## Alaska's Transportation Infrastructure in a Changing Environment

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Understanding the interactions between permafrost, climate and infrastructure is complex especially in regions like Alaska. The most readily available geospatial data on permafrost and infrastructure do not readily show the interactions. This study aims to evaluate the utility of long-term permafrost and climate data in understanding and predicting infrastructure stability on permafrost for Department of Transportation (DOT) assets in Alaska. First, the number of DOT assets on permafrost were summarized per Alaska climate zone for miles of road, bridges and airports. Out of the thirteen Alaska climate divisions, eight contain DOT assets with permafrost. Southeast Interior contains the highest number of assets on permafrost. Thirty-year decadal averages were constructed for 2 different past and projected periods for active layer thickness, permafrost thickness, air temperature and precipitation using data from the Integrated Ecosystem Model (IEM) project obtained at a 1 km spatial resolution. These results were contrasted against trend- detection approaches including LandTrendr and Mann-Kendall. Finally, projects identified from the Alaska Statewide Transportation Improvement Program (STIP) from 2018 to 2023 were compared to these results to understand if either approach could aid in predicting the location or degree to which infrastructure required capital investment.

## Infrastructure’s Adaptation to Climate Change at the Russian Cold Region’s Territories

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A significant part of the territory of Russia is in the field of significant climate changes, and the consequences of these changes have a significant impact on the socio-economic development of the country, living conditions and human health, as well as on the state of the economy. According to many years of observations by the Federal Service of Russia for Hydrometeorology and Monitoring of the Environment, the average annual air temperature at the Earth’s surface in the Russian Federation since the mid-1970s has been increasing by an average of 0.47 ° C over 10 years, which is 2.5 times exceeds the growth rate of average global air temperature, which is 0.18 ° C for 10 years. Under these conditions, the adoption of measures to adapt to climate change is simply necessary. The ongoing climate change in Russia creates new opportunities for the country's economy, the use of which also relates to the field of adaptation. What does Russian National Plan mean? This means that economic and social measures have been identified that will be implemented by federal and regional authorities in order to reduce the vulnerability of the Russian population, the economy and natural objects to the effects of climate change, as well as to take advantage of the opportunities arising from such changes. The solution of the problems of geocryological forecasting as the scientific basis for reducing economic losses associated with anthropogenic impact on permafrost seems to us an interesting scientific problem, which we devoted our research to problem, which we devoted our research to.

## Regional-scale investigation of pile bearing capacity for Canadian permafrost regions in a warmer climate

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Climate change is being experienced particularly intensely in the Arctic and therefore adaptation of engineering systems for this region cannot be further delayed. However, one of the major barriers to studies focussed on adapting northern engineering systems is the lack of information at the spatial and temporal scales required for engineering applications. This study presents the development of ultra-high resolution (4 km) climate change information using the Global Environmental Multiscale (GEM) model for Canada’s northern regions, and subsequent application to investigate pile bearing capacity for different pile material and configurations, for current and future climates.

Comparison of the ultra-high resolution GEM simulation with available observations and a coarse resolution GEM simulation demonstrates added value for several variables such as temperature, precipitation and wind extremes and in surface-related fields such as near-surface permafrost. The estimated adfreeze contribution to the total bearing capacity, for current climate, for a standard cement pile, is found to be of the order of 15% for regions with shallow bedrock and 80% for regions with deeper bedrock. Application of the GEM climate change simulation, for RCP8.5 scenario, point to projected decreases to adfreeze contribution in the 5-30% range by 2040, with the largest differences noted for regions with deeper bedrock. For steel piles of same configuration, although the adfreeze contributions are only about 70% of that for cement piles, the projected percentage changes are of similar magnitude. Further downscaling of results to 250 m resolution for important transport corridors, using simulations performed with the land surface model of GEM, provides many useful insights. The results of this study, including the ultra-high resolution climate change information, will form the basis for additional detailed investigations on climate-infrastructure interactions and climate resiliency studies.

