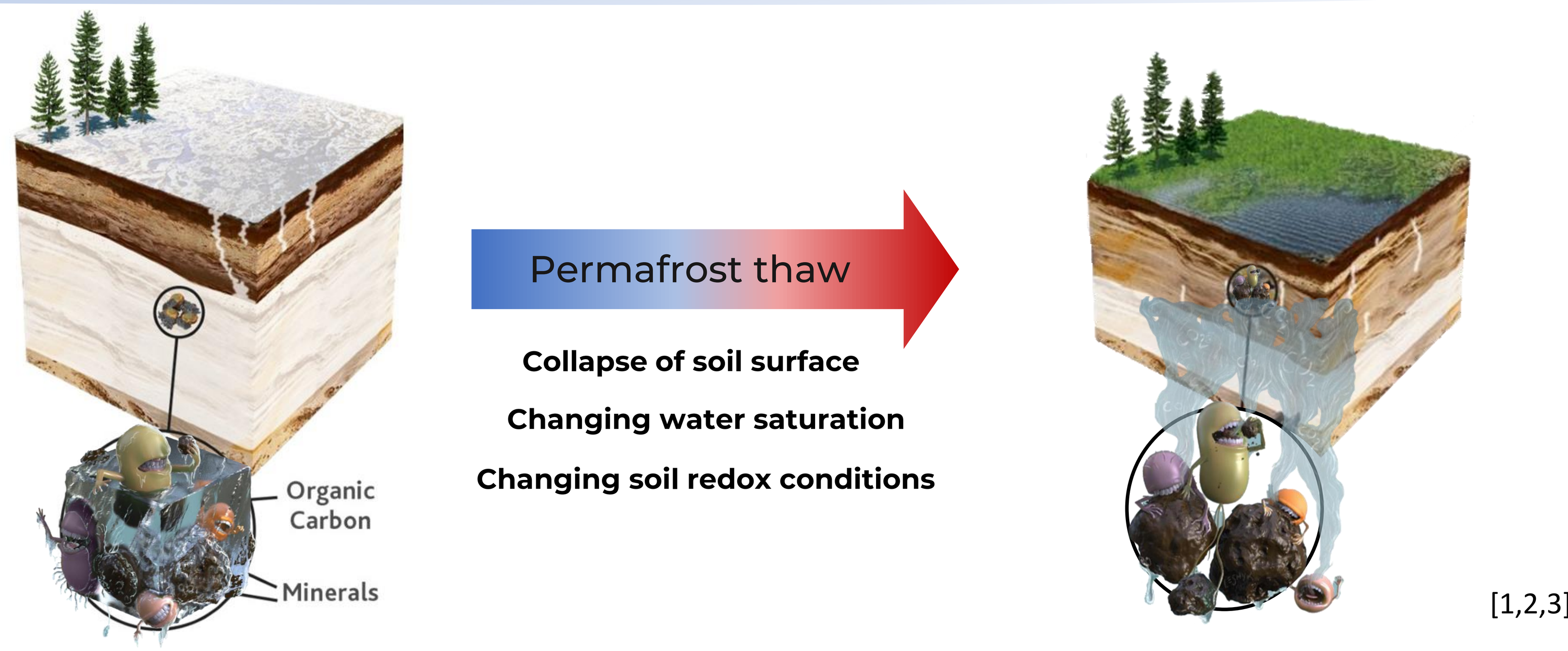
High-Resolution insights into permafrost thaw: Remote Sensing and Geochemical Techniques for Mapping soil physico-chemical changes

Eléonore DU BOIS D'AISCHE[1,2], Sophie OPFERGELT[1], Jordan BATES[3], Maëlle VILLANI[1], Maxime THOMAS[1], Cécile OSY[1], Sébastien LAMBOT[1], Kristof VAN OOST[1], Veerle VANACKER[1], Edward A.G. SCHUUR[4], François JONARD[2]

