Investigating the relationship between permafrost, climate change, and the built environment in Arctic coastal and riverine environments

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Environmental processes can have dramatic effects on community infrastructure in Arctic environments. In many communities, the impacts of these processes are intensifying with climate change. The thawing of permafrost, in particular, poses a serious threat to the built environment in the Arctic. Permafrost when thawed creates unstable soil conditions which are more susceptible to larger magnitudes of settlement as well as erosion in coastal and riverine environments. Currently, there exist several knowledge gaps on the relationship between permafrost thaw and the built environment. Additionally, the interactions between permafrost thaw and other climate-change-driven processes that impact civil infrastructure such as coastal flooding and riverine erosion are not well understood. In this study, we present a synthesis of a detailed literature review and workshop on currently available data and observations on the interaction between permafrost thaw and the built environment in Arctic communities and provide an outlook towards future trends in the context of climate change. Initial observations suggest that erosion, flooding, and permafrost thaw damage infrastructure in over 40% of all communities in Alaska. Furthermore, we discuss existing knowledge gaps and pathways to fill these gaps through innovative and sustainable data collection strategies.

Permafrost Characterization Using Ground Penetrating Radar (GPR) in support of land use planning, Inukjuak, Nunavik

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With climate warming affecting the high latitudes, there is a growing need of knowledge concerning the spatial and vertical distribution of soil properties at the scale of communities in order to assess terrain sensitivity to permafrost thawing, estimate bearing capacity for infrastructure and ensure proper design foundations for buildings. Given a strong demographic growth in Inukjuak, there is an important need for the development of housing projects and municipal infrastructure. It is therefore essential to proceed to high resolution permafrost characterization (about 100 m2 resolution) to support urban land use planning and to select foundation designs for buildings in accordance with local permafrost conditions.

The main objective of this project was to compile a map of geomorphological and permafrost features that are key to support decision making in land use planning and construction. Those features are : the depth to bedrock, the distribution of surface geological units and strata and the extents of zones of thaw sensitive ice-rich permafrost zones in the community area. The final map provides necessary information for selecting the best choices of foundation designs such as pads, piles to bedrock, adjustable studs and thermosiphons throughout the urban area with a concerted vision for urban planning.

GPR was use as a key research tool in the mapping project. A total of 21 km of GPR profiles surveyed in the summers of 2015 and 2017 were interpreted with the help of other sources of information such as analysis of aerial photographs, surficial geology maps, excavations, drill holes and field observations. Some sectors of the Inukjuak area are underlain by thaw sensitive permafrost, mostly because of the presence of ice-rich silty glacio-marine sediments under low lying ground between bedrock outcrops. The largest part of the community, however is either on thick marine sand with low ice content or has bedrock at shallow depths, i.e. between 3,5 and 6,5 m below the surface.

The compilation of permafrost data and the map of depth to bedrock shall help decision making by the community and the supporting regional government and will be a tool to plan an adaptation strategy to climate change.

Multi-disciplinary hazard mapping framework for critical infrastructure on permafrost, Ilulissat, West-Greenland

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In the face of climate change, degrading permafrost and inappropriate construction practices often threaten the integrity of the built environment. As a result, Arctic communities become increasingly vulnerable and exposed to hazards. The implementation of adaptation strategies integrating future climate scenarios is fundamental to guide urban planning and expansion onto permafrost areas. In order to provide reliable decision support tools to local governments, hazard and risk assessments resulting from collaborative science and multi-disciplinary approaches have the potential to address stakeholder's needs, while taking account of local resources, data availability, and societal and environmental settings.

Like other Arctic settlements, Ilulissat, West Greenland, experiences many construction challenges and infrastructure stability issues, notably due to the presence of ice-rich and saline permafrost. For this reason, the area was chosen to develop and implement a community-scale risk assessment framework. Based on the methodology deployed in the Canadian Arctic (Allard et al., 2012) and supplemented by permafrost modelling, the core of the approach consists in characterizing surficial geology, topography, and ground ice distribution from field measurements and remote-sensing products.

Here, we present preliminary results from a multi-disciplinary study combining INSAR (interferometric synthetic aperture radar) measurements, field data and local knowledge. Processing Sentinel 1 images covering thawing seasons from 2015 to 2019, we derived average seasonal deformation and long-term permafrost degradation rate maps at the community scale. Results were validated by cross-referencing available geotechnical information from borehole networks, and maps of existing infrastructure conditions and damages produced in collaboration with stakeholders. Sensitive high-risk permafrost areas, affected by amplified ground movements and/or long-term subsidence, could be identified. Easily accessible interactive web maps and stories, were finally developed for outreach purposes and with the aim to support urban development, help prioritizing maintenance operations and raise awareness regarding local permafrost conditions.