# Developing a Framework for Assessing the Vulnerability of Infrastructure on Permafrost to Climate Change

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Observed permafrost warming and increase in the active-layer thickness are having significant, detrimental effects on sustainable development in high-latitudes. An increase in permafrost temperature decreases the ability of the frozen ground to carry a load imposed by infrastructure which can potentially cause deformation and collapse. Active layer thickening, especially in regions underlain by ice-rich permafrost, promotes differential thaw subsidence which undermines the stability of linear infrastructure (roads, railroads, pipelines, airstrips). Climate projections indicate that amplified Arctic warming will persist through the 21st century causing pronounced changes in permafrost conditions. Moreover, permafrost changes are likely to be more evident in areas where the ground thermal regime is significantly modified by intensive urban and/or industrial development causing negative impacts to Arctic socio-economic systems. In this study, we employ a subset of CMIP6 models using the SSP585 scenario to compare present (2015-2024) and future Arctic climate conditions (2055-2064). Daily temperature and precipitation were used as inputs for a permafrost-geotechnical model to estimate changes in permafrost temperature, active layer thickness, subsidence, and bearing capacity. Simple interpolation techniques was used to estimate changes within cities and other centers of economic activity. A circumpolar infrastructure geodatabase was assembled to determine locations and infrastructure types particularly threatened by changing climatic and permafrost conditions. Costs associated with projected damages were then estimated for all Arctic states using country-specific construction statistics. The framework presented can be used to translate complex climatic inputs into series of accessible graphics and interactive maps for stakeholders to examine and communicate potential impacts of climate change and permafrost degradation from national to municipal scales. An online version of this diagnostic tool is currently being developed.

## A spatially consistent account of infrastructure across the entire Arctic

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Infrastructure and anthropogenic impacts are expanding across the Arctic. A consistent record is required in order to quantify the changes and to assess climate change impacts including permafrost thaw on the communities.

Satellite data offer spatially continuous coverage but the separation of infrastructure from natural environments is challenging due to spatial resolution and spectral similarities with natural features. Sentinel-2 provides an advance in this context compared to Landsat (10m versus 30m). We used Sentinel-1 (Synthetic Aperture Radar) in combination with Sentinel-2 (multispectral) observations covering the entire Arctic coastal region to identify areas impacted by humans. Machine learning techniques are implemented in a first step. Manual post-processing has been carried out for two different classification type results and eventually they have been merged. Due to the size of the study area, several editors have been involved in the manual postprocessing step. To evaluate the comparability of the results, the performance of individual editors has been assessed through a benchmarking exercise.

Mapped objects include roads, buildings and other areas such as gravel pads or open pit mining areas. These represent only part of relevant infrastructure for Arctic communities, but a consistent database can be obtained. In total, 0.02% of the land area within the 100 km buffer was identified as human-impacted.

As an example, results are combined with ground temperature trends derived from the ESA CCI+ Permafrost time series (1997-2019). If trends continue as observed during this time period, the majority of areas with human presence will be subject to thaw by mid-21st century.

## Early Warning Frost Detection System

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Occurrence of freeze/thaw conditions in rural roadway subgrades over the years resulted in significant labor efforts from Whatcom County Public Works engineers to monitor and evaluate conditions for implementing road restrictions. Extended periods of frost conditions followed by warmer temperatures can result in extensive damage to the road system, if restrictions are not applied. Previously, manual subsurface temperatures were measured at various locations throughout the county to assist with evaluation of roadway conditions. Recently, a network of automated measurement and remote communication systems were designed and implemented to facilitate improved monitoring and response for the County engineers. Sixteen remote monitoring locations were selected throughout the county and at each site a 1-meter long tube with 18 thermistors at 50 mm spacing was installed into the roadway subgrade. Additional instrumentation at each site included ambient air temperature sensors and moisture sensors for the datalogger enclosures. Data is collected and transmitted to a web-based data management system for County personnel to access, as well as provide alarm notifications to County personnel with indications as to when temperature thresholds are exceeded. Having the automated system allows the County to monitor the thaw process more accurately and be more confident in when road restrictions are applied and the duration. The current monitoring system has increased the effectiveness and efficiency of the County's rural roadway management process during freeze/thaw cycles, resulting in significant savings in operating and maintenance costs.

## On the influence of complex and changing Arctic conditions on historic and future waste disposal sites - a multi-criteria risk assessment

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Management of waste from both human settlements and mining activities has been a major challenge in the Arctic region. Historically, practice has relied on permafrost conditions in the soil to stabilize waste and to prevent contaminants from being released into the environment. Increased temperatures in Arctic regions, due to climate change, might result in mobilization of contaminants from historic waste. In addition, traditional approaches for the handling of mine waste are no longer valid and new solutions need to be developed.

