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Mercury dynamics in thermokarst lakes in continuous permafrost areas: Zackenberg Valley, Northeast Greenland

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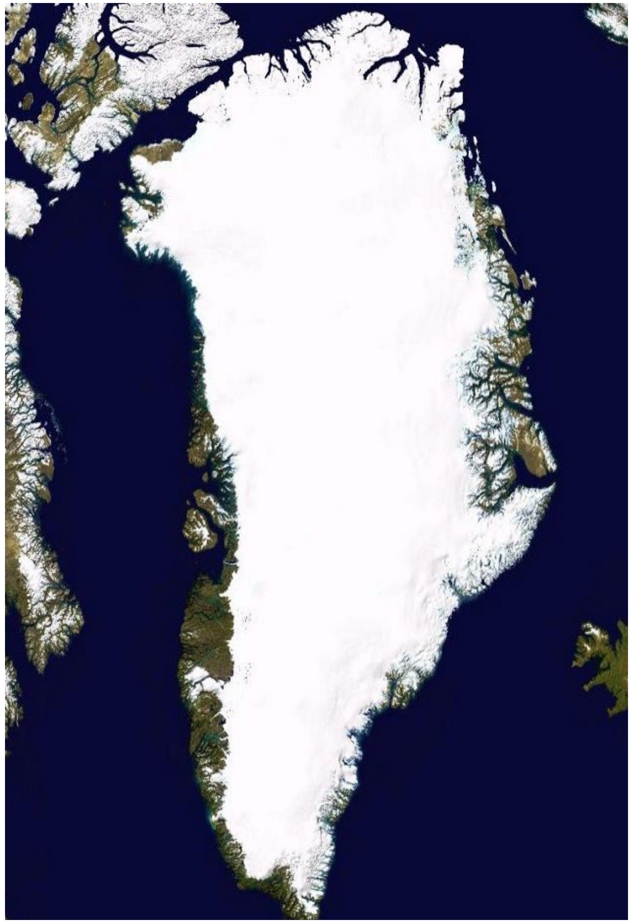
Mercury studies in Greenland



SCIENCE

High mercury levels in Greenland's glaciers

Isabela Martel
06/18/2021

Scientists were alarmed at the amount of dissolved mercury they found in rivers and fjords. The heavy metal raises concerns for the health of indigenous communities. And with global warming, the problem may get worse.

communications earth & environment Article

https://doi.org/10.1038/s43247-024-01474-9

Low mercury concentrations in a Greenland glacial fjord attributed to oceanic sources

Check for updates

M. R. Lindeman[1,2], F. Straneo[1], H. M. Adams[1], M. J. S. Nelson[1] & A. T. Schartup[1]

As the role of the Greenland Ice Sheet in the Arctic mercury (Hg) budget draws scrutiny, it is crucial to understand mercury cycling in glacial fjords, which control exchanges with the ocean. We present full water column measurements of total mercury (THg) and methylmercury (MeHg) in Sermilik Fjord, a large fjord in southeast Greenland fed by multiple marine-terminating glaciers, whose circulation and

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ELSEVIER

Rapid temporal decline of mercury in Greenland halibut (*Reinhardtius hippoglossoides*)☆

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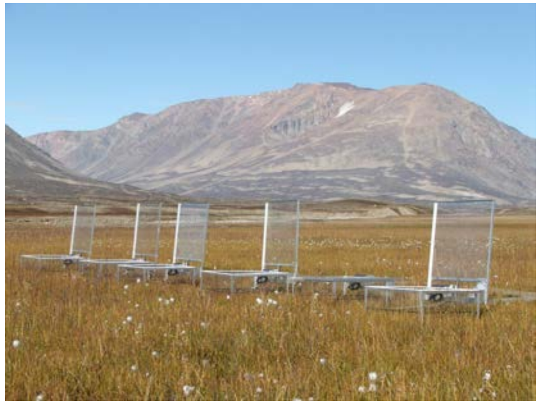
Zackenberg Valley - Greenland

The study area around **Zackenberg** is in the **zone of continuous permafrost** area with an **active layer thickness varying from 20 to 100 cm**. A major geological flexure and thrust zone dissecting *Zackenbergdalen*, separates Caledonian gneiss bedrock from Cretaceous sandstones and Tertiary basalts.

