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Geomorphic impact and rapid subsequent recovery from the 1996 Skeiðarársandur jökulhlaup, Iceland, measured with multi-year airborne lidar

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Abstract

The November 1996 jökulhlaup that burst from the Vatnajökull ice cap onto Skeiðarársandur was the highest-magnitude flood ever measured on the largest active glacial outwash plain (sandur). Centimeter-scale elevation transects, measured from repeat-pass airborne laser altimetry missions flown in 1996 (pre-flood), 1997, and 2001, show that sediment deposition exceeded erosion across the central Skeiðarársandur and established an average net elevation gain of +22 cm for the event. Net elevation gains of +29 and +24 cm occurred in braided channels of the Gígjukvísl and Skeiðará rivers, respectively. Nearly half of these gains, however, were removed within 4 years, and the two rivers contrast strongly in style of erosional/depositional impact and subsequent recovery. In the Gígjukvísl, the 1996 jökulhlaup caused massive sediment deposition (up to ~12 m) near the ice margin and intense "mega-forming" of braided channels and bars downstream. Post-jökulhlaup recovery (1997–2001) was characterized by rapid erosion (−0.5 m) of ice-proximal sediments and their transport to downstream reaches, and eradication of the mega-forms. In contrast, the Skeiðará displays minimal post-jökulhlaup sediment erosion in its upstream reaches and little change in braided channel relief. This contrast between river systems is attributed to the presence of a previously studied ~2-km wide ice-marginal trench, caused by glacier retreat and lowering, which contained flows of the Gígjukvísl but not the Skeiðará prior to dispersal onto the outwash plain. Rapid removal of jökulhlaup deposits from this trench suggests that in terms of long-term evolution of the sandur, such features only delay downstream migration of jökulhlaup-derived sediment. These results, therefore, suggest that the net geomorphic impact of jökulhlaups on surface relief of Skeiðarársandur, while profound in the short term, may be eradicated within years to decades.

Keywords: Iceland; Skeiðarársandur; Vatnajökull; Jökulhlaup; Flood; Erosion; Lidar; DEM; Remote sensing

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1. Introduction

The volcanically triggered 5–6 November 1996 jökulhlaup across Skeiðarársandur, Iceland (Guðmundsson et al., 1997) remains one of the larger floods in recorded history (Magilligan et al., 2002). The event was remarkably well-documented and, as such, affords a rare opportunity to witness the geomorphic impact of a low-frequency, high-magnitude jökulhlaup on an active glacial outwash plain (*sandur*). Study of associated sediment erosion and deposition patterns also allows evaluation of current theories on sandur genesis, including the idea that jökulhlaups dominate sediment supply (Maizels, 1991, 1997), and the classic conceptual lithofacies model for sandur evolution (diffuse flow, with uniform downstream sediment fining), developed in proglacial areas and subsequently applied to many other depositional environments including alluvial fans (Boothroyd and Nummedal, 1978; Krzyszkowski, 2002), petroleum reservoirs (Maizels, 1993a), and Mars (Rice and Edgett, 1997; Fishbaugh and Head, 2002). A third model is that sandur architecture is comprised of jökulhlaup and non-flood deposits, and is not necessarily dominated by any one magnitude and frequency regime (Russell and Marren, 1999; Marren et al., 2002).

To address these theories, a fundamental question about the 1996 jökulhlaup is whether it represented a net erosional or aggradational event for the Skeiðarársandur outwash plain. Both processes were severe in the ~40 km^2 ice-proximal zone, where massive ice-marginal deposition ($+38 \times 10^6$ m^3) outpaced channel erosion (-25×10^6 m^3) for a net volumetric gain of $+13 \times 10^6$ m^3 of sediment (Smith et al., 2000). Except for some distal channel incision observed by satellite (Magilligan et al., 2002), however, net geomorphic impact elsewhere on the ~1250 km^2 Skeiðarársandur is unknown. Here, we use repeat-pass, airborne scanning laser altimeter data collected in 1996 (pre-jökulhlaup), 1997, and 2001 to evaluate (1) net geomorphic impact of the jökulhlaup on the distal sandur, further downstream of all previous studies; and (2) post-jökulhlaup changes and recovery in the Gígjukvísl and Skeiðará, the two largest rivers flowing across the sandur. At a broader level, this study examines the response and recovery of fluvial systems to an extreme event, building upon earlier studies of how the dynamics of an ice terminus may condition the geomorphic