To address these challenges, we developed a multi-criteria risk assessment approach that considers the various processes that can apply pressure on Arctic waste site systems, including:

•Climate change-induced increases in temperatures and changes in precipitation patterns can lead to increased erosion;

•Permafrost is expected to lose its role as a geological barrier for the containment of environmental contaminants;

•Landslides and avalanches could impact stability and safety on-site;

•Changes in geotechnical stability will impact stored waste and potentially lead to the release of contaminants;

•Hydrological conditions guide the functioning of barriers between the waste and its environment;

•Properties of the deposited waste fractions are drivers for the release of contaminants and therefore require a clear classification.

All of these factors are interrelated, and the risk they pose can be addressed by combining their probability of occurrence and the consequences in a risk matrix. This integration allows both a qualitative as well as a quantitative approach of the involved risks to both humans and the environment. Thereby it is possible to find solutions which will be sustainable under future climate change scenarios in the Arctic. In our presentation we show how this multi-criteria risk assessment approach can be applied to historic and future waste disposal sites on Svalbard, Norway.

## Understanding the Changing Natural-Built Landscape in an Arctic Community: An Integrated Sensor Study in Utqiaġvik, Alaska


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Arctic communities face many challenges in the context of a rapidly changing environment. These challenges include coastal erosion, permafrost thaw, and ecosystem change. Arctic cities need to prepare for critical decisions in the future, which traditional geochemical approaches alone are unable to address adequately. Instead, an interdisciplinary, community-based approach is necessary. This project is developing and deploying a network of terrestrial and aquatic sensors, in addition to conducting geophysical surveys, within the community of Utqiaġvik, Alaska, in order to improve our understanding of the interactions between the built and natural environments in the Arctic. Community collaborators are involved in the planning process for sensor and surveying locations, and the ongoing maintenance and interpretation of the data. At peak thaw this summer, we conducted ground-penetrating radar and electrical resistivity tomography survey along transects throughout Utqiaġvik, and placed the first two of 20 proposed meteorological stations. This research will investigate two essential challenges for the Arctic city of Utqiaġvik: i) the impacts of existing community infrastructure practices on the surrounding tundra, coastal, and lagoon landscapes within and around the city, and ii) the impacts of a changing environment on the design and future planning of community infrastructure and buildings. The process of co-production of knowledge among researchers and community collaborators is also being studied to better understand how these relationships can successfully build and maintain equitable sharing of knowledge and data, and provide benefits for the residents of Utqiaġvik and the broader scientific community.

## Performance of climate projections used for engineering design in Yukon and adjacent Northwest Territories, 1991-2020

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Permafrost foundation design recognises the potential impact of climate change on soil bearing capacity so that foundation integrity is maintained throughout the intended service life of structures. Canadian scientists and engineers have published a guideline for considering climate change in foundation design (CSA PLUS 4011-19). However, there is no guidance as to the climate scenarios most prudent to adopt. In 2003, climate change scenarios were outlined for the Mackenzie Gas Project in consideration of its proposed 30-year service life. In this paper, we ranked these projections and compared them with Environment and Climate Change Canada (ECCC) data to determine the scenarios most representative of the 1991-2020 climate record. The greatest climate change in Canada during the last 50 years has been measured in the western Arctic, where annual fluctuations in air temperature are regionally correlated. The rate of change in mean annual air temperature (MAAT) has ranged from 0.72 °C/decade at Inuvik, NT to 0.43 °C/decade at Dawson, YT. The warming has been concentrated in winter. No statistically significant trends in precipitation have been observed for 1971-2020 and these records are poorly correlated among regional stations. Twenty-nine ranked climate projections from SRES scenarios derived using seven global climate models (GCMs) were examined for the region. The observed regional climate change in 1991-2020 has surpassed the upper MAAT and winter air temperature projections. For example, at Inuvik the 2.0 °C increase in MAAT between 1961-1990 and 1991-2020 already exceeds the median projection of +1.6 °C and is approaching the upper value of +2.4 °C for projected change by 2011-2040. No consistent relations between observed and projected precipitation have been determined. These observations indicate that future projections for regional temperature change may prudently adopt higher or more extreme scenarios. Projections for precipitation exhibit less systematic behaviour with respect to the record.