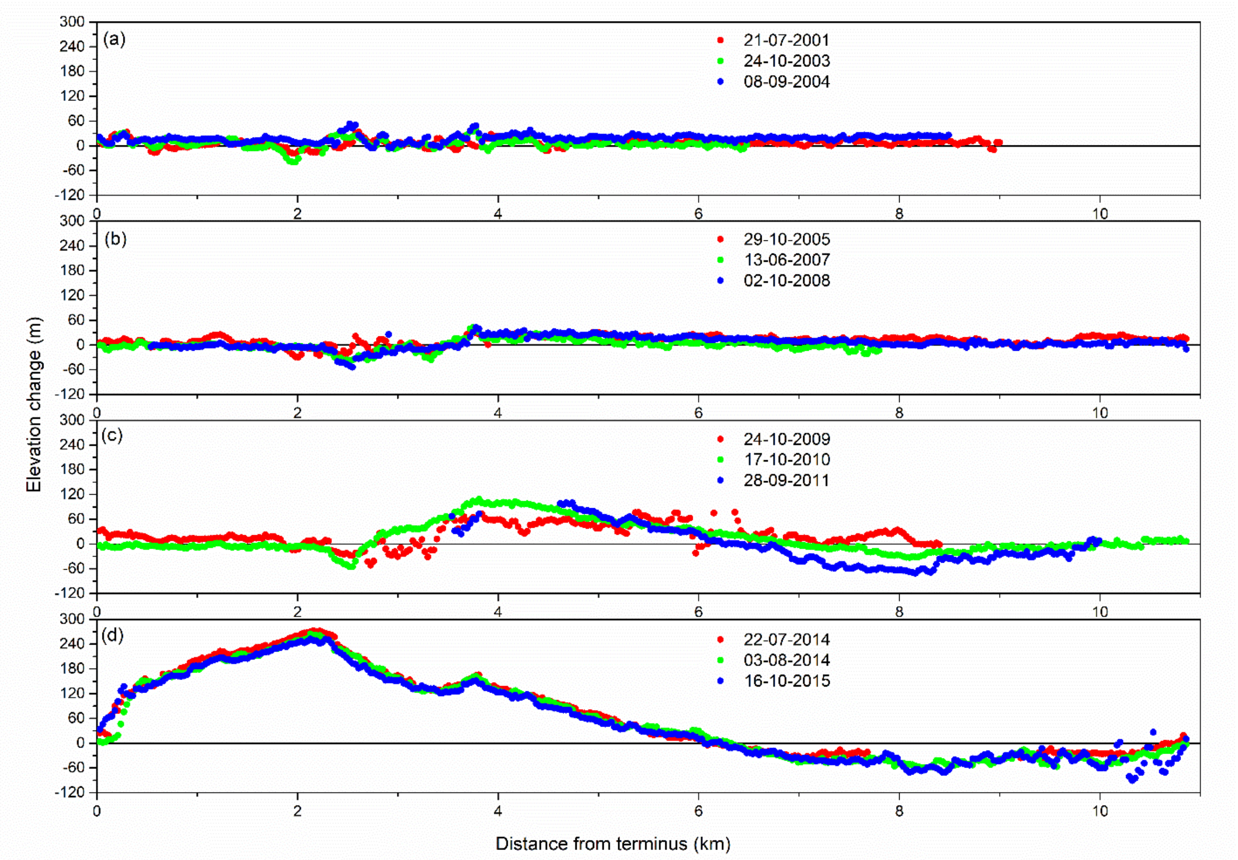

Figure 4: Surface elevation changes of West Chamshen Glacier. Elevation changes were extracted using central line left 2 (shown in Figure 1). All the ASTER DEMs (in legend) were subtracted with reference SRTM DEM.

