## 2.3 Terrestrial Ecology Observing Systems (TEOS)

Our goals for the 2010–2011 TEOS activities were to expand our testbed network to extend and integrate our observing systems at the James Reserve, testing ecological theory, expand our network to additional testbeds with different environmental conditions, and to scale from the microscopic-level observations and measurements to continental-scale analysis of phenology which can be used in understanding dynamics of global change (Figure 2). These goals emphasize our focus on research and technology application, education, and outreach.

The first goal was to expand our testbed. The sensors have been widely accepted and used. However, coupling those measurements with direct observations of soil processes using systems similar to our Automated MiniRhizotron (AMR), has not previously occurred. We made several design changes from our previous prototype unit, adding stability, networking capacity, and accessibility by outside researchers. These have been incorporated and most of the images acquired and currently being taken are available to anyone interested in downloading (http://ccb.ucr.edu/amarss.html). We expanded the network across the James Reserve and at additional locations. At the James Reserve, the prototype is still operating in the meadow adjacent to the weather station. At the AMARSS transect, 4 AMR units and soil sensor nodes are actively running focusing on observing and measuring soils at the same locations as the Networked InfoMechanical System (NIMS) cable and instrumentation (with complete energy-balance measurements), the phenology camera, sapflow flux sensors, standard above-ground sensors (PAR, T, RH, PPT) and a newly installed within-canopy eddy co-variance measurement system. All measurements correspond to previous measurements of leaf area (canopy camera), $CO_2$ assimilation measurements, with T, and PAR through the seasons, and within the footprint of a canopy-scale eddy covariance measurement system (Michael Goulden, UCI).

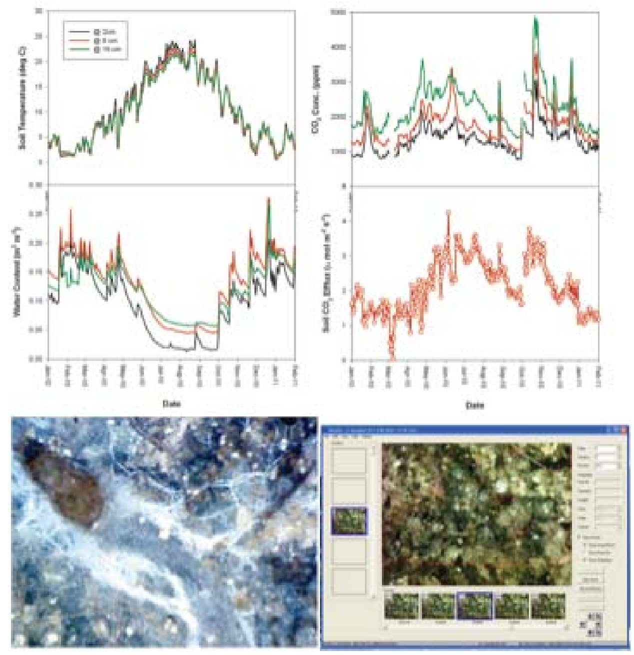

Figure 2. 2010 integrated sensor studies of soil fungi and the processes they catalyze, at the James Reserve. Show is the daily averages (5min intervals) for T (upper left), soil $CO_2$ (upper right), θ (middle left), and $R_s$ (middle right). Shown are images of an ectomycorrhiza, with the mantle and radiating hyphae (lower left) and an automated tracing (using @RootFly) outlining an arbuscular mycorrhizal network. Individual hyphae can be traced through time (lower panel) and dynamics of C production and turnover in fungal biomass directly measured to integrate into ecosystem models. These data extend the initial measurements started in the 2010 report to minute-hour-scale data for describing short- (events, diel dynamics) and long- (season, environmental change) scale processes.

We added an additional set of AMR and soil sensor nodes at the La Selva Biological Station. This deployment was stimulated by the PASI course (described below), but remains running.

Finally, we provided an AMR unit to NEON as a test deployment with their soil sensor network, which is identical to that we deployed at the James Reserve.

