STUDYING THE OUTBURST OF THE MERZBACHER LAKE OF INYLCHEK GLACIER, KYRGYZSTAN WITH REMOTE SENSING AND FIELD DATA

A. Bormudoi[* a] *Dr. A. Shabunin*[b] *Dr. M. K .Hazarika*[a] *V. Zaginaev*[c] *Dr. L. Samarakoon*[a]

[a] *Geoinformatics Center, Asian Institute of Technology, Pathumthani, 12120, Thailand;*
Tel: + 66-2-5246148
E-mail: bormudoi@gmail.com
[b] *Central Asian Institute of Applied Geosciences, Timur F Rd.73/2, Bishkek 720027,Kyrgyz Republic;*
Tel: +996-312-555111
E-mail: a.shabunin@caiag.kg

[c] *The Ministry of Mineral Resources, Erohin Sergey, Bokonbaevo str.1, Bishkek, Kyrgyz Republic*
Tel: +996- 312- 621394
E-mail: zagivit@mail.ru

KEY WORDS: Glacier Lake, Flood

Abstract: The Merzbacher lakes in Kyrgyzstan are moraine glacier lakes situated between the North and South Inylchek Glacier. From time to time, water of the Merzbacher Lakes burst out with a flow up to 1000 m^3/second, causing severe floods in the Inylchek River. This high water leads to the destruction of bridges and other infrastructures on the riverbank in the territory of Kyrgyzstan and often threatens the hydraulic infrastructures in the Aksu River in the Chinese territory. As the area is located in the high mountain zones and in a very harsh climate, remote sensing methods coupled with field data can prove to be a great tool for monitoring and investigating the lake outbursts. This paper tried to find a relationship between the temperatures of the lake surface with the outburst events and a growth of the lakes since a few past decades. MODIS 8 days composite from year 2000 to 2011 were used to get the surface temperature of the lakes. It was found that the lake outbursts occur when there is a rise of temperature a little above 10 C and the frequency of outbursts are more if it is near to 15 C or more. It was found that the critical areas for the lower and upper lakes before an outburst were a little above 3.0km^2 whereas the critical water volumes were 0.06 km^3 and 0.07 km^3 respectively. Further investigations revealed that while the southern glacier tongue has been quite stable, the northern tongue retreated about 1.18 kms from 1975 to 1990.

1. INTRODUCTION

Glacier Lake Outburst Flood (GLOF)s are sudden release of water from the lakes formed in the glaciers that can threaten a community living downstream with little warning to prepare. In the heart of the mountain ranges of Tien Shan, towards the Khan Tengri (6995m), the Inylchek Glaciers are situated in the country of Kyrgyzstan. They are the North and the South Inylchek. In the North Inylchek Glacier, the lakes of Merzbacher are formed. They are the Lower and the Upper Merzbacher Lakes. German explorer, cartographer and alpinist Gottfried Merzbacher (1843-1926) accidentally discovered the original lake in an expedition in 1903. It is highly likely that the Upper Lake was formed with the further retreat of the North Inylchek Glacier in the middle of the 20 th century(Glazirin, 2010). From time to time, the Lower Lake has shown outbursts in a regular basis causing destruction of bridges and other infrastructures on the riverbank in the territory of Kyrgyzstan and the hydraulic infrastructures in the Aksu River in the Chinese territory. Flash floods have occurred 62 times from a period of 1932-2008 (Ping, et al., 2009). Though the cause of the sudden release of the water from the Lower Lake is still not understood fully, it is believed that the release of the lake water begins when the ice dam of the advancing South Inylchek Glacier buoys upwards. This makes a system of englacial channels in the damming glacier open and the lake gets a chance to discharge (Glazirin, 2010).

2. PROBLEM STATEMENT

It is observed that there has been an increase in the melting of the glaciers in almost all the high mountains of world. It is likely that the melting water of the glaciers will cause the overfilling of the glacial lakes and this will eventually increase the rate of outbursts from these lakes(Jansky, Sobr, & Engel, 2010). This has happened in the Tien Shan also. The glaciers of Tien Shan have reduced in area as a result of rapid melting due to the increase in the summer temperature (Narama, Kääb, Duishonakunov, & Abdrakhmatov, 2009). A Few forecast models are there for the Merzbacher Lake flood outburst and as the place is located in a terrain not easily reachable, limited ground data is available to build up a model. In this condition, remote sensing can prove to be an effective way to gather information in order for a forecast to be developed. An index IGLOF has been developed by (Xie, ShangGuan, Zhang, Ding, & Liu, 2012). It is found that when the IGLOF is more than 0.5 and the lake area is larger than 3km^2, the outburst will occur in the next 5-8 days. But there is still no model that can narrow down the day of outburst into a single day.

