A new glacier monitoring site in West Greenland

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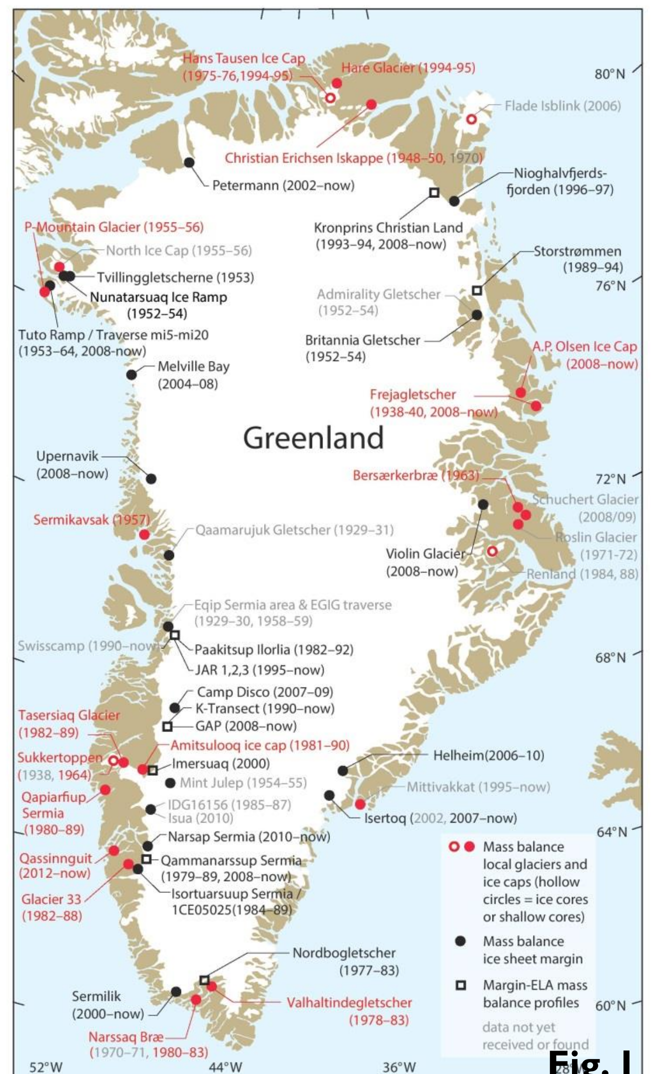
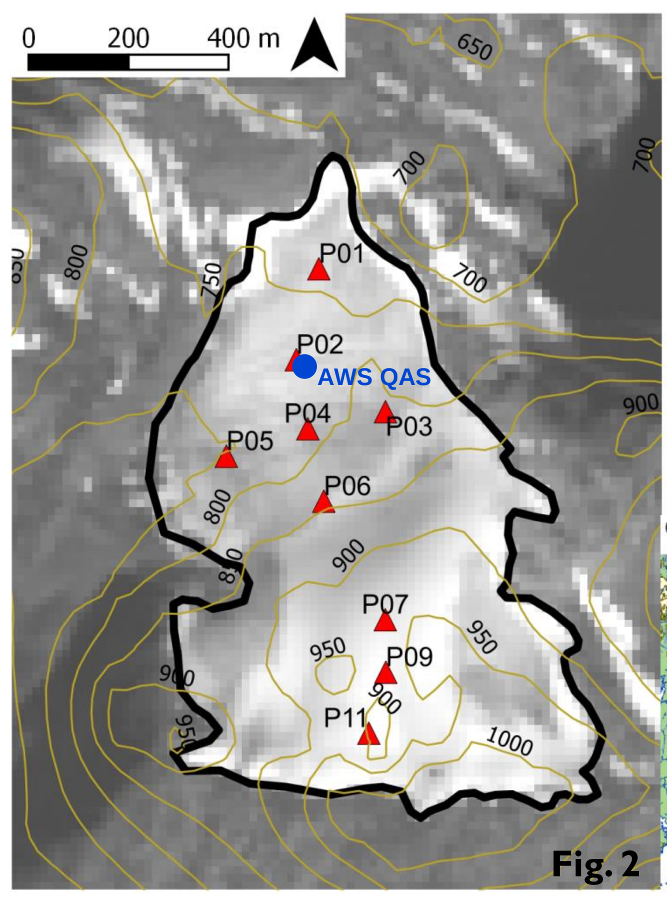
Introduction