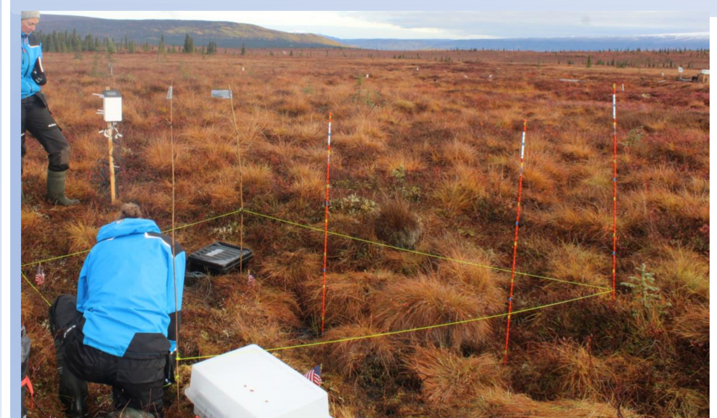
[1]Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[2]Earth Observation and Ecosystem Modelling Laboratory, SPHERES Research Unit, Université de Liège, Liège, Belgium
[3] Institute of Bio- and Geosciences: Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, 52428 Jülich, Germany
[4] Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, AZ, USA
**email: eleonore.dubois@uclouvain.be*

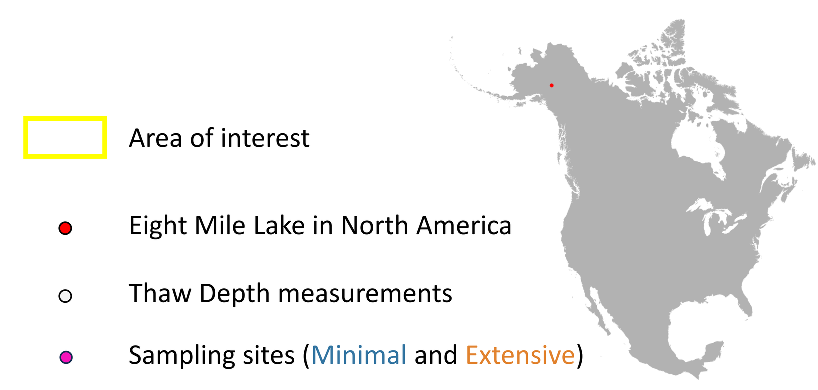
Climate change causes permafrost thaw, altering the physicochemical conditions of Arctic soils, potentially emitting greenhouse gases

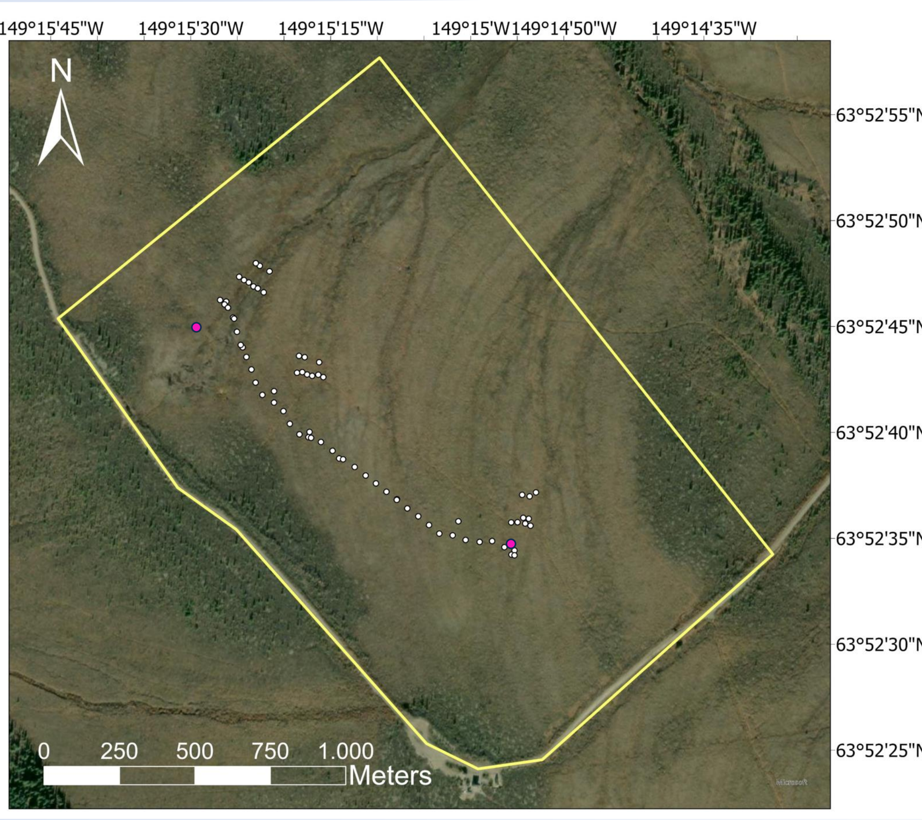


→ How do hydrological and topographical variations resulting from permafrost thaw impact the physico-chemical conditions of the soil and what are the implications at the site scale ?