3. STUDY AREA

The study area is in the Tien Shan Mountains in Kyrgyzstan and is bordering China on the South and South East as shown in Figure 1. It is near the Khan Tengri (6995m) and Pobeda Peak (7439m) near to the Chinese border(Xie, et al., 2012). In this region the South Glacier is the biggest and covers a length of 65.3 km and 567.2 km^2 in area. The North Glacier is 41.1 km and 247.2 km^2 in length and area. The Figure 1 shows the location of the lakes. The lower lake is dammed by the South Glacier. There is the Merzbacher River connecting the Upper and the Lower lakes stretching a gap of about 3-4 Kms.

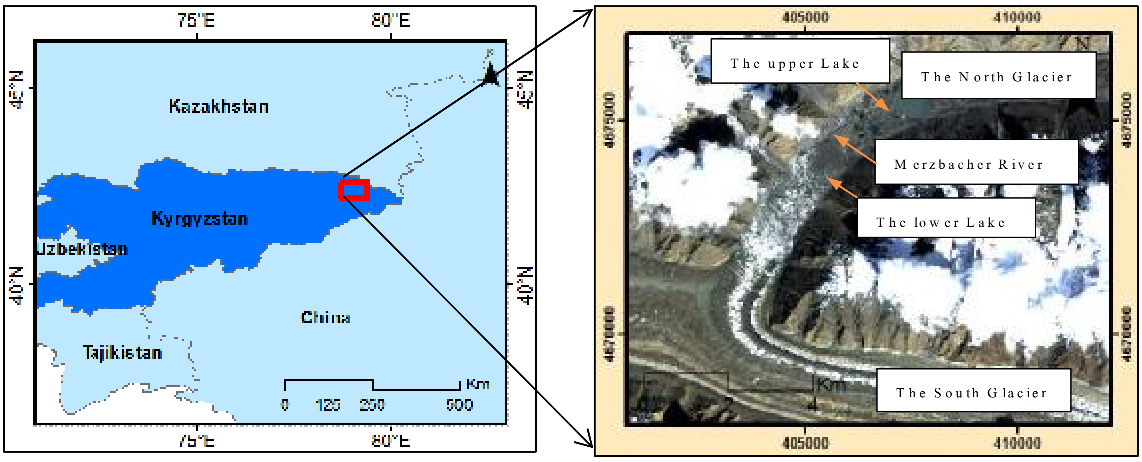


Figure 1: The study area showing Lake Merbacher

4. OBJECTIVES

The main objectives of the study were to-

- Find a relationship between the lake outburst and remotely sensed data (surface temperature of the lake from MODIS 8 day composite)
- Find the development/change of the lake area over the years

The secondary objectives were-

- Estimation of the volume of the lake
- Estimation of glacier movements

5. DATA USED

The data used in the study were remote sensing data coupled with the data received from the ground. The Moderate Resolution Imaging Spectroradiometer (MODIS) 8 day composite was used as the primary data in order to derive the temperature above the lake surface which was verified by the data from the field at Merzbacherl automatic meteorology station. Moderate resolution images of the Japanese satellite Advanced Land Observation Satellite (ALOS) were used in order to monitor the changes of the lake surface and the movement of the glacier. These images were used in conjunction with some Landsat and Aster images and aerial photographs of an early period. The satellite images of ALOS/PRISM were used to create a Digital Elevation

Model (DEM) of the lake bottom surface after an outburst event. This was done to model the volume of the lake critical to its outburst. Additional data of the dates of outbursts and GIS layers were used from sources as Central Asian Institute of Applied Geosciences (CAIAG) in Kyrgyzstan. A topographic map of 1981 from CAIAG has been used as the base map upon which the necessary geometric corrections were carried out for the analysis of the satellite images. A detail of the data is provided in the Table 1 showing the exact dates of acquisition and the spatial resolutions.