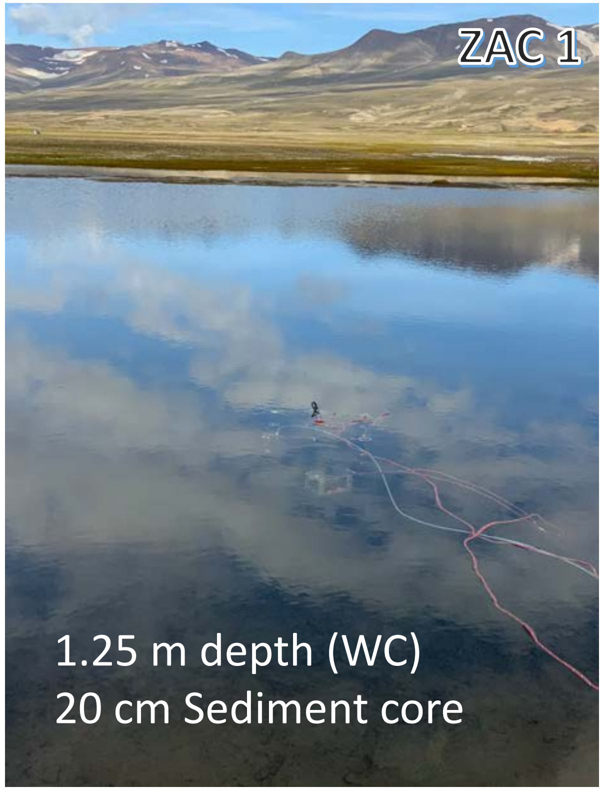
The study area was deglaciated *ca.* 8,000 years ago and it holds a great diversity of biotopes like ponds, fens, heaths, fell field plateaus and grasslands.

Recently, signs of permafrost degradation are being observed with thermokarst features appearing in the landscape. The **area is well documented in terms of greenhouse gas fluxes** but information on **Hg biogeochemistry is absent.**

