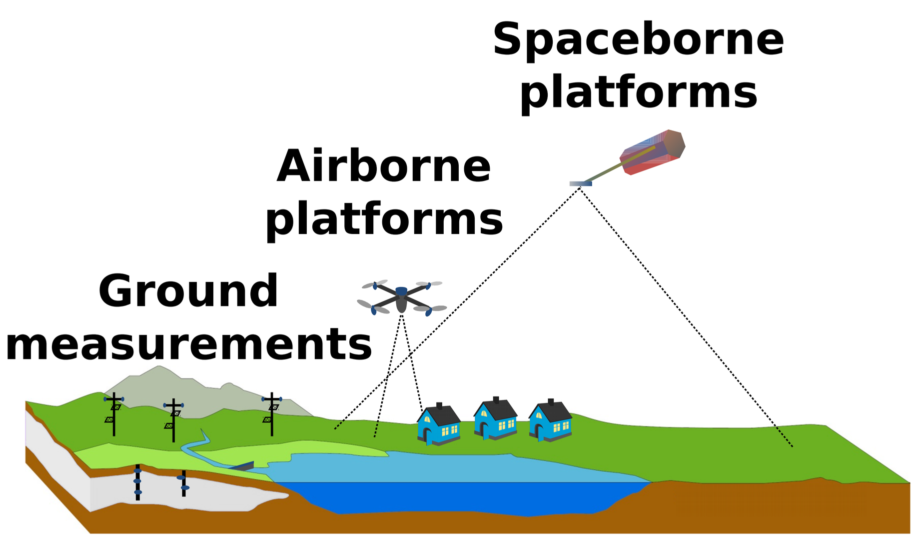
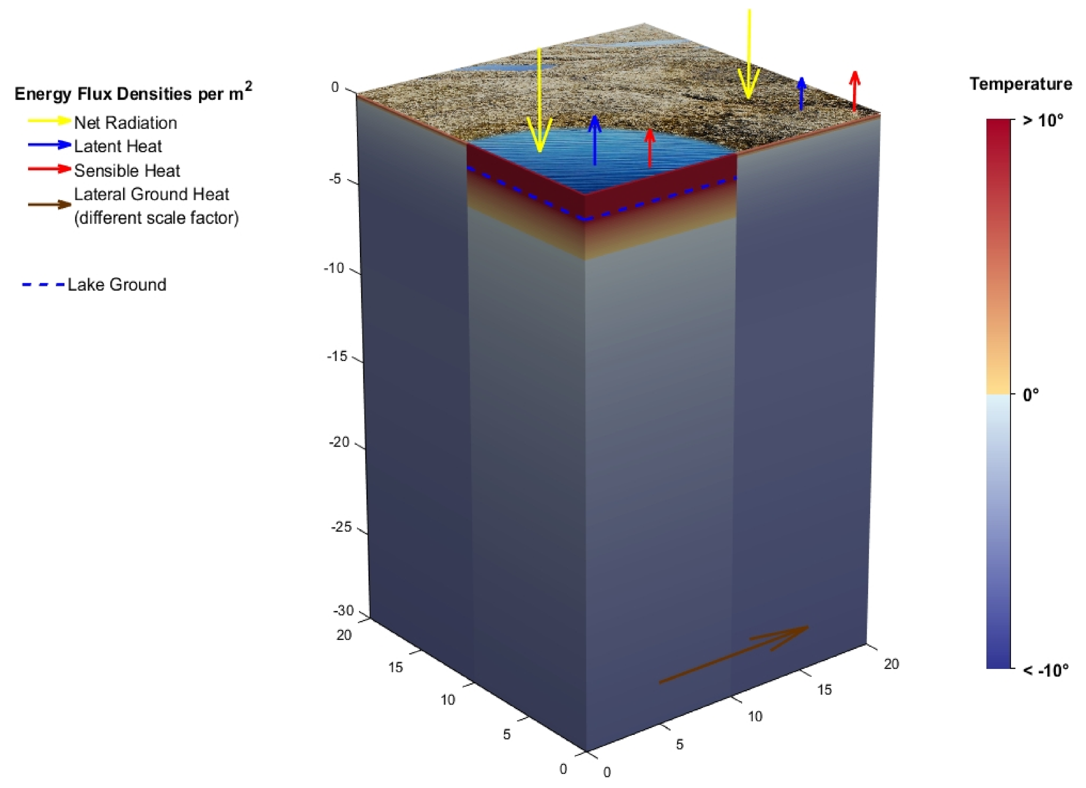
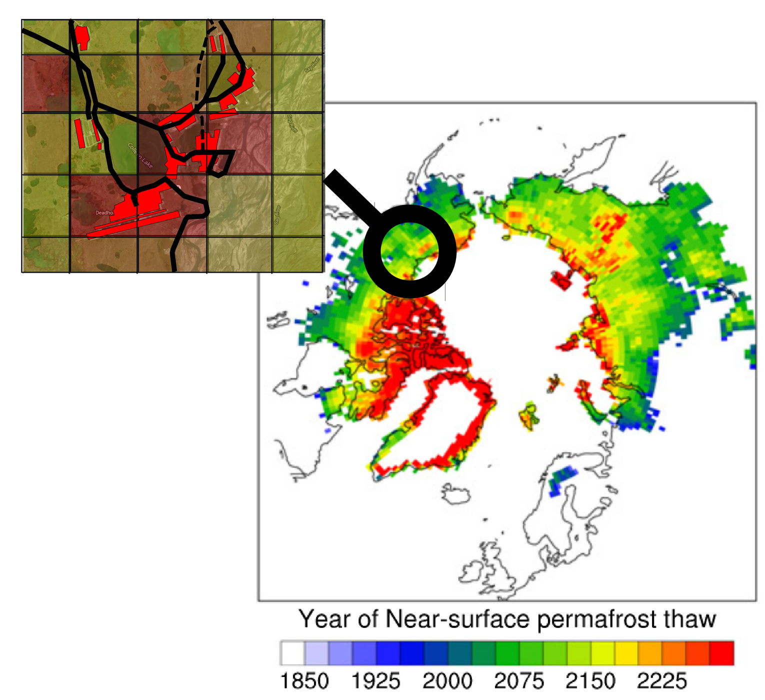
Simulating erosion processes in permafrost landscapes under a warming climate – a risk assessment for ecosystems and infrastructure within the Arctic



