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Influences of the 2004 Jökulhlaup on Ice Dynamics of Skeiđarárjökull, Iceland, Using Terra-ASTER Imagery

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Summary: On 01–06 November 2004 a volcanic eruption occurred at the subglacial Grímsvötn caldera sited under the western part of Vatnajökull ice cap. The accompanying jökulhlaup travelled subglacially over a distance of 50 km under the Skeiđarárjökull outlet and finally flooded huge areas of the Skeiđarársandur plain in the south. Meltwater discharge peaked on 2 November and finally ended in early December, having released a total volume of $\sim 0.8\,\mathrm{km}^3$ from Grímsvötn. The influences of this jökulhlaup on the ice dynamics of Skeiđarárjökull were investigated applying image cross-correlation on five optical images pairs (October 2001 to July 2005) of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) aboard the EOS Terra satellite. The average horizontal surface displacement of nearly annual periods (2001–2002, 2002–2003, 2003–2004, 2004–2005) were compared to the velocity obtained from a 64 day image pair covering the period of the jökulhlaup. A considerable acceleration of up to $0.4\,\mathrm{m\,d^{-1}}$ over nearly the whole width of the glacier appeared during the jökulhlaup in contrast to the annual velocities. This extensive increase of surface velocity is only hardly explainable by the classical jökulhlaup theory of floodwater drainage in a single subglacial conduit. Considering the results, a sheet flow or coupled sheet and tunnel flow leading to a widespread basal lubrification seems more likely.

Zusammenfassung: *Der Einfluss des Jökulhlaup im Jahr 2004 auf die Eisdynamik des Skeiđarárjökull, Island, unter Verwendung von Terra-ASTER Daten.* Zwischen dem 01. 11. 2004 und 06. 11. 2004 ereignete sich eine Vulkaneruption am südwestlichen Rand der Grímsvötn-Caldera unter dem westlichen Vatnajökull. Der begleitende Jökulhlaup floss subglazial über ca. 50 km unter dem Auslassgletscher Skeiđarárjökull ab und überflutete schließlich weite Bereiche des im Süden gelegenen Skeiđarársandur. Der Jökulhlaup erreichte seinen Spitzenabfluss am 02. 11. 2004 und endete Anfang Dezember. Insgesamt wurde ein Schmelzwasservolumen von ca. $0{,}8\,\mathrm{km}^3$ freigesetzt. Ziel dieser Studie ist die Untersuchung des Einflusses dieses Gletscherlaufs auf die Eisdynamik des Skeiđarárjökull. Dabei wurde Kreuzkorrelation zwischen fünf optischen Datenpaaren (Zeitraum Oktober 2001 – Juli 2005) des Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) durchgeführt. Die durchschnittliche horizontale Oberflächengeschwindigkeit nahezu einjähriger Zeitabschnitte (2001–2002, 2002–2003, 2003–2004, 2004–2005) wurde den Korrelationsergebnissen eines Datenpaares mit 64tägigem Abstand zur Zeit des Jökulhlaup gegenübergestellt. Die Resultate zeigen während des Jökulhlaup eine im Verhältnis zu den einjährigen Datenpaaren bis zu 0.4 m/Tag erhöhte Oberflächengeschwindigkeit des Skeiđarárjökull über dessen nahezu gesamte Breite. Dieser flächenhafte Geschwindigkeitsanstieg kann nur schwer mit der klassischen Jökulhlaup-Theorie in Einklang gebracht werden, die den subglazialen Abfluss der Wassermassen über einen einzigen Schmelzwassertunnel beschreibt. Die Ergebnisse zeigen, dass Blockschollenbewegung oder eine Kombination aus Blockschollenbewegung und Tunnelabfluss, die zu einem großflächig basalen Gleitfilm führt, wahrscheinlicher ist.

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1 Introduction

The objective of this study is the determination of two-dimensional ice-surface velocity fields of the Skeiðarárjökull, a southward trending outlet of the Vatnajökull ice cap, by cross-correlation of ASTER image pairs.

Due to its climatic and physical conditions Iceland presents an ideal test site for monitoring glacier dynamics. At present approx. 11% of the 103,000 km^2 of the volcanic island is ice-covered, represented mainly by the four large ice caps Vatnajökull (8,100 km^2), Langjökull (925 km^2), Hofsjökull (900 km^2) and Mýyrdalsjökull (600 km^2) (BJÖRNSSON et al. 2004).

The large ice masses cover several active volcanic systems with central volcanoes, crater chains, and fissures (BJÖRNSSON & EINARSSON 1990).