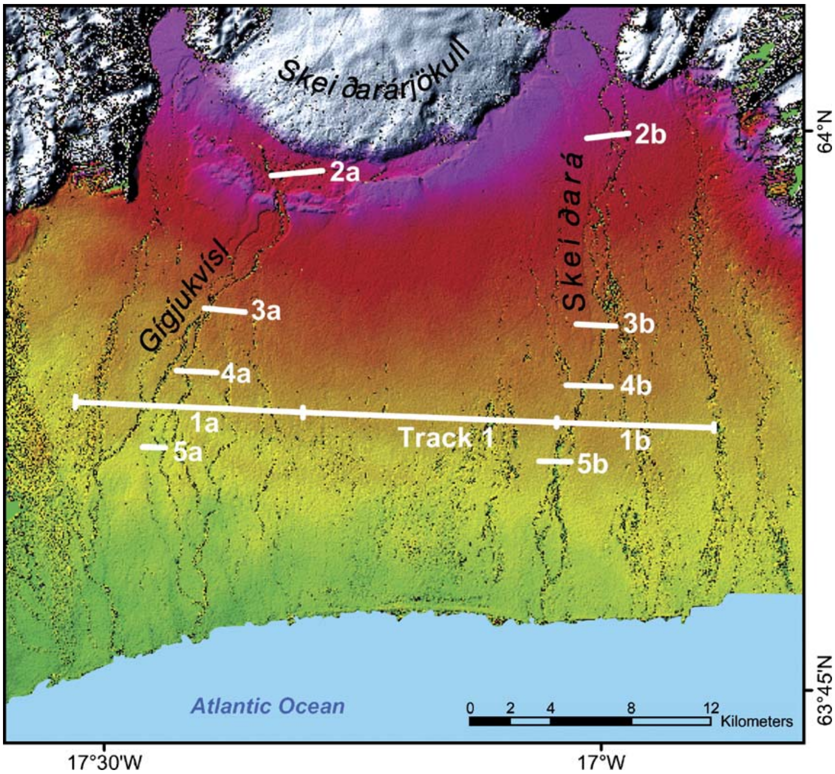

Fig. 1. Locations of repeat-pass airborne laser altimetry transects presented in this study. Track 1 was flown in 1996 (pre-jökulhlaup), 1997, and 2001. Additional transects were flown in 1997 and 2001. Background image is a post-jökulhlaup digital elevation model of Skeiðarársandur, constructed from satellite synthetic aperture radar interferometry (Smith et al., 2000).

response of Skeiðarársandur to large jökulhlaups (Gomez et al., 2000, 2002; Smith et al., 2000; Magilligan et al., 2002).

1.1. Study site and the 1996 jökulhlaup

Skeiðarársandur is the largest active glacial outwash plain in the world, and extends from the terminus of the Skeiðarárjökull outlet glacier of the Vatnajökull ice cap to the Icelandic coast (Fig. 1). In addition to a variety of non-flood facies (Russell and Marren, 1999; Marren, 2002), its stratigraphy is characterized by massive, coarsening-upward sequences of clast-supported pebbles and cobbles interpreted as deposition by a series of jökulhlaups (Maizels, 1991, 1993b), which historically have occurred every 1 to 7 years and are commonly associated with volcanic activity (Guðmundsson et al., 1995). Meltwater from subglacial eruptions and/or geothermal heat accumulates in the subglacial Grímsvötn caldera lake, where increasing hydrostatic pressure eventually breaches an ice dam at the glacier bed and triggers a jökulhlaup (Björnsson, 1992). From 30 September to 13 October, 1996, a large subglacial volcanic fissure eruption melted through 500–750 m of the overlying ice cap, causing accumulation of 3.6 km^3 of meltwater in Grímsvötn during the next 5 weeks (Guðmundsson et al., 1997). On 4 November 1996, failure of the ice dam on the eastern margin of the caldera released a record jökulhlaup that flowed subglacially for 50 km beneath Skeiðarárjökull before breaking onto Skeiðarársandur. Flows first appeared in the Skeiðará by 0720 hours UT on 5 November, followed by additional breakouts that occurred progressively westward along a ~25 km length of the glacier terminus. Peak discharge, estimated at ~53,000 $m^3\ s^{-1}$ (Snorrason et al., 1997), was reached within 15 h. Except for bypassed surfaces in the ice-proximal zone and a N–S strip down the central sandur, flows coalesced to inundate about 750 km^2, or ~75% of the outwash plain (Sigurðsson et al., 1996; Smith et al., 2000; Gomez et al., 2000). Initial flows were hyperconcentrated debris lobes that surged from the glacier margin at velocities of up to 6 $m\ s^{-1}$, and sediment supply remained high even in the waning stages of flow (Russell and Knudsen, 1999a). Within ~48 h the jökulhlaup had created a spectacular suite of proglacial features, including transported giant clasts and ice blocks, massive aggradation deposits, eroded scarps, turbidite sequences englacial sediment deposition, supraglacial features, and a supraglacial collapse em-

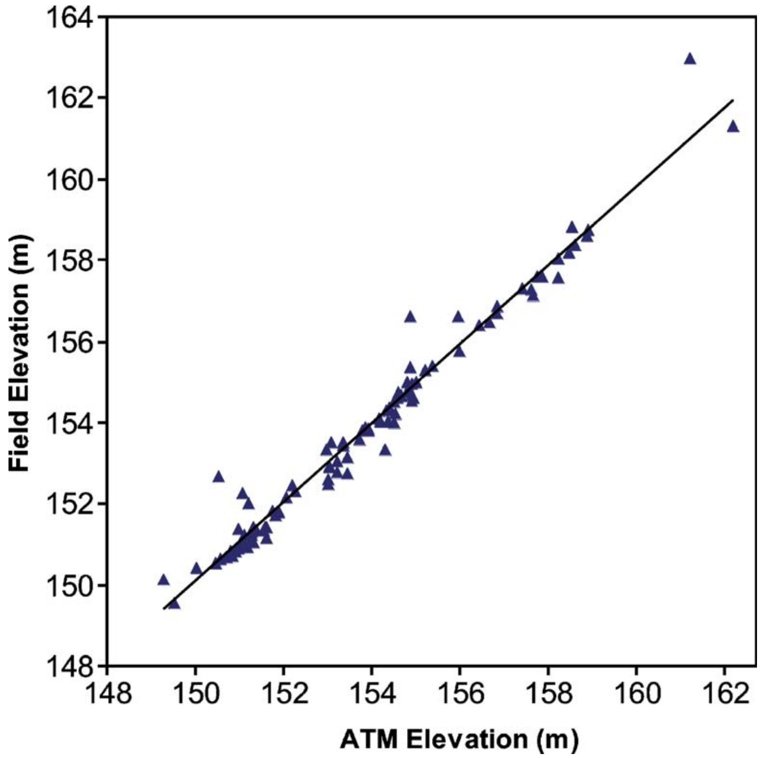

Fig. 2. Validation of NASA Airborne Topographic Mapper (ATM) laser altimeter elevation data from ground-survey measurements taken simultaneously with the 2001 mission.

bayment (Russell and Knudsen, 1999a,b, Russell et al., 1999, 2001; Smith et al., 2000; Gomez et al., 2000; Roberts et al., 2000; Roberts et al., 2001; Waller et al., 2001; Smith, 2002; Magilligan et al., 2002).

