ORKUSTOFNUN
Vatnamælingar

Greinargerð um uppsetningu og kvörðun afkomu- og afrennslislíkans

Þorsteinn Þorsteinsson og Bergur Einarsson

Greinargerð THOR-BEE-2006/001

ORKUSTOFNUN
Vatnamælingar

Lykilsíða

Greinargerð nr.:	Dags.:	Dreifing: Opin ☒ Lokuð ☐
THOR-BEE-2006/001	12. janúar 2006	**Skilmálar:**

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Uppsetning og kvörðun afkomulíkans	7-581931

Unnið fyrir:

Auðlindadeild Orkustofnunar

Samvinnuaðilar:

Útdráttur:

Nýtt líkan til reikninga á jökulafkomu hefur verið sett upp á Vatnamælingum Orkustofnunar og kvarðað fyrir Hofsjökul með afkomugögnum frá 1988–2004. Líkanið er reitskipt hefðbundið gráðudagastuðla-líkan en einnig er hægt að nota í því sérstaka stuðla sem taka tillit til bráðnunar vegna inngeislunar frá sólu.

Lykilorð:

Hofsjökull, afkomulíkan, afkoma, gráðudagastuðlar og afrennsli.

Undirskrift verkefnisstjóra:

Yfirfarið af:

OSig, KE

Uppsetning og kvörðun afkomu- og afrennslislíkans

Nýtt líkan til reikninga á jökulafkomu og afrennsli frá jöklum hefur nú verið sett upp á Vatnamælingum Orkustofnunar og var endanlegri kvörðun og stillingu lokið í desember 2005. Höfundur líkansins er Dr. Regine Hock, jöklafræðingur við Stokkhólmsháskóla og hefur því áður verið beitt við reikninga á afrennsli frá jöklum í Skandinavíu og Alpafjöllum. Í febrúar 2005 kynnti Regine Hock starfsfólki Vatnamælinga, Veðurstofunnar og Raunvísindastofnunar uppbyggingu og notkun líkansins á 2ja daga námskeiði, sem haldið var á Orkustofnun. Á sama námskeiði voru einnig flutt erindi um fjarkönnun jökla á vegum evrópsku geimferða-stofnunarinnar, ESA, og lögð drög að notkun fjarkönnunarmynda í tengslum við líkanreikninga á afkomu Hofsjökuls.

Líkanið nýtir gögn frá veðurstöð til að reikna ákomu jökuls sem fall af hæð yfir sjávarmáli. Hiti með hæð er fundinn út frá hitafalli með hæð og hitamælingum á sömu stöð. Líkanið gerir ráð fyrir að úrkoma falli sem snjór er lofthiti fellur undir +1 °C. Veðurgögn frá Hveravöllum voru notuð við líkanreikningana og auk þess var gert ráð fyrir breytileika úrkomu í A-V og N-S stefnu, skv. líkani sem þróað hefur verið af Tómasi Jóhannessyni. Leysing er reiknuð með hefðbundnum aðferðum gráðudagalíkana; þ.e. gert er ráð fyrir að heildarleysing á tilteknu tímabili sé í réttu hlutfalli við margfeldi dagafjölda og meðalhita yfir þröskuldshæð á sama tímabili. Líkanið gerir ráð fyrir sérstökum gráðudagastuðlum fyrir snjó, frábrugðnum sams konar stuðlum fyrir jökulís. Reikna má leysingu með og án sérstakra leysingarstuðla vegna inngeislunar frá sólu. Líkanið reiknar klukkutímagildi og skilar dægursveiflu afrennslis.

Líkanið var kvarðað með afkomumælingagögnum, sem aflað hefur verið á Hofsjökli á árunum 1988–2004. Öll mæligögn voru yfirfarin sérstaklega vegna þessa verkefnis og útbúnar gagnaskrár sem lesa má inn í afkomulíkanið. Reiknaðir voru gráðudagastuðlar fyrir Hofsjökul og bornar saman niðurstöður sem fengust með og án sólgeislunar. Við kvörðun voru frávik líkanreiknaðrar vetrar- og sumarafkomu Hofsjökuls frá mældri afkomu lágmörkuð með stillingu líkanstuðla. Stöðugleiki kvörðunarinnar var kannaður með sérstökum frávikareikningi fyrir átta fyrstu og átta síðustu ár ofangreinds tímabils og einnig fyrir átta hlýjustu og átta köldustu árin. Einnig var reiknað sérstaklega fyrir mælilínurnar þrjár á Hofsjökli; á Sátujökli, Þjórsárjökli og Blágnípujökli.

Þorsteinn Þorsteinsson og Bergur Einarsson hafa unnið að uppsetningu, kvörðun og tilraunakeyrslum í náinni samvinnu við Tómas Jóhannesson (Veðurstofu Íslands), formann jöklahóps norræna verkefnisins *Climate and Energy*. Kvörðunarniðurstöðurnar voru kynntar á fundi Norðurlandadeildar alþjóðasambands jöklafræðinga (IGS) í Kaupmannahöfn þann 5. nóv. 2005 (sjá meðfylgjandi útprentun erindis). Unnið er að lokafrágangi CE-skýrslu um kvörðun hins nýja líkans og samanburð á niðurstöðum, sem fengist hafa með og án sólgeislunar. Áætlað er að skýrslan verði tilbúin til prentunar um mánaðamót janúar-febrúar 2006.

Að kvörðun lokinni voru reyndar fyrstu tilraunakeyrslur til afrennslisreikninga með dægursveiflu frá Sátujökli til Vestari-Jökulsár og niðurstöður bornar saman við rennslisgögn frá vatnshæðarmæli í Vestari-Jökulsá við Skiptabakka. Þessar keyrslur tókust vel, en bæta þarf inn í líkanið áætluðum framlögum úr grunnvatnsgeymi áður en tekið verður til við bestun afrennslishluta líkansins.

Viðauki I

Erindi Tómasar Jóhannessonar og fleiri sem flutt var á fundi Norðurlanda-deildar IGS í Kaupmannhöfn þann 5.nóv. sl. (Mass balance and precipitation modeling on the Langjökull, Hofsjökull and Vatnajökull ice caps in Iceland)

Mass balance and precipitation modeling on the Langjökull, Hofsjökull and Vatnajökull ice caps in Iceland

Tómas Jóhannesson[1], Helgi Björnsson[2],
Finnur Pálsson[2], Oddur Sigurðsson[3],
Þorsteinn Þorsteinsson[3] and Bergur Einarsson[3]

[1]Icelandic Meteorological Office
[3]Institute of Earth Sciences, University of Iceland
[2]National Energy Authority, Hydrological Service Division

