

2.3 Terrestrial Ecology Observing Systems (TEOS)

Our goal for the TEOS program was to develop a dense network of sensors that would allow us to track the spatial and temporal dynamics of ecosystem processes. Our overall hypothesis is that events, both spatially, such as animal disturbances or an individual tree mortality, and temporally, such as a monsoon, snowfall, or even hurricane, drive ecosystem processes far beyond the averaging or infrequent measurements that characterize ecosystem studies. Flux towers (such as the Ameriflux network) provide long-term, high temporal resolution of carbon and water fluxes, but cannot penetrate the within-footprint pipes and perturbations that drive dynamics. Soil cores can provide high spatial resolution of activity at a time, but turn a site into swiss cheese and cannot track dynamics through time. Other efforts to place sensors provide information at a point, but fail to describe the incredible spatial variation that simultaneously occurs temporally.

A second goal was to integrate the independent data provided by sensors (e.g., CO₂, temperature (T), soil moisture (θ)) with organisms that can only be determined by human observing systems, such as roots and, at very high resolution, individual fungal hyphae (Figure 1).

Roots have been measured either by infrequent cores (essential because the disturbances provide opportunities for invasive species), or by minirhizotron observations that scale to roots, but because of they must be hand-manipulated, are taken monthly to annually. In addition, in all current studies, dense temporal measurements in environmental conditions are taken above ground, but not in soils where the conditions regulating ecosystem processes (T, θ), are not taken within the footprint of the measurement or at the resolution of the process. In both cases, dynamics are missed, because perturbations are not sampled, or the sampling intensity is inadequate to capture production and mortality events. Even with high-resolution observations, roots have a large lag between changing environmental conditions and either production or mortality. Therefore, processes such as soil respiration rarely can be tightly fit with root dynamics.

Because fungal hyphae, as microorganisms (diameter 2-5 μ m), exist by growing from roots and pieces of organic matter and across soil pores or along soil particles, they are extremely sensitive to immediate changes in the soil environment. For this reason, we developed an in situ microscope that can be directed remotely, and frequently. Our automated minirhizotron (AMR) has the resolution to observe fine hyphae (2-5 μ m) such that we can visualize growth and death of these hyphal networks simultaneously with the dynamics roots and coarse soil organic particles. By running up to 4x daily, we can determine if, and when roots and hyphae respond to diel processes, or specific events.

At this stage, we have been running and testing the prototype unit. Among other important observations, we can watch hyphal growth, observe invertebrate (e.g., mite) grazing on hyphal networks, all in synchrony with measurements of T, θ , and soil CO₂ production. We have been able to observe seasonal changes through a cycle of a moist winter, under snow, to snow melt and increased soil moisture, to increasing soil temperatures and decreasing moisture. We have been able to identify morphotypes of EM fungi that we know, from nearby core samples and isotopic analyses, their ecological strategies for interacting with host plants. From the large number of windows, we can see the range of ecological strategies of symbiotic mycorrhizal fungi with a single host plant. Further, because we can take multiple observations daily, we are able to measure growth in response to changing soil temperature and

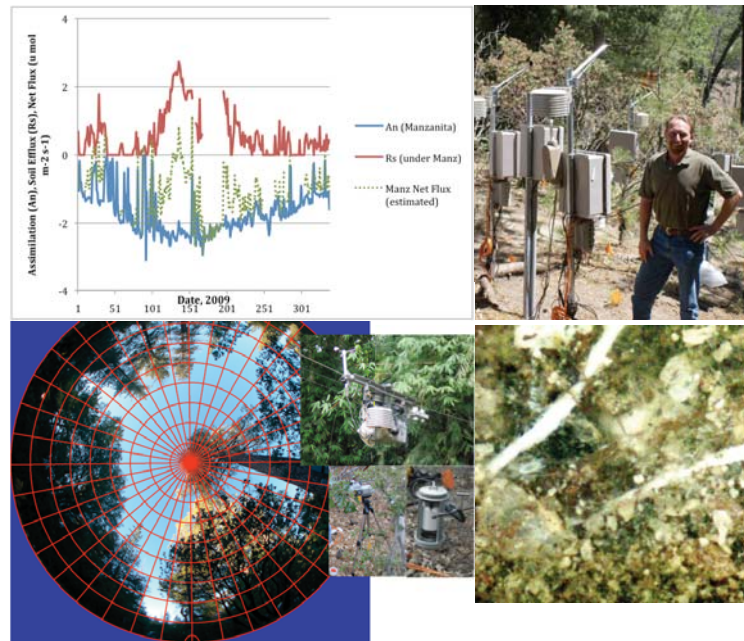


Figure 1. Clockwise from upper left. Carbon assimilation (An), soil respiration (Rs) and net flux of a Manzanita stand using the Williams et al. 1996 model for assimilation and our sensor-based soil respiration for 2009. Manzanita stand used for this study. AMR image with fine roots, rhizomorphs, fungal hyphae, and a mite grazing on the fungal hyphae. Hemispherical photograph of AMARSS transect point, and coupled measurements of PAR and atmospheric conditions, and chambers for ACI curves and calibrating soil respiration from our sensor network.

respiration. These technologies provide a window that heretofore has been limited to laboratory simulations with single, or a few combinations, but never the wide array of ecological strategies that we observed in a single small patch through time.

Through this testing, we have refined the software and hardware, to the point that we are completing 5 additional units for our field site to assess the range in dynamics at a single transect, as well as provide units for NEON and LTER testbeds. As an offshoot of this work, we filed a Disclosure and Record of Invention with UCR and initiated the formation of a new company (RhizoSystems, LLC) to undertake commercialization of the AMR technology

By linking the soils networks to aboveground plant communities, through a dense network of sensors, such as stemflow units and the NIMS mobile, we have been able to couple soil dynamics at diehl time scales. For example, plants fix CO₂ during the daylight and shut down at night, the rates of which can be measured and modeled by the stemflow sensors. We can see that signal in fungal growth patterns (using the AMR) and soil CO₂ production (using the CO₂, T and θ arrays) with the lag necessary for carbon to flow from leaves of open stomata, down the trunks, out roots, and into mycorrhizal fungal hyphae. We can visualize the extension of the growing season for the microbial components, likely due to the hydraulic redistribution, based on the sensor network, with a temporal resolution impossible with conventional instrumentation.

Finally, by using these site-based images, rich datasets, and subsequent modeling, we can take these intensive systems and, by understanding phenological relationships, can expand across the large array of camera systems placed along highways and in national parks. This approach should provide a powerful means of scaling ecological dynamics among scales of ecological systems.