2. Methods

The National Aeronautics and Space Administration Airborne Topographic Mapper (ATM) is a conically scanning airborne laser altimeter system that can acquire narrow swaths of closely spaced (~1–3 m) elevation data with height errors of only ~8.5 cm (Krabill et al., 2002). Even denser echo spacing (~5 cm) may be obtained by operating the instrument in profiling mode. The ATM obtains range estimates by firing short duration laser pulses (<2 ns) at a 5 kHz rate, directed in a 30° or 45° cone to intercept the ground surface. When deployed on an aircraft, ATM ranging data are combined with post-flight differential GPS tracking (providing vertical and horizontal aircraft trajectory) and laser ring gyro attitude (providing pointing angle) to produce an array of observations of surface elevations georeferenced to the center of the Earth in an International Terrestrial Reference Frame (ITRF) ellipsoidal coordinate system. Absolute precision of derived elevations is a function of instrument stability and calibration, and accuracies in GPS and inertial navigation system estimates of aircraft position, attitude and motion. The ATM is deployed on a Twin Otter or P-3 aircraft from the NASA Goddard Space Flight Center/Wallops Flight Facility, Virginia. Further description of the NASA ATM instrument, its capability and errors is provided by Brock et al. (2002) and Krabill et al. (2002).

A NASA P-3 aircraft was deployed to collect ATM profiles and scans over fluvially impacted portions of

