



Mass Balance Freya Glacier 2014-15

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Meteorologie und
Geodynamik



Summary

The annual surface mass balance 2014/15 of Freya Glacier was the 3rd most positive mass balance since the start of monitoring in 2008, with an amount of **97 +/-50 mm w.e.** The equilibrium altitude line (ELA) was at **670m a.s.l.** and the accumulation area ration (AAR) around **70%**. As in the years 2012 and 2014 the positive annual balance corresponds to a high winter balance with **935 +/-120 mm w.e.** Both, winter mass balance (6.5.2015) and annual mass balance (17.8.2015) were measured at 15 points on the glacier. Two consecutive high winter mass balances and positive annual mass balances burried and the automatic weather station (AWS) near stake 8 at 780 m a.s.l. From now on, the monitoring strategy at Freya Glacier will change to only one visit per year, which is planned to be in spring by using aluminium stakes and more automatic measurements.

Winter Mass Balance 2014/15:

Field work in spring was done on 6.5.2015 by Daniel Binder (ZAMG) and Michele Citterio (GEUS). Due to time restrictions and snow scooter problems they could only visit the glacier by foot on one single day. They managed to dig one snow pit, and measured snow depth with probes on the centre line of the glacier, changed batteries at the automatic cameras. The snowpit was located near the new (2nd) AWS site at stake no 8., but the AWS was not found because it was burried in 280cm winter snow and 100cm of firn 2014.

Table: Snow pit on Freya Glacier near the second AWS site.

LAT	LON	ELEV	DATE-TIME	snow depth [cm]	density [kg/m3]	swe [mm]
74,379557	-20,815687	775	06.05.2015 17:21	278	395	1105



Figure: Snowpit on Freya Glacier on 6.5.2015 next to the burried AWS at stake 8. (Foto: D. Binder)

Table: Snow probings. Mean snow depth from measurements is 216cm (853 mm swe).

no	gps	Latitude	Longitude	elev	snow depth	
					[cm]	time
1	147	74,380872	-20,818045	768	260	06.05.2015 19:00
2	148	74,382473	-20,820876	739	220	06.05.2015 19:03
3	149	74,384282	-20,82589	715	330	06.05.2015 19:09
4	150	74,386388	-20,832133	690	270	06.05.2015 19:13
5	152	74,388788	-20,840393	665	240	06.05.2015 19:19
6	153	74,391714	-20,851067	632	235	06.05.2015 19:27
7	154	74,393779	-20,856922	603	230	06.05.2015 19:34
8	155	74,39579	-20,861308	565	195	06.05.2015 19:38
9	156	74,398165	-20,8683	518	220	06.05.2015 19:44
10	157	74,400445	-20,875516	475	210	06.05.2015 19:50
11	158	74,402562	-20,881953	427	201	06.05.2015 19:54
12	159	74,404428	-20,888312	375	98	06.05.2015 19:59
13	160	74,406137	-20,894713	304	110	06.05.2015 20:04
14	161	74,406462	-20,895971	285	205	06.05.2015 20:06