The Greenland Ice Sheet (GIS) is surrounded by numerous mountain glaciers (ca 20.000)[a]. They cover in total an area of about 130.000 km^2 and their total annual mass balance is estimated to be about 38 Gt/yr[b] which equals ca 27%[b,c] of the Greenland ice sheet's mass balance.

Field data coverage of Greenland's mountain glaciers however is very scarce. Although there exist some historical records and several stations on the ice sheet, only 5 mountain glacier or local ice cap mass balance series are active (**Fig. 1**).





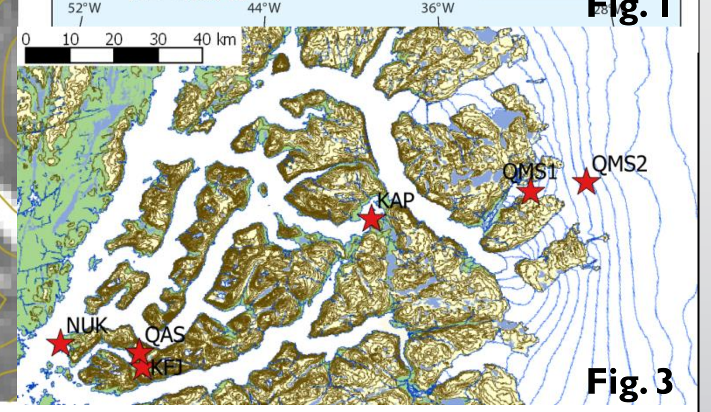


Fig. 1: Mass balance observations in Greenland (from: Machguth et al., 2014)[d]. Red: local glaciers and ice caps; black: ice sheet. Fig. 2: Qasigiannguit glacier with its 2014 glacier margin (black) and a Lansat 8 image in the background. The Mass balance stake positions (P01-P11) are marked red. Fig. 3: The automated weather stations (AWS) used in this study. Nuuk (NUK), Qasigiannguit (QAS), Kobbefjord (KFJ), Kapisillit (KAP), Qamanaarsuup Sermia (QMS).

An interdisciplinary monitoring program was started in 1996 (ZERO) and expanded in 2006 (NERO) to GEM (www.g-e-m.dk) with a focus on a holistic view of the ecosystem. It is divided into five sub-programmes (BioBasis, ClimateBasis, GeoBasis, GlacioBasis, MarineBasis) each studying the respective ecosystem component. This study was performed in the framework of ClimateBasis, which deals with climate and hydrology.

In 2012, QAS (**Fig. 2**), a mountain glacier near Nuuk, Greenland's capital was chosen to study the glacier's significance for the local hydrological cycle. The glacier's size is 0.70 km^2 and it spans an elevation from 670 m to 1000 m. The monitoring program has since been expanded and now includes the local glacier's mass and energy balance, its dynamics, and its runoff. Furthermore, a ground-penetrating radar (GPR) campaign was undertaken in May 2014 in order to investigate the ice thickness and its temperature regime.

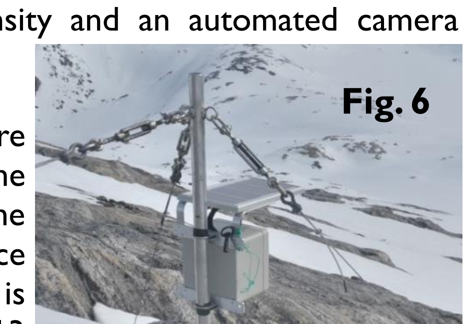
Apart from presenting the results of our monitoring activities at QAS, we investigate the East-West gradient in climate parameters and in the resulting mass balance. AWS-data at QMS1 and QMS2, which are about 100 km East of QAS at the GIS are compared to QAS for summer 2014. NUK, KFJ and KAP AWS (**Fig. 3**) serve as valley stations with longer time-records to place the findings in a larger spatio-temporal context.