Table 1: List of aerial and satellite images used

Satellite/Sensor	Product	Date of Acquisition	Spatial Resolution/Scale
MODIS	MOD11A2.005	2000-2011 (8days composite)	1 km
Aerial photograph		1943 Aug 18	-
		1981 Jul 20	-
		1990 Jul 20	-
ASTER	3Visible+1NIR band	2002 Oct 05	15m
		2002 Jun 25	
		2003 Jun 25	
LANDSAT MSS	3Visible+1NIR band	1975 Aug 30	60m
		1976 Oct 16	
LANDSAT TM		1990 Sep 10	30m
LANDSAT ETM		2000 Sep13	
ALOS	AVNIR2	2006 Aug 23	10m
		2006 Oct 08	
		2007 Oct 11	
		2008 Jul 13	
		2009 Mar 29	
		2009 Oct 16	
		2010 July 02	
		2010 Oct 19	
		2011 Apr 21	
	PRISM	2006 Oct 08	2.5m
Topographic Map		1981	1: 100,000

6. METHODOLOGY

The methodology consisted of four parts. For the first objective of finding a relationship of the lake temperature with the outburst, a trend was established between the outburst events and the lake temperature. This was done by observing the dates of outbursts with the temperature over the lake surface obtained from MODIS. The ground data of the lake temperature obtained from the Merzbacher1 automatic meteorology station from a period 2009-2010 was used to verify the accuracy of the MODIS data. It was seen that for the available data, a good co-relation with the r-squared value of 0.79 was established between them. The outburst was observed for a period of almost one decade from 2000-2011 against the MODIS data. Here, the minimum temperature of the lake surface that was necessary for an outburst was found to be quite consistent.

For the second objective, satellite images and aerial photographs have been used to monitor the changes over the years on the lake surface itself. The base map used for the analysis was a topographic map of 1:100,000 scale obtained from CAIAG from the year 1981. All the aerial photographs and the optical satellite images were geo-coded using this base map. After that, atmospheric correction was done in ENVI software. The image was subset and the North Glacier was divided in the Upper and the Lower Lakes. In order to calculate the area of the water cover on the lake surface, Normalized Difference Vegetation Index (NDVI) was found out to be highly effective. For the delineation of the ice cover, supervised classification was adopted for all the multispectral images.

For an estimation of the lake volume, it was necessary to find a stereo pair image of the lake surface when the outburst occurred. It was obtained from the ALOS/PRISM image of 2006 Oct 08. A standard method using the ERDAS LPS software was used for this purpose where the height values for the selected GCPs were obtained from the topographic map of 1981. The purpose of the DEM generation was to calculate the volume of the lakes for different levels of water. For this, the truncated paraboloid equation was used. After processing the volume calculation, the area volume dependency curves for the lakes were generated. From the area volume dependency curves, it was possible to estimate a volume of the lake from the area calculated from the satellite images in different periods of time. For the last objective of estimation of the glacier movements, cloud free optical images were chosen and co-registered. The images used for this purpose were Landsat MSS 1975, Landsat TM 1990 and ALOS/AVNIR2 of 2006, 2008 and 2010, details of which are given in Table 1. To detect the movement of the glacier tongue, a total of five points were chosen from the image. The past knowledge of working with the glacier and the lakes being on board of the tongue, helped to find out these points in the images. The movement of the glacier tongue was determined from the movement of these points over the period of time. Finally the velocity of the glacier movement was calculated by dividing the distance travelled by the same features detected on the images by the period of time under consideration.

7. RESULTS

The comparison of the MODIS surface temperature and the date of outbursts of the lakes have been shown in a graphical form in Figure 2 below.