Besides the usual volcanic hazards (lava flows, pyroclastic clouds, tephra fall, etc.), the volcano-ice interaction leads to enormous melt water torrents (icl.: jökulhlaup), devastating large areas in the neighbourhood of the affected glacier. Conventional theory explains jökulhlaups by floodwater travelling from a water reservoir within a single pre-existing conduit of fixed geometry and diameter eroded into the bottom of a glacier (NYE 1976). The frictional heat of meltwater flow enlarges the tunnel along the flood path leading to an almost exponential increase of discharge (RÖTHLISBERGER 1972, NYE 1976, BJÖRNSSON 1975, NG 1998). This theory established by NYE (1976) was adapted several times, but its main principles endure. However, new studies on some catastrophic flood events in Iceland have revealed that besides the exponentially rising jökulhlaups, a second type of glacier torrents exists (ROBERTS 2005).

For example the enormous jökulhaup from Grímsvötn in 1996 (~ 3.2 km^3) is characterized by a steep short-time linear rise to maximum water discharge. This hydrograph curve cannot be explained solely by tunnel enlargement due to mechanical and thermal energy (BJÖRNSSON et al. 2001, BJÖRNSSON 2002, FLOWERS et al. 2004). Sheet-like flow across large portions of a glacier bed is necessary to explain this type of rapidly rising jökulhlaup (JÓHANNESSON 2002, FLOWERS et al. 2004).

Results of MAGNÚSSON et al. 2005, deriving a widespread increase of the ice flow velocities at Skeiðarárjökull due to basal spreading of the water reducing friction between the bedrock and the glacier during the jökulhlaup in 1996 by the use of Interferometric Synthetic Aperture Radar (InSAR), support this theory.

In autumn 2004 another jökulhlaup occurred at the Skeiðarárjökull outlet associated with a subglacial eruption at the Grímsvötn volcanic system. For this event, a pre (27/09/2004) and a post (30/11/2004) jökulhlaup ASTER image of Skeiðarárjökull is at our disposal. We investigated the impact of this jökulhlaup on the ice dynamics of the glacier, compared to the mean annual flow velocities derived for the period 2001–2005 by ASTER cross-correlation likewise.

2 Test site

Skeiðarárjökull is the largest southward trending outlet of Vatnajökull (Fig. 1). The catchment area of Skeiðarárjökull comprises approx. 1,428 km^2 (AÐALSGEIRSDÓTTIR 2003). Its elevation ranges from 1,740 m down to 100 m a.s.l. at the terminus. Three medial moraines divide the glacier into four different flow bands. Situated in a maritime climate, with relatively low summer temperatures and heavy winter precipitation, the glacier is characterized by high rates of surface mass exchange, resulting in high balance velocities (AÐALSGEIRSDÓTTIR 2003). Its dynamic character is intensified by the convergent flow of the ice mass from a wide accumulation area into a narrow channel (~ 7.4 km) between the ice free mountains of Skaftafellsfjöll and Eystrafjall, east and west of the glacial tongue.

Additionally the glacier is affected by subglacial drainage of episodic jökulhlaups. Skeiðarárjökull encompasses the floodpath of the Grímsvötn caldera, one of the most famous jökulhlaup systems throughout the

