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Quantifying continental-scale silicate weathering fluxes and coupled human-natural impacts using machine learning techniques

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Silicate weathering, a principal natural process that fixes atmospheric carbon dioxide, significantly influences landscape formation, soil development, and nutrient distribution within the global ecosystem. Despite ongoing progress in predicting the riverine fluxes of silicate weathering, conventional modeling methods struggle to accurately simulate real-world data, particularly in previously ungauged rivers. Some of these modeling efforts also have limited capability in distinguishing the impacts of human activities on the silicate weathering flux from natural processes. In our work, we utilize North America as a testbed to develop and apply a data-driven workflow, consisting of multiple machine learning techniques, to generate high-resolution, continental-scale predictions of silicate weathering. We gather and normalize data from gauge stations and integrate long-term environmental and geological information from the contiguous United States (CONUS) watersheds. Using a non-negative matrix factorization (NMF) machine learning model, we differentiate the river bicarbonate sources into those from silicate or carbonate weathering, thus estimating the silicate weathering flux for each watershed. These calculated silicate weathering fluxes and watershed characteristics are then used to train another machine learning model, which is subsequently applied to project the silicate weathering flux across North America. On a subset of data, we further apply machine learning models to quantitatively distinguish the impact of human activities from natural processes on the spatial distribution pattern of total riverine silicate flux under current and projected future climatic conditions.