ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
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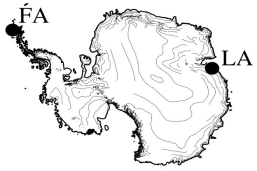
Water and thermal balances of Antarctic Lakes



Shevnina E., Kurzeneva E.

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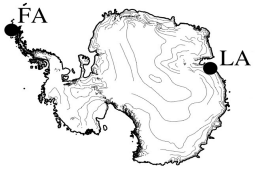


West and East Antarctica

FA: Fildes peninsula
(62° 12' S / 58° 54' W)
Bellinsgausen (89050)
Great Wall (89058)

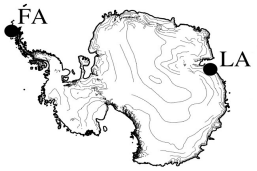
Climate: DJF

Station ID	Air TMP[C]	RHum. [%]	PRE [mm]	WS [ms^{-1}]	Cloud [Okta]	LowCl [okta]	Sun Dur. [H]
89050	0.6	88	53.4	6.7	9.2	7.9	84.7

LA: Larsemann Hills
(69° 30' S / 76° 20' E)
Progress (89574)
Zong Shan (89573)

Climate: DJF

Station ID	Air TMP[C]	RHum. [%]	PRE [mm]	WS [ms^{-1}]	Cloud [Okta]	LowCl [okta]	Sun Dur. [H]
89574	-1.6	60	6.2	5.2	6.4	2.9	300.8



Observation and Methods

Measurements:

- 10/60 min: Water temperature.
- Daily: water level (Lakes and Inflow/Ouflow), water temperature.
- Ones for 3-4 days: water discharge (Inflow/Outflow), snow depth/density.

Methods to estimate water/thermal balances:

- Water Inflow/Outflow: water level – discharge curves.
- Rain and Snow melting income: based on meteorological and snow observation.
- Evaporation: Empirical equations and Flake experiments.

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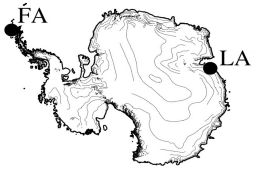
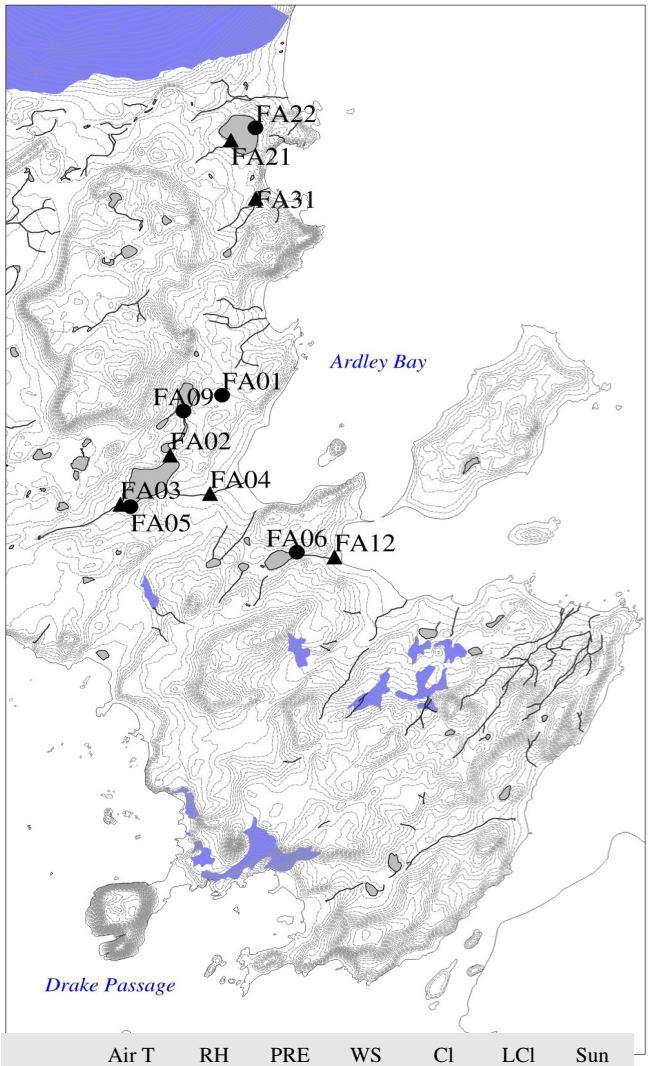


FA vs LA

15.01. – 31.03.12

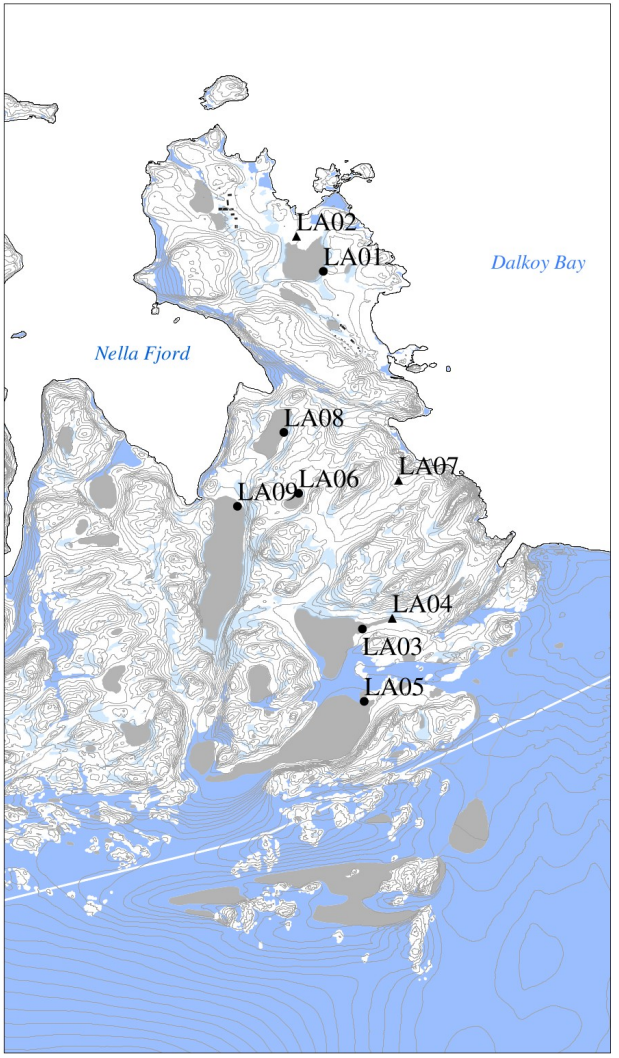


	Air T C	RH %	PRE mm	WS ms^{-1}	Cl okt	LCl okt	Sun H
JAN	1.5	89	38.8	6.5	9.0	8.0	128
FEB	0.8	85	61.7	6.9	8.4	7.3	128
MAR	0.9	88	68.2	6.6	9.2	8.1	80