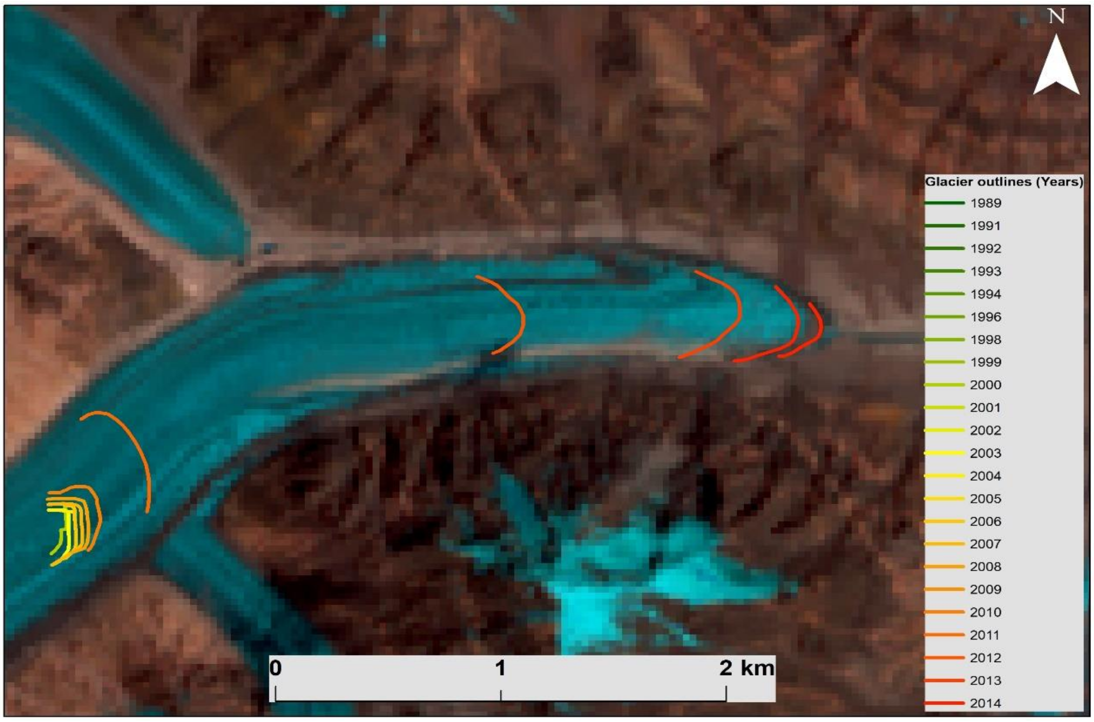

Figure 5: Fluctuation in the terminus position of West Chamshen Glacier from 1989 to 2014.

CONCLUSION

The present study estimated the duration of the active and termination phase of West Chamshen Glacier. The maximum surface displacement 1500 m y^{-1} observed during 2010-2011 and the glacier terminus advanced ~3.5 km during the surge (2007-2013). The transfer of ice mass between 2007 and 2014 resulted in a net loss of -422.1 x 10^6 m^3 and a net gain of +616.9 x 10^6 $m^3$of ice in the reservoir and receiving zones, respectively. The mass transfer from the upper reservoir zone of main trunk and tributaries to lower receiving zone suggests that the whole West Chamshen Glacier system experienced surge from 2007 to 2013.

Acknowledgements

ASTER data were provided at no cost by NASA/USGS under the flagship of the GLIMS project. We also thank the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/) for providing Landsat satellite image.

REFERENCES

Bhambri, R., Bolch, T., Kawishwar, P., Dobhal, D.P., Srivastava, D. and Pratap, B., 2013. Heterogeneity in glacier response in the upper Shyok valley, northeast Karakoram. The Cryosphere, 7(5), pp.1385-1398.

Bhambri, R., Hewitt, K., Kawishwar, P., Kumar, A., Verma, A., Snehmani, Tiwari, S., Misra, A., 2019. Ice-dams, outburst floods, and movement heterogeneity of glaciers, Karakoram. Global and Planetary Change 180, pp. 100–116.

Bhambri, R., Hewitt, K., Kawishwar, P., Pratap, B., 2017. Surge-type and surge-modified glaciers in the Karakoram. Scientific Reports 7, 1–53. doi:10.1038/s41598-017-15473-8

Bhambri, R., Watson, C.S., Hewitt, K., Haritashya, U.K., Kargel, J.S., Pratap Shahi, A., Chand, P., Kumar, A., Verma, A., Govil, H., 2020. The hazardous 2017–2019 surge and river damming by Shispare Glacier, Karakoram. Scientific Reports 10, pp. 1–14.

Bolch, T., Kulkarni, A., Kääb, A., Huggel, C., Paul, F., Cogley, J.G., Frey, H., Kargel, J.S., Fujita, K., Scheel, M. and Bajracharya, S., 2012. The state and fate of Himalayan glaciers. Science, 336(6079), pp.310-314.

Donghui, S., Liu, S., Ding, Y., Guo, W., Xu, B., Xu, J., Jiang, Z., 2016. Characterizing the May 2015 Karayaylak Glacier surge in the eastern Pamir Plateau using remote sensing. Journal of Glaciology 62, pp. 944–953.

