

Long-term Monitoring of Surging Glaciers in Upper Shyok Valley, Karakoram Range, India: A Case Study of Rimo and Kumdan Groups of Glaciers

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Abstract: Glaciers in the Himalaya are generally showing a recessional pattern since the little ice age. In contrast to this, some glaciers in the Karakoram are either advancing or stagnant. Such behaviours of glaciers in the region have been termed as “Karakoram Anomaly” (Hewitt Kenneth, 2005; Raina, 2008; Kumar et al., 2015). In the present study, an attempt has been made to analyze the surging phenomena of four selected glaciers viz. Chong Kumdan, Kichik Kumdan, Aqtash and Rimo group of glaciers in the Shyok valley of Karakoram Himalaya; and also to analyze the inter-annual variations in their behaviour by using high temporal resolution remote sensing satellite images acquired from 1975 to 2013. These glaciers responded for surging phenomena differently in different time periods. The present study also fills the gaps of the earlier study of Bhambri et al. (2013) on the Rimo glacier, and demonstrates a different and unique pattern of snout movement. Findings of the present investigation depicts that the short-term variations in surging phenomena of the glaciers can be easily monitored using satellite images acquired from Indian Remote Sensing (IRS) Satellite and Landsat Satellite Sensor. Further, as it is well established that the surging phenomenon is a rapid process, we suggest that annual to biennial data should be used to monitor the movements and understanding the dynamics of surging process.

Keywords: Kumdan group of glaciers; Karakoram Himalaya; IRS; Rimo glacier.

Introduction

Himalaya ‘the water tower of Asia’ is the highest, youngest and one of the most fragile mountain ecosystems of the world. The Karakoram Himalayan

range covers one of the largest glacierized area (~40,800 km²) on the Earth outside the Polar region (Bolch et al., 2012). Any change in the global climate has affected the entire earth with more dramatic effects on the high Himalayan glaciers. Glaciers in Karakoram

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Himalayan range are significantly affected by two major weather systems viz. mid latitude westerlies and Indian Summer Monsoon (ISM) that have significant spatial variability in terms of the amount of precipitation. The complex climatic diversity results in a contrasting pattern of glacier change throughout the Karakorma Himalayan range (Fujita and Nuimura, 2011; Scherler et al., 2011; Kamp, 2011; Bolch et al., 2012; Kääb et al., 2012; Gardelle et al., 2013).

During last decade, several studies have reported less shrinkage of glaciers in the northwestern parts of Himalaya than the eastern parts (Bhambri and Bolch, 2009; Bolch et al., 2012; Kääb et al., 2012). However, some of the glaciers in the western and central Karakoram region have shown a long-term irregular behaviour with frequent advance and possibly slight mass gain since 2000 (Bhambari et al., 2013; Hewitt, 2011; Copland et al., 2011; Bolch et al., 2012; Gardelle et al., 2012, 2013; Kääb et al., 2012; Minora et al., 2013). Raina and Srivastava (2008) have reported individual glacier advance/surge in the Shyok valley, eastern Karakoram during the last decade. Sharp (1988) suggested that “the glacier surge is a cyclic phenomena that is not directly triggered or influenced by the outer events, but instead are caused by repetitive variations that occur at the bed of the glacier”. Barrand and Murray (2006) found that “the surge-type of glaciers experience cyclic flow instabilities characterized by alternating periods of slow and fast flow and the significance of glacier perimeter on surging may be explained by an increased availability of avalanche-fed snow and debris material which may act as a mass balance proxy”.

Out of 150 glaciers in Karakoram region, 19 glaciers have been identified as surging glaciers. Barrand and Murry (2006) and Copland et al. (2011) have reported an increase in glacier surging after 1990 in the western and central Karakoram regions. However, few studies have reported the surging phenomenon of individual glaciers such as Rimo, Chong Kumdan, Kichik Kumdan and Aqtash glaciers in the eastern Karakoram region (Raina and Srivastva, 2008; Tangri et al., 2013). Due to global climate change, most of the glaciers including the Himalayan glaciers are retreating; however, a few glaciers in the Karakoram are either static or advancing. However, some glaciers in the Shyok Valley (Karakoram Himalaya) are also surging ahead. Glacier advancing and retreat are normal climate driven behaviours and the rates of advancing/retreat are normally 1 to 40 metre per year, while, surging is an abnormal advancing or retreating characterized by rapid movement i.e. 200 to more than 2000 metres in a year (Raina and Srivastava,

2008). These glaciers are showing a prominent surging trend, although the retreating/melting behaviour cannot be neglected.

The present study investigates snout positions of Kumdan group of glaciers namely Chong Kumdan, Kichik Kumdan, Aqtash glacier and Rimo glaciers and their surging patterns with the help of SoI toposheets and optical satellite data. These four glaciers (Rimo, Chong Kumdan, Kichik Kumdan and Aqtash) in east Karakoram cover an area of ~65% of the total surge type glaciers in Karakoram Himalaya (Bhambri et al., 2013) and, hence, need to be investigated extensively. Although, Bhambri et al. (2013) have studied the heterogeneity in the behaviour of glaciers from 1973 to 2011 in this region. The present study is an attempt to fill temporal data gap for Rimo glacier from 1989 to 1999 and to update the earlier work of Bhambri et al. (2013). We have tried to use all the available annual to biennial data sets to understand the behaviour of the glaciers under investigation.