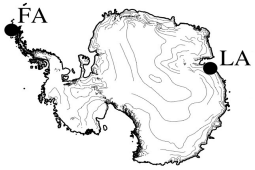
Point	Lake	Altitude, m a.s.l.	Depth, m	Feeding/outflow
FA00	Mirag	30.0	1.0	Snow / No
FA01	Slalomnoe	25.0	6.6	Snow / Yes
FA05	Kitiesh	16.1	12.0	Snow / Yes
FA09	Srednee	18.9	5.3	Snow / Yes
FA11	Dlinnoe	14.5	4.3	Snow / Yes
FA22	Glubokoe	20.4	16.1	Snow / No
LA01	Stepped	5.7	5.5	Snow / Yes
LA03	Sibhorp	60.0	0.7	Ice and Snow / Yes
LA05	Progress	60.0	34.0	Ice and Snow / Yes
LA06	Sarah Tarn	60.0	2.5	Snow / No
LA08	Scandrett	20.0	18.0	Ice and Snow / Yes
LA09	Reid	30.0	3.8	Snow / No

Point	Area, km^2
Outflow from Slalomnoe Lake (FA02)	0.610
Inflow to Kitiesh (FA03)	0.160
Outflow from Kitiesh Lake (FA04)	2.86
Outflow from Dlinoe Lake (FA12)	0.820
Inflow to Glubokoe (FA21)	0.265
Ouflow to Ardley Bay (FA31)	0.224
Outflow from Stepped Lake (LA02)	[0.197]/[0.270]
Ouflow from Siphorph Lake (LA04)	[0.580]/[1.43]
Inflow to Seal Cove (LA07)	0.206
Outflow from Scandrett Lake (LA10)	1.14

25.012.12 – 01.02.13



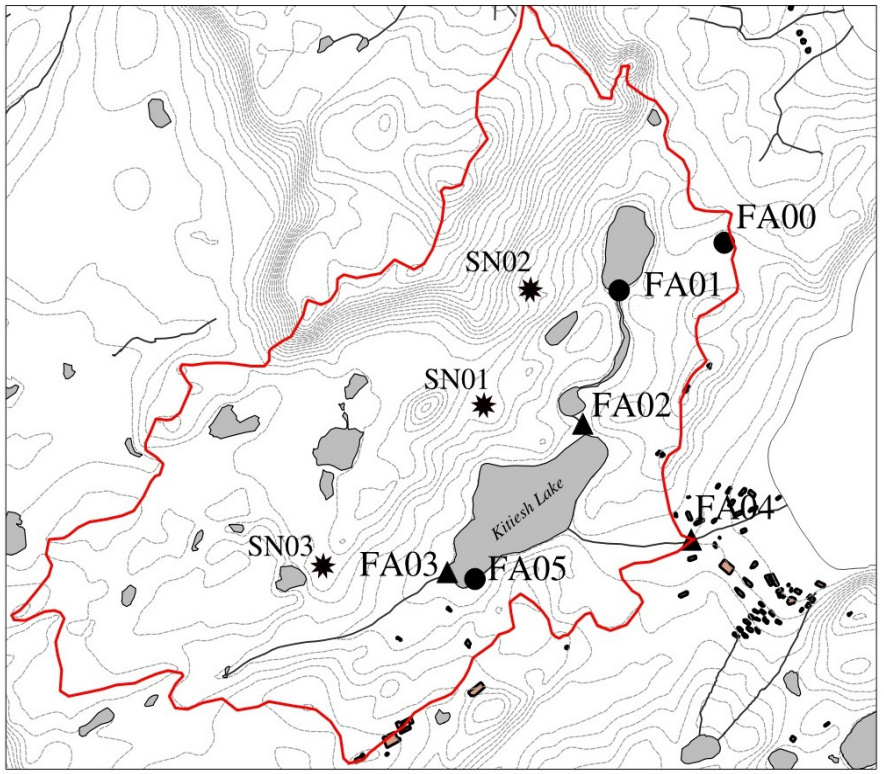
	Air T C	RH %	PRE mm	WS ms^{-1}	Cl okt	LCl okt	Sun H
DEC	1.5	69	8.8	4.5	7.8	3.3	NA
JAN	1.0	68	6.2	4.6	8.1	3.4	NA

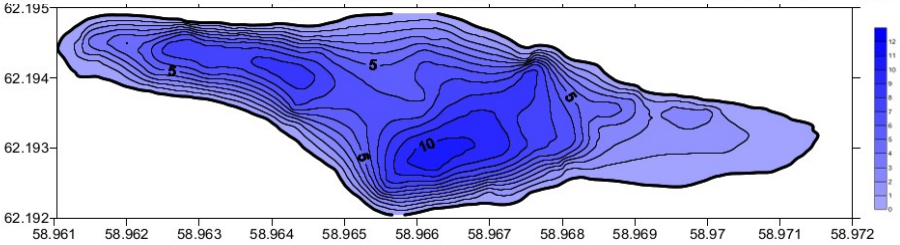


FA: Kitiesh Lake

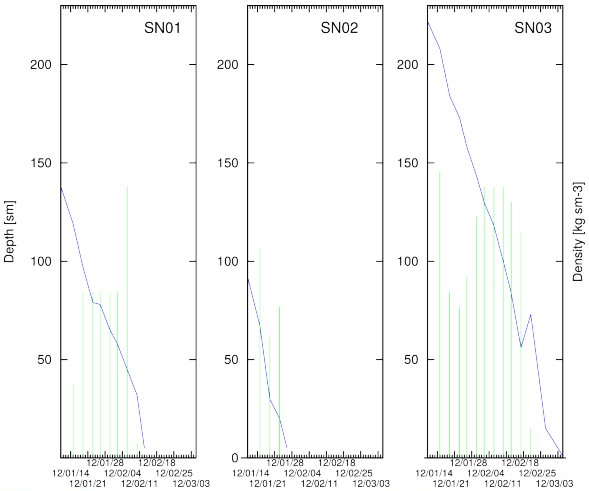
$$InR + SnM + Pre - OutR - WSup - ELs - ECs = \pm \Delta W$$

Scheme





InR – stream inflow from two tributaries; *SnW* – Surface inflow due to snow melting; *Pre* – rainfall to lake and catchment areas; *OutR* – stream outflow; *WSup* – water supply of Russian and Chilean stations; *ELs* – evaporation from Lake surface; *ECs* - evaporation from catchment surface; ΔW – changes of the Lake water storage.

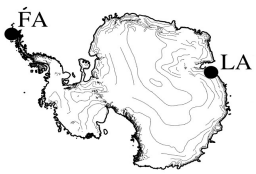


Snow Measurements:

1. Depth and Density of snow cover at representative points;
2. Visual observation of percentage snow cover area.

Point / Lake	Altitude, m	Depth, m	Area, $10^3 m^2$	Feed / Outflow
FA05 /Kitiesh	16.1	7.5	145.0	Snow / Yes

Inflow / Outflow Points	Area, km^2
FA02: Inflow to Kitiesh	0.610
FA03: Inflow to Kitiesh	0.160
FA04: Outflow from Kitiesh	2.86



FA: Kitiesh Lake Water Balance

Seasonal Incomes:

Term	Income in depth of water per watershed unit area, [mm]	Coefficient of variation of daily values	Volume of water, [10^3 m^3]
Inflow FA03	459	0.68	73.4
Inflow FA02	317	0.82	193.4
Snow melting	103	1.26	215.3
Precipitation	127	1.61	265.4

Total income: 747.5

Seasonal Outcomes:

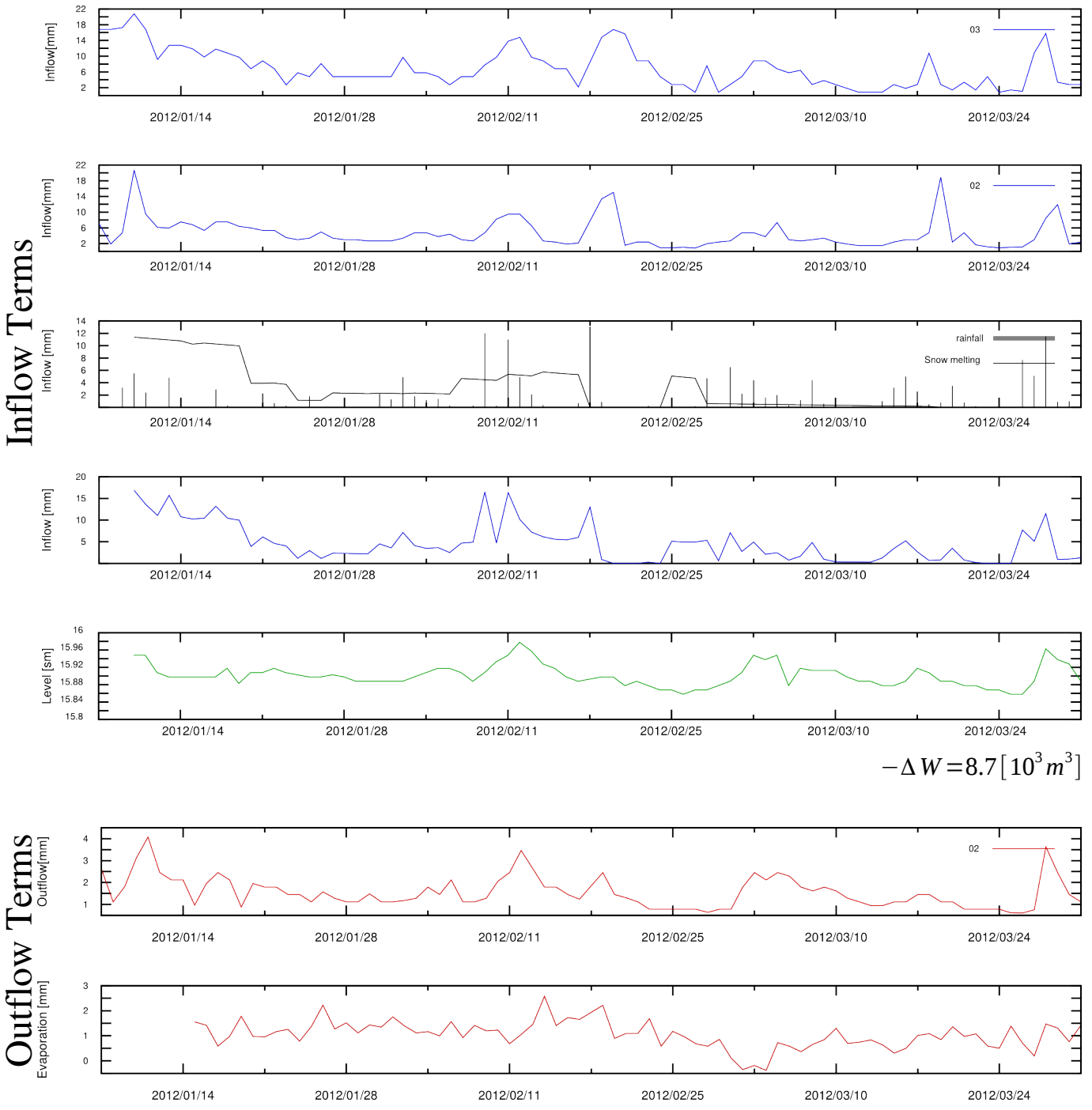
Term	Outcome in depth of water per watershed unit area, [mm]	Coefficient of variation of daily values	Volume of water, [10^3 m^3]
Outflow FA04	111	0.44	317.5
Evaporation from lake surface	79.0	0.51	11.5

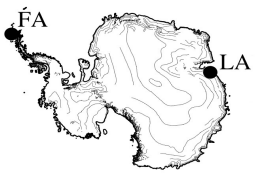
Total outcome: 328.9

Additional outcomes:

Water supply of Russian and Chilean Stations is about 290 [10^3 m^3];

Evaporation from catchment surface is about 180 [10^3 m^3].