5 November 2005

CHIN Chiefs of the Hydrological Institutes in the Nordic Countries

Nordic Council of Ministers

Hofsjökull

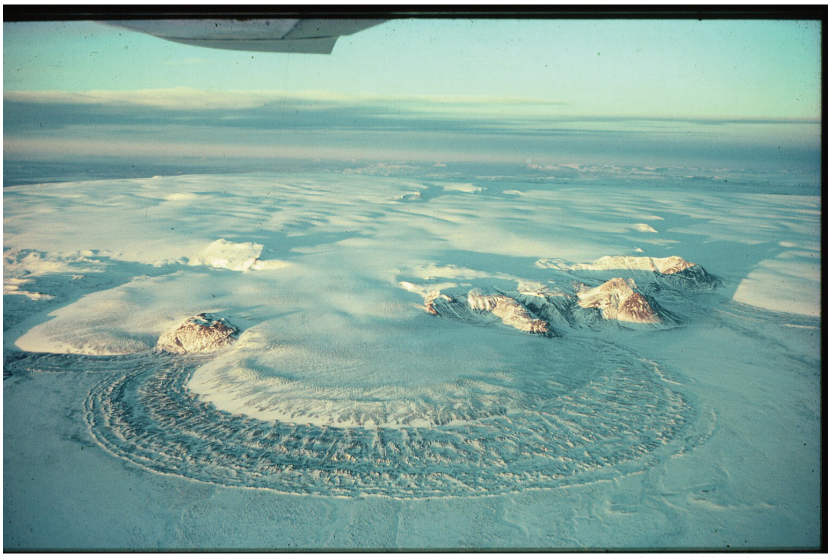

Photo: Oddur Sigurðsson

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Nordic Energy Research

Overview

- The Climate and Energy project
- Mass balance data
- Mass balance modeling
- Model calibration
  - Traditional degree-day modeling
  - Distributed precipitation
  - Degree-day modeling with potential direct radiation
- Precipitation modeling

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The Climate and Energy project

- Funded by the Nordic Energy Fund, NEFP
- 2003-2006
- Budget of 10 millj. NOK + national contributions
- Effect of climate change on hydropower, other energy sources, energy systems
- Hydrology, glaciology, time-series analysis, climate scenarios, ...

The snow and ice work group

- Tómas Jóhannesson, Philippe Crochet (Icelandic Meteorological Office)
- Þorsteinn Þorsteinsson, Oddur Sigurðsson, Jóna Finndís Jónsdóttir, Gunnar O. Gröndal (Hydrological Service, NEA)
- Helgi Björnsson, Guðfinna Aðalgeirsdóttir, Finnur Pálsson, Sverrir Guðmundsson (Science Institute, University of Iceland)
- Hallgeir Elvehøy, Liss Andreassen, Rune Engeset, Miriam Jackson (Glaciers and Snow Section, NVE)
- Regine Hock, Mattias de Woul, Valentina Radić, Per Holmlund, Per Jansson (Stockholm University)
- Andreas Ahlstrøm, Niels Reeh (ØDTU)
- Mikko Huokuna (Finnish Environmental Institute, SYKE)

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Water in Iceland as an average over the whole country

	Amount (m)
Ground water	≈100
Glaciers and ice caps	30–40
Lakes	0.13
Atmosphere	0.007
Rivers	≈0.005

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The Icelandic mass balance data set

- Langjökull
  - 1997-2004
  - 348 winter and summer mass balance values
- Hofsjökull
  - 1988-2004
  - 1106 winter and summer mass balance values
- Vatnajökull
  - 1992-2004
  - About 900 winter and summer mass balance values

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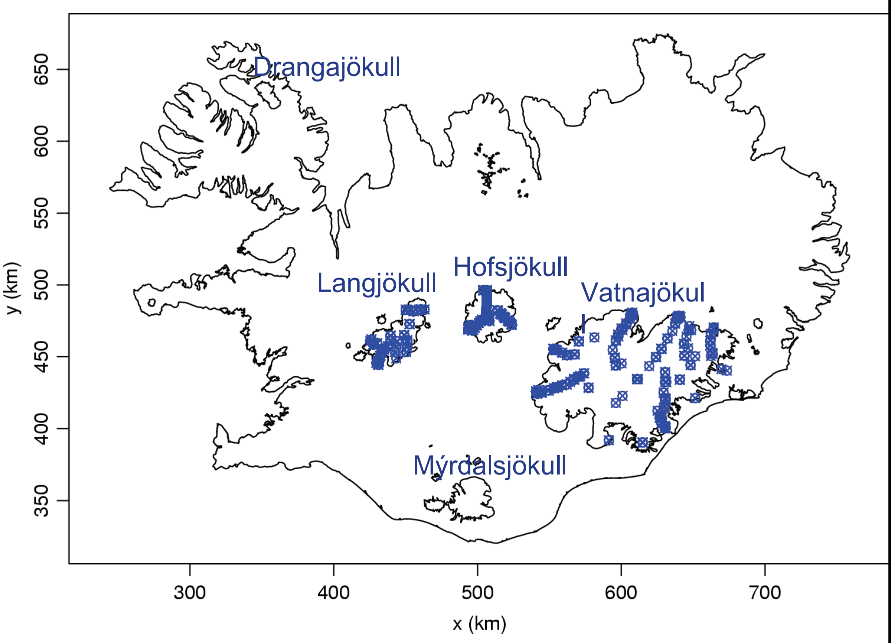
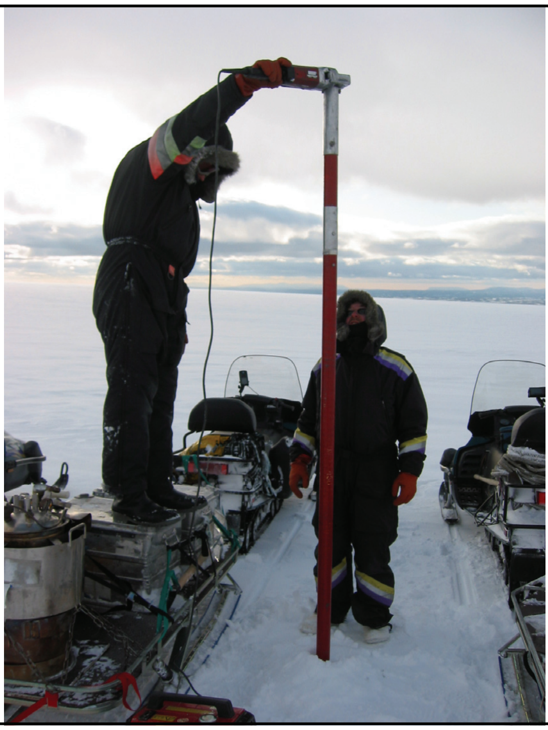
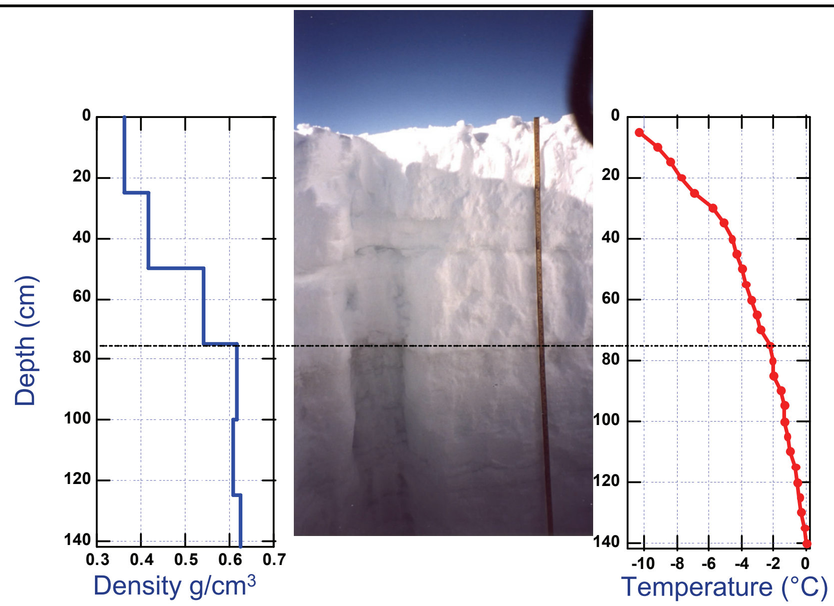
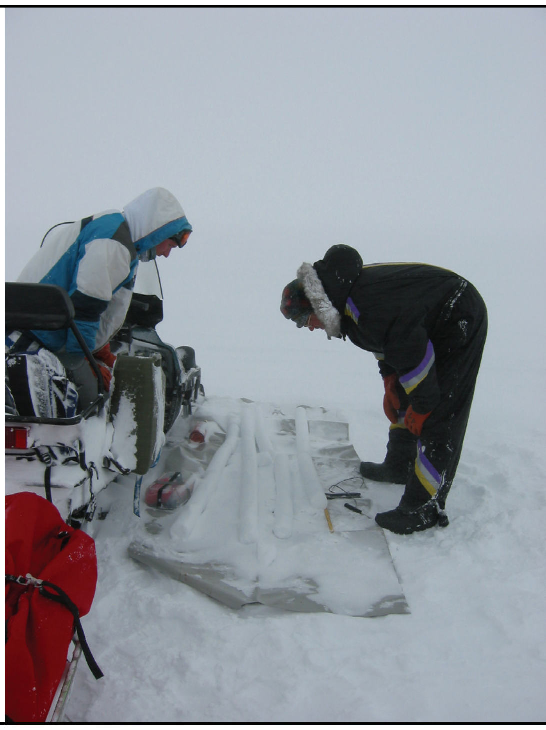
Stake locations, 1988–2004



