The Soil Water and Temperature System (SWATS): Progress Toward a Calibrated Network

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Introduction

The Soil Water and Temperature System (SWATS) network at the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed (CART) Southern Great Plains (SGP) site is a unique collaboration between the ARM Program, the National Oceanographic and Atmospheric Administration's National Severe Storms Laboratory (NOAA/NSSL) and Office of Global Programs (NOAA/OGP), the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma, Oklahoma State University, and the Global Energy and Water Experiment (GEWEX) Continental-scale International Project (GCIP). Discussions at GCIP meetings in 1993 focused attention on both the potential and shortcomings (from a GCIP point of view) of the instrumentation planned for the SGP site. It was agreed that the data from the 22 planned extended facilities would be more valuable to GCIP scientists if they were augmented with measurements of soil water through and below the rooting zone. ARM was willing to host such instrumentation, and subsequent discussions led to an effort sponsored by NOAA's Office of Global Programs and the ARM Program to develop and install robust, automated soil moisture profiling systems at the SGP site.

The development of the ARM SWATS network was coordinated with similar installations in the Little Washita watershed (managed by the U.S. Department of Agriculture/Agricultural Research Service [USDA/ARS] Grazinglands Research Laboratory) and across the Oklahoma Mesonetwork (managed by the Oklahoma Climatological Survey). Our goal was to develop overlapping networks, on three different physical scales, simultaneously observing soil water, soil temperature, and some measure of the atmospheric fluxes of heat and water. The three networks (dubbed MOISTNET) share a common soil water sensor: the Campbell Scientific 229-L heat dissipation matric potential sensor. Installation, deployment, and calibration approaches differ between the networks, but all parties collaborate and communicate on sensor calibration issues.

Current Status

SWATS have been installed at the central facility and 20 extended facilities (all except Okmulgee and Cement). Data from 17 of the SWATS have been in beta release since June 1997, and the data from the remaining four SWATS will be released this spring after calibration and ingest procedures are completed. A full data release for all SWATS is planned during the summer of 1999.

Each SWATS measures soil temperature (°C), soil matric potential (kPa), and estimates volumetric soil water (m^3/m^3), hourly, in two profiles, at eight depths in each of profile at each site. Sensor depths are 5, 15, 25, 35, 60, 85, 125, and 175 cm below the surface (rock allowing). Data is both shipped electronically in the manner standard for SGP extended facilities, and saved internally as backup over a three-week period.

Technically, the SWATS development has been a success. The systems have proven themselves to be relatively robust in the harsh SGP environment, with a minimum of problems. The few recurring physical or electronic problems (flooded electronics enclosures at low sites; datalogger program losses; loose thermisters) are being addressed with either changes in maintenance procedure or retrofits. Data quality metrics are also being developed to maximize the scientific utility of these systems.

Calibration Issues

The 229-L calibration approach developed for the SWATS by D. K. Fisher has proven to be immediately useful: the SWATS calibration is the most complete of the three MOISTNET networks at this date. The SWATS sensors were calibrated in the laboratory by a three-step process before installation. The first calibration relates the temperature change over the measurement cycle of each sensor to that of a "reference" sensor (Eq. [1]). The second calculates matric potential as a function of the temperature change of the reference sensor (Eq. [2]). Estimates of volumetric water are then calculated from the potential, using fitted values of the van Genuchten retention model to measured soil water retention characteristics (Eq. [3]).

In a separate effort, pairs of triplicate gravimetric measurements were performed at each site to test the accuracy of SWATS estimates of volumetric water.(a) Results from this sparse sample (Figure 1) indicate accuracies within ± 0.10 m/m.

Validation measurements to date are too sparse to define the performance of the 229-L under a wide range of field conditions. In particular, we need to observe the volumetric water estimates versus data from reference systems during drying conditions, as the potential approaches and exceeds the wilting point of vegetation. Efforts are under way to validate the volumetric estimates in situ against other sensors that measure volumetric or gravimetric water directly. This is a collaborative program with the Oklahoma Mesonet and the USDA/ARS Grazinglands Research Laboratory, dubbed SWAMI (Soil Water Measurement Intercomparison). The first intercomparison site will be established this summer at the Grazinglands Research Laboratory, adjacent to the SWATS El Reno site.

It is virtually impossible to validate the dry end of the matric potential measurements in the field (no suitable system currently exists). Accordingly, a parallel effort (in collaboration with the Oklahoma Mesonet) is being considered to validate the matric potential measurements, as well as the gravimetric estimates, using new materials to improve standard pressure plate measurement techniques.