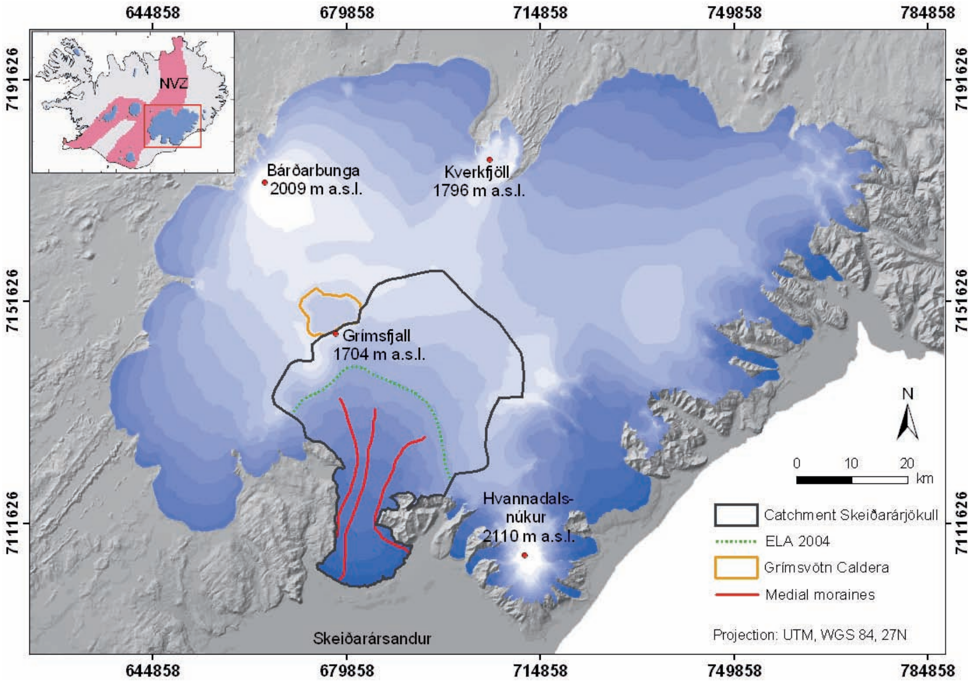

Fig. 1: Vatnajökull and its outlet glacier Skeiđarárjökull.

world. The approx. 60 km^2 large subglacial caldera is situated in the central part of western Vatnajökull. The caldera is filled by the geothermally fed subglacial lake Grímsvötn, which itself is overlain by glacier ice, up to 250 m thick, forming the inner surface at approx. 1,450 m a.s.l. (Björnsson & Einarsson 1990). For several hundred years, Grímsvötn has been the most active volcano beneath Vatnajökull (Guðmundsson & Björnsson 1991). Due to the ice cover, eruptions of Grímsvötn are phreato-magmatic and produce huge amounts of meltwater. The most recent eruption occurred on 1–6 November 2004, after a dormant phase of only six years since a last outbreak in December 1998 (Sigmundsson & Guðmundsson 2004). In spite of the usual eruption characteristics, the jökulhlaup preceded the eruption, starting on 29 October 2004.

The jökulhlaup peaked on 2 November with maximum flood discharge of 3,300 m^3 s^{-1}. Over a five day period 0.5 km^3 of melt water were released. The phreato-magmatic eruption, triggered by the release of overburden water pressure, increased the total amount of outflowing water to 0.8 km^3 and prolongated the flood until early December (Hardardóttir et al. 2005, Münzer et al. 2007). The floodwater ran approx. 50 km beneath Skeiđarárjökull and reached the Skeiđarársandur outwash plain with its braided river systems Skeidará, Súla and Gígjukvísl. During the subglacial outflow, Roberts et al. (2005) detected several speedup events of the glacier's surface by the use of high-precision GPS. The measurements yield a tenfold increase in horizontal velocity from 0.03 m h^{-1} to 0.3 m h^{-1} that was sustained for up to 10 hours.

3 Data and methodology

Six ASTER images were used to determine the surface velocity fields of Skeiđarárjökull by cross correlation (Tab. 1). The measurements were based on the nadir looking spectral band 3N (0.76–0.86 µm, spatial resolution 15 m). Compared to the other high-resolution VNIR bands 1 and 2, the spectral band 3N is less affected by atmospheric influences due to its longer wavelength.

Cross correlation of optical satellite imagery is an established method to derive glacier flow velocities (e. g. SCAMBOS et al. 1992, KÄÄB et al. 2005, BERTHIER et al. 2003), especially in cases when in situ measurements or terrestrial photogrammetry (e. g. MAAS et al. 2006, RENTSCH et al. 1997) are not possible.

In total, five image pairs were generated: Four image pairs with a time interval of nearly one year covering the period 2001–2005 (05/10/2001 – 13/09/2002, 13/09/2002 – 09/09/2003, 09/09/2003 – 27/09/2004, 27/09/2004 – 28/07/2005). They were used to calculate the mean annual velocity field of the Skeiðarárjökull glacier tongue. One image pair spans a period of 64 days in autumn 2004 (27/09/2004 – 30/11/2004) comprising the above mentioned jökulhlaup event from the Grímsvötn caldera. This image pair was used to study the impact of increased subglacial drainage on the surface velocity of the glacier, in comparison to the annual mean velocity. Glacier motion is strongly linked to precipitation and the amount of melt water available at the glacier base. Therefore, glacier velocity follows an annual cycle, reaching maximum velocities during the summer month. It can be assumed that without influences of a jökulhlaup the velocity of the 64 day period in autumn should give more or less the same values than the annual average velocity. This time interval covers a transitional period between high summer velocities and strongly reduced basal water and therefore flow velocity due to the beginning of the winter half.

Before applying the cross correlation algorithm on the data pairs, the individual images had to be pre-processed. First stripe noise was removed using the destriping algorithm implemented in ERDAS Imagine as a routine function. Thereafter the images were geocoded. This is the most important step in pre-processing because it influences the accuracy of the derived velocities, especially in case of short time separation.

