

# Modeling of circumpolar permafrost and permafrost-thaw related geohazards affecting infrastructure

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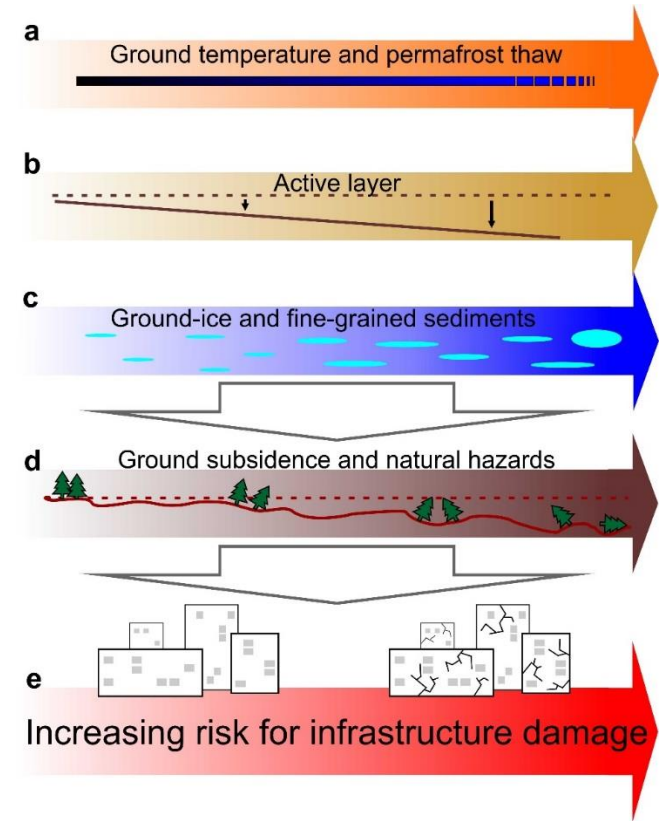
*RATIC Workshop 26 May 2019, Arkhangelsk*

Juha Aalto<sup>2,3</sup>, Miska Luoto<sup>2</sup>, Sebastian Westermann<sup>4</sup>, Vladimir E. Romanovsky<sup>5</sup>, Frederick E. Nelson<sup>7</sup>, Bernd Etzelmüller<sup>4</sup> & Jan Hjort<sup>1</sup>



# Background

- Arctic permafrost environments are undergoing rapid changes
- In addition to the negative effects on **global climate** and **ecosystems**, degradation of permafrost may **damage infrastructure**
- Benchmark reports (e.g. ACIA, AMAP) called for pan-Arctic geohazard mapping and infrastructure risk assessments, but detailed **data** and **quantifications** have been missing



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# Aims

- (i) Predict the distribution of **pan-Arctic permafrost** under climate change
- (ii) Produce infrastructure **hazard maps** at unprecedentedly high spatial resolution
- (iii) Quantify **infrastructure elements at risk** by 2040-2060

We focused on **residential, transportation** and **industrial** infrastructure (plus special investigation targets: current population and hydrocarbon extraction fields in the Russian Arctic)



*Infrastructure: facilities with permanent foundations on ice-free land*





# Data and methods

**Data for modelling ground temperatures and thaw depths**

MAGT and ALT variables

- Mean annual ground temperature (MAGT) (°C) at or near zero annual amplitude for 2000–2014 (n = 797 boreholes)
- Active layer thickness (ALT) (cm) for 2000–2014 (n = 303 observation sites)

Environment data at 30 arc second resolution

- Freezing and thawing degree days (°C)
- Precipitation (mm) when air temperature is above (water) and below (snow) 0°C
- Soil organic carbon content (g kg<sup>-1</sup>)
- Topography-based solar radiation (Mj cm<sup>-2</sup> year<sup>-1</sup>)
- Water bodies (%)

**Model calibration**

Statistical fitting of GLM, GAM, RF, GBM and model ensemble in R environment

**Model evaluation**

Internal

- R<sup>2</sup> of distance-based cross-validation based on 500 model realizations

External

- Hindcast (prediction error in 1970–1984 and 1985–1999)
- Qualitative (visual) comparison with published modelling results and permafrost maps

