Supplementary Information for:

Thawing permafrost poses environmental threat to thousands of sites with legacy industrial contamination

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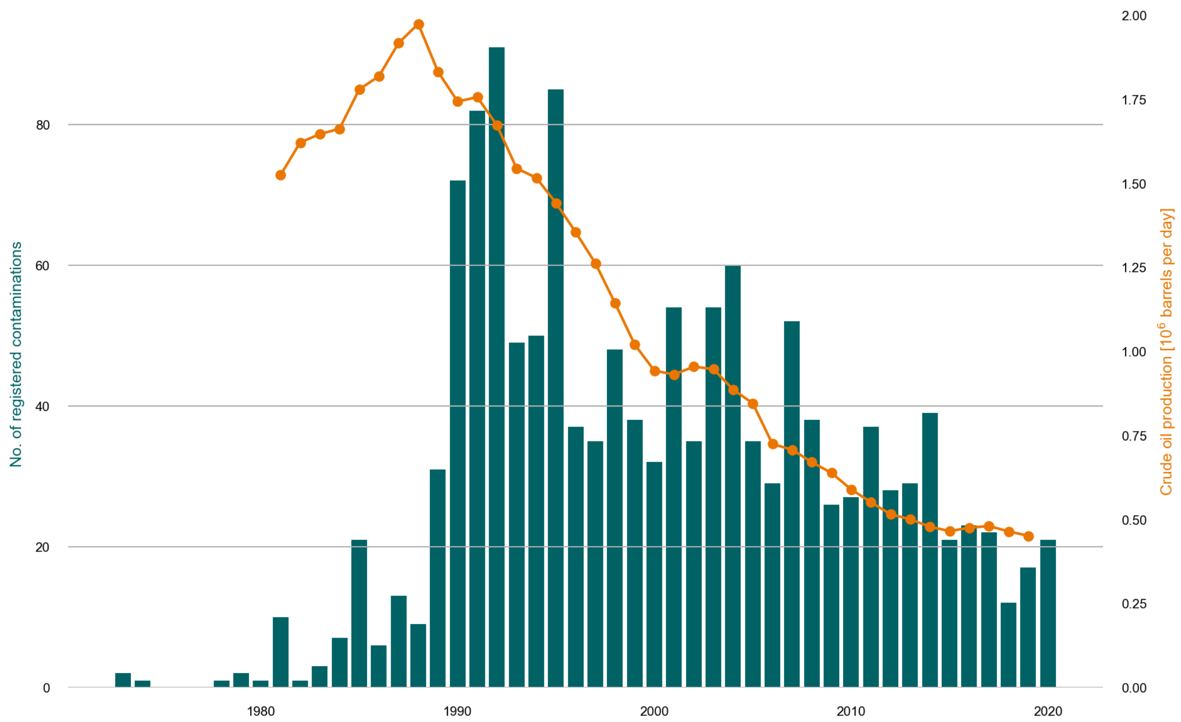
Supplementary Tables