Study Area

The study area lies between Siachen glacier in the west, feeding Nubra river and Aksai Chin area in the east (Figure 1). The four glaciers under investigation are located on the right bank of Shyok river that is one of the major tributaries of the Indus river. The Chong Kumdan watershed covers an area of 172 km² out of which ~105 km² is glacierized (Raina and Srivastava, 2008). The Chong Kumdan is a south east trending glacier having a length of 26 km with an average width of 2.5 km. This glacier has three prominent limbs i.e. Northern, Central and Southern and originates from a compound basin cirque glacier. It has three main melt water streams that flow in an easterly direction and ends in the sandy bed of the Shyok river. Towards the front, width of the glacier varies from 1.2 to 3 km while at the source (head wall) it is less than 1 km. The glacier, throughout its length, is characterised by the presence of huge ice pinnacles (Figure 1).

The glacier has got its name from Turkish word Chong (Large) and Kumdan (Black kiln) probably because of the dark colour of glacier ice. ‘Chong Kumdan’ also means big obstruction and the name has probably been given because the glacier forms a huge dam forming glacier lake blocking the Shyok river during the episodes of surging and a huge reservoirs of water have been reported due to this blocking of the Shyok river in the past (Raina and Srivastva, 2008).

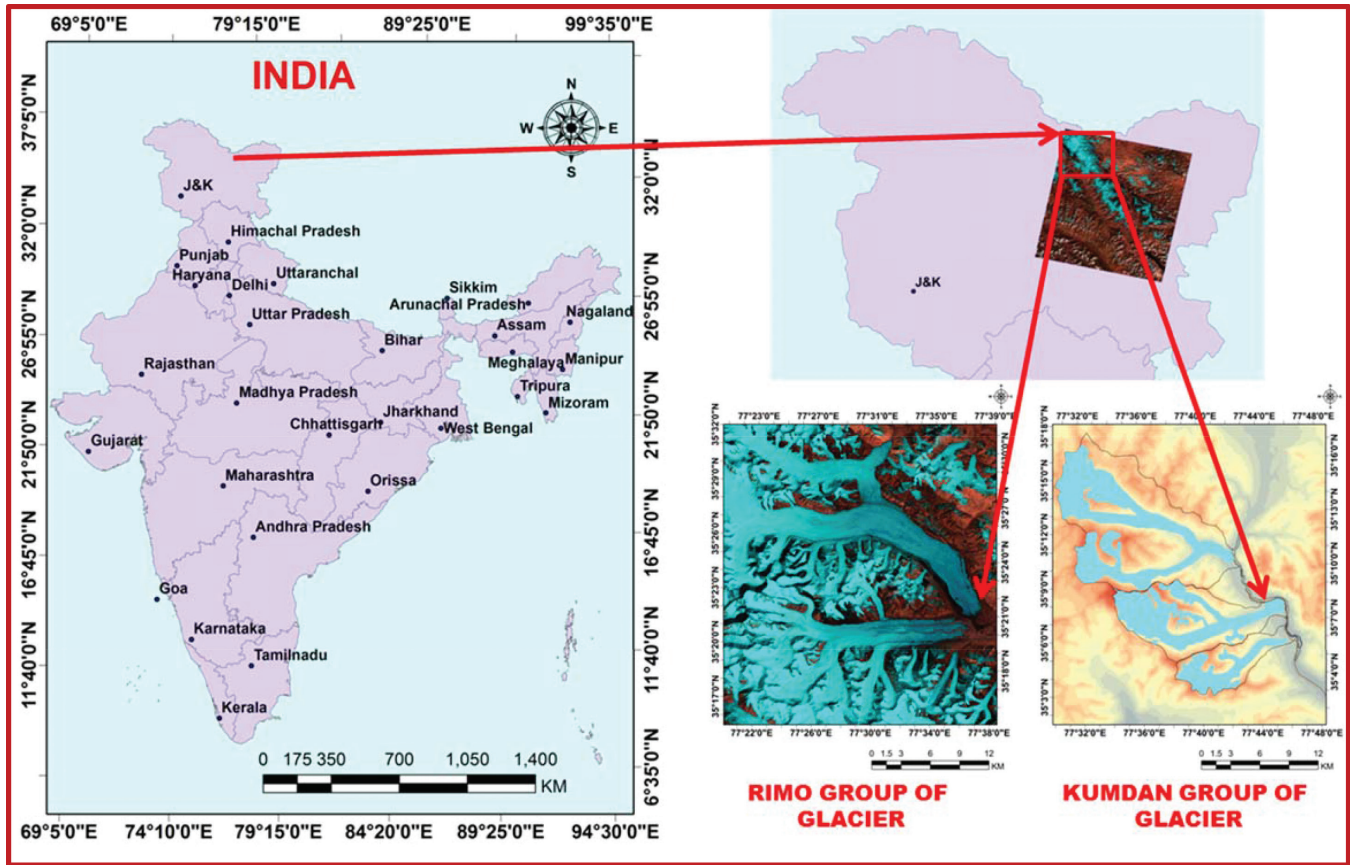


Figure 1: Location of Rimo group and Kumdan group of glaciers.

The second glacier under investigation is Kichik Kumdan glacier covering an area of about 46 km². This is an east trending ~18 km long glacier with a width of ~1.5 km. This glacier is characterized by two limbs i.e. northern and southern limb. The name of the glacier originated from Turkish word 'Kichik' meaning small and 'Kumdan' meaning Kiln. 'Kichik Kumdan' also denotes small obstructions because of the fact that after an ice surge, a lake has been formed upstream of the obstruction.

The Aqtash glacier occupies an area of 20 km² and is east facing. This glacier is 12 km long and less than 1 km wide. Aqtash means white and takes its name from the exposure of marble close to its snout along the western bank. The Rimo group of glaciers consists of three major glaciers that are referred as north, central and southern limbs. Besides this, these limbs are having their own tributaries that actually contribute to the main glacier system. The southern limb of the Rimo glacier demonstrates folding in medial moraines or undulating topography which is a characteristic of surging glaciers (Tangri et al., 2013).