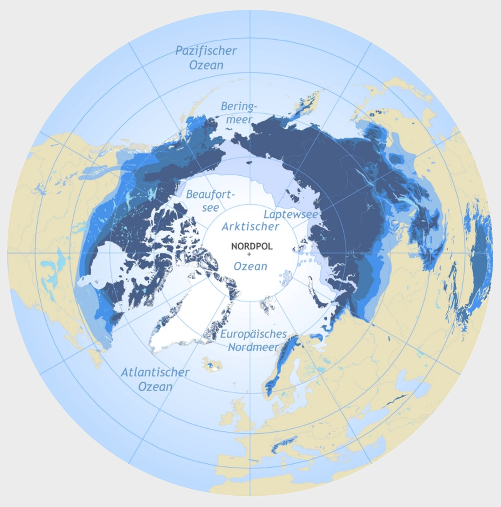




Observational studies → **Model development & validation** → **Climate impact simulations and risk assessments**

Background:

Permafrost under a warming Climate:



Current distribution of permafrost on the northern hemisphere.

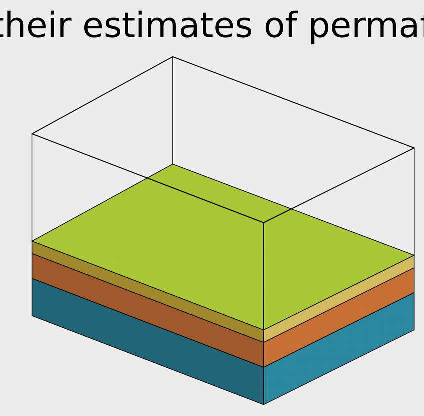
Permafrost landscapes and northern infrastructure are under threat of erosion of thawing permafrost across the Arctic due to a rapidly warming climate. Diverse ecological, social, and financial risks are associated with potential damages to ecosystem functions and infrastructure caused by permafrost thaw. The economic development of the Arctic requires highly resilient infrastructure such as supply roads, pipelines, fuel storages, airports, and other buildings to be constructed on highly sensitive frozen ground.

