Permafrost Degradation

Summary

The continuous permafrost zone on the North Slope plays a large role in the landscape, affecting ground stability, hydrology, downslope movement of soil, habitat and human activities in the region. Observed increases in permafrost temperatures and increasing permafrost thaw have expanded thermokarst, increased erosion, and affected the flow of water above and below ground. Climate change and changing fire regimes may also affect rates of permafrost thaw. Thawing permafrost also releases methane and carbon dioxide causing positive feedbacks for climate change.

Permafrost degradation acts as a driver in resource extraction activities by decreasing ground stability, and increasing the potential hazards to building foundations, roads and airstrips from thaw subsidence and erosion. Changes in hydrology related to permafrost degradation may also affect water availability for resource extraction and energy development.

Overview

Permafrost is ground with temperatures less than $0^{o}C$ for at least two consecutive years (1). It is frozen ground ice that does not thaw in summer. Permafrost perches water near the surface, making soils wet and runoff fast. Most of the North Slope belongs to the continuous permafrost zone with a thickness greater than 200 m, and can reach maximum depths over 600 m in Prudhoe Bay (2). Overlying the permafrost is the active layer which freezes and thaws annually.

The Arctic coastal plain landscape is dominated by permafrost-related landforms including patterned ground, ice-wedge polygons, pingos, thaw lakes and beaded streams. The Beaufort coast soils are extremely ice-rich and are vulnerable to thaw. South of the North Slope warming temperatures influence the northward movement of the southern permafrost boundary.

In the marine environment subsea permafrost can be found in the continental shelf from the coast to water depths of about 100 m. The state of subsea permafrost is affected by water temperatures and sediment salinity (3).

Figure 1. Eroding low-centered polygons in the North Slope. Photo: Ronald Daanen.

Permafrost formation

Permafrost formation is mostly climate-driven. Permafrost forms when summer warmth is not sufficient to thaw the ground that freezes in winter. As layers of vegetation or peat form over the permafrost it can insulate the ground from thaw. This subsequently reduces the active layer depth. Ice wedges are the most common form of ice that occur as a result of rapid cooling during winter that causes the formation of thermal contraction cracks. These cracks can then get filled by water and undergo repeated cracking, filling, and freezing to form large ice wedges. Pingos, buried ice and tabular massive ice bodies are other forms of large ground ice masses. Polygonal features observed on the North Slope form as a result of boundaries between ice wedges.

Permafrost thaw

The upper permafrost in the Arctic coastal plain has a total content of over 70% ice by volume (2). Thermokarst, which is ground subsidence due to thaw of permafrost, and thawing permafrost is a threat to much of this region. Thawing permafrost is influenced by many factors. Snow and water accumulation in polygon troughs may speed up thaw while vegetation growth may reduce thermokarst or lead to recovery of ice wedges (6,8). Soil moisture, substrate and heat transfer modes also can affect rates of thermokarst.

As permafrost thaws it can affect the stability of the ground and result in the release of previously stored carbon. Thawing permafrost results in the formation of thermokarst lakes which in turn influences the hydrology of the North Slope causing landscape-wide changes.

Trends

Permafrost temperatures on the North Slope have shown trends of increasing temperatures over the last decade. The magnitude of warming on the North Slope ranges from 2-3°C (4) since the 1980's. Active layer thickness has increased in some sites and decreased in some sites on the North Slope (7), but has been more variable by site and year.

Risk of subsidence due to permafrost thaw is likely to increase from 2010 to 2050 for large parts of the study area, and particularly in Northwest Alaska (5). Within Prudhoe Bay thermokarst formation has been expanding across the landscape resulting in more small ponds and active lake erosion (6).

Uncertainties

Projected changes in permafrost do not directly correspond with changes in air temperatures. Uncertainties in human-caused changes to vegetation, variation in ground ice content, snow cover, vegetation, soil properties and ecosystem characteristics can affect rates of permafrost degradation. We also do not know the ground ice content in many areas which is important because it controls the amount of potential subsidence in an area.

Fires: Most fires in the North Slope result from lighting strikes and could increase permafrost thaw. Climate change and increasing human activities could influence future fire regimes (e.g. through changes in vegetation), but changes in fire regime and its effect on permafrost is difficult to predict.

Technology improvements: Even in areas identified as high risk for permafrost thaw and subsidence it is difficult to predict the timing and magnitude of thaw that could affect the integrity of structures in the region. New technology may help to decrease the potential negative effects of permafrost thaw, but the long-term success of such applications are not well known.

