

## TEOS 07 New Technologies in Tropical Forest Research

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### Overview

Sensor networks offer a powerful combination of distributed sensing capacity and open possibilities for countless applications in ecological research. The frontiers of ecology expand as biologists think of new applications and engineers develop the necessary tools, extending what can be done with sensor networks. Ecology and engineering iteratively inform and transform each other. Nested data streams from local sources, adjacent networks, and remote sensing sources, multiply the capacity of ecologists to observe systems in near real-time and address questions at temporal and spatial scales otherwise unobtainable. All these advances are providing a new and better understanding of our ecological systems by revealing previously unobservable phenomena and promoting a new generation of ecological questions.

Tropical ecology has lagged behind other environmental areas of research in the use of embedded sensors due to a variety of factors including limited accessibility and the difficulty of working with sensors and instrumentation in rainforest conditions. This project has focused on ways to incorporate novel technologies to make research more effective expediting our understanding of tropical ecosystems.

### Approach

The approach used by this project has involved two activities, each aided by funding from NSF. The first was the involvement of the project in working with Costa Rican staff at the La Selva Biological Station to complete the installation of sensors on the three canopy towers and to develop the protocols for the servers that collect the sensor data via a fiber optic cable back to the laboratory area of La Selva. The conceptualization and development of the NSF MRI-funded canopy tower project was described in a previous annual report.

The second area of activity was to hold a Pan-American Advanced Studies Institute (PASI) course at La Selva to introduce tropical ecologists to recent developments in sensor networks and cyberinfrastructure. This course, *PASI: - Expanding the frontier of tropical ecology through embedded sensors*, focused on exploring potential new applications in tropical ecology, and how the field can be reshaped as we generate hypotheses to uncover new aspects of the ecology of tropical forests. It was expected that this PASI would have its highest impact among Latin American tropical ecologists, because in Latin America this technology is just emerging.

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

### System(s) Description and/or Experiments

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 (Figure 2).



Figure 1. Tropical rainforest canopy at the La Selva Biological Station in Costa Rica. This is the site of the new infrastructure of three instrumented canopy towers and walkway. The tropical forest sensor network project has carried out the deployment of instrumentation on these towers as well as the fiber optic system connecting the towers to servers in the laboratory area of the field station

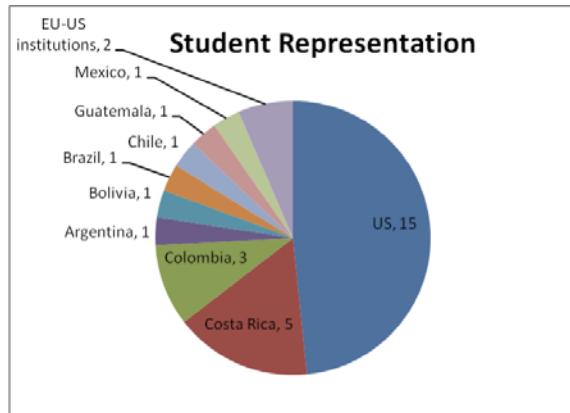


Fig. 2. Nationalities of students admitted to the PASI

The course was held over a two-week period from August 15-31, 2010, and involved 16 participating faculty who were each responsible for covering specific topics within the broader theme of the course. Six of these faculty had major connections with CENS, and formed the core faculty contingent for the course. Other participating faculty came from the University of California, Florida International University, University of Southern California, New York State Museum, University of Puerto Rico, and NEON. The emphasis was on a breadth of coverage of technological approaches rather than a detailed exploration of any single theme.

The course was organized so that each faculty member led the participants for one day, commencing by giving them a general topic introduction and synthesis of current research in their field, and then moving the classroom into the field or

laboratory for hands-on practical demonstrations and workshops in setting up sensor arrays and collecting data. These workshops were usually followed by classroom analysis of data and where applicable student presentations on their findings. Some faculty members grouped together over several days because their technical material had strong overlaps, and worked by rotating among small groups of students.

To facilitate student exchange of ideas, and to give them the opportunity to showcase their own work, we asked each student to give a 10-minute presentation. These presentations took place the first week, in one hour after-dinner sessions. In the second week the evenings were used to enable further data analysis and presentations of faculty led student projects and round table discussions of key themes relating to the utilization of sensor technology and promotion of the development of new research ideas.

In addition to the lectures and hands-on exercises, a critical component of the the PASI was a series of round table discussions on key themes relating to the utilization of sensor technology and the development of new research ideas. Students and faculty were given a discussion guide in advance in order to make the evening session more productive. Discussion questions included:

- Q1. In what ways are sensors employed in ecological research?
- Q2. Why use sensors?
- Q3. How should sensors be employed in ecological research?
- Q4. What are the benefits of using sensors and sensor networks?
- Q5. What are the potential pitfalls of using sensors?
- Q6. What kinds of projects can afford sensors?
- Q7. How should large amounts of sensor data be shared?
- Q7. Which of the modes/ways above best describe how you might employ sensors in your work?