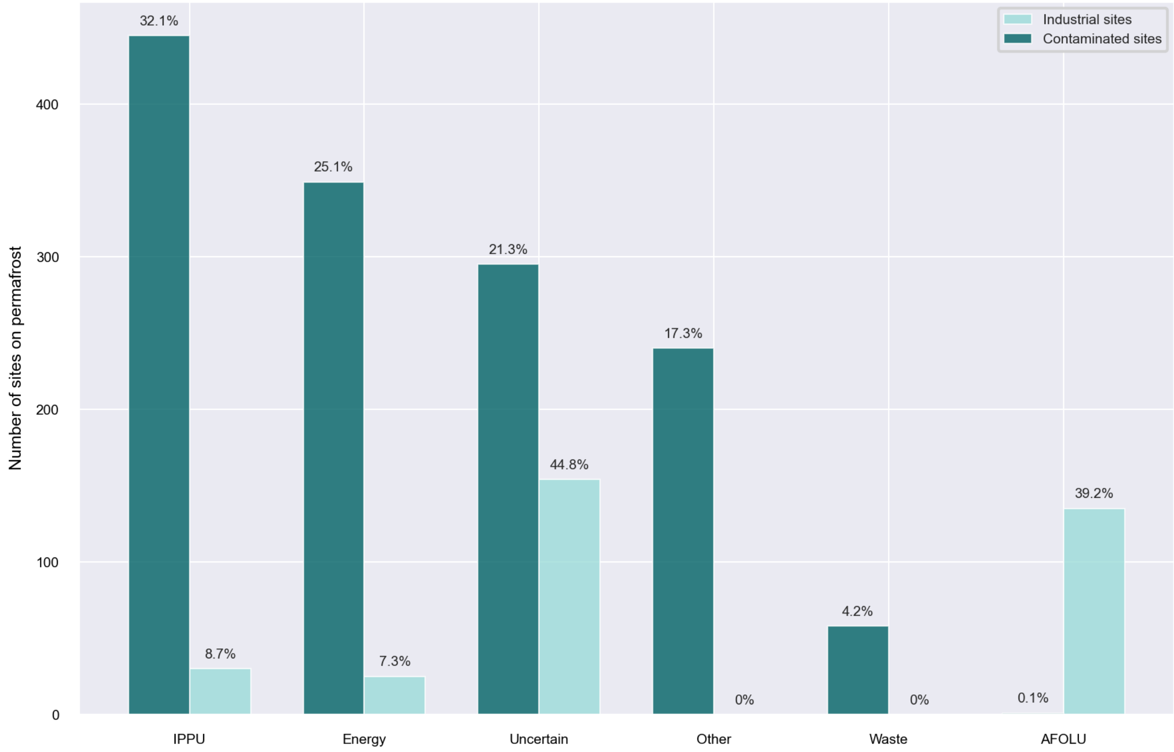
Supplementary Table 1: Overview of different types of toxic industrial substances stored, spilled, or lost in or on top of permafrost based on a sample of the literature.

Sector	Activity group	Example of pollutants / damages	References
Energy	Resource exploration and transportation	Drilling fluids (surfactants, detergents, large quantities of highly concentrated saline solutions primarily potassium chloride), fuel	1-6
Industrial Production and Product Use (IPPU)	Mining Military	fuel, radioactive waste, acid mine drainage (Al, Mn, Cu, Hg), flotation chemicals, mining leachate	7-18
Waste	Industrial landfills	Heavy metal contamination (e.g. Cadmium, Mercury, and Lead), organic waste, synthetic materials	19-24
Agriculture, Forestry and Other Land Uses (AFOLU)	Pollution	Deforestation, fertilizers, pesticide, urbanization, fuels	25
Other	Accidental	Hydrocarbon (oil, diesel, etc) spills, nuclear accidents and non industrial wastes	26-30