**MAGT and ALT at 30 arc second resolution in current conditions**

- Ensemble prediction of MAGT and ALT
- Permafrost occurrence based on ensemble model
- Permafrost occurrence considering model uncertainty

**Climate change simulations**

- RCP2.6, RCP4.5 and RCP8.5
- 2041–60 and 2061–80

**MAGT and ALT at 30 arc second resolution in future**

- Ensemble prediction of MAGT and ALT
- Permafrost occurrence based on ensemble model
- Permafrost occurrence considering model uncertainty

**Geohazard indices and maps**

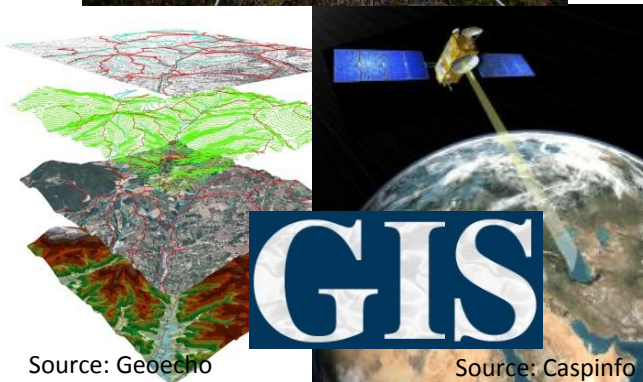
- Settlement index
- Risk zonation index
- Analytic hierarchy process based index
- A consensus index
- Geohazard maps based on different indices (hazard zonation: low, moderate and high)

**Infrastructure, population and hydrocarbon fields data**

- Residential (settlements and buildings)
- Transportation (roads, railways and airports/airfields)
- Industry (pipelines and industrial areas)
- Population
- Hydrocarbon extraction fields in the Russian Arctic

**Infrastructure hazard assessment**

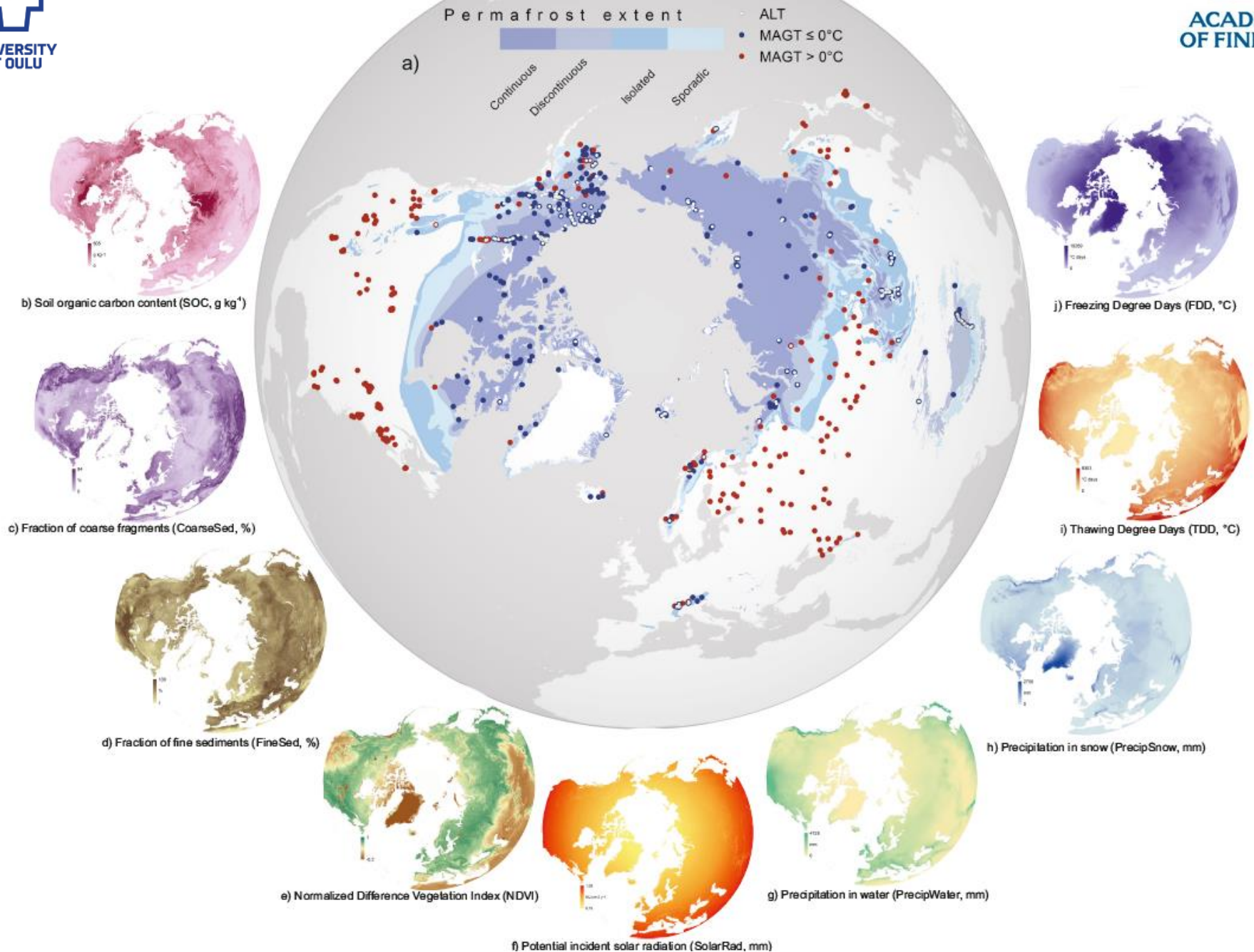
- Infrastructure threat spots of northern hemisphere permafrost region by 2041–2060 and 2061–2080
- Amount of infrastructure elements at risk by 2041–2060 and 2061–2080 (circumpolar and geographic assessment)



