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GLACIOLOGICAL RESULTS OF THE 2005 EXPEDITION TO INYLCHEK GLACIER, CENTRAL TIAN SHAN

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Abstract

Like many other glaciers in Central Asia, Southern Inylchek glacier in the Kyrgyz Tian Shan is covered by supraglacial moraine, which drastically influences melt rates and complicates the estimation of ablation. The quantification of sub-debris melt from simple parameters is still an unsolved problem, but also essential to predict future yield from high mountains. Snow cover and glacier ice are the main water storages for the surrounding arid lowlands and a better understanding of ablation processes is the prerequisite for a sustainable water resources management. Another interesting feature of Southern Inylchek glacier is the existence of an ice dammed lake in a tributary valley, which is drained regularly by outburst floods. Improvements in predicting these floods would lower the risk potential for the downstream population. The main objectives of a group of glaciologists which participated in an expedition to the glacier in 2005 were to investigate melt rates on debris covered glacier parts and to quantify the ice flux into the glacier lake. The results of their field experiments are reported in this paper.

Key words: Inylchek, Tian Shan, glacier, Lake Merzbacher, water resources, jökulhlaup

1. Introduction

Southern Inylchek is the largest glacier of the Pobeda-Khan Tengri massif, the most heavily glaciated part of the Tian Shan mountains. Glacier runoff from this massif feeds the Aksu River, the main tributary of the Tarim River, one of the world´s largest closed drainage systems. After being excessively used for irrigation, the water of the Tarim river dries up near Daxihazi reservoir in the Taklamakan desert. According to Dikich (1993), almost 50% of the Tarim discharge is glacier runoff. Southern Inylchek glacier dams meltwater from Northern Inylchek glacier, which forms a lake that is drained frequently by massive glacier lake outburst floods (GLOFs), also called jökulhlaups. These GLOFs last for a few days only, but they imply a severe risk potential for the inhabitants of Sary-Dzhaz valley and they represent a waste of irrigation water further downstream. Therefore, predictions of timing and volume of the floods would greatly improve hazard management and sustainable water resources planning.

In 2005, an international expedition was organised by the Central Asian Institute for Applied Geosciences (CAIAG) in Bishkek in cooperation with the GeoForschungsZentrum (GFZ) in Potsdam, Germany. The aim was to monitor a lake outburst and to investigate the mechanism of such a jökulhlaup by a bundle of methods and techniques. The expedition was composed of 20 scientists, alpinists and journalists who formed five work teams. One team was in charge of establishing a local differential GPS network, another team of speleologists explored the intraglacial drainage systems and a third tested a method to observe lake level changes from GPS signals reflected by the lake water surface (Helm et al. 2007). A geological reconnaissance of the site was conducted by specialists and a group of three German glacier experts performed ablation measurements, ice flow observations, tracer experiments, radar depth sounding and photogrammetric documentations.

2. Description of investigation site

In 1903, the German explorer Gottfried Merzbacher discovered a large ice dammed lake on his way to Khan Tengri (6995 m a.s.l.), which he misleadingly considered to be the highest mountain of the Tian Shan. He was fascinated by the beauty of the water surface and icebergs, but not only happy about his discovery, because the lake obstructed the passage into the side valley, where Merzbacher assumed the direct access to the peak. After proceeding another 14 km in the main valley, Merzbacher achieved his aim anyhow and reached the slopes of Khan Tengri. In 1926, Russian alpinists named the lake after its discoverer on the occasion of an expedition to Khan Tengri, three years after Merzbacher passed away.

Southern Inylchek glacier, where Merzbacher finally found his route, is a valley type glacier and stretches about 60 km from east to west, covering and altitude interval from 7400 to 2900 m a.s.l. The lower parts of the glacier are covered with a thick debris layer. Northern Inylchek glacier, a former tributary of Southern Inylchek glacier, now terminates about 6 km up-valley in a proglacial lake. Having a smaller accumulation area than Southern Inylchek, the glacier was stronger affected by degradation, lost contact with its bigger neighbour and retreated from the former confluence. Melt water from Northern Inylchek glacier flows through the proglacial lake (Verkhnee Lake), where it is warmed up to more than 2 °C (2,4 °C on 30.07.1990, Mavlyudov 1997). Further downstream the water is dammed by Southern Inylchek glacier, forming Lake Merzbacher. A major part of Southern Inylchek glacier turns off from its normal flow direction into the side valley where the lake appears and forms the ice dam. Calving removes large amounts of ice from the dam which increases the ice flux and thus the ice velocities towards the lake considerably.