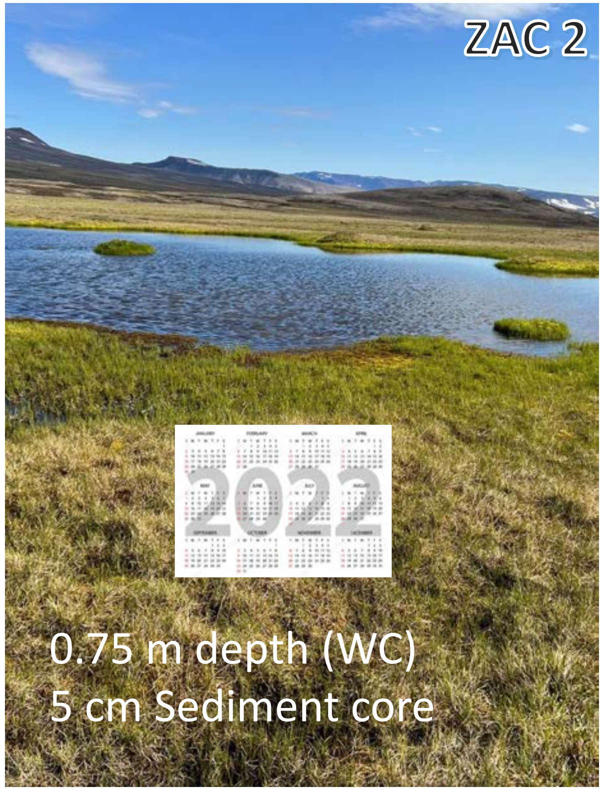


Sampling

20 soil samples



6 depths for water
3 depths for sediment
2+3 incubations

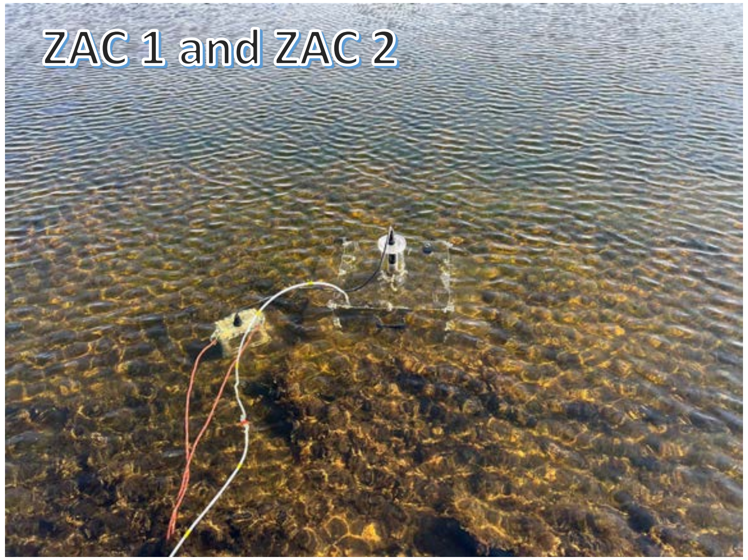


3 depths for water
1 depths for sediment
2+2 incubations

8 times water sampling
(t=0 – t=6h)

Sampling

- Lake water samples with 25-cm resolution depth
- Lake sediment samples with 5-cm resolution depth
- Soil samples
- Water sampling using a benthic flux chamber during 8h



- Hg and MMHg concentrations
- Other parameters (e.g. DOC, Fe(II), SO_4^{2-}, etc)
- Hg methylation and MMHg demethylations rates with and without amendments
- Flux measurements

Results

Hg and MMHg in Soils





14,5 cm AL	↔	48.5 cm AL
27% H_20	↔	85% H_20
3.7 % $_{Corg}$	↔	22% C_{org}
12 % BGB	↔	36 % BGB
1.4 % Fe	↔	7.7 % Fe
29 ng Hg/g	↔	**140 ng Hg/g**
0.1 ng MMHg/g	**(0,5 – 8,2 % MMHg)** ↔	**7.6 ng MMHg/g**

Hg and MMHg in Soils

$r_s = 0.742$; $p < 0.05$

$r_s = 0.786$; $p < 0.05$

$r_s = 0.867$; $p < 0.05$

$r_s = 0.828$; $p < 0.05$

Higher permafrost degradation
(AL deepening + water content)
↓
Higher Hg in the soil
↓
Thawing permafrost: main Hg source (?)

Higher water content
↓
Higher Hg and MMHg in soils
↓
Higher Hg → Higher MMHg
↓
Availability of Hg for methylation (?)

Thaw progression appears to influence Hg speciation and dynamics in permafrost soils