Source: Geoecho

Source: Caspinfo

# Geothermal and environmental data





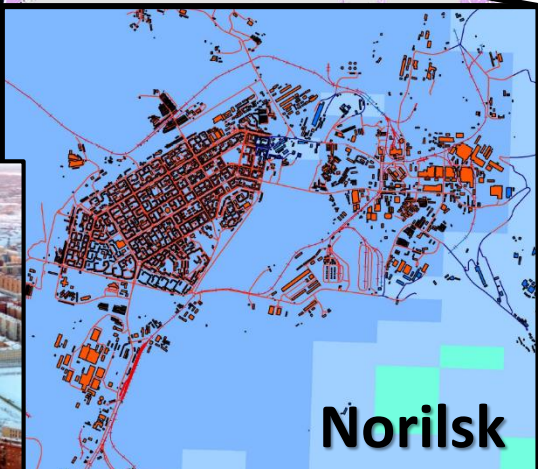
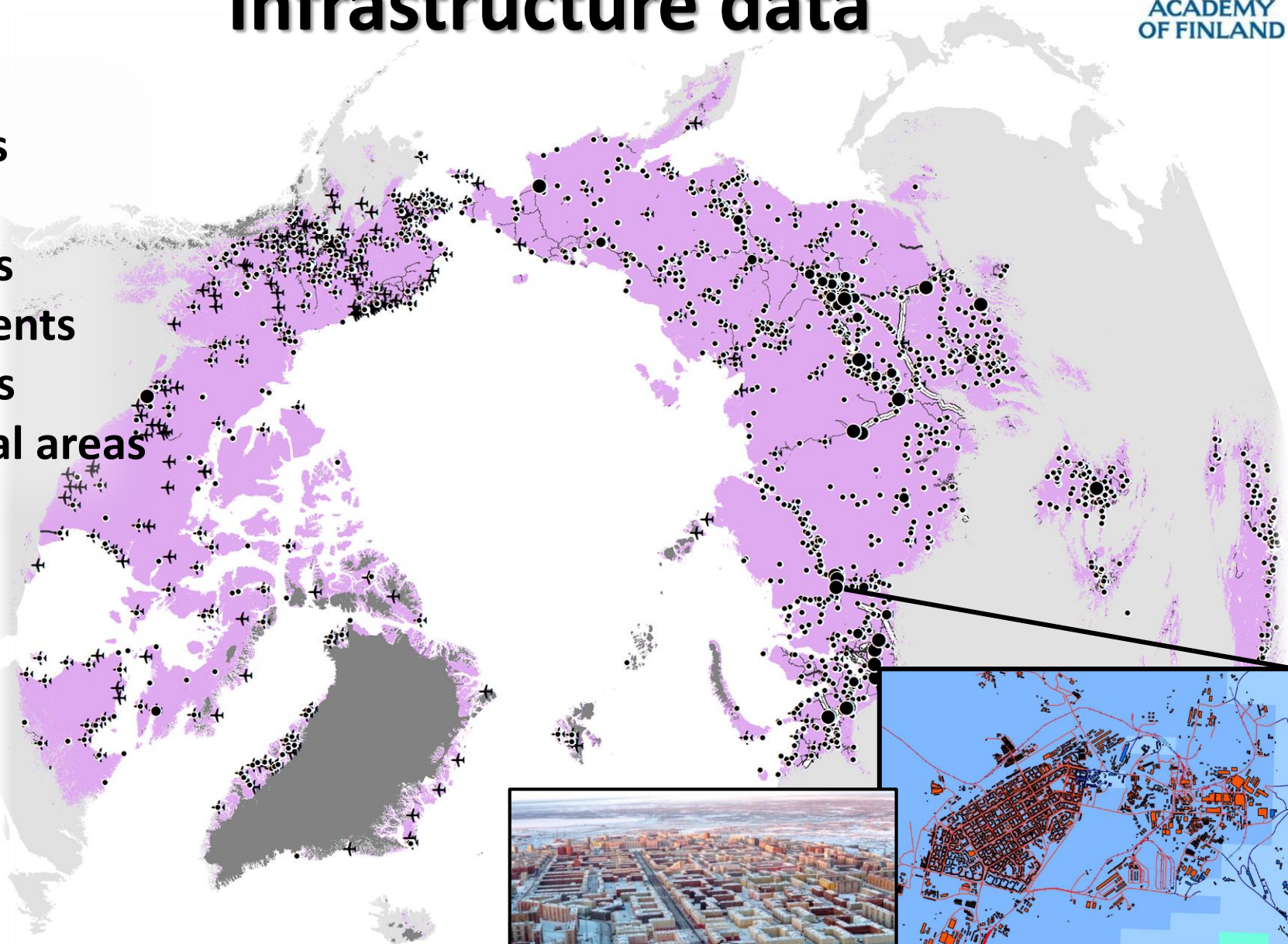