Due to its higher density in respect to the lake water, which is close to the freezing point, the relative warm water from Northern Inylchek glacier flows along the lake bottom towards the ice dam and thus provides a considerable energy input for melting processes. Nevertheless, bigger icebergs are not melted in one ablation season. They endure the winter on the lake bottom (after lake drainage) and become afloat by the next years rising lake level.

With an area of up to 4 km² and a volume of 0.15 km³ (Mavlyudov 1997) Lake Merzbacher is the largest glacial lake in Central Asia. The rising lake level due to increased melt rates in early summer leads to a seepage of lake water through a 14 km long sublacial system to the snout of Southern Inylchek glacier. Subsequent fast erosion of the water channels creates massive GLOFs with outflow rates of more than 1000 qm^3/s. Historical records of the floods began in 1932, since then they occurred every year with only few exceptions (Glazirin and Kagan 1986). It seems that date and occurrence of a jökulhlaup correlate with weather patterns. In warm summers lake filling is quicker due to stronger ablation on Northern Inylchek glacier and increased iceberg melting, whereas in cool summers the lake level rises slower and the critical elevation where parts of the dam begin to float is reached late in the year or not at all (Mavlyudov 1997).

The discharge volume of the jökulhlaups varied from 0.12-0.22 km^3 in the years 1963-1965 (Golubev 1974) and from 0.14-0.21 km^3 in 1982 and 1984-1987 (Konovalov 1990). First efforts to estimate the outburst date by sums of air temperature have been made by Sokolova and Leonovoij (1981). Glazirin and Kagan (1986) applied this approach and experienced an untolerable mean error of 40 days, but they failed in improving the method. Numerically simulated flood hydrographs by Vinogradova (1977) and Glazirin and Kagan (1986) yielded equivalent results, but they could not be verified due to the lack of measured data. The nearest gauging station is located in a broad valley section 60 km downstream and its runoff data is inept for validation (Glazirin and Kagan 1986). In recent years, lake outbursts occurred quite regularly within a relatively narrow time span between end of July and beginning of August (27-28 July 2001, 1-2 August 2002, 22-23 July 2003, 6-7 August 2004).

3. Course of action

It was planned to reach Southern Inylchek glacier around 20 July and to stay there for three weeks, which should secure a good chance to observe the jökulhlaup. Unfortunately, the outburst in 2005 occurred earlier than in the years before and on 20 July the members of the expedition, still preparing the field trip in Bishkek, found out that the event had already happened from 13 to 15 July. Since only part of the work was directly connected to the lake outburst, the expedition started from Bishkek anyhow on 22 July. The situation shortly after the dam failure is still of scientific interest, because many effects and impacts of the event are still visible or detectable.

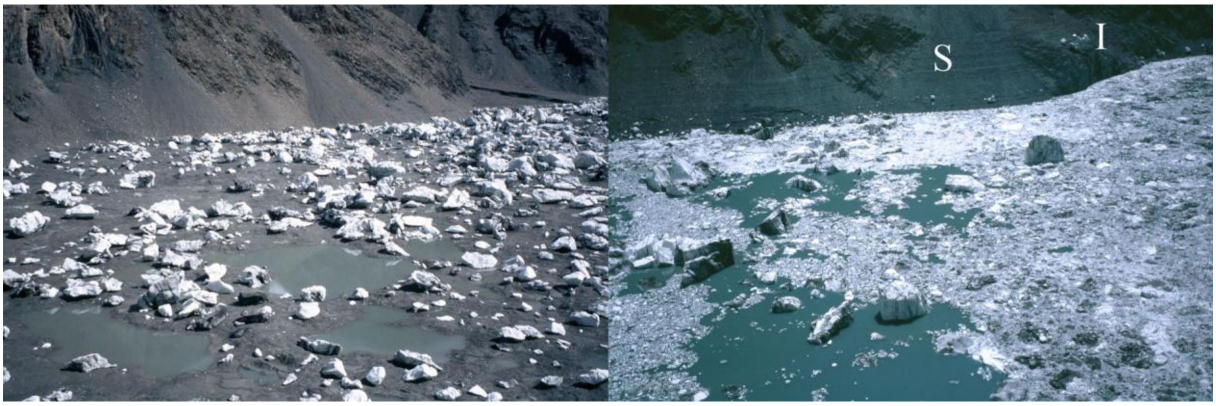

Photo 1: (a) Upper part of the drained lake floor, covered with icebergs. The average sized icebergs are approximately 15 m in diameter (b) remaining water surface after the main

outburst. Shorelines on the slope (S) indicate former lake levels and icebergs (I) document the minimum extent of this year´s lake. Photos: W. Hagg.

