Poster #21-16

A Radioisotope-Enabled Reactive Transport Model for Deep Vadose Zone Carbon

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BER Program: SBR
Project: University Award

In upland forested hillslopes, such as those observed across the East River watershed, roots extend well beneath the classically defined soil layer into partially weathered, unsaturated rock to access both water and nutrients. Yet current carbon cycle models rarely extend below shallow soils, and the contribution of this deeper subsurface nutrient cycling to carbon stocks and fluxes is virtually unknown. We are now directly constraining this previously disguised component of the carbon cycle through a novel Vadose zone Monitoring System (VMS) installed at the Eel River watershed in Northern California, which is similarly underlain by a shale lithology and hosts a mature forest ecosystem. The VMS consists of a pair of sub-horizontal bore holes instrumented with flexible plastic sleeves which allow both passive and active suction cup sampling of fluids draining through the partially saturated shale weathering profile, as well as gas sampling ports, moisture and temperature sensors. Our exploratory efforts are now constraining carbon stocks and fluxes as an analog to the hillslopes of the East River, providing new evidence that approximately 30% of net CO_2 flux from the terrestrial environment to the atmosphere is sourced many meters below the soil layer. We have shown that this CO_2, though produced well below what would classically be defined as soil, is radiocarbon modern. Thus, in total, this work indicates that modern carbon is being delivered rapidly to the deep subsurface, likely as a result of the rooting depth of mature trees, and this previously undocumented carbon cycle is a substantial component of the CO_2 generated in the terrestrial environment. To extend these results, we are now working with the LBNL SFA team to generate comparable datasets of CO_2 and O_2 gradients, complementary fluid phase DIC and DOC, and radiocarbon to constrain the contribution of deeply rooted vegetation to this subsurface carbon cycle. Modeling will be supported by the radioisotope-enabled version of CrunchTope, capable of simultaneous and explicit simulation of the three isotopes of carbon including both stable isotope fractionation and radioactive decay. Model development has been completed and aspects have been benchmarked against several other multi-component software platforms. Through this advanced modeling capability, the rates of carbon oxidation, contribution to weathering and thus the development of soils and sustainability of forest ecosystems will be embedded within an adaptive and predictive model framework.