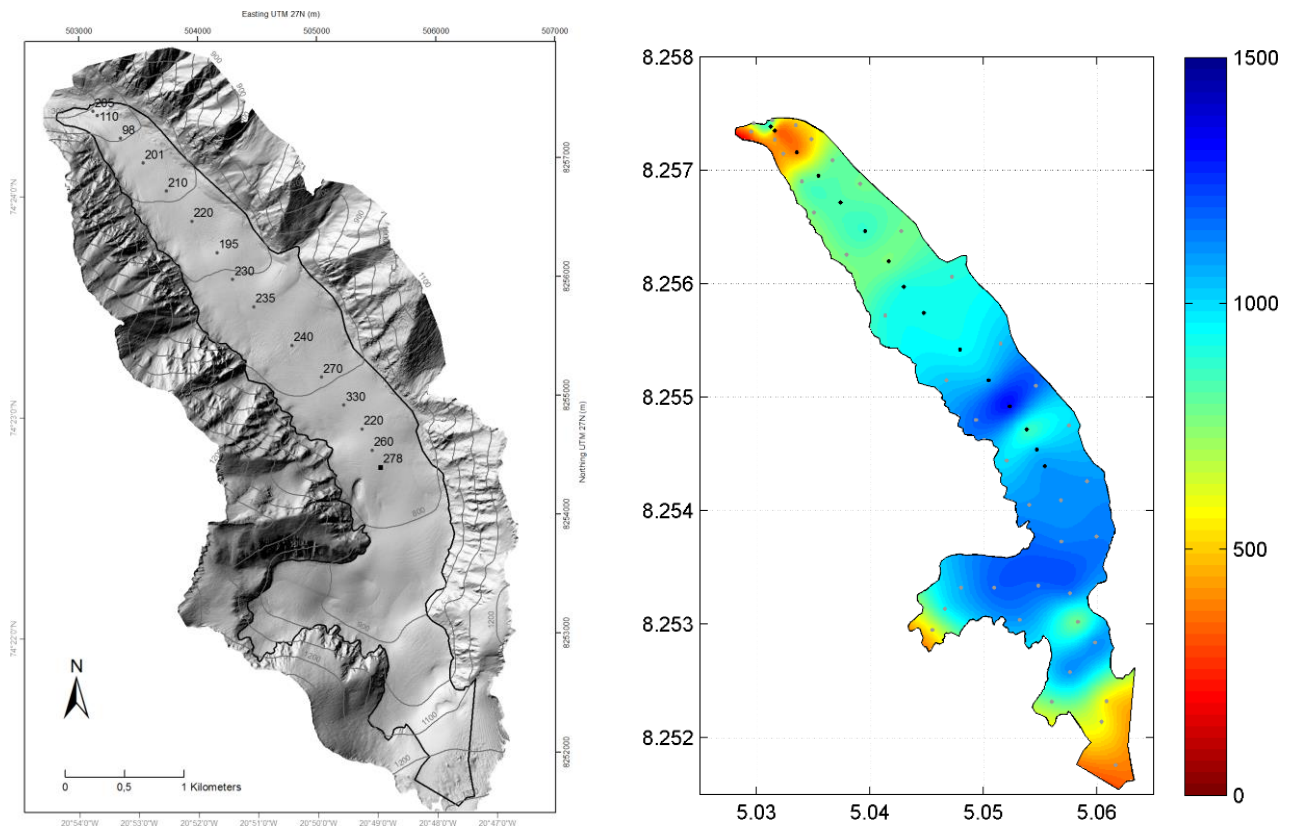


Figure: Snow probings and snow pit location (left). Best estimated inter- and extrapolation of swe distribution over the glacier in mm (right).

Results of the overall glacier mass balance interpretation:

bw = 935 +/- 120 mm swe

sh = 237 +/- 30 cm



Fotos from the location of the automatic camera. (Fotos: D. Binder)



Fieldwork on 6.5.2015. (Fotos: D. Binder)



Fieldwork on 6.5.2015. (Fotos: D. Binder)

Annual Mass Balance 2014/15:

Starting point of the mass balance year is an almost totally snow covered glacier in August 2014.

After an extremely negative mass balance 2012/13, where the glacier was almost totally snowfree, the mass balance 2013/ 2014 was positive (394mm w.e.), with very little snowfree patches on 2014-08-18, when fieldwork was carried out by Daniel Binder (ZAMG) and Charalampos Charalampidis (GEUS). Only two stakes were found on the lower part of the glacier with almost zero ablation. The mean snowdepth was 73cm. $MB \sim 0$ at the lower part of the glacier.

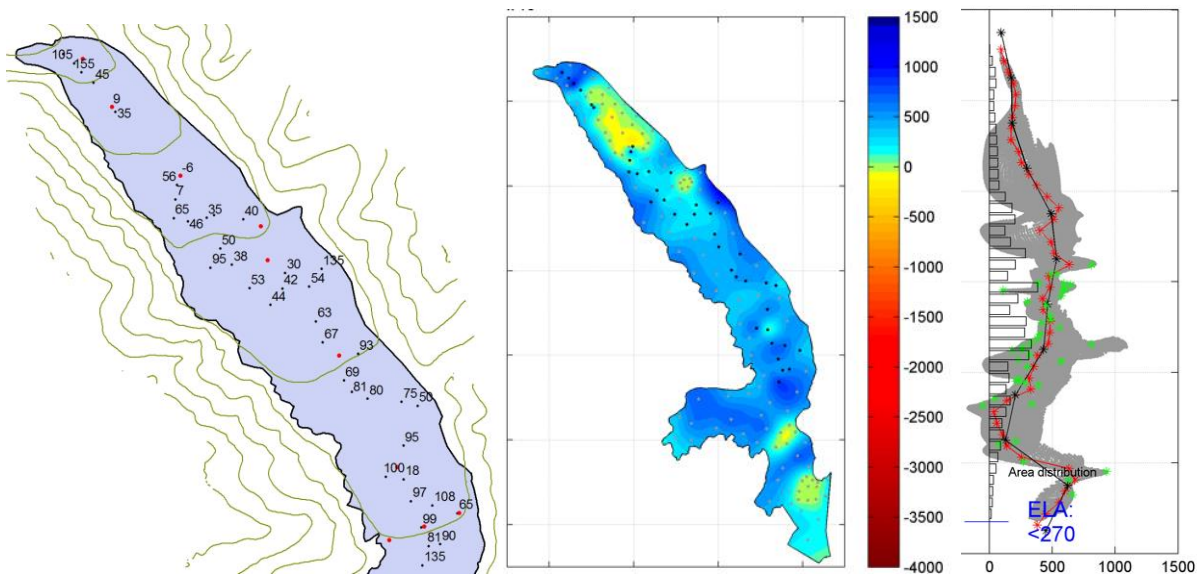


Figure: Left: Mass balance point measurements of 2014-08-18. Two stakes with a dh of 9 and – 6 cm and 38 accumulation measurements (snow depth probing) using an estimated end of summer snow density of 0.6 kg/m^3 . Center: Spatial mass balance interpretation of 2013/14. Right: Mass balance distribution with elevation of 2013/14.



Fotos from 18.8.2014 from Autom. Cam Position.
(Fotos: D. Binder)