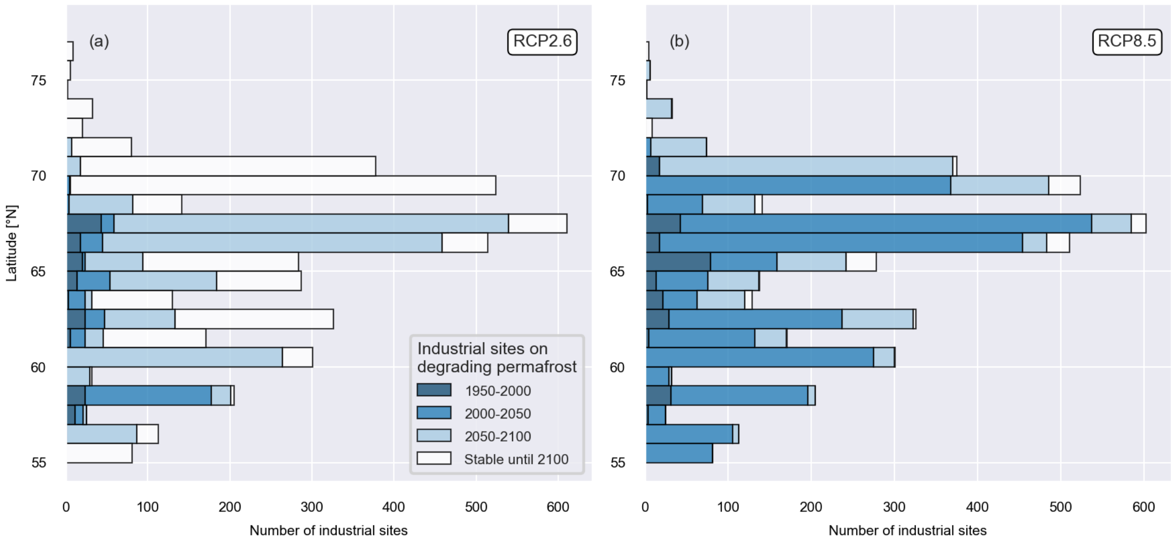
Supplementary Figures



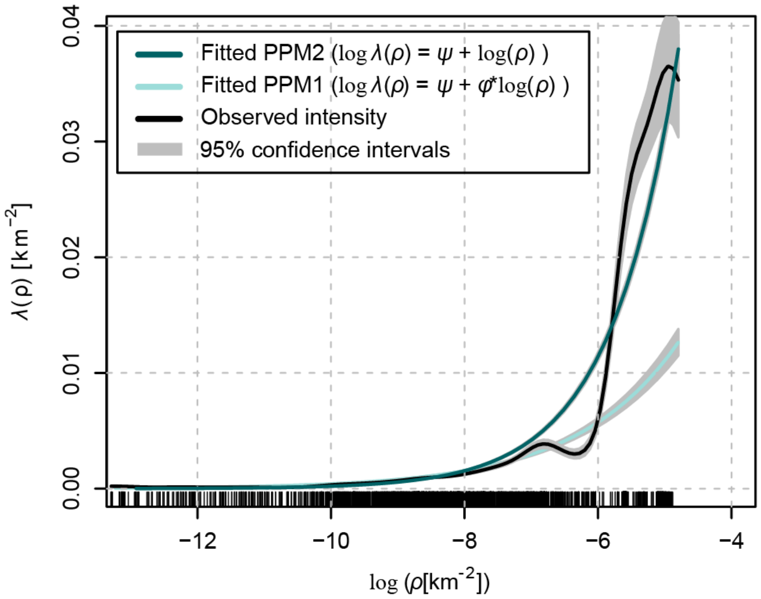
Supplementary Fig. 1: Number of contaminations in the permafrost dominated region of Alaska according to the first date of registration within the CSP together with quantities of crude oil production on the North Slope as provided by the U.S. Energy Information Administration (EIA) (31).