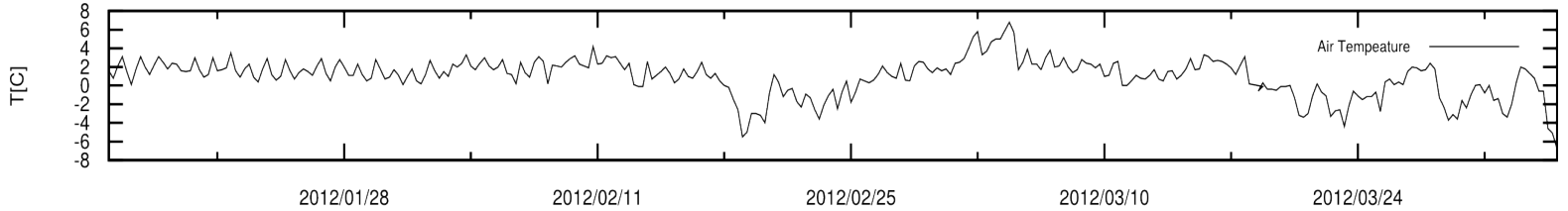


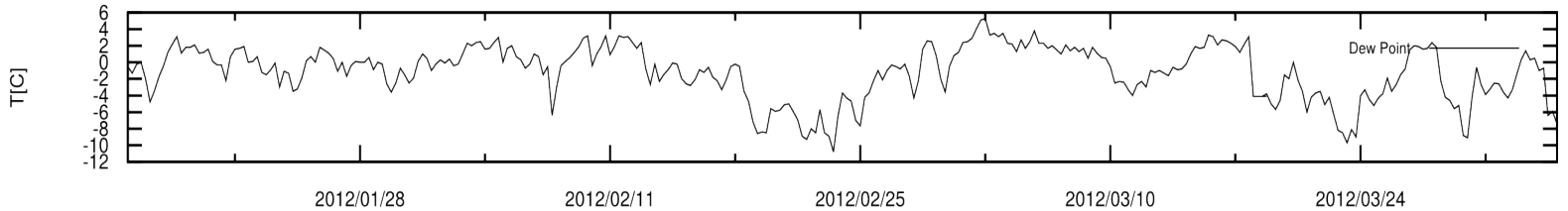


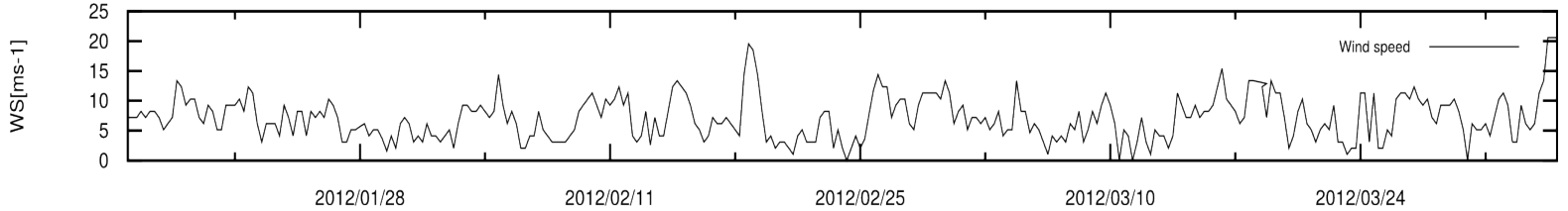
FA: Kitiesh FLake Experiments

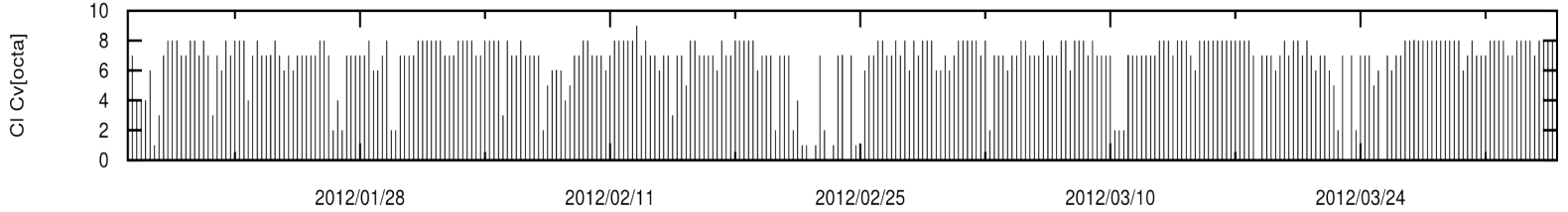
Flake Experiment	Description
RUN 1.1	Start date 01.01.2012: depth of mixed layer equals to 1.5 m; mixed layer temperature equals to air temperature; bottom temperature equals to 2 C, parameters of water transparency equals to 1.0.
RUN 1.2	Same, but parameter of water transparency equals to 0.2.

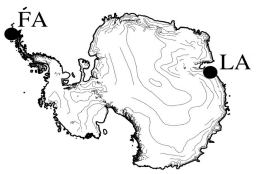
Forcing: 6 hours meteorology from Bellinsgausen Station (89050) : NADC, Arctic and Antarctic Research Institute.











FA: Kitiesh FLake Results

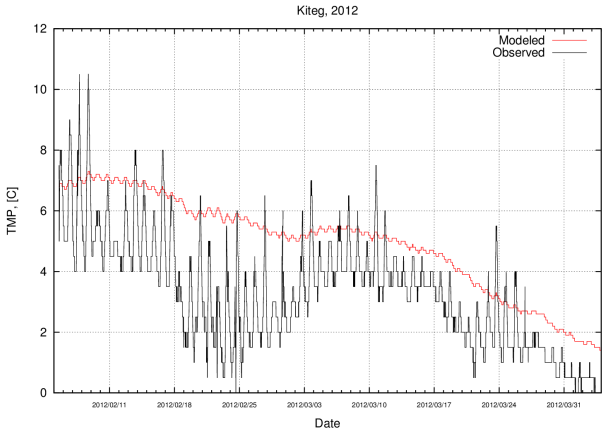
Modeled vs Observed mean values of surface water temperature.

	10 min	Daily	Day	Noon	Night	Midnight
Observed	3.2	3.2	4.0	4.2	2.5	2.4
RUN 1.1	4.8	4.8	4.8	4.9	4.7	4.6
RUN 1.2	3.2	3.3	3.3	3.3	3.1	3.1

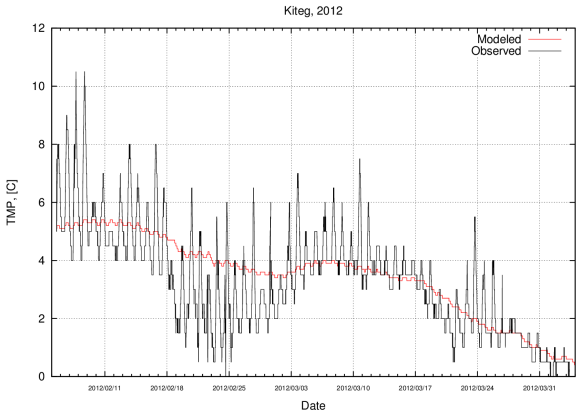
Modeled vs Calculated mean values of Evaporation from water surface.

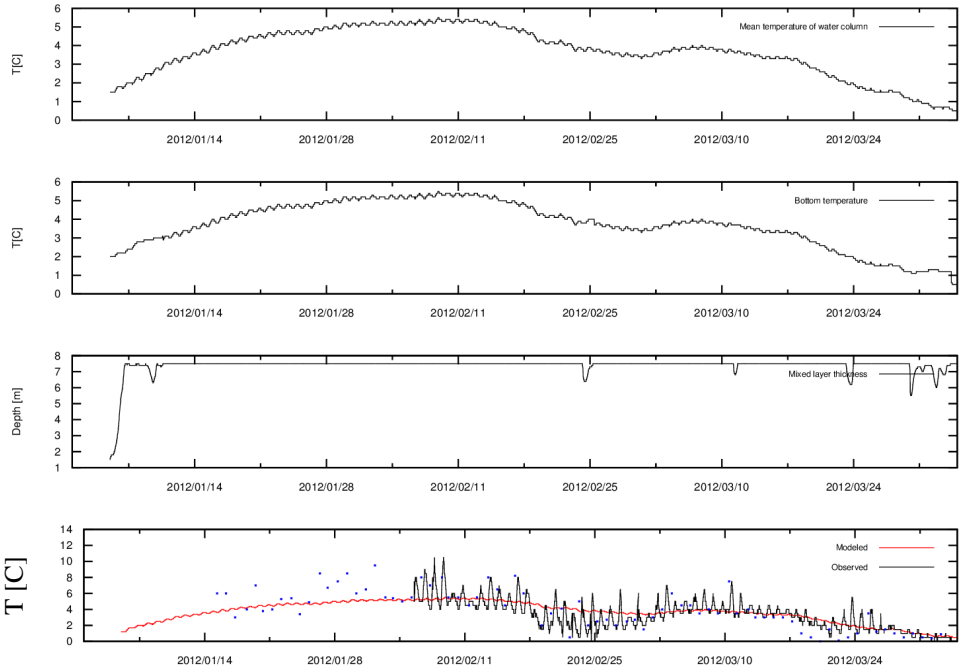
Method of calculation	Mean daily value [mm]	Cv	Sum [mm]
Empirical equation [Guidelines, 1964]	1.0	0.51	79.0
RUN 1.1	1.7	0.36	131.1
RUN 1.2	1.2	0.47	93.1

RUN 1.1

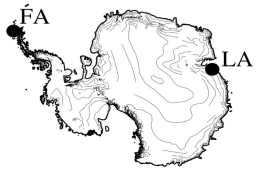


RUN 1.2





*Local time: UTC-4. Day: 05:00, 06:00, 07:00, **08:00**, 09:00, 10:00, 11:00. Night: 17:00, 18:00, 19:00, **20:00**, 21:00, 22:00, 23:00.