(a) The soil water retention measurements and gravimetric measurements were performed under the supervision of Drs. Elliott and Brown at Oklahoma State University.

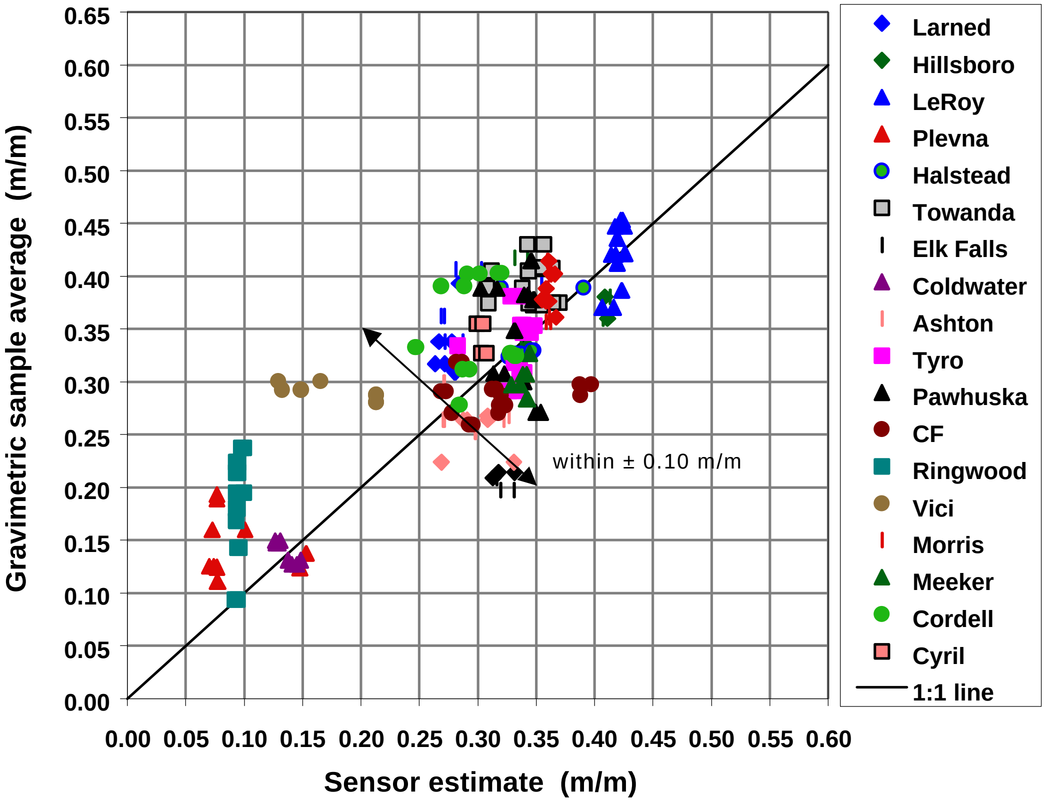

Figure 1. Sensor estimate versus gravimetric water content.

Our goal in the coming year is to provide a more complete specification of the accuracy of the matric potential and volumetric water measurements, over a wide range of wetness and soil types.

Eq. (1): Adjustment of Individual Sensor Response to "Reference" Sensor Response

Removes sensor-to-sensor variability; coefficients m and b are unique for each individual sensor.

$$dT_{ref} = m * dT_{sensor} + b \tag{1}$$

where dT_{ref} = "reference" sensor response (°C)
dT_{sensor} = individual sensor response (°C)
m = slope
b = intercept.

Eq. (2): "Reference" Sensor Calibration Equation

Estimates potential as a function of reference sensor response; coefficients dT_d, dT_w, a, n are constant for all sensors.

$$\psi = \frac{1}{a}\left[\frac{dT_w - dT_d}{dT_{ref} - dT_d} - 0.9\right]^{\frac{1}{n}} \tag{2}$$

where ψ = potential (kPa)
dT_d = 4.00 (°C)
dT_w = 1.45 (°C)
a = -0.01 (kPa)
n = 0.77.

Eq. (3): Soil Water Retention Curve

Estimates water content as a function of potential; coefficients Θ_r, Θ_s, α, n are unique for each different soil layer at each site.

$$\Theta = \Theta_r + \frac{\Theta_s - \Theta_r}{\left[1+\left(\alpha\left(\frac{-\psi}{100}\right)\right)^n\right]^{(1-1/n)}} \tag{3}$$

where Θ = volumetric soil water content (m^3/m^3)
Θ_r = residual water content (m^3/m^3)
Θ_s = saturated water content (m^3/m^3)
α, n = empirical constants
ψ = potential (kPa).