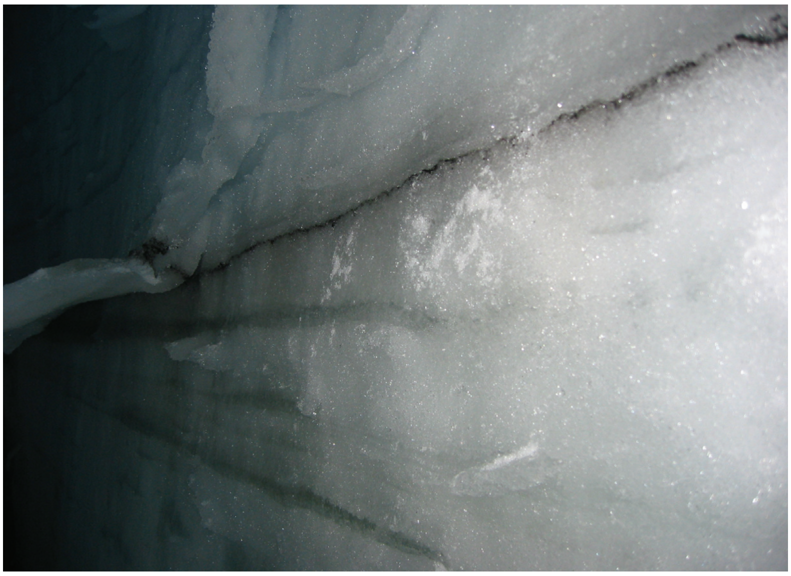




A snow pit at 1790 m a.s.l. at the top of Hofsjökull on 25 September 2003, summer snow is found at 75 cm depth



Tephra from the Hekla eruption in 1991 at 18 m depth in a crevasse in the NE corner of network (B55)



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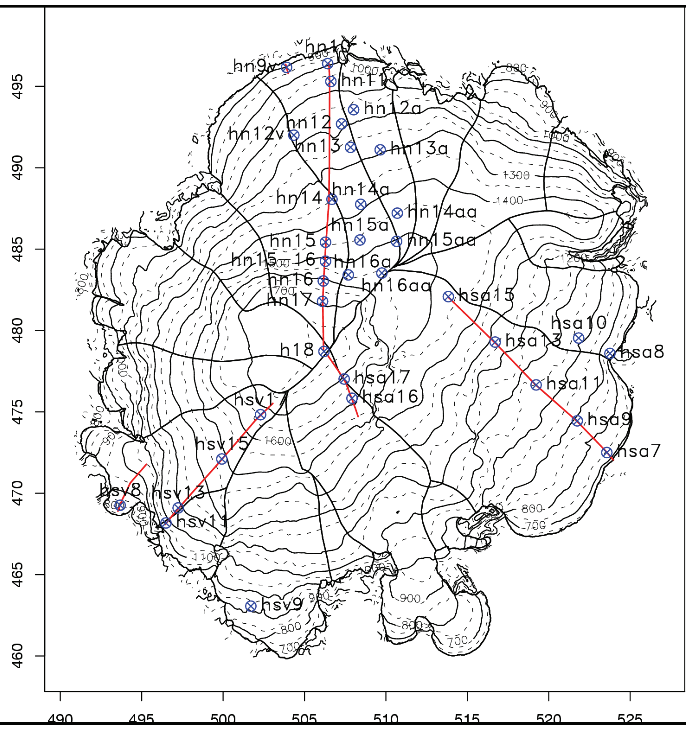