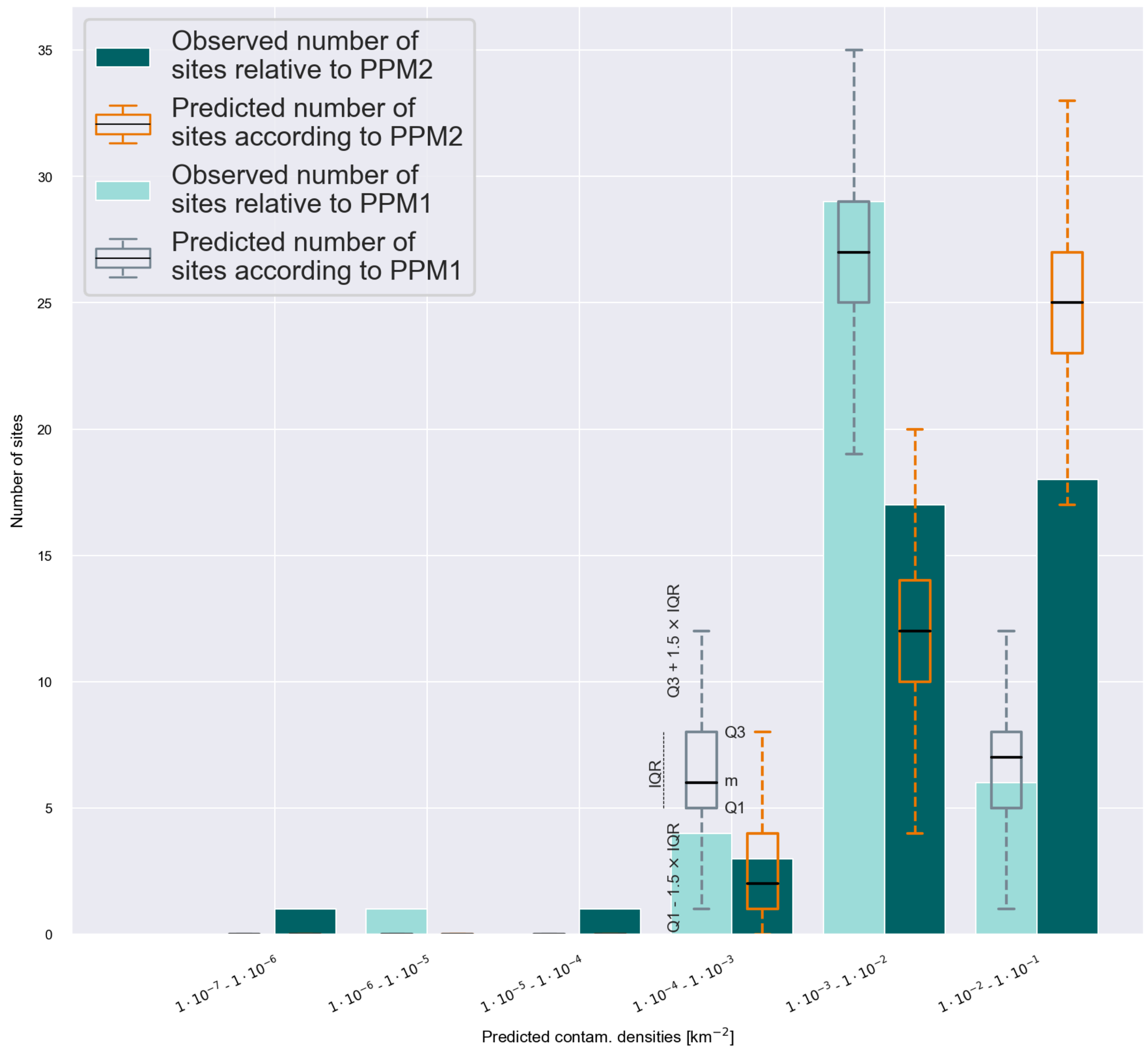
Supplementary Fig. 2: Occurrence of industrial sites and contaminated sites in permafrost dominated region of Alaska according to industrial sectors defined by the semantic classification undertaken (see Supplementary Fig. 7). Numbers on the bars indicate relative occurrence. More than 50% of the existing contaminated sites are attributed to industry within the sectors Industrial Processes and Product Use (IPPU) and Energy which together represent less than 20% of the existing industrial sites. Agriculture, forestry, and other land uses (AFOLU) account for the largest number of known industrial sites in Alaska.



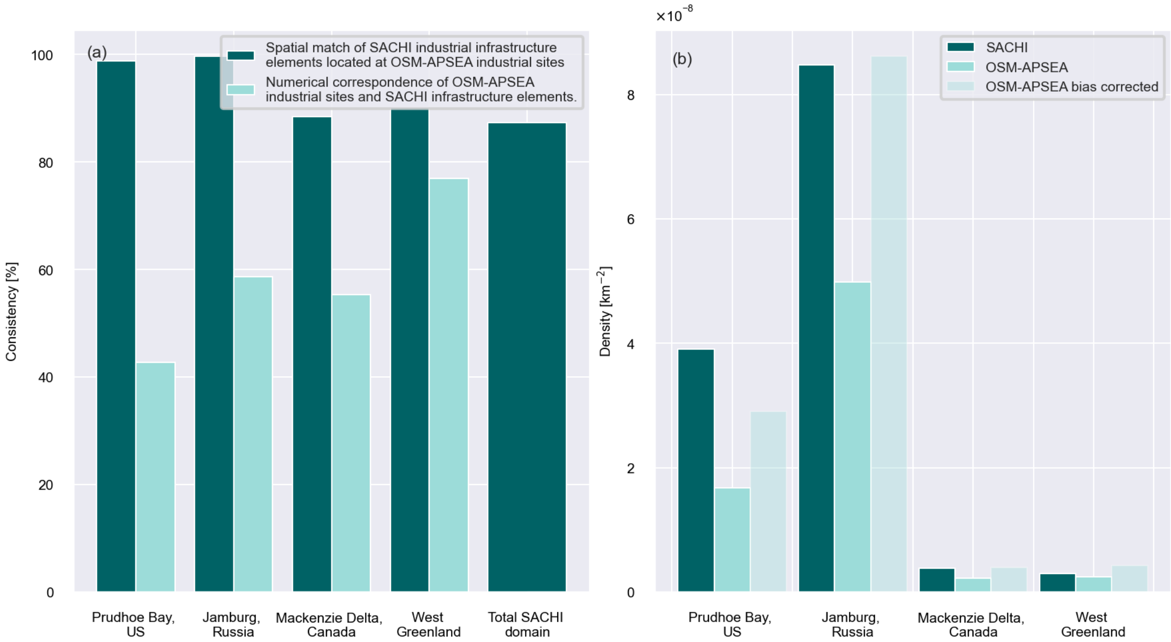
Supplementary Fig. 3: The latitudinal distributions of industrial sites that experience permafrost degradation in different time frames illustrated for the (a) “best case” (CCSM4, RCP2.6) and (b) “worst case” scenario (HADGEM2-ES, RCP8.5).



