



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F404

Soil Temperature Profiles

Standard Operating Procedure

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1. Purpose

This SOP describes procedures for measuring soil temperature at multiple depths to construct soil temperature profiles. Soil temperature influences biological activity (microbial respiration, root growth, seed germination), chemical reaction rates (nutrient mineralization, decomposition), and physical processes (evaporation, frost heave) (Ham, 2002; Hillel, 1998). Temperature profiles are especially relevant for photovoltaic panel studies, where shading alters the soil thermal regime.

The amplitude and phase lag of diurnal and seasonal temperature waves attenuate with depth according to the thermal diffusivity of the soil profile, making multi-depth measurement essential for characterizing subsurface energy budgets (Hillel, 1998). Soil temperature also governs rates of microbial respiration and nitrogen mineralization, with Q_{10} values typically ranging from 2 to 3 for the biologically active zone (Onwuka & Mang, 2018). When continuous monitoring is not feasible, air-temperature-based models can be used to estimate soil temperature, but these require site-specific calibration (Zheng et al., 1993).

2. Scope

- **Applies to:** Spot measurements using handheld probe thermometers and continuous monitoring using datalogger-based thermocouple or thermistor systems at all EA Program field sites
- **Does not apply to:** Soil heat flux measurements (requires heat flux plates); fire-related soil heating studies
- **Location:** All EA Program field sites, including photovoltaic panel study areas, Bernard Field Station, and restoration sites

3. Responsibilities

Role	Responsibility
Lab PI	Approve monitoring plan, ensure training compliance
Field Lead	Coordinate installation, assign measurement schedules
Trained Personnel	Install sensors, collect data, maintain equipment
New Students	Complete training before independent measurement

4. Definitions

- **Diurnal temperature variation:** The cycle of soil temperature change over a 24-hour period driven by solar radiation and radiative cooling; amplitude decreases with depth and is nearly zero below about 50 cm in most soils.
- **Horizon temperature:** The temperature measured at a defined soil depth corresponding to a specific genetic horizon (e.g., A, B, C); used to characterize the thermal environment of the root zone and microbial communities.
- **Soil temperature:** The thermal energy state of the soil, expressed in °C; controls rates of microbial activity, organic matter decomposition, plant root growth, and soil gas fluxes.
- **Temperature gradient:** The rate of change in temperature with depth (°C cm⁻¹); drives heat flux between soil layers and between the soil surface and the atmosphere.
- **Temperature profile:** A set of soil temperature measurements taken at multiple depths simultaneously or sequentially at a single location; used to characterize heat storage, heat flux, and seasonal thermal dynamics.
- **Thermistor:** A temperature sensor whose electrical resistance changes predictably with temperature; commonly used in data loggers for continuous soil temperature monitoring; requires calibration against a traceable reference thermometer.
- **Thermocouple:** A temperature sensor composed of two dissimilar metals joined at a measuring junction; produces a small voltage proportional to the temperature difference between the junction and a reference; used in handheld soil thermometers.

5. Safety and Hazards

Hazards

- **Physical:** Sharp probe tips, rebar stakes, hammering pilot holes in hard soil
- **Biological:** Ticks, snakes, and other field hazards (see SOP-F001)
- **Electrical:** Datalogger batteries and wiring (low voltage, minimal risk)
- **Environmental:** Heat exposure during summer measurements in southern California

5.1. Required PPE

- ☐ Closed-toed shoes or field boots
- ☐ Gloves (when hammering pilot holes or handling rebar)
- ☐ Sun protection (hat, sunscreen)
- ☐ Safety glasses (when hammering)

5.2. Required Training

- [SOP-F001 Field Safety](#)

6. Summary of Methods

Two approaches are described in this SOP. Select based on your project requirements. Both methods are described in the SSSA Methods of Soil Analysis (Ham, 2002). The handheld method follows the GLOBE soil temperature protocol ([globe2014soil?](#)), which has been widely adopted for teaching and citizen-science applications.

Method	Best For	Temporal Resolution	Cost
Handheld probe	Spot measurements, surveys across many points	Single time point per visit	Low
Datalogger system	Continuous monitoring, diurnal and seasonal patterns	Minutes to hours (automated)	High

6.1. Standard Measurement Depths

Depth	Rationale
2 cm	Near-surface; responds rapidly to air temperature and solar radiation
5 cm	Root zone surface; standard GLOBE protocol depth
10 cm	Upper root zone; dampened diurnal signal
20 cm	Mid root zone; minimal diurnal variation
50 cm	Deep reference; seasonal variation only

Choosing Depths

For most EA Program projects, 5 cm and 10 cm are the minimum. Add 2 cm for surface energy balance studies and 20 cm or 50 cm for deep profile characterization.