Permafrost in Land Surface Models:

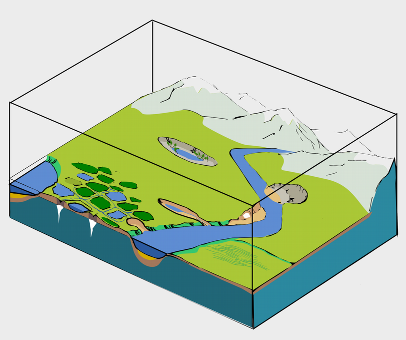
Photos: Josefine Lenz

Photographs showing typical features of permafrost degradation in the Arctic. Permafrost thaw is usually associated with intensive erosion and mass wasting.

Current Land Surface Models (LSMs) used to simulate the degradation of permafrost under a warming climate are highly simplistic since they only consider one-dimensional (top-down) thawing and ignore lateral processes such as soil erosion and mass wasting which are the most abundant form of thaw in many regions. Thus, current model assessments are most likely far to conservative in their estimates of permafrost thaw impacts.



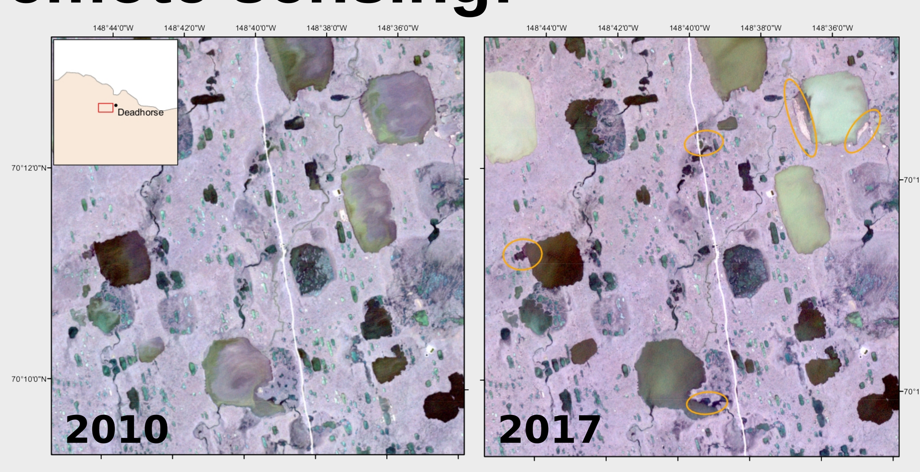
Schematic grid cell representation of a one dimensional LSM. With frozen and unfrozen soil layers



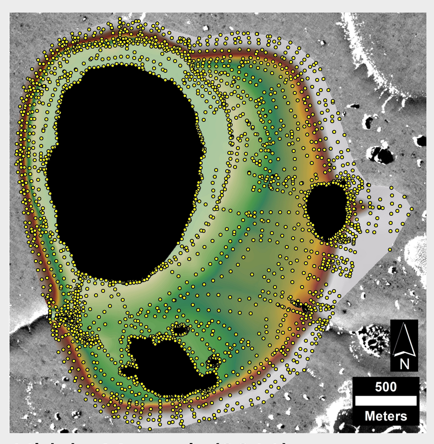
Envisioned representation of sub-grid landscape units and process within one grid cell.

Methods:

Field mapping and remote sensing:



Using high resolution satellite data (RapidEye) for detecting landscape changes (e.g. growth of thermokarst lakes).