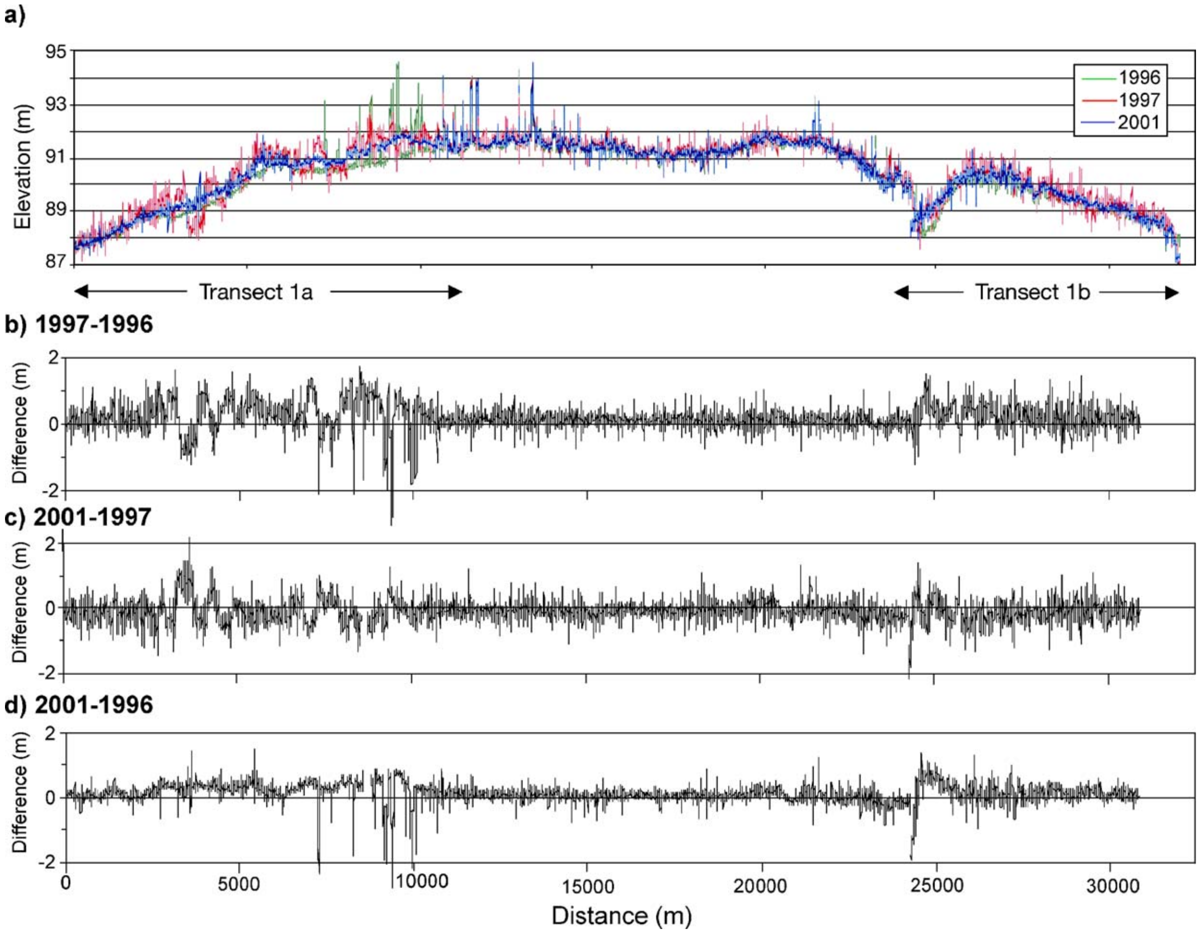

Fig. 3. (a) NASA Airborne Topographic Mapper (ATM) elevation profiles acquired along Track 1 in 1996 (pre-jökulhlaup), 1997 and 2001. Subtraction of these data yield difference-profiles representing (b) net topographic changes caused by the 1996 jökulhlaup (1997–1996); (c) post-event modification to jökulhlaup deposits and channels (2001–1997); and (d) net topographic changes after ~5 years (2001–1996). Erosional losses and depositional gains occurred in primarily in braided channel complexes of the Gígjukvísl (Transect 1a) and Skeiðará (Transect 1b) rivers.

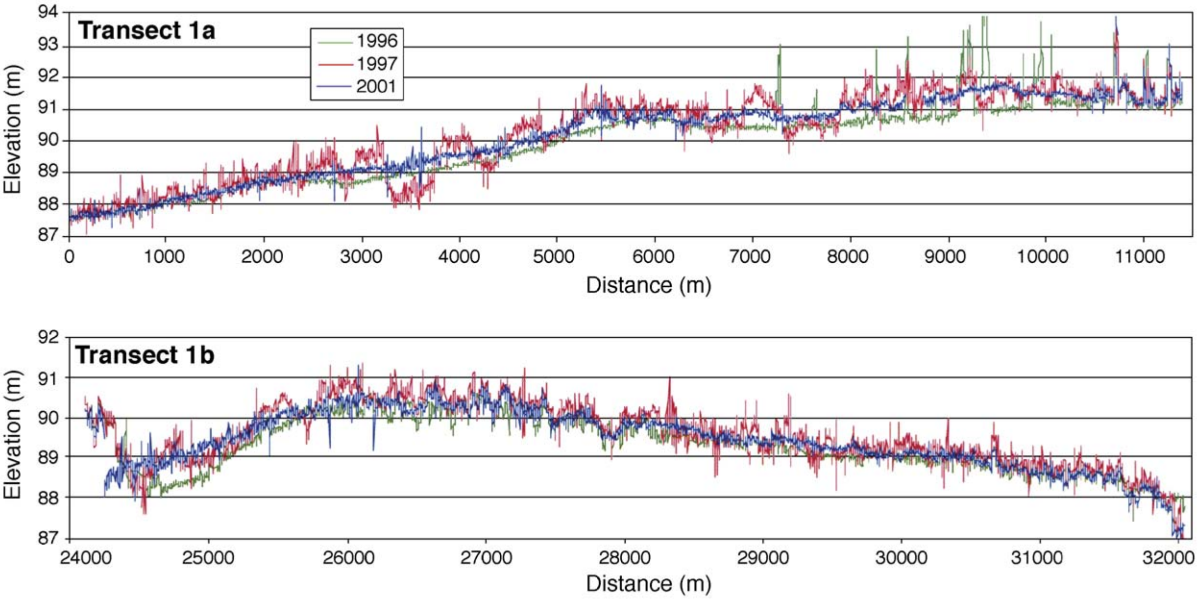

Fig. 4. Expanded views of 1996, 1997 and 2001 NASA Airborne Topographic Mapper (ATM) elevation profiles (from Fig. 3a) along Transect 1a (Gígjukvísl) and 1b (Skeiðará).

Skeiðarársandur on 1 June, 1996 (pre-jökulhlaup), 6 May, 1997 and 19 May, 2001. Fig. 1 shows the locations of these transects, superimposed on a post-jökulhlaup digital elevation model constructed using satellite synthetic aperture radar interferometry (InSAR) (Smith et al., 2000). As compared with InSAR, airborne laser altimetry offers poor spatial coverage but superior spatial and vertical resolution (Smith, 2002). Missions were flown in late spring when snow and water cover on the sandur were minimal. The 1996 data are limited to a single profiling track running from east to west across the central sandur (Track 1, Fig. 1). In 1997 and 2001, additional profiling and scanning-mode data were taken from a series of parallel E–W transects, from the

Table 1
Geomorphic impact and recovery from the 1996 jökulhlaup, computed from 1996, 1997, and 2001 NASA Airborne Topographic Mapper (ATM) elevation data along Track 1

	Year		Deposition	Erosion	Net
Transect 1a (Gígjukvísl)	1997–1996	Depth (cm)	46.4	−40.0	29.0
		Distance (m)	8986	2262	11,263
	2001–1997	Depth (cm)	29.6	−29.5	−9.2
		Distance (m)	3789	7247	11,048
	2001–1996	Depth (cm)	29.0	−35.3	19.4
		Distance (m)	9475	1651	11,138
Transect 1b (Skeiðará)	1997–1996	Depth (cm)	34.2	−20.9	24.4
		Distance (m)	6436	1384	7824
	2001–1997	Depth (cm)	21.1	−27.9	−14.2
		Distance (m)	2180	5599	7789
	2001–1996	Depth (cm)	23.9	−19.9	10.3
		Distance (m)	5423	2437	7881
Track 1 (total)	1997–1996	Depth (cm)	31.5	−25.2	21.5
		Distance (m)	26,066	5567	31,657
	2001–1997	Depth (cm)	21.7	−23.8	−10.3
		Distance (m)	9255	22,061	31,365
	2001–1996	Depth (cm)	21.7	−19.1	11.1
		Distance (m)	23,400	8198	31,670