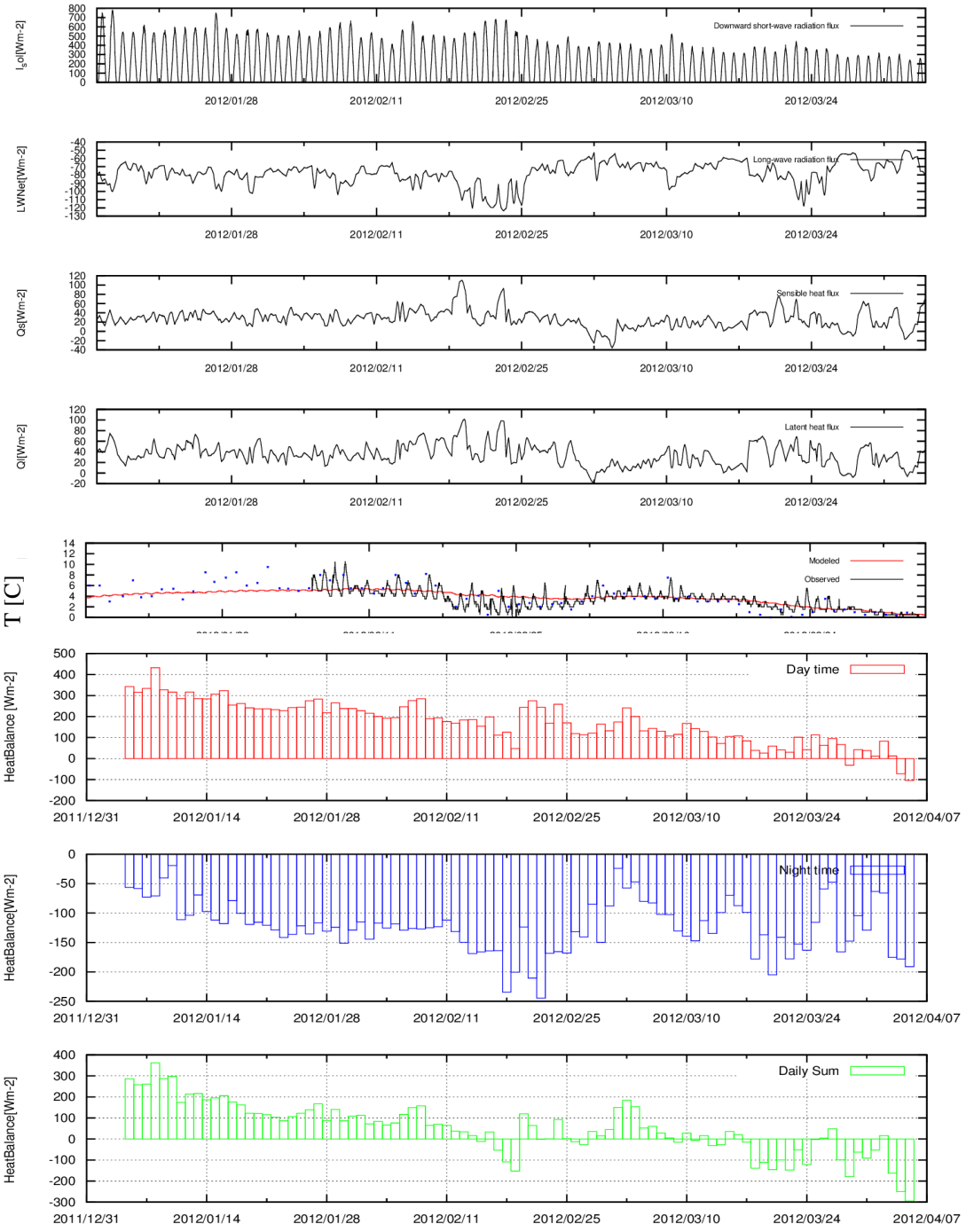
FA: Kitiesh Lake Thermal Balance

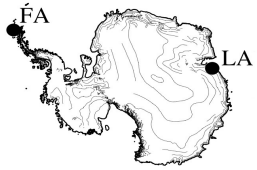
RUN 1.1

Term	Day		Night	
	Mean	Cv	Mean	Cv
Net Short Wave [Wm^2]	307.3	3.29	8.8	0.92
Net Long Wave [Wm^2]	-85.3	-6.21	-83.7	-6.76
Q sensible [Wm^2]	43.2	2.34	40.3	2.28
Q latent [Wm^2]	48.2	2.38	51.1	2.80

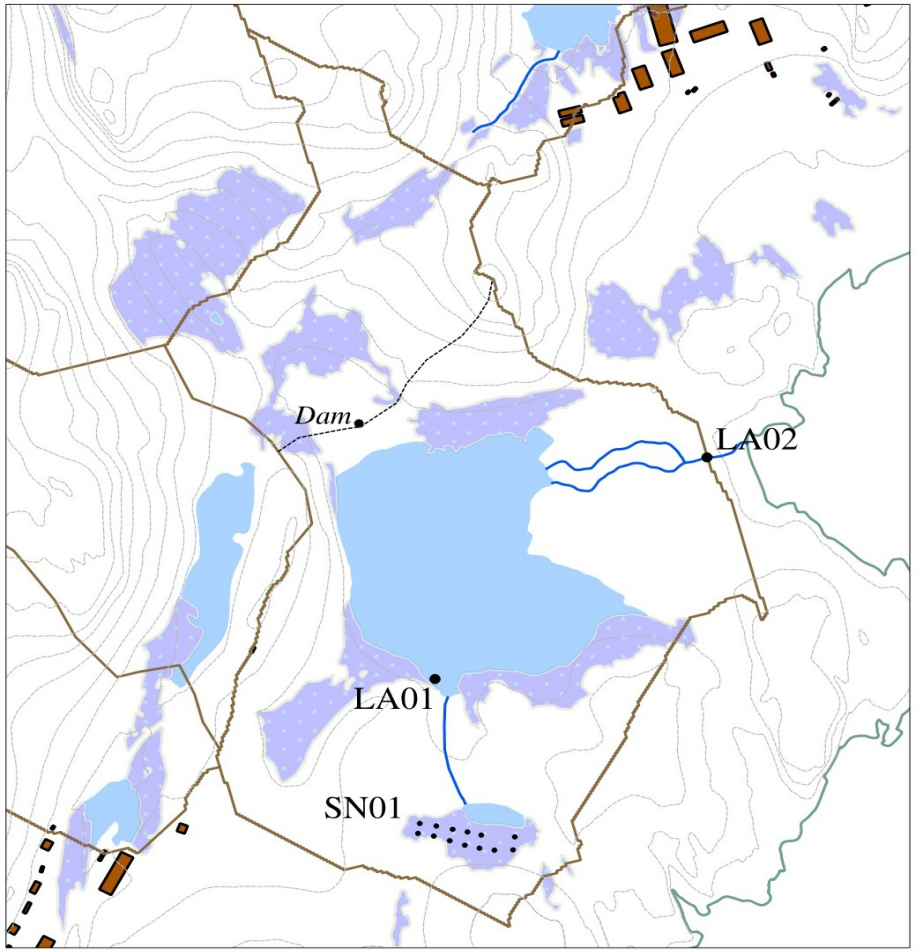
RUN 1.2

Term	Day		Night	
	Mean	Cv	Mean	Cv
Net Short Wave [Wm^2]	307.2	3.29	8.8	0.92
Net Long Wave [Wm^2]	-78.1	-5.88	-76.5	-6.36
Q sensible [Wm^2]	28.9	1.75	24.9	1.48
Q latent [Wm^2]	34.3	1.88	36.3	2.09



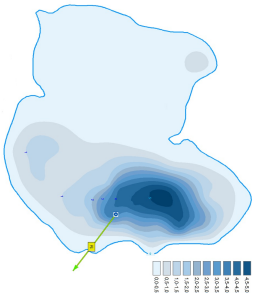


LA: Stepped Lake (LA)



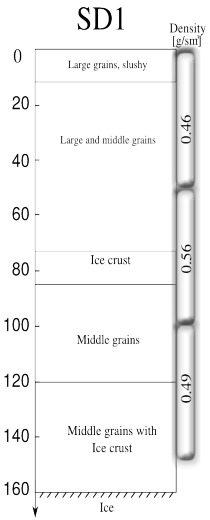
$$SnM + Pre - OutR - WSup - ELs - ECs = \pm \Delta W$$