### Accomplishments

Five CENS staff and faculty have worked with the staff of the Organization for Tropical Studies to make the NSF MRI-deployment of instrumented towers a reality. This effort involved a considerable amount of staff training, both via Skype conferencing and in the field at La Selva.

This PASI course leveraged previous NSF investment from CENS as well as at La Selva. For the last 40 years, NSF has supported large-scale research at La Selva on a variety of topics and using a diverse set of tools, including more recently embedded sensors. With this PASI we were able to train a new generation of scientists on how to incorporate sensor technology into their research and to develop future NSF proposals and to maximize the potential of this new infrastructure.

### Future Directions

CENS faculty and staff continue to work with La Selva staff to assist in the operation of the instrumented canopy towers. An NSF Macrosystems proposal has now been submitted to develop a La Selva research program using these facilities. Planning is also underway for a small PASI follow-up course to be held at La Selva in June 2011.



## 2.4 Contaminant Transport Assessment and Management (CONTAM)

The Contam research area focuses on developing technology to observe and manage mass and energy distributions and fluxes across a range of temporal and synoptic scales. In 2010–2011, the contaminant transport group continued its emphasis on integrated sensing and model-driven analysis. Projects continued to focus on high resolution river observation and modeling with respect to whole stream metabolism, groundwater-surface water exchanges, and hydrodynamic mixing. In addition, new emphases have emerged in the areas of (1) managed aquifer recharge aimed at increasing the sustainability of groundwater supplies and (2) integrating remote (aerial) sensing products with CENS embedded sensing strategies in order to extend our approaches to larger spatial scales (i.e., watershed).

The **major accomplishment** in the Contam application area for 2010–2011 was **the installation of a major new observational network at a managed aquifer recharge site in Fresno, CA.** After more almost 2 years of uninterrupted data from the Palmdale water reclamation and irrigation site, and the dairy wastewater irrigations sites near Merced, CA, we shifted sensing resources to the managed aquifer recharge site in Fresno, CA. This newest Contam site is called **MARnet** (managed aquifer recharge network). One of the observational nodes is shown Figure 3 during the initial flooding of the infiltration pond. At this site, we aim to successfully demonstrate integrated modeling and observational techniques which **will enable managed aquifer recharge with reclaimed water to be used more readily in arid and semi-arid climates, thereby increasing the sustainability of water resources.**



Figure 3. The new CENS-CITRIS managed aquifer recharge network (MARnet) prototype presently installed at the Fresno city wastewater treatment facilities.

Overall the Contam group focused on three projects over the past year, including (1) the new managed aquifer recharge site, (2) continued development of high temporal resolution dissolved oxygen data collection and net daily metabolism estimation at high spatial resolution, (3) developing new approaches to integrating CENS' embedded sensing approaches with larger scale remote sensing data.

After transitioning sensor to the MARnet site, we also focused effort on the interpretation of long-term data at the Palmdale and Merced dairy sites. Findings from these sites are summarized in one doctoral dissertation and two M.S. theses. These focus on the development and testing of long-term simulation models and data assimilation methods for forecasting the effects of irrigating with reclaimed water on groundwater quantity and quality in terms of nitrate and salinity levels, and on the long-term problem of soil salinization. Our results indicate that **by hardening the demonstrated approaches we can build robust embedded sensing systems reporting higher level information than simply moisture changes over time, reporting instead on the sustainability of current practices** and proposing modifications to improve upon the current approach. Furthermore, to enable scale up of the MARnet approach we have developed parsing algorithms that sort hydrologic and geospatial properties and socioeconomic features over large areas, such as counties, to identify the most promising areas for developing MAR operations. In the coming year this aspect of Contam research will continue to operate and assess the MARnet prototype while working with local water agencies to

identify additional test sites. In particular, we are interested in identifying a floodwater diversion site to contrast with the existing wastewater reclamation site.

In the second project area, we have extended our aquatic sensing capabilities on the Lower Merced Rivers, having installed a long-term water quality monitoring station in September 2010. This station is enabling us to continuously examine water quality parameters at high temporal resolution in a critical agricultural reach of the river. In addition, we have continued our synoptic monitoring efforts over this river reach on a roughly quarterly basis, including both water quality and imagery to capture human influences in the form of inputs (canals, drain pipes) and outputs (pumps and diversions). **By combining the temporal and synoptic data we are learning to separate the influences of human disturbances from natural background processes.** At this time we are focusing mainly on temperature, dissolved oxygen (DO), and nitrate changes in the river, and using the ecosystem metrics associated with net daily metabolism (primary production, community respiration) as a method for quantifying the river's response to natural