Hall, D.K., Bayr, K.J., Schöner, W., Bindschadler, R.A., Chien, J.Y.L., 2003. Consideration of the errors inherent in mapping historical glacier positions in Austria from the ground and space (1893-2001). Remote Sensing of Environment 86, pp. 566–577.

Hewitt, K. and Liu, J., 2010. Ice-dammed lakes and outburst floods, Karakoram Himalaya: historical perspectives on emerging threats. Physical geography, 31(6), pp.528-551.

Hewitt, K., 1982. Natural dams and outburst floods of the Karakoram Himalaya. IAHS, 138, pp.259-269.

Hewitt, K., 2011. Glaciers of the Karakoram Himalaya, Encyclopedia of Earth Sciences Series.

Jiskoot, H., 2011. Glacier surging. In Encyclopedia of Snow, Ice and Glaciers. Springer, pp. 415–428.

Mason, K., 1930. The glaciers of the Karakoram and neighborhood. Rec. Geol. Surv. India 63 (2), pp.214–278.

Meier, M.F. and Post, A., 1969. What are glacier surges?. Canadian Journal of Earth Sciences, 6(4), pp.807-817.

Mukherjee, K., Bolch, T., Goerlich, F., Kutuzov, S., Osmonov, A., Pieczonka, T., Shesterova, I., 2017. Surge-Type Glaciers in the Tien Shan (Central Asia). Arctic, Antarctic, and Alpine Research 49, pp. 147–171.

Nuth, C., Kääb, 2011. Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change. Cryosphere 5, pp. 271–290.

Paul, F., Strozzi, T., Schellenberger, T., Kääb, A., 2017. The 2015 surge of Hispar glacier in the karakoram. Remote Sensing 9, pp. 11–14.

Pitte, P., Berthier, E., Masiokas, M.H., Cabot, V., Ruiz, L., Ferri Hidalgo, L., Gargantini, H., Zalazar, L., 2016. Geometric evolution of the Horcones Inferior Glacier (Mount Aconcagua, Central Andes) during the 2002-2006 surge. Journal of Geophysical Research F: Earth Surface 121, 111–127. doi:10.1002/2015JF003522

Quincey, D.J., Braun, M., Glasser, N.F., Bishop, M.P., Hewitt, K. and Luckman, A., 2011. Karakoram glacier surge dynamics. Geophysical Research Letters, 38(18).

Quincey, D.J., Luckman, A., 2014. Brief communication: On the magnitude and frequency of Khurdopin glacier surge events. Cryosphere 8, pp. 571–574.

Raina, V. K. and Srivastava, D., 2008. Glacier atlas of India. Bangalore: Geological Society of India, pp. 316.

Rashid, I., Abdullah, T., Glasser, N.F., Naz, H., Romshoo, S.A., 2018. Surge of Hispar Glacier, Pakistan, between 2013 and 2017 detected from remote sensing observations. Geomorphology 303, pp. 410–416.

RGI Consortium, 2017. Randolph Glacier Inventory–A Dataset of Global Glacier Outlines: Version 6.0: Technical Report, Global Land Ice Measurements from Space, Boulder, Colorado, USA. Digital Media.

Round, V., Leinss, S., Huss, M., Haemmig, C., Hajnsek, I., 2017. Surge dynamics and lake outbursts of Kyagar Glacier, Karakoram. Cryosphere 11, pp. 723–739.

Singh, R.M., Govil, H., Shahi, A.P. and Bhambri, R., 2020. Characterizing the glacier surge dynamics in Yarkand basin, Karakoram using remote sensing. Quaternary International.

Steiner, J.F., Kraaijenbrink, P.D.A., Jiduc, S.G., Immerzeel, W.W., 2017. Brief Communication: The Khurdopin glacier surge revisited extreme flow velocities and formation of a dammed lake in 2017. The Cryosphere Discussions 1999, pp. 1–7.

Thayyen, R.J. and Gergan, J.T., 2010. Role of glaciers in watershed hydrology: a preliminary study of a" Himalayan catchment". The Cryosphere, 4(1), pp.115.

Yao, X., Iqbal, J., Li, L. jing, Zhou, Z. kai, 2019. Characteristics of mountain glacier surge hazard: learning from a surge event in NE Pamir, China. Journal of Mountain Science 16, pp. 1515–1533.