Since the outburst flood damaged the road through Inylchek valley and the helicopter landing place at Mayda Adir was not accessible, the expedition headed for Kar-Kara at the border to Kazakhstan, from where they were flown to the investigation site on 25 July. The glaciological team stayed at camp "Peremishka" north of the glacier lake and on the following days, they performed terrestrial photogrammetry from a base line to the west of Lake Merzbacher (figure 1). To reach this location, the team had to cross Northern Inylchek glacier, because the passage of the stream draining Verkhnee Lake was impossible. On 29 July, the team and its equipment were airlifted to the camp "Paliana" at a location named Merzbacher meadow (figure 1). Subsequently, ablation stakes have been drilled into Southern Inylchek glacier from 31 July to 2 August. These stakes were frequently remeasured until 11 August. A tracer experiment was conducted on 1 August. Radar sounding was executed from 3 to 5 August and ice albedo was observed on 6 and 7 August. On 6 August, the two journalists who had documented the expedition left by helicopter and witnessed a crash of the same, while they waited at Khan Tengri base camp for the MI-8 helicopter which should bring some mountaineers to a higher camp. Although the helicopter burned almost instantly, the accident caused no fatalities, but the whole equipment and documentation was lost. The victims of the crash were recovered by a military helicopter, which also flew out the members of the expedition on 12 August. On 7 August, a memorial tablet reminding of Gottfried Merzbacher was attached to a big boulder on the lateral moraine of Southern Inylchek glacier next to Merzbacher meadow.
During the period of our observations, the level of Lake Merzbacher increased with a rate of 0.5 m/d until 1 August. Afterwards a smaller jökulhlaup occurred, aligned with a quick lowering of the lake level by 14 m within two days (Helm et al. 2007). This pattern of an early outburst, followed by a smaller second event was already observed in 1966 (Mavlyudov 1997).