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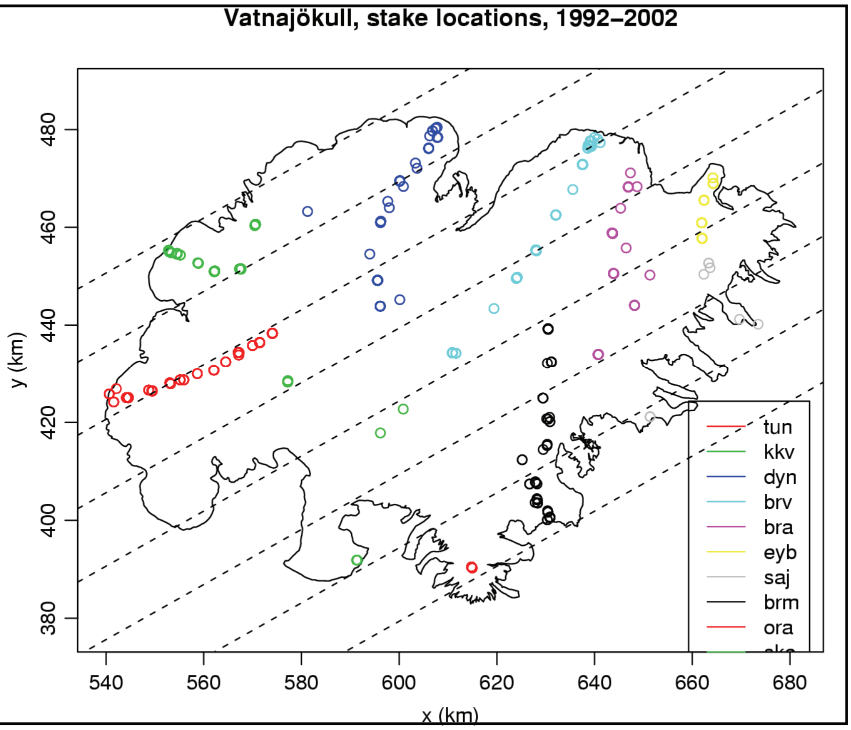

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Glacier mass balance modeling

- Mass balance measurements provide an estimate of the *difference* between snowfall and ablation and they contain *implicit* information about precipitation
- The mass balance is modeled based on daily temperature and precipitation measurements at a weather station
- The spatial distribution of the precipitation
  - horisontal and vertical gradients
- The fraction of the precipitation that falls as snow
  - a constant temperature threshold
- Degree-day melt model for computing ablation of snow and ice
  - separate degree-day factors for snow and ice
  - constant temperature lapse rate with altitude
- Non-linear least squares parameter fitting
- Modeling may be used to *transfer* mass balance observations in space and time and estimate unmeasured quantities such as precipitation

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Traditional precipitation measurements

- High time resolution
  - typically several measuremens per day or even per hour
- Long time series at many weather stations
  - but often affected by inhomogeneity problems
- Point measurements
  - difficult to obtain good spatial resolution for example for hydrological applications or for verification of NWP models
- Affected by undercatch
  - especially in high winds and during snowfall
- Bad data availability in highland areas
  - leads to problems to estimate the gradient of precipitation with altitude or analyse processes related to orographically induced precipitation

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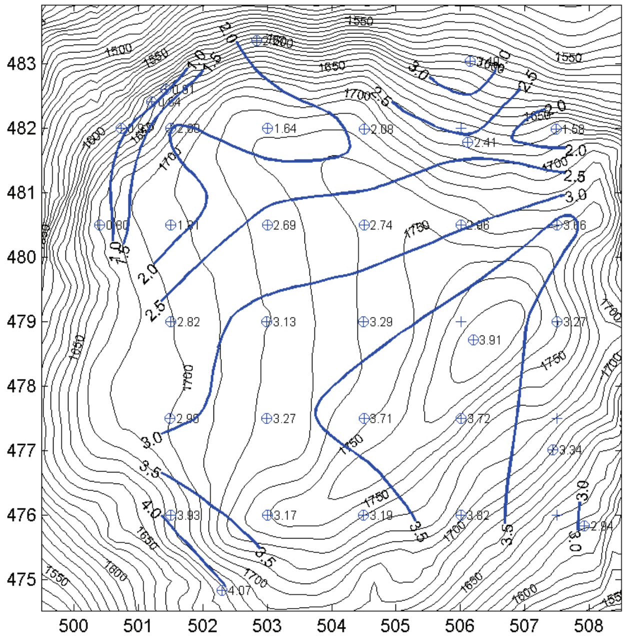
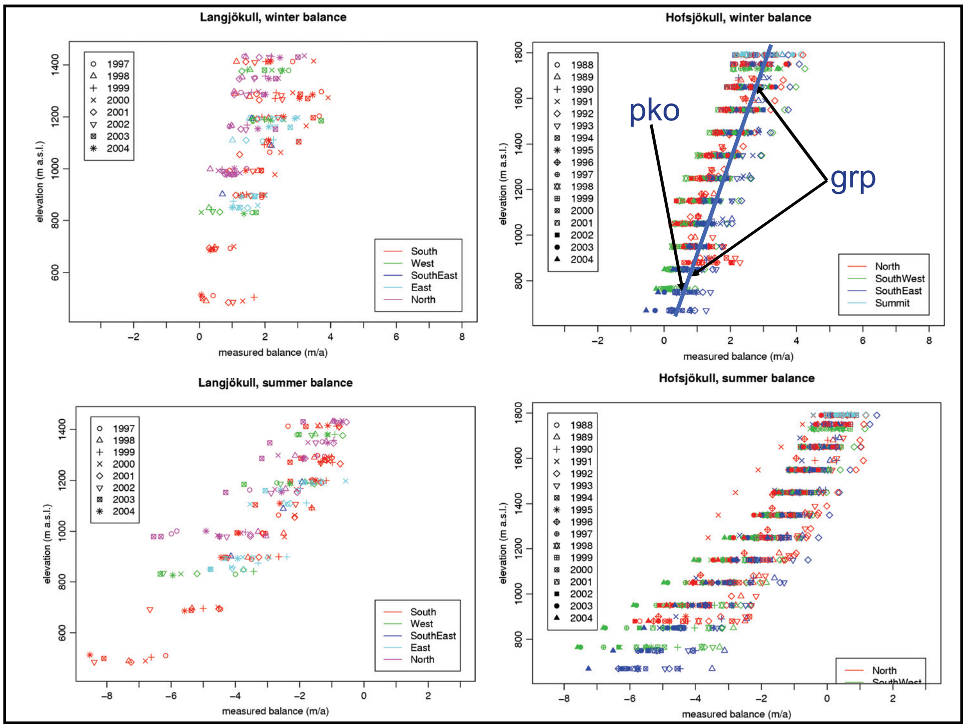
Precipitation estimates based on glacier mass balance measurements

- Mainly from highland areas and become more accurate with increasing altitude
  - important for hydrological applications
- Point measurements
  - but may be representative for large areas
  - good spatial resolution may be obtained with a limited effort
- Not affected by undercatch
  - but most rain is lost as run-off
  - ablation of snow and ice affect the mass balance
- Not direct measurement of precipitation
  - affected by snow drift and evaporation/sublimation
- Bad time resolution
  - typically two measurements per year
  - not useful for some applications such as the study of floods

Winter balance 2002-2003, isolines of w.e.