Data Used

Recent changes in the configuration of Glacier frontal positions of Kumdan groups of glacier have been traced from Indian Remote Sensing (IRS) series of satellite images of the years 1990, 1994-1997, 2000, 2003, 2005, 2009 and Landsat satellite data acquired during 2011 to 2013. The details of images used have been provided in Tables 1 and 2. A base map has been prepared from the Survey of India (SoI) topographical sheets (52E/12 & 16) surveyed in the year 1975 on 1:50,000 scale. Although Bhambri et al. (2013) and our present study share almost the same time period, however, we have used higher resolution data sets and the frequency of the data has been increased, keeping in view the fact that surging is a very fast phenomenon and lasts for a limited time period. Therefore, our study brackets more precisely the dynamics in the glacier changes in Kumdan group of glaciers (Tables 1.1 and 1.2).

Table 1: Satellite data used**Table 1.1: Chong Kumdan, Kichik Kumdan and Aqtash glacier**

<i>S.No.</i>	<i>Satellite</i>	<i>Sensor</i>	<i>Special resolution</i>	<i>FCC band composition</i>	<i>Year</i>
1	52E/12 52E/16	Topographical Sheets	NA	NA	1975
2	IRS 1A	LISS IIA	36.25	3,2,1	1990
3	IRS P6	LISS III	24	3,2,1	1997
4	IRS P6	LISS III	24	3,2,1	2000
5	IRS 1C	LISS III	24	3,2,1	2005
6	IRS P6	LISS III	24	3,2,1	2006
7	IRS P6	LISS III	24	3,2,1	2007
8	IRS P6	LISS III	24	3,2,1	2008
9	Landsat-5	MSS-TM	30	5,4,3	2011
10	Landsat-8	OLI	30	6,5,4	2013

Table 1.2: Rimo glacier

<i>S.No.</i>	<i>Satellite</i>	<i>Sensor</i>	<i>Special resolution</i>	<i>FCC band composition</i>	<i>Year</i>
1	IRS 1A	LISS IIA	36.25	3,2,1	1990
2	IRS 1B	LISS IIA & IIB	36.25	3,2,1	1992
3	IRS 1B	LISS IIA & IIB	36.25	3,2,1	1994
4	Landsat-5	MSS-TM	30	5,4,3	1995
5	IRS 1C	LISS III	24	3,2,1	1997
6	IRS P6	LISS III	24	3,2,1	1999
7	IRS P6	LISS III	24	3,2,1	2000
8	IRS P6	LISS III	24	3,2,1	2001
9	IRS P6	LISS III	24	3,2,1	2003
10	IRS P6	LISS III	24	3,2,1	2004
11	IRS P6	LISS III	24	3,2,1	2005
12	IRS P6	LISS III	24	3,2,1	2006
13	IRS P6	LISS III	24	3,2,1	2007
14	IRS P6	LISS III	24	3,2,1	2008
15	IRS P6	LISS III	24	3,2,1	2009
16	Landsat-5	MSS-TM	30	5,4,3	2011
17	Landsat-8	OLI	30	6,5,4	2013

Methodology

In case of Rimo glacier, IRSP6 Satellite image of LISS-III (Linear Imaging Self Scanning Sensor) for the year 2009 has been used as a base map. For rest of the glaciers, the SoI topographical maps/sheets of 1975 have been used as the base map. Furthermore, these two base maps have been used to rectify the respective multi-sensor and multi-date remote sensing satellite images of IRS and Landsat Satellites covering

the studied glaciers. The co-registration error has been computed using equation (1) (Hall et al., 2003). This formula is used by different authors for computing resolution error (Bhambari et al., 2012; Ye et al., 2006).

$$e = \sqrt{(x_1)^2 + (x_2)^2} + E_{reg} \quad (1)$$

where x_1 is resolution of image 1, x_2 is the resolution of image 2 and E_{reg} is the registration error. The uncertainty involved with the length computed in the present study

was found to be $\pm$ average 35.96 m. Visual interpretation of False Colour Composite (FCC) image has been done to identify the glaciers of the study region. Length of the glaciers has been quantified by drawing lines along the central flow of the glacier tongue from head to the terminus of the glacier and length of the line has been considered as the glacier length.

Results

The present study has been carried out to investigate the behaviour of four identified and predictable surging glaciers in the upper Shyok valley of Karakoram Himalaya. The study demonstrates that these glaciers (surging) have a short-term variability in their movement patterns. A clear manifestation of these changes can be seen at the frontal part of terminus or snout and reported to be most prominent below the equilibrium line altitude (ELA). The present investigation reveals that between years 1962 and 1990, different limbs of Rimo glacier individually showed variable behaviours. The central limb of the glacier showed retreating pattern (~ 38 m/year) whereas the southern limb recorded an advance of ~ 129 m during the same period. Chong Kumdan, Kichik Kumdan and Aqtash glaciers also showed a variable pattern in their movements during 1975 to 1990 (Tables 1-5). All the limbs of the Chong Kumdan glacier were merged together forming a single glacier snout in 1975. However, between 1975 and 1990, the southern limb of Chong Kumdan glacier demonstrated a retreat of ~ 480 m, while the northern and central limbs got defragmented and got separated by a medial moraine running throughout the frontal part of these two glacier limbs as inferred from the satellite images (Figures 2 and 3). The Kichik Kumdan glacier retreated by ~ 950 m between 1975 and 1990. Whereas, the Aqtash glacier showed a contrasting behaviour between 1975 and 1990 and glacier has advanced by ~ 350 m.