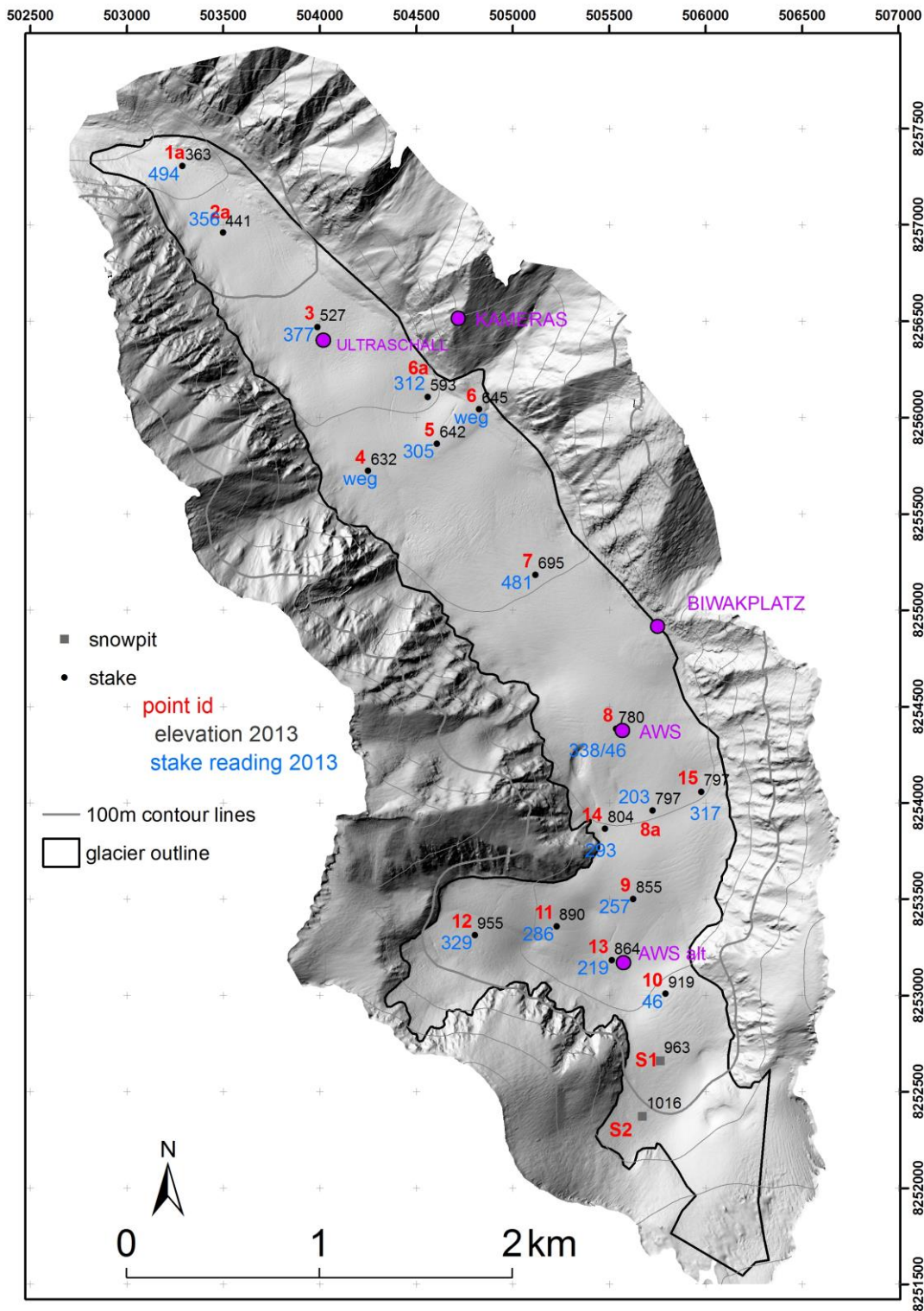


Figure: Map of the monitoring network on Freya Glacier in 2014/15, Hillshade, outline and contour lines from a SfM-DEM of 2013.

Mass balance fieldwork in Autumn was carried out by Jakob Abermann (Asiaq) and Mikkel P. Tarmstorf (Univ. Aarhus) on 17.8.2015. They read ablation stakes, dug a snowpit at S1, visited the top and bottom air temp station, retrieved data and sensors from the broken AWS at stake 8, retrieved data from the automatic cameras and scouted for a location for a discharge station below Freya Glacier.

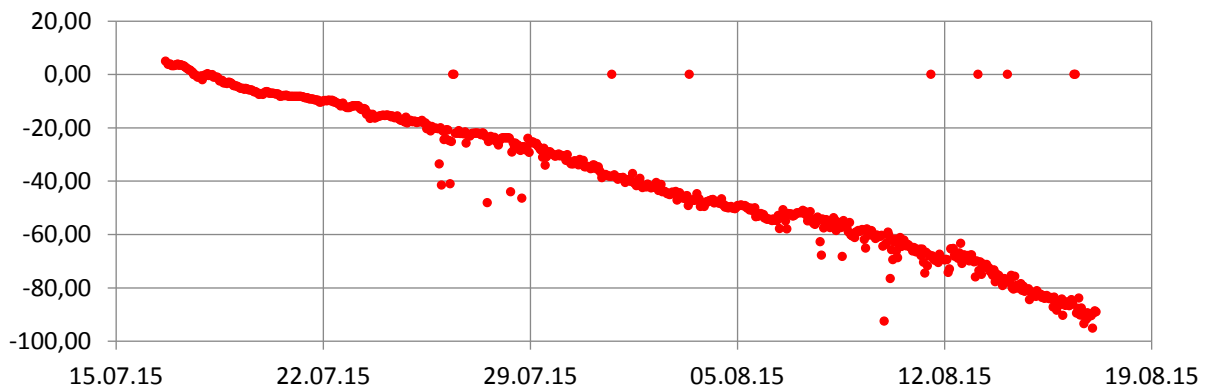
Documentaion of mass balance fieldwork on 17.8.2015:



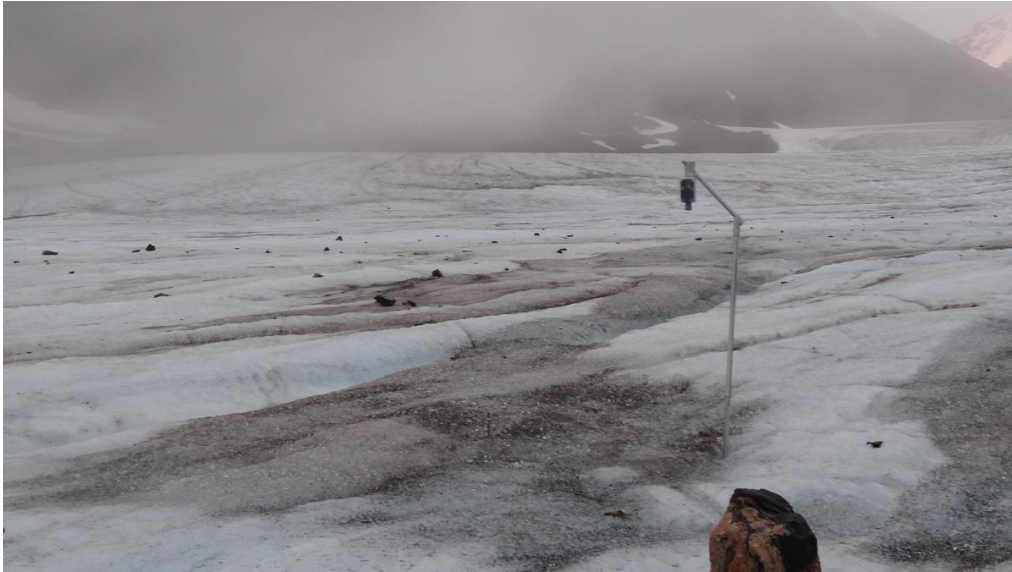
Only little river icings, snout snowfree, avalanche snow around stake 1a and orographically right.



Ablation stake 2a. 17cm firn ablation, 90cm ice ablation maek -912mm w.e. (Fotos: J. Abermann)



Data of the ultrasonic ablation sensor at stake 3. Ice melt startet around 20.7.17. Sensor height was 149 cm.



Automatic ablation sensor near stake 3 and stake 3 with 93cm ice ablation in 2017.



Above stake 3.



Stake 5. 60 cm ablation of ice and 35 cm ablation of firn 2014. (b= -750 mm w.e.)



Ablation stake 7. 50 cm snow accumulation.



At stake 10. 30 cm snow accumulation.

Table: Snow pit at S1:

depth from	depth to	weight with ripcutter	density [kg/m ³]	Info	swe [mm]	swe sum [mm]	mean density [kg/m ³]
0	10	1,312	0,542	new snow	54,2		
10	20	1,244	0,474	new snow	47,4		
20	30	1,334	0,564	melt form	56,4		
30	40	1,304	0,534	melt form	53,4		
40	50	1,3	0,53	melt form	53		
50	60	1,301	0,531	melt form	53,1		
60	70	1,303	0,533	melt form	53,3		
70	80	1,291	0,521	melt form	52,1		
80	90	1,291	0,521	melt form	52,1		
90	96		0,52	melt form	31,2		
96	99		0,9	Ice	27	533,2	0,539
99	110	1,306	0,536	Firn	58,96		
110	120		0,52	Firn	52		
120	130	1,279	0,509	Firn	50,9		
130	140	1,282	0,512	Firn	51,2	213,06	0,520

} With ice layers





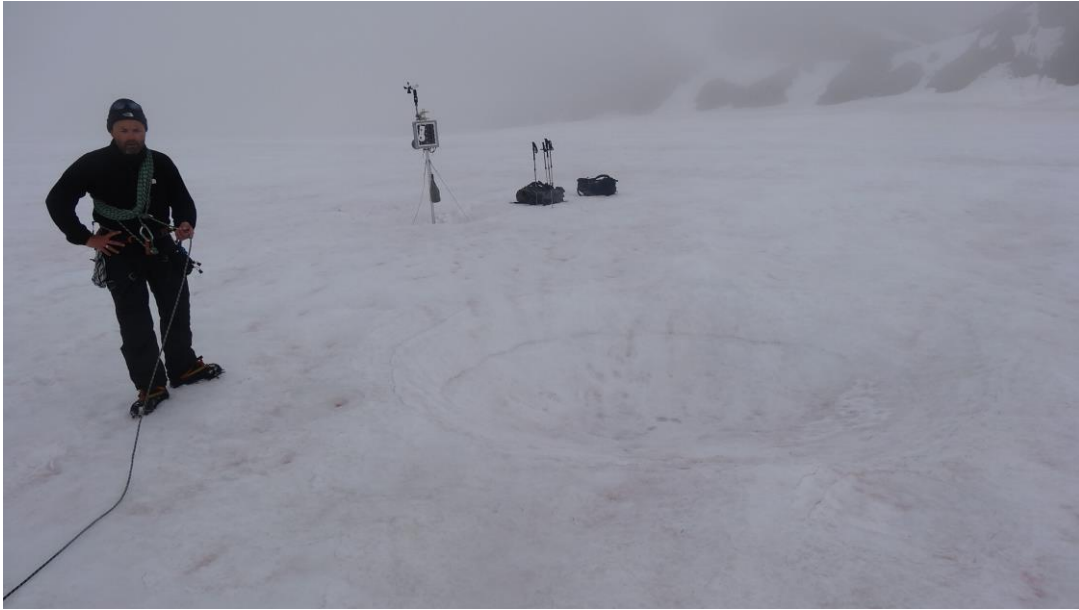
Above stake 3.



Below stake 5.



Above stake 5.



Top and bottom left: The broken AWS after being buried in 1m accumulation 2014 and 2.8m winter snow 2014/15. Sensors, datalogger and batteries have been retrieved. Right: the mast of the old AWS at stake 13, which is drilled into the ice. (Fotos: J. Abermann)

Table: Mass Balance Point Values 2014/15.