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Model calibration

- $SSQ_w = \sum(bw_o - bw_m)^2$
- $SSQ_s = \sum(bs_o - bs_m)^2$
- $SSQ = f(pko,prg,pgx,pgy,ddi,dds,...)$

```
> nls(bal ~
  balance(years,c("pko","grp","pgx","pgy","ddi","dds"),
    c(pko,grp,pgx,pgy,ddi,dds),what="ws"),
    data.frame(bal=b8804ws),
  list(pko=1.1,grp=0.2,pgx=0.02,
       pgy=0.015,ddi=0.007,dds=0.005))
  pko     grp       pgx       pgy        ddi        dds
1.101  0.2075  0.02019 -0.01655  0.007288  0.005039
residual sum-of-squares:  189.2035
>
```

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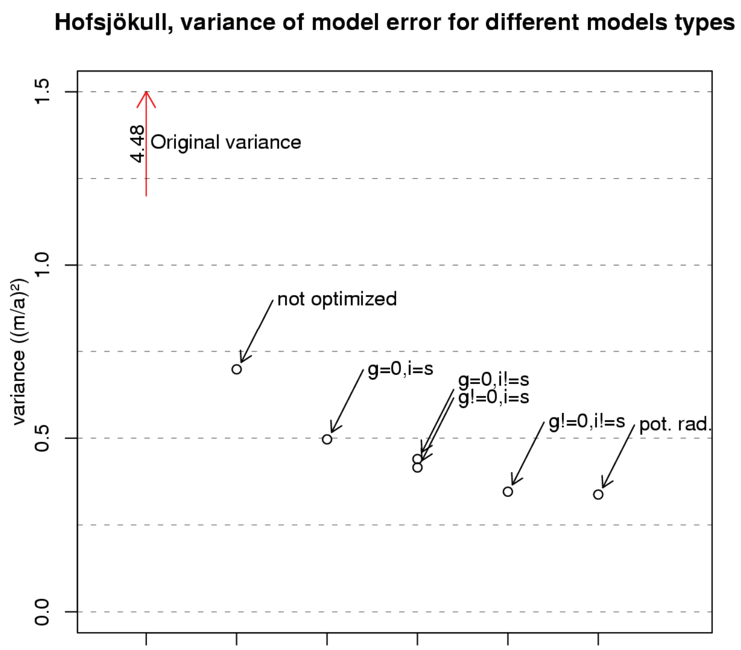