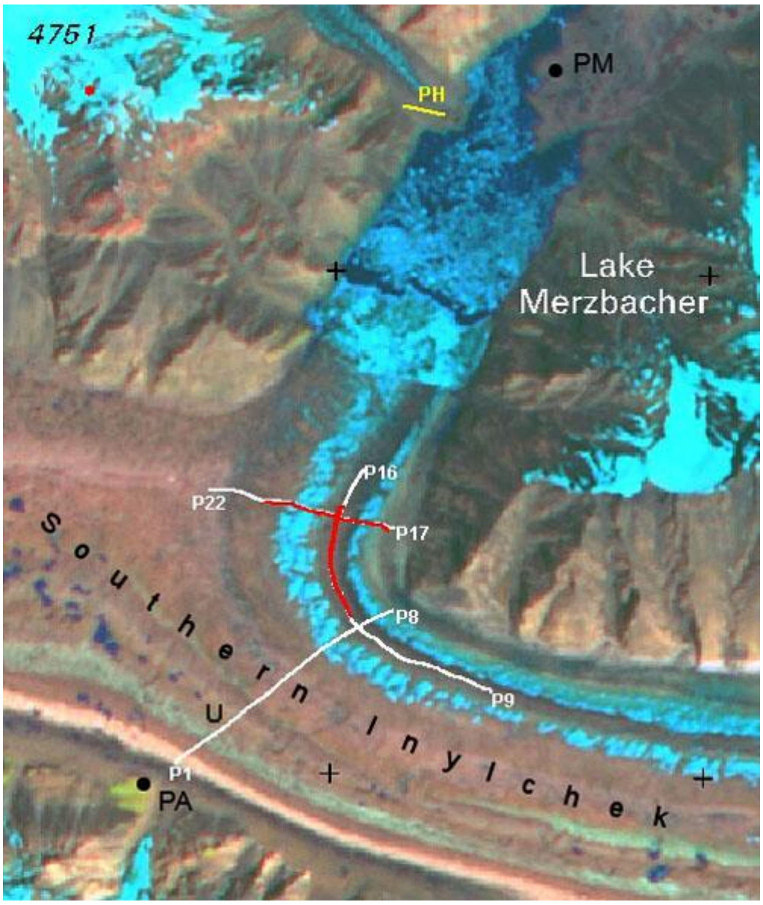

Figure 1: Location map of glaciological activities at Southern Inylchek glacier. The white profiles show the location of velocity- and ablation stakes (P1-P22), red lines indicate radar soundings. PH is the photogrammetric base line, U is the location of tracer injection and PM and PA symbolise the camps Peremishka and Paliana, respectively.

4. Results

4.1. Ablation measurements

Ablation was measured from 30 July to 10 August 2005 at 22 stakes that were placed into the ice using a steam drill (Photo 2).

Photo 2: The Heucke ice drill is able to penetrate glacier ice up to 15 m depth.

Ablation stakes were placed at locations with different types of debris cover, from bare ice to 35 cm thickness. To minimize the influences of aspect and slope, the stakes were placed at almost horizontal surfaces. At some stakes readings were taken twice a day, whereas at more remote spots only the total melt during the observed period was recorded. Melt rates varied from 2.8 to 6.7 cm/d with a mean of 4.4 cm/d. Fig. 2 shows the relation between debris cover thickness and melt rates.

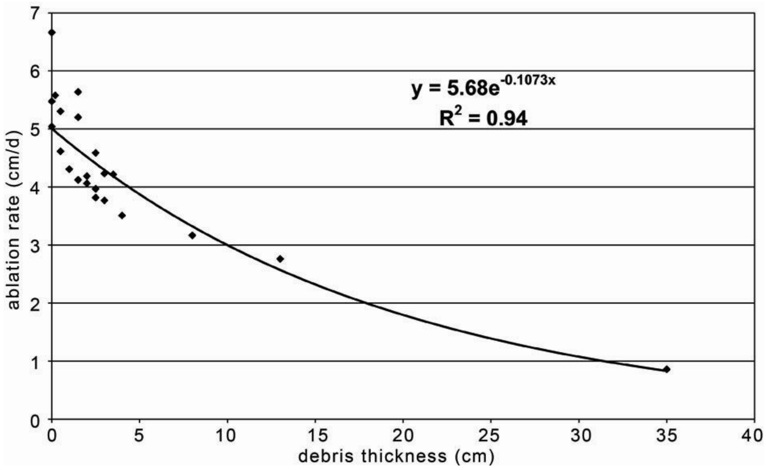

Fig. 2: Relation between debris cover and melt rate.

The full record of measurements is visualised in Fig. 3. The zigzag profiles at some stakes arise from measurements on mornings and evenings and illustrate differences in ablation between day and night.