Monitoring at Qasigiannguit

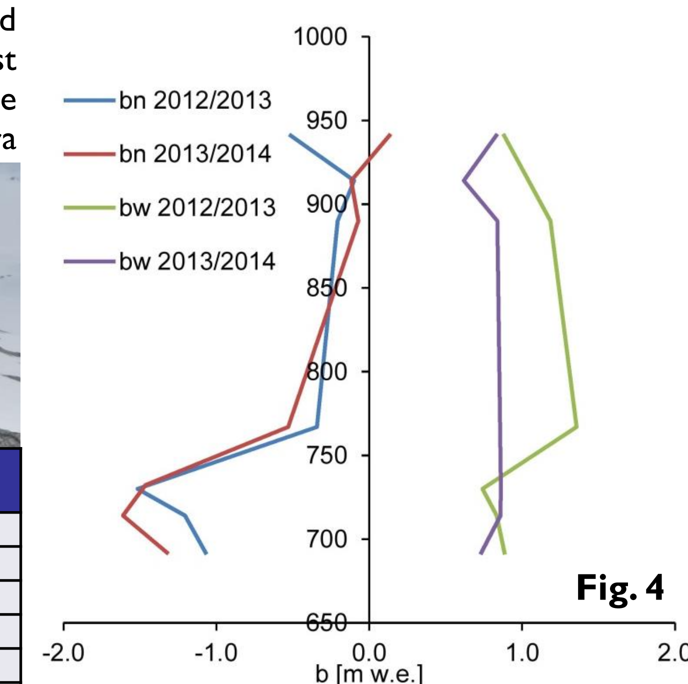
Glaciological investigations on QAS have started in 2012. The mass balance is measured with the glaciological method. Nine stakes are measured between 692 and 941 m. At least two campaigns per year are performed in order to distinguish winter from net-balance (**Fig. 4** and **Fig. 5**). Snow-pits give information on density and an automated camera programmed (**Fig. 6** and see bottom) to take two pictures per day allows for an assessment of firn patterns.

While vertical gradients of the net balance b are pronounced, accumulation is rather uniform across the glacier. The total volume mass balance is determined by the glacier's area-elevation distribution. Winter volume balance B has two maxima around 770 and 890 m, while net B is most negative around 750 m. The two seasons 2012/2013 and 2013/2014 differ in that the previous shows more accumulation while the latter lost more mass through ablation. Total values for b are -0.40 m w.e. for 2012/2013 and -0.32 m w.e. for 2013/2014.

Along with the mass balance also measurements of the glacier dynamics are performed with DGPS (RTK) on an annual basis at the stakes (**Tab. 1**). The two seasons show very low and similar values with maxima of less than 2 m/yr.



Tab. 1 stake	z [m]	12/13 [m/yr]	13/14 [m/yr]
1	692	0.21	0.37
2	714	0.64	0.21
3			0.69
4	729	1.19	
5	730	1.19	1.29
6	767	1.96	0.94
7	890	0.24	0.26
9	914	0.23	0.16
11	941	0.22	0.23