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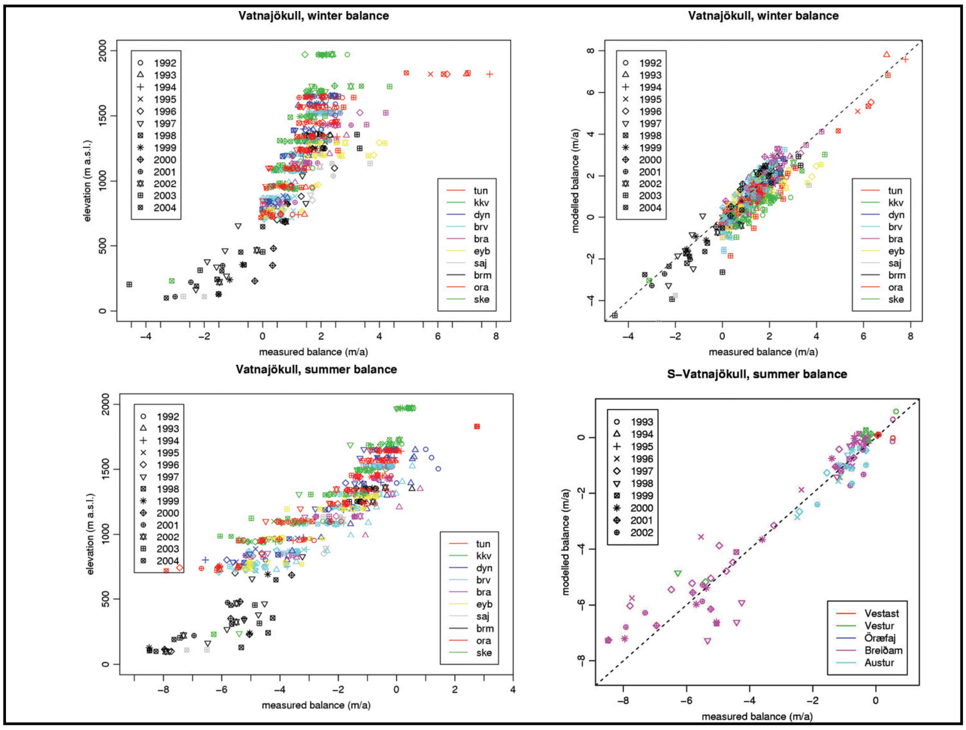
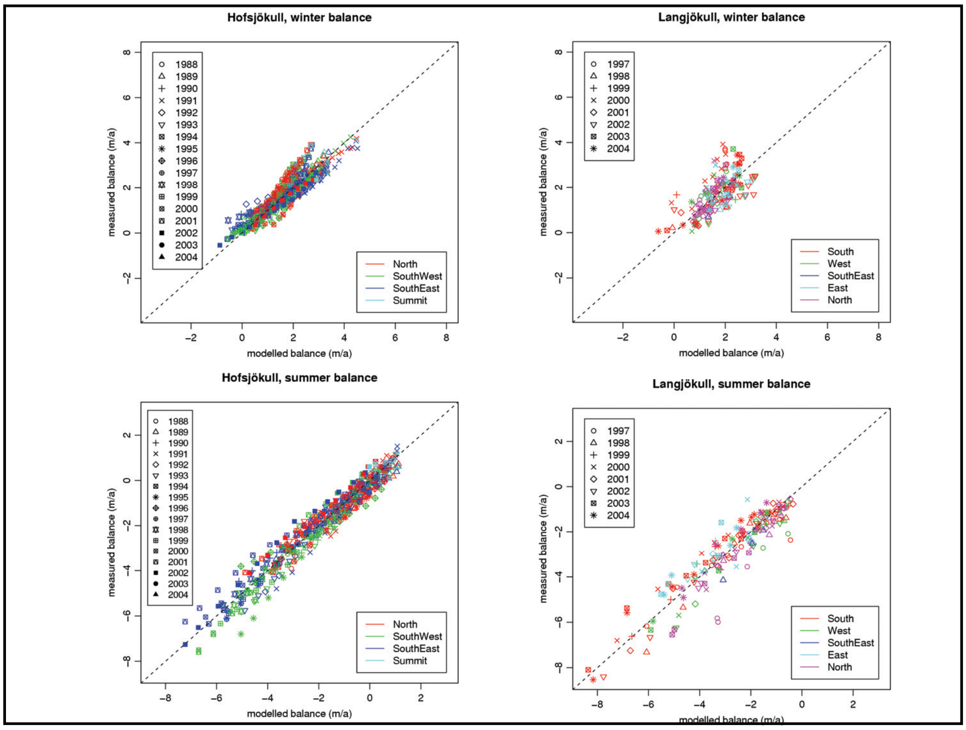
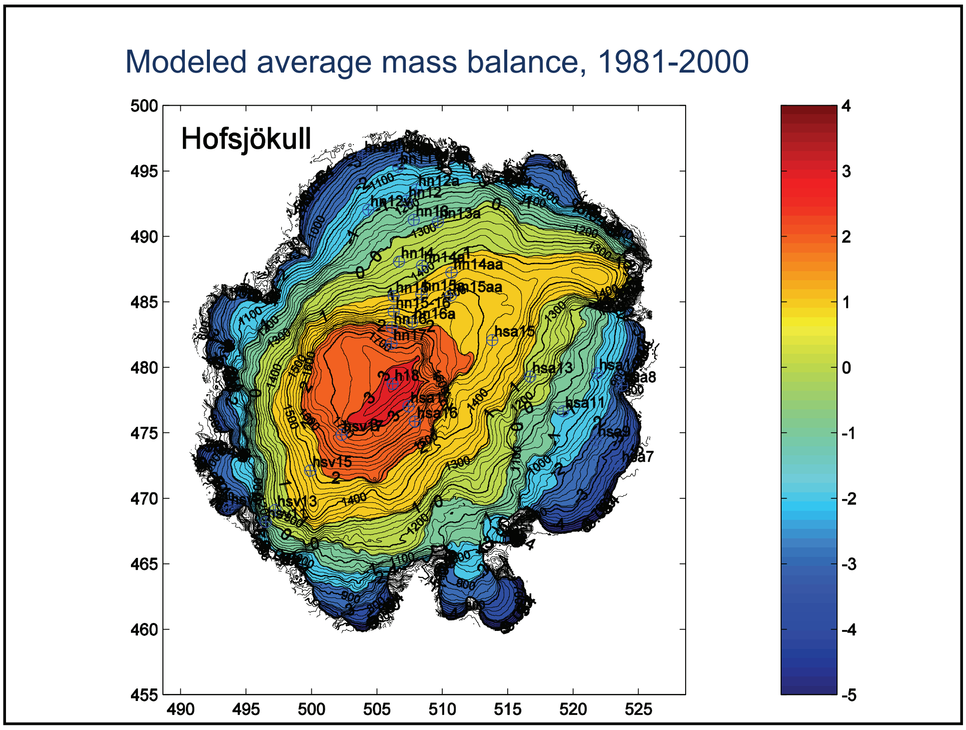
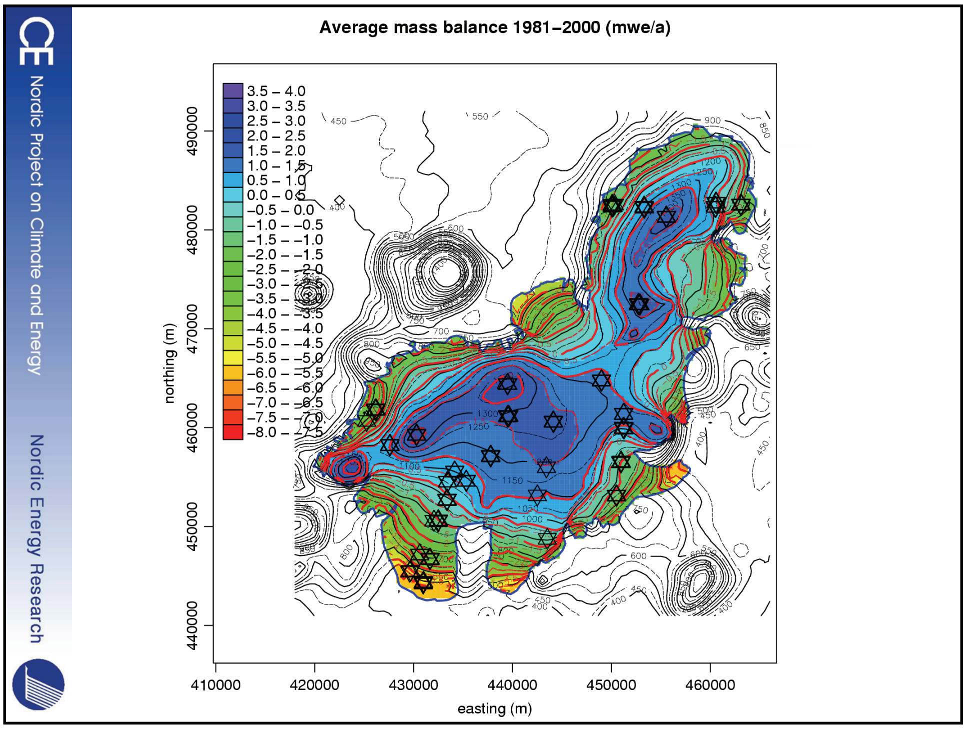
Parameter stability / reasonability of results?

- Calibrate on subsets of the data
  - first half / second half of the years
  - coldest half / warmest half of the years
  - geographic subsets
- Mass balance of ice flow basins
  - glacier geometry is the way it is for a good reason
  - it is very unlikely that the average mass balance over a decade or several decades is for example +0.5 m/a in one ice flow basin and –0.5 m/a in another nearby if the basins are known to have behaved similarly during this time period




Hofsjökull, winter balance
Langjökull, winter balance
Hofsjökull, summer balance
Langjökull, summer balance
measured balance (m/a)
modelled balance (m/a)
North
SouthWest
SouthEast
Summit
South
West
East