For Rimo glacier, Bhambri et al. (2013) used Landsat TM satellite images of the years 1989 and 1999. However, in this study, we have used IRS satellite images of LISS-II and LISS-III sensor for the years 1990, 1992, 1994, 1995, 1996, 1997 and 1999. The main objective of this temporally high frequency data is to see the yearly changes in movement of Rimo glacier and try to fill the data gaps (Table 1.2).

The central and southern limbs of Rimo glacier did not show similar pattern of movement (Figure 2). Between 1990 and 1992, the central limb has advanced by ~ 271 m, whereas, the southern limb receded by ~ 15 m. This was followed by an inverse pattern between

Table 2: Length change in frontal part of Rimo group of glaciers

<i>Year</i>	<i>Rimo central frontal part [snout] in m</i>	<i>Rimo southern frontal part [snout] in m</i>
1990-92	271.4 (± 24.63)	Static
1992-94	-104.13 (± 24.63)	Static
1994-95	377.57 (± 47.05)	155.13 (± 47.05)
1995-97	708.49 (± 16.97)	-230.4 (± 16.97)
1997-99	164.03 (± 33.94)	-48.37 (± 33.94)
1999-00	-65.31 (± 33.94)	Static
2000-01	Static	67.75 (± 33.94)
2001-03	Static	-68.02 (± 16.97)
2003-04	Static	Static
2004-05	-70.25 (± 33.94)	Static
2005-06	100.16 (± 33.94)	Static
2006-07	134.27 (± 33.94)	Static
2007-08	Static	-82.23 (± 33.94)
2008-09	Static	Static
2009-11	-73.25 (± 33.94)	Static
2011-13	Static	Static

Table 3: Area change in frontal part of Rimo group of glaciers

<i>Year</i>	<i>Rimo central frontal part [snout] area occupied/vacated (km²)</i>	<i>Rimo southern frontal part [snout] area occupied/vacated (km²)</i>
1990-92	-0.201 (± 0.00002)	0.210 (± 0.00002)
1992-94	-1.614 (± 0.00002)	0.119 (± 0.00002)
1994-95	1.101 (± 0.00005)	2.381 (± 0.00005)
1995-97	1.414 (± 0.00003)	-3.912 (± 0.00003)
1997-99	0.904 (± 0.00003)	-0.113 (± 0.00003)
1999-00	0.315 (± 0.00003)	0.146 (± 0.00003)
2000-01	1.521 (± 0.00003)	0.795 (± 0.00003)
2001-03	-0.324 (± 0.00003)	0.013 (± 0.00003)
2003-04	-0.811 (± 0.00003)	0.594 (± 0.00003)
2004-05	-0.724 (± 0.00003)	-2.416 (± 0.00003)
2005-06	-1.642 (± 0.00003)	0.127 (± 0.00003)
2006-07	1.780 (± 0.00003)	0.105 (± 0.00003)
2007-08	0.421 (± 0.00003)	0.311 (± 0.00003)
2008-09	-1.312 (± 0.00003)	-1.388 (± 0.00003)
2009-11	-1.512 (± 0.00001)	-1.916 (± 0.00001)
2011-13	-1.204 (± 0.00002)	-0.281 (± 0.00002)