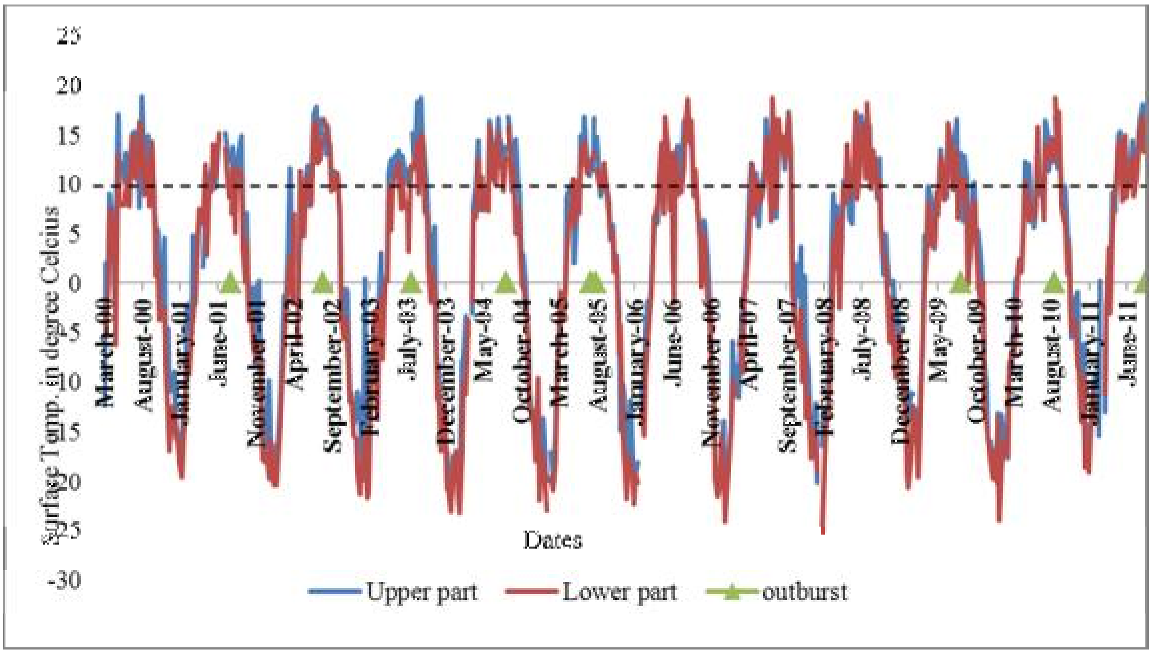


Figure 2: Surface temperature from MODIS 8day composite for both the lakes and the dates of outbursts

It is seen that the dates of outbursts occur more in the days when the surface temperature of the lake is towards the warmer side and it crosses the 10 C level. There have been records of outbursts happening twice in a same year particularly in the year 2005. On the other hand, the date of outburst in the figure is not shown for the years 2000, 2006, 2007and 2008 as those were not available in the original data. The Table 2 shows the area of the lake surfaces during the date of image acquisition starting from the period of 1943. The available dates of the lake outburst are obtained from various sources. It is seen that the minimum difference in terms of the day of acquisition of an image and the outburst that year is about one week in the year 1990 from the aerial image of Jul 29. It shows that the critical areas for both the lake prior to an outburst can be a little more than 3Km^2. ALOS/AVNIR2 images of the year 2006 was used to derive the DEM of the lake bottom surface. From this, an area-volume dependency curve has been generated as shown in Figure 3 and the critical lake volume prior to the outburst is calculated for the date of 1990 Jul 29. This is found out to be 0.06 Km^3 and 0.07 Km^3 respectively for the Upper and the Lower Lake. The Table 3 shows the water/ice ratio of the Upper and the Lower Lake during the image acquisition dates. It shows that the ratio increases prior to the outbursts but to find a definite number, images have to be analyzed close to the exact dates of outbursts which were not available in this study. Figure 4 shows the spatial distribution of the water and the floating ice in the lakes during the dates of image acquisition.

Table 2: The Areas of upper and lower lakes for different periods

Source	Date	Lake Area(km^2)		Date of Outburst in the corresponding year
		Upper	Lower	
Aerial Photo	1943 Aug 18	-	3.25	1943 Sep 22
	1981 Jul 20	2.43	-	1981 Jul 08, Aug 08
	1990 Jul 29	3.01	3.07	1990 Aug 05
Landsat MSS	1975 Aug 30	2.32	-	No records
	1976 Oct 16	2.29	-	No records
Landsat TM	1990 Sep 10	3.77	-	1990 Aug 05
Landsat ETM	2000 Sep 13	0.28	-	No records
ASTER	2002 Jul 08	0.35	2.24	2002 Aug 01-02
	2002 Oct 05	0.35	0.63	2002 Aug 01-02
	2003 Jun 25	0.34	1.91	2003 Jul 22-23