7. Required Materials

7.1. Method A: Handheld Probe

Item	Notes
Thermocouple (Type T or Type K) or Resistance Temperature Detector (RTD) probes	Probe length must exceed deepest measurement depth + 2 cm. These probes carry a systematic measurement error; raw readings must be corrected using the probe-specific formula (see Data Correction under Data Management).
Electronic reader for probes	For the RTD probes, use either of the Omega HH804 readers. For the Type T probes, pair probe 1 with cable 1 and reader T819, and probe 3 with cable 2 and reader T299. The cable and reader both affect the reading, and the correction formulas are valid only for these specific equipment pairings.
Permanent marker, tape, or heat-shrink band	For marking measurement depths along the probe (see Prepare Depth Guide Marks)
Nail or awl	Same diameter as thermometer probe, for making pilot holes in hard soil
Hammer	For driving the nail into compacted soil
Field data sheet	Printed from Appendix A
Clipboard and pencil	Mechanical pencil preferred
GPS unit or smartphone	For recording measurement locations
Timer or watch	For tracking equilibration time

7.2. Method B: Datalogger System

Item	Notes
Datalogger	Campbell Scientific CR1000, CR300, or equivalent
Thermocouple probes	Type T or Type E; one per measurement depth
Thermistor probes (alternative)	Campbell Scientific 109SS or equivalent
Averaging thermocouple probe (optional)	Campbell Scientific TCAV-L for energy balance studies
Soil temperature profiler (optional)	Hukseflux STP01 or METER TEROS 06
Signal cable	Sufficient length from sensors to datalogger
Weatherproof enclosure	For datalogger and battery
12V battery and solar panel	For continuous power
PVC conduit	For protecting cable runs
Shovel or soil knife	For sensor installation
Laptop with datalogger software	For programming and data download

8. Estimated Time

Task	Time
Handheld: per measurement point (all depths)	10–15 minutes (including equilibration)
Datalogger: initial installation	2–4 hours per station
Datalogger: data download visit	15–30 minutes
Datalogger: sensor replacement	30–60 minutes

9. Procedure: Method A – Handheld Probe

9.1. Prepare Depth Guide Marks

Before going to the field, mark each measurement depth directly on the probe. The temperature sensor is at the tip of the probe, so each mark is placed at the target depth measured from the tip. In the field, push the probe in until the mark for the target depth is level with the soil surface.

Target Depth	Mark Distance from Tip
5 cm	5 cm
10 cm	10 cm
20 cm	20 cm

Use a permanent marker, a wrap of tape, or a heat-shrink band at each depth. Verify the marks against a ruler before each field season, since tape and marker can shift or wear off with use.

9.2. Select Measurement Locations

1. Navigate to the predetermined sampling location and record GPS coordinates
2. Select a representative spot with undisturbed soil surface
3. Gently brush away surface litter without disturbing the mineral soil

9.3. Take Measurements

1. If the soil is hard, use the nail and hammer to make a pilot hole to the target depth. Make the hole the same diameter as the probe to ensure good thermal contact.
2. Insert the probe and gently push until the mark for the target depth is level with the soil surface
3. Wait at least 2 minutes for the probe to equilibrate with the soil. Equilibration time depends on the thermal conductivity of the soil and the thermal mass of the probe; dry sandy soils may require 5 minutes or longer (Ham & Senock, 1992).
4. Read the temperature every 1 minute until two consecutive readings are within 0.5 C of each other
5. Record the stabilized temperature, depth, time, and location on the data sheet
6. Remove the probe and repeat at the next depth in the same hole (work from shallowest to deepest)

7. Move to the next measurement location

! Equilibration Is Essential

Do not rush readings. An un-equilibrated probe will read too warm in cool soil and too cool in warm soil. Two minutes is the minimum; 3–5 minutes may be needed in dry or very cold soil.

9.4. Timing

- For comparable data across sites, complete all measurements within 1 hour of local solar noon (approximately 12:00–13:00 PST)
- For diurnal profiles, measure at consistent intervals (e.g., every 2–3 hours over a 24-hour period)
- Record the exact time of each measurement

10. Procedure: Method B – Datalogger System

10.1. Sensor Installation

1. Select a representative location and record GPS coordinates
2. Dig a narrow trench or pit to the deepest sensor depth on one side of the measurement point (do not disturb the soil column directly above the sensors)
3. Insert sensors horizontally into the undisturbed soil wall at each target depth, pressing firmly to ensure good thermal contact
4. Backfill the trench carefully, maintaining the original soil layering as much as possible
5. Route cables through PVC conduit to the datalogger enclosure
6. Mark the sensor locations with discreet, flush-to-ground markers

i Settling Period

Soil disturbed during installation needs time to return to representative thermal conditions. Allow a minimum of 48 hours before using data for analysis. One to two weeks is ideal for deep sensors.