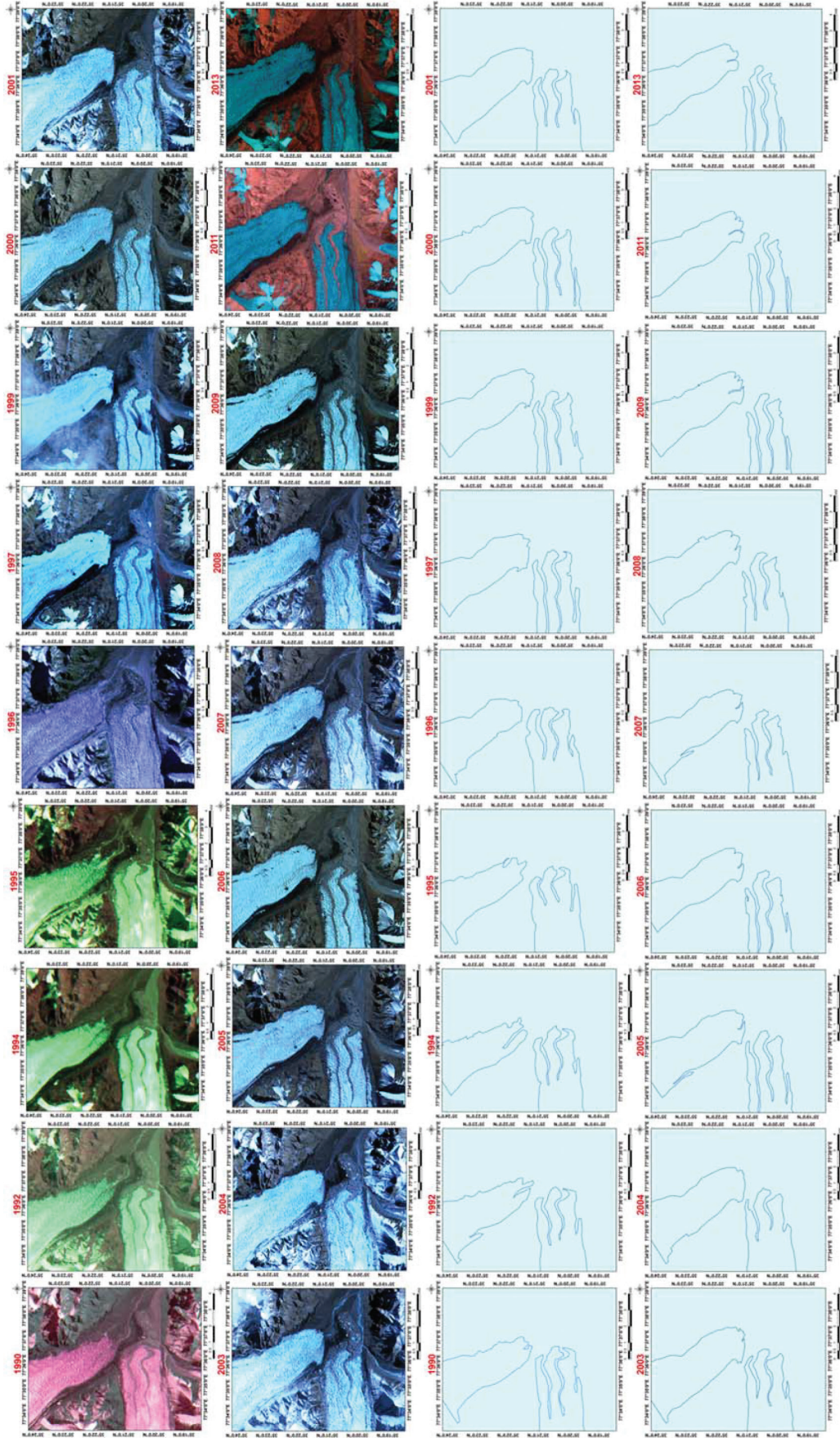


Figure 2: Satellite data and image interpretation of Rimo group of glaciers.

1992 and 1994 when the central limb receded by ~104 m and the southern limb showed an advance of ~12 m. This behaviour of variable and contrasting movements suggest a complex interplay of governing factors in a similar catchment. During 1994 to 1999, the magnitude of the changes showed a significant increase. Thereafter, the glacier showed a very feeble retreating pattern or static except for the years 2004 to 2006 when the glacier again showed an advance of ~100 m during 2005-06, and almost 134 m during 2006-07 along the central limb (Table 2).

Southern limb of Chong Kumdan glacier blocked the Shyok river during its surging phase. Satellite image of Landsat 8 Sensor indicates a significant change in the frontal part of the southern limb (Table 4). This particular limb advanced by ~530 m during 2005-06, receded by ~420 m during 2006-07 and again showed an advance of ~570 m during 2007-08. However in case of northern limb, the glacier experienced an overall advancing trend since 2000, while, an advance of ~580, ~850 and ~480 m has been recorded during 2005-06, 2006-07 and 2007-08 respectively (Figure 3).

The Kichik Kumdan glacier showed variable trends (Table 4). However, between 1997 and 2005, this glacier has advanced (Figure 4).

Prominent changes in the Aqtash glacier started after 2005. During 2005-2006, the glacier retreated by ~100 m and since then, it showed an advancing trend at variable rates. This glacier demonstrated an advance of ~260, ~310 and ~172 m during 2006-07, 2007-08 and 2008-2011 respectively. The satellite image of 2011 showed that the glacier crossed the Shyok river between 2008 and 2011. It is also evident that the river cut down the ice and flowed near to the glacier front in the year 2013 (Figure 5).

Discussions

Although, the abnormal pattern of movement in surging glaciers is not fully understood, however, during the last decade, studies have been carried out to identify the glaciers exhibiting surging patterns in the Himalaya (Raina, 2008). A prominent group of glaciers in the upper Shyok valley of Ladakh has been studied and some unique frontal movements with surging characteristics have been investigated.

Our study revealed that the Rimo glacier exhibited a varying and unique pattern of the glacier frontal movement. The two limbs of Rimo glacier demonstrated almost reverse surging trends. Moreover, the rate of movement in the central limb was very conspicuous

than the southern limb. Changes in the central limb were advancing during 1990-92, 1994-95 and 1996-97 while retreating during 1992-94 and 1995-96. Thereafter, the glacier demonstrated relatively slow rate of advance and retreat till 2004. Between 2005 and 2007, the glacier again resumed the advancing trend and was retreating since 2007-2013. On the other hand, the southern limb of the glacier demonstrated a limited movement during the period under investigation. However, during 1994-95 an advance of ~155 m was observed whereas, the southern limb showed a retreat of ~213 m during 1996-97. According to Bhambri et al. (2013), central and southern branch of the Rimo glacier were merging together in 1930 and separated in 1974. The central limb receded during 1930-1989. However, they have also reported an advance between 1989 and 1999 while the glacier retreated again until 2011. As they have mentioned the non-availability of the satellite images between 1989 and 1998, it is difficult to determine the advancing trend of Rimo Glacier. In this study, an attempt has been made to fill gaps in data. The gap years have proved to be important archives to understand the short-term variability in the glacier movement patterns (Retreating or Advancing).

The Chong Kumdan glacier has three prominent limbs, each limb is showing a variable pattern of movement. The Chong Kumdan glacier has blocked the Shyok river in the past and hence, it is very important to understand the trend of the movements of this glacier. The northern limb of this glacier demonstrated a retreat during the 1997-2000 and then, started advancing as well as surging ahead continuously upto 2013. It has further been estimated that the surging rate has been continuously increasing from year 2000 to 2007 (Table 4). The glacier has advanced by ~142 m/year between 2000 and 2005. The rate of advancing increased to ~580 m/year between 2005-2006 and during 2006-2007 the glacier showed a further increase in advance and reached to ~850 m/year. The Central limb also advanced during 2000 and 2008 and started retreating after 2008. The southern limb of Chong Kumdan glacier has a history of fluctuating behaviour, but this limb showed a retreating pattern. This pattern is also corroborated with Bhambri et al. (2013), as they have also reported a similar surging trend after 2002. However, the coalesce of these two limbs has already taken place before 2004. The Kichik Kumdan glacier also demonstrated an advancing trend during 1997-2000.