ID	dh f2014 cm	roh f2014 kg/m ³	dh ice cm	roh ice kg/m ³	dh s2015 cm	roh s2015 kg/m ³	mb 2015 mm.w.e.	dh 2015 cm	roh 2015 kg/m ³
1a		0,6			58	0,54	313	58	0,54
2a	-17	0,6	-90	0,9	0	0,54	-912	-107	0,85
3			-93	0,9	0	0,54	-837	-93	0,90
4					40	0,54	216	40	0,54
5	-35	0,6	-60	0,9	0	0,54	-750	-95	0,79
6a					200	0,54	1080	200	0,54
7					50	0,54	270	50	0,54
8					80	0,54	432	80	0,54
8a					112	0,54	605	112	0,54
9					73	0,54	394	73	0,54
10					30	0,54	162	30	0,54
13					121	0,54	653	121	0,54
14					134	0,54	724	134	0,54
15					125	0,54	675	125	0,54
S1					99	0,54	535	99	0,54



During fieldwork on 17.8.2015. (Fotos: J. Abermann)

Automatic cameras:

The camera in direction upward the glacier was still working. The cam directed downward the glacier did not work. Interesting is the growing of a white surface from 14.8. to 15.8., very likely the refreezing of meltwater. Bad visibility during fieldwork and the days before hinder the exact delineation of the evolution of the snowline.

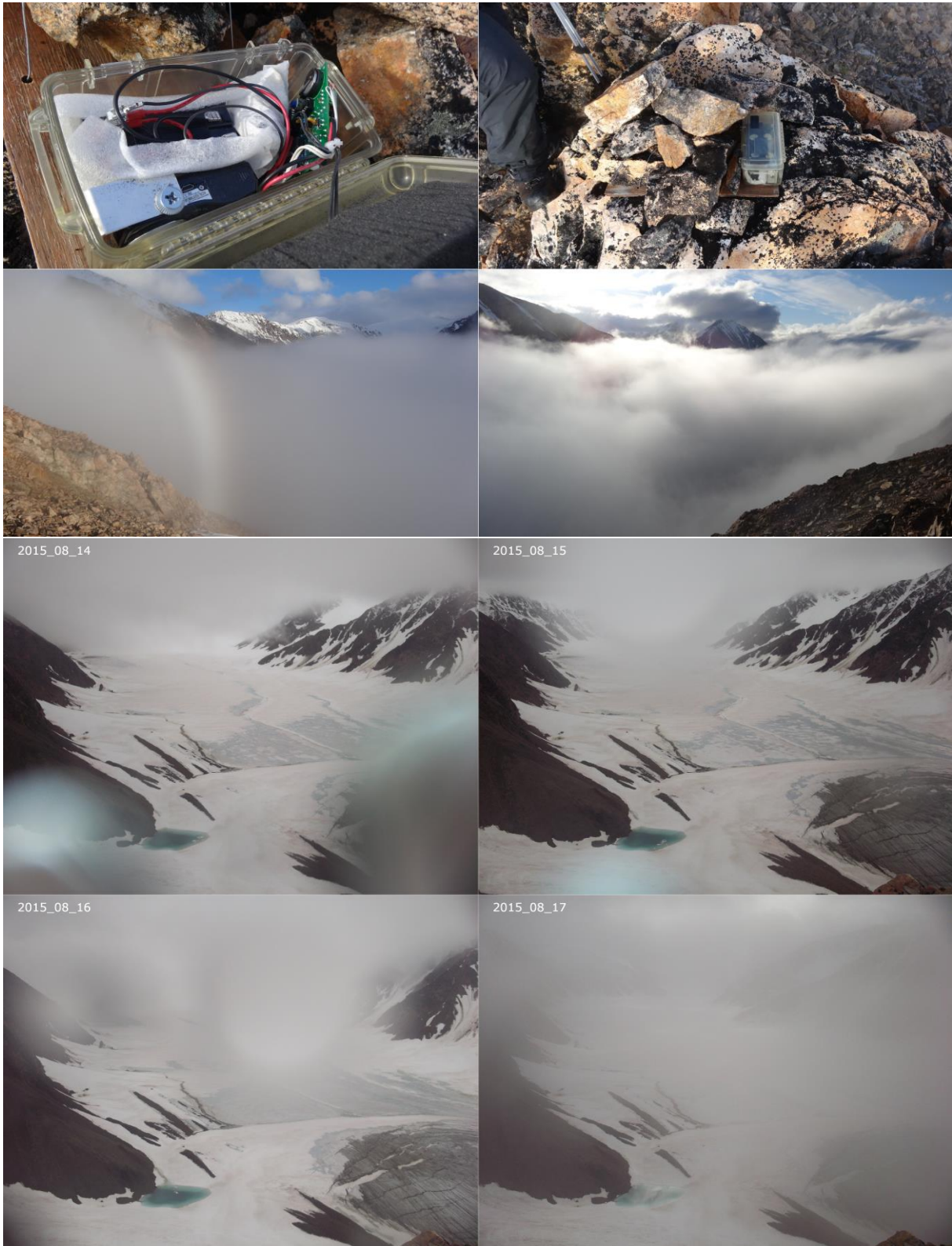


Figure: Fotos from the automatic camera in the period of minimum snow cover on the glacier.