Total erosion, deposition and net change are computed over varying time intervals (1996–1997, 1997–2001, and 1996–2001) for the Gígjukvísl river (Transect 1a), the Skeiðará river (Transect 1b), and the total track (Track 1). Corresponding lengths of deposition, erosion, and the total track are also shown.

ice margin to the distal sandur (Fig. 1). Following median-filter removal of data outliers caused by uncompensated aircraft motion and other noise, temporal elevation changes were computed by subtracting individual repeat-pass laser echoes along a straight profile. The 2001 flight mission was supported by a simultaneous field campaign to validate the ATM elevation estimates. Using a laser total station, several long elevation transects were measured across areas simultaneously scanned by the ATM. These ground-based elevations were tied into permanent Icelandic geodetic benchmarks and located with differentially corrected GPS. Close agreement between ground and altimetry data ($r^2 = 0.97$) confirms the capability of the instrument to resolve bedform-scale fluvial structures observed in the field (Fig. 2).

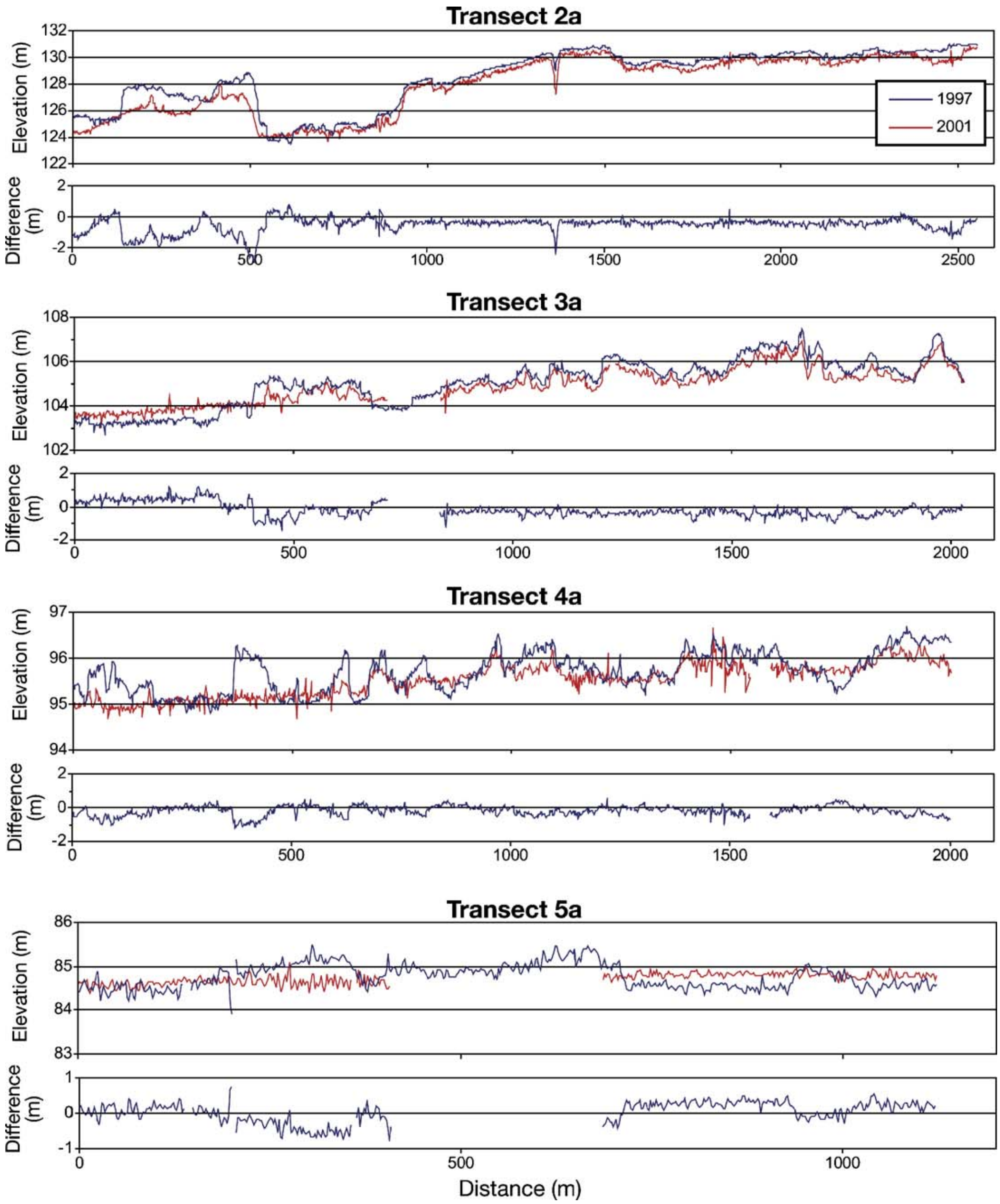

Fig. 5. Elevation and difference profiles showing post-jökulhlaup topographic changes between 1997 and 2001 in four transects across the Gígjukvísl river. Transect locations are shown in Fig. 1.