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# Infrastructure data



- Roads
- Railways
- Airports
- Pipelines
- Settlements
- Buildings
- Industrial areas



# Statistical modeling

We built an ensemble model using

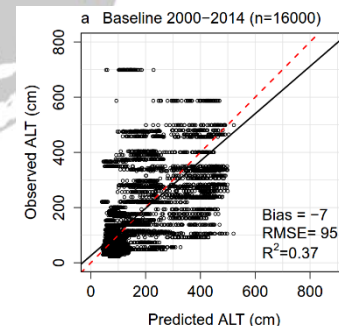
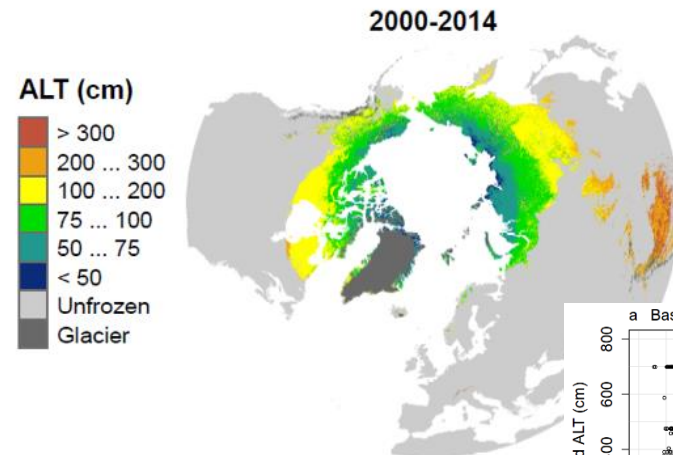
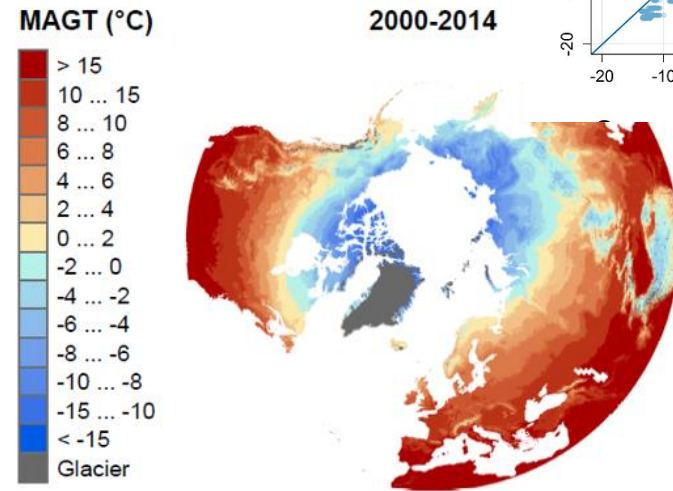
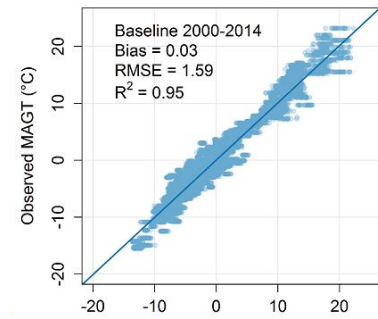
- *Generalized linear modelling (GLM)*
- *Generalized additive modelling (GAM)*
- *Generalized boosting method (GBM)*
- *Random forest (RF)*

