

# Mass balance of Vatnajökull (1991–2001) and Langjökull (1996–2001), Iceland

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**Abstract** — *The mass balance of the Vatnajökull ice cap has been monitored since 1991 and since 1996 on the Langjökull ice cap. On Vatnajökull the mass balance was positive from 1991 to 1994, close to zero 1994–1995, but negative since then. Vatnajökull has lost 0.6% of the total ice mass, 2.37 m of water evenly spread over its area during the entire 11 year survey period. The mass balance for Langjökull was negative after 1996, in total by 5.73 m, or 3% of the total ice mass. The mass balance of the two ice caps is directly correlated reflecting low winter snow accumulation and high annual temperatures. However, larger variations are seen in the mean specific winter balance of Langjökull than of Vatnajökull.*

## INTRODUCTION

Since 1991–92 annual mass balance measurements have been carried out on Vatnajökull (8100 km<sup>2</sup>) in collaboration between the National Power Company and the Science Institute, University of Iceland. The spatial and temporal distribution of the mass balance of Vatnajökull during the years 1991–95 was described in detail by Björnsson *et al.* (1998) but this paper summarizes results of the 11 year period. Furthermore, we present outcome of similar work on Langjökull (925 km<sup>2</sup>) from 1996 to 2001.

## METHODS

The mass balance was calculated by a stratigraphic method, measuring changes in thickness and density relative to the summer surface. The methodology has been described in detail by Björnsson *et al.* (1998). Mass balance observations were carried out at 45–50 locations on the Vatnajökull ice cap and 22 locations on the Langjökull ice cap (Figure 1). The survey sites are situated along a number of selected flow lines,

which span the elevation range of these glaciers. The mass balance values span the time interval between given survey dates, which are not fixed annually. The dates in the autumn are separated by approximately one calendar year, which roughly coincides with the hydrological year between October 1 and September 30. The surveys in the spring were carried out between late April and mid-May. Digital maps of the specific mass balance were constructed and volumes of mass balance were obtained by integrating the specific mass balance over the total area of the glacier. Mean mass balance values were derived as volumes divided by the glacier drainage area; which were delineated using surface elevation maps drawing the ice flow lines perpendicular to smoothed elevation contours. Error limits for the area integrals of the mass balance components are assigned less than 20%.

## RESULTS

The mass balance measurements on Vatnajökull span over 11 years (Table 1 and Figure 2). The annual net mass balance was positive in 1991 to 1994, close to



Figure 1. Typical location of mass balance stakes on Vatnajökull and Langjökull. Ice divides, separating various outlet glaciers, are drawn on Vatnajökull. – *Lega mælistika við afkomumælingar á Vatnajökli og Langjökli. Línur á Vatnajökulskorti afmarka skriðjökla.*

zero in 1994–1995 but since then it has been negative. The winter balance was highest during the first years of the decade, reached a minimum in 1996–97 and has since then been slowly increasing. The summers were colder during the first half of the decade, which is reflected in the summer ablation. The high ablation during the summer of 1997, however, was too a large extent caused by low average albedo following the exposure of the tephra layer from the Gjalp eruption in October 1996. Moreover, dust from Skeiðarársandur, originating from the jökulhaup deposits in November 1996, also spread over large parts of the ice cap. In contrast the high summer melting in 2000 was primarily attributable to warm and windy weather. The total mass loss 1991–2001 has been 2.37 m (water equivalent) or  $19.4 \text{ km}^3$  (which amounts to 1.5 times the average winter balance of the ice cap), i. e.

the ice cap lost about 0.6% of its total ice mass. In addition to this surface melting the volcanic eruption in October 1996 melted  $4.0 \text{ km}^3$  of ice.

In years of zero net balance, the equilibrium line on Vatnajökull lies at about 1100 m on the southern outlet glaciers, at 1200–1300 m on the northwestern and northern outlet glaciers. The accumulation area is thus typically about 60% of the total glacier area. During 1991–2001 the accumulation area varied from 20–70% of the total area of the outlet glaciers, the equilibrium line altitude fluctuated by 200–300 m and the annual net balance from plus to minus one metre. A 100 m rise in the equilibrium line would reduce the net balance by about 0.75 m per year.