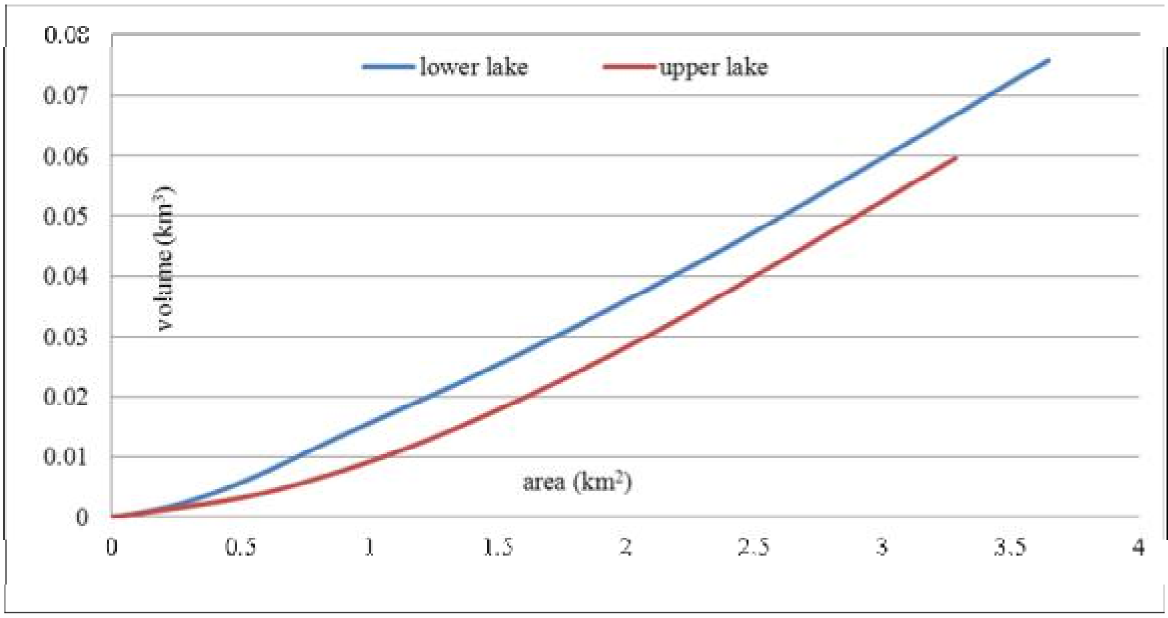
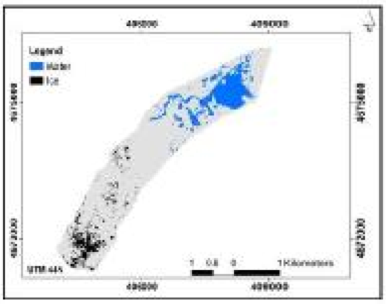