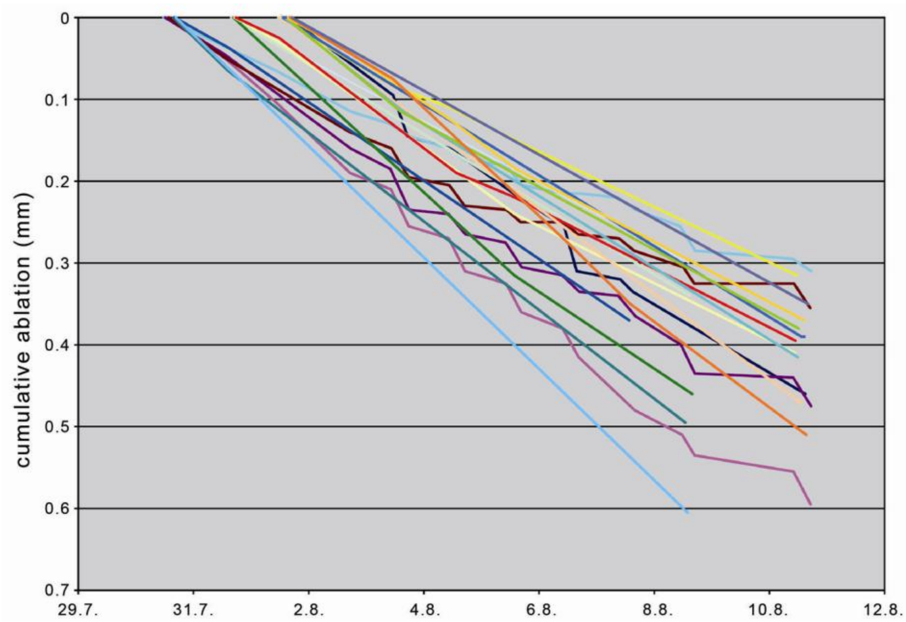

Figure 3: Cumulative ablation at the 22 stakes. The time series start at three different days, according to the installation date of the different stakes.

Degree-day factors (DDF) are calculated by dividing ablation by the sum of positive daily mean air temperatures. They can be used to estimate melt over larger areas only from air temperature, which can extrapolated fairly well to different altitudes due to rather constant lapse rates. The air temperature recorded at Paliana allowed the determination of degree-day factors for Southern Inylchek glacier, which range from 4.1 to 9.3 mm/(K*d) with a mean value of 6.1 mm/(K*d).

The relative strong correlation between DDF and debris cover thickness (R^2=0.85) allows an estimation of DDF from debris cover and the calculation of sub-debris melt for any debris thickness across the glacier (Hagg et al. 2008). This kind of parameterisation will enable us to calculate sub-debris melt for larger glacier parts, as soon as we will be able to derive the spatial distribution of debris thickness by means of remote sensing (Suzuki et al. 2007).

4.2. Meteorological conditions and ice albedo

A Vaisala weather station recorded air temperature, relative humidity and air pressure from 31 July to 11 August at Paliana. Daily means of air temperature ranged between 3.7°C and 9.7°C, with a mean of 7.6°C. Lowest and highest temperatures recorded are 0.1°C and 18.6°C, respectively. Relative humidity was 59% on average and the mean air pressure 673 hPa. The whole dataset is shown in figure 4.

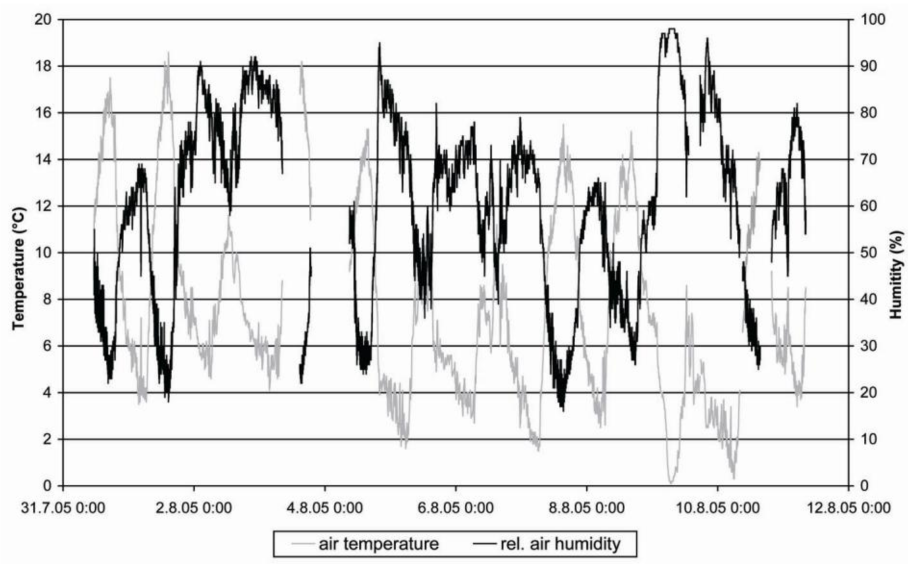

Figure 4: Air temperature and relative air humidity on Merzbacher meadow from 31 July to 11 August.

Ice albedo was measured on two consecutive days using a horizontally mounted Pyranometer (Kipp and Zonen CM7B). The first day was overcast and wet with mean air temperature and humidity during observation of 7.9°C and 56%, respectively. The second day was cloudless and dry, yielding mean values of 12.1°C and 26% relative humidity. Ablation rates were 1 cm/h on the cooler and 0.6 cm/h on the warmer day, which illustrates how strong ablation is controlled by air humidity and latent heat fluxes in this continental climate. On the warmer day the air was drier, increasing evaporation and therefore lowering the energy available for melt.