3. Results

3.1. Central transect: 1996, 1997 and 2001

The single pre-jökulhlaup ATM transect acquired in 1996 across the central Skeiðarársandur (Track 1, Fig. 1) was successfully re-flown in 1997 and 2001, allowing direct evaluation of the geomorphic impact of the jökulhlaup and subsequent recovery in this previously unstudied area (Figs. 3 and 4). Three “difference profiles” (1996–1997, 1997–2001, and 1996–2001) represent (1) elevation gains or losses caused by the jökulhlaup (Fig. 3b), (2) subsequent modification to the jökulhlaup deposits (Fig. 3c), and (3) jökulhlaup gains/

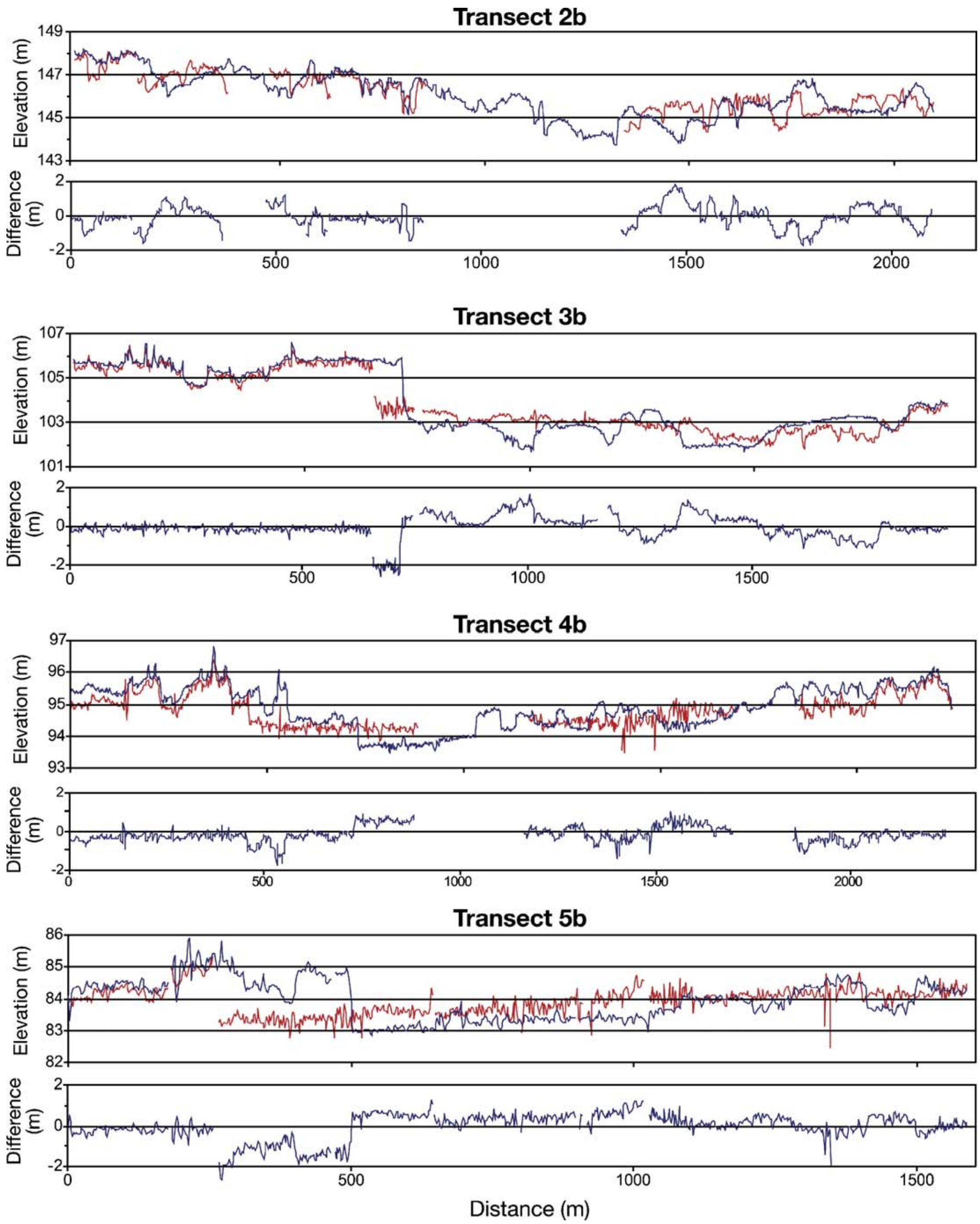

Fig. 6. Elevation and difference profiles showing post-jökulhlaup topographic changes between 1997 and 2001 in four transects across the Skeiðará river. Transect locations are shown in Fig. 1.

Table 2
Post-jökulhlaup changes in four transects of the Gígjukvísl river, computed from NASA Airborne Topographic Mapper (ATM) elevation profiles measured in 1997 and 2001

		Deposition	Erosion	Net
Transect 2a	Depth (cm)	20.6	− 58.6	− 52.8
	Distance (m)	182	2352	2536
Transect 3a	Depth (cm)	43.0	− 38.2	− 19.7
	Distance (m)	430	1461	1891
Transect 4a	Depth (cm)	14.9	− 31.2	− 18.2
	Distance (m)	551	1401	1952
Transect 5a	Depth (cm)	23.4	− 26.8	3.4
	Distance (m)	498	330	828

Corresponding lengths of deposition, erosion and each total transect are also shown.