Study case of an Arctic peatland with a natural permafrost thawing gradient in Eight Mile Lake in late summer of 2023 (Alaska (USA))





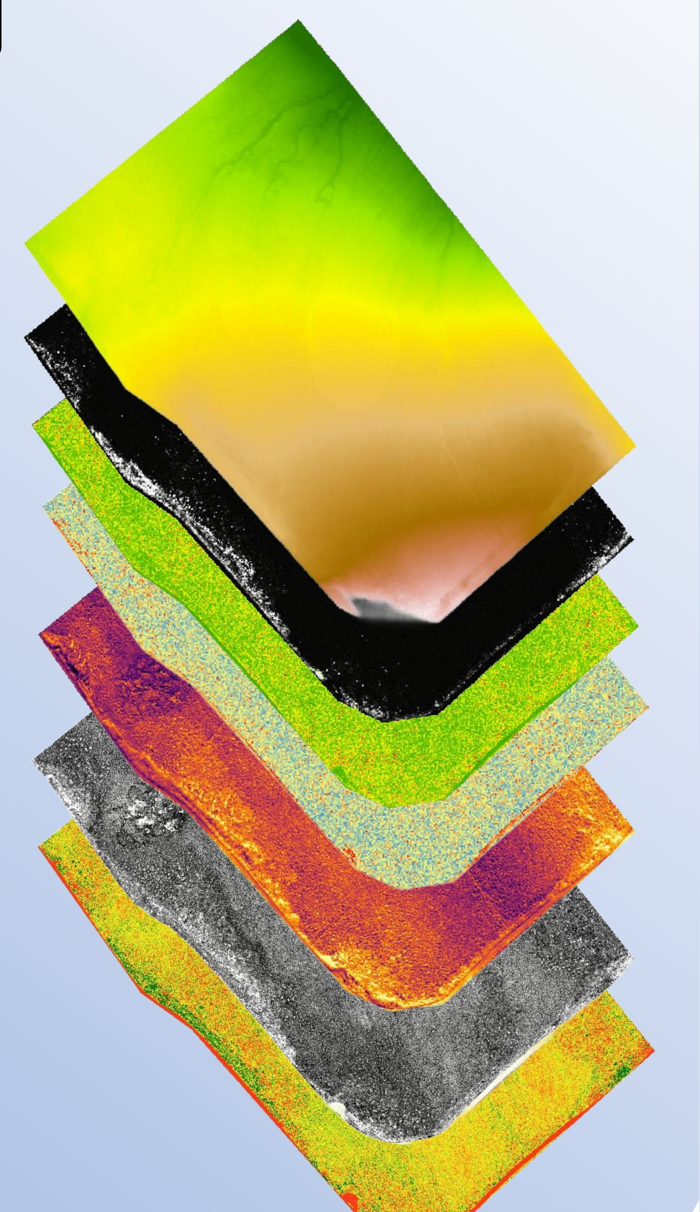


Combining geochemical and very-high resolution remote sensing techniques to better understand the impact of permafrost thaw and resulting thaw depth increase at the profile scale and at the site scale