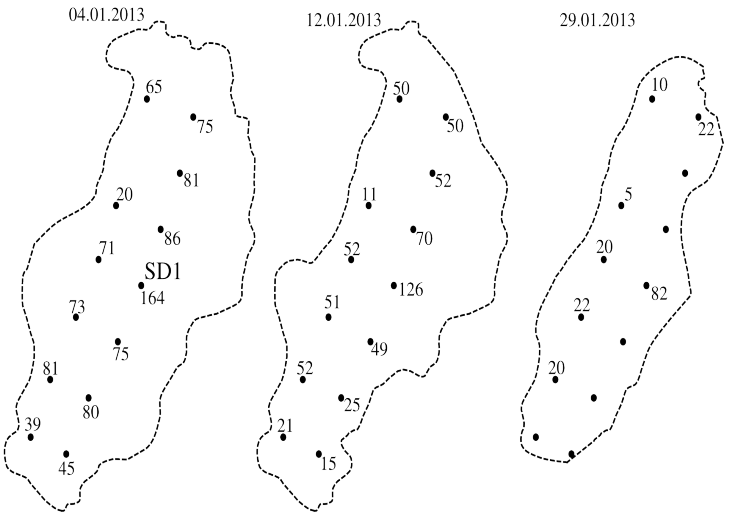
SnW – Surface inflow due to snow melting; *Pre* – rainfall to lake and catchment areas; *OutR* – stream outflow; *WSup* – water supply of Russian station; *ELs* – evaporation from Lake surface; *ECs* - evaporation from catchment surface; ΔW – changes of the Lake water storage.



2013/01/13 – Dam breaking at appoximately 09:00 LT

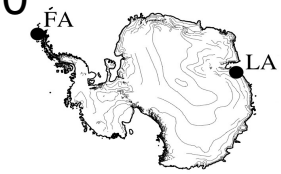
Snow Measurements





Point / Lake	Altitude, m	Depth, m	Area, $10^3 m^2$	Feed / Outflow
LA01 / Stepped	5.7	4.5	47.5	Snow / Yes

Inflow / Outflow Points	Area, km^2
LA02: Outflow from Stepped	[0.197]/[0.270]



LA: Stepped Lake Water Balance

Seasonal Incomes:

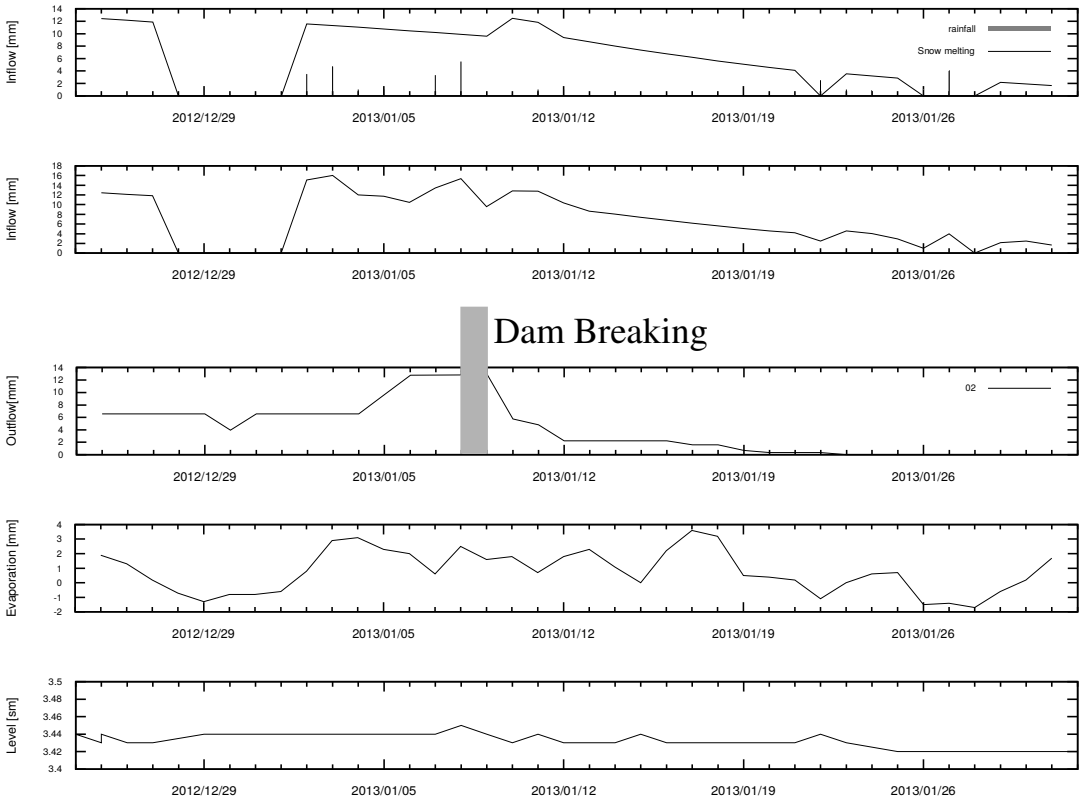
Term	Income in depth of water per watershed unit area, [mm]	Coefficient of variation of daily values	Volume of water, [10^3 m^3]
Snow melting	121.2 / 92.2	0.77	23.9 / 25.1
Precipitation	31.4	1.77	3.7 / 3.3

Total income: 56.1

Seasonal Outcomes:

Term	Outcome in depth of water per watershed unit area, [mm]	Coefficient of variation of daily values	Volume of water, [10^3 m^3]
Outflow LA02	95.2 / 23.4	0.34 / 0.84	[25.1]
Evaporation from lake surface	62.2	0.33	2.9

Total Outcome: 28.0

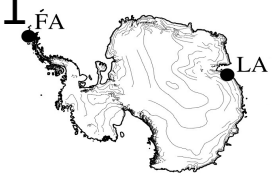


Additional outcomes:

Water supply of Russian Station is about 17.1 [10^3 m^3];

Outflow due to dam breaking is about 8.0 [10^3 m^3]???;

