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Equilibrium Spin-up of Cold and Warm Permafrost Models

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Initialization (spin-up) of a numerical ground temperature model is a critical but often neglected step for solving heat transfer problems in permafrost. Improper initialization can lead to significant underlying model drift in subsequent transient simulations, distorting the effects on ground temperature from future climate change or applied infrastructure. In a typical spin-up simulation, a year or more of climate data are applied at the surface and cycled repeatedly until ground temperatures are declared to be at equilibrium with the imposed boundary conditions, and independent of the starting conditions.

Spin-up equilibrium is often simply declared after a specified number of spin-up cycles. In few studies, equilibrium is visually confirmed by plotting ground temperatures vs spin-up cycles until temperatures stabilize; or is declared when a certain inter-cycle-temperature-change threshold is met simultaneously at all depths, such as $\Delta T \leq 0.01^{o}$C per cycle. In this study, we investigate the effectiveness of these methods for determining an equilibrium state in a variety of permafrost models, including shallow and deep (10 – 200 m), high and low saturation soils (S = 100 and S = 20), and cold and warm permafrost (MAGT = ~-10 ^{o}C and >-1 ^{o}C). The efficacy of equilibrium criteria 0.01^{o}C/cycle and 0.0001^{o}C/cycle are compared. Both methods are shown to prematurely indicate equilibrium in multiple model scenarios. Results show that no single criterion can programmatically detect equilibrium in all tested models, and in some scenarios can result in up to 10^{o}C temperature error or 80% less permafrost than at true equilibrium. A combination of equilibrium criteria and visual confirmation plots is recommended for evaluating and declaring equilibrium in a spin-up simulation.

Long-duration spin-up is particularly important for deep (10+ m) ground models where thermal inertia of underlying permafrost slows the ground temperature response to surface forcing, often requiring hundreds or even thousands of spin-up cycles to establish equilibrium. Subsequent transient analyses also show that use of a properly initialized 100 m permafrost model can reduce the effect of climate change on mean annual ground temperature of cold permafrost by more than 1 ^{o}C and 3 ^{o}C under RCP2.6 and RCP8.5 climate projections, respectively, when compared to an identical 25 m model. These results have important implications for scientists, engineers and policy makers that rely on model projections of long-term permafrost conditions.