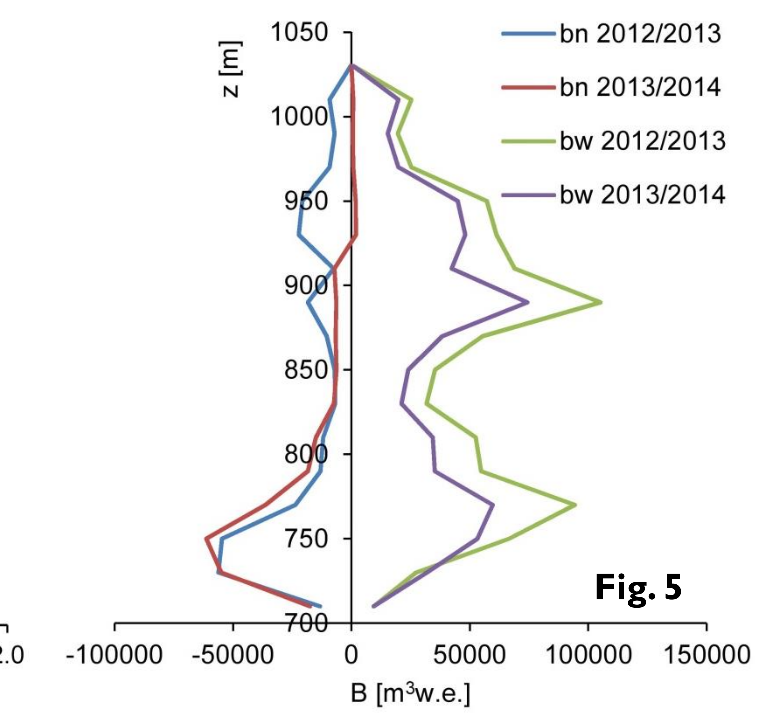
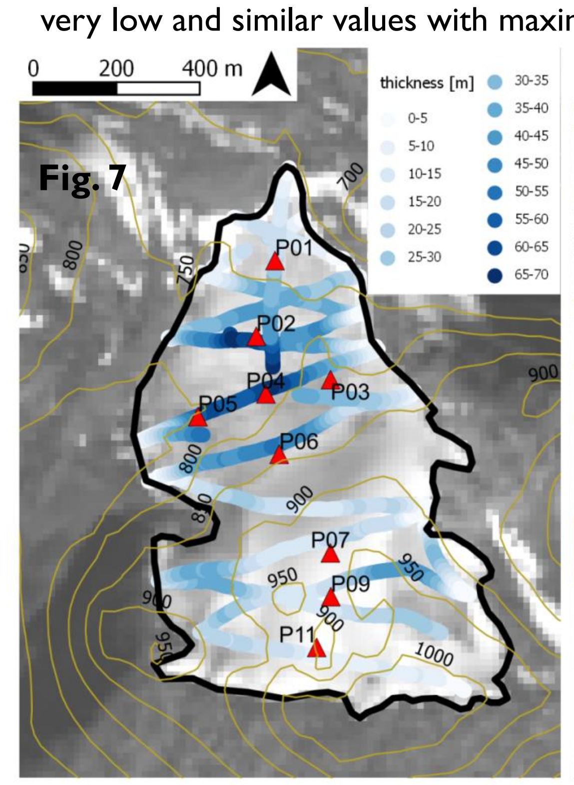
