# A new technique for upscaling sap flow transpiration measurements to stand or landscape scale fluxes


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## Abstract

Measurements of individual tree transpiration, obtained using the sap flow technique, are easier to collect and less expensive than other traditional measurements of ecosystem evapotranspiration, such as eddy-covariance and lysimetery. Upscaling these point measurements to a stand or a landscape level, however, is a challenge, especially in water-controlled ecosystems. At these scales, sap flow cannot be treated solely as a function of diameter; available soil moisture strongly influences transpiration, and this can vary considerably across a landscape.

In this study, geostatistical and partitional clustering methods were used to locate a network of sap flow and soil moisture sensors across a California Oak Savanna. Eight "representative trees" were monitored; each was systematically selected to represent a subgroup of the population within a 200 x 200 m plot. All trees in a subgroup had similar diameters and soil moisture status and were presumed to have correspondingly similar sap flow. The sensors collected half-hour data over the course of the 2007 growing season, during which unusually low rainfall occurred.

The sap flow data for each tree was transformed into specific water flux, and a total stand level water flux was computed at hourly and daily time-steps. Large diameter trees in wet areas typically contributed to almost 40% of the total stand flux, while they accounted for less than 10% of the total population. To test the method, these fluxes were then compared to the measurements of stand level tree transpiration collected using the eddy-covariance towers on site. In the future, this technique could be used to measure transpiration of targeted trees over a broader area or in terrain or situations where eddy-covariance is not feasible.


## I. Introduction

### Site Information

- Mediterranean blue oak savanna in Ione, California (Baldocchi and Xu, 2007)
- Semi-arid climate (~550 mm $yr^{-1}$ rain)
- Micrometeorological monitoring station to measure $CO_2$ and latent heat flux
- Annual ET between 290 and 430 mm

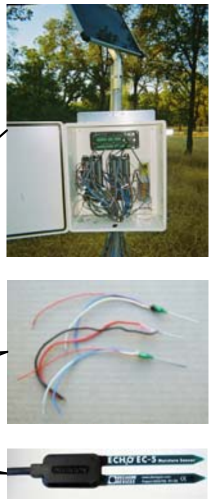
### Study Objectives

- Develop and test a novel method for using transpiration measurements at individual trees to estimate stand or landscape level fluxes, i.e. upscaling
- Monitor sap flow at "representative trees" throughout stand
- Compare upscaled sap flow to flux measured at eddy-covariance towers

### Current Status

- Partial dataset for 2007 growing season
- Monitoring to continue through 2008

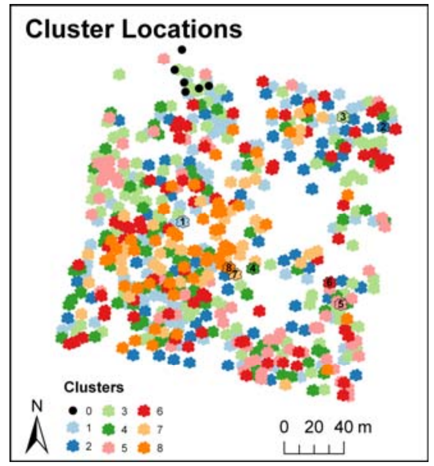
*Above: Aerial view of oak savanna site from Google Earth with 200 m x 200 m study area outlined. Below: understory (left) and overstory (right) flux towers.*



### System Components

- Solar powered control panel and data logger
- Sap flow probes at 0.3 and 1 m from ground
- EC-5 soil moisture sensors at stem, drip-line, and open space at 5, 20, and 50 cm depths
- Soil temperature sensors at stem and drip-line at 5 and 20 cm depths
- Eight trees monitored

*Sap flow monitoring system. From left clockwise: tree representing "Cluster 1", data logger and solar panel, sap flow probe set, and EC-5 soil moisture sensor.*




*Cluster membership for each tree in study area and the locations of representative trees with sap flow monitoring.*

## II. Experimental Design

### Locating the Sap Flow Sensors

- Upscaling depends on selectively locating sensors using statistical techniques
- Partitioning Around Medoids (PAM) cluster analysis method (Kaufmann and Rousseeuw, 2005) used to identify eight main groups of trees
- Tree classification based on diameter and soil properties
- Sensors placed on medoid tree, the most "representative tree" in each group

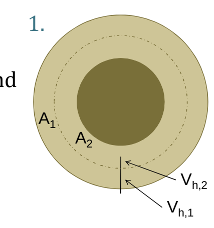
| Cluster | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| DBH (cm) | 30 | 45 | 31 | 22 | 15 | 10 | 30 | 18 |
| Trees (num.) | 97 | 56 | 94 | 83 | 71 | 80 | 42 | 52 |
| Slope | L | H | H | L | H | H | L | L |
| Elevation | L | H | L | H | H | H | H | L |
| Sand content | L | H | H | L | H | H | L | L |

L represents a medoid tree with a value lower than stand average, H represents higher than average.

### From Heat Pulse Velocity to Stand Transpiration

1. Heat pulse velocity ($V_h$) measured using the Heat Ratio Method (Burgess, 2001)
2. $V_h$ converted to sap flow velocity ($V_s$) based on wood properties: density ($\rho_b$), wood and sap specific heat capacity ($C_w$ and $C_s$), moisture content ($m_c$), and wounding factor ($\beta$)
3. Find tree flux ($Q_{sap}$) from $V_s$, sap wood cross-sectional area (A) and ray cell factor ($\gamma$)
4. Sum product of representative tree ($Q_{sap,i}$) and number of trees in cluster ($n_i$)
5. Divide $Q_{stand}$ by total area included in study ($A_{stand}$) and compare to ET from towers

1.