The mass balance on Langjökull shows similar variations as on Vatnajökull. However, Langjökull is smaller and lower than Vatnajökull. Snow

Year	Winter m	Summer m	Annual m	ELA m a.s.l.	AAR %
Tungnaárjökull (352 km <sup>2</sup> )					
1991-1992	1,74	-1,50	0,24	1125	67
1992-1993	1,87	-1,74	0,13	1130	65
1993-1994	1,70	-1,84	-0,14	1160	60
1994-1996	surge				
1996-1997	0,96	-2,84	-1,88	1420	21
1997-1998	0,81	-2,3	-1,5	1460	18
1998-1999	1,15	-2,17	-1,02	1230	51
1999-2000	1,36	-2,64	-1,28	1310	40
2000-2001	1,05	-2,64	-1,71	1310	41
Köldukvíslarjökull (313 km <sup>2</sup> )					
1991-1992	1,9	~ -0,9	~ 1,0	1200	72
1992-1993					
1993-1994	~ 1,43	~ -1,47	~ -0,03	1300	61
1994-1995	1,30	-1,89	-0,59	1410	52
1995-1996	1,37	-1,76	-0,39	1410	50
1996-1997	1,39	-2,56	-1,17	1590	28
1997-1998	0,97	-2,00	-1,03	1540	35
1998-1999	1,23	-1,77	-0,54	1300	61
1999-2000	1,31	-2,04	-0,73	1450	47
2000-2001	0,88	-1,85	-0,97	1480	44
Dyngjujökull (1040 km <sup>2</sup> )					
1991-1992	2,08	~ -0,4	~ 1,7	1200	75
1992-1993	1,6	-0,33	1,27	1100	86
1993-1994	1,44	-1,25	0,19	1250	71
1994-1995	1,47	-1,45	0,02	1310	62
1995-1996	1,37	-1,76	-0,39	1410	53
1996-1997	1,13	-2,19	-1,06	1490	47
1997-1998	1,21	-1,7	-0,5	1385	59
1998-2000	surge				
2000-2001	no data				
Brúarjökull (1695 km <sup>2</sup> )					
1992-1993	1,63	-0,54	1,09	1070	77
1993-1994	1,75	-1,47	0,28	1140	67
1994-1995	1,64	-1,84	-0,20	1260	50
1995-1996	1,66	-1,88	-0,22	1230	58
1996-1997	1,13	-2,48	-1,35	1350	34
1997-1998	1,19	-1,9	-0,7	1220	59
1998-1999	1,42	-1,72	-0,30	1200	62
1999-2000	1,33	-2,44	-1,01	1450	42
2000-2001	1,66	-1,55	0,11	1200	62
Eyjabakkajökull (119 km <sup>2</sup> )					
1995-1996	2,38	-3,23	-0,85	1080	53
1996-1997	1,19	-3,41	-2,22	1290	10
1997-1998	1,21	-2,60	-1,40	1240	21
1998-1999	1,39	-2,50	-1,12	1120	45
1999-2000	1,05	-3,07	-2,02	1240	21
2000-2001	2,10	-2,02	0,08	1040	60
Breiðamerkurjökull (905 km <sup>2</sup> )					
1995-1996		-3,01		1100	53
1996-1997	0,77	-2,61	-1,84	1240	44
1997-1998	1,01	-2,44	-1,43	1180	48
1998-1999	no data			1150	51
1999-2000	1,30	-2,52	-1,22	1180	48
2000-2001	1,13	-2,37	-1,24	1150	51
Langjökull (925 km <sup>2</sup> )					
1996-1997	1,90	-3,20	-1,30	1100*, ?**	30
1997-1998	1,12	-2,82	-1,70	1175*, 1375**	10
1998-1999	1,50	-2,27	-0,77	1050*, 1300**	40
1999-2000	2,13	-2,88	-0,75	1025*, 1300**	43
2000-2001	1,28	-2,55	-1,27	1150*, 1300**	28

Table 1. MASS BALANCE between 1991–1992 and 2000–2001. Winter, summer and annual balance. ELA: equilibrium line altitude. AAR: accumulation area ratio. ELA for Langjökull is divided between its southern (\*) and northern dome (\*\*). – *Afkoma Langjökuls og skriðjökla Vatnajökuls 1991–2001. Vetrar-, sumar- og ársafkoma. ELA: hæð jafnvægislínu. AAR: hlutfall safnsvæðis af heildarflatarmáli jökulsins. Hæð jafnvægislínu á syðra hveli (\*) Langjökuls er aðgreind frá nyrðra (\*\*\*) hveli hans.*

