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Achieving the NOAA Arctic Action Plan: The Missing Permafrost Element

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1. Overview

Permafrost is ground at or below freezing for at least two consecutive years. It occupies about one quarter of the land in the northern hemisphere and 80% of the land in Alaska (see Figure 1a). Permafrost temperature and active layer thickness (ALT) are the two essential climate variables to monitor the status of permafrost (Brown *et al.*, 2008). ALT is the maximum annual depth of thaw and permafrost temperature is the temperature of the permanently frozen soil below the active layer. Observations indicate near surface permafrost has already begun to degrade (Figure 1b). The results of regional modeling of permafrost temperatures in Alaska in high spatial resolution during the 21st century indicate vast permafrost degradation throughout the whole State of Alaska (Jafarov *et al.*, 2012). Observed and projected permafrost degradation imply significant impacts on infrastructure and ecosystems (Oberman, 2008; Callaghan *et al.*, 2011; Schaefer *et al.*, 2014).

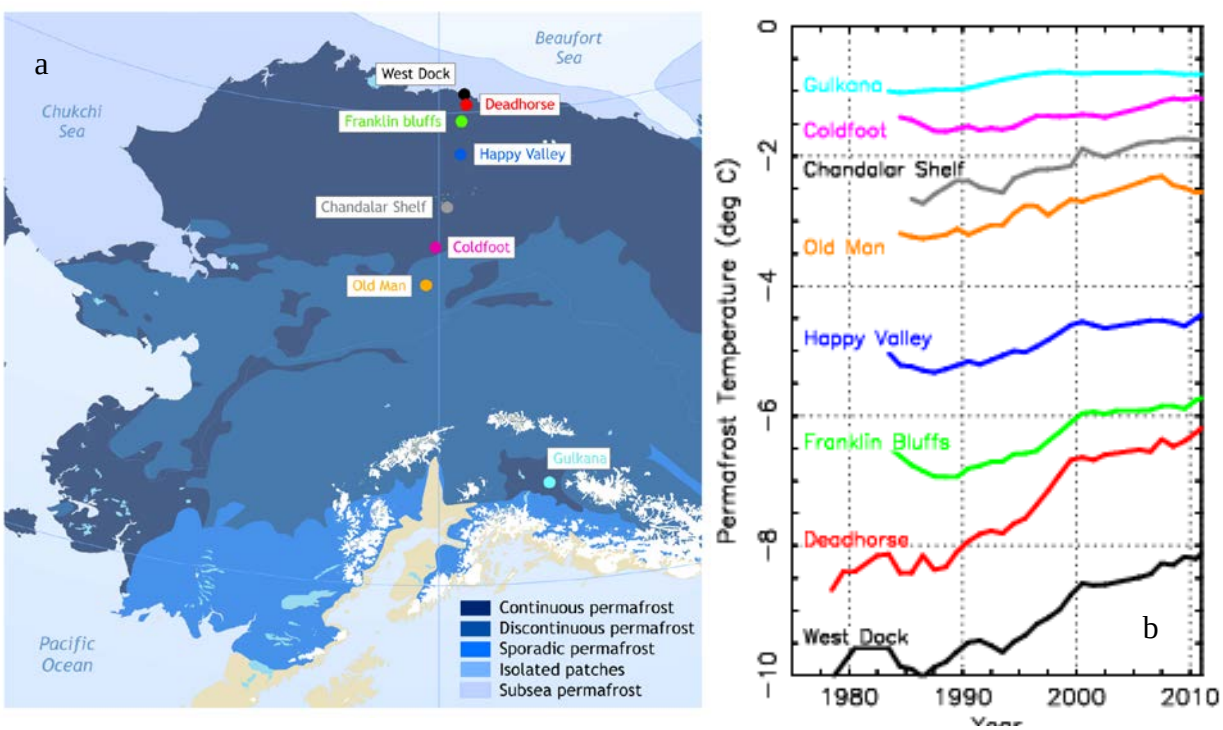

Fig. 1 Time series of annual permafrost temperatures at 20m depth (b) measured from north to south across Alaska (a). Source: http://www.arctic.noaa.gov/report11/permafrost.html

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Among the important Arctic resources threatened by thawing permafrost are vast reserves of oil and gas (O&G) and the associated exploration, production, and transportation infrastructure (Larsen, *et al.*, 2008; Callaghan *et al.*, 2011). The Interagency Working Group on Coordination of Domestic Energy Development and Permitting in Alaska (Clement, *et al.*, 2013) noted that the shorter frozen season for permafrost "presents challenges for land-based development" and details the large number of stakeholders affected by thawing permafrost in Alaska. It calls on the federal government to "strengthen the capacity of science programs to provide focused, ecosystem-based information needed by decision-makers for wise stewardship and development of natural resources."

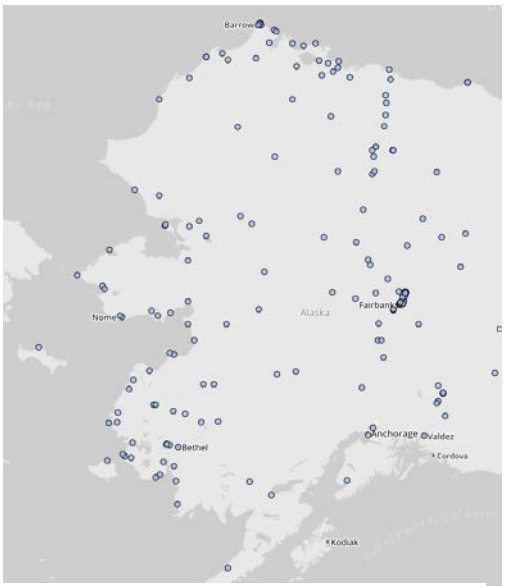

Fig. 2 Locations of existing ground temperature measurements in Alaska.