to reduce uncertainty associated with single models (Araújo & New 2007).

High predictive performance with MAGT, ALT was more challenging

Climate-forcing scenarios

- RCP 2.6, 4.5 and 8.5
- 2041-60 and 2061-80

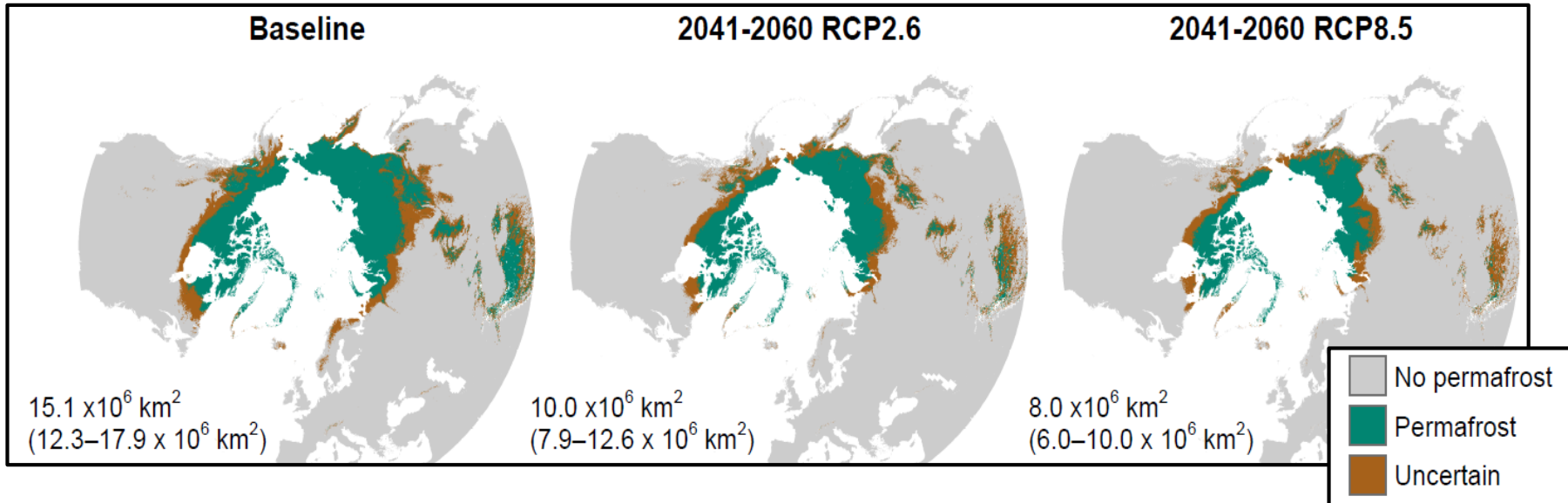




# **Main results and conclusions**



# (i) Substantial loss of near-surface permafrost






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## Geophysical Research Letters