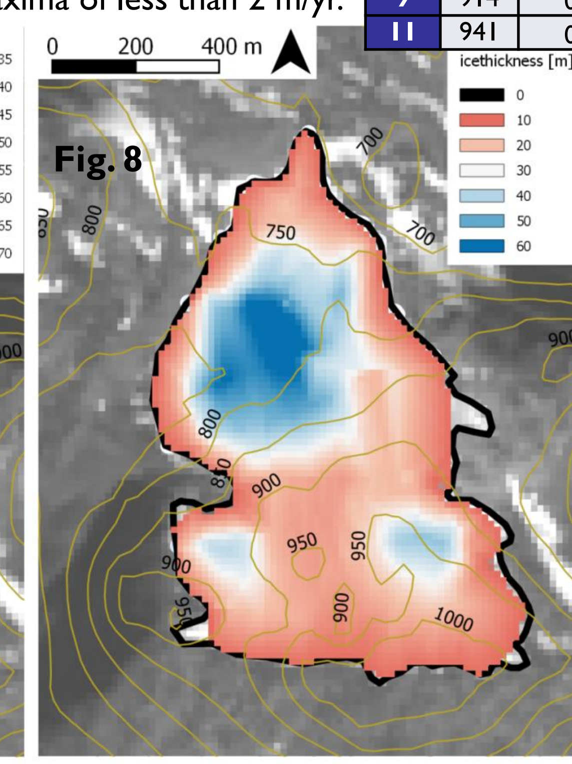
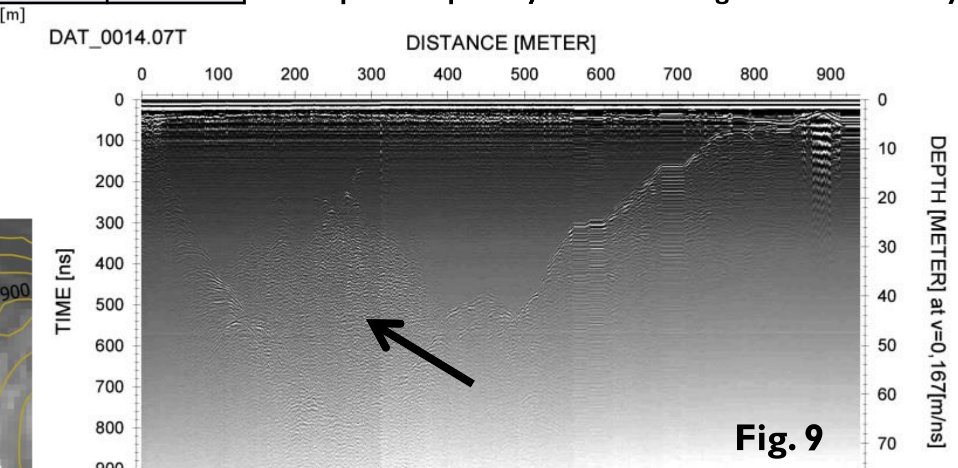