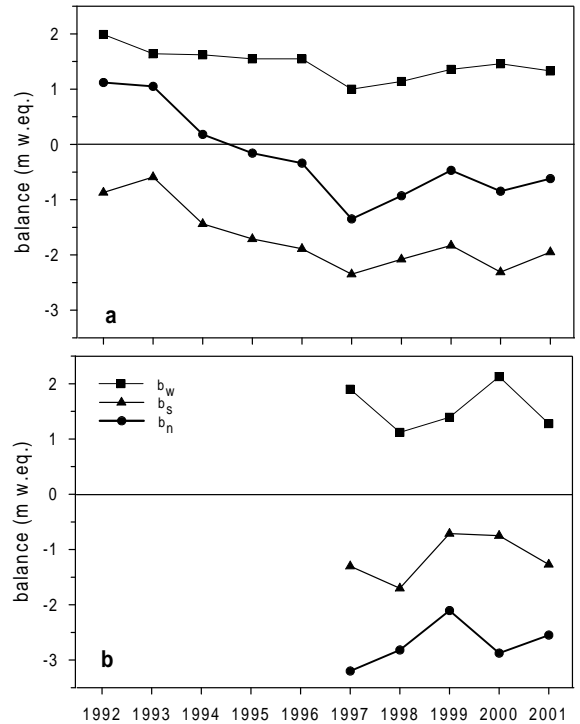


Figure 2. a. Specific mass balance of Vatnajökull from 1991–1992 to 2000–2001. The winter mass balance ( $b_w$ ) is defined as the mass of snow accumulated during the winter months, the summer balance ( $b_s$ ) is the mass balance during the summer, and the net balance ( $b_n$ ) is defined as their sum. The specific mass balance is expressed in terms (m) of the equivalent water accumulation. b. Specific mass balance of Langjökull 1996–1997 – 2000–2001. – *a. Ársafkoma Vatnajökuls frá 1991 til 2001. Vetrarafkoma ( $b_w$ ), sumarafkoma ( $b_s$ ) og ársafkoma ( $b_n$ ) í metrum vatns á ári. b. Ársafkoma Langjökuls frá 1996 til 2001.*

accumulation there is fairly sensitive to the winter temperature and position of the paths of the North Atlantic lows pressure weather fronts passing Iceland. No simple relationship can be seen between the winter balance on Langjökull and the winter precipitation at a nearby meteorological station (Hveravellir). The minimum winter balance in 2001, however, coincided with a minimum winter precipitation at the station. The net balance has been negative over the entire survey period from 1996 to 2001 and the accumulation area has varied from 10% to 40% of the glacier area. The total mass loss over the period 1996–2001 was 5.73 m (5.36 km<sup>3</sup> water equivalent), or 3% of the total ice mass of Langjökull.

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## ÁGRIP

### Afkoma Vatnajökuls (1991–2001) og Langjökuls (1996–2001)

Raunvísindastofnun Háskólans hefur á hverju ári 1991 til 2001 mælt afkomu Vatnajökuls í samstarfi við Landsvirkjun, og frá 1996 með styrkjum frá Evrópu-sambandinu. Á sama hátt hefur afkoma Langjökuls verið mæld frá 1996 til 2001. Afkoman var mæld vor og haust í punktum, sem voru dreifðir með hæð frá sporðum til hæstu svæða, 40–50 á Vatnajökli og 22 á Langjökli. Fyrstu þrjú árin var afkoma Vatnajökuls jákvæð, nálægt jafnvægi fjórða árið en hefur síðan verið neikvæð. Alls rýrnaði Vatnajökull um 19,4 km<sup>3</sup> frá 1991 (2,37 m af vatni jafndreift yfir jökulinn) og missti um 0,6% af ísmassa sínum. Afkomutölur einstaka skriðjökla eru í töflu I. Afkoma Langjökuls hefur verið neikvæð öll þau fimm ár sem hún hefur verið mæld, 1996–2001, samtals um 5,36 km<sup>3</sup> (5,73 m), og ísforði hans rýrnaði um 3%.

## REFERENCES

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