Therefore, about 20–25 ground control points were measured at nunataks and in the ice free areas around the glacier in the individual images. Digital topographic maps (1 : 50,000) and already geocoded satellite images were used as references to transform the scenes into a common map projection by a second order polynomial (UTM, WGS 84 Zone 27). Additionally, in order to avoid also minor displacements, the two images of every data pair were co-registered, whereas the prior image always served as the master scene.

Subsequently the ice free areas surrounding the outlet were removed, by clipping the images with the glacier outline. This avoids correlation of surface features close to the glacier margin with the neighbouring ice free areas. Finally, the images were converted into TIF format with reduced image depth of 8 bit and imported into the IMCORR cross correlation software. The IMCORR software package is provided as freeware by the National Snow and Ice Data Center (SCAMBOS et al. 1992). The software computes the maximum correlation between the two images to subpixel precision using a fast Fourier-transform version of the normalized cross-covariance method (SCAMBOS et al. 1992, BERENSTEIN 1983). This technique tracks the motion of small-scale features like crevasses, debris, ash cones or other objects at the glacier surface. One of the critical factors of this method is the time separation between the acquired data: On the one hand a long interval reduces the efficiency of cross correlation technique due to the changing of surface features by physical effects like melting processes or snow accumulation. On the other hand the time interval must be long enough to determine glacier displacements significantly above the co-registration and the software induced errors (BERTHIER et al. 2003).

For runtime purposes IMCORR compares subscenes (image chips) from each of the two full images to restrict the area over which it attempts to find displacements. The smaller reference chip is taken from the respective former scene of each image pair, the larger search chip from the data set recorded afterwards. The size of the search chip is manually adapted to the expected maximum displacement. In this study a consistent reference chip size of 32 × 32 pixel (480 × 480 m) and a search chip size of 80 × 80 pixel (1200 × 1200 m) for the image pairs with an annual interval and 64 × 64 pixel (960 × 960 m) for the shorter interval were chosen. The used grid size was 4 pixel (60 m), i. e., a search window was centred around every fourth pixel. At each of these gridpoints IMCORR matches the search chip to the reference chip by calculating the correlation values, leading to dense but overly smooth estimates, the latter due to the strong correlation between the highly overlapping chips.

The offset between the two chips at the peak correlation therefore corresponds to the displacement of the glacier. Considering the time separation between the data records and the spatial resolution of the images the offset values are converted into velocities per day and visualized as vector arrows in a GIS environment.

Furthermore, quality control parameters listed in the IMCORR output file were used to validate the correlation results, e. g. error estimations in x- and y-directions exceeding one pixel were rejected. A reliable threshold for the maximum velocity was defined by trial and error. By comparing the azimuth direction of the velocity vectors with the steepest downward slope of the Skeiðarárjökull using a digital elevation model (DEM) it has been found that values exceeding a velocity of 1.1 m d^{-1} return wrong flow vectors in the majority of cases. Additionally vectors deviating $+/-20°$ from the direction of the steepest topographic gradient were eliminated.

4 Error estimation

The individual processing steps introduce some uncertainties in the flow velocity field derived from every image pair. The total error σ_v, computed in the standard deviation of the offset values, consists of the systematic σ_{syst} and the random error σ_{rand} (Berthier et al. 2003):

$$\sigma_v = \sqrt{\sigma_{syst}^2 + \sigma_{rand}^2}$$

The systematic error depends on the accuracy of the co-registration of the ASTER data. It was calculated indirectly by applying cross-correlation to stable, ice-free areas of the respective image pairs. The offset of such areas would correspond to the co-registration error. This led to an error value of about one pixel (15 m).

The cross-correlation inherent random error (σ_{rand}) can be determined by the error estimations for the x- and y-offsets returned by the IMCORR software. These values are derived from a correlation-peak-height-to-peak-width comparison (http://nsidc.org/data/velmap/imcorr.html). The σ_{rand} varies between 0.19–0.24 pixel in the ASTER correlation results. Now, calculating σ_v with the above equation a total error between 1.01–1.03 pixel is derived for all correlation pairs. The uncertainty of the velocity values (m d^{-1}) depends on the spatial resolution of the used data, the time separation between the correlated images, and on the flow velocity of the glacier. Thus, correlation outputs for the image pairs spanning an annual interval show possible error values of 0.04–0.05 m d^{-1} (cf. Tab. 1). This minor uncertainty is sufficient for a velocity analysis over the whole glacier. In contrast, the total error/day e. g. of the image pair 27/09/2004 – 30/11/04 is increased to 0.24 m d^{-1} due to its short time separation. The relative error would be 100 % in a region moving 0.24 m d^{-1}, so velocity measurements are more confident in the fast moving central part of the glacier where the flow reaches higher values than the potential error.