Fig. 4: Specific winter (bw) and net (bn) mass balance [m w.e.] for 2012/2013 and 2013/2014. Fig. 5: same as 4 but total volume balance B [m^3 w.e.] per 20m elevation interval. Fig. 6: An automated camera is taking two pictures per day. Tab. 1: total glacier flow velocity [m/yr].





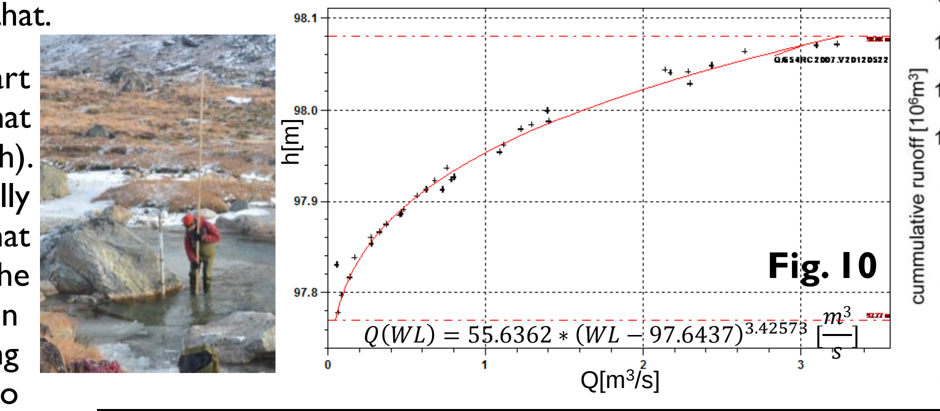


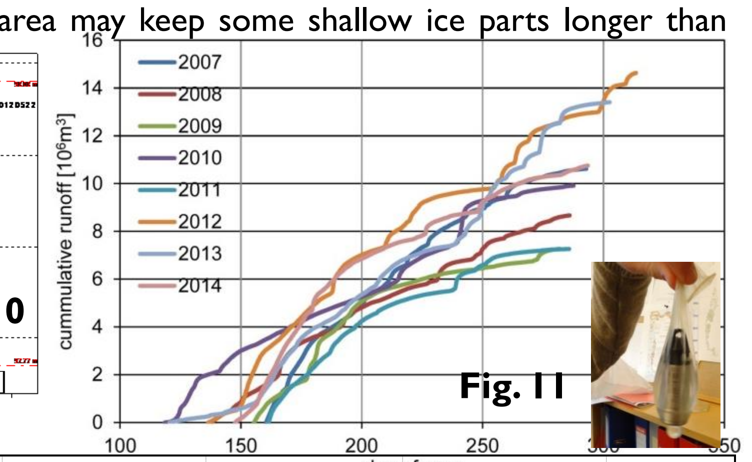
As a baseline for exploring future glacier evolution and in order to define the thermal regime, a GPR campaign was undertaken in 2014 with a Malå RAMAC GPR and a 100 MHz antenna. The coverage of the profiles and the inferred point thickness are displayed in **Fig. 7**, while **Fig. 8** displays the interpolated thickness map using the TIN interpolation routine in Qgis. The radar signal was generally of good quality. And ice thickness of up to almost 70 m have been found. The glacier is generally cold but some temperate ice was found near the bedrock at its deepest part (arrow in **Fig. 9**). The total ice volume amounts to 16*10^6 m^3 which corresponds to a mean ice thickness of 22 m. Assuming the same total volume loss as in the past two years, the entire ice volume will have vanished in about 60 years, however, given the balance profile of **Fig. 5**, it will be more likely that the lowest part will be ice-free earlier than that while the firn area may keep some shallow ice parts longer than that.

The runoff in Qasigiannguit basin (10.1 km^2) has been measured since the start of NERO. A stage-discharge relation (**Fig. 10**) was established over the years that allows for calculation of Q (discharge, m^3) from measurements of h (stage, h). The total runoff varies considerably interannually (**Fig. 11**) which generally follows variations in precipitation (**Tab. 2**). A drawback of the method is that divers to measure the waterlevel are placed at the beginning and the end of the season, which leads to potential underestimation of the total runoff. This autumn we installed a diver in a preservative containing anti-freeze (**Fig. 11**) and hope to be able to catch entire seasons in the future.

The glacier's net mass balance only accounts for ca. 2% of the total annual runoff, however, ice melt is clearly visible as a strong diurnal signal in summer (**Fig. 12**)

Tab. 2 year	Q [10^{6}m^3]	q [m]	P in KOB [m]	Bn [10^{6}m^3]
2007	10.62	1.05	0.65	
2008	8.67	0.86	1.05	
2009	7.27	0.72	0.84	
2010	9.91	0.98	0.91	
2011	7.26	0.72	0.54	
2012	14.63	1.45	1.05	
2013	13.40	1.33	1.05	-0.29
2014	10.75	1.06		-0.23





