Estimates of Soil Taxonomic Change Due to Near-Surface Permafrost Loss in Alaska

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Background and Objective:

Rapid environmental change in Alaska is projected to significantly decrease near-surface permafrost distribution across the state in the next century (Pastick et al., 2015, Pastick et al., 2017). Gelisols (permafrost-affected soils) are currently widely distributed across Alaska, covering an estimated 7.34 x 10^5 km^2 or approximately 43% of the land area (Soil Survey Staff, 2018). Under current rules for soil taxonomy (Soil Survey Staff, 2014), Gelisols must have permafrost within 1m or (if materials indicating cryoturbation or ice segregation - *gelic materials* - are present) 2m of the soil surface. Therefore, near-surface permafrost change has the potential to have a large impact on Gelisol distribution. The three Gelisol suborders (Turbels, Histels, and Orthels) are not equally distributed across the state (***Figure 1***) and differ in their susceptibility to taxonomic change due to near-surface permafrost changes. The objective of this work was to provide an estimate of potential changes in Gelisol distribution due to near surface permafrost change under the A1B emissions scenario.

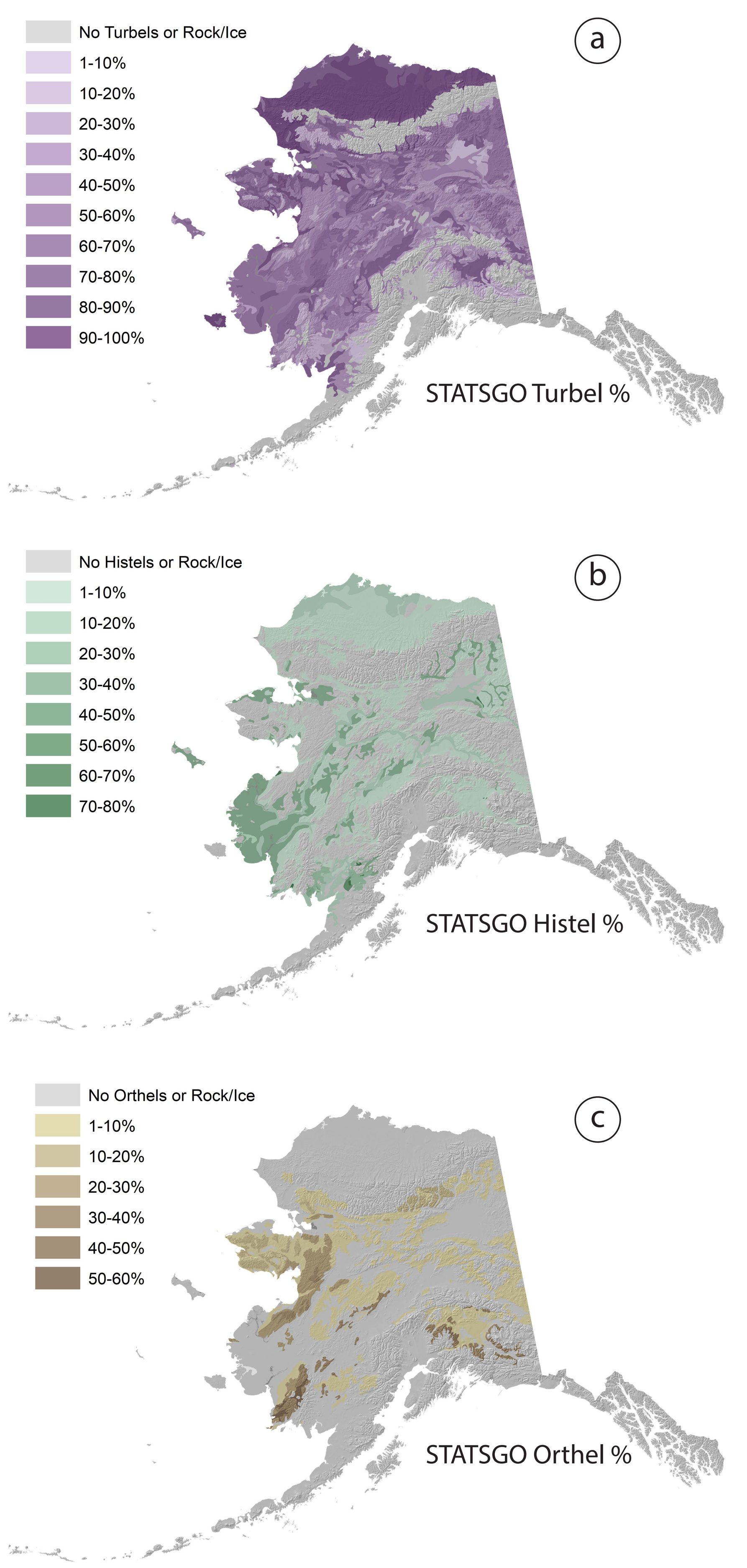
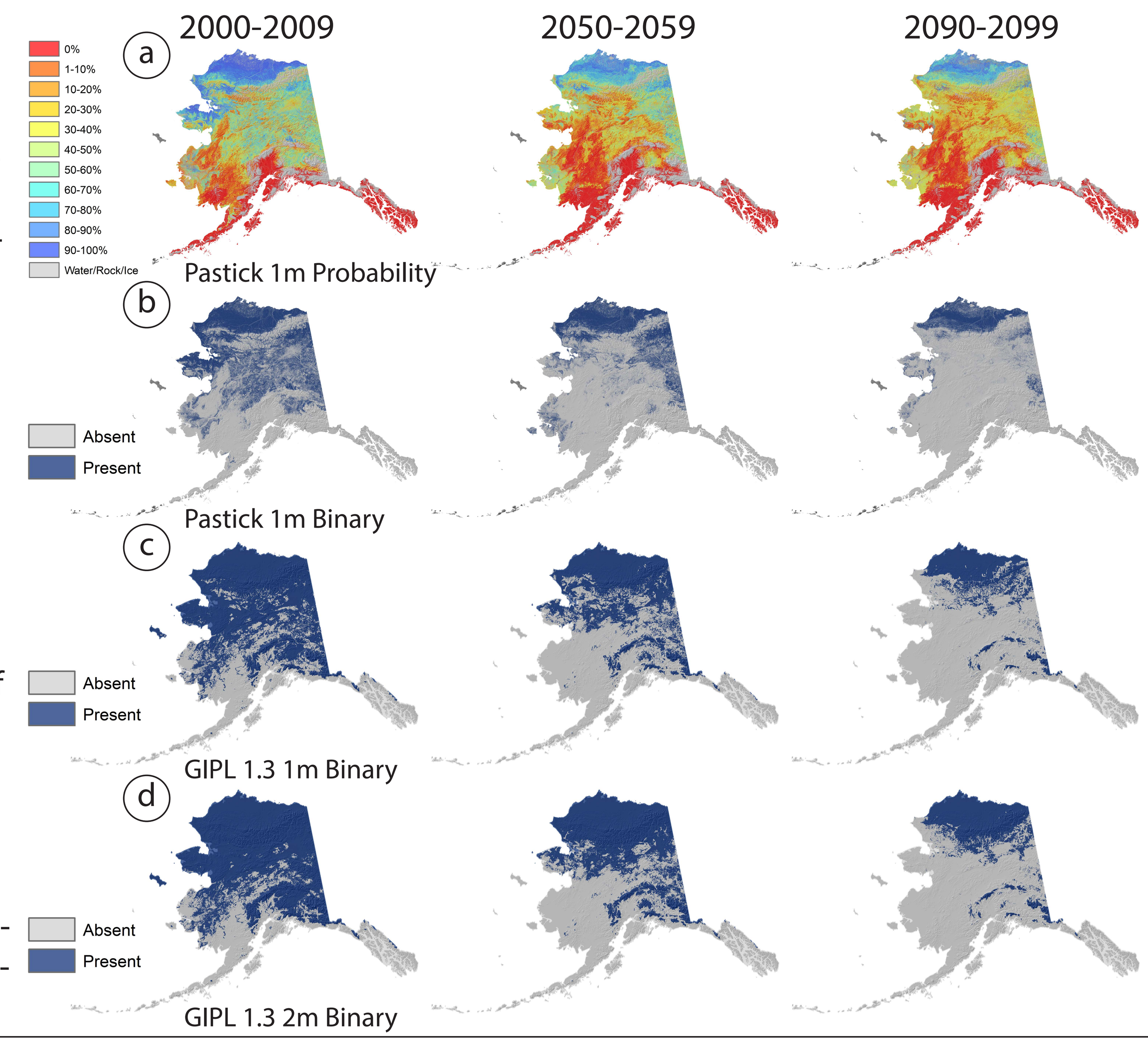


