Hyper-resolution land surface modeling enables 30-m SMAP-based soil moisture at continental scales

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Accurate and detailed soil moisture information is essential for, among other things, irrigation, drought and flood prediction, water resources management, and field-scale (i.e., tens of m) decision making. Microwave-based satellite remote sensing offers unique opportunities for the large-scale monitoring of soil moisture at frequent temporal intervals. However, the utility of these satellite products is limited by the large footprint of the microwave sensors. Several downscaling techniques based on high-resolution remotely sensed data proxies have been proposed (1 km to 100 m). Although these techniques yield aesthetically pleasing maps, by neglecting how the water and energy fluxes physically interact with the landscape, these approaches often fail to provide soil moisture estimates that are hydrologically consistent.

This work introduces a state-of-the-art framework that combines a process-based hyper-resolution land surface model (LSM), a radiative transfer model (RTM), and a Bayesian scheme to merge and downscale coarse resolution brightness temperature to a 30-m spatial resolution. The framework is based on HydroBlocks, an LSM that solves the field-scale spatial heterogeneity of land surface processes through interacting hydrologic response units (HRUs). We demonstrate this framework by coupling HydroBlocks with the Tau-Omega RTM used in the Soil Moisture Active Passive (SMAP) mission and subsequently merging the HydroBlocks-RTM and the SMAP L3-enhanced brightness temperature at the HRU scale. This allows for hydrologically consistent SMAP-based soil moisture retrievals at an unprecedented 30-m spatial resolution over continental domains.

We applied this framework to obtain 30-m SMAP-based soil moisture retrievals over the contiguous United States (2015-2018). When evaluated against sparse and dense in-situ soil moisture networks, the 30-m soil moisture retrievals showed substantial improvements in performance at field and watershed scales, outperforming both the SMAP L3-enhanced and the SMAP L4 soil moisture products. This work leads the way towards hydrologically consistent field-scale soil moisture retrievals and highlights the value of hyper-resolution modeling to bridge the gap between coarse-scale satellite retrievals and field-scale hydrological applications.