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Baseliner: An open-source, interactive tool for processing sap flux data from thermal dissipation probes

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Abstract

Estimating transpiration from woody plants using thermal dissipation sap flux sensors requires careful data processing. Currently, researchers accomplish this using spreadsheets, or by personally writing scripts for statistical software programs (e.g., R, SAS). We developed the Baseliner software to help establish a standardized protocol for processing sap flux data. Baseliner enables users to QA/QC data and process data using a combination of automated steps, visualization, and manual editing. Data processing requires establishing a zero-flow reference value, or "baseline", which varies among sensors and with time. Since no set of algorithms currently exists to reliably QA/QC and estimate the zero-flow baseline, Baseliner provides a graphical user interface to allow visual inspection and manipulation of data. Data are first automatically processed using a set of user defined parameters. The user can then view the data for additional, manual QA/QC and baseline identification using mouse and keyboard commands. The open-source software allows for user customization of data processing algorithms as improved methods are developed.

Keywords: Sap flux; Thermal dissipation probe; Granier probe; Data processing

Code metadata

Current Code version	4.0
Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00055
Legal Code License	*GNU General Public License v3.0*
Code Versioning system used	*git*
Software Code Language used	*MATLAB*
Compilation requirements, Operating environments & dependencies	
If available Link to developer documentation/manual	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00055/blob/master/README.md
Support email for questions	*acoishi@fs.fed.us*

Software metadata

Current software version	4.0
Permanent link to executables of this version	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00055
Legal Software License	*GNU General Public License v3.0*
Computing platform/Operating System	*Microsoft Windows, MATLAB*
Installation requirements & dependencies	
If available Link to user manual — if formally published include a reference to the publication in the reference list	https://github.com/ElsevierSoftwareX/SOFTX-D-16-00055/blob/master/README.md
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1. Motivation and significance

Quantifying water use by woody plants is a vital component of research in plant physiology, hydrology, forest ecology, and environmental science. Currently, the most effective approach for estimating continuous, in-situ, whole-tree water use is with sap flux sensors. Various types of sap flux sensors have been developed over the past several decades, but all operate on similar principles. Sensors apply heat to a portion of the tree's water-conducting tissue and measure how the flow of xylem water (henceforth sap) affects changes in sensor temperature over time.

One of the most commonly used type of sap flux sensor is the thermal dissipation probe (TDP) [1,2]. These probes are commercially available or can be constructed by researchers with relative ease and low cost. TDPs measure the difference in temperature between a heated and unheated sensor (details in Section 2: Theory of Thermal Dissipation Probe Operation) and output a raw voltage signal that can be recorded by an automated datalogger. Accurately estimating sap flux from the raw TDP signal requires addressing several important challenges, including data quality assurance and quality control (QA/QC), and converting raw data to sap flux. Improper data processing will propagate error in subsequent analyses, resulting in incorrect estimates of tree- and stand-level water use and nocturnal sap flux [3,4]. Data from TDPs may exhibit considerable variability, both for an individual probe over time and among different probes. Currently, there is no universal algorithm available for data QA/QC and processing.

Here, we present software that enables users to QA/QC and convert raw TDP data into sap flux. This software combines both automated and manual approaches to data QA/QC and processing. The open-source design of the software enables improved data processing algorithms to be incorporated as they are developed.

2. Theory of thermal dissipation probe operation

Based on Granier's original design [1], one TDP consists of two, cylindrical metal tubes, each typically 20 mm in length and 2 mm in outer diameter, containing a T-type copper-constantan thermocouple. The tubes are installed radially into the tree's active xylem (sapwood) with vertical separation of approximately 15 cm. The upper probe includes a heating element made of constantan wire, wound around the probe, supplied with 0.200 W. Thermocouples produce a small voltage that varies with temperature and the pair of thermocouples is used to measure the temperature difference ($\mathrm{d}T$; °C) between heated and unheated probes. As the velocity of water movement increases, more heat near the upper probe is dissipated and the $\mathrm{d}T$ declines (Fig. 1a).