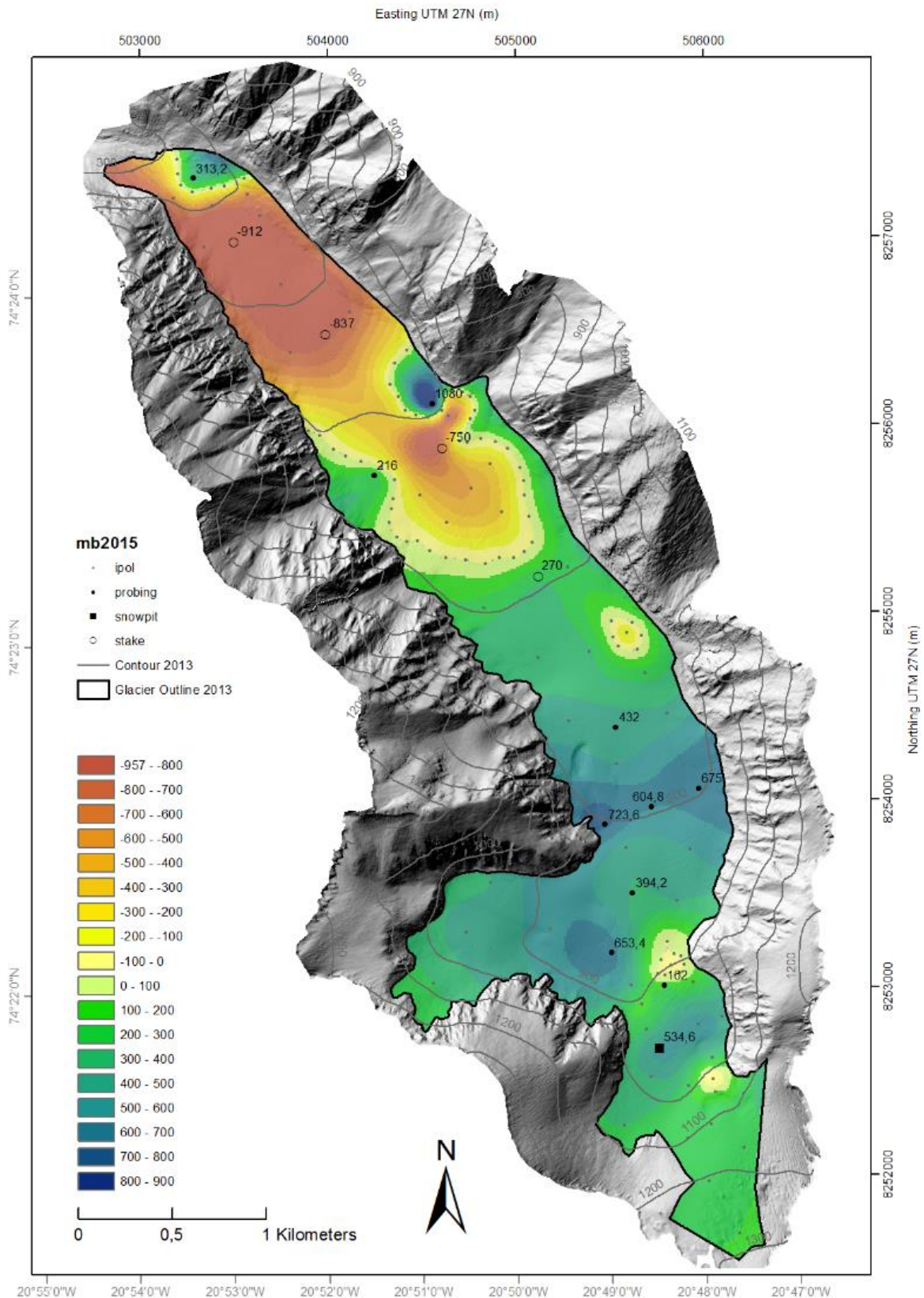


Figure: Annual mass balance distribution on Freya Glacier 2014/15. The interpolation was done without using a mass balance model, but by setting interpolation points (grey dots), which are based on previous mass balance distributions. The estimated error of the glacier wide annual mass balance is 50 mm w.e.

Table: Mass Balance 2014/15 evaluated on elevation bands.

Date/ Time	Date/ Time end	Elev min [m a.s.l.]	Elev max [m a.s.l.]	SaZ [km ²]	BaZ [10 ⁶ kg]	baZ [kg/m ²]	BwZ [10 ⁶ kg]	bwZ [kg/m ²]
2014	2015	1300	1400	0,00	0	192	0	326
2014	2015	1200	1300	0,16	33	212	64	414
2014	2015	1100	1200	0,19	49	257	103	540
2014	2015	1000	1100	0,28	76	273	216	777
2014	2015	900	1000	0,63	252	398	658	1039
2014	2015	800	900	0,80	387	481	916	1140
2014	2015	700	800	1,06	410	385	1157	1087
2014	2015	600	700	1,07	-88	-82	1027	957
2014	2015	500	600	0,59	-277	-472	476	813
2014	2015	400	500	0,37	-296	-799	272	735
2014	2015	300	400	0,14	-20	-149	61	449
2014	2015	200	300	0,01	-9	-653	8	555
2014	2015			5,30	516	97	4958	935

Figure: Mass balance distribution with elevation. Bars: Area distribution. Green: Point measurements. Grey: Grid values of interpolated mb raster. Black: mb mean values on 100m elevation bands. Red: mb mean values on 25m elevation bands.