Hg and MMHg in ZAC 1 and ZAC 2 lakes

Water Column

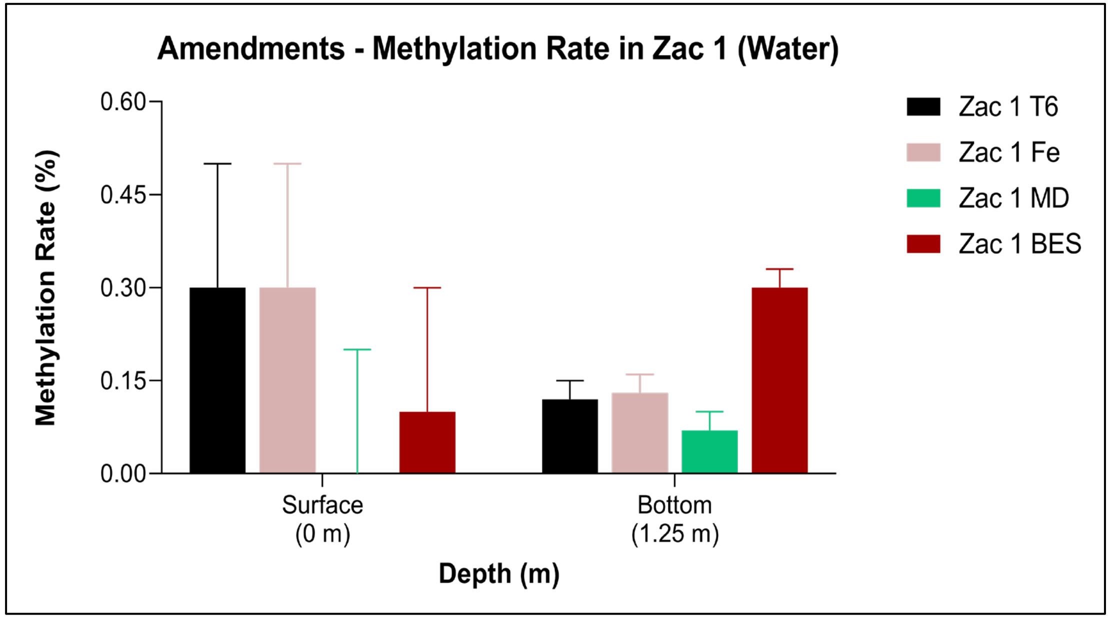
Sediments

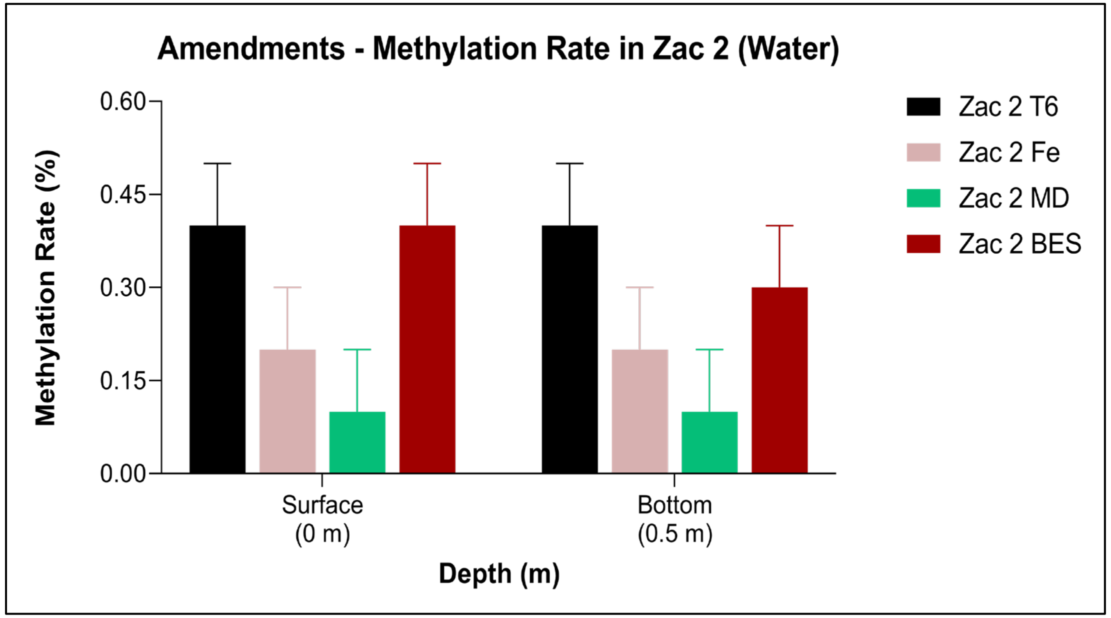
In water column Hg correlates with DOC in ZAC 2; MMHg correlates with Hg in both lakes (stronger in ZAC 2; $p<0.05$)

Hg and MMHg increases with depth in ZAC 2 (sediment source or Hg evasion at the surface?)

Hg and MMHg is significantly higher in sediments of lake ZAC 2 (***youngest lake***)