2. $$V_s = V_h \beta \frac{\rho_b (C_w + m_c C_s)}{\rho_s C_s}$$

3. $$Q_{sap} = \gamma (V_{s,1} A_1 + V_{s,2} A_2)$$

4. $$Q_{stand} = \sum_{i=1}^{8} n_i Q_{sap,i}$$

5. $$q_{stand} = \frac{Q_{stand}}{A_{stand}}$$

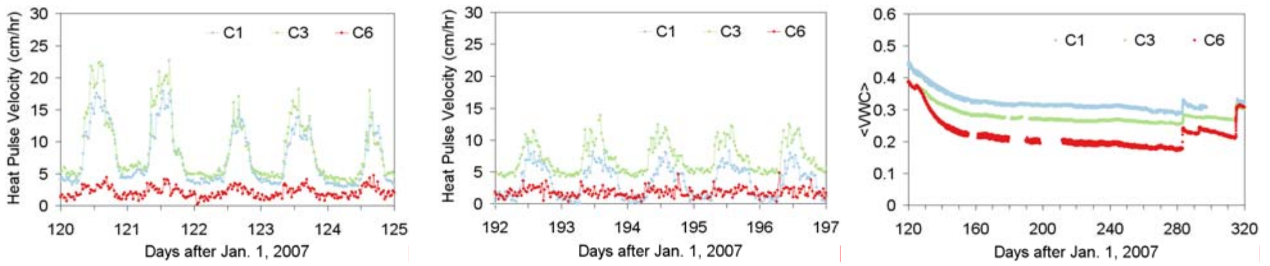
## III. Results and Discussion

### 2007 Growing Season Summary

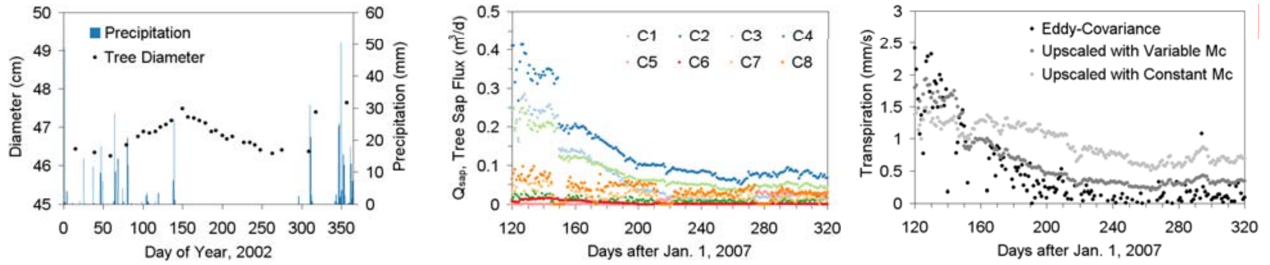
- Total precipitation: 66 mm (DOY 120-320 )
- Volumetric water content of soil: 0.08 to 0.62 $m^3\ m^{-3}$
- Heat pulse velocities: 0 cm $hr^{-1}$ to 51 cm $hr^{-1}$
- Estimated daily transpiration
  - Sap flow: 0.2 to 1.9 mm $d^{-1}$
  - Eddy-covariance: -0.25 to 2.4 mm $d^{-1}$
- Lower than normal rainfall resulted in earlier senescence

### Notes on Upscaling

- Equipment failures limited time when all clusters were operational
- Upscaling performed after gap-filling and in the absence of a complete dataset
- Lower root zone soil moisture did not necessarily induce lower sap velocities
- Stem water content, as indicated by tree diameter, cannot be assumed constant and heavily influences sap velocity calculations



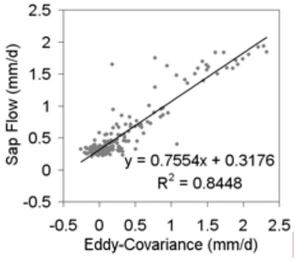

*Raw heat pulse velocity ($V_h$) data for selected representative trees over portions of the wet (left ) and dry (center) seasons. The Cluster 1 and 3 trees, which have similar diameters, typically had similar velocities during the wet season but different velocities during the dry season. This difference is reflected in their root zone averaged soil moisture conditions (<VWC>, right). The Cluster 6 tree has a diameter 1/3 that of the two and lower soil moisture, resulting in consistently lower velocities.*




*Converting the heat pulse velocity to transpiration required calculation of the stem wood thermal properties, as discussed above. In previous studies, the value of $m_c$ had been taken as a constant, but field data from previous years (left) indicates that during the dry season, tree diameters shrink significantly, indicating a decrease in stem water content. Although not measured in 2007, when estimates of $m_c$ and stem diameter changes are incorporated into the calculations, the tree sap flux (center) and overall stand transpiration (right) show patterns more consistent with that measured using the eddy-covariance technique.*

## IV. Conclusions and Future Work

- Technique shows promise but further work needs to be done to improve system reliability
- Upscaling from sap flow over-predicted dry season transpiration - due to highly uncertain $m_c$ and $A$ values?
- Additional characterization of stem diameters, water content, and sap wood area needed during 2008 season
- Modeling could be used to understand differences in sap flow velocity and soil moisture status in same size trees




*Future work will explore the relationship between daily transpiration measured using both techniques.*

## V. References and Acknowledgements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