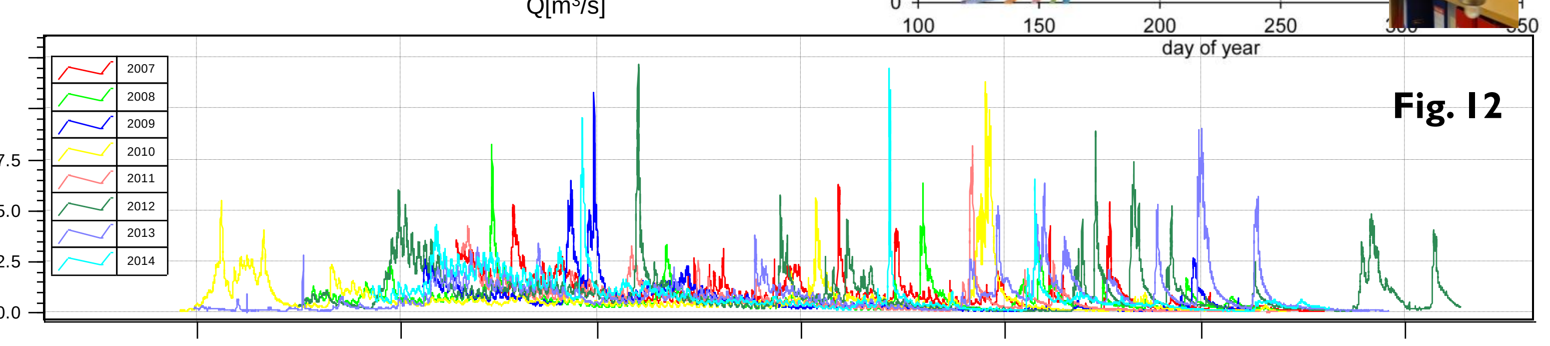
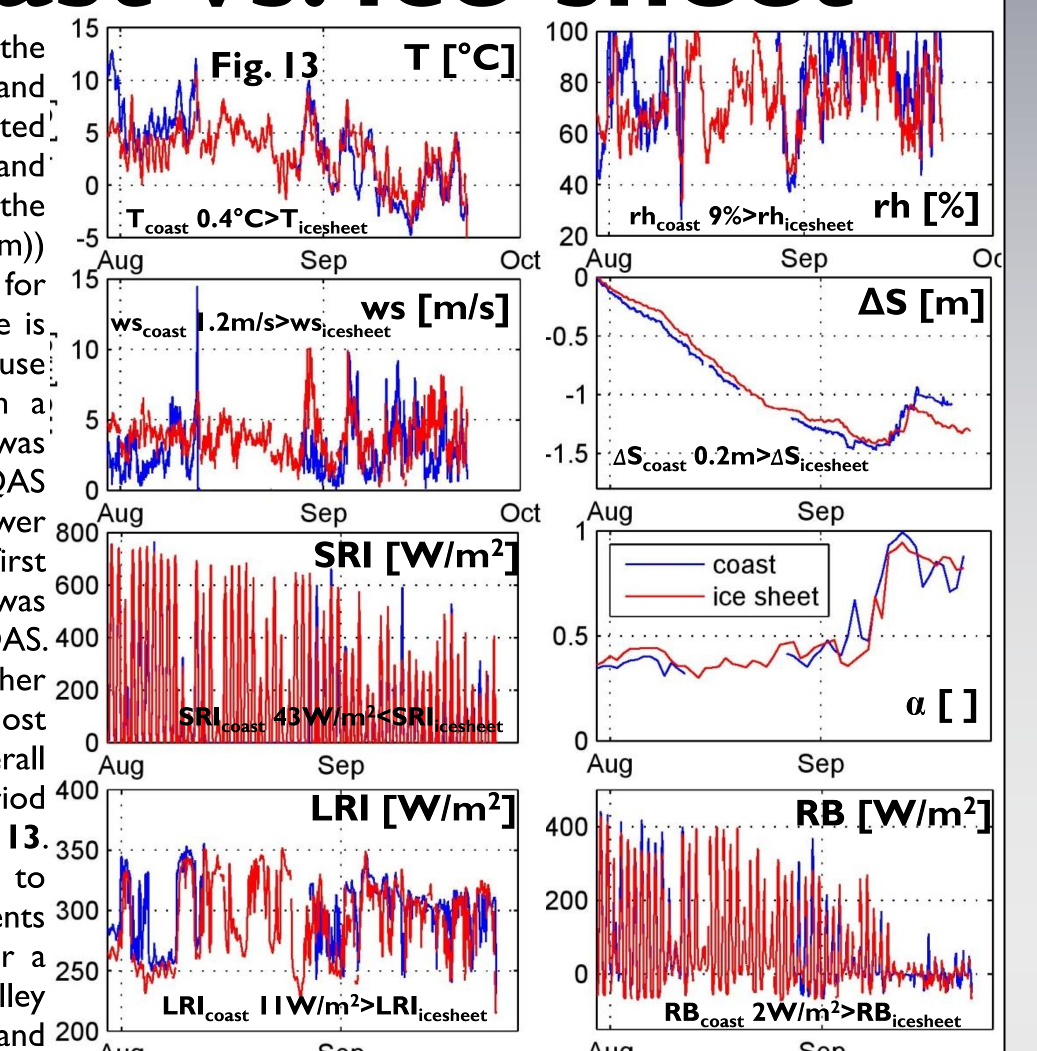
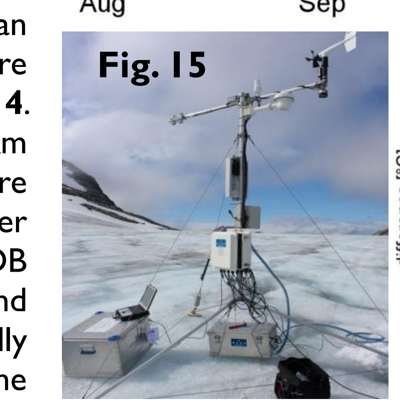