5 Results

The following section describes the cross-correlation results of the five image pairs with a special focus on the Grímsvötn jökulhlaup of 2004. The inferred flow fields of the Skeiðarárjökull glacier tongue are described in terms of their correlation density, flow pattern and flow velocity.

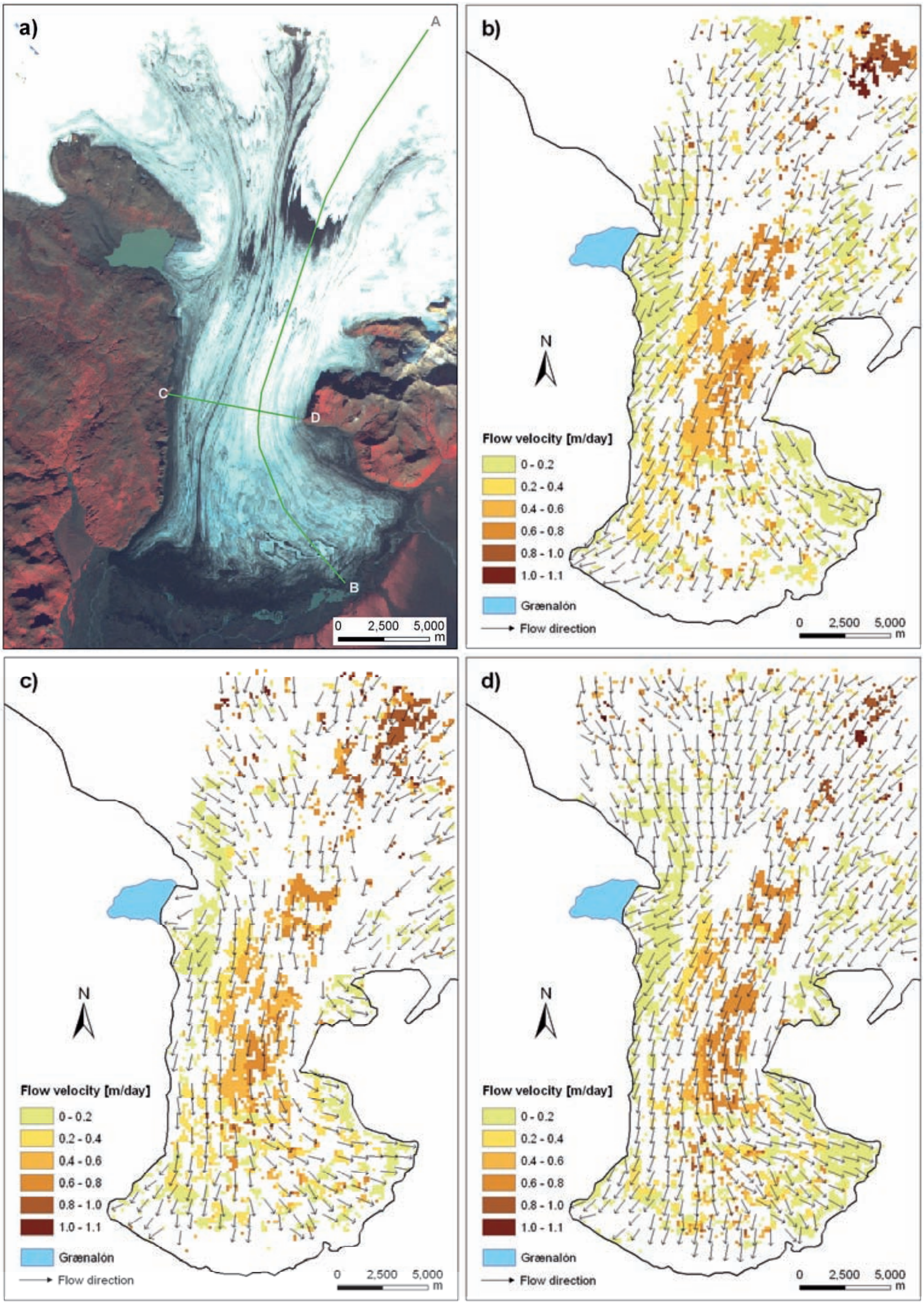

Fig. 2: a) Terra ASTER subscene from 27/09/2004 (RGB), © NASA. Surface velocity field of Skeiðarárjökull outlet, derived from ASTER imagery for the periods b) 05/10/01 – 13/09/02, c) 13/09/02 – 09/09/03, d) 09/09/03 – 27/09/04, e) 27/09/04 – 28/07/05, f) 27/09/04 – 30/11/04.

