Permafrost Thaw Dynamics in Point Lay: Reflections on Infrastructure Challenges in the Context of Climate Change

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Introduction

The Arctic region is at the forefront of climate change impacts, exhibiting some of the most dramatic environmental changes on Earth. As air temperatures have steadily risen in recent decades, Arctic ecosystems are undergoing rapid changes that are having substantial impacts on local communities. One of the most critical consequences of climate change in this region is permafrost warming, which has severe impacts on various ecosystem functions and infrastructure stability which directly threaten the livelihood and safety of Arctic communities.

In many cases, the warming of the frozen ground is exacerbated by the thermal and hydrological effects of infrastructure. Even under relatively cold climate conditions, the effects of infrastructure can initiate permafrost thaw. Thereby, the potential for ground destabilization is closely related to the content and distribution of ground ice, which plays a critical role in altering the mechanical properties of the ground during thaw. Communities located in ice-rich permafrost regions are thus among the most vulnerable to the effects of permafrost degradation.

Point Lay, a remote Inupiaq community located at the coast of the Chukchi Sea, is a standout example of the challenges posed by permafrost degradation. Most of the settlement lies on the ice-rich Yedoma deposits, which are characterized by high ice content, often exceeding 50% by volume and rising to 100% within ice wedges.

Even minor disturbances of the insulating tundra surface can trigger local subsidence at such a site, leading to ponding of water and increased snow accumulations in the resulting depression which can initiate a self-reinforcing positive feedback mechanism known as thermokarst.

Point Lay is a remote and relatively small community with a population of a few hundred residents and is part of the North Slope Borough. The majority of the population is Inupiaq Eskimo, and the community is known for its rich indigenous culture. The economy of Point Lay is primarily subsistence-based. Residents rely on hunting, fishing, and gathering for their sustenance. Traditional activities such as hunting seals, whales, caribou, and fishing for salmon and other fish are essential to the community's way of life.

Observations

In Point Lay, ground subsidence has essentially affected residential buildings. In extreme cases, subsidence from the thaw was observed to exceed 10 meters, exposing a substantial portion of the foundation piles and completely destabilizing these buildings. A significant number of these buildings now appear to have become uninhabitable or should not be inhabited for safety reasons, creating a worrisome situation. In general, extreme thermokarst phenomena are observed within the residential area of Point Lay, often accompanied by the formation of standing water. The presence of standing water is often related to infrastructure elements such as roads that inadvertently impede natural drainage processes. Efforts to address this problem through engineering measures such as the installation of culverts have largely proven ineffective. This ineffectiveness is attributed to persistent ground subsidence, which causes the ground level in the depressions to fall below the bottom of the culverts, rendering them ineffective (Fig. 1).

Figure 1: Ineffective culvert due to progressive surface subsidence resulting in constant standing water between the building and the road. The situation is exacerbated by the fact that the local water treatment system continuously discharges water into this pond.

During the winter months, another problem arises as larger amounts of snow are likely to accumulate in these depressions and along exposed infrastructure. If these snow accumulations are not actively removed, winter ground cooling is impeded, exacerbating the problem and leading also to an increased accumulation of water when the snow melts in the spring.

For some buildings, the use of a decentralized water treatment system was observed, where treated water was flushed into the indirect surroundings of the building. It was relatively obvious that this water inflow also contributed to the thermokarst processes by creating a larger swampy area close to the buildings. In addition to triggering thermokarst, the ponding water between the buildings also appears to worsen sanitary conditions in the residential areas as trash and dog excrement enter the standing water (Fig. 2).

In contrast to the residential area of Point Lay, important public infrastructure such as the power supply building and the sewage treatment plant are located in the lower area of the settlement, which is probably a drained basin of a former thermokarst lake. This area appears to be unaffected or only slightly affected by thermokarst.

Figure 2:Ponding water in thermokarst depressions around houses with dog boxes in close vicinity, creating a potential health risk.

While it was evident that all Yedoma areas within the settlement were affected by severe thermokarst, evidence of permafrost degradation outside the settlement was more subtle. Nevertheless, clear signs of ice wedge degradation were evident in the surrounding tundra, which is largely in a natural (undisturbed) state (Fig. 3). This suggests that permafrost in the region is reaching a thermal state below which regional Yedoma deposits cannot be considered unconditionally stable, and that thermokarst could occur even with greatly reduced thermal and hydrologic impacts from infrastructure.