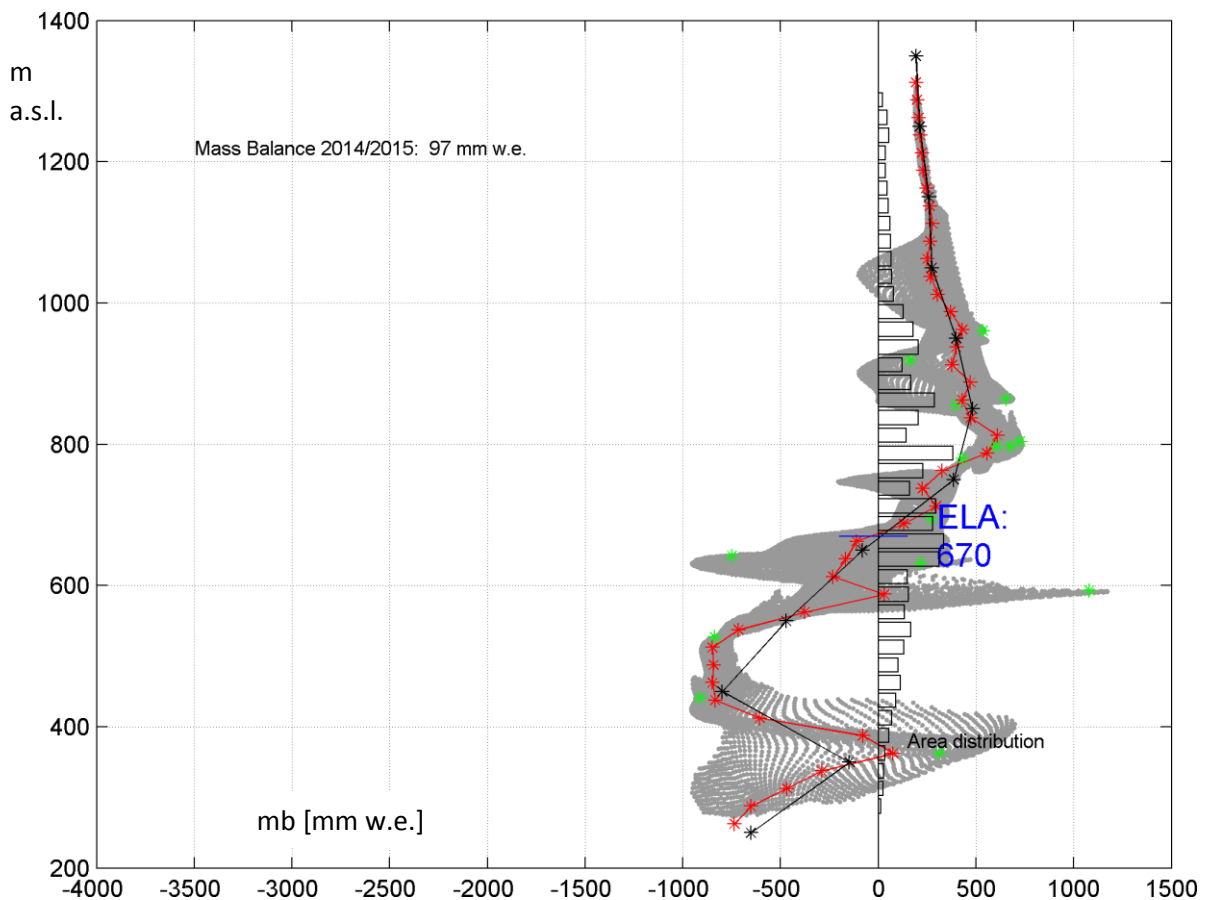


Table: Mass balance periods at Freya Glacier

MB Period	Date/Time start@annual balance	Date/Time end@annual balance	Date/Time start@winter balance	Date/Time end@winter balance
2007/2008	11.08.2007	23.08.2008	01.09.2007	12.05.2008
2008/2009	23.08.2008	24.08.2009		
2009/2010	24.08.2009	21.08.2010		
2010/2011	21.08.2010	23.08.2011		
2011/2012	23.08.2011	14.08.2012	20.09.2011	26.04.2012
2012/2013	14.08.2012	14.08.2013	25.08.2012	05.05.2013
2013/2014	14.08.2013	18.08.2014	14.08.2013	27.04.2014
2014/2015	18.08.2014	17.08.2015	01.09.2014	06.05.2015

Table: Mass Balance Results of Freya Glacier

Year	Sc [km ²]	Bc [10 ⁶ kg]	bc [kg/m ²]	Sa [km ²]	Ba [10 ⁶ kg]	ba [kg/m ²]	S [km ²]	B [10 ⁶ kg]	b [kg/m ²]	Bw [10 ⁶ kg]	bw [kg/m ²]	ELA [m a.s.l.]	AAR
07/08	0,82	116	22	4,48	-2857	-539	5,30	-2741	-517	3682	694	1000	0,16
08/09	2,18	271	51	3,13	-2789	-526	5,30	-2518	-475			800	0,41
09/10	0,32	58	11	4,98	-4365	-823	5,30	-4307	-812			>1300	0,06
10/11	0,31	59	11	5,00	-5020	-946	5,30	-4961	-935			>1300	0,06
11/12	2,27	300	57	3,03	-1345	-254	5,30	-1044	-197	4856	916	750	0,43
12/13	0,16	20	4	5,15	-7413	-1398	5,30	-7393	-1394	1009	190	>1300	0,03
13/14	5,00	2102	396	0,30	-13	-2	5,30	2089	394	5853	1104	< 270	0,94
14/15	3,72	1342	253	1,59	-826	-156	5,30	516	97	4957	935	670	0,70