Figure 1. STATSGO2 (Soil Survey Staff, 2018) distribution of the three Gelisol suborders in Alaska. **(a)** Turbels - Gelisols with morphology characteristic of cryoturbation, **(b)** Histels - Gelisols dominated by organic soil materials, **(c)** Orthels - other Gelisols. The percentages represented in each STATSGO mapping unit are the summed component percentages for each suborder.

Methodology:

We utilized the STATSGO dataset (Soil Survey Staff, 2018 - ***Figure 1***) and two near-surface permafrost distribution datasets (Marchenko et al., 2008 - GIPL 1.3; Pastick et al., 2015) estimating the presence or absence of permafrost at 1m (Pastick et al., 2015, Marchenko et al., 2008) and 2m (Marchenko et al., 2008) depths at three different timepoints (2000-2009; 2050-2059; 2090-2099) (***Figure 2***) to estimate the potential for soil taxonomic change under the A1B emissions scenario. We assumed that the STATSGO dataset represented the current distribution of Gelisols across the state and that loss of permafrost within 2m of the soil surface would result in taxonomic change for all Gelisols, while loss of permafrost within 1m of the soil surface but retention at 2m would result in loss of Histels and Orthels (but not Turbels). Under these rules, we determined normalized changes in Gelisol distribution for each STATSGO mapping unit utilizing the three input distribution datasets and the component percentages for individual Gelisol suborders in STATSGO (Equations 1 and 2).



Changes to the future proportion of Gelisols in each STATSGO soil mapping unit due to near-surface permafrost change were estimated using the following algorithms. For the proportion of each STATSGO mapping unit classified as Gelisols in a future time period (i.e. 2050-2059):