Using Geo-data to adapt to a changing Arctic

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Abstract:

Rapid environmental changes present challenges for infrastructure, land management and natural resource development in the Arctic. Geo-data is critical to understanding, predicting and addressing the impacts of anthropogenic and climate-driven changes on these assets.

This presentation will address current Geo data needs in the Arctic and present methodologies for collecting this information. Improvements in Geo-data accuracy and increased autonomy will be discussed in a context of three challenges, common to the Arctic and cold regions: 1) coastal hazards; 2) geologic hazards related to permafrost degradation; and 3) data sharing and management across disciplines and sectors. This presentation will benefit Geo-data users and anyone with the responsibility of making infrastructure, land and resource planning and managing decisions.

Geomorphological Mapping in Permafrost Terrain to Inform the Routing and Planning of the Kivalliq Hydro-Fibre Link, Manitoba to Nunavut, Canada

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The proposed 1,200 km-long corridor for the Kivalliq Hydro-Fibre Link (KHFL), between Gillam, Manitoba, and Baker Lake, Nunavut, extends from sporadic discontinuous to continuous permafrost, traverses the forest-tundra transition, and crosses diverse Quaternary deposits commonly within the marine limit. The aerial cables for the KHFL are proposed to be suspended from towers founded on piles every 300 to 500 m. Initial conceptual routing of the KHFL was based on regional land use planning and previous studies of a proposed all-season road. A systematic and phased approach for establishing a preferred alignment for the KHFL, from a terrain and permafrost perspective, was initiated through a collaboration between geomorphologists and permafrost scientists.

A 1,200 m-wide corridor within which terrain conditions appear most favourable for the KHFL was delineated following review of regional surficial geology mapping, models of potential ground ice distribution, and scarce geotechnical data for previous infrastructure projects (e.g. PolarGas pipeline proposed in the 1970s, Gillam to Churchill hydro line energized in 1987). Geomorphological mapping has focused on identification of frost-susceptible soils and indicators of ground ice, based on field reconnaissance and interpretation of stereo imagery. More detailed mapping will be completed within a narrowed corridor based on recent LiDAR/imagery and geophysical surveys and shallow permafrost drilling.

Preliminary mapping indicates strong associations between surficial geology and ground ice. Gravelly beach ridges and till veneers exhibit few surface indicators of ground ice. Small thermokarst depressions commonly punctuate thicker till units. Wave action during marine regression modified till surfaces, with at least local effects on permafrost possible. Large ice-wedge polygons typify sandy beaches and eskers. Numerous thermokarst ponds have recently formed and coalesced in fine-grained glaciolacustrine and marine deposits. Transmission towers will optimally take advantage of localized beach deposits and wave-washed tills, where bedrock and well-drained materials are unavailable along the finalized alignment.

Mesoscopic-Model Simulation of Freeze and Thaw with Groundwater Flow for Terrain Change in Permafrost Regions

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Recently, in permafrost regions, it becomes known that terrain change including consecutive subsidence may be caused by abnormally high air temperature or wildfire. Such a phenomenon affects the safety, stability and reliability of existing infrastructures. This study aims to simulate terrain change in permafrost regions due to environmental disturbance such as abnormally high air temperature or wildfire with a numerical analysis originally developed by the authors. Based on the simulation, the authors attempt to explain the phenomenon, and to propose countermeasures for mitigation and prevention of terrain change.

This quasi 3-dimensional simulation combines a vertical heat transfer model of soil column for freeze and thaw analysis of permafrost with a 2-dimensional finite difference model for groundwater flow which covers several hundred square kilometers of the region as a mesoscopic model. By introducing environmental conditions such as air temperature and precipitation, it becomes possible to follow the freeze and thaw process in the region with groundwater flow, and to evaluate the surface subsidence and frost heave. Then, the effects of abnormally high air temperature or wildfire on the terrain change can be evaluated.

The authors conducted simulations to assess the effect of wildfire happened in Siberia on the terrain change. By comparing the simulation results with the evaluation by InSAR, the authors verified the validity of the simulation. For example, the consecutive subsidence calculated by the simulation shows a good coincidence with the monitoring results by InSAR. The simulation results imply that the frost heave in Winter and the subsidence in Summer are seriously affected by the groundwater flow based on the characteristics of terrain as well as the insulation effects near the surface. Those findings must be helpful to predict the upcoming terrain change due to abnormally high air temperature or wildfire, and to maintain infrastructures healthy in permafrost regions.