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Can satellite soil moisture retrievals improve permafrost monitoring?

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In permafrost regions, there is a strong coupling between a soil's moisture content and its thermal dynamics. However, dynamic changes in soil moisture have not been given much attention in permafrost monitoring, partially due to a previous shortage of observations. The questions hence arises: can novel remotely-sensed soil moisture estimates improve permafrost monitoring? Data assimilation seems a promising avenue, as it can improve the predicted temperatures and soil moisture by exploiting their complex, model-predicted coupling while accounting for uncertainties in both modelled and observed soil moisture. To explore its potential benefit, we conduct synthetic and real-world (Radarsat-2 soil moisture estimates over the Mackenzie River Delta Uplands, Canada) data assimilation experiments. We use an Ensemble Kalman Filter to ingest surface soil moisture into the state-of-the art CryoGrid-3 permafrost model, which has a flexible two-layer hydrology scheme. We address two questions.

1) Where can surface soil moisture information improve modelled temperatures? We find that it mainly does so for porous, organic soils, but not for mineral soils. As organic soils dry, the cooling effect by the insulating soil wins out over the competing warming effect induced by decreasing evaporation. Surface soil moisture observations thus provide valuable information on deeper soil temperatures, a finding that is largely consistent with field observations. In mineral soils, by contrast, the thermal conductivity decreases much less upon drying, and surface soil moisture provides little information on deeper soil temperatures.

2) How big are the improvements in organic soils? In our synthetic experiments, we find that estimates of the active layer thickness improve by up to a factor of two (down to 10 cm) upon assimilation, even when soil moisture observations are of limited precision. The modelled soil temperatures improve throughout the entire profile, with the largest improvements below 10 cm. We will compare those synthetic results with the Radarsat-2 observations.

We conclude that satellite soil moisture information can help to reduce one major uncertainty in permafrost monitoring. We predict that advances in remote sensing and models will improve our knowledge of active layer and permafrost dynamics, not just of the water and energy balance, but also of ecological and biogeochemical processes.