Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.28457

Revealing the Hidden Pollutant Pool: Behaviors of Nonextractable Halogenated Organic Chemicals in Tibetan Permafrost Under Simulated Warming-Cooling

XIAOJING ZHU[1] AND QIULEI GUO[2]

[1]Helmholtz-Centre for Environmental Research - UFZ
[2]China University of Geosciences

Halogenated organic chemicals (HOC) are globally distributed pollutants recognized for their toxicity and bioaccumulative potential. Although most environmental assessments focus on their solvent-extractable fraction (EF) in soils, a large proportion of HOC often exists as nonextractable residues (NER), strongly associated within soil matrices and thus easily overlooked by standard analytical methods. This hidden fraction poses latent ecological risks, especially under climate change scenarios. In our previous works (*Nat. Geosci.* 2023; *ES&T Lett*. 2024), we observed a significantly negative correlation between mean annual temperature and the ratio of NER-HOC to EF-HOC across soils from different areas. We also discovered an unexpectedly high amount of HOC in Tibetan Plateau permafrost, with over 99% stored as NER, a record-high value that signals substantial yet unrecognized risks if warming accelerates their remobilization. Motivated by these findings, we conducted a controlled experiment on three representative Tibetan permafrost soils (as well as the sterilized control of one soil) to simulate 105 days of gradual warming from -4 to 4 °C followed by 80 days of cooling to -4 °C. Results showed that approximately 2% of the former NER-HOC, primarily aliphatic and monocyclic aromatic, were remobilized as EF during warming, elevating EF by up to 50-fold. Upon cooling, many of these remobilized HOC were re-incorporated into the NER fraction. Comparisons with sterilized controls indicated that microbial activities are critical to NER-HOC remobilization, while abiotic reactions continuously facilitate the conversion of EF-HOC to NER-HOC. More than half of the HOC initially bound via ester and amide bonds to soil organic matter (SOM) were hydrolyzed under warming and subsequently re-incorporated via physical sequestration during cooling. Even the NER-HOC which were bound via unsaturated C–C bonds (the strongest covalent bonding investigated) to SOM showed partial release. In general, soils with higher total organic carbon exhibited lower remobilized proportions and slower remobilization processes. These results highlight that climate warming can drive substantial remobilization of HOC formerly stored in permafrost soils, posing a potential risk for secondary pollution. This further highlights the urgent need to integrate NER into global monitoring and risk models, climate vulnerable regions such as alpine and polar regions.