Hg methylating rates in water samples

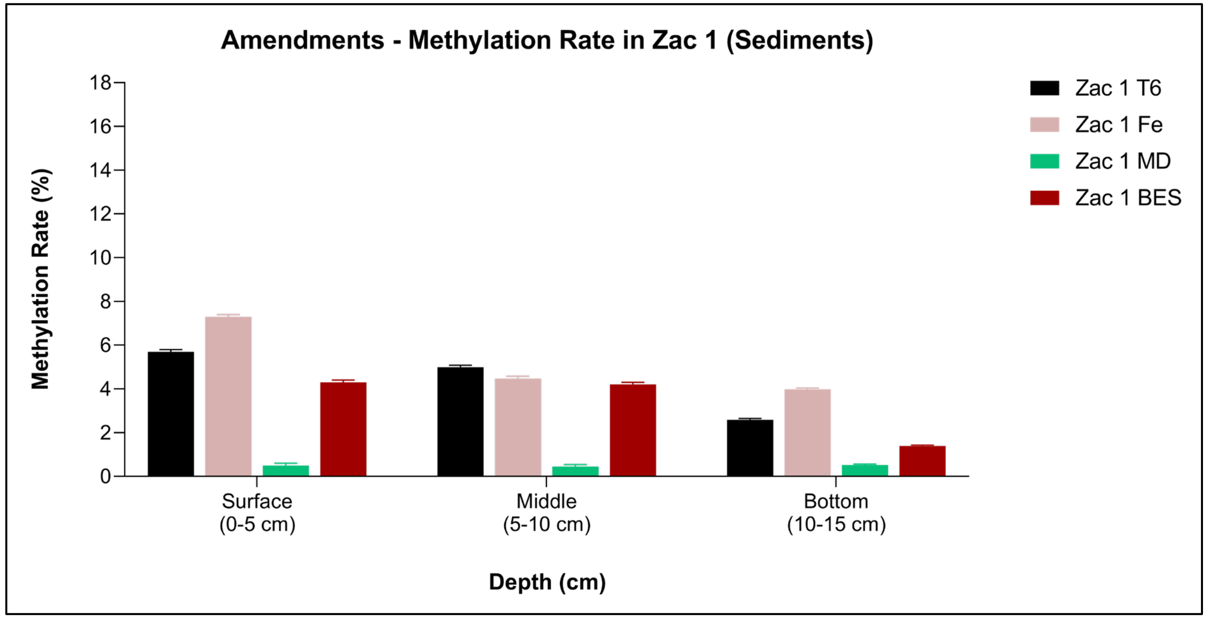


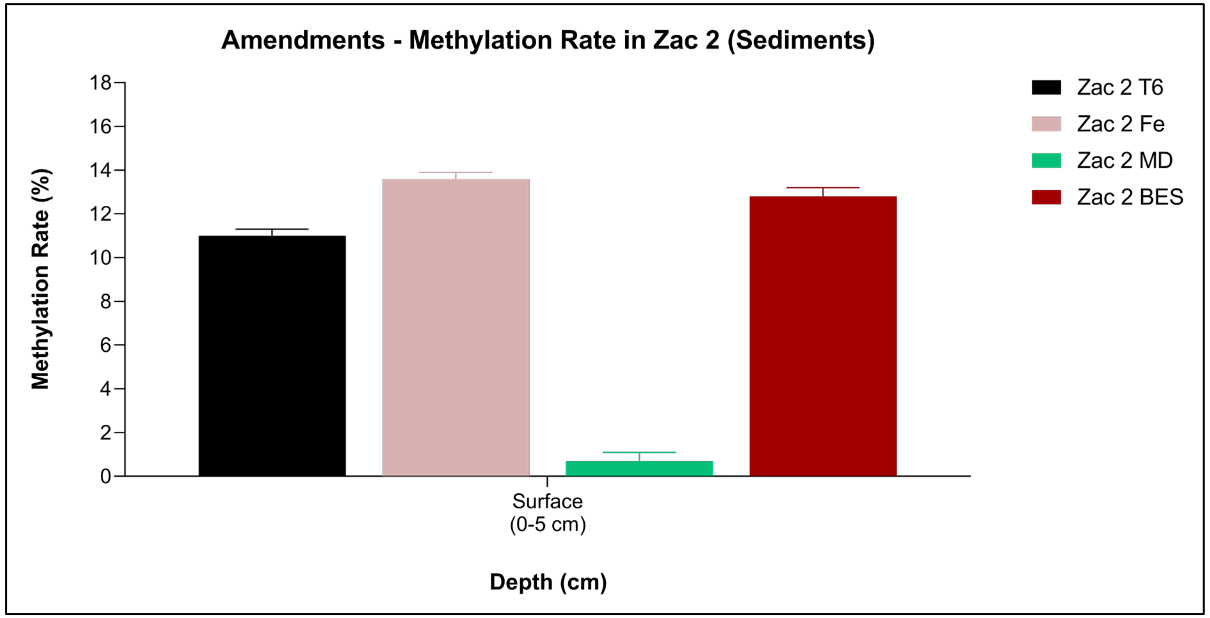


- Mercury methylation rates are in average higher in ZAC 2 waters – ***youngest lake*** –
- Sulphate reduction bacteria appears to be the main methylators on ZAC lake waters
- Despite the relatively high content of Fe in the water column, addition of iron as not measurable effect
- Methanogens showed no trend in the incubations (e.g. ZAC 1)