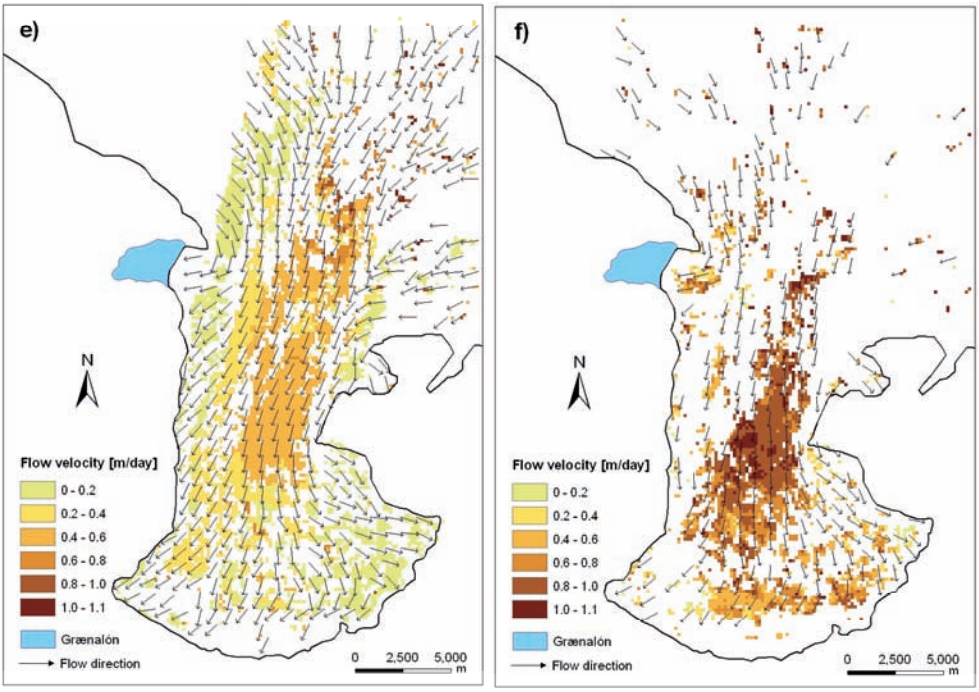

Fig. 2: continued

5.1 *Correlation density*

The number of velocity points derived by the cross-correlation algorithm (four pixel grid size) varies between 14,201 and 30,482 (cf. Tab. 1) for the individual image pairs. In relation to the image overlap, the density of velocity points per km^2 ranges between 31.1 (27/09/2004 – 30/11/04) and 78.4 (27/09/2004 – 28/07/2005). Generally the annual ASTER pairs show a higher density of correlated points, due to the similar surface conditions during the summer period where the bare ice is exposed on the whole glacier tongue. Therefore surface features like crevasses or ash cones can easily be correlated. In contrast to that, snow coverage complicates cross correlation in the ASTER scene acquired on 30/11/2004 especially at higher elevations of Skeiđarárjökull. In the lower parts of the glacier tongue correlation point density is reduced only marginally, because surface features are not completely masked

Tab. 1: Characteristics of the correlation pairs.

Correlation pair	Accuracy ($m\ d^{-1}$)	Correlation area overlap (km^2)	Correlated pixel	Correlated pixel / km^2
05/10/2001 – 13/09/2002	± 0.05	412.9	27,583	66.8
13/09/2002 – 09/09/2003	± 0.04	413.4	23,192	56.1
09/09/2003 – 27/09/2004	± 0.04	455.9	25,170	55.2
27/09/2004 – 28/07/2005	± 0.05	388.8	30,482	78.4
27/09/2004 – 30/11/2004	± 0.24	456.6	14,201	31.1

by the thin snow cover. It was found, that some areas of the glacier generally show sparse coverage with correctly matched pixels: the ash-laden lateral glacier margins as well as the glacier terminus, the medial moraines and the higher elevations close to the equilibrium line. The nearly analogue grey values in these areas often result in a multi-modal correlation surface without a distinctive peak, preventing a clear point-to-point correlation.