### Statistical Forecasting of Current and Future Circum-Arctic Ground Temperatures and Active Layer Thickness

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# (ii) Infrastructure hazard areas by 2050

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN Data Descriptor: Circumpolar permafrost maps and geohazard indices for near-future infrastructure risk assessments

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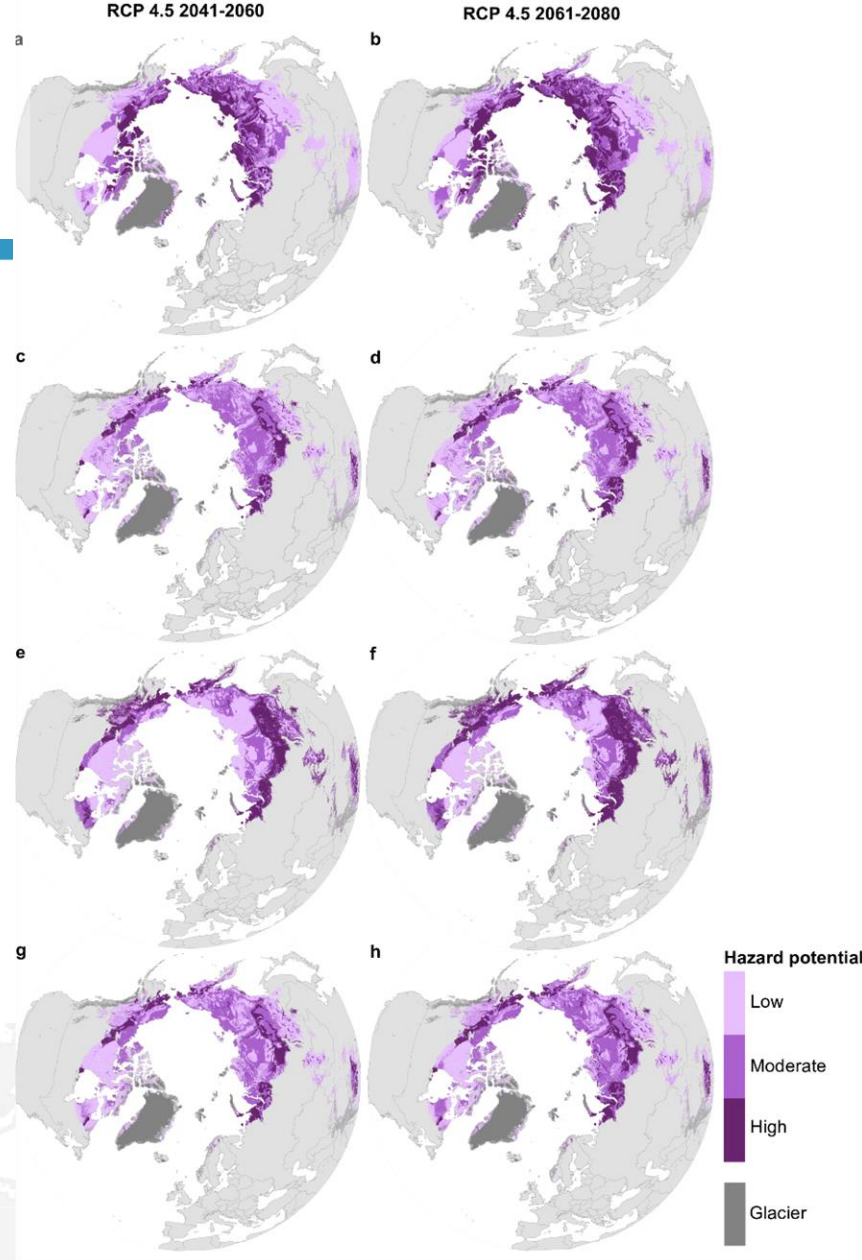
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**PANGAEA.**