The Aqtash glacier showed a significant retreat during 2005-06 and henceforth has been advancing. The rate of advance showed a phenomenal decrease in 2011-13,

Table 4: Length change in frontal part of Kumdan group of glaciers

Year	Chong Kumdan Glacier				Kichik Kumdan Glacier				Aqtash Glacier	
	Northern limb		Central limb		Southern limb					
	Maximum length (m)	Rate of length (m /yr)	Maximum length (m)	Rate of length (m /yr)	Maximum length (m)	Rate of length (m /yr)	Maximum length (m)	Rate of length (m/yr)	Maximum length (m)	Rate of length (m/yr)
1975-1990	Both Limbs are merged with Southern Limb in Topographical Sheets				-480	-32	-950	-63.3	350	23.3
1990-1997	140 (±6.2)	20(±6.2)	-70 (±6.2)	-10 (±6.2)	310 (±6.2)	44.29 (±6.2)	-310 (±6.2)	-44.3 (±6.2)	100(±6.2)	14.3(±6.2)
1997-2000	-130(±11.3)	-43.33(±11.3)	Static	Static	-500 (±11.3)	-166.67 (±11.3)	570 (±11.3)	190 (±11.3)	-60(±11.3)	-20(±11.3)
2000-2005	710(±6.8)	142(±6.8)	520(±6.8)	104(±6.8)	120(±6.8)	24(±6.8)	390(±6.8)	78(±6.8)	-170(±6.8)	-34(±6.8)
2005-2006	580(±6.8)	580(±6.8)	610(±6.8)	610(±6.8)	530(±6.8)	530(±6.8)	-200(±6.8)	-200(±6.8)	-100(±6.8)	-100(±6.8)
2006-2007	850(±6.8)	850(±6.8)	640(±6.8)	640(±6.8)	-420(±6.8)	-420(±6.8)	Static	Static	260(±6.8)	260(±6.8)
2007-2008	480(±6.8)	480(±6.8)	490(±6.8)	490(±6.8)	570(±6.8)	570(±6.8)	Static	Static	310(±6.8)	310(±6.8)
2008-2011	202(±12.8)	67.33(±12.8)	-312(±12.8)	-104(±12.8)	-549(±12.8)	-183(±12.8)	-110(±12.8)	-36.7(±12.8)	516(±12.8)	172(±12.8)
2011-2013	21(±14.1)	10.5(±14.1)	35(±14.1)	17.5(±14.1)	-80(±14.1)	-40(±14.1)	-85(±14.1)	-42.5(±14.1)	110(±14.1)	55(±14.1)

