ABSTRACT: A critical scientific question is what are the present day sources and sinks of carbon dioxide (CO₂) in the natural environment and how will these sinks evolve under rising CO₂ concentrations, expected climate change, ecosystem response, and land-use change. Globally, more carbon is stored in belowground as soil organic matter than in terrestrial vegetation and the atmosphere combined. This vast pool of carbon is derived primarily from decomposed plant and microbial cell material, and the fluxes that control the size of this pool are critical to the global carbon cycle. Carbon initially enters the belowground soil pools as plant detritus, roots and (root) exudates. Once in the soil, this organic matter serves as a carbon source for decomposer organisms including soil animals, bacteria, and fungi. Most of this carbon is consumed and respired as CO₂, but some is converted to microbial biomass and byproducts, which may leave the soil as dissolved organic carbon, be used as a substrate by other microbes, or be stabilized within the soil mineral matrix. Mechanisms that result in the stabilization of soils include: climate stabilization; intrinsic recalcitrance due to chemical structure; physical stabilization whereby organic molecules are in association with aggregates and mineral surfaces; and microbial metabolic activity and or protection of potential substrate due to physiochemical barriers. It is these processes that span time and spatial scales, which are poorly constrained in many dynamic land surface models.

We have deployed a suite of analytical tools that allow us to follow the movement of carbon at the cell to landscape scale. Experiments, field-based and in vivo, allow us to further the mechanistic understanding of the factors that control the fate, transport, and sequestration potential of, primarily, belowground carbon. Novel techniques include ChipSIP and STXM-SIMS. ChipSIP allows us, for example, to understand which microbial enzymes efficiently degrade cellulose - either for the production of biofuels, or to better elucidate enzymes and energy (carbon) transfer in wetlands and soils. To disentangle the complex interactions at soil-microbial-film-mineral interfaces with minimal disruption we utilize a combination of high-resolution spectroscopy (STXM-NEXAFS), electron microscopy, and nano-scale imaging mass spectrometry collectively known as STXM-SIMS. This approach allows us to measure the role of microorganisms in the formation of microaggregates and elucidate how organic matter source and environmental conditions influences the microaggregates. Isotopic characterization of CH₄, CO₂, and physical sources of carbon provides the mechanistic fingerprints of the biogeochemical pathways that cycle carbon through the landscape. Building on our expertise for "conventional" graphite-based AMS-¹⁴C analyses and our bio-expertise in tracer level pulse chase experiments we are developing methods for 'direct injection' of CO₂ for AMS-¹⁴C analyses. Our initial focus has been on a liquid-sample (HPLC) sample interface. The ability to handle liquid samples and continuous flows of liquid will enable more widespread and routine use of AMS in biological and environmental applications.