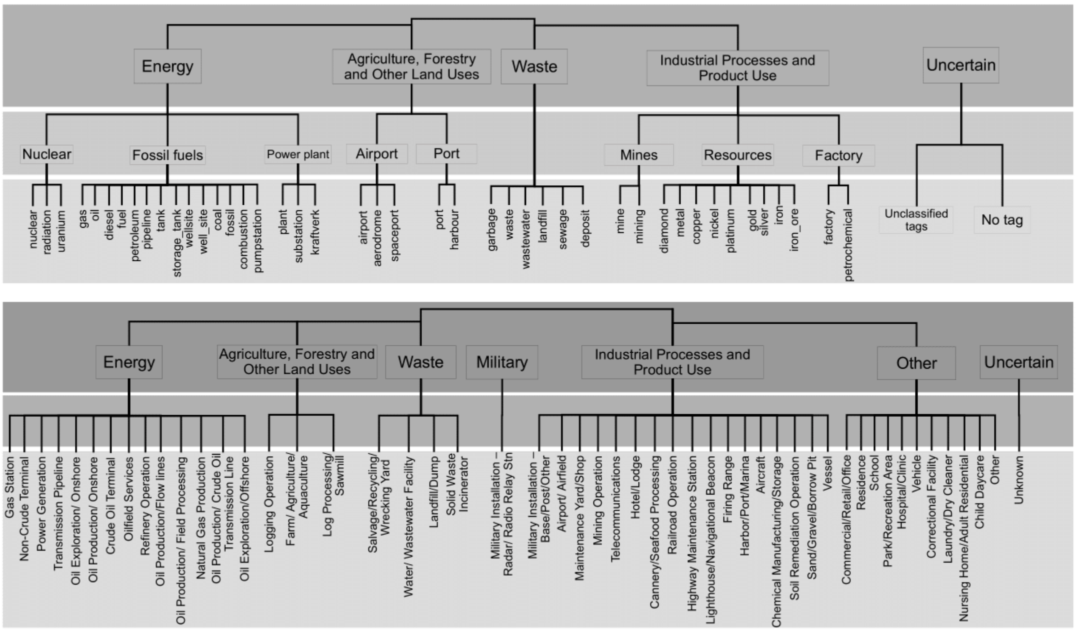
Supplementary Fig. 4: The observed and modeled point intensities of contaminated sites λ with the point density of industrial sites ρ for the permafrost dominated regions of Alaska and Canada. Two basic inhomogeneous poisson point models (PPM1 and PPM2) are applied where the covariate ρ is the density of industrial sites, ψ and φ are unknown scale parameters derived by model fitting, and $\lambda(\rho)$ is the expected conditional intensity of contaminated sites. The shaded areas around the curves relate to the 95% confidence intervals of the fitted parameters. The models do not exactly reproduce the observed spatial relationship, but mark the upper and lower limits given by the large variations at higher industrial site densities.