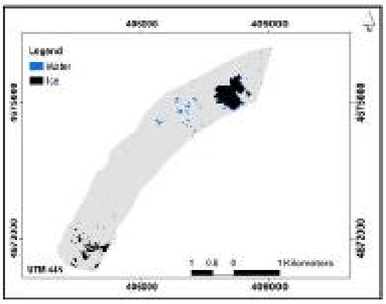
Figure 3: Area-Volume dependency curve

Table 3: Water Ice ratio for different dates

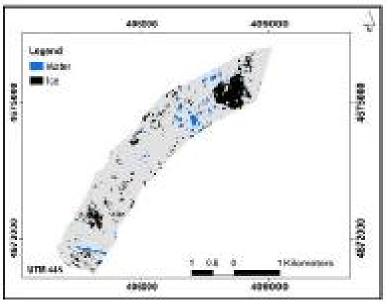
Date of image	Upper Lake Area(km^2)				Lower Lake Area(km^2)				Date of Outburst in corresponding year
AVNIR2	Water(W)	Ice(I)	Total	W/I	Water(W)	Ice(I)	Total	W/I	2006 Aug (Evidence from ALOS/PRISM)
2006 Aug 23	0.90	-	0.90		-	0.38	0.38	-	
2006 Oct 08	0.09	0.31	0.40	0.29	-	0.13	0.13	-	
2007 Oct 11	0.15	0.54	0.69	0.28	0.05	0.30	0.35	0.17	No records
2008 Jul 13	0.65	0.36	1.01	1.81	2.06	0.84	2.90	2.45	No records
2009 Mar 29	0.12	0.20	0.32	0.60	-	0.41	0.41	-	2009 Aug 06-09
2009 Oct 16	0.46	-	0.46	-	-	0.65	0.65	-	
2010 Jul 02	0.54	-	0.54	-	0.53	1.36	1.89	0.39	2010 Aug 16-18
2010 Oct 19	0.18	0.32	0.50	0.56	-	0.95	0.95	-	
2011 Apr 21	-	0.47	0.47	-	-	0.62	0.62	-	2011 Aug 16-18