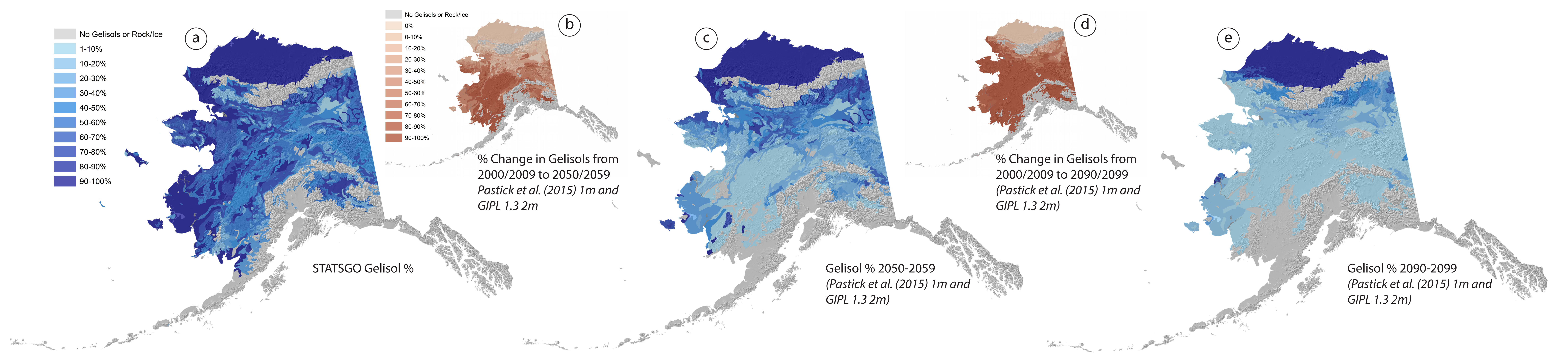
$$(1)\quad P_{Gel,50-59,i} = \frac{\left[1+\left(\frac{A_{GIPL,00-09,2m,i}-A_{GIPL,50-59,2m,i}}{A_{GIPL,00-09,2m,i}}\right)A_{STATSGO,Turbels}\right]+\left[1+\left(\frac{A_{Past,00-09,1m,i}-A_{Past,50-59,1m,i}}{A_{Past,00-09,1m,i}}\right)A_{STATSGO,Histels}\right]+\left[1+\left(\frac{A_{Past,00-09,1m,i}-A_{Past,50-59,1m,i}}{A_{Past,00-09,1m,i}}\right)A_{STATSGO,Orthels}\right]}{A_{T,i}}$$

where $P_{Gel,\ 50\text{-}59,i}$ is the proportion (*P*) of Gelisols in STATSGO mapping unit *i* in 2050-2059; $A_{GIPL,50\text{-}59,2m,i}$ is the area of near-surface permafrost within 2m of the soil surface in STATSGO mapping unit *i* in 2050-2059 from the GIPL 1.3 dataset; $A_{GIPL,00\text{-}09,2m,i}$ is the area of near-surface permafrost within 2m of the soil surface in STATSGO mapping unit *i* in 2000-2009 from the GIPL 1.3 dataset; $A_{Pastick,50\text{-}59,1m,i}$ is the area (km^2) of near-surface permafrost within 1m of the soil surface in STATSGO mapping unit *i* in 2050-2059 from the Pastick et al. (2015) dataset; $A_{Pastick,00\text{-}09,1m,i}$ is the area (km^2) of near-surface permafrost within 1m of the soil surface in STATSGO mapping unit *i* in 2000-2009 from the Pastick et al. (2015) dataset; $A_{STATSGO,Turbels}$ is the area (km^2) of Turbels in STATSGO mapping unit *i*; $A_{STATSGO,Histels}$ is the area (km^2) of Histels in STATSGO mapping unit *i*; $A_{STATSGO,Orthels}$ is the area (km^2) of Orthels in STATSGO mapping unit *i*; and $A_{T,i}$ is the total area of STATSGO mapping unit *i*. Then, for the percentage change in Gelisols by STATSGO mapping unit from present:

$$(2)\quad \Delta P_{Gel,50-59,i} = 1 - \frac{[P_{Gel,50-59,i}A_{T,i}]}{A_{STATSGO,Gel,i}}$$

where $\Delta P_{Gel,\ 50\text{-}59,i}$ is the % change in Gelisol area in STATSGO mapping unit *i* from STATSGO to 2050-2059; and $A_{STATSGO,Gel,i}$ is the total Gelisol area from STATSGO in mapping unit *i*. All other variables are as in Equation 1.

Figure 2 (left). Input data utilized to estimate the spatial extent of near-surface permafrost-change in Alaska. **(a)** Near-surface (1m) permafrost probability maps for the A1B emissions scenario derived from modern permafrost presence/absence observations (Pastick et al., 2015) were converted to **(b)** binary 1m presence/absence maps using a probability threshold of 0.5. GIPL 1.3 Permafrost Dynamics Model (Marchenko et al., 2008) active layer thickness was used to generate a binary presence/absence dataset of near-surface permafrost at **(c)** 1m and **(d)** 2m under the A1B emissions scenario for modern, mid- and late-century timepoints.