Modeled average mass balance, 1981-2000
Hofsjökull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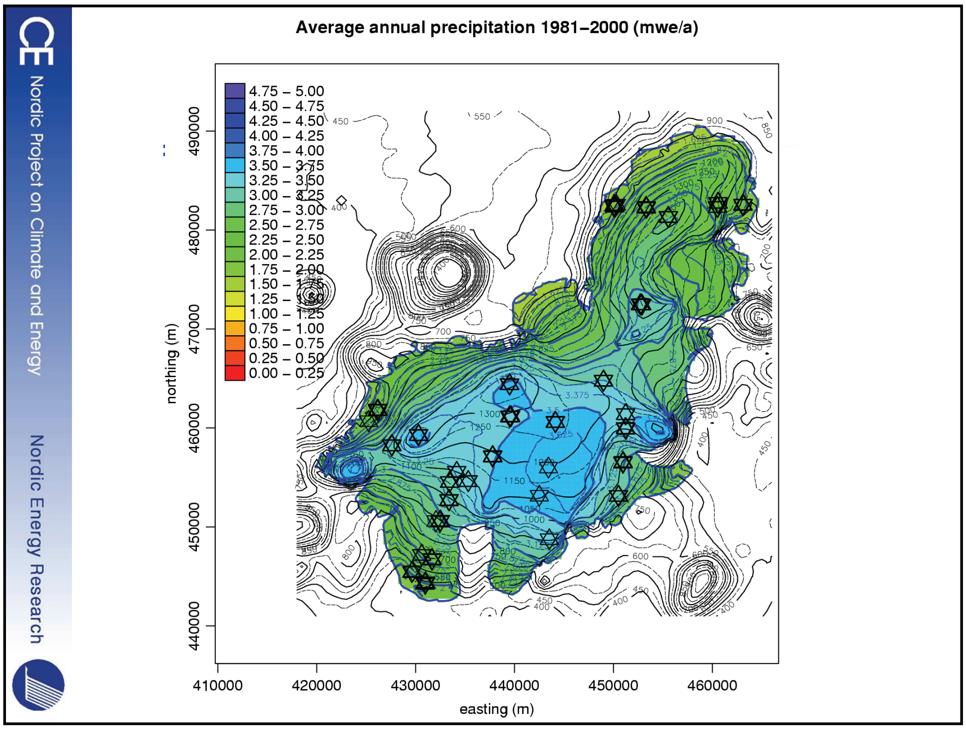
Average mass balance 1981–2000 (mwe/a)
3.5 – 4.0
3.0 – 3.5
2.5 – 3.0
2.0 – 2.5
1.5 – 2.0
1.0 – 1.5
0.5 – 1.0
0.0 – 0.5
−0.5 – 0.0
−1.0 – −0.5
−1.5 – −1.0
−2.0 – −1.5
−2.5 – −2.0
−3.0 – −2.5
−3.5 – −3.0
−4.0 – −3.5
−4.5 – −4.0
−5.0 – −4.5
−5.5 – −5.0
−6.0 – −5.5
−6.5 – −6.0
−7.0 – −6.5
−7.5 – −7.0
−8.0 – −7.5
northing (m)
easting (m)
410000
420000
430000
440000
450000
460000
440000
450000
460000
470000
480000
490000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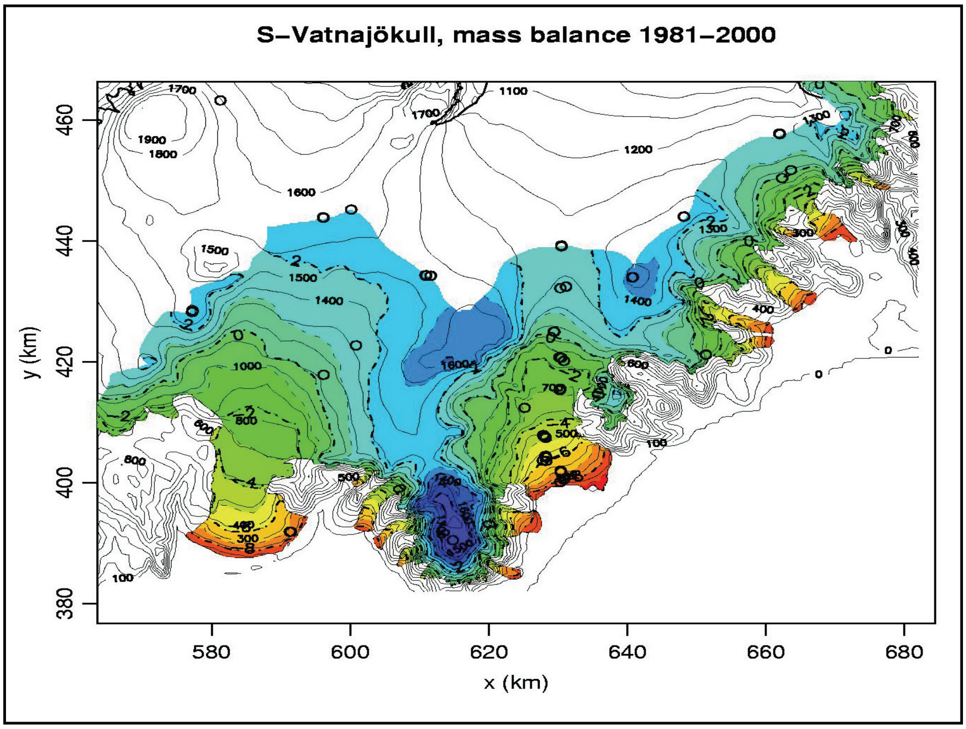
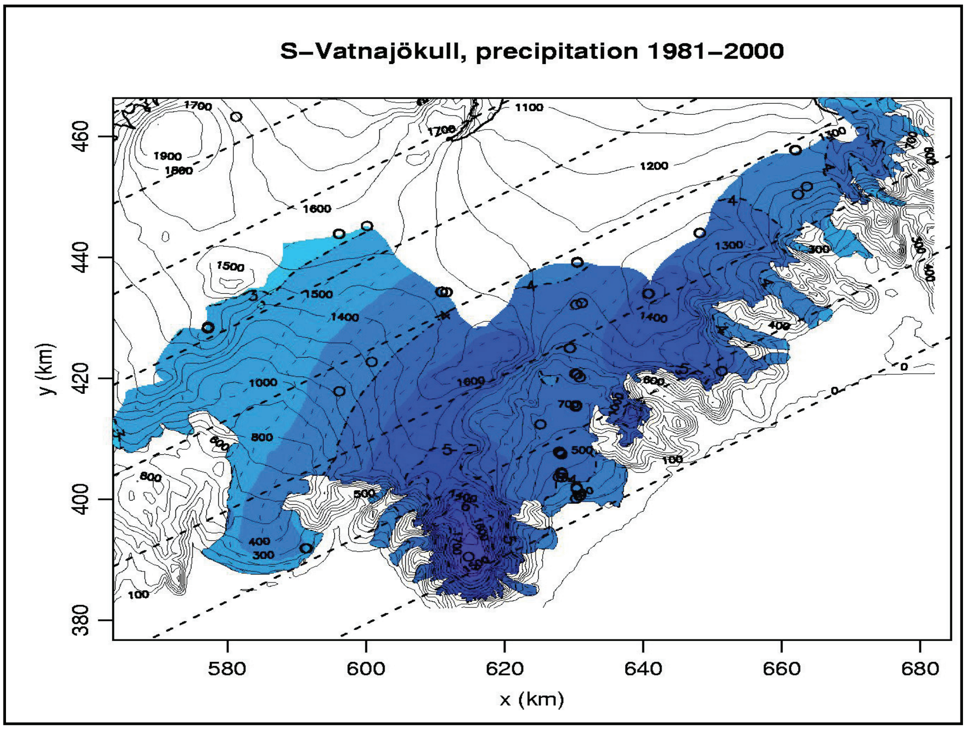
Average annual precipitation 1981–2000 (mwe/a)
4.75 – 5.00
4.50 – 4.75
4.25 – 4.50
4.00 – 4.25
3.75 – 4.00
3.50 – 3.75
3.25 – 3.50
3.00 – 3.25
2.75 – 3.00
2.50 – 2.75
2.25 – 2.50
2.00 – 2.25
1.75 – 2.00
1.50 – 1.75
1.25 – 1.50
1.00 – 1.25
0.75 – 1.00
0.50 – 0.75
0.25 – 0.50
0.00 – 0.25
northing (m)
easting (m)
410000
420000
430000
440000
450000
460000
440000
450000
460000
470000
480000
490000