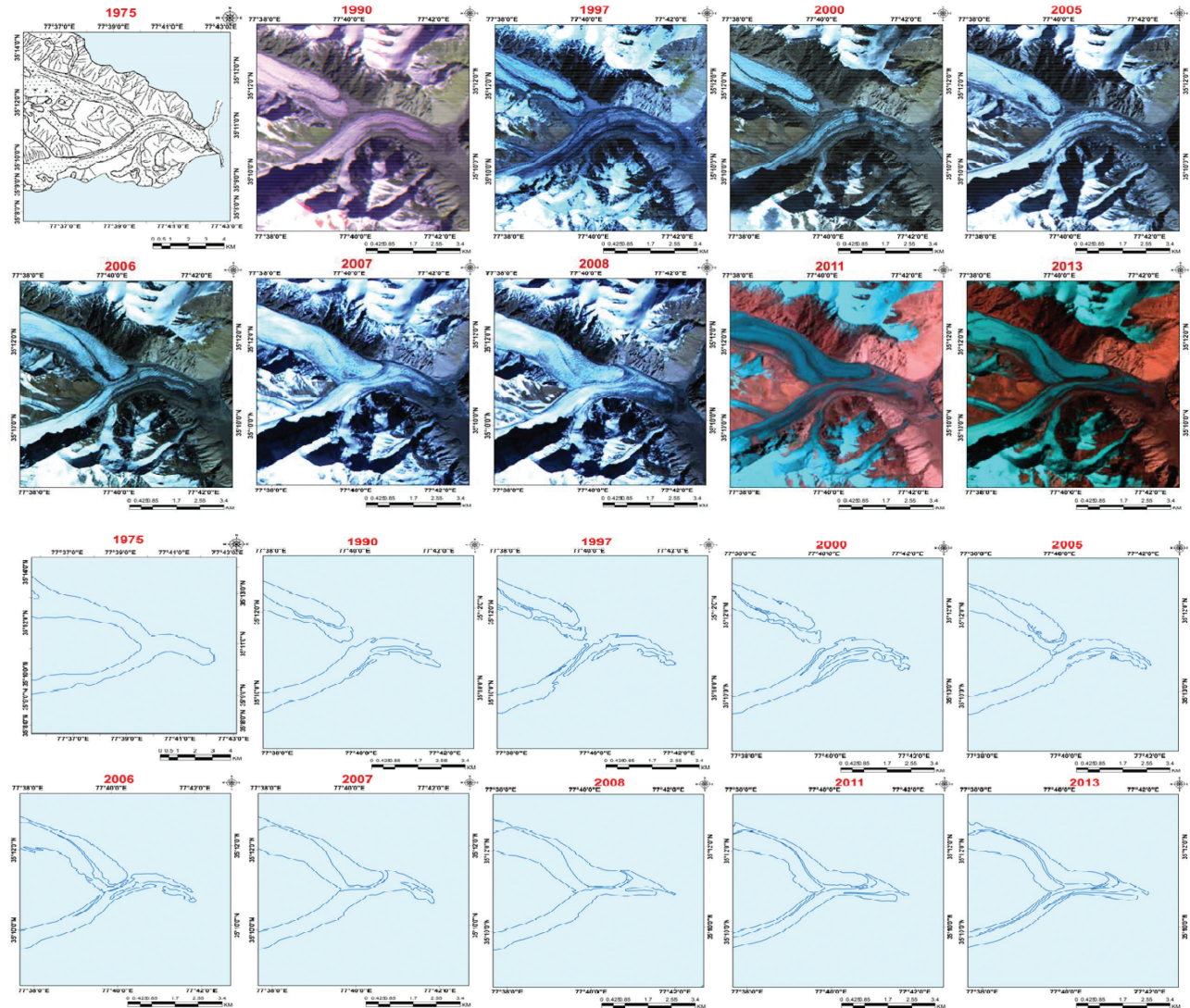


Figure 3: Satellite data and image interpretation of Chong Kumdan Glacier.

Table 5: Area change in frontal part of Kumdan group of glaciers

Year	Chong Kumdan Glacier			Kichik Kumdan Glacier	Aqtash Glacier
	Northern limb	Central limb	Southern limb	Area occupied/vacated (km ²)	Area occupied/vacated (km ²)
	Area occupied/vacated (km ²)	Area occupied/vacated (km ²)	Area occupied/vacated (km ²)		
1975-1990	All limbs merges together in topographical sheets			-2.541	0.791
1990-1997	-0.271(±0.00001)	-0.720(±0.00001)	-0.581(±0.00001)	-0.398(±0.00001)	0.855(±0.00001)
1997-2000	0.151(±0.00001)	0.151(±0.00001)	0.256(±0.00001)	3.910(±0.00001)	-0.324(±0.00001)
2000-2005	1.284(±0.00001)	0.780(±0.00001)	0.031(±0.00001)	-1.40(±0.00001)	-0.710(±0.00001)
2005-2006	0.228(±0.00001)	0.051(±0.00001)	-0.610(±0.00001)	-0.315(±0.00001)	0.510(±0.00001)
2006-2007	0.549(±0.00001)	0.811(±0.00001)	1.010(±0.00001)	-0.041(±0.00001)	-0.110(±0.00001)
2007-2008	-0.098(±0.00001)	0.049(±0.00001)	0.304(±0.00001)	0.059(±0.00001)	-0.712(±0.00001)
2008-2011	-0.498(±0.00001)	-0.005(±0.00001)	-1.701(±0.00001)	-0.675(±0.00001)	2.100(±0.00001)
2011-2013	-0.020(±0.00001)	-0.010(±0.00001)	-0.011(±0.00001)	0.041(±0.00001)	0.011(±0.00001)