Results:

Our results indicate the potential for dramatic changes in Gelisol distribution due to near-surface permafrost loss by the end of this century under the A1B emissions scenario (***Figure 3***). These projections result in estimates of taxonomic change for 43-46% of currently mapped Gelisols by 2059 and 69-70% by 2099. The choice of differing combinations of dataset inputs and 1m or 2m near-surface permafrost requirements for Orthels and Histels had minimal impact on the final results (***Figure 4***). However, utilizing the Pastick et al. (2015) 1m dataset instead of the GIPL 1m dataset resulted in lower estimates of taxonomic change (1-3% statewide), largely because of increased retention of near-surface permafrost in the Histels of the Yukon-Kuskokwim Delta (***Figure 3***). Taxonomic change from Gelisols to other soil orders (Histosols, Inceptisols, Mollisols and Entisols) in the western Interior and the southern Seward peninsula is projected to be extensive by mid-century, while taxonomic changes by the end of the century may be widespread across the Interior but minimal north of the Brooks Range.

Implications:

Widespread taxonomic change in Alaskan Gelisols has important implications for soil mapping and classification. When mapping in areas that are projected to undergo significant taxonomic change, soil survey leaders should consider adding non-permafrost classifications, properties, and interpretations as phases in the database to every Gelisol component to extend the lifetime and usefulness of the mapping product.

References: Marchenko et al. 2008. Proceedings of 9th Int. Conf. on Permafrost pp. 1125-1130. Soil Survey Staff. 2018. U.S. General Soil Map (STATSGO2). Pastick et al. 2015. Rem. Sens. Env. 168: 301-315. Pastick et al. 2017. Ecol. App. 27(5): 1383-1402. Soil Survey Staff. 2014. Keys to Soil Taxonomy, 12th Ed.
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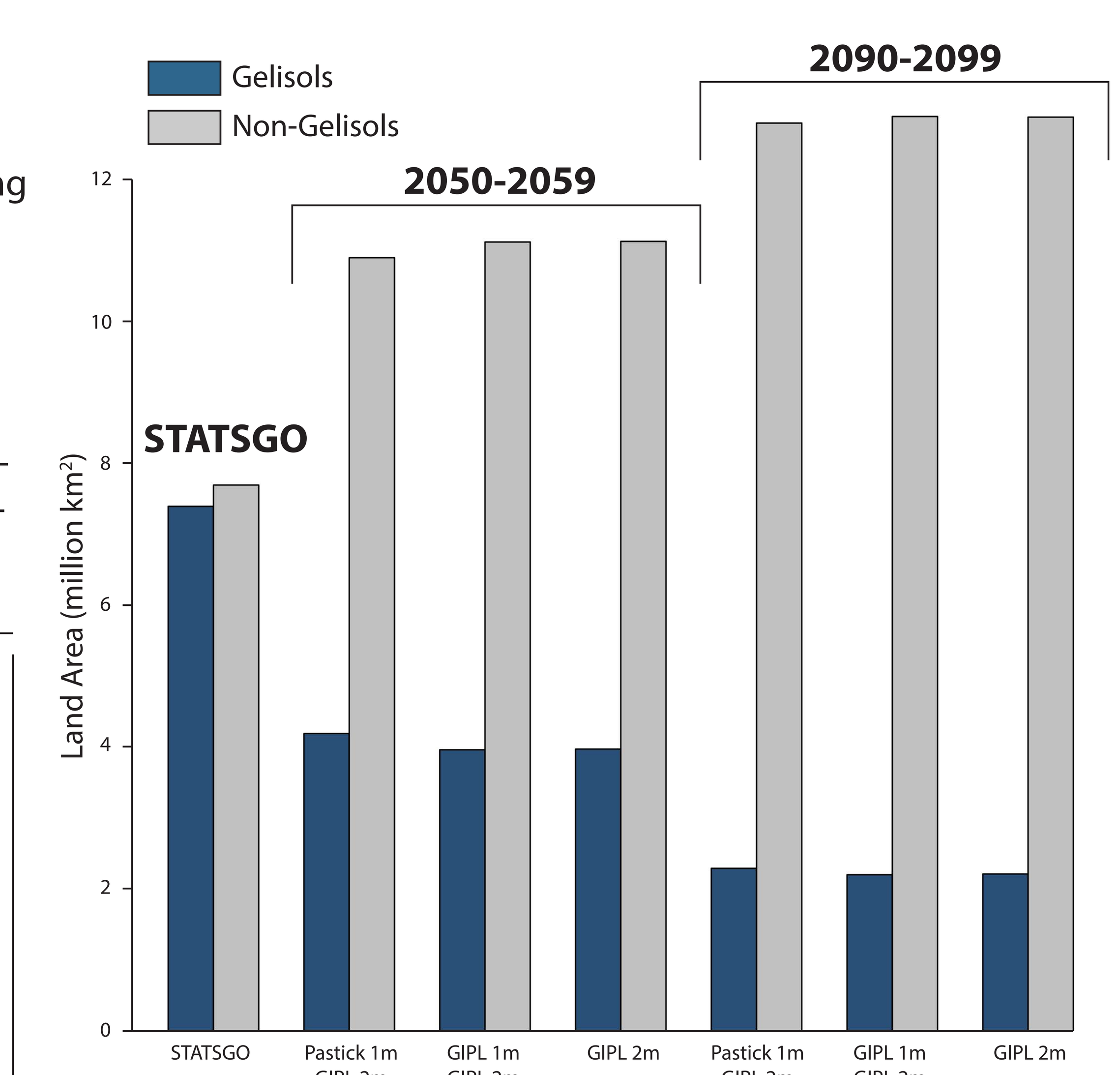

