Assessing the chemical availability and environmental fate of fallout radionuclides in cryoconite

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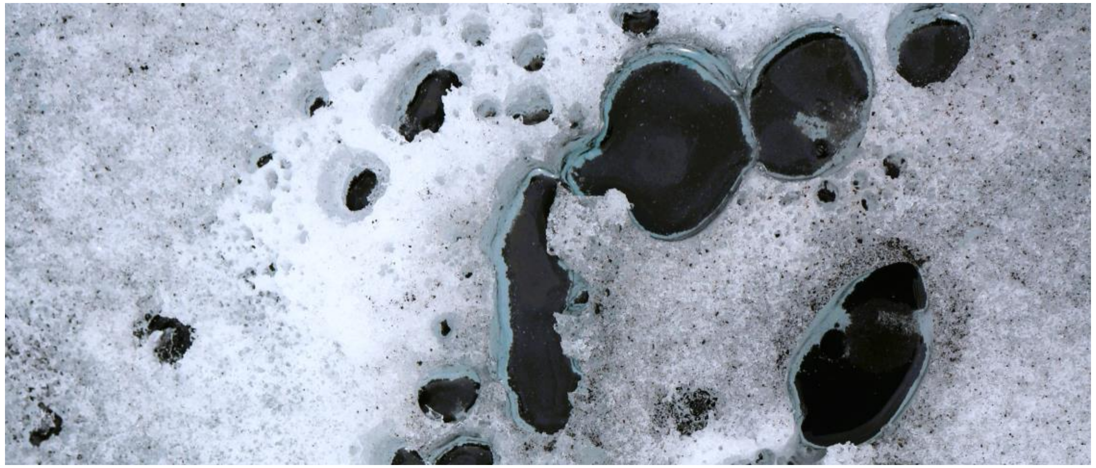
Environmental quality and water security in glacierized catchments

- Glaciers are both stores and secondary sources of natural and anthropogenic contaminants, while meltwater provides a range of **ecosystem services** to glacierized catchments.

- Water security relies on **quantity** and **quality** of supply, but many catchments are approaching or have surpassed **peak water**, and contaminant release increases pressures on both water supply and ecosystem health.

Clason et al. (2023), *Journal of Glaciology*

Fallout radionuclides (FRNs) in cryoconite



- Cryoconite is a dark material found in wet and dry deposits on the surface of glaciers. **Primarily composed of minerogenic materials but also of organic matter**, including microbial life.

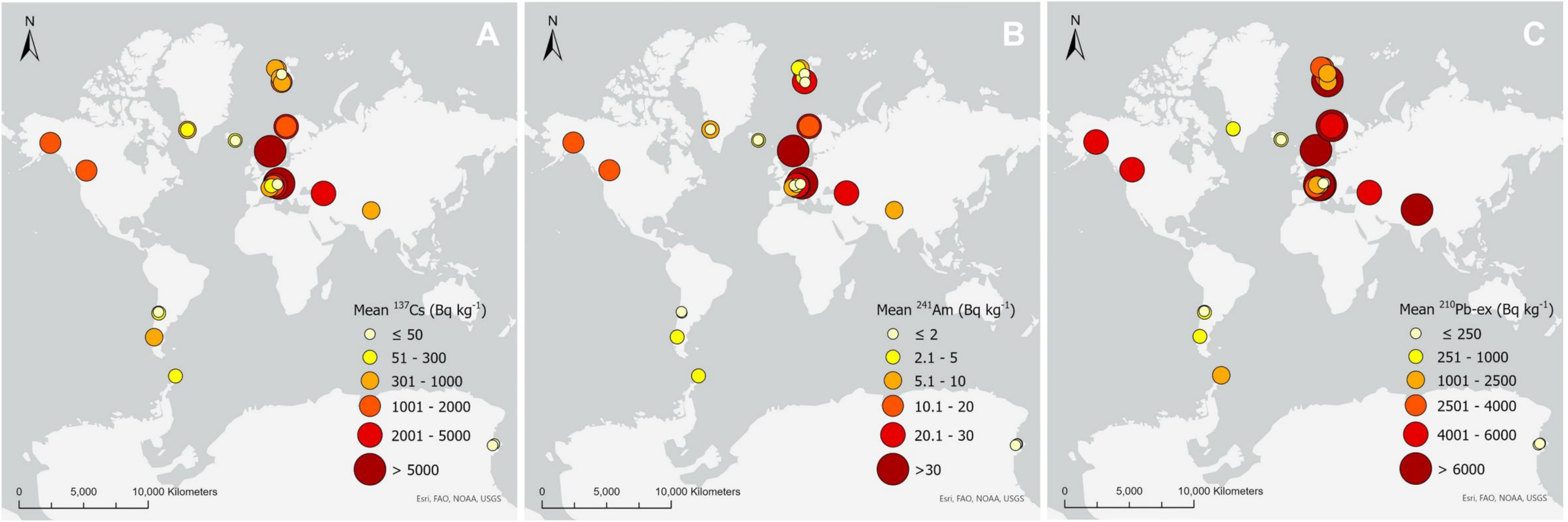
- Cryoconite accumulates atmospherically (historically) deposited FRNs released through ice and snow melt which are remobilized and transported by meltwater (supported by presence of ^{7}Be in cryoconite).