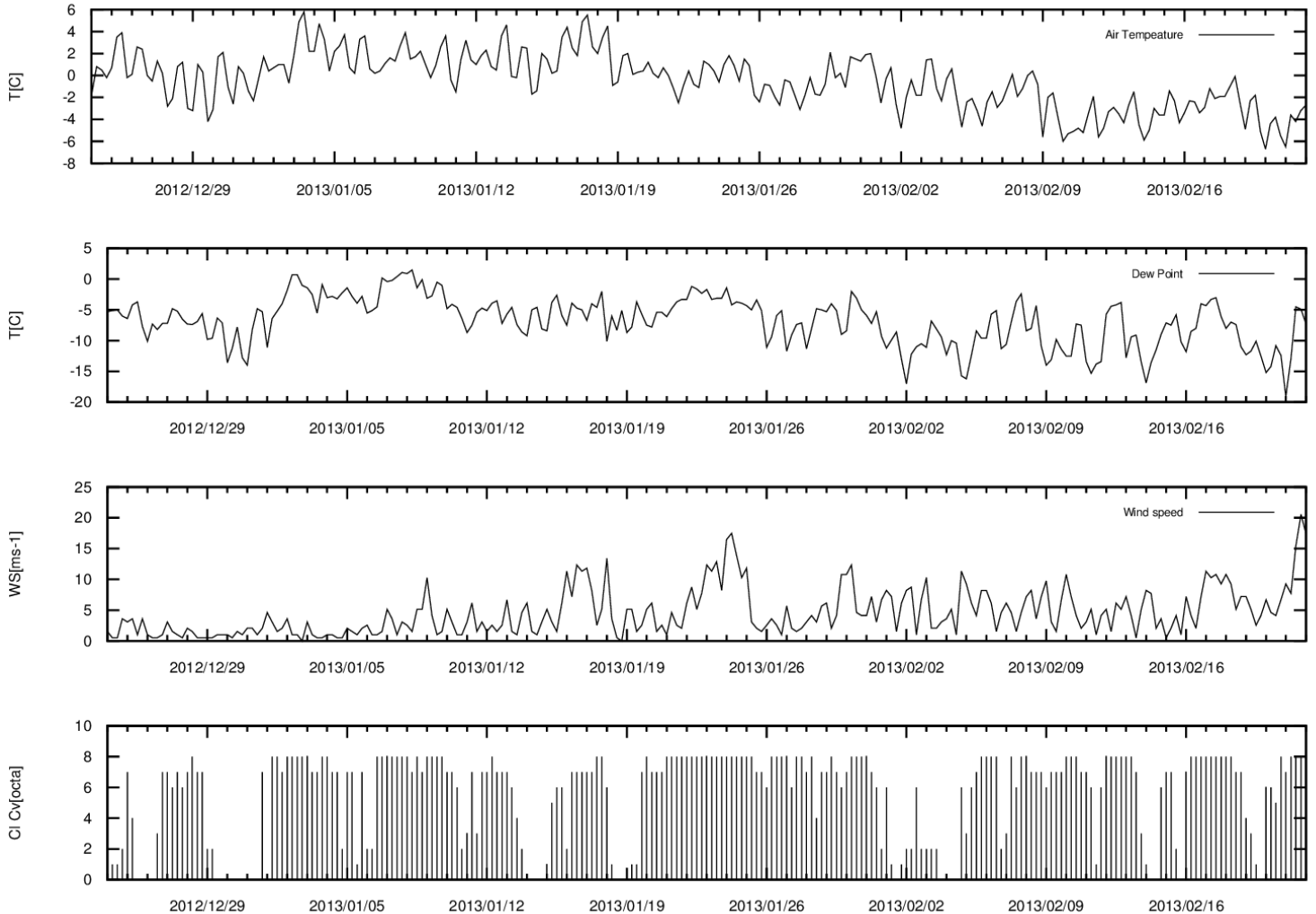
Evaporation from catchment surface is about 2.0 [10^3 m^3]???.

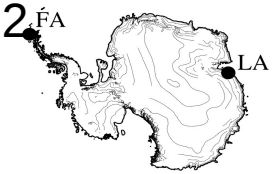


LA: Stepped FLake Experiments

Flake Experiment	Description
RUN 1.1	Start date 05.01.2012: lake is mixed; water temperature equals to night minimum or 4.5 C; parameters of water transparency equals to 2.0.
RUN 1.2	Same, but parameter of water transparency equals to 1.0.

Forcing: 6 hours meteorology from Progress Station (89574) : NADC, Arctic and Antarctic Research Institute.



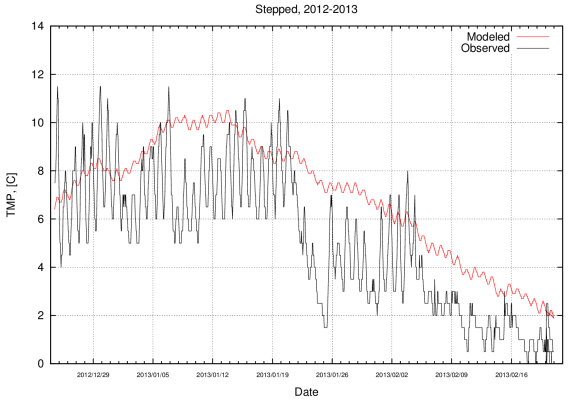


LA: Stepped FLake Result

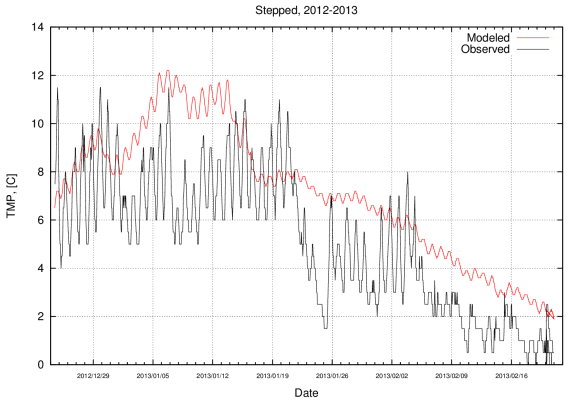
Modeled vs Observed mean values of surface water temperature.

	60 min	Daily	Day	Noon	Night	Midnight
Observed	4.9	5.0	5.7	5.8	4.1	4.0
RUN 1.1	6.7	7.0	6.9	6.9	6.6	6.9
RUN 1.2	6.9	7.2	7.1	7.1	6.7	6.7

RUN 1.1



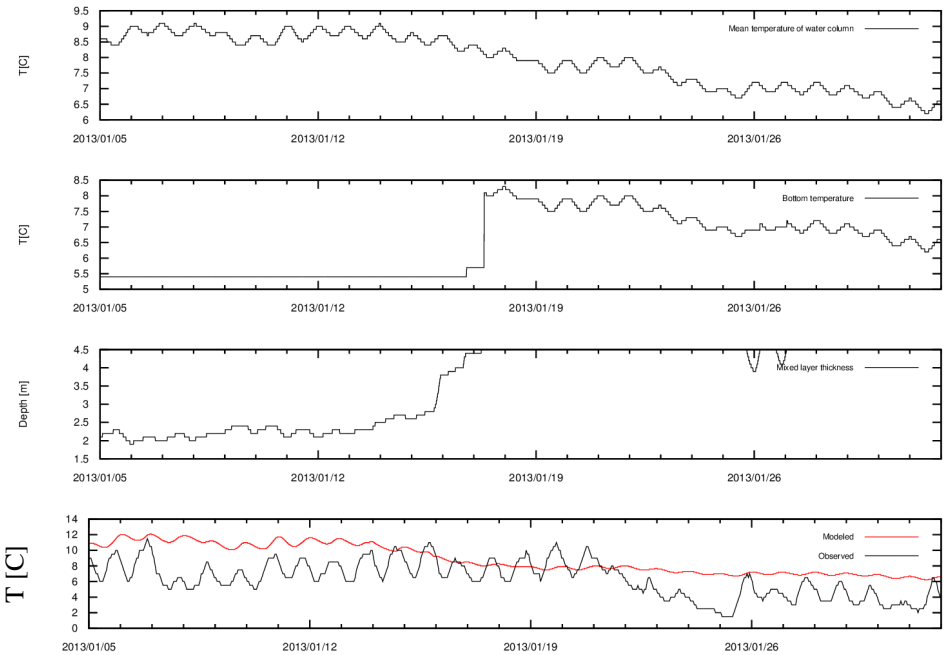
RUN 1.2



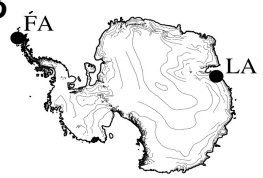
Modeled vs Calculated mean values of Evaporation from water surface.