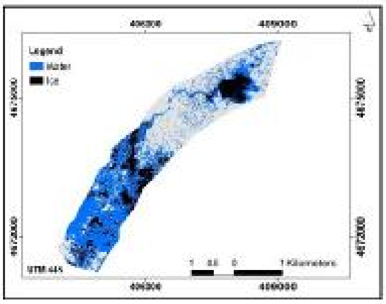
2006 Aug 23



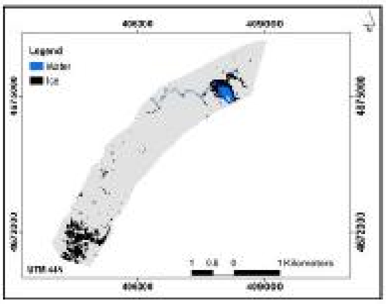
2006 Oct 08



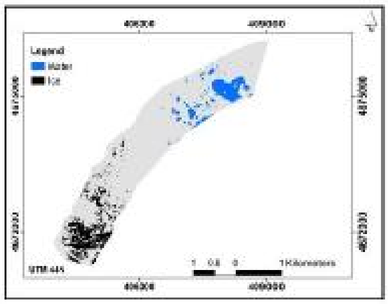
2007 Oct 11



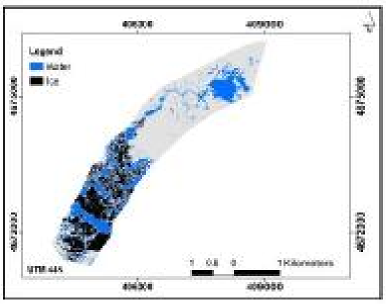
2008 Jul 13



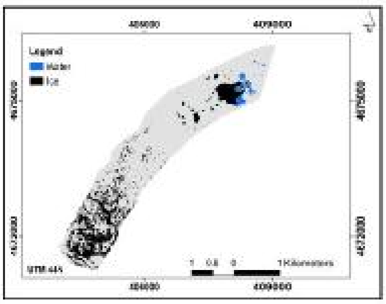
2009 Mar 29



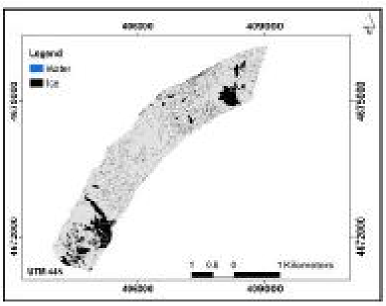
2009 Oct 16



2010 Jul 02



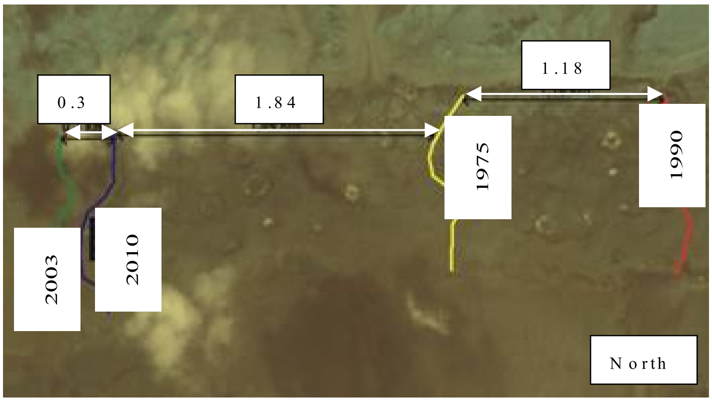
2010 Oct 19



2011 Apr 21

Figure 4: Water and ice cover in the upper and the lower lake area

It can be seen from Table 2 that in some years like 1981, there has been two outbursts taking place within the same year. In this case, the water accumulation is happening at a very fast rate between the outburst dates which indicates that the interglacial passage plugging and some other regeneration process is taking place which needs to be further investigated. One of the contributing factors in the process may be the air temperature opening the interglacial canals. Figure 5 shows the movement of the glacier tongue over a period of 1975 to 2010. From the Northern Inylchek Glacier tongue movements, we can recognize one situation. From 1975 to 1990, this tongue retreated about 1.18 km (about 80 m/y), and from 1990 to 2003, it advanced 3.32 km (about 250 m/y).From the same figure, it can be seen that the Southern Inylchek Glacier tongue is quite stable. The movement of this tongue from 1975 to 2010 is about 1 km. This can be explained that this tongue is strongly covered by the debris and the ice on the glacier edge is the dead ice. For detection of the Northern and southern Inylchek movement by the feature tracking method, ALOS/AVNIR2 images of dates 2006 Aug 23, 2008 Aug 28 and 2010 Aug 17 were used. A number of features were detected on both the glaciers, and the movement in different areas from 2006 to 2010 was found out. This helped to calculate the velocity of the glaciers at these points. Figure 6 show the movement of the glacier surface over a period of 2006-2010. It is interesting to see that the movement of the Southern Glacier is more towards the North than the Northern Glacier itself. From Figure 7, we can see that the highest velocity for period of 2006-2010 was in the lower part of the Southern Inylchek Glacier (about 0.31 m/d). Near the turn of the glacier, the velocity is decreased up to 0.28 m/d. After the glacier turned North, the velocity is very less (0.09 m/d).