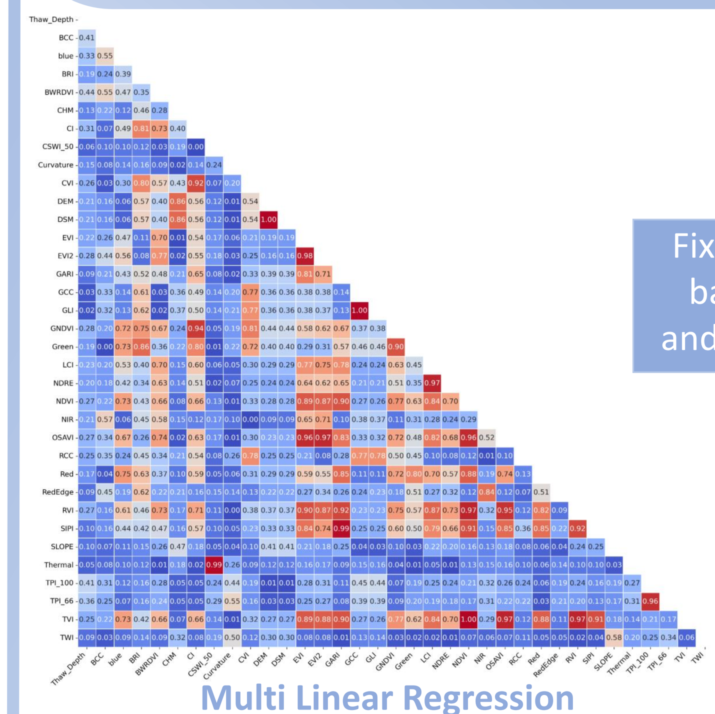
Site scale: prediction of the thaw depth across the site

4 sensors | 30 indices

- **LiDAR**: DEM, DSM, Canopy Height Model (CHM), Curvature, Slope angle, Terrain wettness Index (TWI), Topographic Position Index (TPI)
- **Thermal**: Land Surface Temperature (LST), Crop Water Stress Index (CSWI)
- **Multispectral**: Red, Green, Blue, Red Edge, NIR, NDRE, NDVI, BWRDVI, CI, CVI, EVI2, GARI, GCC, GLI, GNDVI, LCI, OSAVI, RCC, RVI, SIPI, TVI
- **RGB**



DJI M 300
13, 16, and 19th of Sept



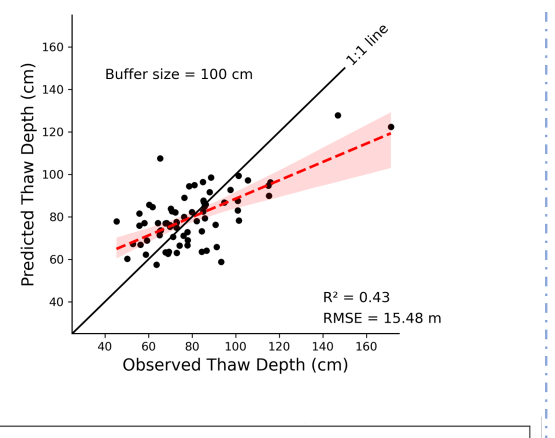
Fixing for collinearity based on VIF score and correlation matrix

Remaining Parameters

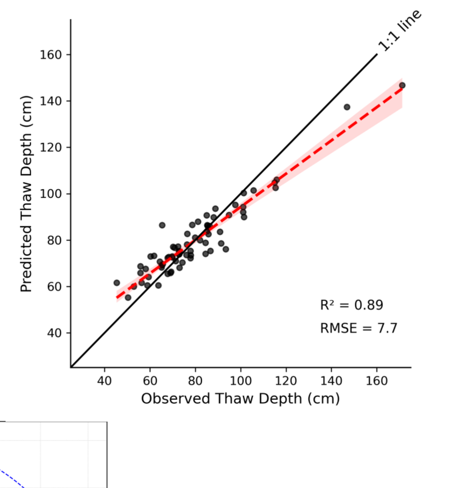
Thermal : CSWI
Multispectral : Blue, RedEdge, CVI, NDRE, SIPI
LiDAR : SLOPE, CHM, Curvature, TPI, TWI, CSWI