- Known to be an efficient accumulator of C and N. Recent work is revealing **widespread accumulation of high concentrations of FRNs and potentially toxic elements**.

Efficient accumulation of FRNs

- FRNs in cryoconite recently assessed for 32 sites around the global cryosphere, demonstrating **large inter-regional variability** in activity concentrations, and often much higher than nearby proglacial sediments.

- **Some activity concentrations orders of magnitude higher than found in other environmental matrices** (^{137}Cs up to 12,300 Bq kg^{-1} (Norway); ^{241}Am up to 120 Bq kg^{-1} (Swiss Alps); ^{210}Pb-ex up to 27,500 Bq kg^{-1} (Himalayas)).

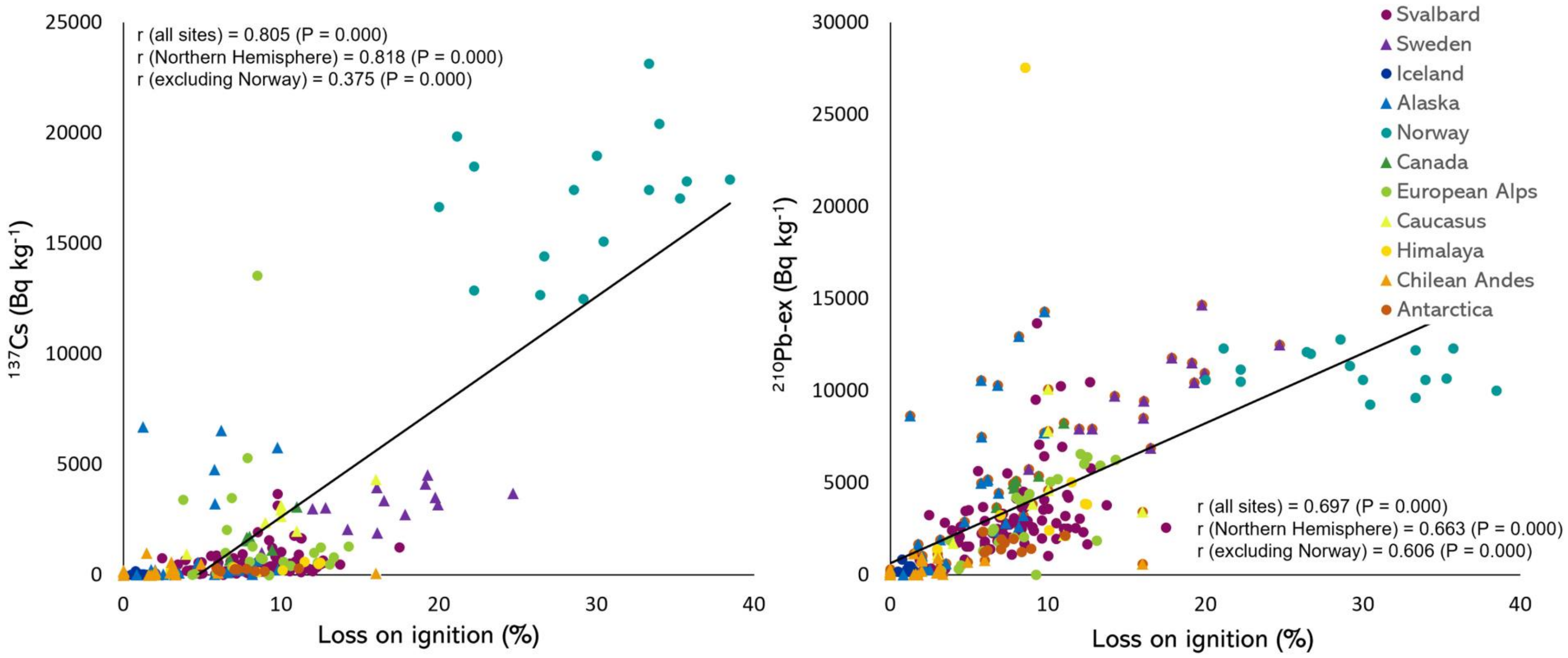


Clason et al. (2023), *STOTEN*

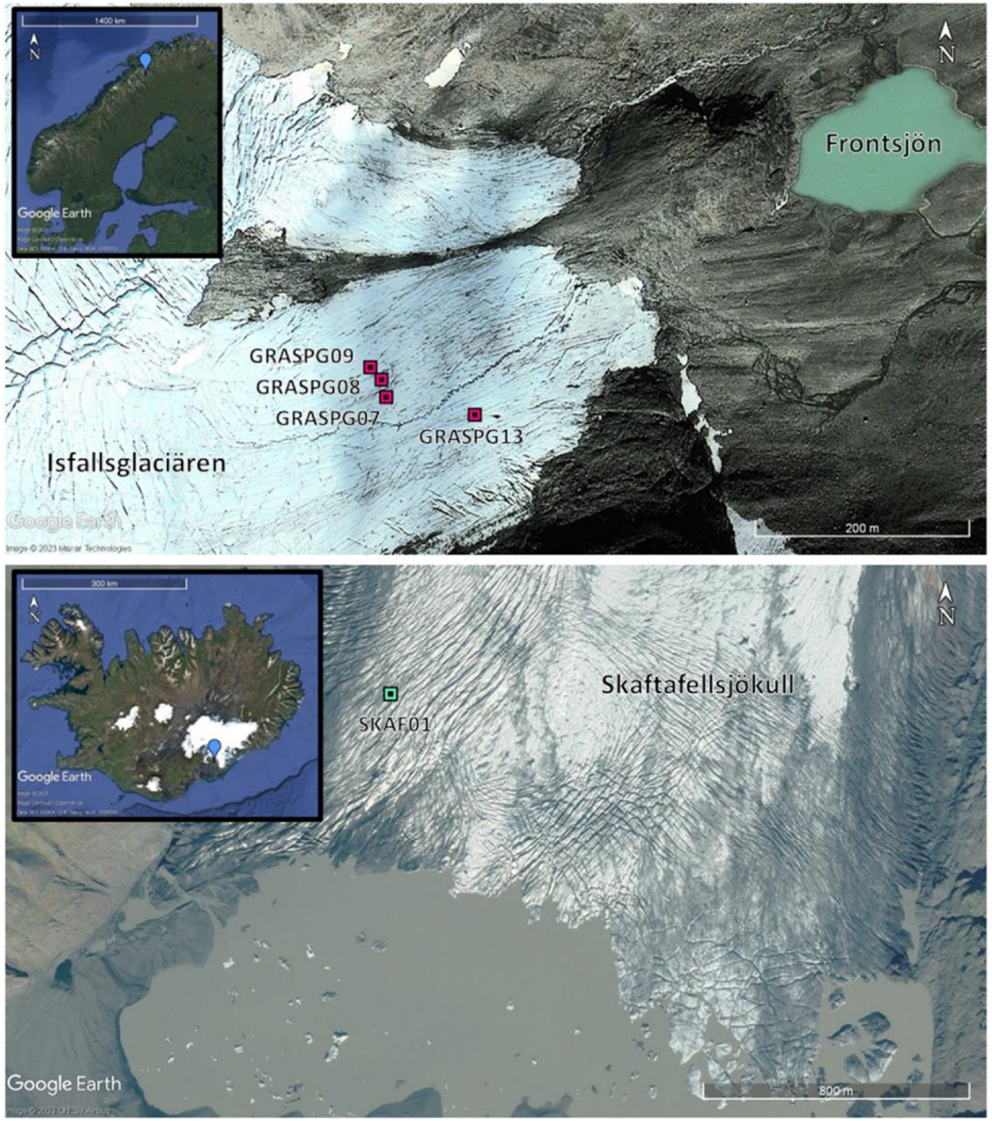
Controls on FRN accumulation

- Assessment of correlations with environmental and physical characteristics identified that **organic content of cryoconite is a key control on activity concentrations** of ^{137}Cs and ^{210}Pb-ex.