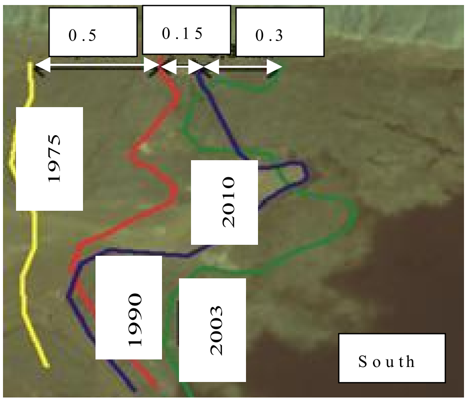


Figure 5: Movement of the glacier tongue in Km

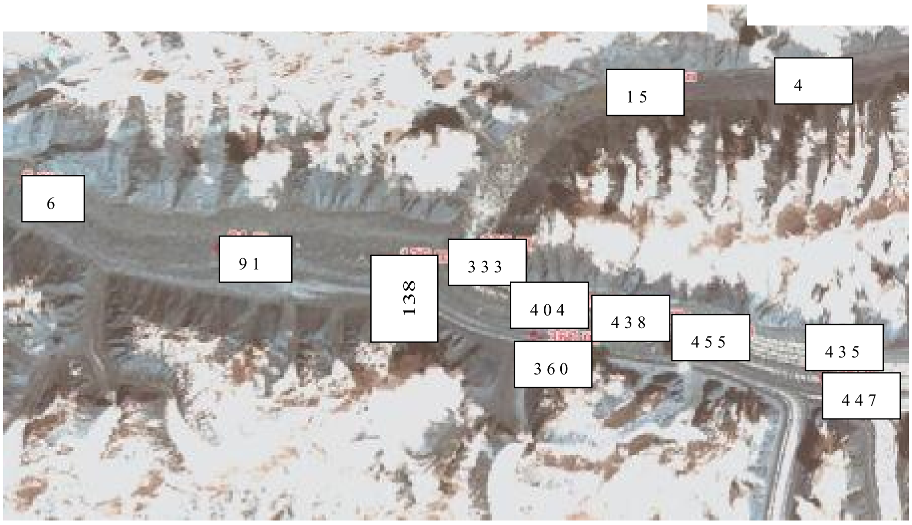


Figure 6: Glaciers movement (m), for the period 2006-2010

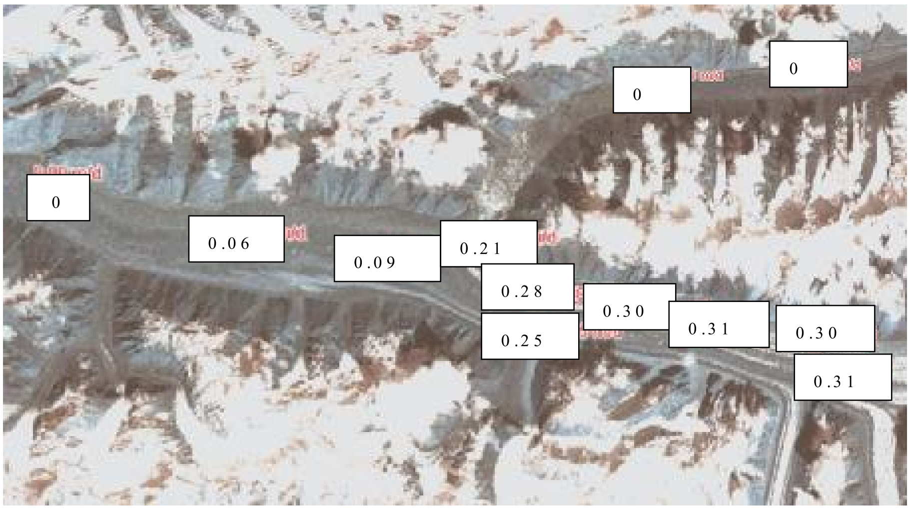


Figure 7: Velocity of the glaciers surface (m/day)

8. CONCLUSIONS & RECOMMENDATIONS

It is seen that remote sensing can prove to be an effective tool of choice for monitoring and studying GLOFs in high and remote mountains. In this study, it is evident that the outbursts take place if the temperature of the lake surface is more than 10 C and are frequent when it is close to 15 C. For an improved validation of the lake surface temperature from MODIS data, water temperature directly from the lake has to be measured against the MODIS data for a longer period. In this purpose, CAIAG has planned the installation of water sensors in the Merzbacher Lake from 2012. In order to find a more realistic relationship between the dates of outbursts and parameters of the lake such as area and volume of water and ice cover, images of dates closer to the outburst will prove more effective. The DEM generated from the ALOS/PRISM needs to be checked for the accuracy in this study. Since we see that in some years, there is a fast regeneration of the lake water after the outburst, a study to find this relationship with the geomorphological characteristics of the interglacial passage will open new dependencies of the outburst phenomenon. From the movement of the glaciers an interesting finding discovered is that actually it is the Southern Glacier that is more active recently since 2006-10, but the movement of the Northern Glacier tongue was more active from 1975-90.

9. REFERENCE

Glazirin, G. E. (2010). A century of investigations on outbursts of the icedammed lake Merzbacher (central Tien Shan). *Austrian Journal of Earth Sciences, 103*(2), 171-179.

Jansky, B., Sobr, M., & Engel, Z. (2010). Outburst flood hazard: Case studies from the Tien-Shan Mountains, Kyrgyzstan. *Limnologica - Ecology and Management of Inland Waters, 40*(4), 358-364.

Narama, C., Kääb, A., Duishonakunov, M., & Abdrakhmatov, K. (2009). Spatial variability of recent glacier area changes in the Tien Shan Mountains, Central Asia, using Corona (~1970), Landsat (~2000), and ALOS (~2007) satellite data. *Global and Planetary Change*.

Ping, S. Y., Ya, W. G., Jian, D. Y., Chao, S. H., Yi, M. W., De, W. S., et al. (2009). Changes in Merzbacher Lake of Inylchek Glacier and Glacial Flash Floods in Aksu River Basin,Tianshan during the Period of 1903-2009. *Journal of Glaciology and Geocryology, 2009-06*.

Xie, Z., ShangGuan, D., Zhang, S., Ding, Y., & Liu, S. (2012). Index for hazard of Glacier Lake Outburst flood of Lake Merzbacher by satellite-based monitoring of lake area and ice cover. *Global and Planetary Change*(0).