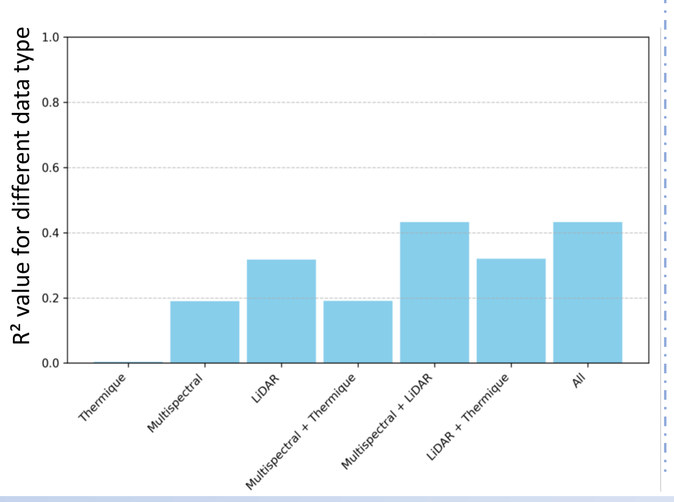
Statistical Models

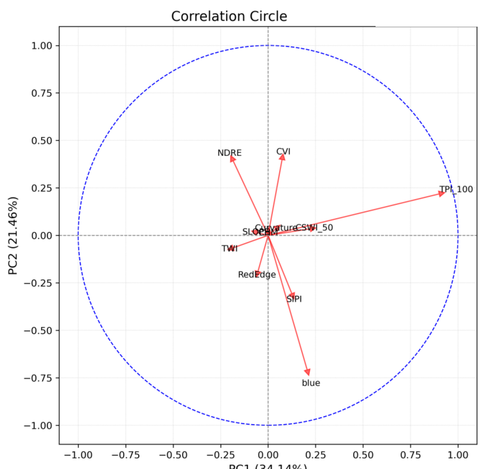
Multi Linear Regression

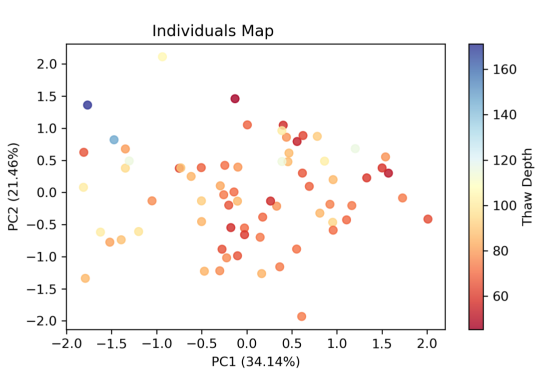


Mixed Multi Linear Regression



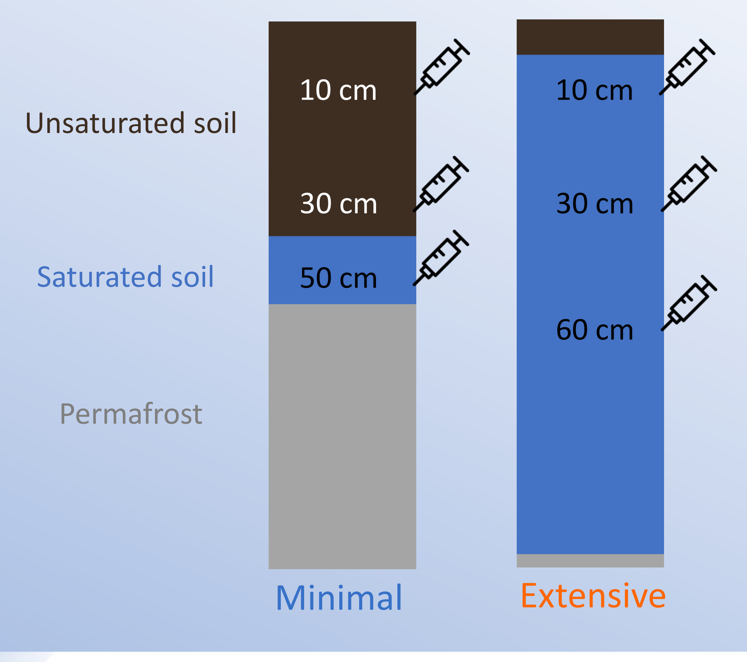


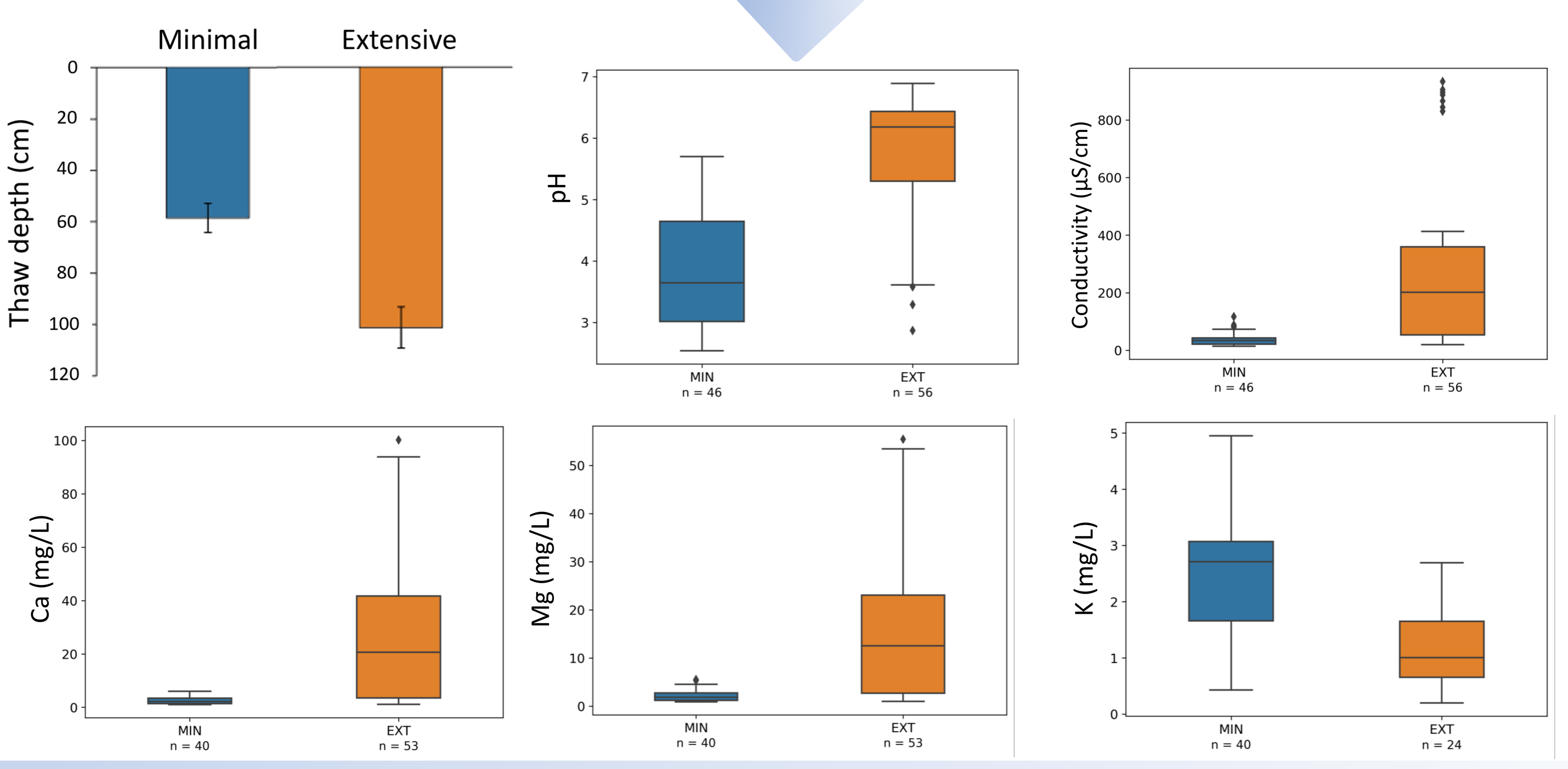




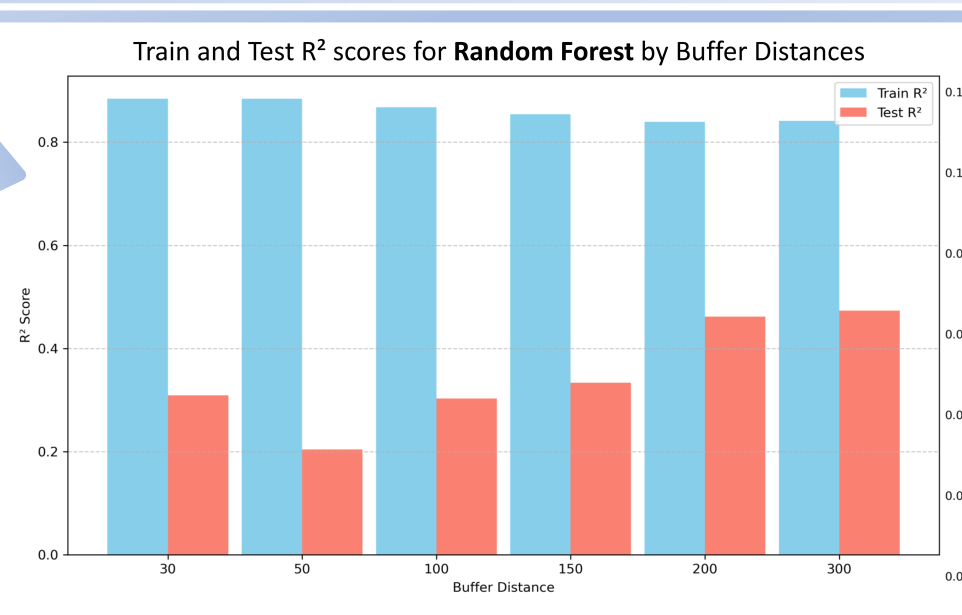
Profile scale: impact of the thaw depth increase on the geochemistry of soil pore water

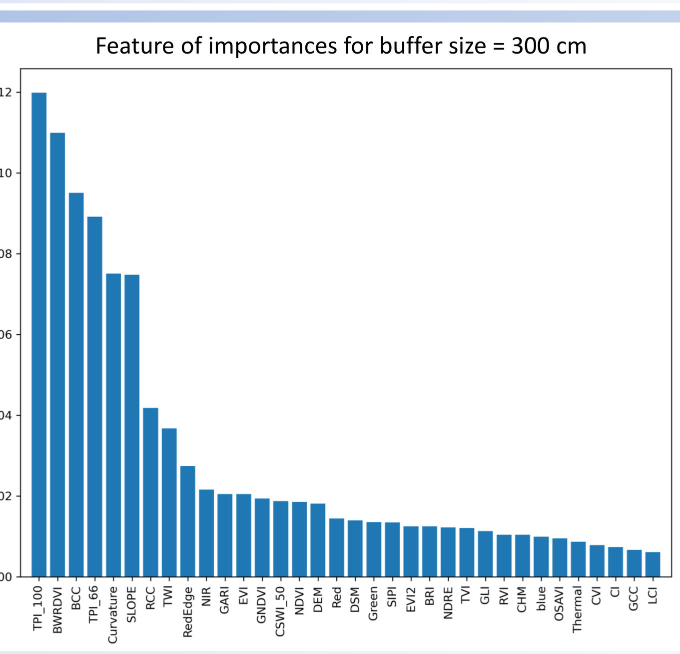
- 17 days of sampling: 16th Sept- 2nd Oct
- In 1 bottle: 3-days water collection
- 2 sites with triplicates at each site
- 3 depths
- 39 Thaw Depth measurements





Machine learning Models





Take home messages and perspectives

- **Permafrost thaw** leads to a significant **pH increase** (over 2.5 units) and enhances soil pore water conductivity due to **calcium and magnesium release**
- **Topographic** and **multispectral indices** explain most of the variability in thaw depth
- Including **random effects** in the dataset using a mixed multilinear model improves the prediction quality of thaw-related variables
- Machine learning algorithms such as **Random Forest** better capture the complexity of thaw depth models, although it suffers from overfitting. Topographic and multispectral indices remain the most explanatory features

Acknowledgements

We thank C. Hirst, J. Ledman, and A. Kelly for their help during the fieldwork mission in Alaska (USA). We thank Laurence Monin, Elodie Devos, Claudine Givron, Hélène Dailly from the MOCA analytical plateform in ELI.

Funding

This project received funding from FWB for the LandSense project (Action de Recherche Concertée).
E.DBDA acknowledges funding from the Fund for Scientific Research FNRS in Belgium.

References

[1] Opfergelt, S. Environ. Res. Lett. 15, 091003 (2020).
[2] Illustration of organic matter by Victor Leshyk
[3] Rodenhizer, H., et al. JGR Biogeosciences. 150, 6 (2020).