Fig. 10: Q/h-relation; Fig. 11: cumulative runoff 2007-2014 [10^{6}m^3/yr]; Fig. 12: discharge [m^3/s]. Tab. 2: total annual runoff Q, specific runoff q, precipitation P and net balance Bn 2007-2014.

Coast vs. ice-sheet

Gradients between the AWS (**Fig. 15**) at QAS and QMS (interpolated between QMS1 (545m) and QMS2 (1130m) to the elevation of QAS (713m)) are shown in **Fig. 13** for the summer 2014. There is a data gap at QAS because the station fell over in a storm. Total ablation was more negative at QAS despite significantly lower SRI. Especially in the first part of the period T was notably higher at QAS. Both LRI and rh are higher at QAS, total RB is almost the same. Mean/overall values for the entire period are summarized in **Fig. 13**. It will be interesting to investigate the gradients throughout the year. For a first estimate 3 valley stations have been used and their climatological mean monthly air temperature displayed in **Fig. 14**. Although less than 20 km apart temperature differences are higher between NUK and KOB than between KOB and KAP. Winter is generally colder inland and the reverse in summer.





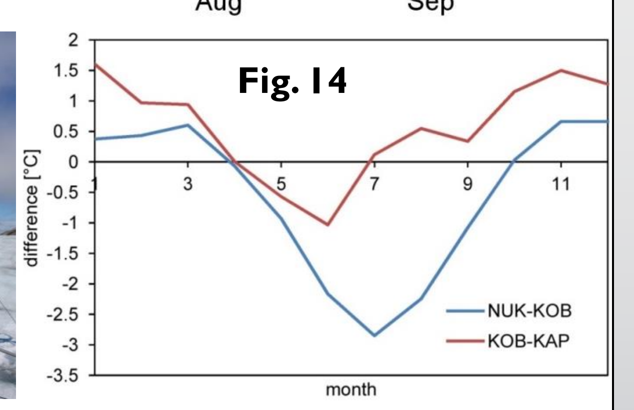


Fig. 13: Climate parameter at QAS (blue) and at QMS (red). From top to bottom: temperature [°C], relative humidity [%], wind speed [m/s], surface elevation change [m], short-wave incoming radiation [W/m^2], albedo [ ], longwave incoming radiation [W/m^2] and the radiation balance [W/m^2]. Fig. 14: mean monthly temperature difference NUK-KOB and KOB-KAP. Fig. 15: the AWS at QAS.

Conclusions

- *QAS is a polythermal glacier*
- *Area: 0.7 km^2; volume: 16*10^6 m^3*
- *Mass balance: weak gradients in winter, strong in summer and in net balance*
- *Mean annual mass balance -0.36 m w.e. on average*
- *Runoff has a strong inter-annual variability (> factor 2)*
- *Runoff is determined by precipitation and snow-melt*
- *Only ca. 2% of total runoff comes from ice melt*
- *Climate gradients are significant*
- *They likely outbalance each other partly (T vs SRI)*
- *Largest climate gradients right at the coast, much weaker further inland*
- *Seasonal cycle of spatial temperature gradient*
- *Future: SEB gradient; 'high altitude' vs. valley gradient; model evaluation*

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