10.2. Datalogger Programming

1. Connect all sensors to the datalogger following the wiring diagram for your sensor type
2. Program the datalogger to scan sensors at the desired interval (typically every 1–5 minutes)
3. Configure storage to record averages at 15-minute or 30-minute intervals
4. Set the datalogger clock to local standard time (do not use daylight saving time)
5. Verify readings against a calibrated handheld thermometer at 5 cm depth

10.3. Data Download

1. Visit the station at regular intervals (weekly to monthly, depending on battery and storage capacity)
2. Connect a laptop and download data using the manufacturer's software
3. Check for gaps, sensor failures, or anomalous readings in the field
4. Transfer data to the project database within 48 hours

11. Calibration

11.1. Handheld Probes

1. Prepare an ice-water bath (crushed ice + deionized water, stirred); this should read 0.0 C
2. Insert the probe and allow to equilibrate for 3 minutes
3. Record the reading; it should be within 0.5 C of 0.0 C
4. If outside tolerance, adjust or replace the thermometer
5. Calibrate before each field season and after any suspected damage

The ice-point calibration is a single-point check; for research requiring higher accuracy, a two-point calibration (ice-water and warm-water bath at approximately 40 C) is recommended (Ham, 2002).

Type K Probes

Type K probes require a multi-point calibration to build their error-correction formula. Measure the reading at a minimum of three temperatures: an ice bath (approximately 0 C), room temperature, and a heating plate at approximately 50 C. Use a reference thermometer at each point and fit the correction from the paired readings (see Data Correction).

11.2. Datalogger Sensors

1. Before installation, place all sensors in a well-stirred water bath
2. Record readings from all sensors simultaneously
3. All sensors should agree within 0.3 C
4. Document any offsets and apply corrections in post-processing if needed

12. Quality Control

- Calibrate all thermometers and sensors before each field season
- For handheld measurements, take readings at a minimum of 3 replicate locations per plot
- Record the time of every measurement (soil temperature changes throughout the day)
- For datalogger systems, inspect data weekly for drift, gaps, and anomalous values
- Include a surface air temperature measurement alongside soil temperatures for context
- Photograph each measurement location at the start of each season

13. Data Management

13.1. Handheld Data

Enter data from field sheets into the project spreadsheet within 48 hours. Required fields:

- Date, time (local standard time), site, plot ID, observer
- Measurement depth (cm)
- Temperature (C)
- Surface condition (bare soil, litter, vegetated, shaded)
- Notes (e.g., soil was saturated, recent rain)

13.2. Data Correction

The handheld probes carry a systematic measurement error, so raw readings must be corrected before analysis. Apply the calibration formula matched to the specific probe, cable, and reader combination; the corrections below are valid only for the equipment pairings listed. Let T_{raw} be the reading in °C and T_{corr} the corrected temperature in °C.

RTD Probe 1

$$T_{\text{corr}} = 1.160 T_{\text{raw}} - 13.23$$

RTD Probe 2

$$T_{\text{corr}} = 1.167 T_{\text{raw}} - 14.609$$

Type T Probe 1 (Cable 1, reader T819)

$$T_{\text{corr}} = 1.028 T_{\text{raw}} - 8.797$$

Type T Probe 3 (Cable 2, reader T299)

$$T_{\text{corr}} = 1.004 T_{\text{raw}} - 8.121$$

Record which probe, cable, and reader were used for each measurement so the correct formula can be applied during processing. Type K probes must be calibrated and corrected using a formula derived from their own three-point calibration (see Calibration).

13.3. Datalogger Data

- Download raw files and archive unmodified copies
- Process data into a standardized format: timestamp, site, depth, temperature
- Flag and document any corrections (sensor offsets, gap-filling)
- Store processed data in the project database with metadata

14. Waste and Site Impact

- Minimize soil disturbance during installation; backfill trenches carefully
- Remove all temporary equipment, flagging, and markers after the study
- Leave permanent sensors in place for long-term monitoring unless the study is complete
- Pack out all trash and supplies

15. References

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16. Training Record

Before measuring soil temperature independently, personnel must:

1. Read this SOP and [SOP-F001 Field Safety](#) in full
2. Calibrate a handheld probe using an ice-water bath
3. Demonstrate proper use of depth marks and equilibration timing
4. For datalogger work: demonstrate sensor installation, datalogger programming, and data download under supervision
5. Be signed off by the field lead or PI

17. Appendix A: Soil Temperature Field Data Sheet

Print this sheet and use it in the field.

Site: _____ Plot ID: _____ Date: _____

Observer: _____ Instrument ID: _____

Surface condition: _____ Weather: _____

Air temperature (C): _____ Time of air temp reading: _____

Loca- tion #	GPS / Descrip- tion	Time	2 cm (C)	5 cm (C)	10 cm (C)	20 cm (C)	50 cm (C)	Notes
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Calibration check (ice bath reading): _____ C Time: _____