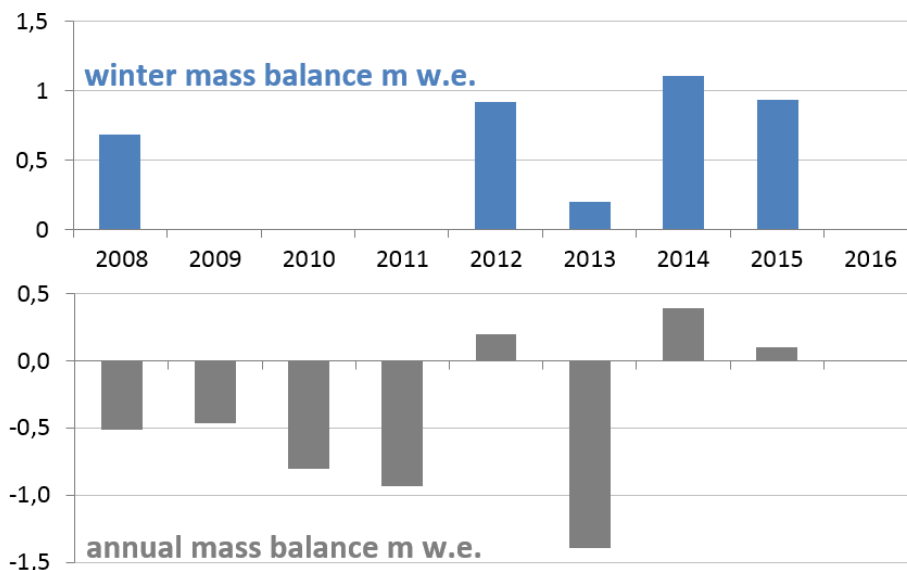


Figure: Time series of mean annual and winter surface mass balance of Freya Glacier in meter water equivalent.

Acknowledgments:

The authors thank Charalampos Charalampidis (GEUS) and Mikkel P. Tamstorf (Univ. Aarhus) for participating fieldwork in 2014/15 and the Zackenberg Research Station for logistic support.

Appendix:

Field Book Entries Winter

FREYA PROBINGS 6.5.2015

P147: 260
P148: 220
P149: 330
P150: 270 (PBT FAKE)
P152: 240
P153: 235
P154: 230
P155: 195
P156: 220
P157: 210
P158: 201
P159: 98
P160: 110
P161: 205

FREYA WINDERTAG:

- Schnee: Sonde
GPS
Dichteset
- AWS: CF Karte
Sonde
- Messer: Neue Kamera + SD
SD
Akkus

FREYA SNOW PIT, 6 MAY 2015
START 18:00

Weight of plastic bag: 7g
(to be removed from measures)
Vertical samples, tube length 21 cm

Layer 1 (0-21): 109 g
L2 (21-42): 163
L3 (42-63): 180
L4 (63-84): 195
L5 (84-105): 215
L6 (105-126): 229
L7 (126-147): 236
L8 (147-168): 232
L9 (168-189): 239
L10 (189-210): 239
Total Snow depth 278
END 18:40

Field Book Entries Summer:

Frage 17/8 15
 APT JAB
 1a not found
 58 cm Firm

02a ~~112~~ in ice 268
 32 cm (orange) tape over ice
 bare ice
 orange?
 03 rolls tape on 16 cm over ice
 2.84 ? in ice bare ice

US: 139 sensor head
 Solpaud shows low. N
 probably is very loose
 turned nearby

04 not found: 40 cm ~~mass~~ Firm!
 CLA can here. SI between 3.84

5 55 cm red above ice
 = 245 cm bare ice

7: 5 cm over blue marker (brown)
 or 1 cm over blue marker

Diagram: 1 cm blue, 1 cm brown, 1 cm blue, 1 cm brown, 1 cm blue, 1 cm brown. *supie?*

50 cm Firm *445?!*
at water surface

08a stable not found
 112 cm rubber on ice
 113 cm
 112

09 stable not found
 72
 74 on ice
 72

8.10 yellow top n = 57 cm
 = 93 cm ~~total~~ *total*
 snow depth: 23 cm
 31 cm
 35 cm
 of ice

F5.1 18/8 2015 13⁰⁰

APT JAB No wind, light snow
 Ripper cutter empty = 0,970 kg

Ripper cutter	Weight	Snow density
0 cm = Snow surface	1,312 kg	542 g/l
0-10 cm = 1,244 kg	1,312 kg	474 g/l
10-20 cm = 1,334 kg	1,312 kg	564 g/l
20-30 cm = 1,304 kg	1,312 kg	534 g/l
30-40 cm = 1,304 kg	1,312 kg	530 g/l
40-50 cm = 1,300 kg	1,312 kg	531 g/l
50-60 cm = 1,301 kg	1,312 kg	533 g/l
60-70 cm = 1,303 kg	1,312 kg	521 g/l
70-80 cm = 1,271	1,312 kg	521 g/l
80-90 cm = 1,291	1,312 kg	521 g/l
90 =		

Firm horizon: 99 cm
 Ice layer between 96 cm and 99 cm

Stratigraphy:
 0-18 cm = New snow
 20 cm Meltforn = med, 2-3 mm
 18-20 cm Ice layer
 20-25 cm Meltforn 0.5-4 mm
 25-27 cm Ice layer
 27-49 cm Meltforn, 4 mm
 49-59 cm Ice layer
 59-76 cm Meltforn, 2-4 mm
 76-99 cm Ice layer
 Layer below 99 cm was colored
 slightly yellow/brown.

AW5 stable 104 cm *emerge*
 Snow depth 122
 121
 120

04 not found
 snow depth 70 cm
 75 cm 2
 158
 137
 230

05 not found
 snow 125
 125
 129

AW5: Winds: Pacific
 Road → back to Ant's
 CF Card → —
 T lower runs OK
 US OK for bin
 Compass 120 over snow road
 Wind 120 195

Low Atppt:
 V. 6.94
 Start 13 end 13 30
 23 23
 Interval 1
 all the globe wires at

Low Atppt 4
 V 7.23
 26 end 12 30
 26 26
 Interval 1

6a 100, 105 snow depth
 stable not found
 Ultrasonic tape depth 2015