6: Sap Flux Sensor Networks at Tier III Sites

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Water use and carbon uptake are intimately linked in plants, as both plant-atmosphere exchanges of water vapor and carbon dioxide (CO_2) occur through the stomata of leaves. Thus, insights about stomatal regulation of plant water use also inform us about carbon assimilation, productivity, and growth. Using a network of hundreds of sensors that measure water movement in the trunks of trees, or sap flux density, PINEMAP researchers can estimate how much water trees within each plot of the Tier III sites are using every half-hour. By comparing this water use to soil water content and atmospheric evaporative demand determined by vapor pressure deficit, we can estimate the conductance of canopy to water vapor (G_C), which is a measure of how tightly stomata are regulating water use and carbon uptake. Temporal change in G_C is a good indicator of plant responses to environmental variables. Here we describe how these measurements are being made and present some preliminary analyses of data collected at a Tier III site.

Figure 6.1. University of Florida M.S. student Maxwell Wightman drills a hole to insert thermal dissipation sensor probes into a tree at the Tier III site in Florida. Photo by Geoffrey Lokuta.

Methods

Sap flux density at each Tier III site is monitored by a network of thermal dissipation sensor probes (Figure 6.1).

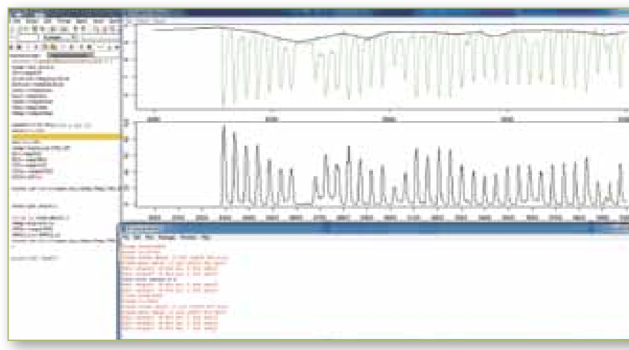

Figure 6.2. Screenshot of sap flux data quality control and processing program developed by PINEMAP researchers. The green line in the top panel shows raw data for a single sensor, and the black line shows the calibration calculated for the sensor based on environmental conditions. The resulting sap flux density in the bottom panel shows the daily rise and fall of water uptake for this tree over several weeks.

There are five such sensors per plot, for a total of 320 trees monitored across all four Tier III sites. Data from these sensors are measured every 60 seconds and averaged every 30 minutes. Additional data collected at a central location at each site includes air temperature, precipitation, relative humidity, and above- and below-canopy photosynthetically active radiation. In addition, a network of soil moisture probes records data for each plot every 30 minutes, with separate measurements below and between throughfall exclusion structures. All these data are collected daily by a central server at North Carolina State University using a cellular modem located at each Tier III site. All equipment is powered using photovoltaic solar panels.

Data quality control and processing have been standardized across PINEMAP sites using a program developed by PINEMAP researchers (Ward et al. in preparation; Figure 6.2) in the open source language R (R Foundation for Statistical Computing, Vienna, Austria). This program is being beta-tested by select research groups in the United States and Australia for eventual public distribution. Because sap flux probes require daily calibration based on predawn data subject to specific environmental thresholds (Oishi, Oren, and

We expect to see an interaction between the effects of fertilization and throughfall exclusion on J_S and G_C at Tier III sites as the experiment progresses.

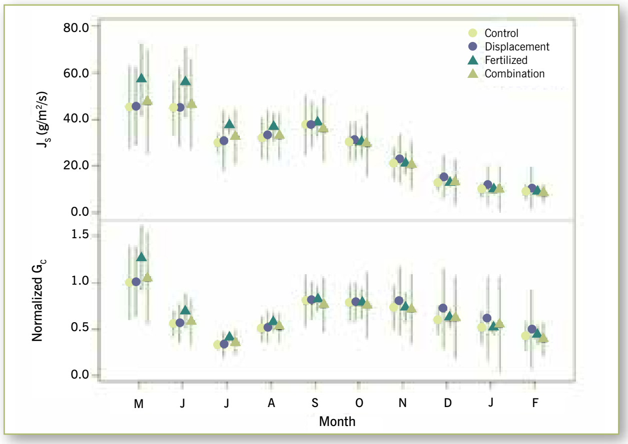

Figure 6.3. The top panel shows monthly daytime averaged sap flux density (J_S) measured in each treatment from May 2012 until February 2013. The bottom panel shows monthly daytime averaged canopy conductance (G_C) values estimated for each treatment, normalized by the maximum value observed in control treatment. Error bars represent 95% confidence interval, based on n=4 plots per treatment.

Stoy, 2008), standardization across sites is essential to ensure comparability of Tier III data.

For the preliminary results presented here, we gap-filled missing data from each sensor by regression against working sensors then calculated daytime averages for each plot. We assumed negligible differences between sapwood areas of treatments in calculating canopy conductance based on surveys of tree diameter. Such differences would be expected to be minimal at this early stage of the study and to increase in following years.

Early Results

Here we present preliminary results from the first nine months of data collection at the Tier III site in Buckingham County, Virginia, as monthly values of measured sap flux density (J_S) and estimated canopy conductance (G_C) for each treatment (Figure 6.3). While J_S directly represents the water use of trees on a sapwood area basis, G_C represents the integrated stomatal aperture of the leaves per unit ground area and corresponds to the limitation that stomatal regulation of water use imposes on carbon uptake. While J_S declines steadily from summer to winter due to falling temperatures and atmospheric evaporative demand, the lowest G_C values are found in July when the trees regulate their water use most tightly.

At this coarse temporal scale, the differences between treatments are minimal ($p > 0.10$ for all pairwise comparisons, Tukey's Honestly Significant Difference test). However, future analyses will employ hierarchical modeling techniques using a Bayesian state-space framework to quantify differences between half-hourly responses to light, atmospheric water demand, and soil moisture (Ward et al., 2013). The one notable feature about the data presented in Figure 6.3 is the tendency toward higher J_S and G_C in the fertilized treatment relative to the control in the summer months. It is likely that finer scale analyses will reveal a difference between the treatments' responses to environmental conditions underlying the monthly averages.

Fertilization is known to increase the leaf area of loblolly pine at many sites, but because loblolly is evergreen and needles live ~18 months, this difference may take multiple growing seasons to establish (McCarthy et al., 2007). The expected increase in leaf area following fertilization will result in higher J_S and G_C unless trees tighten their regulation of water use in future months. Thus, we expect to see an interaction between the effects of fertilization and throughfall exclusion on J_S and G_C at Tier III sites as the experiment progresses. As the amount of leaf area and the regulation of water both impact the capacity of trees for carbon assimilation, any such interaction would be expected to affect the growth of the trees as well. From the high-resolution data provided by Tier III sensor networks for hundreds of trees, we can make robust estimates of stomatal responses to environmental drivers. These responses represent a critical link between data and regional scale models of productivity, water use, and carbon sequestration, such as Water Supply Stress Index (WaSSI) (see *Regional Carbon Sequestration and Climate Change: It's All about Water*, page 24).