$\mathrm{d}T$ is inversely related to sap flux (F; $m^3\ m^{-2}\ s^{-1}$) as a function of the maximum temperature differential between probes when flux is zero ($\mathrm{d}T_{\max}$; °C). Thus, F can be related to $\mathrm{d}T$ with the following equations:

$$K = (\mathrm{d}T_{\max} - \mathrm{d}T)/\mathrm{d}T = (\mathrm{d}T_{\max}/\mathrm{d}T) - 1, \quad (1)$$

$$F = \alpha \times K^{\beta}, \quad (2)$$

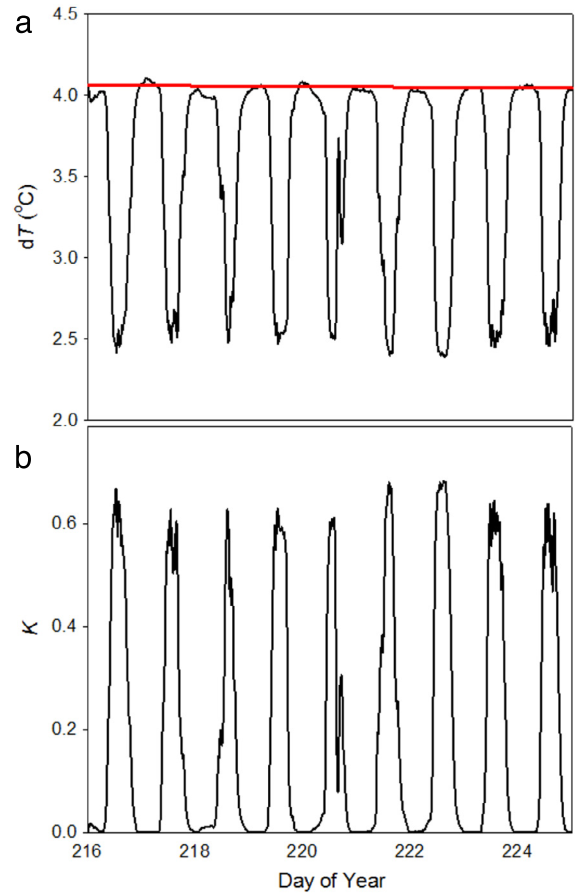

Fig. 1. Example time series of (a) raw temperature differential ($\mathrm{d}T$) from a thermal dissipation probe with zero-flow reference "baseline" ($\mathrm{d}T_{\max}$) in red, and (b) converted flow index (K). This example shows a relatively stable $\mathrm{d}T_{\max}$. Note that K during the second half of day of year 220 was lower than other days due to an afternoon rain event.

where K is a dimensionless "flow index" and α and β are empirical coefficients [1].

The $\mathrm{d}T$ signal has some predictable characteristics. $\mathrm{d}T$ is typically greater than 2 °C and less than 15 °C, with a diel wave-like pattern with a typical amplitude of less than 5 °C (Fig. 1a). However, the amplitude will vary among days with sap flux and the wave-like pattern may be interrupted within a day if sap flux declines dramatically (e.g. as the result of an afternoon rain event; Fig. 1).

TDPs are relatively simple and reliable devices; however, they can output data within the range of expected values, but exhibiting erratic patterns, inconsistent with plant physiological behavior. The $\mathrm{d}T$ signal may be compromised by faulty wiring, power supply interruptions, or other electrical interference (Fig. 2a). These data do not represent the true sap flux and should be filtered out prior to data processing. Additionally, short gaps in reliable data can occur, often due to an interruption in power (Fig. 2b).

Identifying a reliable $\mathrm{d}T_{\max}$ also presents a methodological challenge. $\mathrm{d}T_{\max}$ varies among sensors and changes over time due to tree water status, ambient temperature fluctuations, and variability in the power supplied to the heating element, among other factors [3]. Thus, over time, $\mathrm{d}T_{\max}$ may appear stable (Fig. 1a), drift upward or downward (Fig. 3a), or exhibit

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