4.3. Observations of ice dynamics

To detect variations in glacier surface velocities, the 22 ablation stakes were repeatedly surveyed with differential GPS. The base station for the differential processing was installed on Merzbacher Meadow (reference position: 42°09'55.76'N, 79°49'01.38"E, 3402.64 m a s.l.). The derived horizontal velocities vary between 0.15 m/d (55 m/year) and 0.79 m/d (288 m/year), respectively. In Figure 5, results for all stakes are indicated by arrows. A more detailed description can be found in Mayer et al. (2008).

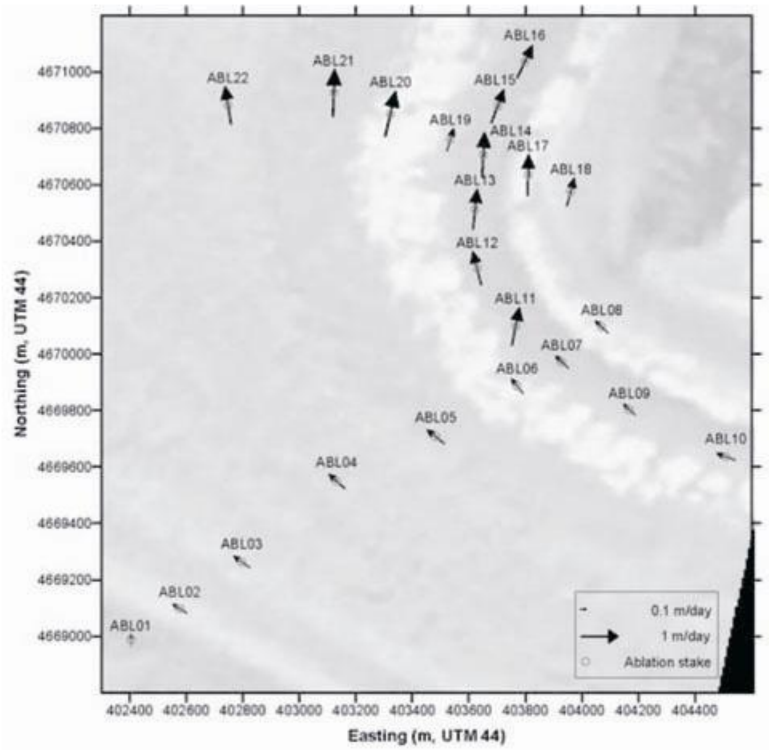

Figure 5: Location of ablation stakes (circles) and horizontal surface velocities (arrows).

The surface velocities at the upstream cross-profile (ABL01–ABL08) show a typical distribution, with increasing speeds from the glacier margins towards the central part. There is no indication of increased ice transport towards the lake across this section. On the contrary, the velocities on the flowlines towards the lake (ABL05 – ABL08) are 18% lower than the velocities on the glacier part directed towards the snout (ABL01 – ABL 04). Downstream of the cross-profile the surface slope steepens towards the ice dam (from ABL07 to ABL12) resulting in an increase of the ice surface velocity by a factor of 2.3. Although the surface slope decreases strongly between stakes ABL12 and ABL 15, the surface velocity increases further by a factor of 1.35. This continued velocity increase in the flatter region, downstream of ABL 12, indicates a growing influence of basal processes for the glacier movement in this part of the glacier.

At the lower cross-profile (ABL18–ABL22) the surface velocity increases from the inner towards the outer part of the glacier bend. Stake ABL22 shows a lower velocity and a rotation of the flow direction away from the ice dam which indicates that this part of the glacier is outside the flow band into Lake Merzbacher.