- ^{137}Cs and ^{241}Am also moderately correlated with precipitation, while ^{210}Pb-ex had moderate correlations with continentality, latitude, and elevation.



Assessing enrichment and chemical availability



Davidson et al. (2023), *Journal of Environmental Radioactivity*

- Cryoconite sampled on the surface of Isfallsglaciären, Sweden (2017) and Skaftafellsjökull, Iceland (2018).
- Elemental composition determined using WD-XRF.
- PTE enrichment factors estimated against values from upper continental crust sediment.
- Three-step sequential extraction procedure and gamma detection used to assess chemical availability of FRNs in the exchangeable, reducible, and oxidisable fractions.

Enrichment of PTEs in cryoconite

- **Severe enrichment of Pb and Cu, and moderate to severe enrichment of Cr and Ni in Swedish cryoconite**; moderate to severe enrichment only found for Cu and Ti in the Icelandic sample.

- **Swedish samples also exceed the Probable Effect Levels for Pb, Cr and Cu** based on the Canadian Sediment Quality guidelines.

Table 2. Enrichment factors for cryoconite samples.

Sample	Enrichment Factors						
	Cr	Pb	Cu	Zn	Ni	Ti	Fe
GRASPG07	6.9	25.2	13	4.3	11.2	3.5	3.5
GRASPG08	8.2	22.9	15.6	4.1	9.1	3.2	3.2
GRASPG09	10.2	19.2	12.1	4.4	8.7	3.2	3.3
GRASPG13	7.7	13.5	12.6	3.2	8.6	3.1	3.0
SKAF01	1.7	4.4	8.8	2.9	4.6	6.0	1.9

1 < EF < 3 indicates minor enrichment

3 < EF < 5 indicates moderate enrichment

5 < EF < 10 indicates moderate to severe enrichment

EF > 10 indicates severe enrichment

FRN activity concentrations and step-wise loss

Sample	Activity Concentrations ± 2σ, Bq kg^{-1}		
	^{137}Cs	$^{210}Pb_{un}$	^{241}Am
GRASPG07	2890±220	10950±880	21.5±7.6
GRASPG08	3300±260	10540±850	24.1±7.4
GRASPG09	2420±190	9620±770	12.6±6.7
GRASPG13	2830±220	8880±720	20.4±8.9
SKAF01	174±16	939±113	6.2±5.7

- Up to **two orders of magnitude difference in activity concentrations between Swedish and Icelandic samples** *(organic content for Swedish samples ~9-20% vs ~1% for Icelandic sample)*
- Majority of ^{210}Pb-ex extracted in reducible phase; significant quantity of ^{137}Cs remaining in residual phase. Variable for ^{241}Am, but notably more lost in oxidisable fraction for Icelandic cryoconite.

(a)

Sample	$^{210}Pb_{un}$ Percentage Loss, %			
	Exchangeable	Reducible	Oxidised	Residual
GRASPG07	7.9	61.9	5.6	24.6
GRASPG08	11.0	58.6	5.1	25.3
GRASPG09	9.1	61.1	13.8	15.9
GRASPG13	8.5	64.3	11.8	15.4
SKAF01	12.5	54.3	18.1	15.1

(c)

Sample	^{137}Cs Percentage Loss, %			
	Exchangeable	Reducible	Oxidised	Residual
GRASPG07	3.5	4.7	8.3	93.4
GRASPG08	6.4	1.3	15.5	76.8
GRASPG09	7.5	1.7	9.6	84.6
GRASPG13	6.1	1.0	5.1	87.9
SKAF01	10.9	10.9	17.8	60.3

(c)

Sample	^{241}Am Percentage Loss, %			
	Exchangeable	Reducible	Oxidised	Residual
GRASPG07	10.9	21.1	7.1	52
GRASPG08	13.9	52.1	6.8	27
GRASPG09	25.6	0.4	44.1	30
GRASPG13	28.3	44.1	2.1	30
SKAF01	0.00	3.6	53.8	43

What's next?

- Investigation of **biogeochemical processes governing contaminant accumulation** in cryoconite, including the role of microbes.

- Assessment of **accumulation and chemical availability of PTEs** in cryoconite from different glaciated regions.

- Quantification of catchment-scale cryoconite mass and modelling contaminant release from glaciers under future climate scenarios → understanding **downstream contaminant flux and environmental risk** (if any).

Questions welcome!

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