S–Vatnajökull, mass balance 1981–2000
y (km)
x (km)


S–Vatnajökull, precipitation 1981–2000
y (km)
x (km)

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Total balance within ice divides

Nr.	Area	A (km^2)	Bal (m/a)
1	West of Skeiðarárjökull	95	-0.39
2	Skeiðarárjökull	1398	0.07
3	Öræfajökull	319	0.94
4	W-Breiðamerkurjökull	160	-1.26
5	M-Breiðamerkurjökull	216	-0.18
6	E-Breiðamerkurjökull	557	0.15
4-6	Breiðamerkurjökull	933	-0.17
7	East of Breiðamerkurjökull	811	-0.14
Tot	S-Vatnajökull	3556	0.03

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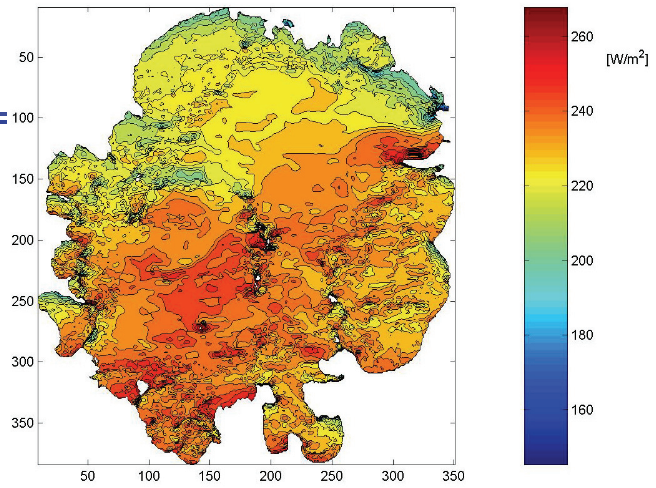
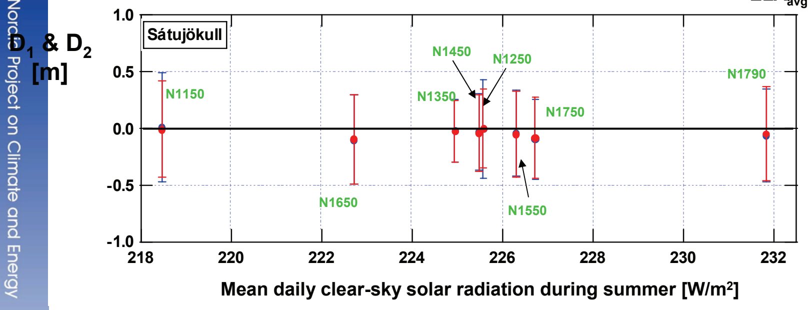


Daily mean values of radiation (May 15 – Sept 15)
~10% lower on Sátujökull

Sátujökull – Northern outlet of Hofsjökull

ELA$_{avg}$ = 13123 m



- D_1 = ($b_{summer, measured}$ - $b_{summer, modelled}$) : Meltmod Type 1 (no radiation)
- D_2 = ($b_{summer, measured}$ - $b_{summer, modelled}$) : Meltmod Type 2 (with radiation)

Averages for the period 1988/89-2003/04, excluding 1990/91.
Error bars: 1 standard deviation

Results for Meltmod 1&2 more or less coincide.
Both models slightly underestimate summer melting on Sátujökull.

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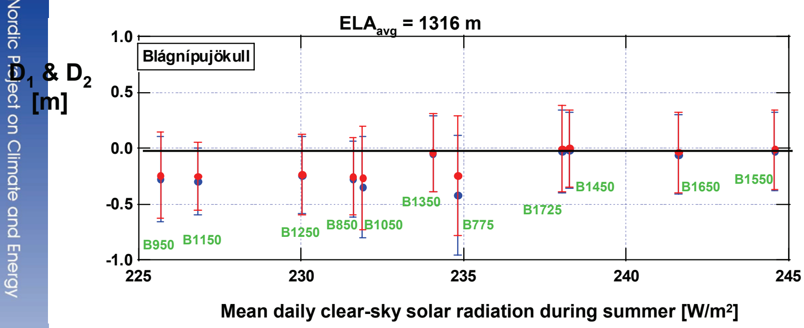
Blágnípujökull – SW outlet of Hofsjökull



- D_1 = ($b_{summer, measured}$ - $b_{summer, modelled}$) : Meltmod Type 1 (no radiation)
- D_2 = ($b_{summer, measured}$ - $b_{summer, modelled}$) : Meltmod Type 2 (with radiation)

Averages for the period 1988/89-2003/04, excluding 1990/91.
Error bars: 1 standard deviation

Both models underestimate summer melting below ELA, but
Type 2 performs better, especially at the lowest point (B775).

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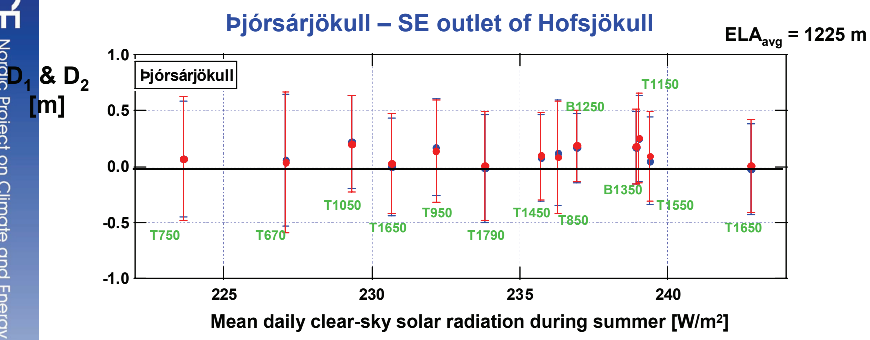

- $D_1 = (b_{summer,\ measured} - b_{summer,\ modelled})$: Meltmod Type 1 (no radiation)
- $D_2 = (b_{summer,\ measured} - b_{summer,\ modelled})$: Meltmod Type 2 (with radiation)

Averages for the period 1988/89-2003/04, excluding 1990/91.
Error bars: 1 standard deviation

Results from both models very similar, both slightly overestimating summer melting on Þjórsárjökull.

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Conclusions

- Degree-day mass balance modeling on the three main ice caps in Iceland is able to capture the main features of the observed winter and summmer mass balance distribution
- The modeling can be used to derive an estimate for precipitation in the highland area that is “almost indipendent” of precipitation measurements at meteorological stations
- Including potential direct radiation does not lead to much improvement in the model performance on these large flat ice caps
- Objective calibration is essential in order to obtain good results