As NOAA works to implement its 2014 Arctic Action Plan (NOAA, 2014) in response to such critical challenges, services related to permafrost change represent a missing piece of the climate service suite. Although the AAP refers to threats posed to Arctic communities and economies from thawing permafrost and identifies permafrost thawing as evidence of widespread and dramatic change, it fails to propose specific actions to address this challenge while acknowledging the need for additional research and integrated management of resources in general. However, it does list as one of NOAA's six Arctic goals: Strengthen foundational science to understand and detect Arctic climate and ecosystem changes (NOAA, 2014, p. 10*ff.*).

2. Recommendations towards permafrost forecasts

To address this missing element in the AAP, we recommend NOAA link existing seasonal forecasts of temperature and precipitation (Yuan, *et al.*, 2011) with an existing high-resolution model of the thermal state of permafrost (Jafarov *et al.*, 2012) to provide near-term (one year ahead) forecasts of permafrost active layer thickness (ALT). To validate ALT we suggest using current ground temperature measurements available throughout Alaska (Figure 2) in combination with ALT measurement from Circumpolar Active Layer Monitoring Network (CALM) available mainly at the North Slope of Alaska. Given the significant observed and projected damages to O&G and transportation infrastructure, local communities, ecosystems, and the large costs associated with such damage (Callaghan, *et al.*, 2011; Larsen, *et al.*, 2008) we recommend that NOAA integrate existing scientific resources such as the National Climate Predictions and Projections Platform (Rood, 2011) to provide information through research activities and services that will contribute to efforts to reduce permafrost-related loss and damage. This recommendation also addresses a previously identified need within the U.S. National Security Community (Jonassen and Alcorn, 2012).

Fig. 3 Thermosiphons protect the trans-Alaska pipeline from permafrost damage. Source: http://www.eoearth.org/article/Permafrost

We distinguish this permafrost <u>forecast</u> service from the available <u>projections</u> of permafrost change (MacCracken, 2001). In particular, the permafrost forecast would be an official NOAA statement[1] of the expected thermal state of

[1] Official operational climate forecasts are specified, defined, and identified in National Weather Service Instruction 10-1001, "Operations and Services, Climate Services, NWSPD 10-10, Climate Outlooks" (October 31, 2011), at http://www.nws.noaa.gov/ directives/sym/pd01010001curr.pdf.

permafrost ALT in Alaska over the coming year on a seasonal basis. It would draw upon seasonal climate forecasts with demonstrated skill (Livezey and Timofeyeva, 2008) for up to a one-year lead. Existing projections are conditional statements of what might happen if certain conditions (particularly greenhouse gas concentration pathways) are realized over long times (decades) in the future (*e.g.* Duchesne, *et al.*, 2008).

A forecast ALT service requires: (1) long-term climate outlooks, (2) detailed understanding of local spatial controls upon soil thermal state such as vegetation and snow cover, soil texture, and ground exposure, (3) high-resolution vertical measurements of the thermal state and characteristics of soils, (4) a permafrost model, (5) integration of climate outlooks and permafrost model, (6) definition of the prognostic permafrost output, and (7) demonstration of forecast skill through pilot studies. Items #2 and #3 are rarely available in Alaska due to the high cost of collecting data and maintaining the relevant databases (Longley, *et al.*, 2001). Thus, pilot efforts at permafrost forecasts should focus on specific sites and infrastructure where the cost of the effort can be justified by the potential returns in avoided loss and damage. O&G production and associated pipelines represents an ideal intersection of commercial and public interests and scientific capabilities for pilot studies. An existing Memorandum of Understanding with three petroleum companies that operate in US Arctic waters (Shell, Conoco-Phillips, and Statoil) provides an example of existing mutually beneficial cooperation (NOAA 2014, p.21).

Examples of the utility of such forecasts begin with the O&G industry where we recommend the first pilot studies would occur. In this case, damage to pipelines is a regular occurrence during normal seasonal variations in ALT and significant engineering effort is required to maintain pipelines and associated infrastructure (Figure 3). Over half of the Trans-Alaska Pipeline System is elevated on vertical support members based on design standards from the period 1950-1970, one of the coldest periods on record (US Arctic Research Commission, 2003). We suggest that, by using ALT forecasts that have demonstrated skill, engineers could identify some months in advance where ALT changes are likely to damage infrastructure. They could focus resources and pre-position equipment so that they could more rapidly respond to pipeline damage and oil spills that might result. If successful, this effort can reduce costs of monitoring and repair as well as ecosystem damage and loss of resources.

3. Future works

Potential applications of ALT forecasts extend beyond the O&G industry. For example, the Inuit Circumpolar Council highlights permafrost degradation as a critical economic issue linked to air transportation, building foundations, and contaminated drinking water (Cochran, 2008). Warming of frozen ground (without thawing) reduces its bearing capacity so that footings and support piles may be destabilized (Williams and Wallace, 1995). Thawing permafrost could add $6 billion in costs for Alaska's public infrastructure, especially transportation infrastructure (Larsen, *et al.*, 2008). NOAA has the opportunity to provide an important new service by offering forecasts of permafrost ALT for Alaska.

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