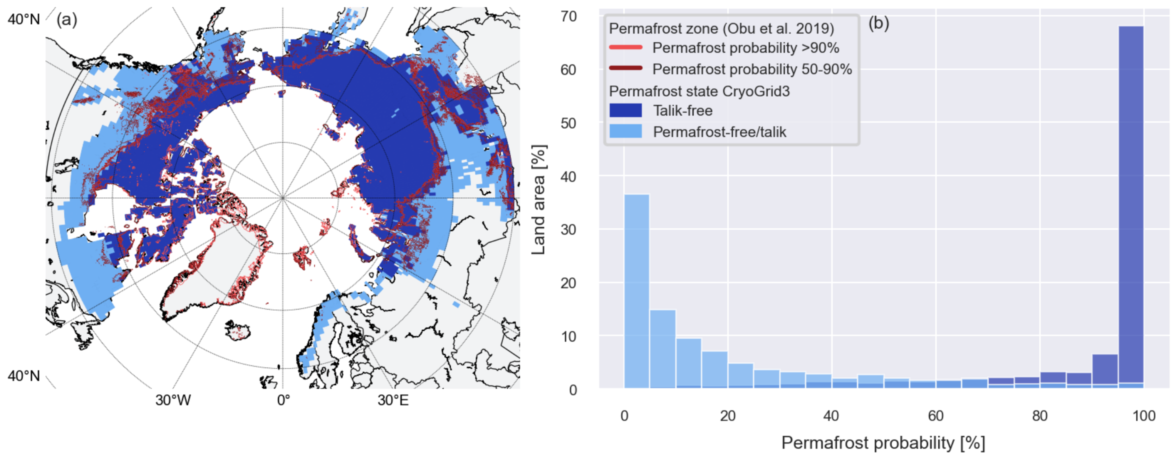
Supplementary Fig. 5: The number of identified contaminated sites in Russia that are located within the predicted intensity classes of the two point process models. To verify that the observed number of contaminated sites matches the expected number according to the models, multiple (N=1000) random samples (n=44) were drawn from the entire model distribution for Russia (shown as a boxplot). The models reproduce the observed distribution well, mostly within the interquartile ranges (boxes) and always within 1.5 times the interquartile ranges (whiskers).



Supplementary Fig. 6: A comparison between the OSM-APSEA database and the Arctic coastal infrastructure satellite product (SACHI) reveals a match of more than 85% (true-positive) for selected test regions as well as for the total SACHI domain (a). This means that wherever OSM-APSEA indicates an industrial site, the SACHI database indicates in more than 85% of the cases the presence of industrial infrastructure. For the test regions, individual industrial infrastructure elements were manually classified within the SACHI dataset to facilitate a direct comparison between the number of industrial sites and the number of infrastructure elements (b). This comparison shows that the number of industrial sites within OSM-APSEA is on average 40 ± 20% lower than the number of industrial infrastructure elements in SACHI. For the test regions the bias might be correct by a simple multiplier.



Supplementary Fig. 7: The dendrogramms illustrating the semantic classification performed on the database of industrial sites synergized from from OpenStreetMap (OSM) and the Nordregio Atlas of population, society and economy in the Arctic from 2019 (top) and the database of contaminated sites from the Contaminated Sites Program (CSP) in Alaska published by the U.S. Department of Environmental Conservation (bottom). After cleaning and translation of the site descriptions, the sites were classified into industrial sectors according to descriptions used by the Intergovernmental Panel on Climate Change (IPCC).



Supplementary Fig. 8: The map (a) shows the outline of the permafrost model domain delineated by permafrost occurrence probabilities (>50%) using the Northern Hemisphere Permafrost Map (NHPM) (32), underlain by persistent talik presence as simulated with the CryoGridLite model for the reference period (2000-2016). The histogram (b) shows the distributions of permafrost occurrence probabilities from the NHPM (32) for the CryoGridLite grid cells stimulated as talik-free and those with talik or permafrost-free between 2000 and 2016. Permafrost occurrence probabilities from the NHPM (32) were aggregated to the spatial resolution of the CryoGridLite grid cells (1 degree) by averaging. Map generated with Python using the Basemap Matplotlib library and the GSHHG datasets (33).

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