5.2 *Flow pattern*

The flow pattern of Skeiðarárjökull is shown Fig. 2b–f, represented by vector arrows. To eliminate small-scale directional variations, the azimuth angles of the flow vectors have been averaged using a grid with a cell size of 800 × 800 meters. Therefore, the vectors originate at the centre pixel of each grid cell. It has been found, that the flow pattern derived from the annual ASTER pairs is constant throughout the period of investigation. Even the 64 days image pair, covering the 2004 Grímsvötn jökulhaup, provides the same pattern. This indicates a good reliability of the results of the individual correlation pairs. Especially the annual correlation results yield an almost complete picture of the flow pattern of Skeiðarárjökull. The southward trending ice influx from the wide accumulation area is funnelled into a narrow channel (~ 740 m a.s.l.) confined by the mountain ridges of Eystrafjall and Skaftafellsfjöll. Here, the ice discharge turns to a SSW direction. In the lower part of the glacier tongue, after passing this bottleneck, the ice disperses in an southeast- (~ 560 m a.s.l.) and southwest-ward direction (~ 400 m a.s.l.) and develops a lobe with a 23 km wide ice front.

5.3 *Surface velocity*

The glacier surface velocities of the annual correlation periods depicted in Fig. 2b-e, show good agreement with other studies (e. g. Magnússon 2005). A well-defined central flow line of maximum speed is clearly detectable, whereas the lateral parts of the outlet glacier reveal considerably slower velocities.

For better comparison of the results derived from the individual correlation pairs, longitudinal (A-B, Fig. 3) and transversal velocity profiles (C-D, Fig. 4) were extracted along predefined lines as shown in Fig. 2a. In order to obtain reliable measurements, velocity values within a distance of 300 m around the profile lines were used. Depending on the point density a running mean was calculated to visualize the data.

The longitudinal velocity profile has a length of 34 km. It starts about 1.5 km beneath the equilibrium line of the year 2004 at an altitude of 1,220 m a.s.l., proceeds along the main flow path and ends at the eastern part of the glacier terminus (~ 100 m a.s.l.).

The annual measurements indicate maximum displacements of up to 1.05 m d^{-1} at a distance of 3–4 km from point A. From there the velocity decreases downglacier to a value of 0.6 m d^{-1} at a distance of 8.5 km from A. The section between 8.5 and 22.5 km along the longitudinal profile line shows almost constant velocity values, followed by another zone of strong deceleration to a flow velocity of about 0.05 m d^{-1} at the glacier terminus (B). This deceleration from the equilibrium line towards the glacier snout results from decreasing accumulation and therefore minor mass input at lower altitude and the reduced driving stress likewise. Furthermore, the high velocities in the upper part of Skeiðarárjökull (~ section 0–11 km) coincide with the steepest surface slope of about 2 degrees. The slower section between 11 and 24 km shows a smoother gradient of about 1.1 degrees. In this section (11–24 km) the decrease of the velocity, caused by the reduced driving stress, is equalized by the lateral constriction of the ice mass, leading to more or less constant velocity values. After passing the bottleneck the glacier tongue slows down due to divergent flow.

The transversal velocity profile extends from west to east across the narrowest part (~ 7.4 km) of Skeiðarárjökull. Graphs of the annual correlation pairs show a similar

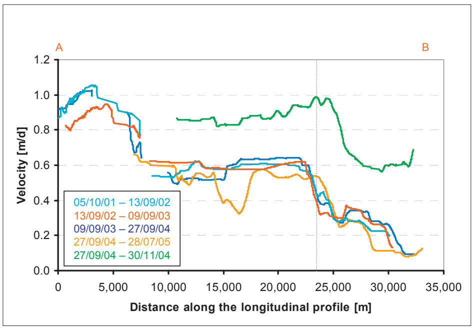

Fig. 3: Longitudinal profiles of ice velocity (A-B, see Fig. 2a). The vertical grey line marks the intersection with the transversal profile (C-D).

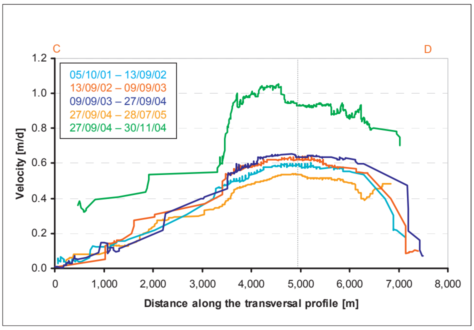

Fig. 4: a) Transversal profiles of ice velocity (C-D, see Fig. 2a). The vertical grey line marks the intersection with the longitudinal profile (A-B).

distribution. Values increase continuously from $< 0.1\,\mathrm{m\ d^{-1}}$ at the western margin. Maximum velocity values of $0.55\,\mathrm{m\ d^{-1}}$ (27/09/2004 – 28/07/2005) and $0.65\,\mathrm{m\ d^{-1}}$ (09/09/2003 – 27/09/2004) respectively, are reached in the central part of the flow path at a distance of 4.5 to 5 km from point C. In the section between 6 km and the endpoint of the transversal profile at D, motion decelerates rapidly to about $0.1\,\mathrm{m\ d^{-1}}$. The reduced speed at the lateral glacier margins is caused by increased friction at the valley sides. Consequently, highest velocities occur near the centre-line.