Competition <-> Microbiology *(on going)*

Hg methylating rates in sediment samples





- Mercury methylation rates are, **also**, in average higher in ZAC 2 sediment – ***youngest lake*** –
- Sulphate reduction bacteria appears to be the main methylators in ZAC lake sediments
- Apart from ZAC 1 middle, addition of Fe(III) seems to slightly increase methylation rates
- ZAC 1 inhibition of methanogens showed a decrease in methylation rates; in ZAC 2 a slightly increase was observed

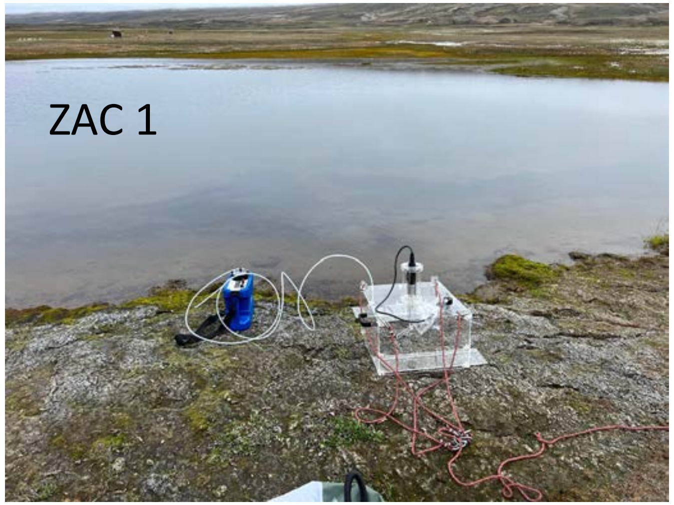
Competition <-> Microbiology *(on going)*

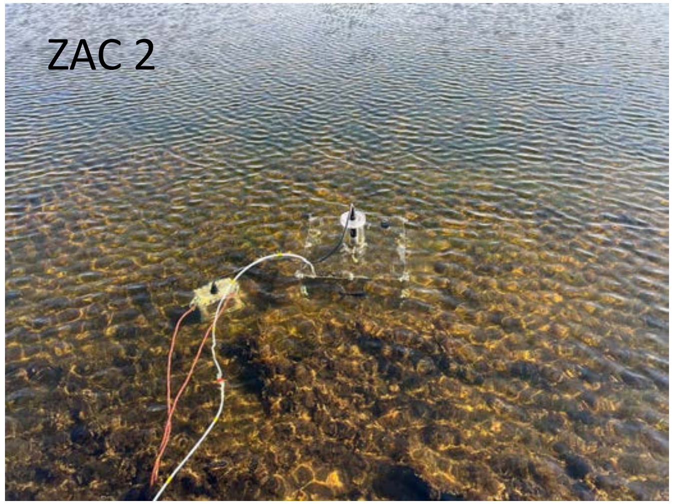
Hg and MMHg in thermokarst lakes (summer)

WATER (Summer)	Hg (ng/L)	MMHg (ng/L)	MMHg (%)	Hg methylation rates (%)	Ref.
SAS Lakes (n=18) (sporadic permafrost)	0.8 – 4.8	0.08 – 1.69	5.2 - 37	0.004 – 0.2	Martins, B.
KANG Lakes (n=8) (discontinuous permafrost)	3-5 – 12	0.7 – 3.1	17 - 42	< DL – 0.50	Martins, B.
ZAC Lakes (n=9) (continuous permafrost)	2.7 – 5.9	0.2 – 0.4	6.2 – 11	0.12 – 0.41	This work

