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A probabilistic analysis of permafrost temperature trends with ensemble modeling of heat transfer

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Over the past few decades, polar research teams around the world have deployed long-term measurement sites to monitor changes in permafrost environments. Many of these sites include borehole sensor arrays which provide measurements of ground temperature as deep as 50 meters or more below the surface. Recent studies have attempted to leverage these borehole data from the Global Terrestrial Network of Permafrost to quantify changes in permafrost temperatures at a global scale. However, temperature measurements provide an incomplete picture of the Earth's subsurface thermal regime. It is well known that regions with warmer permafrost, i.e. where mean annual ground temperatures are close to zero, often show little to no long-term change in ground temperature due to the latent heat effect. Thus, regions where the least warming is observed may also be the most vulnerable to rapid permafrost thaw. Since direct measurements of soil moisture in the permafrost layer are not widely available, thermal modeling of the subsurface plays a crucial role in understanding how permafrost responds to changes in the local energy balance. In this work, we explore a new probabilistic method to link observed annual temperatures in boreholes to permafrost thaw via Bayesian parameter estimation and Monte Carlo simulation with a transient heat model. We apply our approach to several sites across the Arctic and demonstrate the impact of local landscape variability on the relationship between long term changes in temperature and latent heat.