Looking at Fig. 3 and 4 the longitudinal as well as the transversal profile of the image pair 27/09/2004 – 30/11/2004 shows a similar trend but with significantly increased flow velocities compared to the annual correlations. Velocity values are up to $0.4\,\mathrm{m\ d^{-1}}$ higher. This is equivalent to a velocity increase of about 65 %. This speed-up in flow velocity is influenced by the jökulhlaup from Grímsvötn caldera during the period 29/10/2004 – 02/12/2004. The subglacial floodwave propagated beneath Skeiðarárjökull causing an enhanced basal sliding at the glacier bed for several days. As shown in Fig. 4 the speedup nearly affects the whole width of the glacier tongue, whereas the most prominent increase of flow velocity occurs from about 3.4 km towards point D in the cross-profile. Most likely the main part of the melt water was discharged within that region and thus generated the most effective lubrication. MAGNÚSSON et al. (2005) detected a similar variation in flow velocity and flow pattern of Skeiðarárjökull during a jökulhlaup in 1996. They argue that the water disperses laterally at the glacier bed and, contrary to the classical jökulhlaup theory, does not solely drain via a single subglacial conduit. This theory of basal meltwater spreading explains the extensive speedup of Skeiðarárjökull shown in our data set. Therefore, our results concerning the jökulhlaup from Grímsvötn caldera in autumn 2004 contribute to the new intensely discussed theory of meltwater discharge during glacial torrents.

6 Conclusions

Ice dynamics of Skeiðarárjökull were investigated with special focus on autumn 2004, when a jökulhlaup drained subglacially under this outlet. Skeiðarárjökull is the largest southward trending outlet of Vatnajökull ice cap. Its elevation ranges from 1,740 m down to 100 m a.s.l. at the terminus. Three medial moraines divide the glacier into four different flow bands. The jökulhlaup draining under Skeiðarárjökull in autumn 2004 accompanied a volcanic eruption at the subglacial Grímsvötn caldera (01–06 November 2004). Meltwater discharge of this outburst flood peaked on 2 November and finally ended in early December, having released a total volume of $\sim 0.8\,\text{km}^3$ from Grímsvötn.

We used six optical ASTER scenes (spectral band 1: 0.52–0.60 µm) covering the time period 2001–2005 to compare the short-term variation in surface velocity related to the jökulhlaup with the mean annual velocities. Surface velocity values and the flow pattern of the glacier were derived by image-to-image cross-correlation applying the IMCORR software on five ASTER image pairs. Generally the four annual ASTER pairs (2001–2002, 2002–2003, 2003–2004, 2004–2005) show a higher density of correlated points, due to the similar surface conditions during the summer period where the bare ice is exposed on the whole glacier tongue. Therefore surface features like crevasses or ash cones can easily be correlated. Cross-correlation of the annual pairs yield very similar flow patterns with a pronounced NE-SW trending central flow line of maximum speed (up to $1.05\,\text{m}\,\text{d}^{-1}$) in contrast to the lateral parts of slower movement ($< 0.1\,\text{m}\,\text{d}^{-1}$). Cross correlation of the data pair 27/09/04 – 30/11/2004 covering the jökulhlaup, was complicated by snow coverage in the ASTER scene acquired on 30/11/2004 especially at higher elevations of Skeiðarárjökull. Nevertheless, correlation point density is reduced only marginally in the lower parts of the glacier at this date, because surface features are not completely masked by the thin snow cover. A considerable increase in flow velocity of up to $0.4\,\text{m}\,\text{d}^{-1}$ compared to the annual values was observed probably due to enhanced glacier sliding triggered by the higher amount of subglacial meltwater during the jökulhlaup. The extensive acceleration over nearly the whole width of the glacier suggests a widespread lubrification at the glacier bed. This is only hardly explainable by the classical jökulhlaup theory of floodwater drainage in a single subglacial conduit, a sheet flow or coupled sheet and tunnel seems more likely. This corresponds to the new theory of meltwater discharge during glacial torrents already confirmed for a major jökulhlaup at Skeiðarárjökull in 1996. Considering our results, an at least partial spreading of meltwater at the glacier base occurs at Skeiðarárjökull even during moderate jökulhlaups.

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