Figure 3: The photography on the left shows a view on the tundra north of Point Lay with clear signs of ice wedge degradation outside of the settlement. The aerial image on the right shows the presence of thermokarst ponds outside of Point Lay (aerial image: bing.com).

Climate Change Assessment

At Point Lay, mean annual air temperature at 2 m above ground level has increased significantly from below -12

°C to about -9 °C between 1980 and 2022 (Fig. 4). The average warming trend is found to be 0.098 K per decade. This substantial temperature increase implies a significant shift of the thermal state of the local permafrost. In particular in regions with high ground ice content, where changes in the thickness of active layers and subsidence may occur until a new equilibrium is reached, this state shift can induce thermokarst processes. Thermokarst triggered by these transient climatic conditions have been observed in several Arctic permafrost regions, including at very high latitudes.

Climate projections illustrate a compelling picture of the continuing strength of this warming trend in the region, which is expected to persist well beyond 2050. According to the climate projection presented, the mean annual air temperature is projected to increase to levels above -5°C by 2050. The warming trend of the ensemble mean is found to be 1.36 K per decade. The climate projection underscores the fact that within the next three decades we will approach temperature thresholds at Point Lay at which it will become increasingly difficult to implement measures to protect permafrost from further thawing.

While the data survey presented here does not claim to provide a full analysis of climate warming at Point Lay, it does indicate the likely trajectory of further permafrost degradation over the long term.

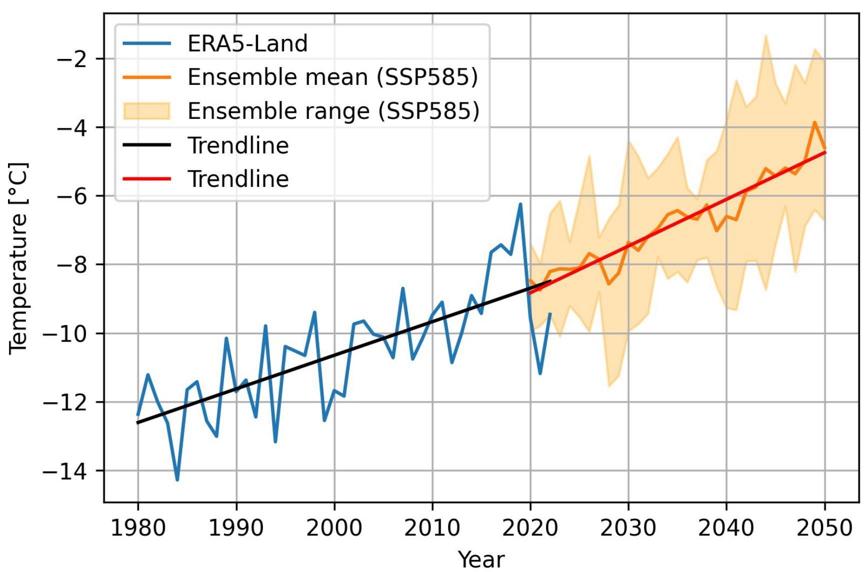

Figure 4: Evolution of the near surface air temperature at Point Lay. The historical data are based on the reanalysis product ERA5-Land. The future climate projections until 20250 are based on a small model ensemble consisting of MPI-ESM1-2-HR, HadGEM3-GC31-MM, GFDL-CM4, CNRM-CM6-1 based on the SSP585 scenario.

Conclusion

Point Lay is one of the Arctic settlements most affected by permafrost degradation, primarily due to its precarious location on the thaw-sensitive Yedoma deposits. The effects are clearly visible everywhere, as virtually the entire settlement area is facing ground subsidence. While it is evident that infrastructure aggravates thermokarst phenomena, we also observe thermokarst that extends well beyond the boundaries of the settlement. This phenomenon suggests pervasive destabilization, even in areas largely undisturbed by human influence.

This finding fits seamlessly into the prevailing trend of strong warming, which, while not necessarily leading to large-scale thawing of permafrost, undeniably triggers a pronounced change in the thermal state of permafrost and thus fosters vulnerability to thermokarst in sensitive locations.

In conclusion, the current thermal conditions still allow the implementation of technical measures for permafrost stabilization. However, it is important to emphasize that climate warming is proceeding inexorably and exacerbating the current challenges. Over time, we expect to see further shifts in the ground thermal regime, potentially leading to a more rapid expansion of thermokarst and potentially outpacing the effectiveness of technical stabilization methods in the coming decades.

In terms of community well-being, long-term mitigation strategies may ultimately prove to be a more reliable and sustainable investment than technical adaptation measures.