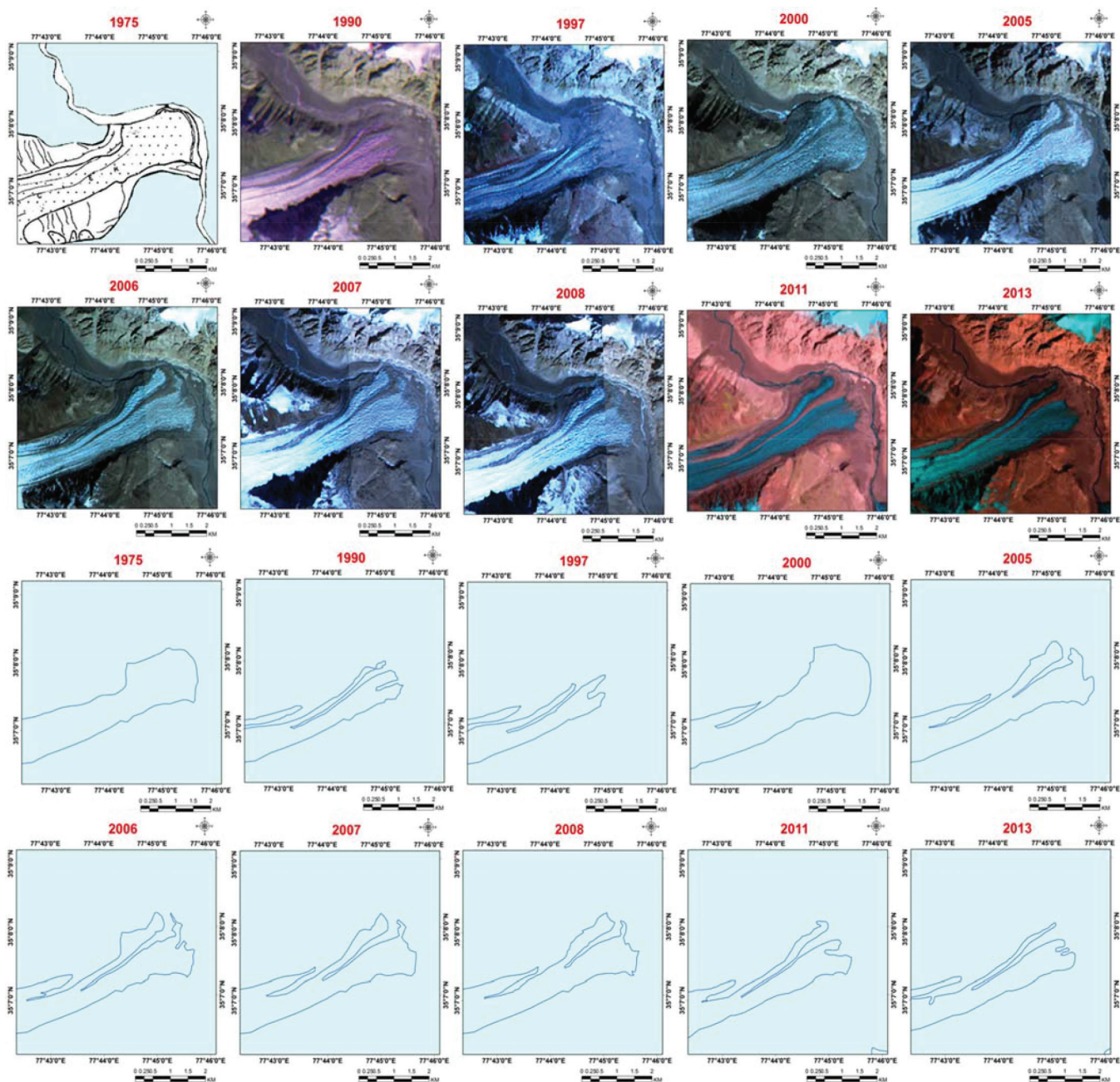


Figure 4: Satellite data and image interpretation of Kichik Kumdan Glacier.

as it has already touched the opposite valley wall of the Shyok river (Figure 5).

Conclusions

Present study has estimated movements of the surging glaciers in the upper Shyok valley, Ladakh and also filled gaps of earlier studies carried out in this region. Investigations reveal that in general Rimo glacier

exhibits the most prominent contrasting trend in the frontal movement of limbs. The Chong Kumdan glacier has shown an important phase of advance in all the limbs simultaneously. Whereas in general, a retreating phase has been seen in all the glacier under investigation using continuous data sets for temporal monitoring of the short-term fluctuations and also in the movement pattern of the surging glaciers. Long-term monitoring

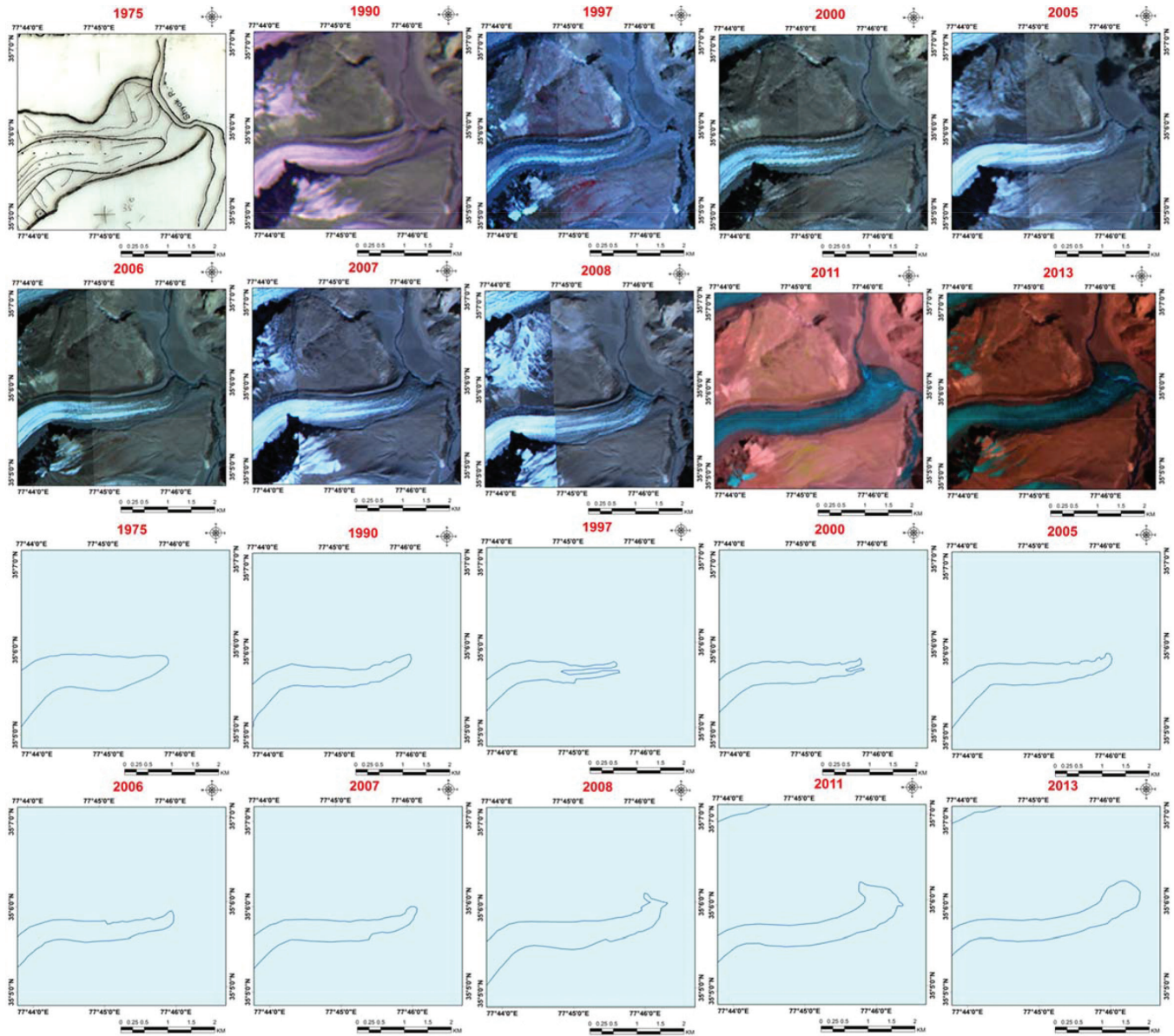


Figure 5: Satellite data and image interpretation of Aqtash Glacier.

of these surging glacier is required to understand the controlling factors and dynamics of surging and that will lead us to a meaningful outcome.

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