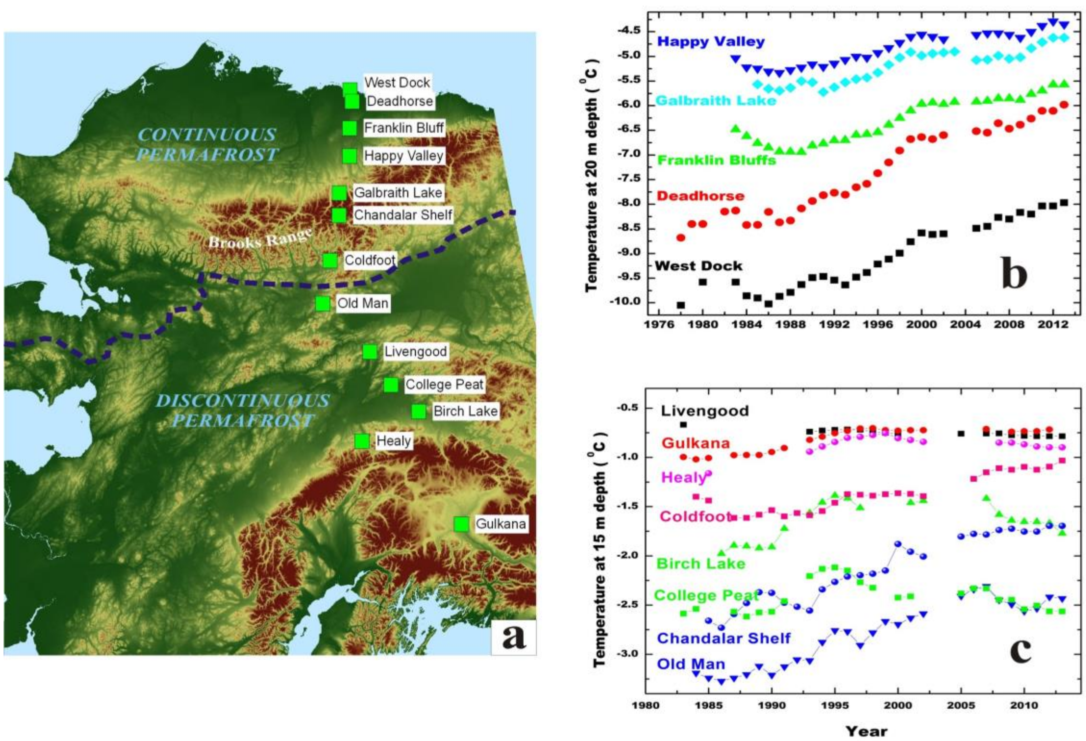

Figure 2. Map of continuous and discontinuous permafrost in Alaska (a) with permafrost temperature measurements at 20 m (b), and 15 m (c). Source: Romanovsky et al. 2013 (4)

Driver interactions

Resource development

Projected changes in temperature and permafrost thaw lead to increasing erosion, ground subsidence and changing hydrology. Permafrost-associated erosion threatens buildings, roads, airstrips and other infrastructure. Support pilings may need to be deeper to allow for less stable warming permafrost. Alternatively, structures such as those used in the Trans Alaska Pipeline System could be installed to remove heat and reduce permafrost thaw. Delayed freezing of the active layer can reduce the duration of permitted tundra travel. Frost heaves and differential thaw settlement can damage roads and pipelines. Although not specifically related to warming, large, moving lobes of frozen debris can cause potentially hazardous road conditions that may also damage structures. The relationship between permafrost, thermokarst and hydrology also has the potential to impact activities that require a reliable source of water for extraction and use in ice-road construction but the impacts on water access are not well known.

Other driver interactions

Indigenous communities are threatened by permafrost-thaw and erosion that affects the stability of homes, critical infrastructure and culturally important sites. However, to date the human-caused surface disturbance on permafrost has been greater than climate-driven permafrost thaw. Permafrost thaw can also affect drainage and water flow, soil erosion, slumps, siltation of streams and lakes, soil moisture and nutrient supplies. These in turn may change vegetation, and subsequently affects the habitat and food sources for many species of fish, birds and mammals. Gases such as methane and carbon dioxide are released by thawing permafrost (both terrestrial and subsea), potentially increasing the feedback of warming effects from climate change. Climate change may also affect the duration and severity of wildfires that subsequently impacts permafrost thaw rates.

Monitoring efforts

Permafrost monitoring on the North Slope includes a network of sites that measure aspects of permafrost change (e.g. borehole temperatures, active layer depths) run by the USGS, the University of Alaska Fairbanks Permafrost Laboratory and partnerships with the Circumpolar Active Layer Monitoring (CALM) Network. Increasingly, remote sensing techniques are being utilized (e.g. SAR, LandSAT) to monitor permafrost degradation and large-scale changes in the landscape.

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