losses still remaining after ~5 years (Fig. 3d). Little or no elevation change is found in the high-elevation sandur interior, confirming previous interpretations of little impact there (Smith et al., 2000, Gomez et al., 2000). Substantial aggradation occurred, however, in braided channel networks of the Gígjukvísl and Skeiðará rivers which flow southward on the western and eastern sides of the sandur, respectively. In the Skeiðará, this aggradation was manifested primarily by partial channel infilling (Figs. 3a,b and 4). Relatively few large new channels were incised, length scales of braid channels and alternate bars were similar in 1996 and 1997, and the Skeiðará thalweg migrated laterally (westward) with little change in base elevation. In the Gígjukvísl, however, jökulhlaup eradicated dunes (removal of spikes, Figs. 3 and 4) and eroded ~6 large new channels ~200–600 m wide and ~1–2 m deep, incised up to ~1 m below previous bed elevations (Figs. 3a,b, and 4). Deposited between these channels were giant alternating bars ~300–400 wide and over 1 m thick. These "megaformed" channels were subsequently filled and bars removed from 1997 to 2001, with a return to gentler, pre-jökulhlaup relief albeit at a higher bed elevation (Figs. 3c,d and 4). In the Skeiðará, jökulhlaup deposits still remaining by 2001 resided primarily as deposits in the main channel (Figs. 3d, and 4).

Summation of the profiles shown in Fig. 3b, c and d yields transect-integrated values for net elevation loss (erosion), gain (deposition) and total net change over the time intervals 1996–1997, 1997–2001, and 1996–2001 (Table 1). The 1996 jökulhlaup caused net aggradation of +29 and +24 cm in the Gígjukvísl (Transect 1a) and Skeiðará (Transect 1b), respectively. Despite similar net gains and a gentler preexisting relief, the Gígjukvísl experienced more pronounced erosion and deposition (− 39 cm and +46 cm, respectively) as compared with the Skeiðará (− 21 and +34 cm). Between 1997 and 2001, net elevations lowered by − 9 and − 14 cm in the Gígjukvísl and Skeiðará, respectively. Averaged across the entire 32 km transect (a computation that includes the non-impacted parts of the central sandur), the 1996 jökulhlaup emplaced +32 cm (distributed over 26.0 km) and removed − 25 cm sediment (distributed over 5.6 km) for an average net aggradation of +22 cm (Table 1). Between 1997 and 2001, nearly half of this material (− 10 cm) was removed. By 2001, the net sediment aggradation from the 1996 jökulhlaup was reduced to +19 cm (Gígjukvísl), +10 cm (Skeiðará) and +11 cm (total transect) across this E–W section of the central Skeiðarársandur.

3.2. Post-jökulhlaup changes (1997–2001)

The NASA ATM flew four shorter, repeat-pass transects in 1997 and 2001, allowing a broader examination of post-event recovery on Skeiðarársandur (Fig. 1). In Gígjukvísl and Skeiðará, these transects range from the ice-proximal zone to the distal sandur, for a total of five transects in each river (including Transects 1a and 1b, subset from 1997 to 2001 along Track 1). Elevation and difference profiles for these smaller transects are shown in Figs. 5 and 6. From 1997 to 2001, the upper Skeiðará displays lateral re-working of braided channels and bars, with little base level change and similar relief scales in both years (Fig. 5, Transect 2b). Downstream, the Skeiðará shows evidence of channel infilling and lateral migration in all three transects (Fig. 5, Transects 3b, 4b, 5b). Some infilling and erosion of larger channels and bars is found in Transect 3b. In the Gígjukvísl, upstream transects (Fig. 6, Transects 2a, 3a) show significant elevation losses (note that Transect 2a is oriented parallel to flow direction so braided channel cross-sections are not seen). Down-

Table 3
Post-jökulhlaup changes in four transects of the Skeiðará river, computed from NASA Airborne Topographic Mapper (ATM) elevation profiles measured in 1997 and 2001

		Deposition	Erosion	Net
Transect 2b	Depth (cm)	51.9	− 49.2	− 2.3
	Distance (m)	696	803	1499
Transect 3b	Depth (cm)	44.5	− 38.8	− 5.5
	Distance (m)	752	1129	1881
Transect 4b	Depth (cm)	35.5	− 35.7	− 17.1
	Distance (m)	466	1321	1788
Transect 5b	Depth (cm)	42.1	− 59.1	− 4.9
	Distance (m)	824	714	1540

Corresponding lengths of deposition, erosion, and each total transect are also shown.

stream, the Gígjukvísl is characterized by the removal of ~1 m bars (Transect 4a) and channel infilling (Transect 5a).

Transect-integrated values of total erosion, deposition and net change over the period 1997–2001 suggest a contrast in post-jökulhlaup response between the two rivers (Table 2). Upstream reaches of the Gígjukvísl (Transects 2a, 3a) experienced the largest net elevation losses seen in this study, especially near the ice margin (−53 cm, Transect 2a). In contrast, upstream losses in the Skeiðará were small (−2 and −6 cm in Transects 2b and 3b, respectively; Table 3). Downstream, both rivers display similar net losses (−18, −17 cm in Transects 4a, 4b) followed by decreasing losses in the Gígjukvísl (−9, +3 cm in Transects 1a, 5b) relative to the Skeiðará (−14, −5 cm in Transects 1b, 5b).

4. Discussion and conclusion

These results show that the 5–6 November 1996 jökulhlaup caused widespread sediment deposition and net aggradation in distal areas of Skeiðarársandur, despite simultaneous and often severe erosion in channels. This finding, when combined with an earlier determination of net deposition in the ice-proximal zone (Smith et al., 2000), establishes that the November 1996 jökulhlaup was a net aggradational event. As such, the idea that jökulhlaups play an important role in delivering large quantities of sediment to glacier outwash plains (Maizels, 1991, 1997) is directly supported by our remotely sensed lidar data, as well as recent ground-penetrating radar studies (Guðmundsson et al., 2002; Cassidy et al., 2003).