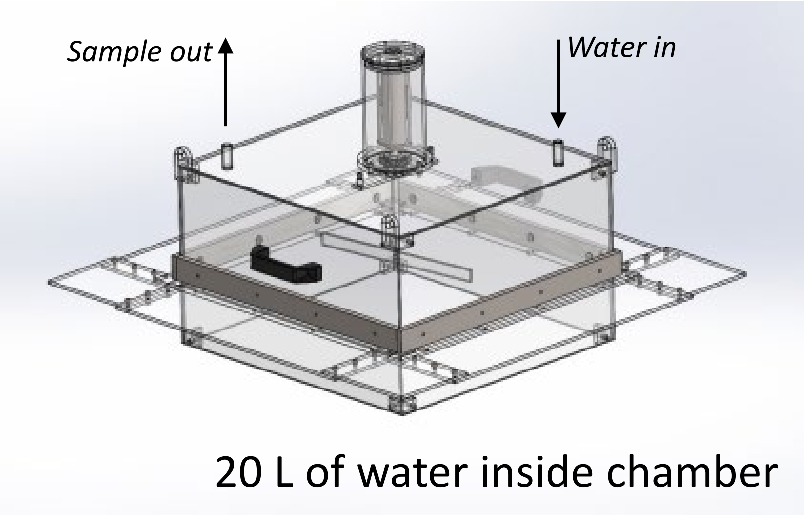
SEDIMENTS/SOILS (Summer)	Hg (ng/g)	MMHg (ng/g)	MMHg (%)	Hg methylation rates (%)	Ref.
SAS Lakes (n=6) (sporadic permafrost)	33 - 55	0.07 – 0.2	0.15 – 0.62	0.03 – 0.15	Martins, B.
KANG Lakes (n=6) (discontinuous permafrost)	40 - 84	0.21 – 1.7	0.47 – 3.5	0.6 – 10.5	Martins, B.
ZAC Lakes (n=4) (continuous permafrost)	12 - 32	0.25 – 2.1	1.2 – 6.2	2.6 - 11	This work
ZAC Soils (n=20) (continuous permafrost)	29 - 140	0.1 – 7.6	0.5 – 8.2	--	This work

Benthic flux Chamber





- t_0 t= 0 min
- t_1 t= 30 min
- t_2 t= 60 min
- t_4 t= 120 min
- t_5 t= 180 min
- t_6 t= 240 min
- t_6 t= 300 min
- t_7 t= 360 min



Sampled volume *per* sample: 400 mL (2%)

(Dilution = 2 %)

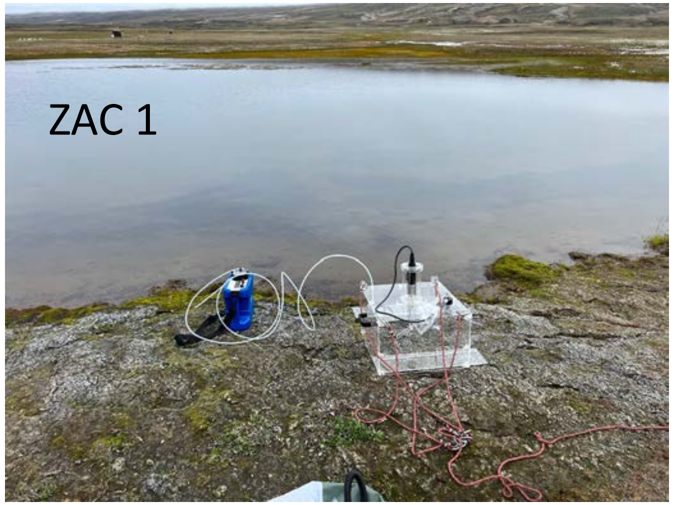
Total volume (8h) = 3.2 L (16%)