Figure 3 (above). Results of projected distribution of Gelisols in Alaska throughout this century due to near-surface permafrost change under the A1B emissions scenario using a combination of the Pastick et al. (2015) 1m binary near-surface permafrost dataset and the GIPL 1.3 (Marchenko et al., 2008) 2m binary near-surface permafrost dataset per Equations 1 and 2. **(a)** Current Gelisol distribution (displayed as proportion of each STATSGO mapping unit classified as Gelisols using component proportions in the STATSGO database). **(b)** Projected % change in Gelisol distribution (i.e. 100% change means a loss of all Gelisols in the mapping unit and 0% change means retention of all Gelisols in the mapping unit) by STATSGO mapping unit between 2000-2009 and 2050-2059. **(c)** Projected Gelisol distribution displayed as proportion of each STATSGO soil mapping unit in 2050-2059. **(d)** Projected % change in Gelisol distribution by STATSGO mapping unit between 2000-2009 and 2090-2099. **(e)** Projected Gelisol distribution displayed as proportion of each STATSGO soil mapping unit in 2090-2099. *Note: Figure 3a, 3c, and 3e share the same legend, and Figures 3b and 3d share the same legend.*

Figure 4 (left). Bar chart of projected land area (km^2) of Gelisols and non-Gelisols in Alaska under differing combinations of dataaset input and near-surface permafrost requirements. Categories on the x-axis refer to the dataset inputs used to derive estimates of Gelisol land areas. The STATSGO category is the current estimate of Gelisol and Non-Gelisol land area (excluding rock, ice and glaciers) for the state of Alaska determined by component percentages of soil mapping units from the STATSGO dataset. The Pastick 1m, GIPL 2m category utilizes the Pastick et al., 2015 1m permafrost estimates and GIPL 1.3 2m estimates as described in Equations 1 and 2. The GIPL 1m, GIPL 2m category utilizes the GIPL 1.3 1m and 2m estimates, while the GIPL 2m category uses only the GIPL 1.3 2m estimates.