Considering the local surface slope, the vertical component of the surface velocity helps to distinguish between local flow and vertical surface changes not directly connected to the local flow. Vertical displacements are measured as true vertical ice movement without the contribution from ablation. Along the longitudinal profile the observed vertical displacement is about three times higher than the vertical component of the surface velocity at the uppermost stakes and this factor increases to almost 50 at stake ABL13. This analysis demonstrates that the vertical displacement in the ice dam region downstream of stake ABL11 cannot be explained by normal glacier flow alone. The maximum vertical displacement in this area was –15.9 m, observed over a period of nine days at stake ABL14. This distribution of

vertical displacement suggests the assumption that during maximum lake level the ice dam is afloat up to the location of ABL12 (1.6 km from the front).
From a multitemporal analysis of ASTER images (Mayer et al. 2008), a mean surface velocity of 80–90 m/year at a crossprofile about 2 km upstream of Merzbacher meadow could be determined. Typically, the surface velocity amounts to 80% of the vertical mean ice velocity at a cross profile. It follows that the annual ice flux from the upper regions of Southern Inylchek glacier is about 0.02 km^3. From our flow line analysis in this region we know that 58% of the glacier drains into the lake. Across the transect, the mean ice thickness is about 160 m (Macheret et al. 1993), which results in a mean annual ice transport towards the ice dam of 0.012 km^3. This volume is roughly 7% of the estimated maximum lake volume (Mavlyudov 1996).

4.4. Terrestrial photogrammetry

On the western shore of Lake Merzbacher a photogrammetric base line was established on the lateral moraine of a small side glacier (42° 13’ 3.29“ N, 79° 51’ 35.1“ E). The whole ice dam was covered by pairs of stereo images. The camera used was the phototheodolite TAF, a combination of a theodolith and a measurement chamber developed by Sebastian Finsterwalder. Photographs are taken on glass plates, just like in the days when Merzbacher discovered this region. More modern were the measurements of the reference positions for the determination of the exterior orientation of the images. For this purpose, prominent points on the glacier and around Merzbacher meadow that are easy to identify in the images were measured by differential GPS after the team moved to Paliana camp. In summer 2008, a repetition from the same base line is planned, which will allow a change-detection of the ice surface in this dynamic part of Southern Inylchek glacier.

Photo 3: Photogrammetric image of the empty lake (icebergs in the foreground) as well as the ice dam (D) and part of Southern Inylchek glacier (background).

4.5. Radar sounding

For the calculation of mass fluxes into Lake Merzbacher, not only ice velocities but also the cross sectional area of the glacier part moving towards the lake has to be known. A ground penetrating radar (Photo 4) was used to determine ice thicknesses along a longitudinal and a cross profile (see Figure 1). Altogether data of more than 300 soundings have been recorded. The processing of these data was very difficult due to conditions on the glacier. Firstly, the thick moraine cover prevented an undisturbed penetration of the radar waves, secondly a major part of the energy was reflected by abundant meltwater on the surface and in the glacier. Altogether, the results are very fragmentary, but in general the findings of Macheret et al. (1993) could be verified.

Photo 4: Ground penetrating radar antennas.

4.6. Tracer experiment

Flow velocity of melt water was determined by a tracer experiment with Uranine in a supraglacial meltwater channel near Merzbacher meadow (42° 10’ 6“ N, 79° 49’ 18“ E) on 3379 m a.s.l. Approximately 2 liters of Uranine powder was dissolved and injected into the channel at 10:22 a.m. (see Photo 5). The tracer was detected optically at the glacier snout 14.2 km downwards at 15:20 p.m., from which a mean flow velocity of 2.8 km/h can be calculated. Unfortunately, this experiment was only conducted on a part of the glacier not directly affected by the GLOF and could not be repeated in the drainage system of the lake. Ideally, this experiment would have taken place at two locations before and after the lake outburst, but nevertheless it gives a first hint on melt water flow velocities and can be compared with future observations.


Photo 5: Colored meltwater after the injection of the tracer.

4.7. Conclusion and outlook

The expedition showed that a bundle of field measurements can be conducted with a small amount of labour and time. Due to the roughness of the terrain it is impossible to reach the lake from Southern Inylchek glacier with heavy equipment. This requires helicopter flights which imply a certain danger potential in this remote mountain region. To ensure the observance of a jökulhlaup it is necessary to reach the location relatively early, risking an extended field trip if the event happens late summer.

The creation of an outburst warning system requires continuous monitoring of several parameters such as lake level, air and water temperatures and ice flow velocity. This could be realised either by remote transmission techniques or by a permanently manned station. The GFZ Potsdam launched a research initiative named “Global Change Observatory Central Asia” with a local focus on the Inylchek area as a model glacier region in Central Asia. Together with the CAIAG Bishkek and an international team of scientists it is intended to install a permanent research platform which will provide the infrastructure necessary for a long-term monitoring of this glacier system.

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