Data Publisher for Earth & Environmental Science

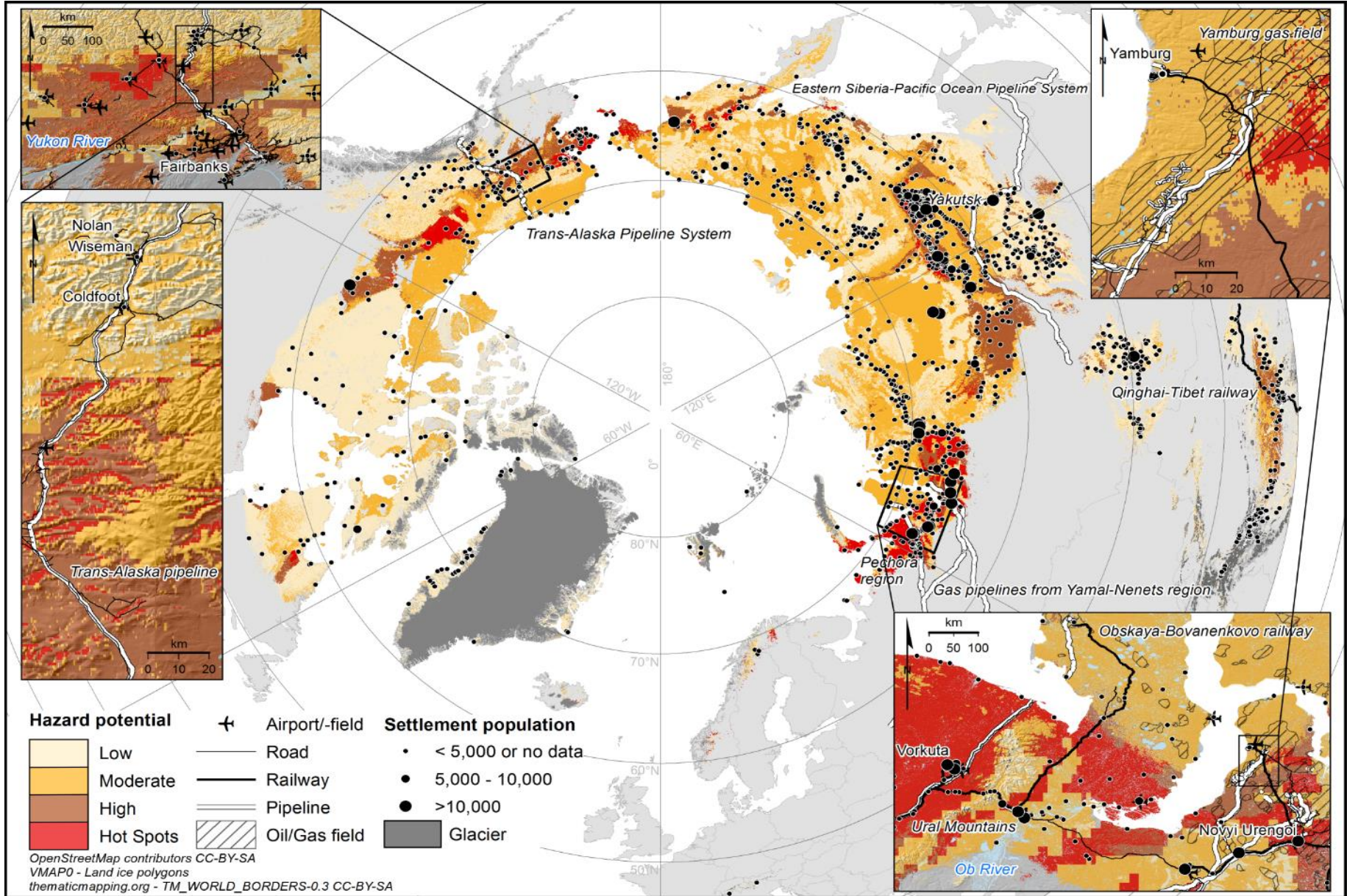








# (ii) Infrastructure hazard areas by 2050









ARTICLE

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OPEN

# Degrading permafrost puts Arctic infrastructure at risk by mid-century

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# (iii) One-third of infrastructure potentially at risk by 2050

- Nearly 70% of the current infrastructure are in areas with high potential for thaw of near-surface permafrost (e.g. more than 1200 settlements; around 40 with population more than 5,000).
- On average, 33% of the current infrastructure occur in high hazard environments (e.g. more than 36,000 buildings, 13,000 km of roads, and 100 airports).