With the expansion of automated data and image retrival, our James Reserve network capacity was no longer adequate to handle the traffic volumn and computational needs. We moved the servers to the UCR campus. Although modifications of software to the AMR units and data management, all data and observations are available.

From the prototype unit, we have been able to document diel *in situ* arbuscular mycorrhizal (AM) hyphal growth dynamics. In 2009, growth preferentially occurred during mid-afternoon, corresponding to the time of maximal photosynthesis (based on PAR and sapflow measurements). In 2010, no diel pattern was found, but the site was cooler and wetter. No diel pattern of mortality was observed, although seasonal dynamics strongly correspond to decreasing soil moisture (θ). As an obligate plant symbiont, arbuscular mycorrhizal fungi utilize new photosynthetic C, not older decomposed C, which should reflect the allocation timing and processing of C (Figure 2).

Soil respiration ($R_s$) measures show strong diel dynamics. In the meadows, dominated by AM grasses, diel hyphal production was also observed. Little diel or seasonal hysteresis occurred in $R_s$ suggesting minimal lag in C fluxes. Alternatively, in the forest, we see little evidence of diel hyphal growth dynamics, and the ecto-mycorrhizal (EM) associations with the woody plants appear to be very long-lived (years), and even rhizomorphs have nearly a year life-span. $R_s$ shows strong daily and seasonal hysteresis, suggesting long lags in C allocation from leaves to roots to fungi in these architecturally-complex systems. Importantly, with snow cover, soil $CO_2$ production ($R_p$) continues even though the soil $CO_2$ does not diffuse through the snow layer. This results in a very high concentration of soil CO2, and a degassing as patches of snowmelt appear. We are currently working on a suite of different ecosystem models both to find some optimal ways of integrating our diverse datasets, and as a means ot testing C flux estimates generated by the models (Figure 2).

Integrating camera and sensor systems has become a critical tool for undertaking ecological research in the field. Our observing systems range from the *in situ* microscopes (AMR units) that are coupled with soil sensors, to field cameras for studying phenology dynamics that are coupled with measurements of soil respiration and activity as well as sap-flow sensor measurements, to events such as snowfall and snowmelt that are coupled to Rs as well as Rp dynamics. From our initial deployment at the James Reserve, new deployments in Chile (with the Chilean LTER group) and with the La Selva Biological Station in Costa Rica shows promise for further development. As a new activity, we are focusing on utilizing color variation to generate a more detailed assessment of finer phenological resolution in collaboration with UC Berkeley. By using these images and color detection approaches, we are comparing local camera measurements to satellite imagery (especially MODIS products) to scale from individual plant phenology to site-scale dynamics.

These camera observing systems can even be scaled to provide warning systems. For example, currently fires must be visually distinguished before warnings can be sent. However, smoke has very different atmospheric properties from clouds, or cloudless days. Both pattern recognition and wavelength differentiation might become feasible from a deployment of camera systems to provide early warning systems for wildfire detection. Given that detection is the first line of defense for control, this approach would make fire protection a more viable option for the future.

Finally, we developed a course in sensor networks and cyberinfrastructure at the La Selva Biological Station in Costa Rica for students and postdocs both from the US and across Latin America through the Pan-American Advanced Studies Institute (PASI). The expected outcomes were: (1) Tropical ecologists enrolled would be able to expand their ecological questions by using embedded sensors; (2) Tropical ecologists would become familiar with the design, set up and management requirements of embedded sensor networks that are appropriate for the temporal and spatial scale of their hypotheses; (3) Groups of tropical ecologists with common interests would be facilitated to encourage partnerships, research alliances and the establishment of their own collaborative networks; and, (4) Critical questions in tropical ecology would be identified where novel applications of sensor networks could have transformative effects

Thirty-one graduate students, post docs and young faculty were selected to enroll in the PASI course, drawn from a pool of 80 applicants. These students were roughly split between Latin American and American students, with the groups including the representation of 14 countries. The instrumentation deployed at the La Selva station remains in place for students and researchers to continue to use.

Together, we believe that we have been able to develop, then demonstrate the viability of sensor networks, including observing systems as components of sensor networks, in ecological research and training. We will continue our integrated studies both technically, and into new systems.