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Unearthing controls on Critical Zone processes from big data in the Anthropocene

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From the top of the canopy to the bottom of circulating groundwater, there are myriad questions about factors controlling riverine and soil chemical signatures, where water and elemental fluxes are changing in the Anthropocene, and what regions of terrestrial ecosystems will exhibit high functional sensitivity to climate change. By leveraging machine learning, we address these questions by inferring patterns from data irregularly collected in space and time. We explore five emerging findings using publicly-available datasets.

First, examining 1500 pedons across the United States revealed that macroporosity (conduits transporting ~70% of water flow) is controlled by clay and organic carbon. Second, soil moisture from ~1502 sensors across 18 ecoregions demonstrated that preferential flow – the rapid movement of water through specific pathways in the unsaturated zone – is a ubiquitous process. While preferential flow is often not included in hydrologic models, our analyses show that at some sites it can occur after 65% of all rainfall events and its occurrence is more likely with greater rainfall intensity, net primary productivity, and clay content. Third, data from 4155 pedons show that changes in vegetation can have rapid, meaningful impacts on soil and pore structure deep within B horizons, and that certain soil orders are more resilient in reclaiming historic soil structure with root reintroduction. Fourth, >31,000 solute measurements from 670 sites along 4 river basins in Texas reveal signals of land cover and land use in riverine chemical fingerprints, but the presence of geologic features arise in these signatures. Finally, data from >200 rivers in the Northern Hemisphere (5-56 years of data) show changes in [Si] and yields over time, particularly at high altitudes and latitudes. Such changes in river Si appear driven by biogeochemical processes, rather than shifting streamflow regimes.

These large-scale datasets highlight patterns in soil structure, water transport, vegetation, and river chemistry that permit inferences about processes driving critical zone functioning. We offer a unique lens with which to view terrestrial responses to compounded pressures of the Anthropocene. Insights from analyzing these datasets also represent phenomenological benchmarks for evaluating process representations in Reactive Transport to Earth System Models.