The rapid post-event lowering of jökulhlaup deposits raises interesting questions about the longevity of flood-induced geomorphic impact at Skeiðarársandur, at least in terms of surface relief. Although the 1996 event caused a net elevation increase of ~+22 cm (as averaged across the entire central sandur), by 2001 nearly half of this elevation gain was removed (Table 1). Along the central and western ice margin, which experienced massive aggradation up to ~12 m thick (Smith et al., 2000), more than 0.5 m of surface lowering has since occurred. Continued sediment removal at these rates will eradicate most net elevation gains from the 1996 jökulhlaup within a decade of emplacement. Even along the central and western ice margin where deposition was very thick, continued sediment removal at current rates will likely remove the surface expression within decades (barring glacial advance over the jökulhlaup deposits, or any large shifts in river flow pattern that create relict surfaces). This is not to suggest that jökulhlaup stratigraphic sequences are short-lived: on the contrary, the Skeiðarársandur jökulhlaups are known to emplace deep scour-and-fill deposits that survive long into the future (Guðmundsson et al., 2002). The geomorphic expression at the sandur surface, however, at least for this particular event, appears to be short-lived. Therefore, the surface elevation profile of Skeiðarársandur may be controlled more by sea level (river base level) and the elevation of the glacier bed than by the total volume of sediment delivered from jökulhlaups.

At a shorter time scale, interesting contrasts are found between the western and eastern rivers draining Skeiðarársandur. Along Track 1, both rivers experienced similar net elevation gains from the jökulhlaup (+29, +24 cm in the Gígjukvísl and Skeiðará, respectively). The 1996 jökulhlaup radically transformed the Gígjukvísl, however, from a low-relief, braided-channel network to a series of giant alternate bars and over-deepened channels, in part because peak flows there (~20,000 $m^3 s^{-1}$) were the largest ever routed through this river course (Russell et al., 1999). By 2001, these features had largely disappeared. From 1997 to 2001, the Gígjukvísl was marked by rapid erosion in its upstream reaches, tapering to small elevation losses or gains downstream. In the Skeiðará, post-jökulhlaup erosion was minimal in its upper reaches, but steadily increased downstream. By 2001 the Skeiðará had removed −14 cm of net jökulhlaup gains, leaving only +10 cm net aggradation remaining (Table 1). In contrast, the Gígjukvísl removed less (−9 cm), leaving nearly double the net jökulhlaup aggradation after 5 years (+19 cm).

The observed spatial contrasts in the impact and recovery from the jökulhlaup are likely driven by a recent change in how water and sediment are dispersed from the ice margin onto Skeiðarársandur. In the late 20th century, recession and lowering of the Skeiðarárjökull terminus formed a~2 km wide, ice-parallel basin along the western and central ice margin (Magilligan et al., 2002; Marren, 2002). This feature can be seen prominently in the InSAR-derived digital elevation model comprising the base map for Fig. 1. Previous studies have noted that the appearance of this basin has transformed the central and western Skeiðarársandur from a diffuse-source braided outwash system to a series of fixed, channelized outlets for the discharge of water and sediment, creating relict surfaces in the proglacial zone and effectively decoupling the glacier from its ice-proximal sandur (Gomez et al., 2000, 2002; Smith et al., 2000; Magilligan et al., 2002). Unlike the Skeiðará, 1996 jökulhlaups in the Gígjukvísl were first ponded in this basin and routed westward along the ice margin, producing extreme sedimentation in the vicinity of Transect 2a. Subsequent erosion of this sediment is indicated by the large elevation losses seen upstream (Transects 2a, 3a), and its downstream transport likely explains the modest losses or slight gains observed in lower reaches of the Gígjukvísl (Transects 1a, 5a). In contrast, the Skeiðará experienced little ice-marginal deposition (Smith et al., 2000) and was also larger, allowing more effective conveyance of water and sediment discharge away from the Skeiðarárjökull terminus. This spatial asymmetry in sediment dispersal provides further support to the contention (Gomez et al., 2000; Magilligan et al., 2002) that the classic sandur lithofacies model may not adequately describe sandur slope and sediment grain-size distributions during periods of glacier recession, especially in geomorphic settings where the ice margin is topographically detached from its outwash plain.

Geomorphic recovery from floods has been well documented in alluvial systems (Schumm and Lichty, 1963; Costa, 1974; Magilligan and Stamp, 1997), but is less understood in ice-marginal environments. The hydrologic regime in jökulhlaup-prone glacial settings is not unlike that of “flashy” semi-arid alluvial systems, where low frequency, high-magnitude floods are followed by sustained periods of lesser flow. The geomorphic impact of rare flood events tends to persist in such systems, because subsequent re-working of flood deposits is competency-limited (Baker, 1977). This study of the spatial- and time-transgressive nature of sediment dispersal and recovery in an ice-marginal setting shows that while the 1996 jökulhlaup caused massive deposition in the proglacial zone, these deposits are being rapidly re-mobilized by post-jökulhlaup meltwater runoff. This phenomenon is likely explained by the presence of higher levels of background discharge at Skeiðarársandur, combined with a contrast in sediment size distribution. In semi-arid alluvial systems, coarse size distributions typically limit post-event sediment transport (Baker, 1977). In contrast, the 1996 jökulhlaup deposits consist of matrix-supported clasts near the ice margin fining to sand or fine gravel downstream, particularly in the Gígjukvísl (Magilligan et al., 2002). Therefore, despite analogues in hydrologic regime, the geomorphic legacy of rare floods may be less lasting in proglacial environments.

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