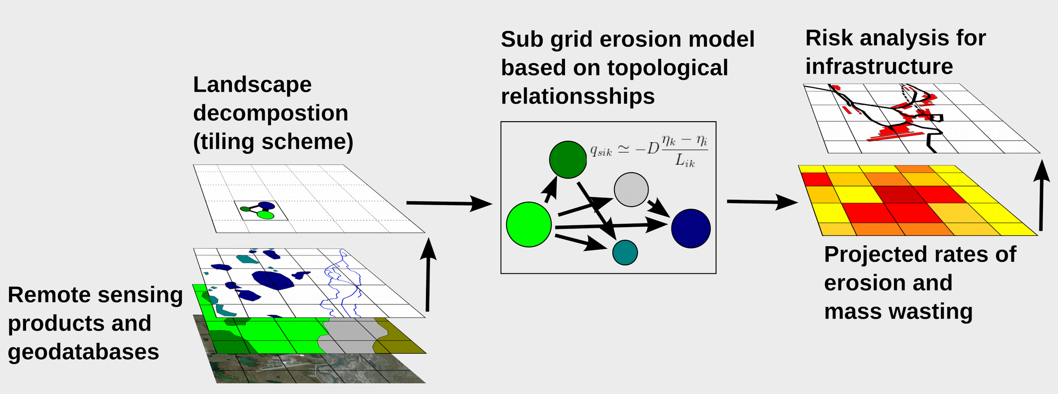
Ulrich, M. et al. (2011)

Using UAVs and terrestrial surveying for high resolution mapping of thermo erosion features.

We make use of available observational databases on permafrost state variables including measurements of permafrost temperatures and thaw depths (active layer thickness). Furthermore, observations of topographic changes inferred from high resolution aerial images, satellite data, and drone surveys are used to measure erosion and mass wasting.

Modeling:

The LSM CryoGrid will extended with a tiling scheme that allows simulating of processes on a sub-grid scale. The tiling scheme will divide the landscape encompassed by one grid cell (typically representing between 25 and 100 km2) into landscape units relevant for erosion and mass wasting. This includes different categories of e.g. lakes, rivers, flood plains, and hill slopes. Only the areal fraction and topological connections of these landscape units are stored as information in the tiles. The land surface is thus decomposed into virtual information allowing reduced order representation of processes much smaller than the nominal spatial resolution of the model.



Concept for implementing erosional and mass wasting processes into the land surface model (LSM) CryoGrid3 based on tiling and the adaptation of routines used in landscape evolution models (LEMs).

Field sites:

Deadhorse, Prudhoe Bay:

The Deadhore / Prudhoe Bay site on Alaska's North Slope is located within a typical low land tundra landscape. The site is characterized by continuous permafrost and typical landscape features. The permafrost soils feature hight contents of excess ice which promote erosion and thaw slumping. wasting processes such as thermokarst and thaw slumping. The site belongs to the National Petroleum Reserve in Alaska. The industrial complex at the site consist of more than 200 exploration and production sites including numerous supply and processing facilities.

Churchill, Manitoba:

Photo: File/Reuters

The Churchill site is located on the southern edge of the zone of continuous permafrost. The landscape is characterized by progressive permafrost degradation and active erosion and mass wasting processes. Churchill has about 900 inhabitants living in a town constructed on permafrost. The community is also center of Arctic tourism in Canada. We aim to contribute to the further development of climate change adaptation strategies for the Churchill community.

Lena River Delta, Siberia:

Photo: AWI

The Lena River Delta site is located in a typical lowland tundra landscape in the zone of continuous permafrost. The tundra landscape features typical permafrost erosion processes such as thermokarst, slope creep, cliff erosion, and gully formation. The high content and strong variability of organic carbon and other nutrients in the permafrost soils makes the study site perfectly suited for investigating the impact of permafrost erosion on Arctic ecosystems.

Relevant references:
Langer et al., 2013: Satellite-based modeling of permafrost temperatures in a tundra lowland landscape. Remote Sensing of Environment 135, 12–24.

Westermann et al., 2016: Simulating the thermal regime and thaw processes of ice-rich permafrost ground with the land-surface model CryoGrid 3, Geosci. Model Dev., 9(2), 523–546.

Langer et al., 2016: Rapid degradation of permafrost underneath waterbodies in tundra landscapes —Toward a representation of thermokarst in land surface models, J. Geophys. Res. Earth Surf., 121.

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