Method of calculation	Mean daily value [mm]	Cv	Sum [mm]
Empirical equation [Guidelines, 1964]	1.6	0.33	62.2
RUN 1.1	2.4	0.38	91.7
RUN 1.2	2.4	0.33	93.7

RUN 1.1



*Local time: UTC+7. Day: 16:00, 17:00, 18:00, **19:00**, 20:00, 21:00, 22:00. Night: 04:00, 05:00, 06:00, **07:00**, 08:00, 09:00, 10:00.



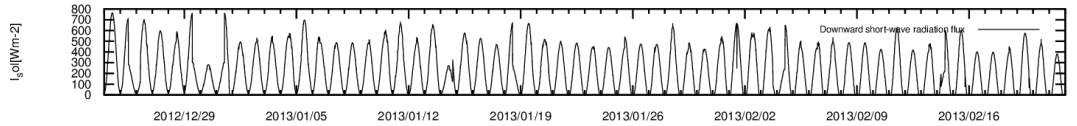
LA: Stepped Lake Thermal Balance

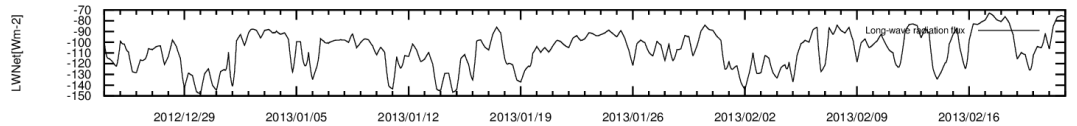
RUN 1.1

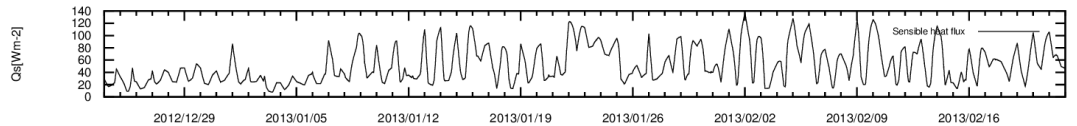
Term	Day		Night	
	Mean	Cv	Mean	Cv
Net Short Wave [Wm^2]	377.8	4.90	75.4	3.69
Net Long Wave [Wm^2]	-110.1	-7.08	-106.5	-7.75
Q sensible [Wm^2]	52.8	44.5	44.5	2.27
Q latent [Wm^2]	70.4	2.36	67.9	2.65

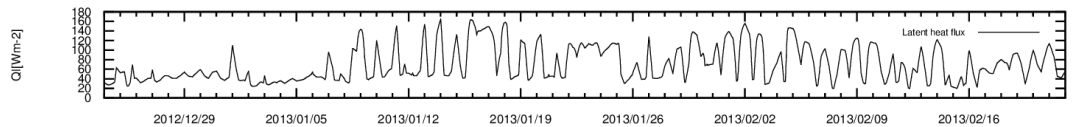
RUN 1.2

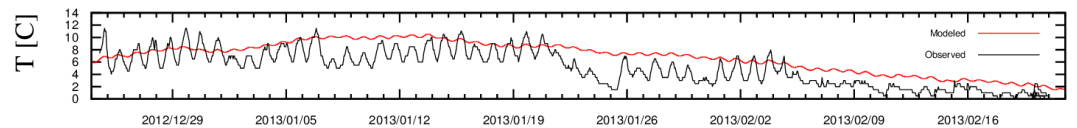
Term	Day		Night	
	Mean	Cv	Mean	Cv
Net Short Wave [Wm^2]	377.8	4.90	75.4	3.69
Net Long Wave [Wm^2]	-109.3	-7.32	-105.2	-8.02
Q sensible [Wm^2]	51.9	2.22	43.9	1.99
Q latent [Wm^2]	68.8	2.12	57.5	2.24

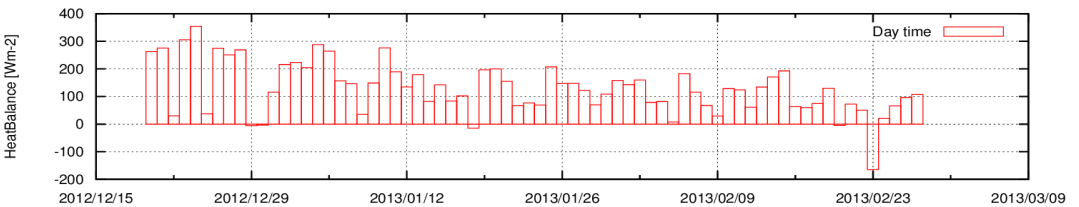


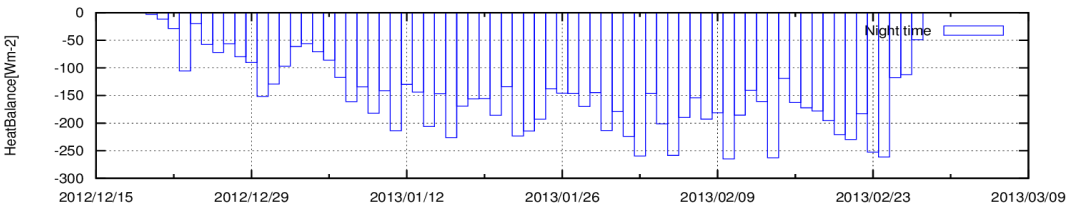


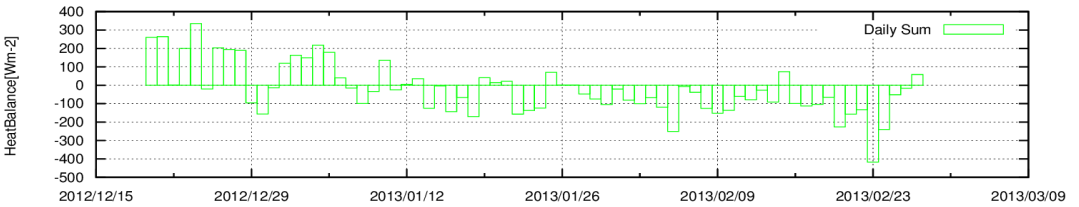


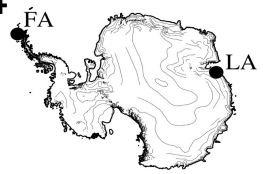






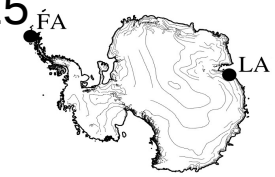






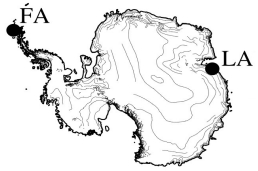
Conclusions

- To close water balance an additional data is required (to be continue...)
- Evaporation is an overlapping component of water and thermal balances: it takes essential amount in water balance for East part of Antarctica (of over 40 % of total outcomes) and less important terms in water balance for Western Antarctica (of over 15-17 % of total outcomes).
- Daily evaporation values estimated by Flake is 30 % (for East part) and is 15 % (West part) larger then estimated by empirical formula commonly used in hydrological application (modification of Dalton formula).



Conclusions

- Thermal balance is positive for day time and negative for night time. Turbulent fluxes are very depend on the wind speed (especially in East Antarctica, where the katabatic winds are common).
- Flake underestimates diurnal cycle of the lakes surface temperature in both considered cases, but can reproduce mean daily values well for the lake in Western Antarctica.
- Flake modeling results are very sensitive to lake water transparency.



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