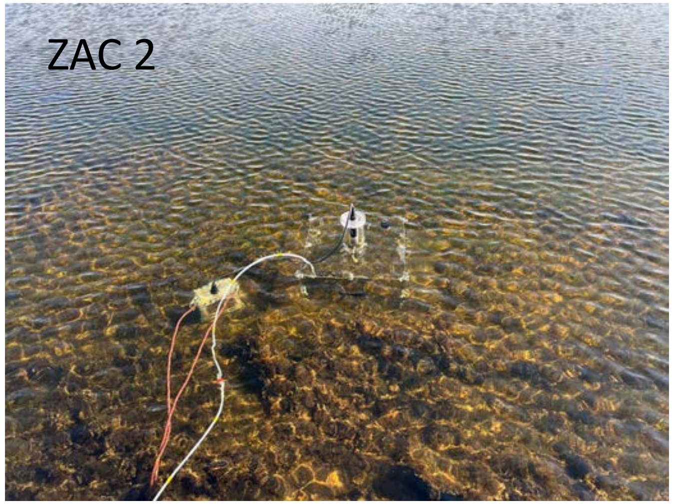
(Total Dilution: 16%)

$$Flux_{solute} = \Delta C_{solute} / (A_c \times \Delta t)$$

⚠ Other processes inside the chamber

Benthic flux Chamber





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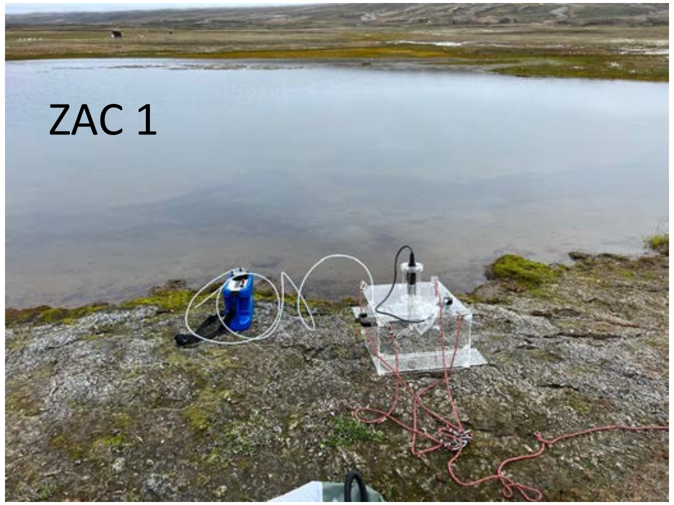
Benthic flux Chamber



Benthic flux Chamber – ZAC 1

Hg	MMHg
0 – 30 min: slight decrease in Hg – acclimatization)	0 – 30 min: slight decrease in MMHg – acclimatization)
Average upward Hg flux (30 – 240min): + 0,20 ng Hg /m^2min	Average upward MMHg flux (30 – 60 min): + 0,005 ng MMHg /m^2min
After 240 min Hg decrease 22ng/L – (only 4% dilution)	After 120 min MMHg decrease

Differences in concentrations overtime cannot be explained only by fluxes
Other processes, are taking place in the chamber

Benthic flux Chamber – ZAC 2

Decrease of both Hg species during the sampled time

Fluxes: - 0,01 ng MMHg /m^2min and - 0.003 ng MMHg /m^2min (**?**)

↓

Probably other processes rather than fluxes need to be considered

- Precipitation or co-precipitation (?)
- Microbial degradation of MMHg (?)

Conclusions

- Zackenberg thawing soils are "hotspots" of Hg and MMHg
- Hg dynamics in lakes: results suggest that the recent ZAC 2 lake is "*more active*" than the "*old*" ZAC 1 lake
- Permafrost thaw systems are excellent environments for MMHg production, and sulphate reduction bacteria appears to be the main Hg methylators (to be confirmed in Zackenberg by the *ongoing* microbiology analysis). However, other bacteria seem to be competing in the methylation process, namely IRB and methanogens
- Benthic flux chamber does not give clear results about fluxes but points to the existence of benthic processes
- In high permafrost degradation areas, Hg studies focuses on the release and impact of Hg species should be performed due to their negative effect on Indigenous Communities and wildlife
- **Thaw progression, rather than the type of permafrost, appear to control the release of Hg and consequent MMHg production in permafrost thaw systems**
- **In high dynamic lakes, like thermokarst lakes, Hg dynamics appears to be more influenced by biogeochemical processes rather than transport phenomena**

Acknowledgements

EXTREME ENVIRONMENTS

ZERO

GEM

Greenland Ecosystem Monitoring